THE FOUNDER'S MANUAL

A PRESENTATION OF MODERN FOUNDRY OPERATIONS

FOR THE USE OF

FOUNDRYMEN, FOREMEN, STUDENTS AND OTHERS

BY

DAVID W. PAYNE

EDITOR OF "STEAM"

245 ILLUSTRATIONS

NEW YORK

D. VAN NOSTRAND COMPANY

25 PARK PLACE

1917

PREFACE

While there is little a foundryman needs to know which has not been fully treated by competent authorities, there is not, so far as I am aware, any summary of this great mass of publications.

In a foundry experience covering many years, I have frequently spent hours at a time in searching for special information. Believing, therefore, that a compilation of this matter, with authoritative instruction for the solution of the many problems which are continually presented in the foundry, all properly arranged for ready reference, would receive a favorable reception, an attempt has been made to meet this need by the production of this book.

The material for the Manual has been drawn from every available source. The proceedings of the American Foundrymen's Association have furnished no end of information. The publications of Professors Turner, Porter, Reis, Dr. Moldenke, Messrs. Keep, Longmuir, Outerbridge, West and others have been most carefully searched. Much has been taken from "The Foundry," "Castings" and "Iron Age." A great many of the "Foundry" records are given in full.

Possibly, in some cases, special credit for extracts has not been accorded; for such omissions indulgence is asked, as there has been no intentional neglect or lack of courtesy.

In the selection of the material for the book, proper consideration has been taken of beginners and others who may have not gotten very far in their acquisition of foundry information. For such men, it is also hoped the book will be of good service.

As regards the price lists and discounts which are given in connection with many foundry supplies, it should be stated that these are not quoted as current prices. They are offered simply as furnishing a guide to close approximation of costs.

The matter for the preliminary portion of the book relating to elementary Mathematics, Mechanics, etc., has been taken in large part from such authorities as Rankine, Bartlett, Wentworth, Trautwine, Kent, Jones and Laughlin, Carnegie Steel Co., and the Encyclopedia Britannica.

D. W. P.

New York, Jan., 1917.

CONTENTS

Page

CHAPTER I

ELEMENTARY MATHEMATICS 1

Ratio and Proportion, 1. Root of Numbers, 3. Percentage, 5. Algebra, 7. Equations, 11. Plane Geometry, 15. The Parabola, 22. The Hyperbola, 23. Properties of Plane Figures, 24. Mensuration, Plane Surfaces, 26. Solids, 30.

CHAPTER II

WEIGHTS AND MEASURES 35

Commercial Weights and Measures, 36. Metric Weights and Measures, 40. Measures of Work, Power and Duty, 45. Mathematical Tables, 46.

CHAPTER III

NATURAL SINES, TANGENTS, ETC 107

Solution of the Right-angled Triangle, 109. Solution of Oblique-angled Triangles, 109. Tables of Sines, Tangents and Secants, 110. Approximate Measurement of Angles, 115. Tapers per foot and Corresponding Angles, 117.

CHAPTER IV

MATERIALS 119

Wire and Sheet Metal Gauges, 119. Weights of Iron and Steel, 122. Cold-rolled Steel Shafting, 140. Galvanized and Corrugated Sheet Iron, 141. Sheet Tin, 142. Copper and Brass, 143. Metal Fillets, 145. Iron Wire, 146. Nails and Tacks, 148. Threads, 149. Bolts, Nuts and Washers, 150. Set Screws, 160. Turnbuckles, 162. Cotters, 164. Thumbscrews, 165. Rivets, 166. Iron Pipe, 167. Tin and Zinc, 169. Lead Pipe, 171. Chains and Cables, 173. Sprocket-wheels, 176. Modulus of Elasticity, 181. Deflections, 184. Modulus of Rupture, 185. Moment of Inertia, 187. Strength of Beams, 188.

Page

CHAPTER V

MECHANICS 191

Acceleration of Falling Bodies, 191. Center of Gravity, 194. Radius of Gyration, 197. Specific Gravities, 108. Physical Constants, 202. Expansion of Solids, 205. Measurement of Heat, 207. Radiation of Heat, 208. Equivalent Temperatures, 211. Strength of Materials, 213. Properties of Air, 215. Pressure of Water, 219. Electrical and Mechanical Units, 220.

CHAPTER VI

ALLOYS 222

Alloys of Copper, Tin and Zinc, 222. Aluminum bronze, 226. Bearing Metals, 226.

BELTING 227

Formulas for Width of Belts, 228. Speed of Belts, 229. Rules for Speeds and Diameters of Pulleys, 231. Formulas for Cast Iron Fittings, 232.

CHAPTER VII

USEFUL INFORMATION 234

Shrinkage of Castings, 234. Window Glass, 236. Fire Clays, 236. Weight of Metals, 239. Iron Ores, 240.

CHAPTER VIII

IRON 241

Physical Properties of Iron, 241. Grading Pig Iron, 242. Standard Specifications for Pig Iron, 246. Machine-cast Pig Iron, 248. Charcoal Iron, 250. Grading Scrap Iron, 250.

CHAPTER IX

CHEMICAL CONSTITUENTS OF CAST IRON 252

Influence of Carbon, 252. Loss or Gain of Carbon in Remelting, 254. Influence of Silicon, 256. Influence of Sulphur, 260. Influence of Phosphorus, 263. Influence of Manganese, 265. Aluminum, 266. Nickel, 267. Titanium, 267. Vanadium, 268. Thermit, 270. Oxygen, 270. Nitrogen, 271.

CHAPTER X

MIXING IRON 273

Mixing by Fracture, 273. Mixing Iron by Analysis, 274. Castings for Agricultural Machinery, Cylinders and Flywheels, 277. Castings for Chills, Motor Frames and Gas En-

Page

gines, 278. Castings for Gears, Hydraulic Machinery and Locomotives, 280. Castings for Pulleys, Radiators and Heaters, 284. Castings for Weaving, Woodworking Machinery, etc., 287.

CHAPTER XI

STEEL SCRAP IN MIXTURES OF CAST IRON 290

Recovering and Melting Shot Iron, 291. Burnt Iron, 293. Melting Borings and Turnings, 293.

CHAPTER XII

TEST BARS 294

Report of Committee on Test Bars of American Foundryman's Association, 294. Proposed Specifications for Gray Iron, 296. Patterns for Test Bars of Cast Iron, 297. Erratic Results, 298. Table of Moduli of Rupture, 299. Comparison of Test Bars, 302. Casting Defects, 304. Circular Test Bars, 304. Effect of Structure of Cast Iron Upon its Physical Properties, 306. Mechanical Tests, 307. Chemical Analysis, 308. Chilled and Unchilled Bars, 310. Forms of Combination of Iron and Carbon, 313.

CHAPTER XIII

CHEMICAL ANALYSES 315

Strength, 315. Elastic Properties, 322. Hardness, 324. Grain Structure, 329. Shrinkage, 329. Fusibility, 332. Fluidity, 334. Resistance to Heat, 335. Electrical Properties, 338. Resistance to Corrosion, 340. Resistance to Wear, 342. Coefficient of Friction, 342. Casting Properties, 343. Micro-structure of Cast Iron, 345.

CHAPTER XIV

STANDARD SPECIFICATIONS FOR CAST IRON CAR WHEELS 350

Chemical Properties, 350. Drop Tests, 350. Marking, 351. Measures, 351. Finish, 351. Material and Chill, 351. Inspection and Shipping, 352. Retaping, 353. Thermal Test, 353. Storing and Shipping, 354. Rejections, 354.

STANDARD SPECIFICATIONS FOR LOCOMOTIVE CYLINDERS 355

Process of Manufacture, 355. Chemical Properties, 355. Physical Properties, 355. Test Pieces, 355. Character of Castings, 355. Inspector, 355.

Page

Standard Specifications for Cast Iron Pipe 356

Allowable Variations, 356. Defective Spigots, 357. Special Castings, 357. Tables of General Dimensions, 358. Marking, 360. Quality of Iron, 360. Tests, 361. Cleaning and Coating, 361. Contractor, Engineer, Inspector, 362. Tables of Weight of Pipe, 364.

CHAPTER XV

Mechanical Analysis 371

Shrinkage Chart, 372. Keep's Strength Table, 375. Standard Methods for Determining the Constituents of Cast Iron, 377.

CHAPTER XVI

Malleable Cast Iron 382

Black Heart, 382. Ordinary or Reaumur Malleable Iron, 385. Temperature Curve for Annealing Oven, 386. Analysis Before and After Annealing, 387. American Practice, 389. Specifications, 392. Comparison of Tests, 392.

CHAPTER XVII

Steel Castings in the Foundry 394

Normal Steels, 396. Bessemer Process, 396. The Baby Converter, 397. Annealing, 400. Tropenas Process, 401. Chemistry in the Process, 403. Converter Linings, 404. Standard Specifications, 409. Open Hearth Methods, 411. Comparative Cost of Steel Castings, 417. Basic Open Hearth, 418. Acid Open Hearth, 419. Converter, 420. Converter with Large Waste, 421. Crucible Castings, 423. Electric Furnace, 424.

CHAPTER XVIII

Foundry Fuels 425

Anthracite Coal, 425. Coke, 425. By-product Coke, 426. Effect of Atmospheric Moisture Upon Coke, 427. Specifications for Foundry Coke, 428. Fluxes, 429. Comparison of Slags, 432. Fire Brick and Fire Clay, 434. Fire Sand, 435. Magnesite, 436. Bauxite, 436.

CHAPTER XIX

The Cupola 437

The Lining, 437. Tuyeres, 439. The Breast, 440. Sand Bottom, 441. Zones of Cupola, 442. Chemical Reaction in

Page

Cupola, 443. Wind box, 445. The Blast, 446. Sturtevant Blowers, 448. Buffalo Blowers, 449. Root Blowers, 449. Diameter of Blast Pipe, 450. Dimensions of Cupolas, 451. Charging and Melting, 452. The Charging Floor, 453. Melting Losses, 454. Melting Ratio, 461. Appliances About Cupola, 462. Ladles, 462. Tapping Bar, 463. Bod Stick, 463. Capacities of Ladles, 464. Applying Metalloids in Ladles, 465. Cranes, 466. Spill Bed, 466. Gagger Moulds, 467.

CHAPTER XX

MOULDING SAND 468

Bonding Power, 468. Permeability and Porosity, 468. Refractoriness, 469. Durability, 469. Texture, 469. Grades, 470. Sand for Brass, 472. Testing Sand, 473. For Dry Sand Moulding, 477. Skin Drying, 469. Core Sand, 479. Core Mixtures, 480. Dry Binders, 481. Parting Sand, 486. Facings, 486.

CHAPTER XXI

THE CORE ROOM AND APPURTENANCES 492

Core Oven Carriages, 496. Mixing Machines, 497. Sand Conveyors, 497. Rod Straighteners, 497. Wire Cutter, 497. Sand Driers, 498. Core Plates, 498. Core Machines, 499. Cranes and Hoists, 499.

CHAPTER XXII

THE MOULDING ROOM 501

Cranes, 502. Hooks, Slings and Chains, 502. Lifting Beams, 503. Safe Loads, 504. Binder Bars, 505. Clamps, 506. Flasks, 506. Iron Flasks, 510. Sterling Steel Flasks, 515. Snap Flasks, 517. Slip Boxes, 519. Pins, Plates and Hinges, 519. Sweeps, 522. Anchors, Gaggers and Soldiers, 523. Sprues, Risers and Gates, 524. Top Pouring Gates, 526. Whirl Gates, 527. Skim Gates, 527. Horn Gates, 527. Strainers and Spindles, 528. Weights, 528. Chaplets, 528. Liquid Pressure on Moulds, 529. Nails, 536. Sprue Cutters, 537.

CHAPTER XXIII

MOULDING MACHINES 538

Jigs, 540. Flasks, 547. Moulding Operations, 549.

Page

CHAPTER XXIV

Continuous Melting 551

Multiple Moulds, 555. Permanent Moulds, 558. Centrifugal Castings, 561. Castings Under Pressure, 562. Direct Casting, 562. Carpenter Shop and Tool Room, 562. The Cleaning Room, 563. Tumbling Mills, 563. Chipping, 566. Grinding, 566. Sand Blast, 566. Pickling, 567.

CHAPTER XXV

Determination of Weight of Castings 569

By Weight of Patterns, 569. Weight of Pattern Lumber, 569. Formulas for Finding Weight of Castings, 570. Formulas for Weight on Cope, 575.

CHAPTER XXVI

Water, Lighting, Heating and Ventilation 577

Water Supply, 577. Lighting, 578. Heating and Ventilation, 579.

CHAPTER XXVII

Foundry Accounts 587

Foundry Requisition, 588. Pattern Card, 589. Pig Iron Card, 590. Core Card, 591. Heat Book, 592. Cleaning Room Report, 597. Weekly Foundry Report, 600. Monthly Expenditure of Supplies, 601. Comparison of Accounts, 605. Transmission of Orders, 611. American Foundrymen's Association Methods, 612. Cost of Metal, 617. Moulding, 619. Cleaning and Tumbling, 620. Pickling, 621. Sand Blasting, 622. Core Making, 623. A Successful Foundry Cost System, 625. Castings Returned, 629.

CHAPTER XXVIII

Pig Iron Directory 633

Classification and Grades of Foundry Iron, 633. Coke and Anthracite Irons, 635. Charcoal Irons, 655.

Authorities 660

Index 663

Most readers of this book will, without doubt, be familiar with the ordinary mathematical processes; to them, such brief references as may appear, will, perhaps, seem superfluous. There may be, however, those who, from disuse or otherwise, are not so circumstanced. For their convenience such information will be given as may facilitate the interpretation of the formulas and calculations herein.

SIGNS AND ABBREVIATIONS

A prime mark ′ above a number means minutes or linear feet; as 10′ means ten minutes or ten linear feet.

Two prime marks ″ likewise mean seconds; or linear inches; as 10″ indicates 10 seconds or 10 linear inches.

The sign □ means square, as □′ square foot, □″ square inch.

The sign ○ means round or circular, as ○″ circular inch.

The sign ∠ means an angle.

The sign ∟ means a right angle.

The sign ⊥ means a perpendicular.

The sign π, called Pi, means the ratio of the circumference of a circle to the diameter, and is equal to 3.14159.

The sign g means acceleration due to gravity and equals 32.16 foot pounds per second.

The sign E indicates the coefficient of elasticity.

The sign f indicates the coefficient of friction.

The sign M indicates modulus of rupture.

The sign *log* indicates the common logarithm.

The sign $\log_\epsilon$ or *log hyp.* hyperbolic logarithm.

R.p.m. revolutions per minute.

H.P. horse power.

K.W. Hr. Kilowatt hours.

A.W.G. American wire gauge.

B.W.G. Birmingham wire gauge.

A.S.M.E. American Society of Mechanical Engineers.

A.F.A. American Foundrymen's Association.

B.F.A. Birmingham Foundrymen's Association.

I.S.I. Iron and Steel Institute.

FOUNDERS MANUAL

ELEMENTARY MATHEMATICS

CHAPTER I

SECTION I

ARITHMETIC

It is deemed unnecessary to present anything under this branch of mathematics, except Ratio and Proportion, Square and Cube Roots, Alligation and Percentage. These operations are applied so frequently in the foundry that, it is believed, a simple explanation of them will not be out of place.

Ratio and Proportion

The ratio of two numbers is the relation which the first bears to the second and is equivalent to a fraction obtained by dividing the first number by the second.

Thus: $5 : 7 = \frac{5}{7}$ or $7 : 5 = \frac{7}{5}$.

When the first of four numbers is the same fraction of the second, as the third is of the fourth, the first has the same ratio to the second as the third has to the fourth, and the four numbers are in proportion. Proportion, therefore, is the equality of two ratios.

Thus:

$$\frac{4}{6} = \frac{10}{15} = \frac{2}{3}.$$

The proportion is expressed, 4 : 6 :: 10 : 15, and is read, 4 is to 6 as 10 is to 15. The first and fourth terms are called the extremes; the second and third the means.

The product of the extremes is equal to the product of the means; thus in the above proportion $4 \times 15 = 6 \times 10 = 60$. Hence where three terms of the proportion are known the fourth can be found.

Thus: Find the number to which 10 bears the same ratio as 4 does to 6.

4 : 6 :: 10 : required number.

Required number equals $\frac{60}{4} = 15$.

Where one extreme and both means are known, to find the other extreme, divide the product of the means by the known extreme.

Where both extremes and one mean are known, to find the other mean, divide the product of the extremes by the known mean.

For the purpose of illustrating these rules replace the figures in a proportion, by the letters A, B, C, D, and write $A : B :: C : D$; then, $AD = BC, \frac{A}{B} = \frac{C}{D}, A = \frac{BC}{D}, D = \frac{BC}{A}, B = \frac{AD}{C}, C = \frac{AD}{B}$.

To state the terms of a simple proportion where three are given; place that as the third term which is of the same kind as the required term; then consider whether the required term should be greater or less than the third term; if greater, make the greater of the two remaining terms the second and the other the first term. But if the required term should be less than the third term, place the smaller of the first two as the second term and the greater as the first.

Thus: What is the price, per net ton, of pig iron sold at $17.50 gross ton?

As the price is required, $17.50 becomes the third term. Since the net price is less than the gross, 2000 is the second term and 2240 the first. The proportion is then written:

2240 : 2000 :: $17.50 : answer.

$$\frac{2000 \times \$17.50}{2240} = \$15.62 = \text{required price.}$$

Again the ratio of net to gross is $\frac{2000}{2240} = .892 +$. Therefore, the net price is equal to the gross multiplied by 0.892 +; or $\$17.50 \times .892 = \$15.62$; or the net price being known the gross is equal to the net multiplied by $\frac{2240}{2000}$; $\$15.62 \times 1.12 = \$17.50$.

Compound Proportion

Where the ratio of two quantities depends upon a combination of other ratios, the proportion becomes a compound proportion. In this as in simple proportion, there is but one third term, and it is of the same kind as the required term; there may be two or more first and second terms. Set down the third term as in simple proportion; consider each pair of terms of the same kind separately and as terms of a simple proportion, and arrange them in the same manner, making the greater of the pair the second term, if the answer considered with reference to this pair alone should be greater than the third term; or the reverse if it should be less.

Set down the terms under each other in their order of first and second terms. Multiply the product of all the second terms by the third term and divide this product by that of all the first terms.

Example. — If 36 men working 10 hours per day perform $\frac{2}{5}$ of a piece of work in 17 days, how long must 25 men work daily to complete the work in 16 days?

The length of the day will be greater the fewer the men, and the fewer the days are; and less, the less the work is; hence, the above problem is stated as follows:

Men	25 : 36 :: 10
Days	16 : 17 ::
Fifths of work	3 : 2

$$\frac{36 \times 17 \times 2 \times 10}{25 \times 16 \times 3} = \frac{51}{5} = 10.2 \text{ hours per day.}$$

Roots of Numbers

To Extract the Square Root of a Given Number

Point off the number into periods of two figures each, beginning with units; if there are decimals, begin at the decimal point, separating the whole number to the left and the decimal to the right into such periods, supplying as many ciphers in groups of two, as may be desired.

Find the greatest number whose square is less than the first left hand period and place this to the right of the given number as the first figure of the root. Subtract its square from the first left hand period and to the remainder annex the second period for a dividend.

Place before this as a partial divisor, double the root figure just found. Find how many times the dividend, exclusive of its right hand figure, contains the divisor, and place the quotient as the second figure of the root, and also at the right of the partial divisor.

Multiply the divisor thus completed, by the second root figure and subtract the product from the dividend. To this remainder annex the next period for a new dividend, and double the two root figures for a new partial divisor. Proceed as before until all the periods have been brought down.

Example. — Extract the square root of 7840.2752 +.

```
           78'40.27'52/88.5453
           64
     168)1440
           1344
    1765)9627
            8825
   17704)80252
             70816
  177085)943600
               885425
 1770903)5817500
                5312709
```

To Extract the Square Root of a Fraction

Find the roots of the numerator and denominator separately; or reduce to a decimal and take its root.

Example.— $\sqrt{\frac{9}{16}} = \frac{\sqrt{9}}{\sqrt{16}} = \frac{3}{4}$; or $\frac{9}{16} = 0.5625$, $\sqrt{0.5625} = 0.75$.

To Extract the Cube Root of a Number

Beginning at the right, point off the number into periods of three figures each. If there are decimals, begin at the decimal point, separate the whole number to the left, and the decimal at the right into such periods; find the greatest cube contained in the left-hand period, and write its root as the first figure of the root required.

Subtract the cube of the first root figure from the left-hand period, and to the remainder annex the next period for a dividend. Then multiply the square of the first figure of the root by 300 and use the product as a trial divisor; write the quotient as the second root figure. Complete the trial divisor by adding to it 30 times the product of the first root figure by the second, and the square of the second; multiply the completed divisor by the second root figure and subtract the product from the dividend. To the remainder annex the next period and proceed as before, to find the third figure of the root, *i.e.*, square the first two figures of the root and multiply by 300 for a trial divisor. To this add 30 times the product of the first two root figures by the third, and the square of the third for the completed divisor, etc.

The cube root will always contain as many figures as there are periods in the given number.

Example. — Extract the cube root of 78,402,752

		78'402'752/428.
		64
$4^2 \times 300 =$	4800	14402
$4 \times 2 \times 30 =$	240	
$2^2 =$	4	
	5044	10088
$42^2 \times 300 =$	529200	4314752
$42 \times 8 \times 30 =$	10080	
$8^2 =$	64	
	539344	4314752

Alligation

Alligation is the process of determining the value of a mixture of different substances, when the quantity and value of each substance is known.

Rule. — Take the sum of all the products of the quantity of each substance by its respective price, and divide it by the total quantity; the result is the value of one unit of the mixture.

Example. — What is the value per ton of a mixture containing 500 lbs. of pig iron at $18.00 per ton, 275 lbs. at $16.50 and 800 lbs. of scrap at $14.00?

500×18	=	9000
275×16.5	=	4537.50
800×14	=	11200.00
1575		24737.50

$$\frac{24737.50}{1575} = \$15.706 \text{ per ton.}$$

Percentage

Per cent means so many parts of 100, and is expressed decimally as three per cent .03, meaning $\frac{3}{100}$; one-fourth of one per cent $.0025 = \frac{25}{10000}$.

Percentage covers the operations of finding the part of a given number at a given rate per cent; as 6 per cent of 2750, $2750 \times .06 = 165.00$; of finding what per cent one number is of another as: What per cent of 780 is 39?

$$39 \div 780 = .05 \text{ per cent;}$$

of ascertaining a number when an amount is given, which is a given per cent of that number; as 62.5 is .04 per cent of what number?

$$62.5 \div .04 = 1562.5.$$

Decimal Equivalents of Parts of One Inch

1-64	.015625	17-64	.265625	33-64	.515625	49-64	.576625
1-32	.031250	9-32	.281250	17-32	.531250	25-32	.781250
3-64	.046875	19-64	.296875	35-64	.546875	51-64	.796875
1-16	.062500	5-16	.312500	9-16	.562500	13-16	.812500
5-64	.078125	21-64	.328125	37-64	.578125	53-64	.828125
3-32	.093750	11-32	.343750	19-32	.593750	27-32	.843750
7-64	.109375	23-64	.359375	39-64	.609375	55-64	.859375
1-8	.125000	3-8	.375000	5-8	.625000	7-8	.875000
9-64	.140625	25-64	.390625	41-64	.640625	57-64	.890625
5-32	.156250	13-32	.406250	21-32	.656250	29-32	.906250
11-64	.171875	27-64	.421875	43-64	.671875	59-64	.921875
3-16	.187500	7-16	.437500	11-16	.687500	15-16	.937500
13-64	.203125	29-64	.453125	45-64	.703125	61-64	.953125
7-32	.218750	15-32	.468750	23-32	.718750	31-32	.968750
15-64	.234375	31-64	.484375	47-64	.734375	63-64	.984375
1-4	.250000	1-2	.500000	3-4	.750000	1	1

Inches to Decimals of a Foot

	0	1	2	3	4	5	6	7	8	9	10	11
....	....	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500	.8333	.9167
$\frac{1}{32}$	.0026	.0859	.1693	.2526	.3359	.4193	.5026	.5859	.6693	.7526	.8359	.9193
$\frac{1}{16}$	.0052	.0885	.1719	.2552	.3385	.4219	.5052	.5885	.6719	.7552	.8385	.9219
$\frac{3}{32}$	.0078	.0911	.1745	.2578	.3411	.4245	.5078	.5911	.6745	.7578	.8411	.9245
$\frac{1}{8}$	.0104	.0938	.1771	.2604	.3438	.4271	.5104	.5938	.6771	.7604	.8438	.9271
$\frac{5}{32}$	.0130	.0964	.1797	.2630	.3464	.4297	.5130	.5964	.6797	.7630	.8464	.9297
$\frac{3}{16}$	.0156	.0990	.1823	.2656	.3490	.4323	.5156	.5990	.6823	.7656	.8490	.9323
$\frac{7}{32}$	.0182	.1016	.1849	.2682	.3516	.4349	.5182	.6016	.6849	.7682	.8516	.9349
$\frac{1}{4}$	.0208	.1042	.1875	.2708	.3542	.4375	.5208	.6042	.6875	.7708	.8542	.9375
$\frac{9}{32}$	.0234	.1068	.1901	.2734	.3568	.4401	.5234	.6068	.6901	.7734	.8568	.9401
$\frac{5}{16}$	.0260	.1094	.1927	.2760	.3594	.4427	.5260	.6094	.6927	.7760	.8594	.9427
$\frac{11}{32}$	.0286	.1120	.1953	.2786	.3620	.4453	.5286	.6120	.6953	.7786	.8620	.9453
$\frac{3}{8}$	.0313	.1146	.1979	.2813	.3646	.4479	.5313	.6146	.6979	.7813	.8646	.9479
$\frac{13}{32}$	.0339	.1172	.2005	.2839	.3672	.4505	.5339	.6172	.7005	.7839	.8672	.9505
$\frac{7}{16}$	.0365	.1198	.2031	.2865	.3698	.4531	.5365	.6198	.7031	.7865	.8698	.9531
$\frac{15}{32}$	.0391	.1224	.2057	.2891	.3724	.4557	.5391	.6224	.7057	.7891	.8724	.9557
$\frac{1}{2}$	.0417	.1253	.2083	.2917	.3750	.4583	.5417	.6250	.7083	.7917	.8750	.9583
$\frac{17}{32}$	.0443	.1276	.2109	.2943	.3776	.4609	.5443	.6276	.7109	.7943	.8776	.9609
$\frac{9}{16}$	.0469	.1302	.2135	.2969	.3802	.4635	.5469	.6302	.7135	.7969	.8802	.9635
$\frac{19}{32}$	.0495	.1328	.2161	.2995	.3828	.4661	.5495	.6328	.7161	.7995	.8828	.9661
$\frac{5}{8}$	.0521	.1354	.2188	.3021	.3854	.4688	.5521	.6354	.7188	.8021	.8854	.9688
$\frac{21}{32}$	.0547	.1380	.2214	.3047	.3880	.4714	.5547	.6380	.7214	.8047	.8880	.9714
$\frac{11}{16}$	.0573	.1406	.2240	.3073	.3906	.4740	.5573	.6406	.7240	.8073	.8906	.9740
$\frac{23}{32}$	.0599	.1432	.2266	.3099	.3932	.4766	.5599	.6432	.7266	.8099	.8932	.9766
$\frac{3}{4}$	.0625	.1458	.2292	.3125	.3958	.4792	.5625	.6458	.7292	.8125	.8958	.9792
$\frac{25}{32}$	.0651	.1484	.2318	.3151	.3984	.4818	.5651	.6484	.7318	.8151	.8984	.9818
$\frac{13}{16}$	.0677	.1510	.2344	.3177	.4010	.4844	.5677	.6510	.7344	.8177	.9010	.9844
$\frac{27}{32}$	.0703	.1536	.2370	.3203	.4036	.4870	.5703	.6536	.7370	.8203	.9036	.9870
$\frac{7}{8}$	.0729	.1563	.2396	.3229	.4063	.4896	.5729	.6563	.7396	.8229	.9063	.9896
$\frac{29}{32}$	.0755	.1589	.2422	.3255	.4089	.4922	.5755	.6589	.7422	.8255	.9089	.9922
$\frac{15}{16}$	.0781	.1615	.2448	.3281	.4115	.4948	.5781	.6615	.7448	.8281	.9115	.9948
$\frac{31}{32}$	.0807	.1641	.2474	.3307	.4141	.4974	.5807	.6641	.7474	.8307	.9141	.9974

PRODUCTS OF FRACTIONS EXPRESSED IN DECIMALS

0	1	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2
1/16	.0625	.0039							
1/8	.1250	.0078	.0156						
3/16	.1875	.0117	.0234	.0352					
1/4	.2500	.0156	.0313	.0469	.0625				
5/16	.3125	.0195	.0391	.0586	.0781	.0977			
3/8	.3750	.0234	.0169	.0703	.0937	.1172	.1406		
7/16	.4375	.0273	.0547	.0820	.1093	.1367	.1641	.1914	
1/2	.5000	.0313	.0625	.0938	.1250	.1562	.1875	.2188	.2500
9/16	.5625	.0352	.0703	.1055	.1406	.1758	.2109	.2461	.2813
5/8	.6250	.0391	.0781	.1172	.1562	.1953	.2344	.2734	.3125
11/16	.6875	.0430	.0859	.1289	.1719	.2148	.2578	.3008	.3438
3/4	.7500	.0469	.0938	.1406	.1875	.2344	.2813	.3281	.3750
13/16	.8125	.0508	.1016	.1523	.2031	.2539	.3047	.3555	.4036
7/8	.8750	.0547	.1094	.1641	.2187	.2734	.3281	.3828	.4375
15/16	.9375	.0586	.1172	.1758	.2344	.2930	.3516	.4102	.4688
1	1.0000	.0625	.1250	.1875	.2500	.3125	.3750	.4375	.5000

0	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
9/16	.3164							
5/8	.3516	.3906						
11/16	.3867	.4297	.4727					
3/4	.4219	.4688	.5156	.5625				
13/16	.4570	.5078	.5586	.6094	.6601			
7/8	.4922	.5469	.6016	.6563	.7109	.7656		
15/16	.5273	.5859	.6445	.7031	.7617	.8203	.8789	
1	.5625	.6250	.6875	.7500	.8125	.8750	.9375	1.0000

SECTION II

ALGEBRA

In algebra quantities of every kind are denoted by letters of the alphabet.

The first letters of the alphabet are used to denote known quantities, and the last letters unknown quantities.

The sign + (plus) denotes that the quantity before which it is placed is to be added to some other quantity. Thus: $a + b$ denotes the sum of a and b.

The sign − (minus) denotes that the quantity before which it is placed is to be subtracted from some other quantity. Thus: $a - b$ denotes that b is to be subtracted from a.

When no sign is prefixed to a quantity, + is always understood.

Quantities are said to have like or unlike signs, according as their signs are like or unlike.

A quantity which consists of one term is said to be simple; but if it consists of several terms connected by the signs + or −, it is said to be compound. Thus: a or $-b$ are simple quantities; but $-a-b$ is a compound quantity.

Addition of Like Quantities

Add together the coefficients of the quantities having like signs, and subtract the negative sum from the positive. Thus: Add $7a+2a$, $3a-a$, and $6a-4a$.

$$\begin{array}{l} 7a - a \\ 2a - 4a \\ 3a \\ 6a \\ \hline 18a - 5a = 13a. \end{array}$$

Addition of Unlike Quantities

If some of the quantities are unlike, proceed as before with each like quantity, and write down the algebraic sum of all the quantities. Thus: Add $7a+2b$, $3a-b$, $6b-4a$ and $5a-4b$.

$$\begin{array}{rrrr} 7a & -4a & 2b & -b \\ 3a & - & 6b & -4b \\ 5a & & & \\ \hline 15a & -4a & 8b & -5b \\ -4a & & -5b & \\ \hline 11a & & 3b & \end{array}$$

$$Answer = 11a + 3b.$$

The process is the same with compound quantities. Thus: Add a^2b+2cd^2 to $-2a^2b+cd^2 = 3cd^2 - a^2b$.

Subtraction

Change the sign of the subtrahend and proceed as in addition. Thus: Subtract $3a^2b-9c$ from $4a^2b+c$; changing the signs of the subtrahend and adding, the expressions may be written

$$4a^2b - 3a^2b + c + 9c \quad \text{or} \quad a^2b + 10c.$$

Multiplication

If the quantities to be multiplied have like signs, the sign of the product is +; if they have unlike signs, that of the product is −.

Of Simple Quantities

Multiply the coefficients together and prefix the + or − sign, according as the signs of the quantities are like or unlike. Thus:

Multiply $+a$ by $+b$. Product equals $+ab$.
Multiply $+5b$ by $-4c$. Product equals $-20bc$.
Multiply $-3ax$ by $+7ab$. Product equals $-21a^2bx$.

Of Compound Quantities

Multiply each term of the multiplicand by all the terms of the multiplier, one after the other as by former rule; collect their products into one sum for the required product.

Example. —

$$\begin{array}{lllll}
\text{Multiply} & a - b + c & & & \\
\text{by} & a + b - c & & & \\
\hline
 & a^2 - \not{ab} + \not{ac} & & & \\
 & \quad + \not{ab} & -b^2 + bc & & \\
 & \qquad - \not{ac} & \quad + bc - c^2 & & \\
\hline
 & a^2 & -b^2 + 2bc - c^2 & &
\end{array}$$

$$\begin{array}{ll}
\text{Multiply} & 2x + y \\
\text{by} & x - 2y \\
\hline
 & 2x^2 + xy \\
 & \quad - 4xy - 2y^2 \\
\hline
 & 2x^2 - 3xy - 2y^2
\end{array}$$

Powers of Quantities

The products arising from the continued multiplication of the same quantity by itself are called powers of that quantity; and the quantity itself is called the root.

The product of two or more powers of any quantity is the quantity with an exponent equal to the sum of the exponents of the powers. Thus:

$$a^2 \times a^3 = a^5; \quad a^2b \times ab = a^3b^2; \quad 4ab \times -3ac = -12a^2bc.$$

The square of the sum of two quantities equals the sum of their squares plus twice their product.

$$(a+b)^2 = a^2 + b^2 + 2ab.$$

The square of the difference of two quantities is the sum of their squares minus twice their product.

$$(a-b)^2 = a^2 + b^2 - 2ab.$$

The product of the sum and difference of two quantities is equal to the difference of their squares.

$$(a + b)\,(a - b) = a^2 - b^2.$$

The squares of half the sum of two quantities is equal to their product plus the square of half their difference.

Thus: $$\frac{(a + b)^2}{2} = ab + \frac{(a - b)^2}{2}$$

The square of a trinomial is equal to the sum of the squares of each term plus twice the product of each term by each of its following terms.

Thus: $$(a + b + c)^2 = a^2 + b^2 + c^2 + 2\,ab + 2\,ac + 2\,bc.$$
$$(a - b - c)^2 = a^2 + b^2 + c^2 - 2\,ab - 2\,ac + 2\,bc.$$

Parenthesis ( )

When a parenthesis is preceded by a plus sign, it may be removed without changing the value of the expression.

Thus: $$(a + b) + (a + b) = 2\,a + 2\,b.$$

But if preceded by a minus sign, if removed, the signs of all the terms within the parenthesis must be changed.

Thus: $$(a + b) - (a - b) = a + b - a + b = 2\,b.$$

When a parenthesis is within a parenthesis, remove the inner one first.

Thus: $$a - [b - [c - (d - e)]] = a - [b - [c - d + e]] =$$
$$a - [b - c + d - e] = a - b + c - d + e.$$

Where the sign of multiplication ($\times$) appears, the operation indicated by it must be performed before that of addition or subtraction.

Division

If the sign of the divisor and dividend be like, the sign of the quotient is plus (+); but if they be unlike the sign of the quotient is minus (−).

To Divide a Monomial by a Monomial

Write the dividend over the divisor with a line between them. If the expressions have common factors remove them.

Thus: $$a^2bx \div aby = \frac{a^2bx}{aby} = \frac{ax}{y}; \quad \frac{a^3}{a^5} = \frac{1}{a^2} = a^{-2}$$

To Divide a Polynomial by a Monomial

Divide each term of the polynomial by the monomial.

Thus: $$(8\,ab - 12\,ac) \div 4\,a = 2\,b - 3\,c.$$

To Divide a Polynomial by a Polynomial

Arrange the terms of both dividend and divisor according to the ascending or descending powers of some letter, and keep this arrangement throughout the operation. Divide the first term of the dividend by the first term of the divisor, and write the result as the first term of the quotient.

Multiply all the terms of the divisor by the first term of the quotient and subtract the product from the dividend. If there is a remainder consider it as a new dividend and proceed as before.

Thus:

$$(a^2 - b^2) \div (a + b)$$

$$\begin{array}{r} a + b)\,a^2 - b^2\,(\underline{a - b} \\ \underline{a^2 + ab\quad} \\ -ab - b^2 \\ \underline{-ab - b^2} \end{array}$$

(1) The difference between two equal powers of the same quantities is divisible by their difference.

(2) The difference between two equal *even* powers of the same quantities is divisible by their sum or difference.

(3) The sum of two equal *even* powers of the same quantities is not divisible by their sum or difference.

(4) The sum of two equal odd powers of the same quantities is divisible by their sum.

(5) The sum of two equal *even* powers, whose exponents are composed of odd and even factors, is divisible by the sum of the powers of the quantities expressed by the *even* factor.

Thus: $(x^6 + y^6)$ is divisible by $(x^2 + y^2)$.

Simple Equations

An equation is a statement of equality between two expressions; as $a + b = c + d$.

A simple equation, or equation of the first degree, is one which contains only the first power of the unknown quantity.

If both sides of the equation be changed equally, by addition, subtraction, multiplication or division, the equality will not be disturbed.

Any term of an equation may be changed from one side to the other provided its sign be changed.

Thus: $a + b = c + d, \quad a = c + d - b.$

To Solve an Equation Having One Unknown Quantity

Transpose all the terms containing the unknown quantity to one side of the equation, and all the other terms to the other side.

Combine like terms, and divide both sides by the coefficient of the unknown quantity.

Thus: $8x - 29 = 26 - 3x,\quad 11x = 55,\quad x = 5.$

Simple algebraic problems containing one unknown quantity, are solved by making x equal the unknown quantity, and stating the conditions of the problem in the form of an algebraic equation, then solving the equation.

Thus: What two numbers are those whose sum is 48 and difference 14?

Let $x =$ the smaller number.

Then $x + 14 =$ the greater number.

$$x + x + 14 = 48,$$
$$2x = 34.$$

Therefore $x = 17,$

and $x + 14 = 31,$

$$31 + 17 = 48.$$

Find the number whose treble exceeds 50 by as much as its double falls short of 40.

Let $x =$ the number.

Then $3x - 50 = 40 - 2x,$

$$5x = 90,\qquad x = 18.$$

Equations Containing Two Unknown Quantities

If one equation contains two unknown quantities, an indefinite number of pairs of values for them may be found, which will satisfy the equation; but if a second equation be given, only one pair of values can be found that will satisfy both equations. Simultaneous equations, or those which may be satisfied by the same values of the unknown quantity, are solved by combining the equations so as to obtain a single equation containing only one unknown quantity.

This process is called elimination.

Elimination by Addition or Subtraction

Multiply the equations by such a number as will make the coefficients of one of the unknown quantities equal in both. Add or subtract according as they have like or unlike signs.

Solve $2x + 3y = 7$

$4x - 5y = 3$

Multiply by 2 $4x + 6y = 14$

Subtract $4x - 5y = 3$

$$11y = 11$$

$$y = 1.$$

Substituting the value of y in the first equation

$$2x + 3 = 7, \quad \therefore x = 2.$$

Elimination by Substitution

From one of the equations obtain the value of one of the unknown quantities in terms of the other. Substitute this value of this unknown quantity for it, in the other equation, and reduce the resulting equations.

Solve $2x + 3y = 8$ (1)

$3x + 7y = 7$ (2)

From (1) $x = \dfrac{8 - 3y}{2}$

Substituting this value in (2)

$$3\frac{(8 - 3y)}{2} + 7y = 7, \quad 24 - 9y + 14y = 14, \quad \therefore y = -2.$$

Substituting this value in (1);

$$2x - 6 = 8, \quad \therefore x = 7.$$

Elimination by Comparison

From each equation obtain the value of one of the unknown quantities, in terms of the other. Form an equation from these equal values of the same unknown quantity and reduce.

Solve $2x - 9y = 11$ (1)

$3x - 4y = 7$ (2)

From (1) $x = \dfrac{11 + 9y}{2}$

From (2) $x = \dfrac{7 + 4y}{3}$

Placing the values of x in a new equation

$$\frac{11 + 9y}{2} = \frac{7 + 4y}{3}, \quad 19y = -19, \quad \therefore y = -1.$$

Substituting this value of y in (1)

$$2x + 9 = 11, \quad \therefore x = 1.$$

If three simultaneous equations are given containing three unknown quantities, one of the unknown quantities must be eliminated between two pairs of the equations, then a second between the two resulting equations.

Quadratic Equations or Equations of the Second Degree

A quadratic equation contains the square of the unknown quantity, but no higher power. A pure quadratic contains the square only; an adfected quadratic contains both the square and the first power.

To Solve a Pure Quadratic

Collect the unknown quantities on one side, and the known quantities on the other; divide by the coefficient of the unknown quantity and extract the square root of each side of the resulting equation.

Solve $$3x^2 - 15 = 0.$$

$$3x^2 = 15, \quad \therefore x^2 = 5, \quad x = \sqrt{5}.$$

A root which is indicated, but can only be found approximately is called a surd.

Solve $$3x^2 + 15 = 0.$$

$$3x^2 = -15, \quad x^2 = -5, \quad \therefore x = \sqrt{-5}.$$

The square root of a negative quantity cannot be found even approximately, for the square of any number is positive; therefore, a root which is indicated, but cannot be found approximately is called imaginary.

To Solve an Adfected Quadratic

First. — Carry all the terms involving the unknown quantities to one side of the equation and the known quantities to the other side. Arrange the unknown quantities in the order of their exponents, changing the signs of the equation if necessary, so that the sign of the term containing the square of the unknown quantity shall be positive.

Second. — Divide both terms by the coefficient of the square of the unknown quantity.

Third. — To complete the square.

Add to both sides of the equation, the square of half the coefficient of the unknown quantity. The side containing the unknown quantity will now be a perfect square.

Fourth. — Extract the square root of both sides of the equation and solve the resulting simple equation.

Example. — $$x^2 + 2x = 35.$$

Add the square of half the coefficient of x, which is 1, to both sides; then $$x^2 + 2x + 1 = 35 + 1 = 36.$$

Extracting the square root

$$x + 1 = \sqrt{36} = \pm 6$$
$$x = 6 - 1 = 5$$
$$x = -6 - 1 = -7.$$

Example: $3x^2 - 4x = 32.$

Divide by the coefficient of x^2

$$x^2 - \frac{4x}{3} = \frac{32}{3}.$$

Add the square of half the coefficient of x, which equals $(\frac{2}{3})^2 = \frac{4}{9}$;
then $$x^2 - \tfrac{4}{3}x + \tfrac{4}{9} = \tfrac{32}{3} + \tfrac{4}{9}.$$

Extracting the square root, the equation becomes

$$x - \tfrac{2}{3} = \sqrt{\tfrac{100}{9}} = \tfrac{10}{3}$$
$$x = \tfrac{10}{3} + \tfrac{2}{3} = 4, \text{ or } x = -\tfrac{10}{3} + \tfrac{2}{3} = -\tfrac{8}{3} = -2\tfrac{2}{3}.$$

Since the square of a quantity has two roots $\pm$, a quadratic equation has apparently two solutions. Both solutions may be correct; but in some cases one may be correct and the other inconsistent with the conditions of the problem.

For the solution of quadratic equations containing two unknown quantities, or for that of equations of a higher order, a more extended treatment of the subject is required, than is permissible in a book of this character.

SECTION III

PLANE GEOMETRY

Problem 1

To Bisect a Straight Line, or an Arc of a Circle

With any radius greater than half *AB* and with *A* and *B* as centers, describe arcs cutting each other at *C* and *D*. Draw the line *CD*, which will bisect the straight line at *E* and the arc at *F*.

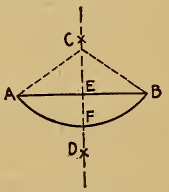


FIG. 1.

Problem 2

To Draw a Perpendicular to a Straight Line, or a Radial Line to the Arc of a Circle

This is the same as Problem 1, Fig. 1.

CD is perpendicular to *AB*, or is radial to the arc.

Problem 3

To Draw a Perpendicular to a Straight Line, from a Given Point on that Line

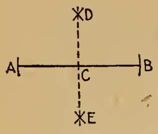


FIG. 2.

With any convenient radius and the given point *C*, as a center, cut the line *AB*, at *A* and *B*. Then with a radius longer than *AC*, describe arcs from *A* and *B* intersecting each other at *D* and *E*. Draw *DC*, perpendicular to *AB*.

In laying out work on the ground or in places where the straight edge and dividers are inapplicable:

Set off six feet from *A* to *B*. Then with *A*, as a center and *AC* = 8′ taken on a tape line, describe an arc at *C*; with *B*, as a center and a radius *BC* = 10′, cut the other arc at *C*. A line through *CA*, will be perpendicular to *AB*. 3, 4 and 5 may be used instead of 6, 8 and 10; or any multiples of 6, 8, 10 will serve.

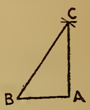


FIG. 3.

Problem 4

From a Point at the End of a Given Line to Draw a Perpendicular

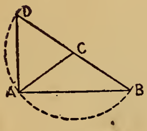


FIG. 4.

From any point *C*, above the line, with the radius *AC*, describe an arc, cutting the given line at *B*. Draw *BC*, and prolong until it intersects the arc at *D*. Then, *DA* will be perpendicular to *AB*, at *A*.

Problem 5

From Any Point Without a Given Straight Line, to Draw a Perpendicular to the Line

Let *BC*, be the given line; then from any point *A*, with any radius *AB*, describe arcs cutting the line at *B* and *C*. From *B* and *C* as centers and any radius greater than half of *BC*, describe arcs intersecting at *D*. Draw *AD*, perpendicular to *BC*. (Fig. 5.)

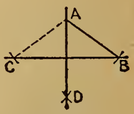


FIG. 5.

Problem 6

To Draw a Straight Line Parallel to a Given Line at a Given Distance from That Line

From any two points on the given line as centers and the given distance as a radius, describe the arcs *B* and *D*. Draw *BD* parallel to *AC*. (Fig. 6.)

FIG. 6.

Problem 7

To Divide a Given Straight Line into Any Nunber of Equal Parts

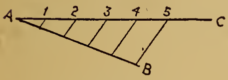


FIG. 7.

Let *AB* be the given line. Draw any line *AC*, intersecting the given line and lay off on it, say, 5 equal parts. Join the last point 5 with *B*. Then through each of the other divisions on *AC*, draw lines parallel to *B* 5, dividing *AB* into 5 equal parts. (Fig. 7.)

Problem 8

To Draw an Angle of 60°, *also One of* 30°

From *A* with any radius describe the arc *CB*, then with the same radius and *B*, as a center, cut the arc at *C*. Then the angle $CAB = 60°$.

From *C* drop *CD* perpendicular to *AB*. The angle $ACD = 30°$.

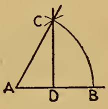


FIG. 8.

Problem 9

To Draw an Angle of 45°

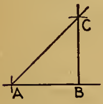


FIG. 9.

Draw *BC*, perpendicular to *AB*. Make $BC = AB$, and draw *AC*. The angle $CAB = 45°$. (Fig. 9.)

Problem 10

To Bisect an Angle

Let *ABC* be the given angle. With *B* as a center and any radius, draw the arc *AC*. Then with *A* and *C* as centers and a radius greater than one-half *AC*, describe arcs cutting each other at *D*. Draw *BD*, which will bisect the angle *ABC*. (Fig. 10.)

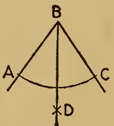


FIG. 10.

Problem 11

Through Two Given Points and With a Given Radius Describe the Arc of a Circle

Referring to Fig. 10. Let A and C be the given points and a distance AB the given radius.

From A and C, with AB as a radius describe arcs cutting each other at B, then with B as a center strike AC.

All Angles in a semicircle are Right Angles.

Problem 12

An Angle at the Center of a Circle is Twice the Angle at the Circumference when Both Stand on the same Arc

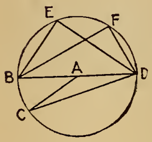


Fig. 11.

Thus the angle BAC is equal to twice the angle BDC. (Fig. 11.)

Problem 13

All the Angles Between an Arc and its Chord, the Sides of the Angle Passing Through the Extremities of the Chord, are Equal. (Fig. 12.)

Thus, the angle $EFG = EHG$.

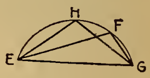


Fig. 12.

Problem 14

To Find the Center of a Circle or of an Arc. (Fig. 13.)

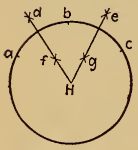


Fig. 13.

Take any three convenient points on the circumference, and with any radius greater than half the distance between any two points, describe arcs cutting each other at d, e, f and g. Through d, f and e, g, draw the lines df and eg; the center is at their intersection H.

Problem 15

To Pass a Circle Through Three Given Points

Referring to Problem 14, let a, b and c be the three given points. Proceed in the same way as to find the center H.

Problem 16

To Describe an Arc of a Circle Passing Through Three Given Points when the Center is not Accessible. (Fig. 14.)

Let A, B and C be the three given points.

From A and B as centers and with AB as a radius, describe the arcs AE and BD.

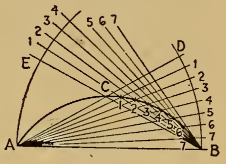


FIG. 14.

Draw AD and BE through C. Lay off on the arc AE, any number of equal parts above E and on BD, the same number below D, numbering the points 1, 2, 3, etc., in the order in which they are taken. Draw from A, lines through 1, 2, 3, etc., on the arc BD; and from B, lines through 1, 2, 3, etc., on the arc AE. The intersections of lines having corresponding numbers will be points on the required arc between C and B.

Proceed in the same manner to find points between C and A. Then draw the arc through the points.

Problem 17

From a Point on the Circumference of a Circle Draw a Tangent to the Circle. (Fig. 15.)

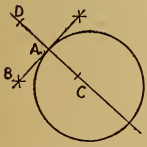


FIG. 15.

Through the given point A draw the radial line AC. Then on AC erect the perpendicular BE, as in Problem 3.

Problem 18

From a Point Without a Circle Draw a Tangent to the Circle. (Fig. 16.)

Let A be the center of the circle, and B the given point. Join A and B, and on the line AB describe a semicircle, with a radius equal to one-half of AB. Through the intersection of the semicircle and the given circle draw the tangent BC.

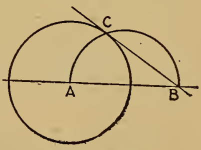


FIG. 16.

Problem 19

Through a Point on a Line, Bisecting the Angle Between Two Lines, Draw a Circle Which Shall be Tangent to the Given Lines. (Fig. 17.)

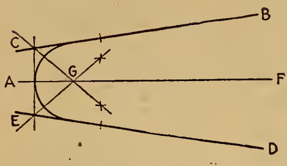


FIG. 17.

Let *A* be the point on a line bisecting the angle between *BC* and *DE*. Through *A* draw *CE* perpendicular to *AF*. Bisect the angles at *C* and *E*. The intersection *G* of the bisecting lines will be on *AF* and at the center of the required circle.

Problem 20

Describe an Arc, Tangent to Two Given Arcs and at a Given Point on one of the Arcs. (Fig. 18.)

Let *A* and *B* be the centers of the given arcs and *C* the point of tangency on the arc, whose center is *B*. Join *A* and *B* and draw *BC* through the given point. Make *CE* equal to the radius *AD*.

Bisect *AE*, draw a perpendicular at its middle point and prolong to intersection with *BC* at *F*, which is the center of the arc required.

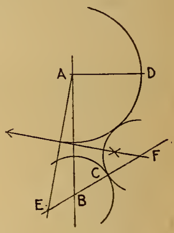


FIG. 18.

Problem 21

To Construct a Pentagon having a Given Side AB. (Fig. 19.)

At *B* erect a perpendicular *BC*, equal to one-half *AB*. Draw *AC* and make *CD* equal *BC*. Then *BD* is the radius of the circle circumscribing a pentagon having sides equal to *AB*.

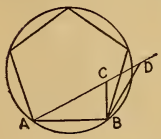


FIG. 19.

The radius of a given circle is the side of an inscribed hexagon.

The radius of a circle circumscribing a hexagon, is equal to the distance from the center of the hexagon to the extremity of one of its sides.

Problem 22

To Construct an Ellipse when the Transverse and Conjugate Axes are Given. (Fig. 20.)

Draw the axes AB and CD intersecting at G. From C, with one-half AB as a radius, cut AB at E and F. Divide GB into any number of parts as at 1, 2, 3, 4, 5.

With E as a center and A 1 as a radius, and with F as a center and radius B 1, strike arcs cutting each other at 1, 1, above and below the transverse axis.

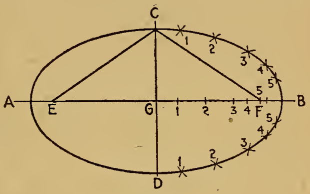


FIG. 20.

Again with E and F as centers and A 2 and B 2, respectively as radii, describe arcs cutting each other at 2, 2. Find as many points as desired in the same way in both halves of the ellipse, then trace the curve.

This construction depends on the property of an ellipse; that the sum of the distances from the foci to any point on the ellipse is equal to the transverse axis.

Problem 23

To Describe an Ellipse Mechanically when the Transverse and Conjugate Axes are Known. (Fig. 21.)

Draw the axes and determine the foci as in Problem 22. Drive two pins at the foci E and F. Fasten to each of the pins one end of a cord whose length is equal to that of the transverse axis.

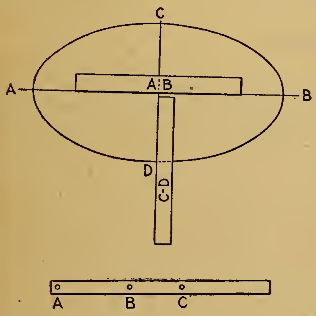


FIG. 21.

Then with a pencil, so placed within the loop of the cord as always to keep it taut and uniformly strained, trace one-half of the curve, from one extremity of the transverse axis to the other. The other half of the curve is traced by changing the cord and pencil to the opposite side of the transverse axis. This method is seldom satisfactory on account of the unequal stretching of the cord.

A better mechanical method of describing an ellipse is to place a straight edge along and above the transverse axis and another along and at one side of the conjugate axis, as at *AB* and *CD* (Fig. 21), leaving a slight opening between the end of the straight edge *CD* and the transverse axis.

There must also be a thin strip of wood with a hole for pencil point at *A* and small pins at *B* and *C*; *AB* being equal to one-half of the conjugate axis; and *AC* equal to one-half the transverse axis. By moving this strip so that the pin *B* is always in contact with *AB* and the pin *C* in like contact with *CD* the upper half of the ellipse may be described.

The straight edges are placed in corresponding positions on the opposite side of the transverse axis to describe the other half of the ellipse.

Except where extreme accuracy is required, it is more convenient to approximate the ellipse with circular arcs.

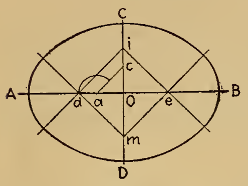


FIG. 22.

Thus: Lay off *AB* and *CD* (Fig. 22) equal to the transverse and conjugate axes respectively. Make *Oa* and *Oc* equal to the difference between the semi-transverse and semi-conjugate axes, and *ad* equal to one-half *ac*. Set off *Oe* equal to *Od*. Draw *di* parallel to *ac*; join *e* and *i* and draw the parallel lines *dm* and *em*. From *m*, with a radius *mC*, strike an arc cutting *md* and *me*. From *i*, with *iD* as a radius, strike an arc cutting *id* and *ie*. Then from *d* and *e*, with radius *Ad*, strike arcs closing the figure.

The Parabola

A parabola is a curve every point of which is equidistant from a line called the directrix and from a point on its axis called the focus. The directrix is a line perpendicular to the axis and at the same distance as the focus from the apex of the curve.

A line perpendicular to the axis, drawn through the focus to the curve, is called the parameter.

If a line be drawn from any point of the curve, perpendicular to the axis, the distance from the apex to the intersection of the perpendicular with the axis is called the abscissa of that point and the distance from the intersection at the axis to the curve is called the ordinate of that point.

Abscissæ of a parabola are as the squares of corresponding ordinates.

Problem 24

To Construct a Parabola when the Focus and Directrix are Given. (Fig. 23.)

Let AB be the directrix, and C the focus of a parabola. Bisect CD at E, which point is the apex of the curve.

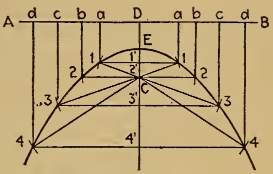


FIG. 23.

Then with C as a center and any radii, as C 1, C 2, etc., strike arcs at 1, 2 and 3, etc. From D as a center and with the radii equal to C 1, C 2, C 3, etc., cut the axis at 1′, 2′, 3′, etc. Through these points draw lines parallel to AB.

The intersection of corresponding parallels and arcs are points on the required curve.

Problem 25

To Construct a Parabola when an Abscissa and Its Corresponding Ordinate are Given. (Fig. 24.)

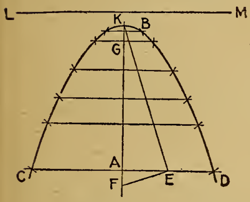


FIG. 24.

Let BA be the given abscissa and AD the ordinate.

Bisect AD at E. Draw EB, and EF perpendicular to EB. Set off BG and BK, each equal to AF. Then will G be the focus and LM (through K) perpendicular to AB, the directrix. Construct the curve as in Problem 24.

The Hyperbola

An hyperbola is a curve, such that the difference of the distances from any point of it to two fixed points is always equal to a given distance.

The two fixed points are called the foci and the given distance is the transverse axis. The conjugate axis is a line perpendicular to the transverse axis at its middle point; and its length is equal to the side of a rectangle, of which the transverse axis is the other side and the distance between the foci, the diagonal.

Problem 26

To Construct an Hyperbola when the Foci and Transverse Axis are Given

Let A and B be the foci and EF the transverse axis. From A set off AG equal to EF. Then, from A as a center and with any distance greater than AF as a radius, strike an arc CD, cutting the transverse axis (prolonged) at H. From B as a center and HG as a radius, describe arcs cutting the arc CD at C and D. C and D will be points on the curve; in like manner any number of points are determined, through which the curve may be traced.

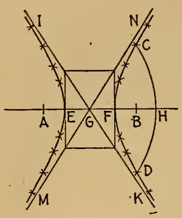


Fig. 25.

Proceeding in the same way on the opposite side of the conjugate axis, the other branch of the curve is constructed.

The diagonals of a rectangle constructed on the transverse and conjugate axes are called the *asymptotes* and are lines to which the curve is tangent at an infinite distance. When the *asymptotes* are at right angles the curve is called an equilateral hyperbola.

It is a property of the equilateral hyperbola, that if the asymptotes be taken as the co-ordinate axes the product of the abscissa and ordinate of any point of the curve is equal to the corresponding product of the co-ordinates at any other point; or that the diagonal of a rectangle constructed by the ordinate and abscissa of any point of the curve passes through the intersection of the axes.

Problem 27

Given the Asymptotes and any Point on the Curve, to Construct the Curve. (Fig. 26.)

Let AB and AG be the asymptotes and D the given point. Multiply AB by AE and divide the product by any other distance AF; then $AG = \frac{AB \times AE}{AF}$, and the intersection at I of lines through F and G, parallel to the axes, is another point on the curve.

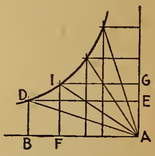


Fig. 26.

Properties of Plane Figures

(1) In a right angle triangle, the square of the hypothenuse is equal to the sum of the squares of the other two sides.

(2) In an equilateral triangle all the angles are equal.

(3) In an isosceles triangle a line drawn from the vertex perpendicular to the base bisects the base and also the angle at the vertex.

(4) An exterior angle of a triangle equals the sum of the two opposite angles.

(5) Similar triangles have equal angles and the sides opposite to corresponding angles are proportional.

(6) In any polygon, the sum of all the interior angles is equal to twice as many right angles as the figure has sides, less four right angles.

(7) In any polygon the sum of all the exterior angles is equal to four right angles, or 360°.

(8) The diagonals of any regular polygon intersect at the center of the figure.

(9) A circle may be passed through any three points, not on the same straight line.

(10) In the same circle, arcs are proportional to the angles at the center.

(11) Any two arcs having the same angle at the center are proportional to their radii.

(12) Areas of circles are proportional to the squares of their diameters or the squares of the radii.

(13) A radius perpendicular to the chord of an arc bisects the arc and its chord.

(14) A straight line tangent to a circle is perpendicular to the radius at the point of tangency.

(15) An angle at the center of the circle is equal to twice the angle at the circumference subtended by the same arc.

(16) Angles at the circumference of a circle, standing on the same arc, are equal.

(17) Any triangle inscribed in a semicircle is a right angled triangle.

(18) In any triangle inscribed in a segment of a circle, the angles at the circumference are equal.

(19) Parallel chords or a chord and a parallel tangent intercept equal arcs.

(20) If two chords of a circle intersect, the rectangles made by the segments of the respective chords are equal.

(21) If one of the chords is a diameter of the circle and the other is perpendicular to it, then one-half of the chord is a mean proportional between the segments of the diameter.

(22) In any circle, with the center as the origin of co-ordinates, the sum of the squares of the abscissa and ordinate of any point is equal to the square of the radius, or $x^2 + y^2 = R^2$.

(23) In any ellipse with same origin, the square of the abscissa of any point multiplied by the square of the semi-conjugate axis plus the square of the ordinate of same point multiplied by the square of the semi-transverse axis is equal to the square of the product of the semi-axes.

Thus: $B^2x^2 + A^2y^2 = A^2B^2$, where A and B are the semi-transverse and semi-conjugate axes.

(24) In an ellipse, lines drawn from any point to the foci make equal angles with a tangent at that point.

(25) The sum of the distances from any point of an ellipse to the foci is equal to the transverse axis.

(26) If from any point of a parabola a line be drawn to the focus, and one parallel to the axis, they will make equal angles with the tangent at that point.

(27) The apex of a parabola bisects the distance on the axis from the focus to the directrix.

(28) The angle between two tangents to a parabola is equal to half the angle at the focus, subtended by the chord joining the points of tangency.

(29) The area included between any chord of a parabola and the curve is equal to two-thirds that of the triangle formed by the chord and tangents through its extremities.

(30) The difference between the focal distances of any point of an hyperbola is equal to the transverse axis.

(31) The product of the perpendiculars from the foci to any tangent of an hyperbola is constant.

(32) A tangent at any point of an hyperbola makes equal angles with the focal distances of the point.

SECTION IV

MENSURATION

PLANE SURFACES

Triangles

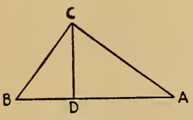


FIG. 27.

The area of any triangle is equal to half the base multiplied by the altitude. (Fig. 27.)

$$\text{Area} = \frac{AB}{2} \times CD.$$

To solve a triangle, three sides, two angles and one side or two sides and one angle must be given.

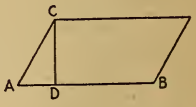


FIG. 28.

The area of a parallelogram is equal to the base multiplied by the perpendicular distance between the sides = $AB \times CD$. (Fig. 28.)

The area of a trapezoid is equal to half the sum of the parallel sides multiplied by the perpendicular distance between them. (Fig. 29.)

$$\text{Area} = \frac{AB + CD}{2} \times CE.$$

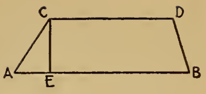


FIG. 29.

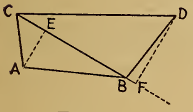


FIG. 30.

The area of a trapezium is equal to the diagonal multiplied by half the sum of the perpendiculars dropped to it from the vertices of the opposite angles. (Fig. 30.)

$$\text{Area} = CB \times \frac{AE + DF}{2}.$$

The area of any quadrilateral is found by multiplying the diagonal by one-half the sum of the perpendiculars dropped from the vertices of the opposite angles. (Fig. 31.)

$$\text{Area} = AC \times \frac{DE + BF}{2}.$$

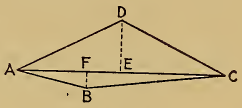


FIG. 31.

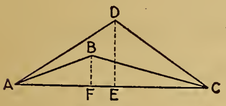


FIG. 32.

If the diagonal falls without the figure, the area is equal to the product of the diagonal by half the difference of the perpendiculars. (Fig. 32.)

$$\text{Area} = ABCD = AC \times \frac{DE - BF}{2}.$$

A polygon is a plane figure bounded by three or more straight lines; it is regular or irregular according as the lines bounding it are equal or unequal.

If straight lines be drawn from the center of a regular polygon to each of the vertices of the interior angles, the polygon will be divided into as many isosceles triangles as it has sides. Each triangle will have for its base one of the sides of the polygon and for its altitude the perpendicular distance from the center of the polygon to that side. The area of the polygon is equal to the sum of the areas of all the triangles, and is found by multiplying one-half the sum of all the sides of the polygon by the perpendicular distance from the center to one of its sides.

To find the area of an irregular polygon, divide the polygon into triangles and take the sum of their areas.

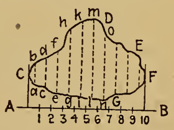


FIG. 33.

To Find the Area of Any Irregular Plane Figure

Let $C\ D\ E\ F\ G$ be any irregular figure. Draw any straight line AB as a base; through the extremities of the figure drop perpendiculars

CA and *FB* to the base. Divide *AB* into any number of equal parts, say 10. Through the middle points of each of the equal divisions draw perpendiculars cutting the boundaries of the figure on opposite sides. Take the sum of the lengths of all these lines within the figure and divide such sum by the number of divisions; the quotient is the mean width of the figure which multiplied by its length *AB* gives the area.

Thus: $ab + cd + ef$ etc. $= H$; then $\frac{H}{10} \times AB$ equals the area of *CDEFG*.

The Circle

The ratio of the circumference of a circle to its diameter is equal to 3.14159. This is represented by the Greek letter π, pronounced Pi.

Let C = the circumference of any circle.
D = the diameter of any circle.
r = the radius of any circle.
A = area of any circle.

The areas of circles are as the squares of their diameters, or as the squares of their radii.

$$C = \pi D = 3.14159 \times D.$$

$$C = 2\pi r = 6.28318 \times r.$$

$$A = \pi r^2 = 3.14159 \times r^2.$$

$$A = \tfrac{1}{4}\pi D^2 = 0.7854 \times D^2.$$

$$A = \frac{C^2}{4\pi} = 0.07958 \times C^2.$$

$$A = 0.7854 \times 4r^2.$$

$$A = \frac{Cr}{2} = \frac{CD}{4}.$$

$$D = \frac{C}{\pi} = 0.3183 \times C.$$

$$D = 2\sqrt{\frac{A}{\pi}} = 1.1284\sqrt{A}.$$

$$r = \frac{C}{2\pi} = 0.5642\sqrt{A}.$$

The Ellipse

The ellipse is a curve formed by the intersection of a plane inclined to the axis of a cone or cylinder, where the plane does not cut the base.

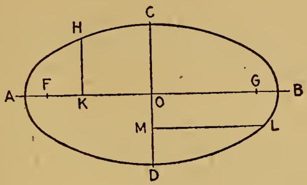


FIG. 34.

To Find the Length of any Ordinate, HK or LM, Knowing the Two Diameters AB and CD, and the Abscissæ OK and OM

$$AB^2 : CD^2 :: AK \times KB : HK^2,$$

$$HK = \sqrt{\frac{CD^2 \times (AK \times KB)}{AB^2}} = \frac{CD}{AB}\sqrt{AK \times KB},$$

or $$LM = \sqrt{\frac{AB^2\,(CM \times MD)}{CD^2}} = \frac{AB}{CD}\sqrt{CM \times MD}.$$

The circumference of an ellipse is found from the formula below, wherein D = transverse diameter and d = conjugate diameter. C = circumference $= 3.1415\,d + 2\,(D - d) - \dfrac{d(D-d)}{\sqrt{(D+d) \times (D + 2\,d)}}$

or $$C = 3.1415\sqrt{\frac{D^2 + d^2}{2} - \frac{(D-d)^2}{8.8}}.$$

These formulas apply where large D is not more than five times as long as d.

The area of an ellipse is equal to that of an annular ring of which the sum and difference of the radii of the limiting circles are respectively equal to the semi-axes of the ellipse.

Thus $\pi\,(r^2 - r'^2) = \pi\,(r + r') \times (r - r')$; then if $(r + r')$ equals the semi-transverse axis equals A, and $(r - r')$ equals the semi-conjugate axis equals B, the area of the ellipse equals $\pi\,(AB)$ or π into the product of the semi-axes or into the product of the axes, divided by four.

SOLIDS

The Prism

A prism is a solid whose bases or ends are similar, equal and parallel polygons and whose sides are parallelograms. The prism is right or oblique according as the sides are perpendicular to or inclined to the ends; regular or irregular, as the ends are regular or irregular polygons.

The surface of any prism is the sum of the areas of the sides added to that of the ends.

To find the surface of a right prism, multiply the perimeter of its base by its altitude; to this product add the areas of the ends.

The volume of any prism is equal to the area of its base multiplied by its altitude, or perpendicular distance between the ends.

The volume of any *frustum* of a prism is equal to the product of the sum of all the edges (divided by their number), and the area of the cross section perpendicular to those edges.

The Pyramid

A pyramid is a solid having any polygon for its base; and for its sides triangles, terminating at one point called the apex.

The axis of a pyramid is a straight line from the apex to the center of gravity of its base.

A pyramid is right or oblique according as the axis is perpendicular or inclined to the base; regular or irregular, as the base is a regular or irregular figure.

The slant height is the distance from the vertex of any of the triangular sides to the middle point of its base.

The surface of any pyramid is equal to the sum of the areas of all the triangles of which it is composed plus the area of the base.

The surface of a right regular pyramid is equal to the perimeter of its base multiplied by half the slant height plus the area of the base.

The volume of any pyramid is equal to the area of the base multiplied by one-third of the altitude; or the perpendicular distance from the apex to the base. It is also equal to one-third the volume of a cylinder having the same base and altitude; or to one-half the volume of a hemisphere having the same base and altitude.

The volumes of a pyramid, hemisphere and cylinder, having the same base and altitude are to each other as 1, 2 and 3.

Frustrum of a Pyramid

The frustrum of a pyramid is the section between two planes which may or may not be parallel.

The slant height of any side of a frustrum of a pyramid is measured from the middle points of the top and bottom sides of the trapezium forming that side.

To find the surface of any frustrum of a pyramid, take the sum of the areas of all the trapeziums forming the sides, to which add the sum of the top and base.

The surface of a frustrum of a right regular pyramid, where the top and base are parallel planes, is equal to one-half the sum of the perimeters of top and base multiplied by the slant height plus the sum of the areas of the top and base.

The volume of any frustrum of any pyramid, with top and base parallel, is equal to one-third the perpendicular distance between top and base multiplied by the sums of the areas of top and base, and the square root of the product of those areas.

Thus H, being the perpendicular and A and A' the areas of top and base, respectively, then the volume equals $\frac{1}{3} H \times (A + A' + \sqrt{A \times A'})$ or A'' being equal to the area of a section midway between and parallel to base and top, the volume $= V = \frac{1}{6} H (A + A' + 4 A'')$.

A prismoid is a solid having six sides, two of which are parallel but unequal quadrangles, and the other sides trapeziums.

To find the Volume of a Prismoid

Let A = area of one of the parallel sides.

a = area of the other parallel side.

M = area of cross section midway between and parallel to the parallel sides.

L = perpendicular distance between the two parallel sides.

Then
$$\text{Volume} = L \times \left(\frac{A + a + 4M}{6}\right).$$

The Wedge

The wedge is a frustrum of a triangular prism. Its volume is equal to the area of a right section multiplied by one-third the sum of the lengths of the three parallel edges.

Let A equal area of section perpendicular to the axis of the prism and BC, DE and FG, the lengths of the parallel edges respectively.

Then
$$\text{Volume of wedge} = A\,\frac{(BC + DE + FG)}{3}.$$

Polyhedra

A polyhedron is a solid bounded by plane surfaces.

A regular polyhedron is one whose bounding faces are all equal and regular polygons.

There are five regular polyhedra as follows:

Name	Bounded by	Surface = sum of surfaces of all the faces = square of the length of one edge by	Volume = product of cube of length of one edge by
Tetrahedron	4 Equilateral triangles	1.7320	.1178
Cube or hexahedron	6 squares	6.000	1.000
Octahedron	8 Equilateral triangles	3.4641	.4714
Dodecahedron	12 Equilateral pentagons	20.6458	7.6631
Icosahedron	20 Equilateral triangles	8.6602	2.1817

The Cylinder

A cylinder may be defined as a prism, of which a section perpendicular to its axis is a circle. It may be right or oblique.

The base of a right cylinder is a circle, that of an oblique cylinder an ellipse.

The surface of any cylinder is equal to the product of the circumference of a circle whose plane is perpendicular to the axis of the cylinder, by the length of the axis, plus the area of the ends.

The volume of a cylinder is equal to the area of a circle perpendicular to the axis multiplied by its altitude.

The Cone

A cone is a pyramid having an infinite number of sides.

Cones are right or oblique according as their axes are perpendicular or inclined to their bases.

The surface of a right cone is equal to the product of the perimeter of the base by half the slant height, plus the area of the base.

The surface of an oblique cone, cut from a right cone having a circular base, is equal to the area of the base, multiplied by the altitude and divided by the perpendicular distance from the axis at the point where it pierces the base, to the surface of the cone, plus the area of the base; or the curved surface of the cone equals $\frac{AH}{R}$. Wherein A is the area of the base, H the altitude and R the perpendicular.

The volume of any cone is equal to the area of the base multiplied by one-third of the altitude.

The volume of a cone is equal to one-third that of a cylinder, or one-half that of an hemisphere having same base and altitude.

The surface of a right circular frustrum of a cone with top and base parallel is found by adding together the circumferences of top and base, multiplying this sum by one-half the slant height; to this product add the area of top and base to get the total surface.

The volume of a frustrum of any cone, with top and base parallel, is equal to one-third of the altitude multiplied by the sum of the areas of top and base plus the square root of the product of those areas, or equals $\frac{1}{3}$ the altitude

$$\times \left(\text{area of top} + \text{area of base} + \sqrt{\text{area of top} \times \text{area of base}}\right).$$

The Sphere

A sphere is a solid generated by revolving a semicircle about its diameter.

The intersection of a sphere with any plane is a circle.

A circle cut by the intersection of the surface of a sphere and a plane passing through its center is a *great circle*.

The volume of a sphere is greater than that of any other solid having an equal surface.

The surface of a sphere equals that of four great circles.

Surface $= 4\pi r^2$.
" $= \pi D^2$.
" = curved surface of a circumscribing cylinder.
" = area of a circle having twice the diameter of the sphere.

The surface of a sphere is equal to that of a circumscribing cube multiplied by 0.5236.

Surfaces of spheres are to each other as the squares of their diameters.

Volume of a Sphere

Volume $= \frac{4}{3}\pi r^3 = 4.1888\, r^3$
" $= \frac{1}{6}\pi D^3 = 0.5236\, D^3$
" $= \frac{2}{3}$ volume of circumscribing cylinder.
" = 0.5236 volume of circumscribing cube.

Volumes of spheres are to each other as the cubes of their diameters.

Radius of a sphere $= 0.62035\sqrt[3]{\text{volume}}.$

Circumference of sphere $= \sqrt[3]{59.2176\ \text{volume}}.$

$= \sqrt{3.1416 \times \text{area of surface}}.$

$= \dfrac{\text{Area of surface}}{\text{Diameter}}.$

The area of the curved surface of a spherical segment is equal to the product of the circumference of a great circle by the height of the segment $= \pi DH$, where D is the diameter of the sphere and H the height of the spherical segment.

The curved surface of a segment of a sphere is to the whole surface of the sphere as the height of the segment is to the diameter of the sphere.

To Find the Volume of a Spherical Segment

Let R = radius of base of segment.
H = height.

Then volume of segment $= \frac{1}{6}\pi H (3 R^2 + H^2)$.

To find the curved surface of a spherical zone, multiply the circumference of the sphere by the height of the zone.

To find the volume of a spherical zone, let A and A' be the radii of the ends of the zone and H be the height and V the volume.

Then $$V = \frac{1}{6}\pi H (3(A^2 + A^{2\prime}) + H^2).$$

Guldin's Theorems

(1) If any plane curve be revolved about any external axis situated in its plane, the surface generated is equal to the product of the perimeter of the curve and the length of the path described by the center of gravity of that perimeter.

(2) If any plane surface be revolved about any external axis situated in its plane, the volume generated is equal to the area of the revolving surface multiplied by the path described by its center of gravity.

CHAPTER II

WEIGHTS AND MEASURES

In the United States and Great Britain measures of length and weight are, for the same denomination, essentially equal; but liquid and dry measures for same denomination differ widely. The standard measure of length for both countries is that of the simple seconds pendulum, at the sea level, in the latitude of Greenwich; in vacuum and at a temperature of 62° F.

The length of such a pendulum is 39.1393 inches; 36 of these inches constitute the standard British Imperial yard. This is also the standard in the United States.

The Troy pound at the U. S. Mint of Philadelphia is the legal standard of weight in the United States.

It contains 5760 grains and is exactly the same as the Imperial Troy pound of Great Britain.

The avoirdupois pound (commercial) of the United States contains 7000 grains, and agrees with the British avoirdupois pound within 0.001 of a grain.

The metric system was legalized by the United States in 1866 but its use is not obligatory.

The metre is the unit of the metric system of lengths and was supposed to be one ten millionth, $\frac{1}{10,000,000}$, of that portion of a meridian between either pole and the equator.

The metric measures of surface and volume are the squares and cubes of the metre, and of its decimal fractions and multiples.

The metric unit of weight is the gramme or grain, which is the weight of a cubic centimeter of pure water at a temperature of 40° F.

The legal equivalent of the metre as established by Act of Congress is 39.37 inches = 3.28083 ft. = 1.093611 yards.

The legal equivalent of the gramme is 15.432 grains.

The systems of weights used for commercial purposes in the United States are as follows:

Troy Weight

For Gold, Silver, Platinum and Jewels, except Diamonds and Pearls

24 grains	=	1 pennyweight (dwt.).
20 pennyweights	=	1 ounce = 480 grains.
12 ounces	=	1 pound = 5760 grains.

Apothecaries Weight

(*For Prescriptions only.*)

20 grains	=	1 scruple	(℈)		
3 scruples	=	1 drachm	(ʒ)	=	60 grains.
8 drachms	=	1 ounce	(℥)	=	480 "
12 ounces	=	1 pound	(℔)	=	5760 "

Avoirdupois Weight

For all Materials except those above named

16 drachms or 437.5 grains	=	1 ounce (oz.).
16 ounces	=	1 pound (lb.) = 7000 grains.
28 pounds	=	1 quarter (qr.).
4 quarters	=	1 hundredweight (cwt.) = 112 lbs.
20 hundredweight	=	1 long or gross ton = 2240 lb.
2000 pounds	=	1 short or net ton.
2204.6 pounds	=	1 metric ton.
1 stone	=	14 pounds.
1 quintal	=	100 pounds.

The weight of the grain is the same for all systems of weights.

A troy ounce	=	1.097 avoirdupois ounces.
An avoirdupois ounce	=	.91146 troy or apoth. ounce.
A troy pound	=	.82286 avoirdupois pound.
An avoirdupois pound	=	1.21528 troy or apoth. pounds.

The standard avoirdupois pound is equal to the weight of 27.7015 cu. in. distilled water at 39.2° F., at sea level and at the latitude of Greenwich.

Long Measure

12 inches	=	1 foot = .3047973 metre.		
3 feet	=	1 yard = 36 in. = .9143919 metre.		
5½ yards	=	1 rod, pole, perch	=	16½ feet = 198 in.
40 rods	=	1 furlong	=	220 yards = 660 ft.
8 furlongs	=	1 statute mile	=	320 rods = 1760 yds. = 5280 ft.
3 miles	=	1 league	=	24 furlongs = 960 rods = 5280 yds.

Land Measure

7.92 inches	= 1 link; 100 links (66 ft.) = 1 chain = 4 rods.
10 chains	= 1 furlong; 8 furlongs (80 chains) = 1 mile.
10 square chains	= 1 acre.

Measures occasionally used

$\frac{1}{72}$ inch = 1 point; 6 points-$\frac{1}{12}$ in. = 1 line.
1000 mils = 1 inch; 3 in. = 1 palm; 4 in. = 1 hand; 9 in. = 1 span.
2 yards = 1 fathom = 6 feet; 120 fathoms = 1 cable length.
A geographical (nautical) mile or knot = 6087.15 ft. = 1855.345 metres = 1.15287 statute miles.
1 knot = 1 minute of longitude or latitude at the equator.

1° latitude at the equator					= 68.70 statute miles.		
1°	"	" latitude		20°	= 68.78	"	"
1°	"	"	"	40°	= 69.00	"	"
1°	"	"	"	60°	= 69.23	"	"
1°	"	"	"	90°	= 69.41	"	"

Square Measure

144	square inches	= 1	square foot.	
9	" feet	= 1	" yard.	
$30\frac{1}{4}$	" yards	= 1	" rod, perch or pole = $272\frac{1}{4}$ sq. ft.	
40	" rods	= 1	rood = 1210 sq. yds. = 108,908 sq. ft.	

4 roods (10 sq. chains) = 1 acre = 160 sq. rods = 4840 sq. yds = 43,560 sq. ft.

640 acres = 1 sq. mile = 1 section.
An acre = a square whose side is 208.71 ft.
A half acre = a square whose side is 147.581 ft.
A quarter acre = a square whose side is 104.355 ft.

A circular inch is the area of a circle 1 inch in diameter and = .7854 sq. inches.

1 square inch = 1.2732 circular inches.

A circular mil is the area of a circle 1 mil or .001 in. in diameter.

1000^2 mils or 1,000,000 circular mils = 1 circular inch.

1 square inch = 1,273,239 circular mils.

A cylinder, 1 inch in diameter and 1 foot high, contains:

1.3056 U. S. gills.
.2805 U. S. dry pints.
.3246 U. S. liquid pints.

A cylinder, one foot in diameter and 1 foot high, contains:

1357.1712 cubic inches.	188.0064 U. S. liquid gills.
.7854 " feet.	47.0016 U. S. " pints.
.02909 " yards.	23.5008 U. S. " quarts.

5.8752 U. S. liquid gallons.
40.3916 U. S. dry pints.
20.1958 U. S. " quarts.
2.5254 U. S. dry pecks.
0.63112 U. S. " bushels.

Liquid Measure

(*United States only*)

4 gills = 1 pint = 28.875 cubic inches.
2 pints = 1 quart = 57.75 cu. ins. = 8 gills.
4 quarts = 1 gallon = 231 cu. in. = 8 pts. = 32 gills.
31½ gallons = 1 barrel = 126 quarts = 4.211 cu. ft.
63 gallons = 1 hogshead.
2 hogsheads = 1 pipe or butt.
2 pipes = 1 tun.

A puncheon contains 84 gallons.

A tierce contains 42 gallons.

A cube 1.615 ft. on edge contains 3.384 U. S. struck bushels; or 31½ gallons = 1 bbl.; or 4.211 cu. ft.

Approximate measure	Diameter	Height	Approximate measure	Diameter	Height
	Inches	Inches		Inches	Inches
1 Gill	1.75	3	1 Gallon	7	6
½ Pint	2.25	3⅝	2 Gallons	7	12
1 Pint	3.50	3	8 Gallons	14	12
1 Quart	3.50	6	10 Gallons	14	15

The basis of this measure is the old British wine gallon of 231 cubic inches; or 8.3388 lbs. of distilled water at 39° F. and 30″ barometer.

A cubic foot contains 7.48 gallons.

Apothecaries' or Wine Measure

Measure	Symbol	Pints	Fluid ounces	Fluid drachms	Minims	Cubic inches	Weight of water: Ounces avoir.	Weight of water: Grains
1 Minim........	m	....	......	......	1	0.0038	......	0.95
1 fluid drachm.	f℥	....	......	1	60	0.2256	......	57.05
1 fluid ounce...	f℥	....	1	8	480	1.8047	1.043	456.4
							Pounds avoir.	
1 pint..........	O	1	16	128	7680	28.875	1.043	7301.9
1 gallon........	Cong.	8	128	1024	61440	231	8.345	58415

Dry Measure

(United States only)

2 pints = 1 quart = 67.2006 cubic inches = 1.16365 liquid quarts.
4 quarts = 1 gallon = 8 pints = 268.80 cubic inches = 1.16365 liq. gal.
2 gallons = 1 peck = 16 pints = 8 qts. = 537.60 cu. inches.
4 pecks = 1 struck bu. = 64 pints = 32 qts. = 8 gallons = 2150.42 cu. in.

The old Winchester struck bushel containing 2150.42 cubic inches or 77.627 pounds, avoirdupois, of distilled water at its maximum density is the basis of this table.

Its legal dimensions are those of a cylinder $18\frac{1}{2}$ inches in diameter and 8 inches deep. When heaped, the cone must not be less than 6 inches high; (the bushel) containing 1.5555 cubic feet and equal to $1\frac{1}{4}$ struck bushels.

Miscellaneous Measures

12 pieces	= 1 dozen.	20 pieces	= 1 score.
12 dozen	= 1 gross.	24 sheets	= 1 quire.
12 gross	= 1 great gross.	20 quires	= 1 ream.
2 pieces	= 1 pair.		

Weights of Given Volumes of Distilled Water at 70° F.

United States Liquid Measure

1 gill	= .26005 lbs.
1 pint	= 1.1402 "
1 quart	= 2.0804 "
1 gallon	= 8 lbs. $5\frac{1}{2}$ oz. = 8.345 lbs.
1 barrel	= $31\frac{1}{2}$ gals. = 262.1310 lbs.

United States Dry Measure

1 pint	= 1.2104 lbs.
1 quart	= 2.4208 "
1 gallon	= 9.6834 "
1 peck	= 19.3668 "
1 bushel (struck)	= 77.4670 "

British Imperial Liquid and Dry Measures

Liquid and Dry Measures

1 gill	= .31214 lbs. avoir. of distilled water.
1 pint	= 1.24858 " " " " "
1 quart	= 2.49715 " " " " "
1 gallon	= 9.9886 " " " " "
1 peck	= 19.9772 " " " " "
1 bushel	= 79.9088 " " " " "

This system supersedes the old ones throughout Great Britain, and is based on the Imperial gallon of 277.274 cubic inches, equal to 10 pounds avoirdupois of pure water at 62° F., 30 in. Bar.

Metric Measures

1 litre	=	2.1981 lbs. avoir. of pure water.	
1 centilitre	=	.02198 " " " " "	= 153,866 gr.
1 decilitre	=	.2198 " " " " "	= 3.5169 oz.
1 decalitre	=	21.9808 " " " " "	
1 metre or stere	=	2198.0786 " " " " "	

Metric Measures of Length in U. S. Standard

	Inches	Feet	Yards	Miles
Millimetre*...........	.039370	.003281		
Centimetre†..........	.393704	.032809		
Decimetre............	3.93704	.328087	.1093623	
Metre‡...............	39.3704	3.28087	1.093623	
Decametre }	393.704	32.80869	10.93623	
Hectometre }	Road	328.0869	109.3623	.0621375
Kilometre }	measures	3280.869	1093.623	.6213750
Myriametre }	....	32808.69	10936.23	6.213750

* About $\frac{1}{25}$ of an inch. † About $\frac{3}{8}$ of an inch. ‡ About 3 feet $3\frac{3}{8}$ inches.

Metric Square Measure by U. S. Standard

Measures	Square inches	Square feet	Square yards	Acres
Square millimetre....	.001550	.00001076	.0000012	
Square centimetre....	.155003	.00107641	.0001196	
Square decimetre....	15.5003	.10764101	.0119601	
Square meter or centare	1550.03	10.764101	1.19601	.000247
Square decametre or aire................	155003	1076.4101	119.6011	.024711
Square decare*.......	....	10764.101	1196.011	.247110
Hectare..............	Square miles	107641.01	11960.11	2.47110
Square kilometre.....	.3861090	10764101	1196011	247.110
Square myriametre..	38.61090	....	....	24711.0

* Seldom used.

Metric, Cubic or Solid Measure by U. S. Standard

	Cubic inches		
Millilitre or cubic centimetre	.0610254	Liquid	.0084537 gill.
		Dry	.0018162 pint.
Centilitre	.610254	Liquid	.084537 gill.
		Dry	.018162 pint.
Decilitre	6.10254	Liquid	.84537 gill.
		Dry	.18162 pint.
Litre or cubic decimetre	61.0254	Liquid	1.05671 quart = 2.1134 pints.
		Dry	.11351 peck = .9031 qt. = 1.816 pts.
Decalitre or centistere	610.254		
	Cubic feet		
	.353156	Liquid	2.64179 gallons
		Dry	.283783 bu. = 1.1351 pks. = 9.081 qts.
Hectolitre or decistere	3.53156	Liquid	26.4179 gallons.
		Dry	2.83783 bushel.
Kilolitre or cubic metre or stere	35.3156	Liquid	264.179 gallons } = 1.3080 cu. yd.
		Dry	28.3783 bushels } = 1.3080 cu. yd.
Myrialitre or decastere	353.156	Liquid	2641.79 gallons } = 13.080 cu. yd.
		Dry	283.78 bushels } = 13.080 cu. yd.

Metric Weights, Reduced to Avoirdupois

Measure	Avoirdupois
Milligramme	.015432 grains
Centigramme	.15432 "
Decigramme	1.5432 "
Gramme	15.432 "
Decagramme	.022046 lbs.
Hectogramme	.22046 "
Kilogramme	2.2046 "
Myriagramme	22.046 "
Quintal	220.46 "
Tonneau, millier or tonne	2204.6 "

The base of the French system of weights is the gramme; which is the weight of a cubic centimeter of distilled water at maximum density, at the sea level and at the latitude of Paris, Barometer 29.922 inches.

Metric Lineal Measure

	Metres	Inches	Feet	Yards	Miles
Millimetre	.001	.03937	.00328	....	....
Centimetre	.01	.3937	.0328	....	....
Decimetre	.1	3.937	.3280	.10936	....
Metre	1	39.3685	3.2807	1.0936	....
Decametre	10	....	32.807	10.936	....
Hectometre	100	....	328.07	109.36	.0621347
Kilometre	1000	....	3280.7	1093.6	.621347
Myriametre	10000	....	32807	10936	6.21347

Metric Square Measure

Measures	Square metres	Square inches	Square feet	Square yards	Acres
Square centimetre	.01	.155			
" decimetre	.1	15.5	.10763	.01196	
" centare	1	1,549.88	10.763	1.196	.00025
Are	10	154,988	1,076.3	119.6	.0247
Hectare	100	....	107,630	11,959	2.47

	Acres	Square miles
Square kilometre	247	.38607
" myriametre	24,708	38.607

Metric, Cubic or Solid Measure

Measures	Cubic metres	Cubic inches	Cubic feet	Cubic yards
Cubic centimetre	.0001	.0610165		
" decimetres	.001	61.0165		
Centistere	.01	610.165	.353105	
Decimstere	.1	6101.65	3.53105	.13078
Stere	1	....	35.3105	1.3078
Decastere	10	....	353.105	13.078
Hectostere	100	....	3531.05	130.78

Metric Weights

Weight	Grammes	Troy grains	Avoirdupois ounces	Avoirdupois pounds
Milligramme	.001	.01543		
Centigramme	.01	.1543		
Decigramme	.1	1.543		
Gramme	1	15.43316	.03528	.0022047
Decagramme	10	....	.3528	.022047
Hectogramme	100	....	3.52758	.2204737
Kilogramme	1,000	....	35.2758	2.204737
Myriagramme	10,000	....	....	22.04737
Quintal	100,000	....	....	220.4737
Tonneau	1,000,000	....	....	2204.737

Metric Dry and Liquid Measures

Measures	Litres	Cubic inches	Cubic feet
Millilitre	.001	.061	
Centilitre	.01	.61	
Decilitre	.1	6.1	
Litre	1	61.02	
Decalitre	10	610.16	
Hectolitre	100	....	3.531
Kilolitre	1,000	....	35.31
Myrialitre	10,000	....	353.1

Circular Measure

60 seconds (″)...........1 minute (′).
60 minutes (′)...........1 degree (°).
90 degrees (°)............1 quadrant.
360 degrees (°)...........circumference.

Time

60 seconds..............1 minute.
60 minutes..............1 hour.
24 hours..... ....1 day.
7 days..................1 week.

365 days, 5 hours, 48 minutes, 48 seconds = 1 year.

Every year whose number is divisible by 4 is a leap year and contains 366 days.

The Centismal years are leap years only when the number of the year is divisible by 400.

Board and Timber Measure

The unit of measurement is a board 12 inches square by one inch thick.

To ascertain the number of feet board measure in a plank or piece of square timber, multiply the length by the breadth in feet and by the thickness in inches.

To find the cubic contents of a stick of timber (all the measurements being reduced to feet), take one-fourth the product of the mean girth by the diameter and the length.

To find the cubic contents of square timber, reduce all measurements to feet, then the product of the length by the breadth and thickness will be the volume in cubic feet.

Miscellaneous Measures and Weights

1 barrel of flour weighs		196 pounds.
1 barrel of salt weighs		280 "
1 barrel of beef or pork weighs		200 "
1 bushel of salt (Syracuse) weighs		56 "
Anthracite coal (broken) averages		54 lbs. to the cubic foot.
Bituminous coal (broken) averages		49 " " " " "
Cement (Portland)	weighs	96 lbs. to the bushel.
Gypsum (ground)	"	70 " " " "
Lime (loose)	"	70 " " " "
Lime (well-shaken)	"	80 " " " "
Sand	"	98 " " " cubic foot or 1.181 tons to the cu. yd.

Useful Factors

Inches................	×	0.08333	= feet
"	×	0.02778	= yards
"	×	0.00001578	= miles
Square inches.........	×	0.00695	= square feet
" "	×	0.0007716	= square yards
Cubic inches..........	×	0.00058	= cubic feet
" "	×	0.0000214	= cubic yards
" "	×	0.004329	= U. S. gallons
Feet..................	×	0.3334	= yards
"	×	0.00019	= miles
Square feet...........	×	144.0	= square inches
" "	×	0.1112	= square yards
Cubic feet............	×	1728	= cubic inches
" "	×	0.03704	= cubic yards
" "	×	7.48	= U. S. gallons

USEFUL FACTORS — (*Continued*)

Yards................	×	36	= inches
"	×	3	= feet
"	×	0.0005681	= miles
Square yards.........	×	1,296	= square inches
" "	×	9	= square feet
Cubic yards..........	×	46,656	= cubic inches
" "	×	27	= cubic feet
Miles................	×	63,360	= inches
"	×	5,280	= feet
"	×	1,760	= yards
Avoirdupois ounces....	×	.0.0625	= pounds
" "	×	0.00003125	= tons
" pounds....	×	16	= ounces
" "	×	.001	= hundredweight
" "	×	.0005	= tons
" "		27.681	= cubic inches of water at 39.2° F
" tons......	×	32,000	= ounces
" "	×	2,000	= pounds
Watts................	×	0.00134	= horse power
Horse power..........	×	746	= watts

Weight of round iron per foot = square of diameter in quarter inches ÷ 6.
Weight of flat iron per foot = width × thickness × 10–3.
Weight of flat plates per square foot = 5 pounds for each 1-8 inch thickness.

Measures of Work, Power and Duty

Work is the result of expenditure of energy in overcoming resistance. The unit of work is the pressure of one pound exerted through a distance of one foot and is called one *foot pound.*

Horse Power. — Term employed to measure the quantity of work.

The unit is one horse power; or the quantity of work performed in raising 33,000 lbs., one foot in one minute

= 33,000 foot pounds per minute
= 550 foot pounds per second
= 1,980,000 foot pounds per hour.

A *heat unit* is the amount of heat required to raise one pound of water at maximum density 1° F., or 1 pound of water from 39° F. to 40° F. = 778 foot pounds.

One horse power = 2545 heat units per hour

$$= \frac{33{,}000}{778} = 42.146 \text{ heat units per minute}$$

= .7021 heat units per second.

TABLE OF SQUARES, CUBES, SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM .1 TO 10

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
.1	.01	.001	.3162	.4642	4.1	16.81	68.921	2.025	1.601
.15	.0225	.0034	.3873	.5313	4.2	17.64	74.088	2.049	1.613
.2	.04	.008	.4472	.5848	4.3	18.49	79.507	2.074	1.626
.25	.0625	.0156	.500	.6300	4.4	19.36	85.184	2.098	1.639
.3	.09	.027	.5477	.6694	4.5	20.25	91.125	2.121	1.651
.35	.1225	.0429	.5916	.7047	4.6	21.16	97.336	2.145	1.663
.4	.16	.064	.6325	.7368	4.7	22.09	103.823	2.168	1.675
.45	.2025	.0911	.6708	.7663	4.8	23.04	110.592	2.191	1.687
.5	.25	.125	.7071	.7937	4.9	24.01	117.649	2.214	1.698
.55	.3025	.1664	.7416	.8193	5	25	125	2.2361	1.710
.6	.36	.216	.7746	.8434	5.1	26.01	132.651	2.258	1.721
.65	.4225	.2746	.8062	.8662	5.2	27.04	140.608	2.280	1.732
.7	.49	.343	.8367	.8879	5.3	28.09	148.877	2.302	1.744
.75	.5625	.4219	.8660	.9086	5.4	29.16	157.464	2.324	1.754
.8	.64	.512	.8944	.9283	5.5	30.25	166.375	2.345	1.765
.85	.7225	.6141	.9219	.9473	5.6	31.36	175.616	2.366	1.776
.9	.81	.729	.9487	.9655	5.7	32.49	185.193	2.387	1.786
.95	.9025	.8574	.9747	.9830	5.8	33.64	195.112	2.408	1.797
1	1	1	1	1	5.9	34.81	205.379	2.429	1.807
1.05	1.1025	1.158	1.025	1.016	6	36	216	2.4495	1.8171
1.1	1.21	1.331	1.049	1.032	6.1	37.21	226.981	2.470	1.827
1.15	1.3225	1.521	1.072	1.048	6.2	38.44	238.328	2.490	1.837
1.2	1.44	1.728	1.095	1.063	6.3	39.69	250.047	2.510	1.847
1.25	1.5625	1.953	1.118	1.077	6.4	40.96	262.144	2.530	1.857
1.3	1.69	2.197	1.140	1.091	6.5	42.25	274.625	2.550	1.866
1.35	1.8225	2.460	1.162	1.105	6.6	43.56	287.496	2.569	1.876
1.4	1.96	2.744	1.183	1.119	6.7	44.89	300.763	2.588	1.885
1.45	2.1025	3.049	1.204	1.132	6.8	46.24	314.432	2.608	1.895
1.5	2.25	3.375	1.2247	1.1447	6.9	47.61	328.509	2.627	1.904
1.55	2.4025	3.724	1.245	1.157	7	49	343	2.6458	1.9129
1.6	2.56	4.096	1.265	1.170	7.1	50.41	357.911	2.665	1.922
1.65	2.7225	4.492	1.285	1.182	7.2	51.84	373.248	2.683	1.931
1.7	2.98	4.913	1.304	1.193	7.3	53.29	389.017	2.702	1.940
1.75	3.0625	5.359	1.323	1.205	7.4	54.76	405.224	2.720	1.949
1.8	3.24	5.832	1.342	1.216	7.5	56.25	421.875	2.739	1.957
1.85	3.4225	6.332	1.360	1.228	7.6	57.76	438.976	2.757	1.966
1.9	3.61	6.859	1.378	1.239	7.7	59.29	456.533	2.775	1.975
1.95	3.8025	7.415	1.396	1.249	7.8	60.84	474.552	2.793	1.983
2	4	8	1.4142	1.2599	7.9	62.41	493.039	2.811	1.992
2.1	4.41	9.26	1.449	1.281	8	64	512	2.8284	2
2.2	4.84	10.648	1.483	1.301	8.1	65.61	531.441	2.846	2.008
2.3	5.29	12.167	1.517	1.320	8.2	67.24	551.368	2.864	2.017
2.4	5.76	13.824	1.549	1.339	8.3	68.89	571.787	2.881	2.025
2.5	6.25	15.625	1.581	1.357	8.4	70.56	592.704	2.898	2.033
2.6	6.76	17.576	1.612	1.375	8.5	72.25	614.125	2.915	2.041
2.7	7.29	19.683	1.643	1.392	8.6	73.96	636.056	2.933	2.049
2.8	7.84	21.952	1.673	1.409	8.7	75.69	658.503	2.950	2.057
2.9	8.41	24.389	1.703	1.426	8.8	77.44	681.472	2.966	2.065
3	9	27	1.7321	1.442	8.9	79.21	704.969	2.983	2.072
3.1	9.61	29.791	1.761	1.458	9	81	729	3	2.081
3.2	10.24	32.768	1.789	1.474	9.1	82.81	753.571	3.017	2.088
3.3	10.89	35.937	1.817	1.489	9.2	84.64	778.688	3.033	2.095
3.4	11.56	39.304	1.844	1.504	9.3	86.49	804.357	3.050	2.103
3.5	12.25	42.875	1.871	1.518	9.4	88.36	830.584	3.066	2.110
3.6	12.96	46.656	1.897	1.533	9.5	90.25	857.375	3.082	2.118
3.7	13.69	50.653	1.924	1.47	9.6	92.16	884.736	3.098	2.125
3.8	14.44	54.872	1.949	1.560	9.7	94.09	912.673	3.114	2.133
3.9	15.21	59.319	1.975	1.574	9.8	96.04	941.192	3.130	2.140
4	16	64	2	1.5874	9.9	98.01	970.299	3.146	2.147

Table of Squares, Cubes, Square Roots and Cube Roots of Numbers from 1 to 1000

Remark on the Following Table. Wherever the effect of a fifth decimal in the roots would be to add 1 to the fourth and final decimal in the table, the addition has been made.

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
1	1	1			50	2,500	125,000	7.0711	3.6840
2	4	8	1.4142	1.2599	51	2,601	132,651	7.1414	3.7084
3	9	27	1.7321	1.4422	52	2,704	140,608	7.2111	3.7325
4	16	64	2	1.5874	53	2,809	148,877	7.2801	3.7563
5	25	125	2.2361	1.7100	54	2,916	157,464	7.3485	3.7798
6	36	216	2.4495	1.8171	55	3,025	166,375	7.4162	3.8030
7	49	343	2.6458	1.9129	56	3,136	175,616	7.4833	3.8259
8	64	512	2.8284	2	57	3,249	185,193	7.5498	3.8485
9	81	729	3	2.0801	58	3,364	195,112	7.6158	3.8709
10	100	1,000	3.1623	2.1544	59	3,481	205,379	7.6811	3.8930
11	121	1,331	3.3166	2.2240	60	3,600	216,000	7.7460	3.9149
12	144	1,728	3.4641	2.2894	61	3,721	226,981	7.8102	3.9365
13	169	2,197	3.6056	2.3513	62	3,844	238,328	7.8740	3.9579
14	196	2,744	3.7417	2.4101	63	3,969	250,047	7.9373	3.9791
15	225	3,375	3.8730	2.4662	64	4,096	262,144	8	4
16	256	4,096	4	2.5198	65	4,225	274,625	8.0623	4.0207
17	289	4,913	4.1231	2.5713	66	4,356	287,496	8.1240	4.0412
18	324	5,832	4.2426	2.6207	67	4,489	300,763	8.1854	4.0615
19	361	6,859	4.3589	2.6684	68	4,624	314,432	8.2462	4.0817
20	400	8,000	4.4721	2.7144	69	4,761	328,509	8.3066	4.1016
21	441	9,261	4.5826	2.7589	70	4,900	343,000	8.3666	4.1213
22	484	10,648	4.6904	2.8020	71	5,041	357,911	8.4261	4.1408
23	529	12,167	4.7958	2.8439	72	5,184	373,248	8.4853	4.1602
24	576	13,824	4.8990	2.8845	73	5,329	389,017	8.5440	4.1793
25	625	15,625	5	2.9240	74	5,476	405,224	8.6023	4.1983
26	676	17,576	5.0990	2.9625	75	5,625	421,875	8.6603	4.2172
27	729	19,683	5.1962	3	76	5,776	438,976	8.7178	4.2358
28	784	21,952	5.2915	3.0366	77	5,929	456,533	8.7750	4.2543
29	841	24,389	5.3852	3.0723	78	6,084	474,552	8.8818	4.2727
30	900	27,000	5.4772	3.1072	79	6,241	493,039	8.8882	4.2908
31	961	29,791	5.5678	3.1414	80	6,400	512,000	8.9443	4.3089
32	1,024	32,768	5.6569	3.1748	81	6,561	531,441	9	4.3267
33	1,089	35,937	5.7446	3.2075	82	6,724	551,368	9.0554	4.3445
34	1,156	39,304	5.8310	3.2396	83	6,889	571,787	9.1104	4.3621
35	1,225	42,875	5.9161	3.2711	84	7,056	592,704	9.1652	4.3795
36	1,296	46,656	6	3.3019	85	7,225	614,125	9.2195	4.3968
37	1,369	50,653	6.0828	3.3322	86	7,396	636,056	9.2736	4.4140
38	1,444	54,872	6.1644	3.3620	87	7,569	658,503	9.3274	4.4310
39	1,521	59,319	6.2450	3.3912	88	7,744	681,472	9.3808	4.4480
40	1,600	64,000	6.3246	3.4200	89	7,921	704,969	9.4340	4.4647
41	1,681	68,921	6.4031	3.4482	90	8,100	729,000	9.4868	4.4814
42	1,764	74,088	6.4807	3.4760	91	8,281	753,571	9.5394	4.4979
43	1,849	79,507	6.5574	3.5034	92	8,464	778,688	9.5917	4.5144
44	1,936	85,184	6.6332	3.5303	93	8,649	804,357	9.6437	4.5307
45	2,025	91,125	6.7082	3.5569	94	8,836	830,584	9.6954	4.5468
46	2,116	97,336	6.7823	3.5830	95	9,025	857,375	9.7468	4.5629
47	2,209	103,823	6.8557	3.6088	96	9,216	884,736	9.7980	4.5789
48	2,304	110,592	6.9282	3.6342	97	9,409	912,673	9.8489	4.5947
49	2,401	117,649	7	3.6593	98	9,604	941,192	9.8995	4.6104

Table of Squares, Cubes, Square Roots and Cube Roots of Numbers from 1 to 1000 — (*Continued*)

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
99	9,801	970,299	9.9499	4.6261	152	23,104	3,511,808	12.3288	5.3368
100	10,000	1,000,000	10	4.6416	153	23,409	3,581,577	12.3693	5.3485
101	10,201	1,030,301	10.0499	4.6570	154	23,716	3,652,264	12.4097	5.3601
102	10,404	1,061,208	10.0995	4.6723	155	24,025	3,723,875	12.4499	5.3717
103	10,609	1,092,727	10.1489	4.6875	156	24,336	3,796,416	12.4900	5.3832
104	10,816	1,124,864	10.1980	4.7027	157	24,649	3,869,893	12.5300	5.3947
105	11,025	1,157,625	10.2470	4.7177	158	24,964	3,944,312	12.5698	5.4061
106	11,236	1,191,016	10.2956	4.7326	159	25,281	4,019,679	12.6095	5.4175
107	11,449	1,225,043	10.3441	4.7475	160	25,600	4,096,000	12.6491	5.4288
108	11,664	1,259,712	10.3923	4.7622	161	25,921	4,173,281	12.6886	5.4401
109	11,881	1,295,029	10.4403	4.7769	162	26,244	4,251,528	12.7279	5.4514
110	12,100	1,331,000	10.4881	4.7914	163	26,569	4,330,747	12.7671	5.4626
111	12,321	1,367,631	10.5357	4.8059	164	26,896	4,410,944	12.8062	5.4737
112	12,544	1,404,928	10.5830	4.8203	165	27,225	4,492,125	12.8452	5.4848
113	12,769	1,442,897	10.6301	4.8346	166	27,556	4,574,296	12.8841	5.4959
114	12,996	1,481,544	10.6771	4.8488	167	27,889	4,657,463	12.9228	5.5069
115	13,225	1,520,875	10.7238	4.8629	168	28,224	4,741,632	12.9615	5.5178
116	13,456	1,560,896	10.7703	4.8770	169	28,561	4,826,809	13	5.5288
117	13,689	1,601,613	10.8167	4.8910	170	28,900	4,913,000	13.0384	5.5397
118	13,924	1,643,032	10.8628	4.9049	171	29,241	5,000,211	13.0767	5.5505
119	14,161	1,685,159	10.9087	4.9187	172	29,584	5,088,448	13.1149	5.5613
120	14,400	1,728,000	10.9545	4.9324	173	29,929	5,177,717	13.1529	5.5721
121	14,641	1,771,561	11	4.9461	174	30,276	5,268,024	13.1909	5.5828
122	14,884	1,815,848	11.0454	4.9597	175	30,625	5,359,375	13.2288	5.5934
123	15,129	1,860,867	11.0905	4.9732	176	30,976	5,451,776	13.2665	5.6041
124	15,376	1,906,624	11.1355	4.9866	177	31,329	5,545,233	13.3041	5.6147
125	15,625	1,953,125	11.1803	5	178	31,684	5,639,752	13.3417	5.6252
126	15,876	2,000,376	11.2250	5.0133	179	32,041	5,735,339	13.3791	5.6357
127	16,129	2,048,383	11.2694	5.0265	180	32,400	5,832,000	13.4164	5.6462
128	16,384	2,097,152	11.3137	5.0397	181	32,761	5,929,741	13.4536	5.6567
129	16,641	2,146,689	11.3578	5.0528	182	33,124	6,028,568	13.4907	5.6671
130	16,900	2,197,000	11.4018	5.0658	183	33,489	6,128,487	13.5277	5.6774
131	17,161	2,248,091	11.4455	5.0788	184	33,856	6,229,504	13.5647	5.6877
132	17,424	2,299,968	11.4891	5.0916	185	34,225	6,331,625	13.6015	5.6980
133	17,689	2,352,637	11.5326	5.1045	186	34,596	6,434,856	13.6382	5.7083
134	17,956	2,406,104	11.5758	5.1172	187	34,969	6,539,203	13.6748	5.7185
135	18,225	2,460,375	11.6190	5.1299	188	35,344	6,644,672	13.7113	5.7287
136	18,496	2,515,456	11.6619	5.1426	189	35,721	6,751,269	13.7477	5.7388
137	18,769	2,571,353	11.7047	5.1551	190	36,100	6,859,000	13.7840	5.7489
138	19,044	2,628,072	11.7473	5.1676	191	36,481	6,967,871	13.8203	5.7590
139	19,321	2,685,619	11.7898	5.1801	192	36,864	7,077,888	13.8564	5.7690
140	19,600	2,744,000	11.8322	5.1925	193	37,249	7,189,057	13.8924	5.7790
141	19,881	2,803,221	11.8743	5.2048	194	37,636	7,301,384	13.9284	5.7890
142	20,164	2,863,288	11.9164	5.2171	195	38,025	7,414,875	13.9642	5.7989
143	20,449	2,924,207	11.9583	5.2293	196	38,416	7,529,536	14	5.8088
144	20,736	2,985,984	12	5.2415	197	38,809	7,645,373	14.0357	5.8186
145	21,025	3,048,625	12.0416	5.2536	198	39,204	7,762,392	14.0712	5.8285
146	21,316	3,112,136	12.0830	5.2656	199	39,601	7,880,599	14.1067	5.8383
147	21,609	3,176,523	12.1244	5.2776	200	40,000	8,000,000	14.1421	5.8480
148	21,904	3,241,792	12.1655	5.2896	201	40,401	8,120,601	14.1774	5.8578
149	22,201	3,307,949	12 2066	5.3015	202	40,804	8,242,408	14.2127	5.8675
150	22,500	3,375,000	12.2474	5.3133	203	41,209	8,365,427	14.2478	5.8771
151	22,801	3,442,951	12.2882	5.3251	204	41,616	8,489,664	14.2829	5.8868

TABLE OF SQUARES, CUBES, SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000 — (*Continued*)

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
205	42,025	8,615,125	14.3178	5.8964	258	66,564	17,173,512	16.0624	6.3661
206	42,436	8,741,816	14.3527	5.9059	259	67,081	17,373,979	16.0935	6.3743
207	42,849	8,869,743	14.3875	5.9155	260	67,600	17,576,000	16.1245	6.3825
208	43,264	8,998,912	14.4222	5.9250	261	68,121	17,779,581	16.1555	6.3907
209	43,681	9,129,329	14.4568	5.9345	262	68,644	17,984,728	16.1864	6.3988
210	44,100	9,261,000	14.4914	5.9439	263	69,169	18,191,447	16.2173	6.4070
211	44,521	9,393,931	14.5258	5.9533	264	69,696	18,399,744	16.2481	6.4151
212	44,944	9,528,128	14.5602	5.9627	265	70,225	18,609,625	16.2788	6.4232
213	45,369	9,663,597	14.5945	5.9721	266	70,756	18,821,096	16.3095	6.4312
214	45,796	9,800,344	14.6287	5.9814	267	71,289	19,034,163	16.3401	6.4393
215	46,225	9,938,375	14.6629	5.9907	268	71,824	19,248,832	16.3707	6.4473
216	46,656	10,077,696	14.6969	6	269	72,361	19,465,109	16.4012	6.4553
217	47,089	10,218,313	14.7309	6.0092	270	72,900	19,683,000	16.4317	6.4633
218	47,524	10,360,232	14.7648	6.0185	271	73,441	19,902,511	16.4621	6.4713
219	47,961	10,503,459	14.7986	6.0277	272	73,984	20,123,648	16.4924	6.4792
220	48,400	10,648,000	14.8324	6.0368	273	74,529	20,346,417	16.5227	6.4872
221	48,841	10,793,861	14.8661	6.0459	274	75,076	20,570,824	16.5529	6.4951
222	49,284	10,941,048	14.8997	6.0550	275	75,625	20,796,875	16.5831	6.5030
223	49,729	11,089,567	14.9332	6.0641	276	76,176	21,024,576	16.6132	6.5108
224	50,176	11,239,424	14.9666	6.0732	277	76,729	21,253,933	16.6433	6.5187
225	50,625	11,390,625	15	6.0822	278	77,284	21,484,952	16.6733	6.5265
226	51,076	11,543,176	15.0333	6.0912	279	77,841	21,717,639	16.7033	6.5343
227	51,529	11,697,083	15.0665	6.1002	280	78,400	21,952,000	16.7332	6.5421
228	51,984	11,852,352	15.0997	6.1091	281	78,961	22,188,041	16.7631	6.5499
229	52,441	12,008,989	15.1327	6.1180	282	79,524	22,425,768	16.7929	6.5577
230	52,900	12,167,000	15.1658	6.1269	283	80,089	22,665,187	16.8226	6.5654
231	53,361	12,326,391	15.1987	6.1368	284	80,656	22,906,304	16.8523	6.5731
232	53,824	12,487,168	15.2315	6.1446	285	81,225	23,149,125	16.8819	6.5808
233	54,289	12,649,337	15.2643	6.1534	286	81,796	23,393,656	16.9115	6.5885
234	54,756	12,812,904	15.2971	6.1622	287	82,369	23,639,903	16.9411	6.5962
235	55,225	12,977,875	15.3297	6.1710	288	82,944	23,887,872	16.9706	6.6039
236	55,696	13,144,256	15.3623	6.1797	289	83,521	24,137,569	17	6.6115
237	56,169	13,312,053	15.3948	6.1885	290	84,100	24,389,000	17.0294	6.6191
238	56,644	13,481,272	15.4272	6.1972	291	84,681	24,642,171	17.0587	6.6267
239	57,121	13,651,919	15.4596	6.2058	292	85,264	24,897,088	17.0880	6.6343
240	57,600	13,824,000	15.4919	6.2145	293	85,849	25,153,757	17.1172	6.6419
241	58,081	13,997,521	15.5242	6.2231	294	86,436	25,412,184	17.1464	6.6494
242	58,564	14,172,488	15.5563	6.2317	295	87,025	25,672,375	17.1756	6.6569
243	59,049	14,348,907	15.5885	6.2403	296	87,616	25,934,336	17.2047	6.6644
244	59,536	14,526,784	15.6205	6.2488	297	88,209	26,198,073	17.2337	6.6719
245	60,025	14,706,125	15.6525	6.2573	298	88,804	26,463,592	17.2627	6.6794
246	60,516	14,886,936	15.6844	6.2658	299	89,401	26,730,899	17.2916	6.6869
247	61,009	15,069,223	15.7162	6.2743	300	90,000	27,000,000	17.3205	6.6943
248	61,504	15,252,992	15.7480	6.2828	301	90,601	27,270,901	17.3494	6.7018
249	62,001	15,438,249	15.7797	6.2912	302	91,204	27,543,608	17.3781	6.7092
250	62,500	15,625,000	15.8114	6.2936	303	91,809	27,818,127	17.4069	6.7166
251	63,001	15,813,251	15.8430	6.3080	304	92,416	28,094,464	17.4356	6.7240
252	63,504	16,003,008	15.8745	6.3164	305	93,025	28,372,625	17.4642	6.7313
253	64,009	16,194,277	15.9060	6.3247	306	93,636	28,652,616	17.4929	6.7387
254	64,516	16,387,064	15.9374	6.3330	307	94,249	28,934,443	17.5214	6.7460
255	65,025	16,581,375	15.9687	6.3413	308	94,864	29,218,112	17.5499	6.7533
256	65,536	16,777,216	16	6.3496	309	95,481	29,503,629	17.5784	6.7606
257	66,049	16,974,593	16.0312	6.3579	310	96,100	29,791,000	17.6068	6.7679

TABLE OF SQUARES, CUBES, SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000 — (*Continued*)

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
311	96,721	30,080,231	17.6352	6.7752	364	132,496	48,228,544	19.0788	7.1400
312	97,344	30,371,328	17.6635	6.7824	365	133,225	48,627,125	19.1050	7.1466
313	97,969	30,664,297	17.6918	6.7897	366	133,956	49,027,896	19.1311	7.1531
314	98,596	30,959,144	17.7200	6.7969	367	134,689	49,430,863	19.1572	7.1596
315	99,225	31,255,875	17.7482	6.8041	368	135,424	49,836,032	19.1833	7.1661
316	99,856	31,554,496	17.7764	6.8113	369	136,161	50,243,409	19.2094	7.1726
317	100,489	31,855,013	17.8045	6.8185	370	136,900	50,653,000	19.2354	7.1791
318	101,124	32,157,432	17.8326	6.8256	371	137,641	51,064,811	19.2614	7.1855
319	101,761	32,461,759	17.8606	6.8328	372	138,384	51,478,848	19.2873	7.1920
320	102,400	32,768,000	17.8885	6.8399	373	139,129	51,895,117	19.3132	7.1984
321	103,041	33,076,161	17.9165	6.8470	374	139,876	52,313,624	19.3391	7.2048
322	103,684	33,386,248	17.9444	6.8541	375	140,625	52,734,375	19.3649	7.2112
323	104,329	33,698,267	17.9722	6.8612	376	141,376	53,157,376	19.3907	7.2177
324	104,976	34,012,224	18	6.8683	377	142,129	53,582,633	19.4165	7.2240
325	105,625	34,328,125	18.0278	6.8753	378	142,884	54,010,152	19.4422	7.2304
326	106,276	34,645,976	18.0555	6.8824	379	143,641	54,439,939	19.4679	7.2368
327	106,929	34,965,783	18.0831	6.8894	380	144,400	54,872,000	19.4936	7.2432
328	107,584	35,287,552	18.1108	6.8964	381	145,161	55,306,341	19.5192	7.2495
329	108,241	35,611,289	18.1384	6.9034	382	145,924	55,742,968	19.5448	7.2558
330	108,900	35,937,000	18.1659	6.9104	383	146,689	56,181,887	19.5704	7.2622
331	109,561	36,264,691	18.1934	6.9174	384	147,456	56,623,104	19.5959	7.2685
332	110,224	36,594,368	18.2209	6.9244	385	148,225	57,066,625	19.6214	7.2748
333	110,889	36,926,037	18.2483	6.9313	386	148,996	57,512,456	19.6469	7.2811
334	111,556	37,259,704	18.2757	6.9382	387	149,769	57,960,603	19.6723	7.2874
335	112,225	37,595,375	18.3030	6.9451	388	150,544	58,411,072	19.6977	7.2936
336	112,896	37,933,056	18.3303	6.9521	389	151,321	58,863,869	19.7231	7.2999
337	113,569	38,272,753	18.3576	6.9589	390	152,100	59,319,000	19.7484	7.3061
338	114,244	38,614,472	18.3848	6.9658	391	152,881	59,776,471	19.7737	7.3124
339	114,921	38,958,219	18.4120	6.9727	392	153,664	60,236,288	19.7990	7.3186
340	115,600	39,304,000	18.4391	6.9795	393	154,449	60,698,457	19.8242	7.3248
341	116,281	39,651,821	18.4662	6.9864	394	155,236	61,162,984	19.8494	7.3310
342	116,964	40,001,688	18.4932	6.9932	395	156,025	61,629,875	19.8746	7.3372
343	117,649	40,353,607	18.5203	7	396	156,816	62,099,136	19.8997	7.3434
344	118,336	40,707,584	18.5472	7.0068	397	157,609	62,570,773	19.9249	7.3496
345	119,025	41,063,625	18.5742	7.0136	398	158,404	63,044,792	19.9499	7.3558
346	119,716	41,421,736	18.6011	7.0203	399	159,201	63,521,199	19.9750	7.3619
347	120,409	41,781,923	18.6279	7.0271	400	160,000	64,000,000	20	7.3681
348	121,104	42,144,192	18.6548	7.0338	401	160,801	64,481,201	20.0250	7.3742
349	121,801	42,508,549	18.6815	7.0406	402	161,604	64,964,808	20.0499	7.3803
350	122,500	42,875,000	18.7083	7.0473	403	162,409	65,450,827	20.0749	7.3864
351	123,201	43,243,551	18.7350	7.0540	404	163,216	65,939,264	20.0998	7.3925
352	123,904	43,614,208	18.7617	7.0607	405	164,025	66,430,125	20.1246	7.3986
353	124,609	43,986,977	18.7883	7.0674	406	164,836	66,923,416	20.1494	7.4047
354	125,316	44,361,864	18.8149	7.0740	407	165,649	67,419,143	20.1742	7.4108
355	126,025	44,738,875	18.8414	7.0807	408	166,464	67,917,312	20.1990	7.4169
356	126,736	45,118,016	18.8680	7.0873	409	167,281	68,417,929	20.2237	7.4229
357	127,449	45,499,293	18.8944	7.0940	410	168,100	68,921,000	20.2485	7.4290
358	128,164	45,882,712	18.9209	7.1006	411	168,921	69,426,531	20.2731	7.4350
359	128,881	46,268,279	18.9473	7.1072	412	169,744	69,934,528	20.2978	7.4410
360	129,600	46,656,000	18.9737	7.1138	413	170,569	70,444,997	20.3224	7.4470
361	130,321	47,045,881	19	7.1204	414	171,396	70,957,944	20.3470	7.4530
362	131,044	47,437,928	19.0263	7.1269	415	172,225	71,473,375	20.3715	7.4590
363	131,769	47,832,147	19.0526	7.1335	416	173,056	71,991,296	20.3961	7.4650

TABLE OF SQUARES, CUBES, SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000 — (*Continued*)

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
417	173,889	72,511,713	20.4206	7.4710	470	220,900	103,823,000	21.6795	7.7750
418	174,724	73,034,632	20.4550	7.4770	471	221,841	104,487,111	21.7025	7.7805
419	175,561	73,560,059	20.4695	7.4829	472	222,784	105,154,048	21.7256	7.7860
420	176,400	74,088,000	20.4939	7.4889	473	223,729	105,823,817	21.7486	7.7915
421	177,241	74,618,461	20.5183	7.4948	474	224,676	106,496,424	21.7715	7.7970
422	178,084	75,151,448	20.5426	7.5007	475	225,625	107,171,875	21.7945	7.8025
423	178,929	75,686,967	20.5670	7.5067	476	226,576	107,850,176	21.8174	7.8079
424	179,776	76,225,024	20.5913	7.5126	477	227,529	108,531,333	21.8403	7.8134
425	180,625	76,765,625	20.6155	7.5185	478	228,484	109,215,352	21.8632	7.8188
426	181,476	77,308,776	20.6398	7.5244	479	229,441	109,902,239	21.8861	7.8243
427	182,329	77,854,483	20.6640	7.5302	480	230,400	110,592,000	21.9089	7.8297
428	183,184	78,402,752	20.6882	7.5361	481	231,361	111,284,641	21.9317	7.8362
429	184,041	78,953,589	20.7123	7.5420	482	232,324	111,980,168	21.9545	7.8406
430	184,900	79,507,000	20.7364	7.5478	483	233,289	112,678,587	21.9773	7.8460
431	185,761	80,062,991	20.7605	7.5537	484	234,256	113,379,904	22	7.8514
432	186,624	80,621,568	20.7846	7.5595	485	235,225	114,084,125	22.0227	7.8568
433	187,489	81,182,737	20.8087	7.5654	486	236,196	114,791,256	22.0454	7.8622
434	188,356	81,746,504	20.8327	7.5712	487	237,169	115,501,303	22.0681	7.8676
435	189,225	82,312,875	20.8567	7.5770	488	238,144	116,214,272	22.0907	7.8730
436	190,096	82,881,856	20.8806	7.5828	489	239,121	116,930,169	22.1133	7.8784
437	190,969	83,453,453	20.9045	7.5886	490	240,100	117,649,000	22.1359	7.8837
438	191,844	84,027,672	20.9284	7.5944	491	241,081	118,370,771	22.1585	7.8891
439	192,721	84,604,519	20.9523	7.6001	492	242,064	119,095,488	22.1811	7.8944
440	193,600	85,184,000	20.9762	7.6059	493	243,049	119,823,157	22.2036	7.8998
441	194,481	85,766,121	21	7.6117	494	244,036	120,553,784	22.2261	7.9051
442	195,364	86,350,888	21.0238	7.6174	495	245,025	121,287,375	22.2486	7.9105
443	196,249	86,938,307	21.0476	7.6232	496	246,016	122,023,936	22.2711	7.9158
444	197,136	87,528,384	21.0713	7.6289	497	247,009	122,763,473	22.2935	7.9211
445	198,025	88,121,125	21.0950	7.6346	498	248,004	123,505,992	22.3159	7.9264
446	198,916	88,716,536	21.1187	7.6403	499	249,001	124,251,499	22.3383	7.9317
447	199,809	89,314,623	21.1424	7.6460	500	250,000	125,000,000	22.3607	7.9370
448	200,704	89,915,392	21.1660	7.6517	501	251,001	125,751,501	22.3830	7.9423
449	201,601	90,518,849	21.1896	7.6574	502	252,004	126,506,008	22.4054	7.9476
450	202,500	91,125,000	21.2132	7.6631	503	253,009	127,263,527	22.4277	7.9528
451	203,401	91,733,851	21.2368	7.6688	504	254,016	128,024,064	22.4499	7.9581
452	204,304	92,345,408	21.2603	7.6744	505	255,025	128,787,625	22.4722	7.9634
453	205,209	92,959,677	21.2838	7.6801	506	256,036	129,554,216	22.4944	7.9686
454	206,116	93,576,664	21.3073	7.6857	507	257,049	130,323,843	22.5167	7.9739
455	207,025	94,196,375	21.3307	7.6914	508	258,064	131,096,512	22.5389	7.9791
456	207,936	94,818,816	21.3542	7.6970	509	259,081	131,872,229	22.5610	7.9843
457	208,849	95,443,993	21.3776	7.7026	510	260,100	132,651,000	22.5832	7.9896
458	209,764	96,071,912	21.4009	7.7082	511	261,121	133,432,831	22.6053	7.9948
459	210,681	96,702,579	21.4243	7.7138	512	262,144	134,217,728	22.6274	8
460	211,600	97,336,000	21.4476	7.7194	513	263,169	135,005,697	22.6495	8.0052
461	212,521	97,972,181	21.4709	7.7250	514	264,196	135,796,744	22.6716	8.0104
462	213,444	98,611,128	21.4942	7.7306	515	265,225	136,590,875	22.6936	8.0156
463	214,369	99,252,847	21.5174	7.7362	516	266,256	137,388,096	22.7156	8.0208
464	215,296	99,897,344	21.5407	7.7418	517	267,289	138,188,413	22.7376	8.0260
465	216,225	100,544,625	21.5639	7.7473	518	268,324	138,991,832	22.7596	8.0311
466	217,156	101,194,696	21.5870	7.7529	519	269,361	139,798,359	22.7816	8.0363
467	218,089	101,847,563	21.6102	7.7584	520	270,400	140,608,000	22.8035	8.0415
468	219,024	102,503,232	21.6333	7.7639	521	271,441	141,420,761	22.8254	8.0466
469	219,961	103,161,709	21.6564	7.7695	522	272,484	142,236,648	22.8473	8.0517

TABLE OF SQUARES, CUBES, SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000 — (*Continued*)

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
523	273,529	143,055,667	22.8692	8.0569	576	331,776	191,102,976	24	8.3203
524	274,576	143,877,824	22.8910	8.0620	577	332,929	192,100,033	24.0208	8.3251
525	275,625	144,703,125	22.9129	8.0671	578	334,084	193,100,552	24.0416	8.3300
526	276,676	145,531,576	22.9347	8.0723	579	335,241	194,104,539	24.0624	8.3348
527	277,729	146,363,183	22.9565	8.0774	580	336,400	195,112,000	24.0832	8.3396
528	278,784	147,197,952	22.9783	8.0825	581	337,561	196,122,941	24.1039	8.3443
529	279,841	148,035,889	23	8.0876	582	338,724	197,137,368	24.1247	8.3491
530	280,900	148,877,000	23.0217	8.0927	583	339,889	198,155,287	24.1454	8.3539
531	281,961	149,721,291	23.0434	8.0978	584	341,056	199,176,704	24.1661	8.3587
532	283,024	150,568,768	23.0651	8.1028	585	342,225	200,201,625	24.1868	8.3634
533	284,089	151,419,437	23.0868	8.1079	586	343,396	201,230,056	24.2074	8.3682
534	285,156	152,273,304	23.1084	8.1130	587	344,569	202,262,003	24.2281	8.3730
535	286,225	153,130,375	23.1301	8.1180	588	345,744	203,297,472	24.2487	8.3777
536	287,296	153,990,656	23.1517	8.1231	589	346,921	204,336,469	24.2693	8.3825
537	288,369	154,854,153	23.1733	8.1281	590	348,100	205,379,000	24.2899	8.3872
538	289,444	155,720,872	23.1948	8.1332	591	349,281	206,425,071	24.3105	8.3919
539	290,521	156,590,819	23.2164	8.1382	592	350,464	207,474,688	24.3311	8.3967
540	291,600	157,464,000	23.2379	8.1433	593	351,649	208,526,857	24.3516	8.4014
541	292,681	158,340,421	23.2594	8.1483	594	352,836	209,584,584	24.3721	8.4061
542	293,764	159,220,088	23.2809	8.1533	595	354,025	210,644,875	24.3926	8.4108
543	294,849	160,103,007	23.3024	8.1583	596	355,216	211,708,736	24.4131	8.4155
544	295,936	160,989,184	23.3238	8.1633	597	356,409	212,776,173	24.4336	8.4202
545	297,025	161,878,625	23.3452	8.1683	598	357,604	213,847,192	24.4540	8.4249
546	298,116	162,771,336	23.3666	8.1733	599	358,801	214,921,799	24.4745	8.4296
547	299,209	163,667,323	23.3880	8.1783	600	360,000	216,000,000	24.4949	8.4343
548	300,304	164,566,592	23.4094	8.1833	601	361,201	217,081,801	24.5153	8.4390
549	301,401	165,469,149	23.4307	8.1882	602	362,404	218,167,208	24.5357	8.4437
550	302,500	166,375,000	23.4521	8.1932	603	363,609	219,256,227	24.5561	8.4484
551	303,601	167,284,151	23.4734	8.1982	604	364,816	220,348,864	24.5764	8.4530
552	304,704	168,196,608	23.4947	8.2031	605	366,025	221,445,125	24.5967	8.4577
553	305,809	169,112,377	23.5160	8.2081	606	367,236	222,545,016	24.6171	8.4623
554	306,916	170,031,464	23.5272	8.2130	607	368,449	223,648,543	24.6374	8.4670
555	308,025	170,953,875	23.5584	8.2180	608	369,664	224,755,712	24.6577	8.4716
556	309,136	171,879,616	23.5797	8.2229	609	370,881	225,866,529	24.6779	8.4763
557	310,249	172,808,693	23.6008	8.2278	610	372,100	226,981,000	24.6982	8.4809
558	311,364	173,741,112	23.6220	8.2327	611	373,321	228,099,131	24.7184	8.4856
559	312,481	174,676,879	23.6432	8.2377	612	374,544	229,220,928	24.7386	8.4902
560	313,600	175,616,000	23.6643	8.2426	613	375,769	230,346,397	24.7588	8.4948
561	314,721	176,558,481	23.6854	8.2475	614	376,996	231,475,544	24.7790	8.4994
562	315,844	177,504,328	23.7065	8.2524	615	378,225	232,608,375	24.7992	8.5040
563	316,969	178,453,547	23.7276	8.2573	616	379,456	233,744,896	24.8193	8.5086
564	318,096	179,406,144	23.7487	8.2621	617	380,689	234,885,113	24.8395	8.5132
565	319,225	180,362,125	23.7697	8.2670	618	381,924	236,029,032	24.8596	8.5178
566	320,356	181,321,496	23.7908	8.2719	619	383,161	237,176,659	24.8797	8.5224
567	321,489	182,284,263	23.8118	8.2768	620	384,400	238,328,000	24.8998	8.5270
568	322,624	183,250,432	23.8328	8.2816	621	385,641	239,483,061	24.9199	8.5316
569	323,761	184,220,009	23.8537	8.2865	622	386,884	240,641,848	24.9399	8.5362
570	324,900	185,193,000	23.8747	8.2913	623	388,129	241,804,367	24.9600	8.5408
571	326,041	186,169,411	23.8956	8.2962	624	389,376	242,970,624	24.9800	8.5453
572	327,184	187,149,248	23.9165	8.3010	625	390,625	244,140,625	25	8.5499
573	328,329	188,132,517	23.9374	8.3059	626	391,876	245,314,376	25.0200	8.5544
574	329,476	189,119,224	23.9583	8.3107	627	393,129	246,491,883	25.0400	8.5590
575	330,625	190,109,375	23.9792	8.3155	628	394,384	247,673,152	25.0590	8.5635

TABLE OF SQUARES, CUBES, SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000 — (*Continued*)

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
629	395,641	248,858,189	25.0799	8.5681	682	465,124	317,214,568	26.1151	8.8023
630	396,900	250,047,000	25.0998	8.5726	683	466,489	318,611,987	26.1343	8.8066
631	398,161	251,239,591	25.1197	8.5772	684	467,856	320,013,504	26.1534	8.8109
632	399,424	252,435,968	25.1396	8.5817	685	469,225	321,419,125	26.1725	8.8152
633	400,689	253,636,137	25.1595	8.5862	686	470,596	322,828,856	26.1916	8.8194
634	401,956	254,840,104	25.1794	8.5907	687	471,969	324,242,703	26.2107	8.8237
635	403,225	256,047,875	25.1992	8.5952	688	473,344	325,660,672	26.2298	8.8280
636	404,496	257,259,456	25.2190	8.5997	689	474,721	327,082,769	26.2488	8.8323
637	405,769	258,474,853	25.2389	8.6043	690	476,100	328,509,000	26.2679	8.8366
638	407,044	259,694,072	25.2587	8.6088	691	477,481	329,939,371	26.2869	8.8408
639	408,321	260,917,119	25.2784	8.6132	692	478,864	331,373,888	26.3059	8.8451
640	409,600	262,144,000	25.2982	8.6177	693	480,249	332,812,557	26.3249	8.8493
641	410,881	263,374,721	25.3180	8.6222	694	481,636	334,255,384	26.3439	8.8536
642	412,164	264,609,288	25.3377	8.6267	695	483,025	335,702,375	26.3629	8.8578
643	413,449	265,847,707	25.3574	8.6312	696	484,416	337,153,536	26.3818	8.8621
644	414,736	267,089,984	25.3772	8.6357	697	485,809	338,608,873	26.4008	8.8663
645	416,025	268,336,125	25.3969	8.6401	698	487,204	340,068,392	26.4197	8.8706
646	417,316	269,586,136	25.4165	8.6446	699	488,601	341,532,099	26.4386	8.8748
647	418,609	270,840,023	25.4362	8.6490	700	490,000	343,000,000	26.4575	8.8790
648	419,904	272,097,792	25.4558	8.6535	701	491,401	344,472,101	26.4764	8.8833
649	421,201	273,359,449	25.4755	8.6579	702	492,804	345,948,408	26.4953	8.8875
650	422,500	274,625,000	25.4951	8.6624	703	494,209	347,428,927	26.5141	8.8917
651	423,801	275,894,451	25.5147	8.6668	704	495,616	348,913,664	26.5330	8.8959
652	425,104	277,167,808	25.5343	8.6713	705	497,025	350,402,625	26.5518	8.9001
653	426,409	278,445,077	25.5539	8.6757	706	498,436	351,895,816	26.5707	8.9043
654	427,716	279,726,264	25.5734	8.6801	707	499,849	353,393,243	26.5895	8.9085
655	429,025	281,011,375	25.5930	8.6845	708	501,264	354,894,912	26.6083	8.9127
656	430,336	282,300,416	25.6125	8.6890	709	502,681	356,400,829	26.6271	8.9169
657	431,649	283,593,393	25.6320	8.6934	710	504,100	357,911,000	26.6458	8.9211
658	432,964	284,890,312	25.6515	8.6978	711	505,521	359,425,431	26.6646	8.9253
659	434,281	286,191,179	25.6710	8.7022	712	506,944	360,944,128	26.6833	8.9295
660	435,600	287,496,000	25.6905	8.7066	713	508,369	362,467,097	26.7021	8.9337
661	436,921	288,804,781	25.7099	8.7110	714	509,796	363,994,344	26.7208	8.9378
662	438,244	290,117,528	25.7294	8.7154	715	511,225	365,525,875	26.7395	8.9420
663	439,569	291,434,247	25.7488	8.7198	716	512,656	367,061,696	26.7582	8.9462
664	440,896	292,754,944	25.7682	8.7241	717	514,089	368,601,813	26.7769	8.9503
665	442,225	294,079,625	25.7876	8.7285	718	515,524	370,146,232	26.7955	8.9545
666	443,556	295,408,296	25.8070	8.7329	719	516,961	371,694,959	26.8142	8.9587
667	444,889	296,740,963	25.8263	8.7373	720	518,400	373,248,000	26.8328	8.9628
668	446,224	298,077,632	25.8457	8.7416	721	519,841	374,805,361	26.8514	8.9670
669	447,561	299,418,309	25.8650	8.7460	722	521,284	375,367,048	26.8701	8.9711
670	448,900	300,763,000	25.8844	8.7503	723	522,729	377,933,067	26.8887	8.9752
671	450,241	302,111,711	25.9037	8.7547	724	524,176	379,503,424	26.9072	8.9794
672	451,584	303,464,448	25.9230	8.7590	725	525,625	381,078,125	26.9258	8.9835
673	452,929	304,821,217	25.9422	8.7634	726	527,076	382,657,176	26.9444	8.9876
674	454,276	306,182,024	25.9615	8.7677	727	528,529	384,240,583	26.9629	8.9918
675	455,625	307,546,875	25.9808	8.7721	728	529,984	385,828,352	26.9815	8.9959
676	456,976	308,915,776	26	8.7764	729	531,441	387,420,489	27	9
677	458,329	310,288,733	26.0192	8.7807	730	532,900	389,017,000	27.0185	9.0041
678	459,684	311,665,752	26.0384	8.7850	731	534,361	390,617,891	27.0370	9.0082
679	461,041	313,046,839	26.0576	8.7893	732	535,824	392,223,168	27.0555	9.0123
680	462,400	314,432,000	26.0768	8.7937	733	537,289	393,832,837	27.0740	9.0164
681	463,761	315,821,241	26.0960	8.7980	734	538,756	395,446,904	27.0924	9.0205

Table of Squares, Cubes, Square Roots and Cube Roots of Numbers from 1 to 1000 — (*Continued*)

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
735	540,225	397,065,375	27.1109	9.0246	788	620,944	489,303,872	28.0713	9.2365
736	541,696	398,688,256	27.1293	9.0287	789	622,521	491,169,069	28.0891	9.2404
737	543,169	400,315,553	27.1477	9.0328	790	624,100	493,039,000	28.1069	9.2443
738	544,644	401,947,272	27.1662	9.0369	791	625,681	494,913,671	28.1247	9.2482
739	546,121	403,583,419	27.1846	9.0410	792	627,264	496,793,088	28.1425	9.2521
740	547,600	405,224,000	27.2029	9.0450	793	628,849	498,677,257	28.1603	9.2560
741	549,081	406,869,021	27.2213	9.0491	794	630,436	500,566,184	28.1780	9.2599
742	550,564	408,518,488	27.2397	9.0532	795	632,025	502,459,875	28.1957	9.2638
743	552,049	410,172,407	27.2580	9.0572	796	633,616	504,358,336	28.2135	9.2677
744	553,536	411,830,784	27.2764	9.0613	797	635,209	506,261,573	28.2312	9.2716
745	555,025	413,493,625	27.2947	9.0654	798	636,804	508,169,592	28.2489	9.2754
746	556,516	415,160,936	27.3130	9.0694	799	638,401	510,082,399	28.2666	9.2793
747	558,009	416,832,723	27.3313	9.0735	800	640,000	512,000,000	28.2843	9.2832
748	559,504	418,508,992	27.3496	9.0775	801	641,601	513,922,401	28.3019	9.2870
749	561,001	420,189,749	27.3679	9.0816	802	643,204	515,849,608	28.3196	9.2909
750	562,500	421,875,000	27.3861	9.0856	803	644,809	517,781,627	28.3373	9.2948
751	564,001	423,564,751	27.4044	9.0896	804	646,416	519,718,464	28.3549	9.2986
752	565,504	425,259,008	27.4226	9.0937	805	648,025	521,660,125	28.3725	9.3025
753	567,009	426,957,777	27.4408	9.0977	806	649,636	523,606,616	28.3901	9.3063
754	568,516	428,661,064	27.4591	9.1017	807	651,249	525,557,943	28.4077	9.3102
755	570,025	430,368,875	27.4773	9.1057	808	652,864	527,514,112	28.4253	9.3140
756	571,536	432,081,216	27.4955	9.1098	809	654,481	529,475,129	28.4429	9.3179
757	573,049	433,798,093	27.5136	9.1138	810	656,100	531,441,000	28.4605	9.3217
758	574,564	435,519,512	27.5318	9.1178	811	657,721	533,411,731	28.4781	9.3255
759	576,081	437,245,479	27.5500	9.1218	812	659,344	535,387,328	28.4956	9.3294
760	577,600	438,976,000	27.5681	9.1258	813	660,969	537,367,797	28.5132	9.3332
761	579,121	440,711,081	27.5862	9.1298	814	662,596	539,353,144	28.5307	9.3370
762	580,644	442,450,728	27.6043	9.1338	815	664,225	541,343,375	28.5482	9.3408
763	582,169	444,194,947	27.6225	9.1378	816	665,856	543,338,496	28.5657	9.3447
764	583,696	445,943,744	27.6405	9.1418	817	667,489	545,338,513	28.5832	9.3485
765	585,225	447,697,125	27.6586	9.1458	818	669,124	547,343,432	28.6007	9.3523
766	586,756	449,455,096	27.6767	9.1498	819	670,761	549,353,259	28.6182	9.3561
767	588,289	451,217,663	27.6948	9.1537	820	672,400	551,368,000	28.6356	9.3599
768	589,824	452,984,832	27.7128	9.1577	821	674,041	553,387,661	28.6531	9.3637
769	591,361	454,756,609	27.7308	9.1617	822	675,684	555,412,248	28.6705	9.3675
770	592,900	456,533,000	27.7489	9.1657	823	677,329	557,441,767	28.6880	9.3713
771	594,441	458,314,011	27.7669	9.1696	824	678,976	559,476,224	28.7054	9.3751
772	595,984	460,099,648	27.7849	9.1736	825	680,625	561,515,625	28.7228	9.3789
773	597,529	461,889,917	27.8029	9.1775	826	682,276	563,559,976	28.7402	9.3827
774	599,076	463,684,824	27.8209	9.1815	827	683,929	565,609,283	28.7576	9.3865
775	600,625	465,484,375	27.8388	9.1855	828	685,584	567,663,552	28.7750	9.3902
776	602,176	467,288,576	27.8568	9.1894	829	687,241	569,722,789	28.7924	9.3940
777	603,729	469,097,433	27.8747	9.1933	830	688,900	571,787,000	28.8097	9.3978
778	605,284	470,910,952	27.8927	9.1973	831	690,561	573,856,191	28.8271	9.4016
779	606,841	472,729,139	27.9106	9.2012	832	692,224	575,930,368	28.8444	9.4053
780	608,400	474,552,000	27.9285	9.2052	833	693,889	578,009,537	28.8617	9.4091
781	609,961	476,379,541	27.9464	9.2091	834	695,556	580,093,704	28.8791	9.4129
782	611,524	478,211,768	27.9643	9.2130	835	697,225	582,182,875	28.8964	9.4166
783	613,089	480,048,687	27.9821	9.2170	836	698,896	584,277,056	28.9137	9.4204
784	614,656	481,890,304	28	9.2209	837	700,569	586,376,253	28.9310	9.4241
785	616,225	483,736,625	28.0179	9.2248	838	702,244	588,480,472	28.9482	9.4279
786	617,796	485,587,656	28.0357	9.2287	839	703,921	590,589,719	28.9655	9.4316
787	619,369	487,443,403	28.0535	9.2326	840	705,600	592,704,000	28.9828	9.4354

TABLE OF SQUARES, CUBES, SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000 — (*Continued*)

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
841	707,281	594,823,321	29	9.4391	894	799,236	714,516,984	29.8998	9.6334
842	708,964	596,947,688	29.0172	9.4429	895	801,025	716,917,375	29.9166	9.6370
843	710,649	599,077,107	29.0345	9.4466	896	802,816	719,323,136	29.9333	9.6406
844	712,336	601,211,584	29.0517	9.4503	897	804,609	721,734,273	29.9500	9.6442
845	714,025	603,351,125	29.0689	9.4541	898	806,404	724,150,792	29.9666	9.6477
846	715,716	605,495,736	29.0861	9.4578	899	808,201	726,572,699	29.9833	9.6513
847	717,409	607,645,423	29.1033	9.4615	900	810,000	729,000,000	30	9.6549
848	719,104	609,800,192	29.1204	9.4652	901	811,801	731,432,701	30.0167	9.6585
849	720,801	611,960,049	29.1376	9.4690	902	813,604	733,870,808	30.0333	9.6620
850	722,500	614,125,000	29.1548	9.4727	903	815,409	736,314,327	30.0500	9.6656
851	724,201	616,295,051	29.1719	9.4764	904	817,216	738,763,264	30.0666	9.6692
852	725,904	618,470,208	29.1890	9.4801	905	819,025	741,217,625	30.0832	9.6727
853	727,609	620,650,477	29.2062	9.4838	906	820,836	743,677,416	30.0998	9.6763
854	729,316	622,835,864	29.2233	9.4875	907	822,649	746,142,643	30.1164	9.6799
855	731,025	625,026,375	29.2404	9.4912	908	824,464	748,613,312	30.1330	9.6834
856	732,736	627,222,016	29.2575	9.4949	909	826,281	751,089,429	30.1496	9.6870
857	734,449	629,422,793	29.2746	9.4986	910	828,100	753,571,000	30.1662	9.6905
858	736,164	631,628,712	29.2916	9.5023	911	829,921	756,058,031	30.1828	9.6941
859	737,881	633,839,779	29.3087	9.5060	912	831,744	758,550,528	30.1993	9.6976
860	739,600	636,056,000	29.3258	9.5097	913	833,569	761,048,497	30.2159	9.7012
861	741,321	638,277,381	29.3428	9.5134	914	835,396	763,551,944	30.2324	9.7047
862	743,044	640,503,928	29.3598	9.5171	915	837,225	766,060,875	30.2490	9.7082
863	744,769	642,735,647	29.3769	9.5207	916	839,056	768,575,296	30.2655	9.7118
864	746,496	644,972,544	29.3939	9.5244	917	840,889	771,095,213	30.2820	9.7153
865	748,225	647,214,625	29.4109	9.5281	918	842,724	773 620,632	30.2985	9.7188
866	749,956	649,461,896	29.4279	9.5317	919	844,561	776,151,559	30.3150	9.7224
867	751,689	651,714,363	29.4449	9.5354	920	846,400	778,688,000	30.3315	9.7259
868	753,424	653,972,032	29.4618	9.5391	921	848,241	781,229,961	30.3480	9.7294
869	755,161	656,234,909	29.4788	9.5427	922	850,084	783,777,448	30.3645	9.7329
870	756,900	658,503,000	29.4958	9.5464	923	851,929	786,330,467	30.3809	9.7364
871	758,641	660,776,311	29.5127	9.5501	924	853,776	788,889,024	30.3974	9.7400
872	760,384	663,054,848	29.5296	9.5537	925	855,625	791,453,125	30.4138	9.7435
873	762,129	665,338,617	29.5466	9.5574	926	857,476	794,022,776	30.4302	9.7470
874	763,876	667,627,624	29.5635	9.5610	927	859,329	796,597,983	30.4467	9.7505
875	765,625	669,921,875	29.5804	9.5647	928	861,184	799,178,752	30.4631	9.7540
876	767,376	672,221,376	29.5973	9.5683	929	863,041	801,765,089	30.4795	9.7575
877	769,129	674,526,133	29.6142	9.5719	930	864,900	804,357,000	30.4959	9.7610
878	770,884	676,836,152	29.6311	9.5756	931	866,761	806,954,491	30.5123	9.7645
879	772,641	679,151,439	29.6479	9.5792	932	868,624	809,557,568	30.5287	9.7680
880	774,400	681,472,000	29.6648	9.5828	933	870,489	812,166,237	30.5450	9.7715
881	776,161	683,797,841	29.6816	9.5865	934	872,356	814,780,504	30.5614	9.7750
882	777,924	686,128,968	29.6985	9.5901	935	874,225	817,400,375	30.5778	9.7785
883	779,689	688,465,387	29.7153	9.5937	936	876,096	820,025,856	30.5941	9.7819
884	781,456	690,807,104	29.7321	9.5973	937	877,969	822,656,953	30.6105	9.7854
885	783,225	693,154,125	29.7489	9.6010	938	879,844	825,293,672	30.6268	9.7889
886	784,996	695,506,456	29.7658	9.6046	939	881,721	827,936,019	30.6431	9.7924
887	786,769	697,864,103	29.7825	9.6082	940	883,600	830,584,000	30.6594	9.7959
888	788,544	700,227,072	29.7993	9.6118	941	885,481	833,237,621	30.6757	9.7993
889	790,321	702,595,369	29.8161	9.6154	942	887,364	835,896,888	30.6920	9.8028
890	792,100	704,969,000	29.8329	9.6190	943	889,249	838,561,807	30.7083	9.8063
891	793,881	707,347,971	29.8496	9.6226	944	891,136	841,232,384	30 7246	9.8097
892	795,664	709,732,288	29.8664	9.6262	945	893,025	843,908,625	30.7409	9.8132
893	797,449	712,121,957	29.8831	9.6298	946	894,916	846,590,536	30.7571	9.8167

Table of Squares, Cubes, Square Roots and Cube Roots of Numbers from 1 to 1000 — (*Continued*)

No.	Square	Cube	Square root	Cube root	No.	Square	Cube	Square root	Cube root
947	896,809	849,278,123	30.7734	9.8201	974	948,676	924,010,424	31.2090	9.9126
948	898,704	851,971,392	30.7896	9.8236	975	950,625	926,859,375	31.2250	9.9160
949	900,601	854,670,349	30.8058	9.8270	976	952,576	929,714,176	31.2410	9.9194
950	902,500	857,375,000	30.8221	9.8305	977	954,529	932,574,833	31.2570	9.9227
951	904,401	860,085,351	30.8383	9.8339	978	956,484	935,441,352	31.2730	9.9261
952	906,304	862,801,408	30.8545	9.8374	979	958,441	938,313,739	31.2890	9.9295
953	908,209	865,523,177	30.8707	9.8408	980	960,400	941,192,000	31.3050	9.9329
954	910,116	868,250,664	30.8869	9.8443	981	962,361	944,076,141	31.3209	9.9363
955	912,025	870,983,875	30.9031	9.8477	982	964,324	946,966,168	31.3369	9.9396
956	913,936	873,722,816	30.9192	9.8511	983	966,289	949,862,087	31.3528	9.9430
957	915,849	876,467,493	30.9354	9.8546	984	968,256	952,763,904	31.3688	9.9464
958	917,764	879,217,912	30.9516	9.8580	985	970,225	955,671,625	31.3847	9.9497
959	919,681	881,974,079	30.9677	9.8614	986	972,196	958,585,256	31.4006	9.9531
960	921,600	884,736,000	30.9839	9.8648	987	974,169	961,504,803	31.4166	9.9565
961	923,521	887,503,681	31	9.8683	988	976,144	964,430,272	31.4325	9.9598
962	925,444	890,277,128	31.0161	9.8717	989	978,121	967,361,669	31.4484	9.9632
963	927,369	893,056,347	31.0322	9.8751	990	980,100	970,299,000	31.4643	9.9666
964	929,296	895,841,344	31.0483	9.8785	991	982,081	973,242,271	31.4802	9.9699
965	931,225	898,632,125	31.0644	9.8819	992	984,064	976,191,488	31.4960	9.9733
966	933,156	901,428,696	31.0805	9.8854	993	986,049	979,146,657	31.5119	9.9766
967	935,089	904,231,063	31.0966	9.8888	994	988,036	982,107,784	31.5278	9.9800
968	937,024	907,039,232	31.1127	9.8922	995	990,025	985,074,875	31.5436	9.9833
969	938,961	909,853,209	31.1288	9.8956	996	992,016	988,047,936	31.5595	9.9866
970	940,900	912,673,000	31.1448	9.8990	997	994,009	991,026,973	31.5753	9.9900
971	942,841	915,498,611	31.1609	9.9024	998	996,004	994,011,992	31.5911	9.9933
972	944,784	918,330,048	31.1769	9.9058	999	998,001	997,002,999	31.6070	9.9967
973	946,729	921,167,317	31.1929	9.9092	1000	1,000,000	1,000,000,000	31.6228	10

To find the square or cube of any whole number ending with ciphers. First, omit all the final ciphers. Take from the table the square or cube (as the case may be) of the rest of the number. To this *square* add *twice* as many ciphers as there were final ciphers in the original number. To the *cube* add *three* times as many as in the original number. Thus, for $90{,}500^2$, $905^2 = 819{,}025$. Add twice 2 ciphers, obtaining 8,190,250,000. For $90{,}500^3$, $905^3 = 741{,}217{,}625$. Add 3 times 2 ciphers, obtaining 741,217,625,000,000.

Table of Square Roots and Cube Roots of Numbers from 1000 to 10,000

No errors

No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root
1005	31.70	10.02	1270	35.64	10.83	1535	39.18	11.54	1800	42.43	12.16
1010	31.78	10.03	1275	35.71	10.84	1540	39.24	11.55	1805	42.49	12.18
1015	31.86	10.05	1280	35.78	10.86	1545	39.31	11.56	1810	42.54	12.19
1020	31.94	10.07	1285	35.85	10.87	1550	39.37	11.57	1815	42.60	12.20
1025	32.02	10.08	1290	35.92	10.89	1555	39.43	11.59	1820	42.66	12.21
1030	32.09	10.10	1295	35.99	10.90	1560	39.50	11.60	1825	42.72	12.22
1035	32.17	10.12	1300	36.06	10.91	1565	39.56	11.61	1830	42.78	12.23
1040	32.25	10.13	1305	36.12	10.93	1570	29.62	11.62	1835	42.84	12.24
1045	32.33	10.15	1310	36.19	10.94	1575	39.69	11.63	1840	42.90	12.25
1050	32.40	10.16	1315	36.26	10.96	1580	39.75	11.65	1845	42.95	12.26
1055	32.48	10.18	1320	36.33	10.97	1585	39.81	11.66	1850	43.01	12.28
1060	32.56	10.20	1325	36.40	10.98	1590	39.87	11.67	1855	43.07	12.29
1065	32.63	10.21	1330	36.47	11	1595	39.94	11.68	1860	43.13	12.30
1070	32.71	10.23	1335	36.54	11.01	1600	40	11.70	1865	43.19	12.31
1075	32.79	10.24	1340	36.61	11.02	1605	40.06	11.71	1870	43.24	12.32
1080	32.86	10.26	1345	36.67	11.04	1610	40.12	11.72	1875	43.30	12.33
1085	32.94	10.28	1350	36.74	11.05	1615	40.19	11.73	1880	43.36	12.34
1090	33.02	10.29	1355	36.81	11.07	1620	40.25	11.74	1885	43.42	12.35
1095	33.09	10.31	1360	36.88	11.08	1625	40.31	11.76	1890	43.47	12.36
1100	33.17	10.32	1365	36.95	11.09	1630	40.37	11.77	1895	43.53	12.37
1105	33.24	10.34	1370	37.01	11.11	1635	40.44	11.78	1900	43.59	12.39
1110	33.32	10.35	1375	37.08	11.12	1640	40.50	11.79	1905	43.65	12.40
1115	33.39	10.37	1380	37.15	11.13	1645	40.56	11.80	1910	43.70	12.41
1120	33.47	10.38	1385	37.22	11.15	1650	40.62	11.82	1915	43.76	12.42
1125	33.54	10.40	1390	37.28	11.16	1655	40.68	11.83	1920	43.82	12.43
1130	33.62	10.42	1395	37.35	11.17	1660	40.74	11.84	1925	43.87	12.44
1135	33.69	10.43	1400	37.42	11.19	1665	40.80	11.85	1930	43.93	12.45
1140	33.76	10.45	1405	37.48	11.20	1670	40.87	11.86	1935	43.99	12.46
1145	33.84	10.46	1410	37.55	11.21	1675	40.93	11.88	1940	44.05	12.47
1150	33.91	10.48	1415	37.62	11.23	1680	40.99	11.89	1945	44.10	12.48
1155	33.99	10.49	1420	37.68	11.24	1685	41.05	11.90	1950	44.16	12.49
1160	34.06	10.51	1425	37.75	11.25	1690	41.11	11.91	1955	44.22	12.50
1165	34.13	10.52	1430	37.82	11.27	1695	41.17	11.92	1960	44.27	12.51
1170	34.21	10.54	1435	37.88	11.28	1700	41.23	11.93	1965	44.33	12.53
1175	34.28	10.55	1440	37.95	11.29	1705	41.29	11.95	1970	44.38	12.54
1180	34.35	10.57	1445	38.01	11.31	1710	41.35	11.96	1975	44.44	12.55
1185	34.42	10.58	1450	38.08	11.32	1715	41.41	11.97	1980	44.50	12.56
1190	34.50	10.60	1455	38.14	11.33	1720	41.47	11.98	1985	44.55	12.57
1195	34.57	10.61	1460	38.21	11.34	1725	41.53	11.99	1990	44.61	12.58
1200	34.64	10.63	1465	38.28	11.36	1730	41.59	12	1995	44.67	12.59
1205	34.71	10.64	1470	38.34	11.37	1735	41.65	12.02	2000	44.72	12.60
1210	34.79	10.66	1475	38.41	11.38	1740	41.71	12.03	2005	44.78	12.61
1215	34.86	10.67	1480	38.47	11.40	1745	41.77	12.04	2010	44.83	12.62
1220	34.93	10.69	1485	38.54	11.41	1750	41.83	12.05	2015	44.89	12.63
1225	35	10.70	1490	38.60	11.42	1755	41.89	12.06	2020	44.94	12.64
1230	35.07	10.71	1495	38.67	11.43	1760	41.95	12.07	2025	45	12.65
1235	35.14	10.73	1500	38.73	11.45	1765	42.01	12.09	2030	45.06	12.66
1240	35.21	10.74	1505	38.79	11.46	1770	42.07	12.10	2035	45.11	12.67
1245	35.28	10.76	1510	38.86	11.47	1775	42.13	12.11	2040	45.17	12.68
1250	35.36	10.77	1515	38.92	11.49	1780	42.19	12.12	2045	45.22	12.69
1255	35.43	10.79	1520	38.99	11.50	1785	42.25	12.13	2050	45.28	12.70
1260	35.50	10.80	1525	39.05	11.51	1790	42.31	12.14	2055	45.33	12.71
1265	35.57	10.82	1530	39.12	11.52	1795	42.37	12.15	2060	45.39	12.72

TABLE OF SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM 1000 TO 10,000 — (*Continued*)

No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root
2065	45.44	12.73	2330	48.27	13.26	2740	52.35	13.99	3270	57.18	14.84
2070	45.50	12.74	2335	48.32	13.27	2750	52.44	14.01	3280	57.27	14.86
2075	45.55	12.75	2340	48.37	13.28	2760	52.54	14.03	3290	57.36	14.87
2080	45.61	12.77	2345	48.43	13.29	2770	52.63	14.04	3300	57.45	14.89
2085	45.66	12.78	2350	48.48	13.30	2780	52.73	14.06	3310	57.53	14.90
2090	45.72	12.79	2355	48.53	13.30	2790	52.82	14.08	3320	57.62	14.92
2095	45.77	12.80	2360	48.58	13.31	2800	52.92	14.09	3330	57.71	14.93
2100	45.83	12.81	2365	48.63	13.32	2810	53.01	14.11	3340	57.79	14.95
2105	45.88	12.82	2370	48.68	13.33	2820	53.10	14.13	3350	57.88	14.96
2110	45.93	12.83	2375	48.73	13.34	2830	53.20	14.14	3360	57.97	14.98
2115	45.99	12.84	2380	48.79	13.35	2840	53.29	14.16	3370	58.05	14.99
2120	46.04	12.85	2385	48.84	13.36	2850	53.39	14.18	3380	58.14	15.01
2125	46.10	12.86	2390	48.89	13.37	2860	53.48	14.19	3390	58.22	15.02
2130	46.15	12.87	2395	48.94	13.38	2870	53.57	14.21	3400	58.31	15.04
2135	46.21	12.88	2400	48.99	13.39	2880	53.67	14.23	3410	58.40	15.05
2140	46.26	12.89	2405	49.04	13.40	2890	53.76	14.24	3420	58.48	15.07
2145	46.31	12.90	2410	49.09	13.41	2900	53.85	14.26	3430	58.57	15.08
2150	46.37	12.91	2415	49.14	13.42	2910	53.94	14.28	3440	58.65	15.10
2155	46.42	12.92	2420	49.19	13.43	2920	54.04	14.29	3450	58.74	15.11
2160	46.48	12.93	2425	49.24	13.43	2930	54.13	14.31	3460	58.82	15.12
2165	46.53	12.94	2430	49.30	13.44	2940	54.22	14.33	3470	58.91	15.14
2170	46.58	12.95	2435	49.35	13.45	2950	54.31	14.34	3480	58.99	15.15
2175	46.64	12.96	2440	49.40	13.46	2960	54.41	14.36	3490	59.08	15.17
2180	46.69	12.97	2445	49.45	13.47	2970	54.50	14.37	3500	59.16	15.18
2185	46.74	12.98	2450	49.50	13.48	2980	54.59	14.39	3510	59.25	15.20
2190	46.80	12.99	2460	49.60	13.50	2990	54.68	14.41	3520	59.33	15.21
2195	46.85	13	2470	49.70	13.52	3000	54.77	14.42	3530	59.41	15.23
2200	46.90	13.01	2480	49.80	13.54	3010	54.86	14.44	3540	59.50	15.24
2205	46.96	13.02	2490	49.90	13.55	3020	54.95	14.45	3550	59.58	15.25
2210	47.01	13.03	2500	50	13.57	3030	55.05	14.47	3560	59.67	15.27
2215	47.06	13.04	2510	50.10	13.59	3040	55.14	14.49	3570	59.75	15.28
2220	47.12	13.05	2520	50.20	13.61	3050	55.23	14.50	3580	59.83	15.30
2225	47.17	13.05	2530	50.30	13.63	3060	55.32	14.52	3590	59.92	15.31
2230	47.22	13.06	2540	50.40	13.64	3070	55.41	14.53	3600	60	15.33
2235	47.28	13.07	2550	50.50	13.66	3080	55.50	14.55	3610	60.08	15.34
2240	47.33	13.08	2560	50.60	13.68	3090	55.59	14.57	3620	60.17	15.35
2245	47.38	13.09	2570	50.70	13.70	3100	55.68	14.58	3630	60.25	15.37
2250	47.43	13.10	2580	50.79	13.72	3110	55.77	14.60	3640	60.33	15.38
2255	47.49	13.11	2590	50.89	13.73	3120	55.86	14.61	3650	60.42	15.40
2260	47.54	13.12	2600	50.99	13.75	3130	55.95	14.63	3660	60.50	15.41
2265	47.59	13.13	2610	51.09	13.77	3140	56.04	14.64	3670	60.58	15.42
2270	47.64	13.14	2620	51.19	13.79	3150	56.12	14.66	3680	60.66	15.44
2275	47.70	13.15	2630	51.28	13.80	3160	56.21	14.67	3690	60.75	15.45
2280	47.75	13.16	2640	51.38	13.82	3170	56.30	14.69	3700	60.83	15.47
2285	47.80	13.17	2650	51.48	13.84	3180	56.39	14.71	3710	60.91	15.48
2290	47.85	13.18	2660	51.58	13.86	3190	56.48	14.72	3720	60.99	15.49
2295	47.91	13.19	2670	51.67	13.87	3200	56.57	14.74	3730	61.07	15.51
2300	47.96	13.20	2680	51.77	13.89	3210	56.66	14.75	3740	61.16	15.52
2305	48.01	13.21	2690	51.87	13.91	3220	56.75	14.77	3750	61.24	15.54
2310	48.06	13.22	2700	51.96	13.92	3230	56.83	14.78	3760	61.32	15.55
2315	48.11	13.23	2710	52.06	13.94	3240	56.92	14.80	3770	61.40	15.56
2320	48.17	13.24	2720	52.15	13.96	3250	57.01	14.81	3780	61.48	15.58
2325	48.22	13.25	2730	52.25	13.98	3260	57.10	14.83	3790	61.56	15.59

TABLE OF SQUARE ROOTS AND CUBE ROOTS OF NUMBERS FROM 1000 TO 10,000 — (*Continued*)

No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root
3800	61.64	15.60	4330	65.80	16.30	4860	69.71	16.94	5390	73.42	17.53
3810	61.73	15.62	4340	65.88	16.31	4870	69.79	16.95	5400	73.48	17.54
3820	61.81	15.63	4350	65.95	16.32	4880	69.86	16.96	5410	73.55	17.55
3830	61.89	15.65	4360	66.03	16.34	4890	69.93	16.97	5420	73.62	17.57
3840	61.97	15.66	4370	66.11	16.35	4900	70	16.98	5430	73.69	17.58
3850	62.05	15.67	4380	66.18	16.36	4910	70.07	17	5440	73.76	17.59
3860	62.13	15.69	4390	66.26	16.37	4920	70.14	17.01	5450	73.82	17.60
3870	62.21	15.70	4400	66.33	16.39	4930	70.21	17.02	5460	73.89	17.61
3880	62.29	15.71	4410	66.41	16.40	4940	70.29	17.03	5470	73.96	17.62
3890	62.37	15.73	4420	66.48	16.41	4950	70.36	17.04	5480	74.03	17.63
3900	62.45	15.74	4430	66.56	16.42	4960	70.43	17.05	5490	74.09	17.64
3910	62.53	15.75	4440	66.63	16.44	4970	70.50	17.07	5500	74.16	17.65
3920	62.61	15.77	4450	66.71	16.45	4980	70.57	17.08	5510	74.23	17.66
3930	62.69	15.78	4460	66.78	16.46	4990	70.64	17.09	5520	74.30	17.67
3940	62.77	15.79	4470	66.86	16.47	5000	70.71	17.10	5530	74.36	17.68
3950	62.85	15.81	4480	66.93	16.49	5010	70.78	17.11	5540	74.43	17.69
3960	62.93	15.82	4490	67.01	16.50	5020	70.85	17.12	5550	74.50	17.71
3970	63.01	15.83	4500	67.08	16.51	5030	70.92	17.13	5560	74.57	17.72
3980	63.09	15.85	4510	67.16	16.52	5040	70.99	17.15	5570	74.63	17.73
3990	63.17	15.86	4520	67.23	16.53	5050	71.06	17.16	5580	74.70	17.74
4000	63.25	15.87	4530	67.31	16.55	5060	71.13	17.17	5590	74.77	17.75
4010	63.32	15.89	4540	67.38	16.56	5070	71.20	17.18	5600	74.83	17.76
4020	63.40	15.90	4550	67.45	16.57	5080	71.27	17.19	5610	74.90	17.77
4030	63.48	15.91	4560	67.53	16.58	5090	71.34	17.20	5620	74.97	17.78
4040	63.56	15.93	4570	67.60	16.59	5100	71.41	17.21	5630	75.03	17.79
4050	63.64	15.94	4580	67.68	16.61	5110	71.48	17.22	5640	75.10	17.80
4060	63.72	15.95	4590	67.75	16.62	5120	71.55	17.24	5650	75.17	17.81
4070	63.80	15.97	4600	67.82	16.63	5130	71.62	17.25	5660	75.23	17.82
4080	63.87	15.98	4610	67.90	16.64	5140	71.69	17.26	5670	75.30	17.83
4090	63.95	15.99	4620	67.97	16.66	5150	71.76	17.27	5680	75.37	17.84
4100	64.03	16.01	4630	68.04	16.67	5160	71.83	17.28	5690	75.43	17.85
4110	64.11	16.02	4640	68.12	16.68	5170	71.90	17.29	5700	75.50	17.86
4120	64.19	16.03	4650	68.19	16.69	5180	71.97	17.30	5710	75.56	17.87
4130	64.27	16.04	4660	68.26	16.70	5190	72.04	17.31	5720	75.63	17.88
4140	64.34	16.06	4670	68.34	16.71	5200	72.11	17.32	5730	75.70	17.89
4150	64.42	16.07	4680	68.41	16.73	5210	72.18	17.34	5740	75.76	17.90
4160	64.50	16.08	4690	68.48	16.74	5220	72.25	17.35	5750	75.83	17.92
4170	64.58	16.10	4700	68.56	16.75	5230	72.32	17.36	5760	75.89	17.93
4180	64.65	16.11	4710	68.63	16.76	5240	72.39	17.37	5770	75.96	17.94
4190	64.73	16.12	4720	68.70	16.77	5250	72.46	17.38	5780	76.03	17.95
4200	64.81	16.13	4730	68.77	16.79	5260	72.53	17.39	5790	76.09	17.96
4210	64.88	16.15	4740	68.85	16.80	5270	72.59	17.40	5800	76.16	17.97
4220	64.96	16.16	4750	68.92	16.81	5280	72.66	17.41	5810	76.22	17.98
4230	65.04	16.17	4760	68.99	16.82	5290	72.73	17.42	5820	76.29	17.99
4240	65.12	16.19	4770	69.07	16.83	5300	72.80	17.44	5830	76.35	18
4250	65.19	16.20	4780	69.14	16.85	5310	72.87	17.45	5840	76.42	18.01
4260	65.27	16.21	4790	69.21	16.86	5320	72.94	17.46	5850	76.49	18.02
4270	65.35	16.22	4800	69.28	16.87	5330	73.01	17.47	5860	76.55	18.03
4280	65.42	16.24	4810	69.35	16.88	5340	73.08	17.48	5870	76.62	18.04
4290	65.50	16.25	4820	69.43	16.89	5350	73.14	17.49	5880	76.68	18.05
4300	65.57	16.26	4830	69.50	16.90	5360	73.21	17.50	5890	76.75	18.06
4310	65.65	16.27	4840	69.57	16.92	5370	73.28	17.51	5900	76.81	18.07
4320	65.73	16.29	4850	69.64	16.93	5380	73.35	17.52	5910	76.88	18.08

Table of Square Roots and Cube Roots of Numbers from 1000 to 10,000 — (*Continued*)

No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root
5920	76.94	18.09	6450	80.31	18.61	6980	83.55	19.11	7510	86.66	19.58
5930	77.01	18.10	6460	80.37	18.62	6990	83.61	19.12	7520	86.72	19.59
5940	77.07	18.11	6470	80.44	18.63	7000	83.67	19.13	7530	86.78	19.60
5950	77.14	18.12	6480	80.50	18.64	7010	83.73	19.14	7540	86.83	19.61
5960	77.20	18.13	6490	80.56	18.65	7020	83.79	19.15	7550	86.89	19.62
5970	77.27	18.14	6500	80.62	18.66	7030	83.85	19.16	7560	86.95	19.63
5980	77.33	18.15	6510	80.68	18.67	7040	83.90	19.17	7570	87.01	19.64
5990	77.40	18.16	6520	80.75	18.68	7050	83.96	19.17	7580	87.06	19.64
6000	77.46	18.17	6530	80.81	18.69	7060	84.02	19.18	7590	87.12	19.65
6010	77.52	18.18	6540	80.87	18.70	7070	84.08	19.19	7600	87.18	19.66
6020	77.59	18.19	6550	80.93	18.71	7080	84.14	19.20	7610	87.24	19.67
6030	77.65	18.20	6560	80.99	18.72	7090	84.20	19.21	7620	87.29	19.68
6040	77.72	18.21	6570	81.06	18.73	7100	84.26	19.22	7630	87.35	19.69
6050	77.78	18.22	6580	81.12	18.74	7110	84.32	19.23	7640	87.41	19.70
6060	77.85	18.23	6590	81.18	18.75	7120	84.38	19.24	7650	87.46	19.70
6070	77.91	18.24	6600	81.24	18.76	7130	84.44	19.25	7660	87.52	19.71
6080	77.97	18.25	6610	81.30	18.77	7140	84.50	19.26	7670	87.58	19.72
6090	78.04	18.26	6620	81.36	18.78	7150	84.56	19.26	7680	87.64	19.73
6100	78.10	18.27	6630	81.42	18.79	7160	84.62	19.27	7690	87.69	19.74
6110	78.17	18.28	6640	81.49	18.80	7170	84.68	19.28	7700	87.75	19.75
6120	78.23	18.29	6650	81.55	18.81	7180	84.73	19.29	7710	87.81	19.76
6130	78.29	18.30	6660	81.61	18.81	7190	84.79	19.30	7720	87.86	19.76
6140	78.36	18.31	6670	81.67	18.82	7200	84.85	19.31	7730	87.92	19.77
6150	78.42	18.32	6680	81.73	18.83	7210	84.91	19.32	7740	87.98	19.78
6160	78.49	18.33	6690	81.79	18.84	7220	84.97	19.33	7750	88.03	19.79
6170	78.55	18.34	6700	81.85	18.85	7230	85.03	19.34	7760	88.09	19.80
6180	78.61	18.35	6710	81.91	18.86	7240	85.09	19.35	7770	88.15	19.81
6190	78.68	18.36	6720	81.98	18.87	7250	85.15	19.35	7780	88.20	19.81
6200	78.74	18.37	6730	82.04	18.88	7260	85.21	19.36	7790	88.26	19.82
6210	78.80	18.38	6740	82.10	18.89	7270	85.26	19.37	7800	88.32	19.83
6220	78.87	18.39	6750	82.16	18.90	7280	85.32	19.38	7810	88.37	19.84
6230	78.93	18.40	6760	82.22	18.91	7290	85.38	19.39	7820	88.43	19.85
6240	78.99	18.41	6770	82.28	18.92	7300	85.44	19.40	7830	88.49	19.86
6250	79.06	18.42	6780	82.34	18.93	7310	85.50	19.41	7840	88.54	19.87
6260	79.12	18.43	6790	82.40	18.94	7320	85.56	19.42	7850	88.60	19.87
6270	79.18	18.44	6800	82.46	18.95	7330	85.62	19.43	7860	88.66	19.88
6280	79.25	18.45	6810	82.52	18.95	7340	85.67	19.43	7870	88.71	19.89
6290	79.31	18.46	6820	82.58	18.96	7350	85.73	19.44	7880	88.77	19.90
6300	79.37	18.47	6830	82.64	18.97	7360	85.79	19.45	7890	88.83	19.91
6310	79.44	18.48	6840	82.70	18.98	7370	85.85	19.46	7900	88.88	19.92
6320	79.50	18.49	6850	82.76	18.99	7380	85.91	19.47	7910	88.94	19.92
6330	79.56	18.50	6860	82.83	19	7390	85.97	19.48	7920	88.99	19.93
6340	79.62	18.51	6870	82.89	19.01	7400	86.02	19.49	7930	89.05	19.94
6350	79.69	18.52	6880	82.95	19.02	7410	86.08	19.50	7940	89.11	19.95
6360	79.75	18.53	6890	83.01	19.03	7420	86.14	19.50	7950	89.16	19.96
6370	79.81	18.54	6900	83.07	19.04	7430	86.20	19.51	7960	89.22	19.97
6380	79.87	18.55	6910	83.13	19.05	7440	86.29	19.52	7970	89.27	19.97
6390	79.94	18.56	6920	83.19	19.06	7450	86.31	19.53	7980	89.33	19.98
6400	80	18.57	6930	83.25	19.07	7460	86.37	19.54	7990	89.39	19.99
6410	80.06	18.58	6940	83.31	19.07	7470	86.43	19.55	8000	89.44	20
6420	80.12	18.59	6950	83.37	19.08	7480	86.49	19.56	8010	89.50	20.01
6430	80.19	18.60	6960	83.43	19.09	7490	86.54	19.57	8020	89.55	20.02
6440	80.25	18.60	6970	83.49	19.10	7500	86.60	19.57	8030	89.61	20.02

Table of Square Roots and Cube Roots of Numbers from 1000 to 10,000 — (*Continued*)

No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root	No.	Sq. root	Cube root
8040	89.67	20.03	8540	92.41	20.44	9040	95.08	20.83	9540	97.67	21.21
8050	89.72	20.04	8550	92.47	20.45	9050	95.14	20.84	9550	97.72	21.22
8060	89.78	20.05	8560	92.52	20.46	9060	95.18	20.85	9560	97.78	21.22
8070	89.83	20.06	8570	92.57	20.46	9070	95.24	20.85	9570	97.83	21.23
8080	89.89	20.07	8580	92.63	20.47	9080	95.29	20.86	9580	97.88	21.24
8090	89.94	20.07	8590	92.68	20.48	9090	95.34	20.87	9590	97.93	21.25
8100	90	20.08	8600	92.74	20.49	9100	95.39	20.88	9600	97.98	21.25
8110	90.06	20.09	8610	92.79	20.50	9110	95.45	20.89	9610	98.03	21.26
8120	90.11	20.10	8620	92.84	20.50	9120	95.50	20.89	9620	98.08	21.27
8130	90.17	20.11	8630	92.90	20.51	9130	95.55	20.90	9630	98.13	21.28
8140	90.22	20.12	8640	92.95	20.52	9140	95.60	20.91	9640	98.18	21.28
8150	90.28	20.12	8650	93.01	20.53	9150	95.66	20.92	9650	98.23	21.29
8160	90.33	20.13	8660	93.06	20.54	9160	95.71	20.92	9660	98.29	21.30
8170	90.39	20.14	8670	93.11	20.54	9170	95.76	20.93	9670	98.34	21.30
8180	90.44	20.15	8680	93.17	20.55	9180	95.81	20.94	9680	98.39	21.31
8190	90.50	20.16	8690	93.22	20.56	9190	95.86	20.95	9690	98.44	21.32
8200	90.55	20.17	8700	93.27	20.57	9200	95.92	20.95	9700	98.49	21.33
8210	90.61	20.17	8710	93.33	20.57	9210	95.97	20.96	9710	98.54	21.33
8220	90.66	20.18	8720	93.38	20.58	9220	96.02	20.97	9720	98.59	21.34
8230	90.72	20.19	8730	93.43	20.59	9230	96.07	20.98	9730	98.64	21.35
8240	90.77	20.20	8740	93.49	20.60	9240	96.12	20.98	9740	98.69	21.36
8250	90.83	20.21	8750	93.54	20.61	9250	96.18	20.99	9750	98.74	21.36
8260	90.88	20.21	8760	93.59	20.61	9260	96.23	21	9760	98.79	21.37
8270	90.94	20.22	8770	93.65	20.62	9270	96.28	21.01	9770	98.84	21.38
8280	90.99	20.23	8780	93.70	20.63	9280	96.33	21.01	9780	98.89	21.39
8290	91.05	20.24	8790	93.75	20.64	9290	96.38	21.02	9790	98.94	21.39
8300	91.10	20.25	8800	93.81	20.65	9300	96.44	21.03	9800	98.99	21.40
8310	91.16	20.26	8810	93.86	20.65	9310	96.49	21.04	9810	99.05	21.41
8320	91.21	20.26	8820	93.91	20.66	9320	96.54	21.04	9820	99.10	21.41
8330	91.27	20.27	8830	93.97	20.67	9330	96.59	21.05	9830	99.15	21.42
8340	91.32	20.28	8840	94.02	20.68	9340	96.64	21.06	9840	99.20	21.43
8350	91.38	20.29	8850	94.07	20.68	9350	96.70	21.07	9850	99.25	21.44
8360	91.43	20.30	8860	94.13	20.69	9360	96.75	21.07	9860	99.30	21.44
8370	91.49	20.30	8870	94.18	20.70	9370	96.80	21.08	9870	99.35	21.45
8380	91.54	20.31	8880	94.23	20.71	9380	96.85	21.09	9880	99.40	21.46
8390	91.60	20.32	8890	94.29	20.72	9390	96.90	21.10	9890	99.45	21.47
8400	91.65	20.33	8900	94.34	20.72	9400	96.95	21.10	9900	99.50	21.47
8410	91.71	20.34	8910	94.39	20.73	9410	97.01	21.11	9910	99.55	21.48
8420	91.76	20.34	8920	94.45	20.74	9420	97.06	21.12	9920	99.60	21.49
8430	91.82	20.35	8930	94.50	20.75	9430	97.11	21.13	9930	99.65	21.49
8440	91.87	20.36	8940	94.55	20.75	9440	97.16	21.13	9940	99.70	21.50
8450	91.92	20.37	8950	94.60	20.76	9450	97.21	21.14	9950	99.75	21.51
8460	91.98	20.38	8960	94.66	20.77	9460	97.26	21.15	9960	99.80	21.52
8470	92.03	20.38	8970	94.71	20.78	9470	97.31	21.16	9970	99.85	21.52
8480	92.09	20.39	8980	94.76	20.79	9480	97.37	21.16	9980	99.90	21.53
8490	92.14	20.40	8990	94.82	20.79	9490	97.42	21.17	9990	99.95	21.54
8500	92.20	20.41	9000	94.87	20.80	9500	97.47	21.18	10000	100	21.54
8510	92.25	20.42	9010	94.92	20.81	9510	97.52	21.19			
8520	92.30	20.42	9020	94.97	20.82	9520	97.57	21.19			
8530	92.36	20.43	9030	95.03	20.82	9530	97.62	21.20			

To find Square or Cube Roots of large numbers not contained in the column of numbers of the table

Such roots may sometimes be taken at once from the table, by merely regarding the columns of powers as being columns of numbers; and those of numbers as being those of roots. Thus, if the *square root* of 25281 is required, first find that number in the column of *squares;* and opposite to it, in the column of numbers, is its square root 159. For the *cube root* of 857375, find that number in the column of *cubes;* and opposite to it, in the column of numbers, is its cube root 95. When the exact number is not contained in the column of squares, or cubes, as the case may be, we may use instead the number nearest to it, if no great accuracy is required. But when a considerable degree of accuracy is necessary, the following very correct methods may be used.

For the square root

This rule applies both to whole numbers and to those which are *partly* (not wholly) decimal. First, in the foregoing manner, take out the tabular number, which is nearest to the given one; and also its tabular square root. Multiply this tabular number by 3; to the product add the given number. Call the sum A. Then multiply the given number by 3; to the product add the tabular number. Call the sum B. Then

$$A : B :: \text{Tabular root} : \text{Required root}.$$

Example. — Let the given number be 946.53. Here we find the nearest tabular number to be 947; and its tabular square root 30.7734. Hence,

947	= tabular number		946.53	= given number
3			3	
2841		and	2839.59	
946.53	= given number		947	= tabular number
3787.53	= A.		3786.59	= B.

	A		B		Tab. root		Req'd root
Then	3787.53	:	3786.59	::	30.7734	:	30.7657+.

The root as found by actual mathematical process is also 30.7657+.

For the cube root

This rule applies both to whole numbers and to those which are *partly* decimal. First take out the tabular number which is nearest to the given one; and also its tabular cube root. Multiply this tabular number by 2; and to the product add the given number. Call the sum A. Then multiply the given number by 2; and to the product add the tabular number. Call the sum B. Then

$$A : B :: \text{Tabular root} : \text{Required root.}$$

Example. — Let the given number be 7368. Here we find the nearest tabular number (in the column of *cubes*) to be 6859; and its tabular cube root 19. Hence,

$$\left.\begin{array}{rl} 6859 & = \text{tabular number} \\ 2 & \\ \hline 13718 & \\ 7368 & = \text{given number} \\ \hline 21086 & = A. \end{array}\right\} \text{ and } \left\{\begin{array}{rl} 7368 & = \text{given number} \\ 2 & \\ \hline 14736 & \\ 6859 & = \text{tabular number} \\ \hline 21595 & = B. \end{array}\right.$$

	A		B		Tab. root		Req'd root
Then	21086	:	21595	::	19	:	19.4585.

The root as found by correct mathematical process is 19.4588.

Areas and Circumferences of Circles for Diameters in Units and Eighths, etc., from 1/64 to 100.

Diameter	Circumference	Area	Diameter	Circumference	Area	Diameter	Circumference	Area
1/64	.049087	.00019	2¼	7.06858	3.9761	5 9/16	17.4751	24.301
1/32	.098175	.00077	5/16	7.26493	4.2000	⅝	17.6715	24.850
3/64	.147262	.00173	⅜	7.46128	4.4301	11/16	17.8678	25.406
1/16	.196350	.00307	7/16	7.65763	4.6664	¾	18.0642	25.967
3/32	.294524	.00690	½	7.85398	4.9087	13/16	18.2605	26.535
⅛	.392699	.01227	9/16	8.05033	5.1572	⅞	18.4569	27.109
5/32	.490874	.01917	⅝	8.24668	5.4119	15/16	18.6532	27.688
3/16	.589049	.02761	11/16	8.44303	5.6727	6	18.8496	28.274
7/32	.687223	.03758	¾	8.63938	5.9396	⅛	19.2423	29.465
¼	.785398	.04909	13/16	8.83573	6.2126	¼	19.6350	30.680
9/32	.883573	.06213	⅞	9.03208	6.4918	⅜	20.0277	31.919
5/16	.981748	.07670	15/16	9.22843	6.7771	½	20.4204	33.183
11/32	1.07992	.09281	3	9.42478	7.0686	⅝	20.8131	34.472
⅜	1.17810	.11045	1/16	9.62113	7.3662	¾	21.2058	35.785
13/32	1.27627	.12962	⅛	9.81748	7.6699	⅞	21.5984	37.122
7/16	1.37445	.15033	3/16	10.0138	7.9798	7	21.9911	38.485
15/32	1.47262	.17257	¼	10.2102	8.2958	⅛	22.3838	39.871
½	1.57080	.19635	5/16	10.4065	8.6179	¼	22.7765	41.282
17/32	1.66897	.22166	⅜	10.6029	8.9462	⅜	23.1692	42.718
9/16	1.76715	.24850	7/16	10.7992	9.2806	½	23.5619	44.179
19/32	1.86532	.27688	½	10.9956	9.6211	⅝	23.9546	45.664
⅝	1.96350	.30680	9/16	11.1919	9.9678	¾	24.3473	47.173
21/32	2.06167	.33824	⅝	11.3883	10.321	⅞	24.7400	48.707
11/16	2.15984	.37122	11/16	11.5846	10.680	8	25.1327	50.265
23/32	2.25802	.40574	¾	11.7810	11.045	⅛	25.5254	51.849
¾	2.35619	.44179	13/16	11.9773	11.416	¼	25.9181	53.456
25/32	2.45437	.47937	⅞	12.1737	11.793	⅜	26.3108	55.088
13/16	2.55254	.51849	15/16	12.3700	12.177	½	26.7035	56.745
27/32	2.65072	.55914	4	12.5664	12.566	⅝	27.0962	58.426
⅞	2.74889	.60132	1/16	12.7627	12.962	¾	27.4889	60.132
29/32	2.84707	.64504	⅛	12.9591	13.364	⅞	27.8816	61.862
15/16	2.94524	.69029	3/16	13.1554	13.772	9	28.2743	63.617
31/32	3.04342	.73708	¼	13.3518	14.186	⅛	28.6670	65.397
1	3.14159	.78540	5/16	13.5481	14.607	¼	29.0597	67.201
1/16	3.33794	.88664	⅜	13.7445	15.033	⅜	29.4524	69.029
⅛	3.53429	.99402	7/16	13.9408	15.466	½	29.8451	70.882
3/16	3.73064	1.1075	½	14.1372	15.904	⅝	30.2378	72.760
¼	3.92699	1.2272	9/16	14.3335	16.349	¾	30.6305	74.662
5/16	4.12334	1.3530	⅝	14.5299	16.800	⅞	31.0232	76.589
⅜	4.31969	1.4849	11/16	14.7262	17.257	10	31.4159	78.540
7/16	4.51604	1.6230	¾	14.9226	17.721	⅛	31.8086	80.516
½	4.71239	1.7671	13/16	15.1189	18.190	¼	32.2013	82.516
9/16	4.90874	1.9175	⅞	15.3153	18.665	⅜	32.5940	84.541
⅝	5.10509	2.0739	15/16	15.5116	19.147	½	32.9867	86.590
11/16	5.30144	2.2365	5	15.7080	19.635	⅝	33.3794	88.664
¾	5.49779	2.4053	1/16	15.9043	20.129	¾	33.7721	90.763
13/16	5.69414	2.5802	⅛	16.1007	20.629	⅞	34.1648	92.886
⅞	5.89049	2.7612	3/16	16.2970	21.135	11	34.5575	95.033
15/16	6.08684	2.9483	¼	16.4934	21.648	⅛	34.9502	97.205
2	6.28319	3.1416	5/16	16.6897	22.166	¼	35.3429	99.402
1/16	6.47953	3.3410	⅜	16.8861	22.691	⅜	35.7356	101.62
⅛	6.67588	3.5466	7/16	17.0824	23.221	½	36.1283	103.87
3/16	6.87223	3.7583	½	17.2788	23.758	⅝	36.5210	106.14

Areas and Circumferences of Circles for Diameters in Units and Eighths, etc. — (*Continued*)

Diameter	Circumference	Area	Diameter	Circumference	Area	Diameter	Circumference	Area
11¾	36.9137	108.43	18⅜	57.7268	265.18	25	78.5398	490.87
⅞	37.3064	110.75	½	58.1195	268.80	⅛	78.9325	495.79
12	37.6991	113.10	⅝	58.5122	272.45	¼	79.3252	500.74
⅛	38.0918	115.47	¾	58.9049	276.12	⅜	79.7179	505.71
¼	38.4845	117.86	⅞	59.2976	279.81	½	80.1106	510.71
⅜	38.8772	120.28	19	59.6903	283.53	⅝	80.5033	515.72
½	39.2699	122.72	⅛	60.0830	287.27	¾	80.8960	520.77
⅝	39.6626	125.19	¼	60.4757	291.04	⅞	81.2887	525.84
¾	40.0553	127.68	⅜	60.8684	294.83	26	81.6814	530.93
⅞	40.4480	130.19	½	61.2611	298.65	⅛	82.0741	536.05
13	40.8407	132.73	⅝	61.6538	302.49	¼	82.4668	541.19
⅛	41.2334	135.30	¾	62.0465	306.35	⅜	82.8595	546.35
¼	41.6261	137.89	⅞	62.4392	310.24	½	83.2522	551.55
⅜	42.0188	140.50	20	62.8319	314.16	⅝	83.6449	556.76
½	42.4115	143.14	⅛	63.2246	318.10	¾	84.0376	562.00
⅝	42.8042	145.80	¼	63.6173	322.06	⅞	84.4303	567.27
¾	43.1969	148.49	⅜	64.0100	326.05	27	84.8230	572.56
⅞	43.5896	151.20	½	64.4026	330.06	⅛	85.2157	577.87
14	43.9823	153.94	⅝	64.7953	334.10	¼	85.6084	583.21
⅛	44.3750	156.70	¾	65.1880	338.16	⅜	86.0011	588.57
¼	44.7677	159.48	⅞	65.5807	342.25	½	86.3938	593.96
⅜	45.1604	162.30	21	65.9734	346.36	⅝	86.7865	599.37
½	45.5531	165.13	⅛	66.3661	350.50	¾	87.1792	604.81
⅝	45.9458	167.99	¼	66.7588	354.66	⅞	87.5719	610.27
¾	46.3385	170.87	⅜	67.1515	358.84	28	87.9646	615.75
⅞	46.7312	173.78	½	67.5442	363.05	⅛	88.3573	621.26
15	47.1239	176.71	⅝	67.9369	367.28	¼	88.7500	626.80
⅛	47.5166	179.67	¾	68.3296	371.54	⅜	89.1427	632.36
¼	47.9093	182.65	⅞	68.7223	375.83	½	89.5354	637.94
⅜	48.3020	185.66	22	69.1150	380.13	⅝	89.9281	643.55
½	48.6947	188.69	⅛	69.5077	384.46	¾	90.3208	649.18
⅝	49.0874	191.75	¼	69.9004	388.82	⅞	90.7135	654.84
¾	49.4801	194.83	⅜	70.2931	393.20	29	91.1062	660.52
⅞	49.8728	197.93	½	70.6858	397.61	⅛	91.4989	666.23
16	50.2655	201.06	⅝	71.0785	402.04	¼	91.8916	671.96
⅛	50.6582	204.22	¾	71.4712	406.49	⅜	92.2843	677.71
¼	51.0509	207.39	⅞	71.8639	410.97	½	92.6770	683.49
⅜	51.4436	210.60	23	72.2566	415.48	⅝	93.0697	689.30
½	51.8363	213.82	⅛	72.6493	420.00	¾	93.4624	695.13
⅝	52.2290	217.08	¼	73.0420	424.56	⅞	93.8551	700.98
¾	52.6217	220.35	⅜	73.4347	429.13	30	94.2478	706.86
⅞	53.0144	223.65	½	73.8274	433.74	⅛	94.6405	712.76
17	53.4071	226.98	⅝	74.2201	438.36	¼	95.0332	718.69
⅛	53.7998	230.33	¾	74.6128	443.01	⅜	95.4259	724.64
¼	54.1925	233.71	⅞	75.0055	447.69	½	95.8186	730.62
⅜	54.5852	237.10	24	75.3982	452.39	⅝	96.2113	736.62
½	54.9779	240.53	⅛	75.7909	457.11	¾	96.6040	742.64
⅝	55.3706	243.98	¼	76.1836	461.86	⅞	96.9967	748.69
¾	55.7633	247.45	⅜	76.5763	466.64	31	97.3894	754.77
⅞	56.1560	250.95	½	76.9690	471.44	⅛	97.7821	760.87
18	56.5487	254.47	⅝	77.3617	476.26	¼	98.1748	766.99
⅛	56.9414	258.02	¾	77.7544	481.11	⅜	98.5675	773.14
¼	57.3341	261.59	⅞	78.1471	485.98	½	98.9602	779.31

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS IN UNITS AND EIGHTHS, ETC. — (*Continued*)

Diameter	Circumference	Area	Diameter	Circumference	Area	Diameter	Circumference	Area
31⅝	99.3529	785.51	¼	120.166	1149.1	44⅞	140.979	1581.6
¾	99.7456	791.73	⅜	120.559	1156.6	45	141.372	1590.4
⅞	100.138	797.98	½	120.951	1164.2	⅛	141.764	1599.3
32	100.531	804.25	⅝	121.344	1171.7	¼	142.157	1608.2
⅛	100.924	810.54	¾	121.737	1179.3	⅜	142.550	1617.0
¼	101.316	816.86	⅞	122.129	1186.9	½	142.942	1626.0
⅜	101.709	823.21	39	122.522	1194.6	⅝	143.335	1634.9
½	102.102	829.58	⅛	122.915	1202.3	¾	143.728	1643.9
⅝	102.494	835.97	¼	123.308	1210.0	⅞	144.121	1652.9
¾	102.887	842.39	⅜	123.700	1217.7	46	144.513	1661.9
⅞	103.280	848.83	½	124.093	1225.4	⅛	144.906	1670.9
33	103.673	855.30	⅝	124.486	1233.2	¼	145.299	1680.0
⅛	104.065	861.79	¾	124.878	1241.0	⅜	145.691	1689.1
¼	104.458	868.31	⅞	125.271	1248.8	½	146.084	1698.2
⅜	104.851	874.85	40	125.664	1256.6	⅝	146.477	1707.4
½	105.243	881.41	⅛	126.056	1264.5	¾	146.869	1716.5
⅝	105.636	888.00	¼	126.449	1272.4	⅞	147.262	1725.7
¾	106.029	894.62	⅜	126.842	1280.3	47	147.655	1734.9
⅞	106.421	901.26	½	127.235	1288.2	⅛	148.048	1744.2
34	106.814	907.92	⅝	127.627	1296.2	¼	148.440	1753.5
⅛	107.207	914.61	¾	128.020	1304.2	⅜	148.833	1762.7
¼	107.600	921.32	⅞	128.413	1312.2	½	149.226	1772.1
⅜	107.992	928.06	41	128.805	1320.3	⅝	149.618	1781.4
½	108.385	934.82	⅛	129.198	1328.3	¾	150.011	1790.8
⅝	108.778	941.61	¼	129.591	1336.4	⅞	150.404	1800.1
¾	109.170	948.42	⅜	129.983	1344.5	48	150.796	1809.6
⅞	109.563	955.25	½	130.376	1352.7	⅛	151.189	1819.0
35	109.956	962.11	⅝	130.769	1360.8	¼	151.582	1828.5
⅛	110.348	969.00	¾	131.161	1369.0	⅜	151.975	1837.9
¼	110.741	975.91	⅞	131.554	1377.2	½	152.367	1847.5
⅜	111.134	982.84	42	131.947	1385.4	⅝	152.760	1857.0
½	111.527	989.80	⅛	132.340	1393.7	¾	153.153	1866.5
⅝	111.919	996.78	¼	132.732	1402.0	⅞	153.545	1876.1
¾	112.312	1003.8	⅜	133.125	1410.3	49	153.938	1885.7
⅞	112.705	1010.8	½	133.518	1418.6	⅛	154.331	1895.4
36	113.097	1017.9	⅝	133.910	1427.0	¼	154.723	1905.0
⅛	113.490	1025.0	¾	134.303	1435.4	⅜	155.116	1914.7
¼	113.883	1032.1	⅞	134.696	1443.8	½	155.509	1924.4
⅜	114.275	1039.2	43	135.088	1452.2	⅝	155.902	1934.2
½	114.668	1046.3	⅛	135.481	1460.7	¾	156.294	1943.9
⅝	115.061	1053.5	¼	135.874	1469.1	⅞	156.687	1953.7
¾	115.454	1060.7	⅜	136.267	1477.6	50	157.080	1963.5
⅞	115.846	1068.0	½	136.659	1486.2	⅛	157.472	1973.3
37	116.239	1075.2	⅝	137.052	1494.7	¼	157.865	1983.2
⅛	116.632	1082.5	¾	137.445	1503.3	⅜	158.258	1993.1
¼	117.024	1089.8	⅞	137.837	1511.9	½	158.650	2003.0
⅜	117.417	1097.1	44	138.230	1520.5	⅝	159.043	2012.9
½	117.810	1104.5	⅛	138.623	1529.2	¾	159.436	2022.8
⅝	118.202	1111.8	¼	139.015	1537.9	⅞	159.829	2032.8
¾	118.596	1119.2	⅜	139.408	1546.6	51	160.221	2042.8
⅞	118.988	1126.7	½	139.801	1555.3	⅛	160.614	2052.8
38	119.381	1134.1	⅝	140.194	1564.0	¼	161.007	2062.9
⅛	119.773	1141.6	¾	140.586	1572.8	⅜	161.399	2073.0

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS IN UNITS AND EIGHTHS, ETC. — (*Continued*)

Diameter	Circumference	Area	Diameter	Circumference	Area	Diameter	Circumference	Area
51½	161.792	2083.1	58⅛	182.605	2653.5	64¾	203.418	3292.8
⅝	162.185	2093.2	¼	182.998	2664.9	⅞	203.811	3305.6
¾	162.577	2103.3	⅜	183.390	2676.4	65	204.204	3318.3
⅞	162.970	2113.5	½	183.783	2687.8	⅛	204.596	3331.1
52	163.363	2123.7	⅝	184.176	2699.3	¼	204.989	3343.9
⅛	163.756	2133.9	¾	184.569	2710.9	⅜	205.382	3356.7
¼	164.148	2144.2	⅞	184.961	2722.4	½	205.774	3369.6
⅜	164.541	2154.5	59	185.354	2734.0	⅝	206.167	3382.4
½	164.934	2164.8	⅛	185.747	2745.6	¾	206.560	3395.3
⅝	165.326	2175.1	¼	186.139	2757.2	⅞	206.952	3408.2
¾	165.719	2185.4	⅜	186.532	2768.8	66	207.345	3421.2
⅞	166.112	2195.8	½	186.925	2780.5	⅛	207.738	3434.2
53	166.504	2206.2	⅝	187.317	2792.2	¼	208.131	3447.2
⅛	166.897	2216.6	¾	187.710	2803.9	⅜	208.523	3460.2
¼	167.290	2227.0	⅞	188.103	2815.7	½	208.916	3473.2
⅜	167.683	2237.5	60	188.496	2827.4	⅝	209.309	3486.3
½	168.075	2248.0	⅛	188.888	2839.2	¾	209.701	3499.4
⅝	168.468	2258.5	¼	189.281	2851.0	⅞	210.094	3512.5
¾	168.861	2269.1	⅜	189.674	2862.9	67	210.487	3525.7
⅞	169.253	2279.6	½	190.066	2874.8	⅛	210.879	3538.8
54	169.646	2290.2	⅝	190.459	2886.6	¼	211.272	3552.0
⅛	170.039	2300.8	¾	190.852	2898.6	⅜	211.665	3565.2
¼	170.431	2311.5	⅞	191.244	2910.5	½	212.058	3578.5
⅜	170.824	2322.1	61	191.637	2922.5	⅝	212.450	3591.7
½	171.217	2332.8	⅛	192.030	2934.5	¾	212.843	3605.0
⅝	171.609	2343.5	¼	192.423	2946.5	⅞	213.236	3618.3
¾	172.002	2354.3	⅜	192.815	2958.5	68	213.628	3631.7
⅞	172.395	2365.0	½	193.208	2970.6	⅛	214.021	3645.0
55	172.788	2375.8	⅝	193.601	2982.7	¼	214.414	3658.4
⅛	173.180	2386.6	¾	193.993	2994.8	⅜	214.806	3671.8
¼	173.573	2397.5	⅞	194.386	3006.9	½	215.199	3685.3
⅜	173.966	2408.3	62	194.779	3019.1	⅝	215.592	3698.7
½	174.358	2419.2	⅛	195.171	3031.3	¾	215.984	3712.2
⅝	174.751	2430.1	¼	195.564	3043.5	⅞	216.377	3725.7
¾	175.144	2441.1	⅜	195.957	3055.7	69	216.770	3739.3
⅞	175.536	2452 0	½	196.350	3068.0	⅛	217.163	3752.8
56	175.929	2463.0	⅝	196.742	3080.3	¼	217.555	3766.4
⅛	176.322	2474.0	¾	197.135	3092.6	⅜	217.948	3780.0
¼	176.715	2485.0	⅞	197.528	3104.9	½	218.341	3793.7
⅜	177.107	2496.1	63	197.920	3117.2	⅝	218.733	3807.3
½	177.500	2507.2	⅛	198.313	3129.6	¾	219.126	3821.0
⅝	177.893	2518.3	¼	198.706	3142.0	⅞	219.519	3834.7
¾	178.285	2529.4	⅜	199.098	3154.5	70	219.911	3848.5
⅞	178.678	2540.6	½	199.491	3166.9	⅛	220.304	3862.2
57	179.071	2551.8	⅝	199.884	3179.4	¼	220.697	3876.0
⅛	179.463	2563.0	¾	200.277	3191.9	⅜	221.090	3889.8
¼	179.856	2574.2	⅞	200.669	3204.4	½	221.482	3903.6
⅜	180.249	2585.4	64	201.062	3217.0	⅝	221.875	3917.5
½	180.642	2596.7	⅛	201.455	3229.6	¾	222.268	3931.4
⅝	181.034	2608.0	¼	201.847	3242.2	⅞	222.660	3945.3
¾	181.427	2619.4	⅜	202.240	3254.8	71	223.053	3959.2
⅞	181.820	2630.7	½	202.633	3267.5	⅛	223.446	3973.1
58	182.212	2642.1	⅝	203.025	3280.1	¼	223.838	3987.1

Areas and Circumferences of Circles for Diameters in Units and Eighths, etc. — (*Continued*)

Diameter	Circumference	Area	Diameter	Circumference	Area	Diameter	Circumference	Area
71⅜	224.231	4001.1	78	245.044	4778.4	84⅝	265.857	5624.5
½	224.624	4015.2	⅛	245.437	4793.7	¾	266.250	5641.2
⅝	225.017	4029.2	¼	245.830	4809.0	⅞	266.643	5657.8
¾	225.409	4043.3	⅜	246.222	4824.4	85	267.035	5674.5
⅞	225.802	4057.4	½	246.615	4839.8	⅛	267.428	5691.2
72	226.195	4071.5	⅝	247.008	4855.2	¼	267.821	5707.9
⅛	226.587	4085.7	¾	247.400	4870.7	⅜	268.213	5724.7
¼	226.980	4099.8	⅞	247.793	4886.2	½	268.606	5741.5
⅜	227.373	4114.0	79	248.186	4901.7	⅝	268.999	5758.3
½	227.765	4128.2	⅛	248.579	4917.2	¾	269.392	5775.1
⅝	228.158	4142.5	¼	248.971	4932.7	⅞	269.784	5791.9
¾	228.551	4156.8	⅜	249.364	4948.3	86	270.177	5808.8
⅞	228.944	4171.1	½	249.757	4963.9	⅛	270.570	5825.7
73	229.336	4185.4	⅝	250.149	4979.5	¼	270.962	5842.6
⅛	229.729	4199.7	¾	250.542	4995.2	⅜	271.355	5859.6
¼	230.122	4214.1	⅞	250.935	5010.9	½	271.748	5876.5
⅜	230.514	4228.5	80	251.327	5026.5	⅝	272.140	5893.5
½	230.907	4242.9	⅛	251.720	5042.3	¾	272.533	5910.6
⅝	231.300	4257.4	¼	252.113	5058.0	⅞	272.926	5927.6
¾	231.692	4271.8	⅜	252.506	5073.8	87	273.319	5944.7
⅞	232.085	4286.3	½	252.898	5089.6	⅛	273.711	5961.8
74	232.478	4300.8	⅝	253.291	5105.4	¼	274.104	5978.9
⅛	232.871	4315.4	¾	253.684	5121.2	⅜	274.497	5996.0
¼	233.263	4329.9	⅞	254.076	5137.1	½	274.889	6013.2
⅜	233.656	4344.5	81	254.469	5153.0	⅝	275.282	6030.4
½	234.049	4359.2	⅛	254.862	5168.9	¾	275.675	6047.6
⅝	234.441	4373.8	¼	255.254	5184.9	⅞	276.067	6064.9
¾	234.834	4388.5	⅜	255.647	5200.8	88	276.460	6082.1
⅞	235.227	4403.1	½	256.040	5216.8	⅛	276.853	6099.4
75	235.619	4417.9	⅝	256.433	5232.8	¼	277.246	6116.7
⅛	236.012	4432.6	¾	256.825	5248.9	⅜	277.638	6134.1
¼	236.405	4447.4	⅞	257.218	5264.9	½	278.031	6151.4
⅜	236.798	4462.2	82	257.611	5281.0	⅝	278.424	6168.8
½	237.190	4477.0	⅛	258.003	5297.1	¾	278.816	6186.2
⅝	237.583	4491.8	¼	258.396	5313.3	⅞	279.209	6203.7
¾	237.976	4506.7	⅜	258.789	5329.4	89	279.602	6221.1
⅞	238.368	4521.5	½	259.181	5345.6	⅛	279.994	6238.6
76	238.761	4536.5	⅝	259.574	5361.8	¼	280.387	6256.1
⅛	239.154	4551.4	¾	259.967	5378.1	⅜	280.780	6273.7
¼	239.546	4566.4	⅞	260.359	5394.3	½	281.173	6291.2
⅜	239.939	4581.3	83	260.752	5410.6	⅝	281.565	6308.8
½	240.332	4596.3	⅛	261.145	5426.9	¾	281.958	6326.4
⅝	240.725	4611.4	¼	261.538	5443.3	⅞	282.351	6344.1
¾	241.117	4626.4	⅜	261.930	5459.6	90	282.743	6361.7
⅞	241.510	4641.5	½	262.323	5476.0	⅛	283.136	6379.4
77	241.903	4656.6	⅝	262.716	5492.4	¼	283.529	6397.1
⅛	242.295	4671.8	¾	263.108	5508.8	⅜	283.921	6414.9
¼	242.688	4686.9	⅞	263.501	5525.3	½	284.314	6432.6
⅜	243.081	4702.1	84	263.894	5541.8	⅝	284.707	6450.4
½	243.473	4717.3	⅛	264.286	5558.3	¾	285.100	6468.2
⅝	243.866	4732.5	¼	264.679	5574.8	⅞	285.492	6486.0
¾	244.259	4747.8	⅜	265.072	5591.4	91	285.885	6503.9
⅞	244.652	4763.1	½	265.465	5607.9	⅛	286.278	6521.8

Areas and Circumferences of Circles for Diameters in Units and Eighths, etc. — (*Concluded*)

Diameter	Circumference	Area	Diameter	Circumference	Area	Diameter	Circumference	Area
91¼	286.670	6539.7	94¼	296.095	6976.7	97¼	305.520	7428.0
⅜	287.063	6557.6	⅜	296.488	6995.3	⅜	305.913	7447.1
½	287.456	6575.5	½	296.881	7013.8	½	306.305	7466.2
⅝	287.848	6593.5	⅝	297.273	7032.4	⅝	306.698	7485.3
¾	288.241	6611.5	¾	297.666	7051.0	¾	307.091	7504.5
⅞	288.634	6629.6	⅞	298.059	7069.6	⅞	307.483	7523.7
92	289.027	6647.6	95	298.451	7088.2	98	307.876	7543.0
⅛	289.419	6665.7	⅛	298.844	7106.9	⅛	308.269	7562.2
¼	289.812	6683.8	¼	299.237	7125.6	¼	308.661	7581.5
⅜	290.205	6701.9	⅜	299.629	7144.3	⅜	309.054	7600.8
½	290.597	6720.1	½	300.022	7163.0	½	309.447	7620.1
⅝	290.990	6738.2	⅝	300.415	7181.8	⅝	309.840	7639.5
¾	291.383	6756.4	¾	300.807	7200.6	¾	310.232	7658.9
⅞	291.775	6774.7	⅞	301.200	7219.4	⅞	310.625	7678.3
93	292.168	6792.9	96	301.593	7238.2	99	311.018	7697.7
⅛	292.561	6811.2	⅛	301.986	7257.1	⅛	311.410	7717.1
¼	292.954	6829.5	¼	302.378	7276.0	¼	311.803	7736.6
⅜	293.346	6847.8	⅜	302.771	7294.9	⅜	312.196	7756.1
½	293.739	6866.1	½	303.164	7313.8	½	312.588	7775.6
⅝	294.132	6884.5	⅝	303.556	7332.8	⅝	312.981	7795.2
¾	294.524	6902.9	¾	303.949	7351.8	¾	313.374	7814.8
⅞	294.917	6921.3	⅞	304.342	7370.8	⅞	313.767	7834.4
94	295.310	6939.8	97	304.734	7389.8	100	314.159	7854.0
⅛	295.702	6958.2	⅛	305.127	7408.9			

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS FROM 1/10 TO 100 ADVANCING BY TENTHS

Diameter	Area	Circumference	Diameter	Area	Circumference
0.0	....	....	5.3	22.0618	16.6504
.1	.007854	.31416	.4	22.9022	16.9646
.2	.031416	.62832	.5	23.7583	17.2788
.3	.070686	.94248	.6	24.6301	17.5929
.4	.12566	1.2566	.7	25.5176	17.9071
.5	.19635	1.5708	.8	26.4208	18.2212
.6	.28274	1.8850	.9	27.3397	18.5354
.7	.38485	2.1991	6.0	28.2743	18.8496
.8	.50266	2.5133	.1	29.2247	19.1637
.9	.63617	2.8274	.2	30.1907	19.4779
1.0	.7854	3.1416	.3	31.1725	19.7920
.1	.9503	3.4558	.4	32.1699	20.1062
.2	1.1310	3.7699	.5	33.1831	20.4204
.3	1.3273	4.0841	.6	34.2119	20.7345
.4	1.5394	4.3982	.7	35.2565	21.0487
.5	1.7671	4.7124	.8	36.3168	21.3628
.6	2.0106	5.0265	.9	37.3928	21.6770
.7	2.2698	5.3407	7.0	38.4845	21.9911
.8	2.5447	5.6549	.1	39.5919	22.3053
.9	2.8353	5.9690	.2	40.7150	22.6195
2.0	3.1416	6.3832	.3	41.8539	22.9336
.1	3.4636	6.5973	.4	43.0084	23.2478
.2	3.8013	6.9115	.5	44.1786	23.5619
.3	4.1548	7.2257	.6	45.3646	23.8761
.4	4.5239	7.5398	.7	46.5663	24.1903
.5	4.9087	7.8540	.8	47.7836	24.5044
.6	5.3093	8.1681	.9	49.0167	24.8186
.7	5.7256	8.4823	8.0	50.2655	25.1327
.8	6.1575	8.7965	.1	51.5300	25.4469
.9	6.6052	9.1106	.2	52.8102	25.7611
3.0	7.0686	9.4248	.3	54.1061	26.0752
.1	7.5477	9.7389	.4	55.4177	26.3894
.2	8.0425	10.0531	.5	56.7450	26.7035
.3	8.5530	10.3673	.6	58.0880	27.0177
.4	9.0792	10.6814	.7	59.4468	27.3319
.5	9.6211	10.9956	.8	60.8212	27.6460
.6	10.1788	11.3097	.9	62.2114	27.9602
.7	10.7521	11.6239	9.0	63.6173	28.2743
.8	11.3411	11.9381	.1	65.0388	28.5885
.9	11.9459	12.2522	.2	66.4761	28.9027
4.0	12.5664	12.5664	.3	67.9291	29.2168
.1	13.2025	12.8805	.4	69.3978	29.5310
.2	13.8544	13.1947	.5	70.8822	29.8451
.3	14.5220	13.5088	.6	72.3823	30.1593
.4	15.2053	13.8230	.7	73.8981	30.4734
.5	15.9043	14.1372	.8	75.4296	30.7876
.6	16.6190	14.4513	.9	76.9769	31.1018
.7	17.3494	14.7655	10.0	78.5398	31.4159
.8	18.0956	15.0796	.1	80.1185	31.7301
.9	18.8574	15.3938	.2	81.7128	32.0442
5.0	19.6350	15.7080	.3	83.3229	32.3584
.1	20.4282	16.0221	.4	84.9487	32.6726
.2	21.2372	16.3363	.5	86.5901	32.9867

Areas and Circumferences of Circles for Diameters from 1/10 to 100 Advancing by Tenths — (*Continued*)

Diameter	Area	Circumference	Diameter	Area	Circumference
10.6	88.2473	33.3009	15.9	198.5565	49.9513
.7	89.9202	33.6150	16.0	201.0619	50.2655
.8	91.6088	33.9292	.1	203.5831	50.5796
.9	93.3132	34.2434	.2	206.1199	50.8938
11.0	95.0332	34.5575	.3	208.6724	51.2080
.1	96.7689	34.8717	.4	211.2407	51.5221
.2	98.5203	35.1858	.5	213.8246	51.8363
.3	100.2875	35.5000	.6	216.4243	52.1504
.4	102.0703	35.8142	.7	219.0397	52.4646
.5	103.8689	36.1283	.8	221.6708	52.7788
.6	105.6832	36.4425	.9	224.3176	53.0929
.7	107.5132	36.7566	17.0	226.9801	53.4071
.8	109.3588	37.0708	.1	229.6583	53.7212
.9	111.2202	37.3850	.2	232.3522	54.0354
12.0	113.0973	37.6991	.3	235.0618	54.3496
.1	114.9901	38.0133	.4	237.7871	54.6637
.2	116.8987	38.3274	.5	240.5282	54.9779
.3	118.8229	38.6416	.6	243.2849	55.2920
.4	120.7628	38.9557	.7	246.0574	55.6062
.5	122.7185	39.2699	.8	248.8456	55.9203
.6	124.6898	39.5841	.9	251.6494	56.2345
.7	126.6769	39.8982	18.0	254.4690	56.5486
.8	128.6796	40.2124	.1	257.3043	56.8628
.9	130.6981	40.5265	.2	260.1553	57.1770
13.0	132.7323	40.8407	.3	263.0220	57.4911
.1	134.7822	41.1549	.4	265.9044	57.8053
.2	136.8478	41.4690	.5	268.8025	58.1195
.3	138.9291	41.7832	.6	271.7164	58.4336
.4	141.0261	42.0973	.7	274.6459	58.7478
.5	143.1388	42.4115	.8	277.5911	59.0619
.6	145.2672	42.7257	.9	280.5521	59.3761
.7	147.4114	43.0398	19.0	283.5287	59.6903
.8	149.5712	43.3540	.1	286.5211	60.0044
.9	151.7468	43.6681	.2	289.5292	60.3186
14.0	153.9380	43.9823	.3	292.5530	60.6327
.1	156.1450	44.2965	.4	295.5925	60.9469
.2	158.3677	44.6106	.5	298.6477	61.2611
.3	160.6061	44.9248	.6	301.7186	61.5752
.4	162.8602	45.2389	.7	304.8052	61.8894
.5	165.1300	45.5531	.8	307.9075	62.2035
.6	167.4155	45.8673	.9	311.0255	62.5177
.7	169.7167	46.1814	20.0	314.1593	62.8319
.8	172.0336	46.4956	.1	317.3087	63.1460
.9	174.3662	46.8097	.2	320.4739	63.4602
15.0	176.7146	47.1239	.3	323.6547	63.7743
.1	179.0786	47.4380	.4	326.8513	64.0885
.2	181.4584	47.7522	.5	330.0636	64.4026
.3	183.8539	48.0664	.6	333.2916	64.7168
.4	186.2650	48.3805	.7	336.5353	65.0310
.5	188.6919	48.6947	.8	339.7947	65.3451
.6	191.1345	49.0088	.9	343.0698	65.6593
.7	193.5928	49.3230	21.0	346.3606	65.9734
.8	196.0668	49.6372	.1	349.6671	66.2876

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS FROM 1/10 TO 100 ADVANCING BY TENTHS — (*Continued*)

Diameter	Area	Circumference	Diameter	Area	Circumference
21.2	352.9894	66.6018	26.5	551.5459	83.2522
.3	356.3273	66.9159	.6	555.7163	83.5664
.4	359.6809	67.2301	.7	559.9025	83.8805
.5	363.0503	67.5442	.8	564.1044	84.1947
.6	366.4354	67.8584	.9	568.3220	84.5088
.7	369.8361	68.1726	27.0	572.5553	84.8230
.8	373.2526	68.4867	.1	576.8043	85.1372
.9	376.6848	68.8009	.2	581.0690	85.4513
22.0	380.1327	69.1150	.3	585.3494	85.7655
.1	383.5963	69.4292	.4	589.6455	86.0796
.2	387.0756	69.7434	.5	593.9574	86.3938
.3	390.5707	70.0575	.6	598.2849	86.7080
.4	394.0814	70.3717	.7	602.6282	87.0221
.5	397.6078	70.6858	.8	606.9871	87.3363
.6	401.1500	71.0000	.9	611.3618	87.6504
.7	404.7078	71.3142	28.0	615.7522	87.9646
.8	408.2814	71.6283	.1	620.1582	88.2788
.9	411.8707	71.9425	.2	624.5800	88.5929
23.0	415.4756	72.2566	.3	629.0175	88.9071
.1	419.0963	72.5708	.4	633.4707	89.2212
.2	422.7327	72.8849	.5	637.9397	89.5354
.3	426.3848	73.1991	.6	642.4243	89.8495
.4	430.0526	73.5133	.7	646.9246	90.1637
.5	433.7361	73.8274	.8	651.4407	90.4779
.6	437.4354	74.1416	.9	655.9724	90.7920
.7	441.1503	74.4557	29.0	660.5199	91.1062
.8	444.8809	74.7699	.1	665.0830	91.4203
.9	448.6273	75.0841	.2	669.6619	91.7345
24.0	452.3893	75.3892	.3	674.2565	92.0487
.1	456.1671	75.7124	.4	678.8668	92.3628
.2	459.9606	76.0265	.5	683.4928	92.6770
.3	463.7698	76.3407	.6	688.1345	92.9911
.4	467.5947	76.6549	.7	692.7919	93.3053
.5	471.4352	76.9690	.8	697.4650	93.6195
.6	475.2916	77.2832	.9	702.1538	93.9336
.7	479.1636	77.5973	30.0	706.8583	94.2478
.8	483.0513	77.9115	.1	711.5786	94.5619
.9	486.9547	78.2257	.2	716.3145	94.8761
25.0	490.8739	78.5398	.3	721.0662	95.1903
.1	494.8087	78.8540	.4	725.8336	95.5044
.2	498.7592	79.1681	.5	730.6167	95.8186
.3	502.7255	79.4823	.6	735.4154	96.1327
.4	506.7075	79.7965	.7	740.2299	96.4469
.5	510.7052	80.1106	.8	745.0601	96.7611
.6	514.7185	80.4248	.9	749.9060	97.0752
.7	518.7476	80.7389	31.0	754.7676	97.3894
.8	522.7924	81.0531	.1	759.6450	97.7035
.9	526.8529	81.3672	.2	764.5380	98.0177
26.0	530.9292	81.6814	.3	769.4467	98.3319
.1	535.0211	81.9956	.4	774.3712	98.6460
.2	539.1287	82.3097	.5	779.3113	98.9602
.3	543.2521	82.6239	.6	784.2672	99.2743
.4	547.3911	82.9380	.7	789.2388	99.5885

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS FROM 1/10 TO 100 ADVANCING BY TENTHS — (*Continued*)

Diameter	Area	Circumference	Diameter	Area	Circumference
31.8	794.2260	99.9026	37.1	1081.0299	116.5531
.9	799.2290	100.2168	.2	1086.8654	116.8672
32.0	804.2477	100.5310	.3	1092.7166	117.1814
.1	809.2821	100.8451	.4	1098.5835	117.4956
.2	814.3322	101.1593	.5	1104.4662	117.8097
.3	819.3980	101.4734	.6	1110.3645	118.1239
.4	824.4796	101.7876	.7	1116.2786	118.4380
.5	829.5768	102.1018	.8	1122.2083	118.7522
.6	834.6898	102.4159	.9	1128.1538	119.0664
.7	839.8185	102.7301	38.0	1134.1149	119.3805
.8	844.9628	103.0442	.1	1140.0918	119.6947
.9	850.1229	103.3584	.2	1146.0844	120.0088
33.0	855.2986	103.6726	.3	1152.0927	120.3230
.1	860.4902	103.9867	.4	1158.1167	120.6372
.2	865.6973	104.3009	.5	1164.1564	120.9513
.3	870.9202	104.6150	.6	1170.2118	121.2655
.4	876.1588	104.9292	.7	1176.2830	121.5796
.5	881.4131	105.2434	.8	1182.3698	121.8938
.6	886.6831	105.5575	.9	1188.4724	122.2080
.7	891.9688	105.8717	39.0	1194.5906	122.5221
.8	897.2703	106.1858	.1	1200.7246	122.8363
.9	902.5874	106.5000	.2	1206.8742	123.1504
34.0	907.9203	106.8142	.3	1213.0396	123.4646
.1	913.2688	107.1283	.4	1219.2207	123.7788
.2	918.6331	107.4425	.5	1225.4175	124.0929
.3	924.0131	107.7566	.6	1231.6300	124.4071
.4	929.4088	108.0708	.7	1237.8582	124.7212
.5	934.8202	108.3849	.8	1244.1021	125.0354
.6	940.2473	108.6991	.9	1250.3617	125.3495
.7	945.6901	109.0133	40.0	1256.6371	125.6637
.8	951.1486	109.3274	.1	1262.9281	125.9779
.9	956.6228	109.6416	.2	1269.2348	126.2920
35.0	962.1128	109.9557	.3	1275.5573	126.6062
.1	967.6184	110.2699	.4	1281.8955	126.9203
.2	973.1397	110.5841	.5	1288.2493	127.2345
.3	978.6768	110.8982	.6	1294.6189	127.5487
.4	984.2296	111.2124	.7	1301.0042	127.8628
.5	989.7980	111.5265	.8	1307.4052	128.1770
.6	995.3822	111.8407	.9	1313.8219	128.4911
.7	1000.9821	112.1549	41.0	1320.2543	128.8053
.8	1006.5977	112.4690	.1	1326.7024	129.1195
.9	1012.2290	112.7832	.2	1333.1663	129.4336
36.0	1017.8760	113.0973	.3	1339.6458	129.7478
.1	1023.5387	113.4115	.4	1346.1410	130.0619
.2	1029.2172	113.7257	.5	1352.6520	130.3761
.3	1034.9113	114.0398	.6	1359.1786	130.6903
.4	1040.6212	114.3540	.7	1365.7210	131.0044
.5	1046.3467	114.6681	.8	1372.2791	131.3186
.6	1052.0880	114.9823	.9	1378.8529	131.6327
.7	1057.8449	115.2965	42.0	1385.4424	131.9469
.8	1063.6176	115.6106	.1	1392.0476	132.2611
.9	1069.4060	115.9248	.2	1398.6685	132.5752
37.0	1075.2101	116.2389	.3	1405.3051	132.8894

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS FROM 1/10 TO 100 ADVANCING BY TENTHS — (*Continued*)

Diameter	Area	Circumference	Diameter	Area	Circumference
42.4	1411.9574	133.2035	47.7	1787.0086	149.8540
.5	1418.6254	133.5177	.8	1794.5091	150.1681
.6	1425.3092	133.8318	.9	1802.0254	150.4823
.7	1432.0086	134.1460	48.0	1809.5574	150.7964
.8	1438.7238	134.4602	.1	1817.1050	151.1106
.9	1445.4546	134.7743	.2	1824.6684	151.4248
43.0	1452.2012	135.0885	.3	1832.2475	151.7389
.1	1458.9635	135.4026	.4	1839.8423	152.0531
.2	1465.7415	135.7168	.5	1847.4528	152.3672
.3	1472.5352	136.0310	.6	1855.0790	152.6814
.4	1479.3446	136.3451	.7	1862.7210	152.9956
.5	1486.1697	136.6593	.8	1870.3786	153.3097
.6	1493.0105	136.9734	.9	1878.0519	153.6239
.7	1499.8670	137.2876	49.0	1885.7409	153.9380
.8	1506.7393	137.6018	.1	1893.4457	154.2522
.9	1513.6272	137.9159	.2	1901.1662	154.5664
44.0	1520.5308	138.2301	.3	1908.9024	154.8805
.1	1527.4502	138.5442	.4	1916.6543	155.1947
.2	1534.3853	138.8584	.5	1924.4218	155.5088
.3	1541.3360	139.1726	.6	1932.2051	155.8230
.4	1548.3025	139.4867	.7	1940.0042	156.1372
.5	1555.2847	139.8009	.8	1947.8189	156.4513
.6	1562.2826	140.1153	.9	1955.6493	156.7655
.7	1569.2962	140.4292	50.0	1963.4954	157.0796
.8	1576.3255	140.7434	.1	1971.3572	157.3938
.9	1583.3706	141.0575	.2	1979.2348	157.7080
45.0	1590.4313	141.3717	.3	1987.1280	158.0221
.1	1597.5077	141.6858	.4	1995.0370	158.3363
.2	1604.5999	142.0000	.5	2002.9617	158.6504
.3	1611.7077	142.3142	.6	2010.9020	158.9646
.4	1618.8313	142.6283	.7	2018.8581	159.2787
.5	1625.9705	142.9425	.8	2026.8299	159.5929
.6	1633.1255	143.2566	.9	2034.8174	159.9071
.7	1640.2962	143.5708	51.0	2042.8206	160.2212
.8	1647.4826	143.8849	.1	2050.8395	160.5354
.9	1654.6847	144.1991	.2	2058.8742	160.8495
46.0	1661.9025	144.5133	.3	2066.9245	161.1637
.1	1669.1360	144.8274	.4	2074.9905	161.4779
.2	1676.3853	145.1416	.5	2083.0723	161.7920
.3	1683.6502	145.4557	.6	2091.1697	162.1062
.4	1690.9308	145.7699	.7	2099.2829	162.4203
.5	1698.2272	146.0841	.8	2107.4118	162.7345
.6	1705.5392	146.3982	.9	2115.5563	163.0487
.7	1712.8670	146.7124	52.0	2123.7166	163.3628
.8	1720.2105	147.0265	.1	2131.8926	163.6770
.9	1727.5697	147.3407	.2	2140.0843	163.9911
47.0	1734.9445	147.6550	.3	2148.2917	164.3053
.1	1742.3351	147.9690	.4	2156.5149	164.6195
.2	1749.7414	148.2832	.5	2164.7537	164.9336
.3	1757.1635	148.5973	.6	2173.0082	165.2479
.4	1764.6012	148.9115	.7	2181.2785	165.5619
.5	1772.0546	149.2257	.8	2189.5644	165.8761
.6	1779.5237	149.5398	.9	2197.8661	166.1903

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS FROM 1/10 TO 100 ADVANCING BY TENTHS — (*Continued*)

Diameter	Area	Circumference	Diameter	Area	Circumference
53.0	2206.1834	166.5044	58.3	2669.4820	183.5914
.1	2214.5165	166.8186	.4	2678.6476	183.4690
.2	2222.8653	167.1327	.5	2687.8289	183.7832
.3	2231.2298	167.4469	6	2697.0259	184.0973
.4	2239.6100	167.7610	.7	2706.2386	184.4115
.5	2248.0059	168.0752	.8	2715.4670	184.7256
.6	2256.4175	168.3894	.9	2724.7112	185.0398
.7	2264.8448	168.7035	59.0	2733.9710	185.3540
.8	2273.2879	169.0177	.1	2743.2466	185.6681
.9	2281.7466	169.3318	.2	2752.5378	185.9823
54.0	2290.2210	169.6460	.3	2761.8448	186.2964
.1	2298.7112	169.9602	.4	2771.1675	186.6106
.2	2307.2171	170.2743	.5	2780.5058	186.9248
.3	2315.7386	170.5885	.6	2789.8599	187.2389
.4	2324.2759	170.9026	.7	2799.2297	187.5531
.5	2332.8289	171.2168	.8	2808.6152	187.8672
.6	2341.3976	171.5310	.9	2818.0165	188.1814
.7	2349.9820	171.8451	60.0	2827.4334	188.4956
.8	2358.5821	172.1593	.1	2836.8660	188.8097
.9	2367.1979	172.4735	.2	2846.3144	189.1239
55.0	2375.8294	172.7876	.3	2855.7784	189.4380
.1	2384.4767	173.1017	.4	2865.2582	189.7522
.2	2393.1396	173.4159	.5	2874.7536	190.0664
.3	2401.8183	173.7301	.6	2884.2648	190.3805
.4	2410.5126	174.0442	.7	2893.7917	190.6947
.5	2419.2227	174.3584	.8	2903.3343	191.0088
.6	2427.9485	174.6726	.9	2912.8926	191.3230
.7	2436.6899	174.9867	61.0	2922.4666	191.6372
.8	2445.4471	175.3009	.1	2932.0563	191.9513
.9	2454.2200	175.6150	.2	2941.6617	192.2655
56.0	2463.0086	175.9292	3	2951.2828	192.5796
.1	2471.8130	176.2433	4	2960.9197	192.8938
.2	2480.6330	176.5575	5	2970.5722	193.2079
.3	2489.4687	176.8717	6	2980.2405	193.5221
.4	2498.3201	177.1858	.7	2989.9244	193.8363
.5	2507.1873	177.5000	.8	2999.6241	194.1504
.6	2516.0701	177.8141	.9	3009.3395	194.4646
.7	2524.9687	178.1283	62.0	3019.0705	194.7787
.8	2533.8830	178.4425	.1	3028.8173	195.0929
.9	2542.8129	178.7566	.2	3038.5798	195.4071
57.0	2551.7586	179.0708	.3	3048.3580	195.7212
.1	2560.7200	179.3849	.4	3058.1520	196.0354
.2	2569.6971	179.6991	.5	3067.9616	196.3495
.3	2578.6899	180.0133	.6	3077.7869	196.6637
.4	2587.6985	180.3274	.7	3087.6279	196.9779
.5	2596.7227	180.6416	.8	3097.4847	197.2920
.6	2605.7626	180.9557	.9	3107.3571	197.6062
.7	2614.8183	181.2699	63.0	3117.2453	197.9203
.8	2623.8896	181.5841	.1	3127.1492	198.2345
.9	2632.9767	181.8982	.2	3137.0688	198.5487
58.0	2642.0794	182.2124	.3	3147.0040	198.8628
.1	2651.1979	182.5265	.4	3156.9550	199.1770
.2	2660.3321	182.8407	.5	3166.9217	199.4911

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS FROM 1/10 TO 100 ADVANCING BY TENTHS — (*Continued*)

Diameter	Area	Circumference	Diameter	Area	Circumference
63.6	3176.9043	199.8053	68.9	3728.4500	216.4556
.7	3186.9023	200.1195	69.0	3739.2807	216.7699
.8	3196.9161	200.4336	.1	3750.1270	217.0841
.9	3206.9456	200.7478	.2	3760.9891	217.3982
64.0	3216.9909	201.0620	.3	3771.8668	217.7124
.1	3227.0518	201.3761	.4	3782.7603	218.0265
.2	3237.1285	201.6902	.5	3793.6695	218.3407
.3	3247.2222	202.0044	.6	3804.5944	218.6548
.4	3257.3289	202.3186	.7	3815.5350	218.9690
.5	3267.4527	202.6327	.8	3826.4913	219.2832
.6	3277.5922	202.9469	.9	3837.4633	219.5973
.7	3287.7474	203.2610	70.0	3848.4510	219.9115
.8	3297.9183	203.5752	.1	3859.4544	220.2256
.9	3308.1049	203.8894	.2	3870.4736	220.5398
65.0	3318.3072	204.2035	.3	3881.5084	220.8540
.1	3328.5253	204.5176	.4	3892.5590	221.1581
.2	3338.7590	204.8318	.5	3903.6252	221.4823
.3	3349.0085	205.1460	.6	3914.7072	221.7964
.4	3359.2736	205.4602	.7	3925.8049	222.1106
.5	3369.5545	205.7743	.8	3936.9182	222.4248
.6	3379.8510	206.0885	.9	3948.0473	222.7389
.7	3390.1633	206.4026	71.0	3959.1921	223.0531
.8	3400.4913	206.7168	.1	3970.3526	223.3672
.9	3410.8350	207.0310	.2	3981.5289	223.6814
66.0	3421.1944	207.3451	.3	3992.7208	223.9956
.1	3431.5695	207.6593	.4	4003.9284	224.3097
.2	3441.9603	207.9734	.5	4015.1518	224.6239
.3	3452.3669	208.2876	.6	4026.3908	224.9380
.4	3462.7891	208.6017	.7	4037.6456	225.2522
.5	3473.2270	208.9159	.8	4048.9160	225.5664
.6	3483.6807	209.2301	.9	4060.2022	225.8805
.7	3494.1500	209.5442	72.0	4071.5041	226.1947
.8	3504.6351	209.8584	.1	4082.8217	226.5088
.9	3515.1359	210.1725	.2	4094.1550	226.8230
67.0	3525.6524	210.4867	.3	4105.5040	227.1371
.1	3536.1845	210.8009	.4	4116.8687	227.4513
.2	3546.7324	211.1150	.5	4128.2491	227.7655
.3	3557.2960	211.4292	.6	4139.6452	228.0796
.4	3567.8754	211.7433	.7	4151.0571	228.3938
.5	3578.4704	212.0575	.8	4162.4846	228.7079
.6	3589.0811	212.3717	.9	4173.9279	229.0221
.7	3599.7075	212.6858	73.0	4185.3868	229.3363
.8	3610.3497	213.0000	.1	4196.8615	229.6504
.9	3621.0075	213.3141	.2	4208.3519	229.9646
68.0	3631.6811	213.6283	.3	4219.8579	230.2787
.1	3642.3704	213.9425	.4	4231.3797	230.5929
.2	3653.0754	214.2566	.5	4242.9172	230.9071
.3	3663.7960	214.5708	.6	4254.4704	231.2212
.4	3674.5324	214.8849	.7	4266.0394	231.5354
.5	3685.2845	215.1991	.8	4277.6240	231.8495
.6	3696.0523	215.5133	.9	4289.2243	232.1637
.7	3706.8359	215.8274	74.0	4300.8403	232.4779
.8	3717.6351	216.1416	.1	4312.4721	232.7920

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS FROM 1/10 TO 100 ADVANCING BY TENTHS — (*Continued*)

Diameter	Area	Circumference	Diameter	Area	Circumference
74.2	4324.1195	233.1062	79.5	4963.9127	249.7566
.3	4335.7827	233.4203	.6	4976.4084	250.0708
.4	4347.4616	233.7345	.7	4988.9198	250.3850
.5	4359.1562	234.0487	.8	5001.4469	250.6991
.6	4370.8664	234.3628	.9	5013.9897	251.0133
.7	4382.5924	234.6770	80.0	5026.5482	251.3274
.8	4394.3341	234.9911	.1	5039.1225	251.6416
.9	4406.0916	235.3053	.2	5051.7124	251.9557
75.0	4417.8647	235.6194	.3	5064.3180	252.2699
.1	4429.6535	235.9336	.4	5076.9394	252.5840
.2	4441.4580	236.2478	.5	5089.5764	252.8982
.3	4453.2783	236.5619	.6	5102.2292	253.2124
.4	4465.1142	236.8761	.7	5114.8977	253.5265
.5	4476.9659	237.1902	.8	5127.5819	253.8407
.6	4488.8332	237.5044	.9	5140.2818	254.1548
.7	4500.7163	237.8186	81.0	5152.9973	254.4690
.8	4512.6151	238.1327	.1	5165.7287	254.7832
.9	4524.5296	238.4469	.2	5178.4757	255.0973
76.0	4536.4598	238.7610	.3	5191.2384	255.4115
.1	4548.4057	239.0752	.4	5204.0168	255.7256
.2	4560.3673	239.3894	.5	5216.8110	256.0398
.3	4572.3446	239.7035	.6	5229.6208	256.3540
.4	4584.3377	240.0177	.7	5242.4463	256.6681
.5	4596.3464	240.3318	.8	5255.2876	256.9823
.6	4608.3708	240.6460	.9	5268.1446	257.2966
.7	4620.4110	240.9602	82.0	5281.0173	257.6106
.8	4632.4669	241.2743	.1	5293.9056	257.9247
.9	4644.5384	241.5885	.2	5306.8097	258.2389
77.0	4656.6257	241.9026	.3	5319.7295	258.5531
.1	4668.7287	242.2168	.4	5332.6650	258.8672
.2	4680.8474	242.5310	.5	5345.6162	259.1814
.3	4692.9818	242.8451	.6	5358.5832	259.4956
.4	4705.1319	243.1592	.7	5371.5658	259.8097
.5	4717.2977	243.4734	.8	5384.5641	260.1239
.6	4729.4792	243.7876	.9	5397.5782	260.4380
.7	4741.6756	244.1017	83.0	5410.6079	260.7522
.8	4753.8894	244.4159	.1	5423.6534	261.0663
.9	4766.1181	244.7301	.2	5436.7146	261.3805
78.0	4778.3624	245.0442	.3	5449.7915	261.6947
.1	4790.6225	245.3584	.4	5462.8840	262.0088
.2	4802.8983	245.6725	5	5475.9923	262.3230
.3	4815.1897	245.9867	6	5489.1163	262.6371
.4	4827.4969	246.3009	7	5502.2561	262.9513
.5	4839.8198	246.6150	.8	5515.4115	263.2655
.6	4852.1584	246.9292	.9	5528.5826	263.5796
.7	4864.5128	247.2433	84.0	5541.7694	263.8938
.8	4876.8828	247.5575	.1	5554.9720	264.2079
.9	4889.2685	247.8717	.2	5568.1902	264.5221
79.0	4901.6699	248.1858	.3	5581.4242	264.8363
.1	4914.0871	248.5000	4	5594.6739	265.1414
.2	4926.5199	248.8141	5	5607.9392	265.4646
.3	4938.9685	249.1283	.6	5621.2203	265.7787
.4	4951.4328	249.4425	.7	5634.5171	266.0929

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS FROM 1/10 TO 100 ADVANCING BY TENTHS — (*Continued*)

Diameter	Area	Circumference	Diameter	Area	Circumference
84.8	5647.8296	266.4071	90.1	6375.8701	283.0575
.9	5661.1578	266.7212	.2	6390.0309	283.3717
85.0	5674.5017	267.0354	.3	6404.2073	283.6858
.1	5687.8614	267.3495	.4	6418.3995	284.0000
.2	5701.2367	267.6637	.5	6432.6073	284.3141
.3	5714.6277	267.9779	.6	6446.8309	284.6283
.4	5728.0345	268.2920	.7	6461.0701	284.9425
.5	5741.4569	268.6062	.8	6475.3251	285.2566
.6	5754.8951	268.9203	.9	6489.5958	285.5708
.7	5768.3490	269.2345	91.0	6503.8822	285.8849
.8	5781.8185	269.5486	.1	6518.1843	286.1991
.9	5795.3038	269.8628	.2	6532.5021	286.5133
86.0	5808.8048	270.1770	.3	6546.8356	286.8274
.1	5822.3215	270.4911	.4	6561.1848	287.1416
.2	5835.8539	270.8053	.5	6575.5498	287.4557
.3	5849.4020	271.1194	.6	6589.9304	287.7699
.4	5862.9659	271.4336	.7	6604.3268	288.0840
.5	5876.5454	271.7478	.8	6618.7388	288.3982
.6	5890.1407	272.0619	.9	6633.1666	288.7124
.7	5903.7516	272.3761	92.0	6647.6101	289.0265
.8	5917.3783	272.6902	.1	6662.0692	289.3407
.9	5931.0206	273.0044	.2	6676.5441	289.6548
87.0	5944.6787	273.3186	.3	6691.0347	289.9690
.1	5958.3525	273.6327	.4	6705.5410	290.2832
.2	5972.0420	273.9469	.5	6720.0630	290.5973
.3	5985.7472	274.2610	.6	6734.6008	290.9115
.4	5999.4681	274.5752	.7	6749.1542	291.2256
.5	6013.2047	274.8894	.8	6763.7233	291.5398
.6	6026.9570	275.2035	.9	6778.3082	291.8540
.7	6040.7250	275.5177	93.0	6792.9087	292.1681
.8	6054.5088	275.8318	.1	6807.5250	292.4823
.9	6068.3082	276.1460	.2	6822.1569	292.7964
88.0	6082.1234	276.4602	.3	6836.8046	293.1106
.1	6095.9542	276.7743	.4	6851.4680	293.4248
.2	6109.8008	277.0885	5	6866.1471	293.7389
.3	6123.6631	277.4026	6	6880.8419	294.0531
.4	6137.5411	277.7168	.7	6895.5524	294.3672
.5	6151.4348	278.0309	.8	6910.2786	294.6814
.6	6165.3442	278.3451	.9	6925.0205	294.9956
.7	6179.2693	278.6593	94.0	6939.7782	295.3097
.8	6193.2101	278.9740	.1	6954.5515	295.6239
.9	6207.1666	279.2876	.2	6969.3106	295.9380
89.0	6221.1389	279.6017	.3	6984.1453	296.2522
.1	6235.1268	279.9159	4	6998.9658	296.5663
.2	6249.1304	280.2301	5	7013.8019	296.8805
.3	6263.1498	280.5442	.6	7028.6538	297.1947
.4	6277.1849	280.8584	.7	7043.5214	297.5088
.5	6291.2356	281.1725	.8	7058.4047	297.8230
.6	6305.3021	281.4867	.9	7073.3033	298.1371
.7	6319.3843	281.8009	95.0	7088.2184	298.4513
.8	6333.4822	282.1150	.1	7103.1488	298.7655
.9	6347.5958	282.4292	.2	7118.1950	299.0796
90.0	6361.7251	282.7433	.3	7133.0568	299.3938

AREAS AND CIRCUMFERENCES OF CIRCLES FOR DIAMETERS FROM 1/10 TO 100 ADVANCING BY TENTHS — (*Concluded*)

Diameter	Area	Circumference	Diameter	Area	Circumference
95.4	7148.0343	299.7079	97.8	7512.2078	307.2478
.5	7163.0276	300.0221	.9	7527.5780	307.5619
.6	7178.0366	300.3363	98.0	7542.9640	307.8761
.7	7193.0612	300.6504	.1	7558.3656	308.1902
.8	7208.1016	300.9646	.2	7573.7830	308.5044
.9	7223.1577	301.2787	.3	7589.2161	308.8186
96.0	7238.2295	301.5929	.4	7604.6648	309.1327
.1	7253.3170	301.9071	.5	7620.1293	309.4469
.2	7268.4202	302.2212	.6	7635.6095	309.7610
.3	7283.5391	302.5354	.7	7651.1054	310.0752
.4	7298.6737	302.8405	.8	7666.6170	310.3894
.5	7313.8240	303.1637	.9	7682.1444	310.7035
.6	7328.9901	303.4779	99.0	7697.6893	311.0177
.7	7344.1718	303.7920	.1	7713.2461	311.3318
.8	7359.3693	304.1062	.2	7728.8206	311.6460
.9	7374.5824	304.4203	.3	7744.4107	311.9602
97.0	7389.8113	304.7345	.4	7760.0166	312.2743
.1	7405.0559	305.0486	.5	7775.6382	312.5885
.2	7420.3162	305.3628	.6	7791.2764	312.9026
.3	7435.5922	305.6770	.7	7806.9284	313.2168
.4	7450.8839	305.9911	.8	7822.5971	313.5309
.5	7466.1913	306.3053	.9	7838.2815	313.8451
.6	7481.5144	306.6194	100.0	7853.9816	314.1593
.7	7496.8532	306.9336			

To compute the area or circumference of a circle of a diameter greater than 100 and less than 1001;

Take out the area or circumference from table as though the number had one decimal, and move the decimal point two places to the right for the area, and one place for the circumference.

Example. — Wanted the area and circumference of 567. The tabular area for 56.7 is 2524.9687, and circumference 178.1283. Therefore area for 567 = 252496.87 and circumference = 1781.283.

To compute the area or circumference of a circle of a diameter greater than 1000,

Divide by a factor, as 2, 3, 4, 5, etc., if practicable, that will leave a quotient to be found in table, then multiply the tabular area of the quotient by the *square* of the factor, or the tabular circumference by the factor.

Example. — Wanted the area and circumference of 2109. Dividing by 3, the quotient is 703, for which the area is 388150.84 and the circumference 2208.54. Therefore area of 2109 = 388150.84 × 9 = 3493357.56 and circumference = 2208.54 × 3 = 6625.62.

Table of Circular Arcs

Length of circular arcs when the chord and the height of the arc are given.

Divide the height by the chord. Find in the column of Heights the number equal to this quotient.

Take out the corresponding number from the column of lengths.

Multiply this last number by the length of the given chord.

Heights	Lengths	Heights	Lengths	Heights	Lengths	Heights	Lengths
.001	1.00002	.049	1.00638	.097	1.02491	.145	1.05516
.002	1.00002	.050	1.00665	.098	1.02542	.146	1.05591
.003	1.00003	.051	1.00692	.099	1.02593	.147	1.05667
.004	1.00004	.052	1.00720	.100	1.02646	.148	1.05743
.005	1.00007	.053	1.00748	.101	1.02698	.149	1.05819
.006	1.00010	.054	1.00776	.102	1.02752	.150	1.05896
.007	1.00013	.055	1.00805	.103	1.02806	.151	1.05973
.008	1.00017	.056	1.00834	.104	1.02860	.152	1.06051
.009	1.00022	.057	1.00864	.105	1.02914	.153	1.06130
.010	1.00027	.058	1.00895	.106	1.02970	.154	1.06209
.011	1.00032	.059	1.00926	.107	1.03026	.155	1.06288
.012	1.00038	.060	1.00957	.108	1.03082	.156	1.06368
.013	1.00045	.061	1.00989	.109	1.03139	.157	1.06449
.014	1.00053	.062	1.01021	.110	1.03196	.158	1.06530
.015	1.00061	.063	1.01054	.111	1.03254	.159	1.06611
.016	1.00069	.064	1.01088	.112	1.03312	.160	1.06693
.017	1.00078	.065	1.01123	.113	1.03371	.161	1.06775
.018	1.00087	.066	1.01158	.114	1.03430	.162	1.06858
.019	1.00097	.067	1.01193	.115	1.03490	.163	1.06941
.020	1.00107	.068	1.01228	.116	1.03551	.164	1.07025
.021	1.00117	.069	1.01264	.117	1.03611	.165	1.07109
.022	1.00128	.070	1.01302	.118	1.03672	.166	1.07194
.023	1.00140	.071	1.01338	.119	1.03734	.167	1.07279
.024	1.00153	.072	1.01376	.120	1.03797	.168	1.07365
.025	1.00167	.073	1.01414	.121	1.03860	.169	1.07451
.026	1.00182	.074	1.01453	.122	1.03923	.170	1.07537
.027	1.00196	.075	1.01493	.123	1.03987	.171	1.07624
.028	1.00210	.076	1.01533	.124	1.04051	.172	1.07711
.029	1.00225	.077	1.01573	.125	1.04116	.173	1.07799
.030	1.00240	.078	1.01614	.126	1.04181	.174	1.07888
.031	1.00256	.079	1.01656	.127	1.04247	.175	1.07977
.032	1.00272	.080	1.01698	.128	1.04313	.176	1.08066
.033	1.00289	.081	1.01741	.129	1.04380	.177	1.08156
.034	1.00307	.082	1.01784	.130	1.04447	.178	1.08246
.035	1.00327	.083	1.01828	.131	1.04515	.179	1.08337
.036	1.00345	.084	1.01872	.132	1.04584	.180	1.08428
.037	1.00364	.085	1.01916	.133	1.04652	.181	1.08519
.038	1.00384	.086	1.01961	.134	1.04722	.182	1.08611
.039	1.00405	.087	1.02006	.135	1.04792	.183	1.08704
.040	1.00426	.088	1.02052	.136	1.04862	.184	1.08797
.041	1.00447	.089	1.02098	.137	1.04932	.185	1.08890
.042	1.00469	.090	1.02146	.138	1.05003	.186	1.08984
.043	1.00492	.091	1.02192	.139	1.05075	.187	1.09079
.044	1.00515	.092	1.02240	.140	1.05147	.188	1.09174
.045	1.00539	.093	1.02289	.141	1.05220	.189	1.09269
.046	1.00563	.094	1.02339	.142	1.05293	.190	1.09365
.047	1.00587	.095	1.02389	.143	1.05367	.191	1.09461
.048	1.00612	.096	1.02440	.144	1.05441	.192	1.09557

Table of Circular Arcs — (*Continued*)

Heights	Lengths	Heights	Lengths	Heights	Lengths	Heights	Lengths
.193	1.09654	.248	1.15670	.303	1.22920	.358	1.31276
.194	1.09752	.249	1.15791	.304	1.23063	.359	1.31437
.195	1.09850	.250	1.15912	.305	1.23206	.360	1.31599
.196	1.09949	.251	1.16034	.306	1.23349	.361	1.31761
.197	1.10048	.252	1.16156	.307	1.23492	.362	1.31923
.198	1.10147	.253	1.16279	.308	1.23636	.363	1.32086
.199	1.10247	.254	1.16402	.309	1.23781	.364	1.32249
.200	1.10347	.255	1.16526	.310	1.23926	.365	1.32413
.201	1.10447	.256	1.16650	.311	1.24070	.366	1.32577
.202	1.10548	.257	1.16774	.312	1.24216	.357	1.32741
.203	1.10650	.258	1.16899	.313	1.24361	.368	1.32905
.204	1.10752	.259	1.17024	.314	1.24507	.369	1.33069
.205	1.10855	.260	1.17150	.315	1.24654	.370	1.33234
.206	1.10958	.261	1.17276	.316	1.24801	.371	1.33399
.207	1.11062	.262	1.17403	.317	1.24948	.372	1.33564
.208	1.11165	.263	1.17530	.318	1.25095	.373	1.33730
.209	1.11269	.264	1.17657	.319	1.25243	.374	1.33896
.210	1.11374	.265	1.17784	.320	1.25391	.375	1.34063
.211	1.11479	.266	1.17912	.321	1.25540	.376	1.34229
.212	1.11584	.267	1.18040	.322	1.25689	.377	1.34396
.213	1.11690	.268	1.18169	.323	1.25838	.378	1.34563
.214	1.11796	.269	1.18299	.324	1.25988	.379	1.34731
.215	1.11904	.270	1.18429	.325	1.26138	.380	1.34899
.216	1.12011	.271	1.18559	.326	1.26288	.381	1.35068
.217	1.12118	.272	1.18689	.327	1.26437	.382	1.35237
.218	1.12225	.273	1.18820	.328	1.26588	.383	1.35406
.219	1.12334	.274	1.18951	.329	1.26740	.384	1.35575
.220	1.12444	.275	1.19082	.330	1.26892	.385	1.35744
.221	1.12554	.276	1.19214	.331	1.27044	.386	1.35914
.222	1.12664	.277	1.19346	.332	1.27196	.387	1.36084
.223	1.12774	.278	1.19479	.333	1.27349	.388	1.36254
.224	1.12885	.279	1.19612	.334	1.27502	.389	1.36425
.225	1.12997	.280	1.19746	.335	1.27656	.390	1.36596
.226	1.13108	.281	1.19880	.336	1.27810	.391	1.36767
.227	1.13219	.282	1.20014	.337	1.27964	.392	1.36939
.228	1.13331	.283	1.20149	.338	1.28118	.393	1.37111
.229	1.13444	.284	1.20284	.339	1.28273	.394	1.37283
.230	1.13557	.285	1.20419	.340	1.28428	.395	1.37455
.231	1.13671	.286	1.20555	.341	1.28583	.396	1.37628
.232	1.13785	.287	1.20691	.342	1.28739	.397	1.37801
.233	1.13900	.288	1.20827	.343	1.28895	.398	1.37974
.234	1.14015	.279	1.20964	.344	1.29052	.399	1.38148
.235	1.14131	.290	1.21102	.345	1.29209	.400	1.38322
.236	1.14247	.291	1.21239	.346	1.29366	.401	1.38496
.237	1.14363	.292	1.21377	.347	1.29523	.402	1.38671
.238	1.14480	.293	1.21515	.348	1.29681	.403	1.38846
.239	1.14597	.294	1.21654	.349	1.29839	.404	1.39021
.240	1.14714	.295	1.21794	.350	1.29997	.405	1.39196
.241	1.14832	.296	1.21933	.351	1.30156	.406	1.39372
.242	1.14951	.297	1.22073	.352	1.30315	.407	1.39548
.243	1.15070	.298	1.22213	.353	1.30474	.408	1.39724
.244	1.15189	.299	1.22354	.354	1.30634	.409	1.39900
.245	1.15308	.300	1.22495	.355	1.30794	.410	1.40077
.246	1.15428	.301	1.22636	.356	1.30954	.411	1.40254
.247	1.15549	.302	1.22778	.357	1.31115	.412	1.40432

TABLE OF CIRCULAR ARCS — (*Concluded*)

Heights	Lengths	Heights	Lengths	Heights	Lengths	Heights	Lengths
.413	1.40610	.435	1.44589	.457	1.48699	.479	1.52931
.414	1.40788	.436	1.44773	.458	1.48889	.480	1.53126
.415	1.40966	.437	1.44957	.459	1.49079	.481	1.53322
.416	1.41145	.438	1.45142	.460	1.49269	.482	1.53518
.417	1.41324	.439	1.45327	.461	1.49460	.483	1.53714
.418	1.41503	.440	1.45512	.462	1.49651	.484	1.53910
.419	1.41682	.441	1.45697	.463	1.49842	.485	1.54106
.420	1.41861	.442	1.45883	.464	1.50033	.486	1.54302
.421	1.42041	.443	1.46069	.465	1.50224	.487	1.54499
.422	1.42221	.444	1.46255	.466	1.50416	.488	1.54696
.423	1.42402	.445	1.46441	.467	1.50608	.489	1.54893
.424	1.42583	.446	1.46628	.468	1.50800	.490	1.55091
.425	1.42764	.447	1.46815	.469	1.50992	.491	1.55289
.426	1.42945	.448	1.47002	.470	1.51185	.492	1.55487
.427	1.43127	.449	1.47189	.471	1.51378	.493	1.55685
.428	1.43309	.450	1.47377	.472	1.51571	.494	1.55884
.429	1.43491	.451	1.47565	.473	1.51764	.495	1.56083
.430	1.43673	.452	1.47753	.474	1.51958	.496	1.56282
.431	1.43856	.453	1.47942	.475	1.52152	.497	1.56481
.432	1.44039	.454	1.48131	.476	1.52346	.498	1.56681
.433	1.44222	.455	1.48320	.477	1.52541	.499	1.56881
.434	1.44405	.456	1.48509	.478	1.52736	.500	1.57080

Lengths of Circular Arcs to Radius 1

To find the length of a circular arc by the following table

Knowing the radius of the circle and the measure of the arc in deg., min., etc.

Rule. — Add together the lengths in the table found respectively opposite to the deg., min., etc., of the arc. Multiply the sum by the radius of the circle.

Example. — In a circle of 12.43 feet radius, is an arc of 13 deg., 27 min., 8 sec. How long is the arc?

Here,	opposite 13 deg. in the table, we find	.2268928
	" 27 min. " " " "	.0078540
	" 8 sec. " " " "	.0000388
	Sum =	.2347856

And .2347856 × 12.43, or radius = 2.918385 feet, the required length of arc.

Lengths of Circular Arcs to Radius 1

Deg.	Length	Deg.	Length	Deg.	Length	Deg.	Length
1	.0174533	46	.8028515	91	1.5882496	136	2.3736478
2	.0349066	47	.8203047	92	1.6057029	137	2.3911011
3	.0523599	48	.8377580	93	1.6231562	138	2.4085544
4	.0698132	49	.8552113	94	1.6406095	139	2.4260077
5	0872665	50	.8726646	95	1.6580628	140	2.4434610
6	.1047198	51	.8901179	96	1.6755161	141	2.4609142
7	.1221730	52	.9075712	97	1.6929694	142	2.4783675
8	.1396263	53	.9250245	98	1.7104227	143	2.4958208
9	.1570796	54	.9424778	99	1.7278760	144	2.5132741
10	.1745329	55	.9599311	100	1.7453293	145	2.5307274
11	.1919862	56	.9773844	101	1.7627825	146	2.5481807
12	.2094395	57	.9948377	102	1.7802358	147	2.5656340
13	.2268928	58	1.0122910	103	1.7976891	148	2.5830873
14	.2443461	59	1.0297443	104	1.8151424	149	2.6005406
15	.2617994	60	1.0471976	105	1.8325957	150	2.6179939
16	.2792527	61	1.0646508	106	1.8500490	151	2.6354472
17	.2967060	62	1.0821041	107	1.8675023	152	2.6529005
18	.3141593	63	1.0995574	108	1.8849556	153	2.6703538
19	.3316126	64	1.1170107	109	1.9024089	154	2.6878070
20	.3490659	65	1.1344640	110	1.9198622	155	2.7052603
21	.3665191	66	1.1519173	111	1.9373155	156	2.7227136
22	.3839724	67	1.1693706	112	1.9547688	157	2.7401669
23	.4014257	68	1.1868239	113	1.9722221	158	2.7576202
24	.4188790	69	1.2042772	114	1.9896753	159	2.7750735
25	.4363323	70	1.2217305	115	2.0071286	160	2.7925268
26	.4537856	71	1.2391838	116	2.0245819	161	2.8099801
27	.4712389	72	1.2566371	117	2.0420352	162	2.8274334
28	.4886922	73	1.2740904	118	2.0594885	163	2.8448867
29	.5061455	74	1.2915436	119	2.0769418	164	2.8623400
30	.5235988	75	1.3089969	120	2.0943951	165	2.8797933
31	.5410521	76	1.3264502	121	2.1118484	166	2.8972466
32	.5585054	77	1.3439035	122	2.1293017	167	2.9146999
33	.5759587	78	1.3613568	123	2.1467550	168	2.9321531
34	.5934119	79	1.3788101	124	2.1642083	169	2.9496064
35	.6108652	80	1.3962634	125	2.1816616	170	2.9670597
36	.6283185	81	1.4137167	126	2.1991149	171	2.9845130
37	.6457718	82	1.4311700	127	2.2165682	172	3.0019663
38	.6632251	83	1.4486233	128	2.2340214	173	3.0194196
39	.6806784	84	1.4660766	129	2.2514747	174	3.0368729
40	.6981317	85	1.4835299	130	2.2689280	175	3.0543262
41	.7155850	86	1.5009832	131	2.2863813	176	3.0717795
42	.7330383	87	1.5184364	132	2.3038346	177	3.0892328
43	.7504916	88	1.5358897	133	2.3212879	178	3.1066861
44	.7679449	89	1.5533430	134	2.3387412	179	3.1241394
45	.7853982	90	1.5707963	135	2.3561945	180	3.1415927

Min.	Length	Min.	Length	Min.	Length	Min.	Length
1	.0002909	6	.0017453	11	.0031998	16	.0046542
2	.0005818	7	.0020362	12	.0034907	17	.0049451
3	.0008727	8	.0023271	13	.0037815	18	.0052360
4	.0011636	9	.0026180	14	.0040724	19	.0055269
5	.0014544	10	.0029089	15	.0043633	20	.0058178

Lengths of Circular Arcs to Radius 1 — (*Continued*)

Min.	Length	Min.	Length	Min.	Length	Min.	Length
21	.0061087	31	.0090175	41	.0119264	51	.0148353
22	.0063995	32	.0093084	42	.0122173	52	.0151262
23	.0066904	33	.0095993	43	.0125082	53	.0154171
24	.0069813	34	.0098902	44	.0127991	54	0157080
25	.0072722	35	.0101811	45	.0130900	55	.0159989
26	.0075631	36	.0104720	46	.0133809	56	.0162897
27	.0078540	37	.0107629	47	.0136717	57	.0165806
28	.0081449	38	.0110538	48	.0139626	58	.0168715
29	.0084358	39	.0113446	49	.0142535	59	.0171624
30	.0087266	40	.0116355	50	.0145444	60	.0174533

Sec.	Length	Sec.	Length	Sec.	Length	Sec.	Length
1	.0000048	16	.0000776	31	.0001503	46	.0002230
2	.0000097	17	.0000824	32	.0001551	47	.0002279
3	.0000145	18	.0000873	33	.0001600	48	.0002327
4	.0000194	19	.0000921	34	.0001648	49	.0002376
5	.0000242	20	.0000970	35	.0001697	50	.0002424
6	.0000291	21	.0001018	36	.0001745	51	.0002473
7	.0000339	22	.0001067	37	.0001794	52	.0002521
8	.0000388	23	.0001115	38	.0001842	53	.0002570
9	.0000436	24	.0001164	39	.0001891	54	.0002618
10	.0000485	25	.0001212	40	.0001939	55	.0002666
11	.0000533	26	.0001261	41	.0001988	56	.0002715
12	.0000582	27	.0001309	42	.0002036	57	.0002763
13	.0000630	28	.0001357	43	.0002085	58	.0002812
14	.0000679	29	.0001406	44	.0002133	59	.0002860
15	.0000727	30	.0001454	45	.0002182	60	.0002909

Table of Areas of Circular Segments

If the segment exceeds a semicircle, its area = area of circle − area of a segment whose rise = (diam. of circle − rise of given segment). Diam. of circle = (square of half chord ÷ rise) + rise, whether the segment exceeds a semicircle or not.

Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by
.001	.000042	.010	.001329	.019	.003472	.028	.006194
.002	.000119	.011	.001533	.020	.003749	.029	.006527
.003	.000219	.012	.001746	.021	.004032	.030	.006866
.004	.000337	.013	.001969	.022	.004322	.031	.007209
.005	.000471	.014	.002199	.023	.004619	.032	.007559
.006	.000619	.015	.002438	.024	.004922	.033	.007913
.007	.000779	.016	.002685	.025	.005231	.034	.008273
.008	.000952	.017	.002940	.026	.005546	.035	.008638
.009	.001135	.018	.003202	.027	.005867	.036	.009008

Table of Areas of Circular Segments — (*Continued*)

Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by
.037	.009383	.087	.033308	.137	.064761	.187	.101553
.038	.009764	.088	.033873	.138	.065449	.188	.102334
.039	.010148	.089	.034441	.139	.066140	.189	.103116
.040	.010538	.090	.035012	.140	.066833	.190	.103900
.041	.010932	.091	.035586	.141	.067528	.191	.104686
.042	.011331	.092	.036162	.142	.068225	.192	.105472
.043	.011734	.093	.036742	.143	.068924	.193	.106261
.044	.012142	.094	.037324	.144	.069626	.194	.107051
.045	.012555	.095	.037909	.145	.070329	.195	.107843
.046	.012971	.096	.038497	.146	.071034	.196	.108636
.047	.013393	.097	.039087	.147	.071741	.197	.109431
.048	.013818	.098	.039681	.148	.072450	.198	.110227
.049	.014248	.099	.040277	.149	.073162	.199	.111025
.050	.014681	.100	.040875	.150	.073875	.200	.111824
.051	.015119	.101	.041477	.151	.074590	.201	.112625
.052	.015561	.102	.042081	.152	.075307	.202	.113427
.053	.016008	.103	.042687	.153	.076026	.203	.114231
.054	.016458	.104	.043296	.154	.076747	.204	.115036
.055	.016912	.105	.043908	.155	.077470	.205	.115842
.056	.017369	.106	.044523	.156	.078194	.206	.116651
.057	.017831	.107	.045140	.157	.078921	.207	.117460
.058	.018297	.108	.045759	.158	.079650	.208	.118271
.059	.018766	.109	.046381	.159	.080380	.209	.119084
.060	.019239	.110	.047006	.160	.081112	.210	.119898
.061	.019716	.111	.047633	.161	.081847	.211	.120713
.062	.020197	.112	.048262	.162	.082582	.212	.121530
.063	.020681	.113	.048894	.163	.083320	.213	.122348
.064	.021168	.114	.049529	.164	.084060	.214	.123167
.065	.021660	.115	.050165	.165	.084801	.215	.123988
.066	.022155	.116	.050805	.166	.085545	.216	.124811
.067	.023653	.117	.051446	.167	.086290	.217	.125634
.068	.023155	.118	.052090	.168	.087037	.218	.126459
.069	.023660	.119	.052737	.169	.087785	.219	.127286
.070	.024168	.120	.053385	.170	.088536	.220	.128114
.071	.024680	.121	.054037	.171	.089288	.221	.128943
.072	.025196	.122	.054690	.172	.090042	.222	.129773
.073	.025714	.123	.055346	.173	.090797	.223	.130605
074	.026236	.124	.056004	.174	.091555	.224	.131438
.075	.026761	.125	.056664	.175	.092314	.225	.132273
.076	.027290	.126	.057327	.176	.093074	.226	.133109
.077	.027821	.127	.057991	.177	.093837	.227	.133946
.078	.028356	.128	.058658	.178	.094601	.228	.134784
.079	.028894	.129	.059328	.179	.095367	.229	.135624
.080	.029435	.130	.059999	.180	.096135	.230	.136465
081	.029979	.131	.060673	.181	.096904	.231	.137307
.082	.030526	.132	.061349	.182	.097675	.232	.138151
.083	.031077	.133	.062027	.183	.098447	.233	.138996
.084	.031630	.134	.062707	.184	.099221	.234	.139842
.085	.032186	.135	.063389	.185	.099997	.235	.140689
.086	.032746	.136	.064074	.186	.100774	.236	.141538

TABLE OF AREAS OF CIRCULAR SEGMENTS — (*Continued*)

Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by
.237	.142388	.287	.186329	.337	.232634	.387	.280669
.238	.143239	.288	.187235	.338	.233580	.388	.281643
.239	.144091	.289	.188141	.339	.234526	.389	.282618
.240	.144945	.290	.189048	.340	.235473	.390	.283593
.241	.145800	.291	.189956	.341	.236421	.391	.284569
.242	.146656	.292	.190865	.342	.237369	.392	.285545
.243	.147513	.293	.191774	.343	.238319	.393	.286521
.244	.148371	.294	.192685	.344	.239268	.394	.287499
.245	.149231	.295	.193597	.345	.240219	.395	.288476
.246	.150091	.296	.194509	.346	.241170	.396	.289454
.247	.150953	.297	.195423	.347	.242122	.397	.290432
.248	.151816	.298	.196337	.348	.243074	.398	.291411
.249	.152681	.299	.197252	.349	.244027	.399	.292390
.250	.153546	.300	.198168	.350	.244980	.400	.293370
.251	.154413	.301	.199085	.351	.245935	.401	.294350
.252	.155281	.302	.200003	.352	.246890	.402	.295330
.253	.156149	.303	.200922	.353	.247845	.403	.296311
.254	.157019	.304	.201841	.354	.248801	.404	.297292
.255	.157891	.305	.202762	.355	.249758	.405	.298274
.256	.158763	.306	.203683	.356	.250715	.406	.299256
.257	.159636	.307	.204605	.357	.251673	.407	.300238
.258	.160511	.308	.205528	.358	.252632	.408	.301221
.259	.161386	.309	.206452	.359	.253591	.409	.302204
.260	.162263	.310	.207376	.360	.254551	.410	.303187
.261	.163141	.311	.208302	.361	.255511	.411	.304171
.262	.164020	.312	.209228	.362	.256472	.412	.305156
.263	.164900	.313	.210155	.363	.257433	.413	.306140
.264	.165781	.314	.211083	.364	.258395	.414	.307125
.265	.166663	.315	.212011	.365	.259358	.415	.308110
.266	.167546	.316	.212941	.366	.260321	.416	.309096
.267	.168431	.317	.213871	.367	.261285	.417	.310082
.268	.169316	.318	.214802	.368	.262249	.418	.311068
.269	.170202	.319	.215734	.369	.263214	.419	.312055
.270	.171090	.320	.216666	.370	.264179	.420	.313042
.271	.171978	.321	.217600	.371	.265145	.421	.314029
.272	.172868	.322	.218534	.372	.266111	.422	.315017
.273	.173758	.323	.219469	.373	.267078	.423	.316005
.274	.174650	.324	.220404	.374	.268046	.424	.316993
.275	.175542	.325	.221341	.375	.269014	.425	.317981
.276	.176436	.326	.222278	.376	.269982	.426	.318970
.277	.177330	.327	.223216	.377	.270951	.427	.319959
.278	.178226	.328	.224154	.378	.271921	.428	.320949
.279	.179122	.329	.225094	.379	.272891	.429	.321938
.280	.180020	.330	.226034	.380	.273861	.430	.322928
.281	.180918	.331	.226974	.381	.274832	.431	.323919
.282	.181818	.332	.227916	.382	.275804	.432	.324909
.283	.182718	.333	.228858	.383	.276776	.433	.325900
.284	.183619	.334	.229801	.384	.277748	.434	.326891
.285	.184522	.335	.230745	.385	.278721	.435	.327883
.286	.185425	.336	.231689	.386	.279695	.436	.328874

TABLE OF AREAS OF CIRCULAR SEGMENTS — (*Continued*)

Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by	Rise divided by diam. of circle	Area = (square of diam.) multiplied by
.437	.329866	.453	.345768	.469	.361719	.485	.377701
.438	.330858	.454	.346764	.470	.362717	.486	.378701
.439	.331851	.455	.347760	.471	.363715	.487	.379701
.440	.332843	.456	.348756	.472	.364714	.488	.380700
.441	.333836	.457	.349752	.473	.365712	.489	.381700
.442	.334829	.458	.350749	.474	.366711	.490	.382700
.443	.335823	.459	.351745	.475	.367710	.491	.383700
.444	.336816	.460	.352742	.476	.368708	.492	.384699
.445	.337810	.461	.353739	.477	.369707	.493	.385699
.446	.338804	.462	.354736	.478	.370706	.494	.386699
.447	.339799	.463	.355733	.479	.371705	.495	.387699
.448	.340793	.464	.356730	.480	.372704	.496	.388699
.449	.341788	.465	.357728	.481	.373704	.497	.389699
.450	.342783	.466	.358725	.482	.374703	.498	.390699
.451	.343778	.467	.359723	.483	.375702	.499	.391699
.452	.344773	.468	.360721	.484	.376702	.500	.392699

Chords of Arcs from One to Ninety Degrees

Dimensions given in inches.

Ang. Deg.	18-inch radius chord	36-inch radius chord	72-inch radius chord	Ang. Deg.	18-inch radius chord	36-inch radius chord	72-inch radius chord
1	5/16	5/8	1 1/4	46	14 1/16	28 1/8	56 17/64
2	5/8	1 1/4	2 1/2	47	14 23/64	28 23/32	57 27/64
3	15/16	1 7/8	3 3/4	48	14 41/64	29 9/32	58 37/64
4	1 1/4	2 1/2	5	49	14 59/64	29 55/64	59 23/32
5	1 37/64	3 9/64	6 9/32	50	15 7/32	30 27/64	60 55/64
6	1 7/8	3 49/64	7 17/32	51	15 1/2	31	62
7	2 13/64	4 25/64	8 51/64	52	15 25/32	31 9/16	63 1/8
8	2 1/2	5 1/64	10 3/64	53	16 1/16	32 1/8	64 1/4
9	2 53/64	5 41/64	11 19/64	54	16 11/32	32 11/16	65 3/8
10	3 9/64	6 9/32	12 35/64	55	16 5/8	33 1/4	66 1/2
11	3 29/64	6 29/32	13 51/64	56	16 29/32	33 51/64	67 39/64
12	3 49/64	7 17/32	15 3/64	57	17 11/64	34 23/64	68 23/32
13	4 5/64	8 5/32	16 19/64	58	17 29/64	34 29/32	69 13/16
14	4 25/64	8 25/32	17 35/64	59	17 23/32	35 29/64	70 29/32
15	4 45/64	9 25/64	18 51/64	60	18	36	72
16	5	10 1/64	20 1/32	61	18 17/64	36 35/64	73 5/64
17	5 21/64	10 41/64	21 9/32	62	18 35/64	37 5/64	74 11/64
18	5 5/8	11 17/64	22 17/32	63	18 13/16	37 5/8	75 1/4
19	5 15/16	11 7/8	23 49/64	64	19 5/64	38 5/32	76 5/16
20	6 1/4	12 1/2	25	65	19 11/32	38 11/16	77 3/8
21	6 9/16	13 1/8	26 15/64	66	19 39/64	39 7/32	78 27/64
22	6 7/8	13 47/64	27 31/64	67	19 7/8	39 47/64	79 15/32
23	7 11/64	14 23/64	28 45/64	68	20 1/8	40 17/64	80 17/32
24	7 31/64	14 31/32	29 15/16	69	20 25/64	40 25/32	81 9/16
25	7 51/64	15 37/64	31 11/64	70	20 41/64	41 19/64	82 19/32
26	8 3/32	16 13/64	32 25/64	71	20 29/32	41 13/16	83 5/8
27	8 13/32	16 13/16	33 5/8	72	21 5/32	42 21/64	84 41/64
28	8 45/64	17 13/32	34 13/16	73	21 13/32	42 53/64	85 21/32
29	9 1/64	18 1/32	36 1/16	74	21 21/32	43 21/64	86 21/32
30	9 5/16	18 41/64	37 17/64	75	21 59/64	43 53/64	87 21/32
31	9 5/8	19 15/64	38 31/64	76	22 5/32	44 21/64	88 21/32
32	9 59/64	19 27/32	39 11/16	77	22 13/32	44 53/64	89 41/64
33	10 7/32	20 29/64	40 57/64	78	22 21/32	45 5/16	90 5/8
34	10 17/32	21 3/64	42 3/32	79	22 57/64	45 51/64	91 19/32
35	10 53/64	21 21/32	43 19/64	80	23 9/64	46 9/32	92 9/16
36	11 1/8	22 1/4	44 1/2	81	23 3/8	46 3/4	93 33/64
37	11 27/64	22 27/32	45 11/16	82	23 39/64	47 15/64	94 15/32
38	11 23/32	23 7/16	46 7/8	83	23 55/64	47 45/64	95 13/32
39	12 1/64	24 1/32	48 1/16	84	24 3/32	48 11/64	96 23/64
40	12 5/16	24 5/8	49 1/4	85	24 21/64	48 41/64	97 9/32
41	12 39/64	25 7/32	50 7/16	86	24 35/64	49 3/32	98 13/64
42	12 29/32	25 51/64	51 39/64	87	24 25/32	49 9/16	99 1/8
43	13 3/16	26 25/64	52 25/32	88	25	50 1/64	100 1/32
44	13 31/64	26 31/32	53 15/16	89	25 15/64	50 15/32	100 15/16
45	13 25/32	27 35/64	55 7/64	90	25 29/64	50 29/32	101 53/64

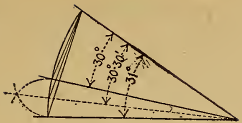


FIG. 35.

To Find the Length of a Chord which will Divide the Circumference of a Circle into N Equal Parts Multiply S by the Diameter

N	*S*	*N*	*S*	*N*	*S*	*N*	*S*
1	....	26	.12054	51	.061560	76	.041325
2	....	27	.11609	52	.060379	77	.040788
3	.86603	28	.11197	53	.059240	78	.040267
4	.70711	29	.10812	54	.058145	79	.039757
5	.58779	30	.10453	55	.057090	80	.039260
6	.50000	31	.10117	56	.056071	81	.038775
7	.43388	32	.098018	57	.055089	82	.038303
8	.38268	33	.095056	58	.054139	83	.037841
9	.34202	34	.092269	59	.053222	84	.037391
10	.30902	35	.089640	60	.052336	85	.036953
11	.28173	36	.087156	61	.051478	86	.036522
12	.25882	37	.084804	62	.050649	87	.036103
13	.23932	38	.082580	63	.049845	88	.035692
14	.22252	39	.080466	64	.049068	89	.035291
15	.20791	40	.078460	65	.048312	90	.034899
16	.19509	41	.076549	66	.047582	91	.034516
17	.18375	42	.074731	67	.046872	92	.034141
18	.17365	43	.072995	68	.046184	93	.033774
19	.16460	44	.071339	69	.045515	94	.033415
20	.15643	45	.069756	70	.044865	95	.033064
21	.14904	46	.068243	71	.044232	96	.032719
22	.14232	47	.066793	72	.043619	97	.032381
23	.13617	48	.065401	73	.043022	98	.032051
24	.13053	49	.064073	74	.042441	99	.031728
25	.12533	50	.062791	75	.041875	100	.031411

Lengths of Chords for Spacing Circle whose Diameter is 1

For circles of other diameters multiply length given in table by diameter of circle.

No. of spaces	Length of chord	No. of spaces	Length of chord	No. of spaces	Length of chord	No. of spaces	Length of chord
....	....	26	.1205	51	.0616	76	.0413
....	....	27	.1161	52	.0604	77	.0408
3	.8660	28	.1120	53	.0592	78	.0403
4	.7071	29	.1081	54	.0581	79	.0398
5	.5878	30	.1045	55	.0571	80	.0393
6	.5000	31	.1012	56	.0561	81	.0388
7	.4339	32	.0980	57	.0551	82	.0383
8	.3827	33	.0951	58	.0541	83	.0378
9	.3420	34	.0923	59	.0532	84	.0374
10	.3090	35	.0896	60	.0523	85	.0370
11	.2817	36	.0872	61	.0515	86	.0365
12	.2588	37	.0848	62	.0507	87	.0361
13	.2393	38	.0826	63	.0499	88	.0357
14	.2225	39	.0805	64	.0491	89	.0353
15	.2079	40	.0785	65	.0483	90	.0349
16	.1951	41	.0765	66	.0476	91	.0345
17	.1838	42	.0747	67	.0469	92	.0341
18	.1736	43	.0730	68	.0462	93	.0338
19	.1646	44	.0713	69	.0455	94	.0334
20	.1564	45	.0698	70	.0449	95	.0331
21	.1490	46	.0682	71	.0442	96	.0327
22	.1423	47	.0668	72	.0436	97	.0324
23	.1362	48	.0654	73	.0430	98	.0321
24	.1305	49	.0641	74	.0424	99	.0317
25	.1253	50	.0628	75	.0419	100	.0314

Computed by W. I. Mann, Pittsburg, Pa.
Supplement to *Machinery*, February, 1903.

Board Measure

Size	Length in feet							
	12	14	16	18	20	22	24	26
	Square feet							
1×8	8	9⅓	10⅔	12	13⅓	14⅔	16	17⅓
1×10	10	11⅔	13⅓	15	16⅔	18⅓	20	21⅔
1×12	12	14	16	18	20	22	24	26
1×14	14	16⅓	18⅔	21	23⅓	25⅔	28	30⅓
1×16	16	18⅔	21⅓	24	26⅔	29⅓	32	34⅔
2×3	6	7	8	9	10	11	12	13
2×4	8	9⅓	10⅔	12	13⅓	14⅔	16	17⅓
2×6	12	14	16	18	20	22	24	26
2×8	16	18⅔	21⅓	24	26⅔	29⅓	32	34⅔
2×10	20	23⅓	26⅔	30	33⅓	36⅔	40	43⅓
2×12	24	28	32	36	40	44	48	52
2×14	28	32⅔	37⅓	42	46⅔	51⅓	56	60⅔
2×16	32	37⅓	42⅔	48	53⅓	58⅔	64	69⅓
3×4	12	14	16	18	20	22	24	26
3×6	18	21	24	27	30	33	36	39
3×8	24	28	32	36	40	44	48	52
3×10	30	35	40	45	50	55	60	65
3×12	36	42	48	54	60	66	72	78
3×14	42	49	56	63	70	77	84	91
3×16	48	56	64	72	80	88	96	104
4×4	16	18⅔	21⅓	24	26⅔	29⅓	32	34⅔
4×6	24	28	32	36	40	44	48	52
4×8	32	37⅓	42⅔	48	53⅓	58⅔	64	69⅓
4×10	40	46⅔	53⅓	60	66⅔	73⅓	80	86⅔
4×12	48	56	64	72	80	88	96	104
4×14	56	65⅓	74⅔	84	93⅓	102⅔	112	121⅓
4×16	64	74⅔	85⅓	96	106⅔	117⅓	128	138⅔
6×6	36	42	48	54	60	66	72	78
6×8	48	56	64	72	80	88	96	104
6×10	60	70	80	90	100	110	120	130
6×12	72	84	96	108	120	132	144	156
6×14	84	98	112	126	140	154	168	182
6×16	96	112	128	144	160	176	192	208
8×8	64	74⅔	85⅓	96	106⅔	117⅓	128	138⅔
8×10	80	93⅓	106⅔	120	133⅓	146⅔	160	173⅓
8×12	96	112	128	144	160	176	192	208
8×14	112	130⅔	149⅓	168	186⅔	205⅓	224	242⅔
8×16	128	149⅓	170⅔	192	213⅓	234⅔	256	277⅓
10×10	100	116⅔	133⅓	150	166⅔	183⅓	200	216⅔
10×12	120	140	160	180	200	220	240	260
10×14	140	163⅓	186⅔	210	233⅓	256⅔	280	303⅓
10×16	160	186⅔	213⅓	240	266⅔	293⅓	320	346⅔
12×12	144	168	192	216	240	264	288	312
12×14	168	196	224	252	280	308	336	364
12×16	192	224	256	288	320	352	384	416
14×14	196	228⅔	261⅓	294	326⅔	359⅓	392	424⅔
14×16	224	261⅓	298⅔	336	373⅓	410⅔	448	485⅓
16×16	256	298⅔	341⅓	384	426⅔	469⅓	512	554⅔

Board Measure — (*Continued*)

Size	Length in feet						
	28	30	32	34	36	38	40
	Square feet						
1×8	18⅔	20	21⅓	22⅔	24	25⅓	26⅔
1×10	23⅓	25	26⅔	28⅓	30	31⅔	33⅓
1×12	28	30	32	34	36	38	40
1×14	32⅔	35	37⅓	39⅔	42	44⅓	46⅔
1×16	37⅓	40	42⅔	45⅓	48	50⅔	53⅓
2×3	14	15	16	17	18	19	20
2×4	18⅔	20	21⅓	22⅔	24	25⅓	26⅔
2×6	28	30	32	34	36	38	40
2×8	37⅓	40	42⅔	45⅓	48	50⅔	53⅓
2×10	46⅔	50	53⅓	56⅔	60	63⅓	66⅔
2×12	56	60	64	68	72	76	80
2×14	65⅓	70	72⅔	79⅓	84	88⅔	93⅓
2×16	74⅔	80	85⅓	90⅔	96	101⅓	106⅔
3×4	28	30	32	34	36	38	40
3×6	42	45	48	51	54	57	60
3×8	56	60	64	68	72	76	80
3×10	70	75	80	85	90	95	100
3×12	84	90	96	102	108	114	120
3×14	98	105	112	119	126	133	140
3×16	112	120	128	136	144	152	160
4×4	37⅓	40	42⅔	45⅓	48	50⅔	53⅓
4×6	56	60	64	68	72	76	80
4×8	74⅔	80	85⅓	90⅔	96	101⅓	106⅔
4×10	93⅓	100	106⅔	113⅓	120	126⅔	133⅓
4×12	112	120	128	136	144	152	160
4×14	130⅔	140	149⅓	158⅔	168	177⅓	186⅔
4×16	149⅓	160	170⅔	181⅓	192	202⅔	213⅓
6×6	84	90	96	102	108	114	120
6×8	112	120	128	136	144	152	160
6×10	140	150	160	170	180	190	200
6×12	168	180	192	204	216	228	240
6×14	196	210	224	238	252	266	280
6×16	224	240	256	272	288	304	320
8×8	149⅓	160	170⅔	181⅓	192	202⅔	213⅓
8×10	186⅔	200	213⅓	226⅔	240	253⅓	266⅔
8×12	224	240	256	272	288	304	320
8×14	261⅓	280	298⅔	317⅓	336	354⅔	373⅓
8×16	298⅔	320	341⅓	362⅔	384	405⅓	426⅔
10×10	233⅓	250	266⅔	283⅓	300	316⅔	333⅓
10×12	280	300	320	340	360	380	400
10×14	326⅔	350	373⅓	396⅔	410	443⅓	466⅔
10×16	373⅓	400	426⅔	453⅓	480	506⅔	533⅓
12×12	336	360	384	408	432	456	480
12×14	392	420	448	476	504	532	560
12×16	448	480	512	544	576	608	640
14×14	457⅓	490	522⅔	555⅓	588	620⅔	653⅓
14×16	522⅓	560	597⅓	634⅔	672	709⅓	746⅔
16×16	597⅓	640	682⅔	725⅓	768	810⅔	853⅓

Note. — By simply multiplying or dividing the above amounts, the number of feet contained in other dimensions can be obtained.

Weight of Lumber per 1000 Feet Board Measure

Character of lumber	Dry	Partly seasoned	Green
	Pounds	Pounds	Pounds
Pine and hemlock	2500	2750	3000
Norway and yellow pine	3000	4000	5000
Oak and walnut	4000	5000	....
Ash and maple	3500	4000	....

Surface and Volumes of Spheres

Spheres. (Original.) Trautwine.

Some errors of 1 in the last figure only.

Diam.	Surface	Solidity	Diam.	Surface	Solidity	Diam.	Surface	Solidity
1/64	.00077	....	1 3/32	3.7583	.68511	2 7/32	15.466	5.7190
1/32	.00307	.00002	1/8	3.9761	.74551	1/4	15.904	5.9641
3/64	.00690	.00005	5/32	4.2000	.80939	9/32	16.349	6.2161
1/16	.01227	.00013	3/16	4.4301	.87681	5/16	16.800	6.4751
3/32	.02761	.00043	7/32	4.6664	.94786	11/32	17.258	6.7412
1/8	.04909	.00102	1/4	4.9088	1.0227	3/8	17.721	7.0144
5/32	.07670	.00200	9/32	5.1573	1.1013	13/32	18.190	7.2949
3/16	.11045	.00345	5/16	5.4119	1.1839	7/16	18.666	7.5829
7/32	.15033	.00548	11/32	5.6728	1.2704	15/32	19.147	7.8783
1/4	.19635	.00818	3/8	5.9396	1.3611	1/2	19.635	8.1813
9/32	.24851	.01165	13/32	6.2126	1.4561	17/32	20.129	8.4919
5/16	.30680	.01598	7/16	6.4919	1.5553	9/16	20.629	8.8103
11/32	.37123	.02127	15/32	6.7771	1.6590	19/32	21.135	9.1366
3/8	.44179	.02761	1/2	7.0686	1.7671	5/8	21.648	9.4708
13/32	51848	.03511	17/32	7.3663	1.8799	21/32	22.166	9.8131
7/16	.60132	.04385	9/16	7.6699	1.9974	11/16	22.691	10.164
15/32	.69028	.05393	19/32	7.9798	2.1196	23/32	23.222	10.522
1/2	.78540	.06545	5/8	8.2957	2.2468	3/4	23.758	10.889
17/32	88664	.07850	21/32	8.6180	2.3789	25/32	24.302	11.265
9/16	.99403	.09319	11/16	8.9461	2.5161	13/16	24.850	11.649
19/32	1.1075	.10960	23/32	9.2805	2.6586	27/32	25.405	12.041
5/8	1.2272	.12783	3/4	9.6211	2.8062	7/8	25.967	12.443
21/32	1.3530	.14798	25/32	9.9678	2.9592	29/32	26.535	12.853
11/16	1.4849	.17014	13/16	10.321	3.1177	15/16	27.109	13.272
23/32	1.6230	.19442	27/32	10.680	3.2818	31/32	27.688	13.700
3/4	1.7671	.22089	7/8	11.044	3.4514	3	28.274	14.137
25/32	1.9175	.24967	29/32	11.416	3.6270	1/16	29.465	15.039
13/16	2.0739	.28084	15/16	11.793	3.8083	1/8	30.680	15.979
27/32	2.2365	.31451	31/32	12.177	3.9956	3/16	31.919	16.957
7/8	2.4053	.35077	2	12.566	4.1888	1/4	33.183	17.974
29/32	2.5802	.38971	1/32	12.962	4.3882	5/16	34.472	19.031
15/16	2.7611	.43143	1/16	13.364	4.5939	3/8	35.784	20.129
31/32	2.9483	.47603	3/32	13.772	4.8060	7/16	37.122	21.268
1	3.1416	.52360	1/8	14.186	5.0243	1/2	38.484	22.449
1/32	3.3410	.57424	5/32	14.607	5.2493	9/16	39.872	23.674
1/16	3.5466	.62804	3/16	15.033	5.4809	5/8	41.283	24.942

SPHERES — (*Continued*)

Diam.	Surface	Solidity	Diam.	Surface	Solidity	Diam.	Surface	Solidity
3 11/16	42.719	26.254	8	201.06	268.08	14 5/8	671.95	1637.9
3/4	44.179	27.611	1/8	207.39	280.85	3/4	683.49	1680.3
13/16	45.664	29.016	1/4	213.82	294.01	7/8	695.13	1723.3
7/8	47.173	30.466	3/8	220.36	307.58	15	706.85	1767.2
15/16	48.708	31.965	1/2	226.98	321.56	1/8	718.69	1811.7
4	50.265	33.510	5/8	233.71	335.95	1/4	730.63	1857.0
1/16	51.848	35.106	3/4	240.53	350.77	3/8	742.65	1903.0
1/8	53.456	36.751	7/8	247.45	366.02	1/2	754.77	1949.8
3/16	55.089	38.448	9	254.47	381.70	5/8	767.00	1997.4
1/4	56.745	40.195	1/8	261.59	397.83	3/4	779.32	2045.7
5/16	58.427	41.994	1/4	268.81	414.41	7/8	791.73	2094.8
3/8	60.133	43.847	3/8	276.12	431.44	16	804.25	2144.7
7/16	61.863	45.752	1/2	283.53	448.92	1/8	816.85	2195.3
1/2	63.617	47.713	5/8	291.04	466.87	1/4	829.57	2246.8
9/16	65.397	49.729	3/4	298.65	485.31	3/8	842.40	2299.1
5/8	67.201	51.801	7/8	306.36	504.21	1/2	855.29	2352.1
11/16	69.030	53.929	10	314.16	523.60	5/8	868.31	2406.0
3/4	70.883	56.116	1/8	322.06	543.48	3/4	881.42	2460.6
13/16	72.759	58.359	1/4	330.06	563.86	7/8	894.63	2516.1
7/8	74.663	60.663	3/8	338.16	584.74	17	907.93	2572.4
15/16	76.589	63.026	1/2	346.36	606.13	1/8	921.33	2629.6
5	78.540	65.450	5/8	354.66	628.04	1/4	934.83	2687.6
1/16	80.516	67.935	3/4	363.05	650.46	3/8	948.43	2746.5
1/8	82.516	70.482	7/8	371.54	673.42	1/2	962.12	2806.2
3/16	84.541	73.092	11	380.13	696.91	5/8	975.91	2866.8
1/4	86.591	75.767	1/8	388.83	720,95	3/4	989.80	2928.2
5/16	88.664	78.505	1/4	397.61	745.51	7/8	1003.8	2990.5
3/8	90.763	81.308	3/8	406.49	770.64	18	1017.9	3053.6
7/16	92.887	84.178	1/2	415.48	796.33	1/8	1032.1	3117.7
1/2	95.033	87.113	5/8	424.56	822.58	1/4	1046.4	3182.6
9/16	97.205	90.118	3/4	433.73	849.40	3/8	1060.8	3248.5
5/8	99.401	93.189	7/8	443.01	876.79	1/2	1075.2	3315.3
11/16	101.62	96.331	12	452.39	904.78	5/8	1089.8	3382.9
3/4	103.87	99.541	1/8	461.87	933.34	3/4	1104.5	3451.5
13/16	106.14	102.82	1/4	471.44	962.52	7/8	1119.3	3521.0
7/8	108.44	106.18	3/8	481.11	992.28	19	1134.1	3591.4
15/16	110.75	109.60	1/2	490.87	1022.7	1/8	1149.1	3662.8
6	113.10	113.10	5/8	500.73	1053.6	1/4	1164.2	3735.0
1/8	117.87	120.31	3/4	510.71	1085.3	3/8	1179.3	3808.2
1/4	122.72	127.83	7/8	520.77	1117.5	1/2	1194.6	3882.5
3/8	127.68	135.66	13	530.93	1150.3	5/8	1210.0	3957.6
1/2	132.73	143.79	1/8	541.19	1183.8	3/4	1225.4	4033.5
5/8	137.89	152.25	1/4	551.55	1218.0	7/8	1241.0	4110.8
3/4	143.14	161.03	3/8	562.00	1252.7	20	1256.7	4188.8
7/8	148.49	170.14	1/2	572.55	1288.3	1/8	1272.4	4267.8
7	153.94	179.59	5/8	583.20	1324.4	1/4	1288.3	4347.8
1/8	159.49	189.39	3/4	593.95	1361.2	3/8	1304.2	4428.8
1/4	165.13	199.53	7/8	604.80	1398.6	1/2	1320.3	4510.9
3/8	170.87	210.03	14	615.75	1436.8	5/8	1336.4	4593.9
1/2	176.71	220.89	1/8	626.80	1475.6	3/4	1352.7	4677.9
5/8	182.66	232.13	1/4	637.95	1515.1	7/8	1369.0	4763.0
3/4	188.69	243.73	3/8	649.17	1555.3	21	1385.5	4849.1
7/8	194.83	255.72	1/2	660.52	1596.3	1/8	1402.0	4936.2

SPHERES — (*Continued*)

Diam.	Surface	Solidity	Diam.	Surface	Solidity	Diam.	Surface	Solidity
21¼	1418.6	5,024.3	27⅞	2441.1	11,341	34½	3739.3	21,501
⅜	1435.4	5,113.5	28	2463.0	11,494	⅝	3766.5	21,736
½	1452.2	5,203.7	⅛	2485.1	11,649	¾	3793.7	21,972
⅝	1469.2	5,295.1	¼	2507.2	11,805	⅞	3821.1	22,210
¾	1486.2	5,397.4	⅜	2529.5	11,962	35	3848.5	22,449
⅞	1503.3	5,480.8	½	2551.8	12,121	⅛	3876.1	22,691
22	1520.5	5,575.3	⅝	2574.3	12,281	¼	3903.7	22,934
⅛	1537.9	5,670.8	¾	2596.7	12,443	⅜	3931.5	23,179
¼	1555.3	5,767.6	⅞	2619.4	12,606	½	3959.2	23,425
⅜	1572.8	5,865.2	29	2642.1	12,770	⅝	3987.2	23,674
½	1590.4	5,964.1	⅛	2665.0	12,936	¾	4015.2	23,924
⅝	1608.2	6,064.1	¼	2687.8	13,103	⅞	4043.3	24,176
¾	1626.0	6,165.2	⅜	2710.9	13,272	36	4071.5	24,429
⅞	1643.9	6,267.3	½	2734.0	13,442	⅛	4099.9	24,685
23	1661.9	6,370.6	⅝	2757.3	13,614	¼	4128.3	24,942
⅛	1680.0	6,475.0	¾	2780.5	13,787	⅜	4156.9	25,201
¼	1698.2	6,580.6	⅞	2804.0	13,961	½	4185.5	25,461
⅜	1716.5	6,687.3	30	2827.4	14,137	⅝	4214.1	25,724
½	1735.0	6,795.2	⅛	2851.1	14,315	¾	4243.0	25,988
⅝	1753.5	6,904.2	¼	2874.8	14,494	⅞	4271.8	26,254
¾	1772.1	7,014 3	⅜	2898.7	14,674	37	4300.9	26,522
⅞	1790.8	7,125.6	½	2922.5	14,856	⅛	4330.0	26,792
24	1809.6	7,238.2	⅝	2946.6	15,039	¼	4359.2	27,063
⅛	1828.5	7,351.9	¾	2970.6	15,224	⅜	4388.5	27,337
¼	1847.5	7,466.7	⅞	2994.9	15,411	½	4417.9	27,612
⅜	1866.6	7,583.0	31	3019.1	15,599	⅝	4447.5	27,889
½	1885.8	7,700.1	⅛	3043.6	15,788	¾	4477.1	28,168
⅝	1905.1	7,818.6	¼	3068.0	15,979	⅞	4506.8	28,449
¾	1924.4	7,938.3	⅜	3092.7	16,172	38	4536.5	28,731
⅞	1943.9	8,059.2	½	3117.3	16,366	⅛	4566.5	29,016
25	1963.5	8,181.3	⅝	3142.1	16,561	¼	4596.4	29,302
⅛	1983.2	8,304.7	¾	3166.9	16,758	⅜	4626.5	29,590
¼	2002.9	8,429.2	⅞	3192.0	16,957	½	4656.7	29,880
⅜	2022.9	8,554.9	32	3217.0	17,157	⅝	4686.9	30,173
½	2042.8	8,682.0	⅛	3242.2	17,359	¾	4717.3	30,466
⅝	2062.9	8,810.3	¼	3267.4	17,563	⅞	4747.9	30,762
¾	2083.0	8,939.9	⅜	3292.9	17,768	39	4778.4	31,059
⅞	2103.4	9,070.6	½	3318.3	17,974	⅛	4809.0	31,359
26	2123.7	9,202.8	⅝	3343.9	18,182	¼	4839.9	31,661
⅛	2144.2	9,336.2	¾	3369.6	18,392	⅜	4870.8	31,964
¼	2164.7	9,470.8	⅞	3395.4	18,604	½	4901.7	32,270
⅜	2185.5	9,606.7	33	3421.2	18,817	⅝	4932.7	32,577
½	2206.2	9,744.0	⅛	3447.3	19,032	¾	4964.0	32,886
⅝	2227.1	9,882.5	¼	3473.3	19,248	⅞	4995.3	33,197
¾	2248.0	10,022	⅜	3499.5	19,466	40	5026.5	33,510
⅞	2269.1	10,164	½	3525.7	19,685	⅛	5058.1	33,826
27	2290.2	10,306	⅝	3552.1	19,907	¼	5089.6	34,143
⅛	2311.5	10,450	¾	3578.5	20,129	⅜	5121.3	34,462
¼	2332.8	10,595	⅞	3605.1	20,354	½	5153.1	34,783
⅜	2354.3	10,741	34	3631.7	20,580	⅝	5184.9	35,106
½	2375.8	10,889	⅛	3658.5	20,808	¾	5216.9	35,431
⅝	2397.5	11,038	¼	3685.3	21,037	⅞	5248.9	35,758
¾	2419.2	11,189	⅜	3712.3	21,268	41	5281.1	36,087

SPHERES — (*Continued*)

Diam.	Surface	Solidity	Diam.	Surface	Solidity	Diam.	Surface	Solidity
41⅛	5313.3	36,418	47¾	7163.1	57,006	54⅜	9,288.5	84,177
¼	5345.6	36,751	⅞	7200.7	57,455	½	9,331.2	84,760
⅜	5378.1	37,086	48	7238.3	57,906	⅝	9,374.1	85,344
½	5410.7	37,423	⅛	7276.0	58,360	¾	9,417.2	85,931
⅝	5443.3	37,763	¼	7313.9	58,815	⅞	9,460.2	86,521
¾	5476.0	38,104	⅜	7351.9	59,274	55	9,503.2	87,114
⅞	5508.9	38,448	½	7389.9	59,734	⅛	9,546.5	87,709
42	5541.9	38,792	⅝	7428.0	60,197	¼	9,590.0	88,307
⅛	5574.9	39,140	¾	7466.3	60,663	⅜	9,633.3	88,908
¼	5608.0	39,490	⅞	7504.5	61,131	½	9,676.8	89,511
⅜	5641.3	39,841	49	7543.1	61,601	⅝	9,720.6	90,117
½	5674.5	40,194	⅛	7581.6	62,074	¾	9,764.4	90,726
⅝	5708.0	40,551	¼	7620.1	62,549	⅞	9,808.1	91,338
¾	5741.5	40,908	⅜	7658.9	63,026	56	9,852.0	91,953
⅞	5775.2	41,268	½	7697.7	63,506	⅛	9,896.0	92,570
43	5808.8	41,630	⅝	7736.7	63,989	¼	9,940.2	93,190
⅛	5842.7	41,994	¾	7775.7	64,474	⅜	9,984.4	93,812
¼	5876.5	42,360	⅞	7814.8	64,961	½	10,029	94,438
⅜	5910.7	42,729	50	7854.0	65,450	⅝	10,073	95,066
½	5944.7	43,099	⅛	7893.3	65,941	¾	10,118	95,697
⅝	5978.9	43,472	¼	7932.8	66,436	⅞	10,163	96,330
¾	6013.2	43,846	⅜	7972.2	66,934	57	10,207	96,967
⅞	6047.7	44,224	½	8011.8	67,433	⅛	10,252	97,606
44	6082.1	44,602	⅝	8051.6	67,935	¼	10,297	98,248
⅛	6116.8	44,984	¾	8091.4	68,439	⅜	10,342	98,893
¼	6151.5	45,367	⅞	8131.3	68,946	½	10,387	99,541
⅜	6186.3	45,753	51	8171.2	69,456	⅝	10,432	100,191
½	6221.2	46,141	⅛	8211.4	69,967	¾	10,478	100,845
⅝	6256.1	46,530	¼	8251.6	70,482	⅞	10,523	101,501
¾	6291.2	46,922	⅜	8292.0	70,999	58	10,568	102,161
⅞	6326.5	47,317	½	8332.3	71,519	⅛	10,614	102,823
45	6361.7	47,713	⅝	8372.8	72,040	¼	10,660	103,488
⅛	6397.2	48,112	¾	8413.4	72,565	⅜	10,706	104,155
¼	6432.7	48,513	⅞	8454.1	73,092	½	10,751	104,826
⅜	6468.3	48,916	52	8494.8	73,622	⅝	10,798	105,499
½	6503.9	49,321	⅛	8535.8	74,154	¾	10,844	106,175
⅝	6539.7	49,729	¼	8576.8	74,689	⅞	10,890	106,854
¾	6575.5	50,139	⅜	8617.8	75,226	59	10,936	107,536
⅞	6611.6	50,551	½	8658.9	75,767	⅛	10,983	108,221
46	6647.6	50,965	⅝	8700.4	76,309	¼	11,029	108,909
⅛	6683.7	51,382	¾	8741.7	76,854	⅜	11,076	109,600
¼	6720.0	51,801	⅞	8783.2	77,401	½	11,122	110,294
⅜	6756.5	52,222	53	8824.8	77,952	⅝	11,169	110,990
½	6792.9	52,645	⅛	8866.4	78,505	¾	11,216	111,690
⅝	6829.5	53,071	¼	8908.2	79,060	⅞	11,263	112,392
¾	6866.1	53,499	⅜	8950.1	79,617	60	11,310	113,098
⅞	6902.9	53,929	½	8992.0	80,178	⅛	11,357	113,806
47	6939.9	54,362	⅝	9034.1	80,741	¼	11,404	114,518
⅛	6976.8	54,797	¾	9076.4	81,308	⅜	11,452	115,232
¼	7013.9	55,234	⅞	9118.5	81,876	½	11,499	115,949
⅜	7050.9	55,674	54	9160.8	82,448	⅝	11,547	116,669
½	7088.3	56,115	⅛	9203.3	83,021	¾	11,595	117,392
⅝	7125.6	56,559	¼	9246.0	83,598	⅞	11,642	118,118

SPHERES — (*Continued*)

Diam.	Surface	Solidity	Diam.	Surface	Solidity	Diam.	Surface	Solidity
61	11,690	118,847	67⅝	14,367	161,927	74¼	17,320	214,333
⅛	11,738	119,579	¾	14,420	162,827	⅜	17,379	215,417
¼	11,786	120,315	⅞	14,474	163,731	½	17,437	216,505
⅜	11,834	121,053	68	14,527	164,637	⅝	17,496	217,597
½	11,882	121,794	⅛	14,580	165,547	¾	17,554	218,693
⅝	11,931	122,538	¼	14,634	166,460	⅞	17,613	219,792
¾	11,980	123,286	⅜	14,688	167,376	75	17,672	220,894
⅞	12,028	124,036	½	14,741	168,295	⅛	17,731	222,001
62	12,076	124,789	⅝	14,795	169,218	¼	17,790	223,111
⅛	12,126	125,545	¾	14,849	170,145	⅜	17,849	224,224
¼	12,174	126,305	⅞	14,903	171,074	½	17,908	225,341
⅜	12,223	127,067	69	14,957	172,007	⅝	17,968	226,463
½	12,272	127,832	⅛	15,012	172,944	¾	18,027	227,588
⅝	12,322	128,601	¼	15,066	173,883	⅞	18,087	228,716
¾	12,371	129,373	⅜	15,120	174,828	76	18,146	229,848
⅞	12,420	130,147	½	15,175	175,774	⅛	18,206	230,984
63	12,469	130,925	⅝	15,230	176,723	¼	18,266	232,124
⅛	12,519	131,706	¾	15,284	177,677	⅜	18,326	233,267
¼	12,568	132,490	⅞	15,339	178,635	½	18,386	234,414
⅜	12,618	133,277	70	15,394	179,595	⅝	18,446	235,566
½	12,668	134,067	⅛	15,449	180,559	¾	18,506	236,719
⅝	12,718	134,860	¼	15,504	181,525	⅞	18,566	237,879
¾	12,768	135,657	⅜	15,560	182,497	77	18,626	239,041
⅞	12,818	136,456	½	15,615	183,471	⅛	18,687	240,206
64	12,868	137,259	⅝	15,670	184,449	¼	18,748	241,376
⅛	12,918	138,065	¾	15,726	185,430	⅜	18,809	242,551
¼	12,969	138,874	⅞	15,782	186,414	½	18,869	243,728
⅜	13,019	139,686	71	15,837	187,402	⅝	18,930	244,908
½	13,070	140,501	⅛	15,893	188,394	¾	18,992	246,093
⅝	13,121	141,320	¼	15,949	189,389	⅞	19,053	247,283
¾	13,172	142,142	⅜	16,005	190,387	78	19,114	248,475
⅞	13,222	142,966	½	16,061	191,389	⅛	19,175	249,672
65	13,273	143,794	⅝	16,117	192,395	¼	19,237	250,873
⅛	13,324	144,625	¾	16,174	193,404	⅜	19,298	252,077
¼	13,376	145,460	⅞	16,230	194,417	½	19,360	253,284
⅜	13,427	146,297	72	16,286	195,433	⅝	19,422	254,496
½	13,478	147,138	⅛	16,343	196,453	¾	19,483	255,713
⅝	13,530	147,982	¼	16,400	197,476	⅞	19,545	256,932
¾	13,582	148,828	⅜	16,456	198,502	79	19,607	258,155
⅞	13,633	149,680	½	16,513	199,532	⅛	19,669	259,383
66	13,685	150,533	⅝	16,570	200,566	¼	19,732	260,613
⅛	13,737	151,390	¾	16,628	201,604	⅜	19,794	261,848
¼	13,789	152,251	⅞	16,685	202,645	½	19,856	263,088
⅜	13,841	153,114	73	16,742	203,689	⅝	19,919	264,330
½	13,893	153,980	⅛	16,799	204,737	¾	19,981	265,577
⅝	13,946	154,850	¼	16,857	205,789	⅞	20,044	266,829
¾	13,998	155,724	⅜	16,914	206,844	80	20,106	268,083
⅞	14,050	156,600	½	16,972	207,903	⅛	20,170	269,342
67	14,103	157,480	⅝	17,030	208,966	¼	20,232	270,604
⅛	14,156	158,363	¾	17,088	210,032	⅜	20,296	271,871
¼	14,208	159,250	⅞	17,146	211,102	½	20,358	273,141
⅜	14,261	160,139	74	17,204	212,175	⅝	20,422	274,416
½	14,314	161,032	⅛	17,262	213,252	¾	20,485	275,694

SPHERES — (*Continued*)

Diam.	Surface	Solidity	Diam.	Surface	Solidity	Diam.	Surface	Solidity
80⅞	20,549	276,977	87⅜	23,984	349,269	93⅞	27,686	433,160
81	20,612	278,263	½	24,053	350,771	94	27,759	434,894
⅛	20,676	279,553	⅝	24,122	352,277	⅛	27,833	436,630
¼	20,740	280,847	¾	24,191	353,785	¼	27,907	438,373
⅜	20,804	282,145	⅞	24,260	355,301	⅜	27,981	440,118
½	20,867	283,447	88	24,328	356,819	½	28,055	441,871
⅝	20,932	284,754	⅛	24,398	358,342	⅝	28,130	443,625
¾	20,996	286,064	¼	24,467	359,869	¾	28,204	445,387
⅞	21,060	287,378	⅜	24,536	361,400	⅞	28,278	447,151
82	21,124	288,696	½	24,606	362,935	95	28,353	448,920
⅛	21,189	290,019	⅝	24,676	364,476	⅛	28,428	450,695
¼	21,253	291,345	¾	24,745	366,019	¼	28,503	452,475
⅜	21,318	292,674	⅞	24,815	367,568	⅜	28,577	454,259
½	21,382	294,010	89	24,885	369,122	½	28,652	456,047
⅝	21,448	295,347	⅛	24,955	370,678	⅝	28,727	457,839
¾	21,512	296,691	¼	25,025	372,240	¾	28,802	459,638
⅞	21,578	298,036	⅜	25,095	373,806	⅞	28,878	461,439
83	21,642	299,388	½	25,165	375,378	96	28,953	463,248
⅛	21,708	300,743	⅝	25,236	376,954	⅛	29,028	465,059
¼	21,773	302,100	¾	25,306	378,531	¼	29,104	466,875
⅜	21,839	303,463	⅞	25,376	380,115	⅜	29,180	468,697
½	21,904	304,831	90	25,447	381,704	½	29,255	470,524
⅝	21,970	306,201	⅛	25,518	383,297	⅝	29,331	472,354
¾	22,036	307,576	¼	25,589	384,894	¾	29,407	474,189
⅞	22,102	308,957	⅜	25,660	386,496	⅞	29,483	476,029
84	22,167	310,340	½	25,730	388,102	97	29,559	477,874
⅛	22,234	311,728	⅝	25,802	389,711	⅛	29,636	479,725
¼	22,300	313,118	¾	25,873	391,327	¼	29,712	481,579
⅜	22,366	314,514	⅞	25,944	392,945	⅜	29,788	483,438
½	22,432	315,915	91	26,016	394,570	½	29,865	485,302
⅝	22,499	317,318	⅛	26,087	396,197	⅝	29,942	487,171
¾	22,565	318,726	¼	26,159	397,831	¾	30,018	489,045
⅞	22,632	320,140	⅜	26,230	399,468	⅞	30,095	490,924
85	22,698	321,556	½	26,302	401,109	98	30,172	492,808
⅛	22,765	322,977	⅝	26,374	402,756	⅛	30,249	494,695
¼	22,832	324,402	¾	26,446	404,406	¼	30,326	496,588
⅜	22,899	325,831	⅞	26,518	406,060	⅜	30,404	498,486
½	22,966	327,264	92	26,590	407,721	½	30,481	500,388
⅝	23,034	328,702	⅛	26,663	409,384	⅝	30,558	502,296
¾	23,101	330,142	¼	26,735	411,054	¾	30,636	504,208
⅞	23,168	331,588	⅜	26,808	412,726	⅞	30,713	506,125
86	23,235	333,039	½	26,880	414,405	99	30,791	508,047
⅛	23,303	334,492	⅝	26,953	416,086	⅛	30,869	509,975
¼	23,371	335,951	¾	27,026	417,774	¼	30,947	511,906
⅜	23,439	337,414	⅞	27,099	419,464	⅜	31,025	513,843
½	23,506	338,882	93	27,172	421,161	½	31,103	515,785
⅝	23,575	340,352	⅛	27,245	422,862	⅝	31,181	517,730
¾	23,643	341,829	¼	27,318	424,567	¾	31,259	519,682
⅞	23,711	343,307	⅜	27,391	426,277	⅞	31,338	521,638
87	23,779	344,792	½	27,464	427,991	100	31,416	523,598
⅛	23,847	346,281	⅝	27,538	429,710			
¼	23,916	347,772	¾	27,612	431,433			

Capacity of Rectangular Tanks in U. S. Gallons for Each Foot in Depth

Width of tank		Length of tank								
Ft.	Ins.	2 feet	2 feet, 6 ins.	3 feet	3 feet, 6 ins.	4 feet	4 feet, 6 ins.	5 feet	5 feet, 6 ins.	6 feet
2		29.92	37.40	44.88	52.36	59.84	67.32	74.81	82.29	89.77
2	6	.....	46.75	56.10	65.45	74.80	84.16	93.51	102.86	112.21
3		.....	.....	67.32	78.54	89.77	100.99	112.21	123.43	134.65
3	6	.....	.....	.....	91.64	104.73	117.82	130.91	144.00	157.09
4		.....	.....	.....	.....	119.69	134.65	149.61	164.57	179.53
4	6	.....	.....	.....	.....	......	151.48	168.31	185.14	201.97
5		.....	.....	.....	.....	......	......	187.01	205.71	224.41
5	6	.....	.....	.....	.....	......	......	......	226.28	246.86
6		.....	.....	.....	.....	......	......	......	......	269.30

Width of tank		Length of tank					
Ft.	Ins.	6 feet, 6 ins.	7 feet	7 feet, 6 ins.	8 feet	8 feet, 6 ins.	9 feet
2		97.25	104.73	112.21	119.69	127.17	134.65
2	6	121.56	130.91	140.26	149.61	158.96	168.31
3		145.87	157.09	168.31	179.53	190.75	202.97
3	6	170.18	183.27	196.36	209.45	222.54	235.63
4		194.49	209.45	224.41	239.37	254.34	269.30
4	6	218.80	235.63	252.47	269.30	286.13	302.96
5		243.11	261.82	280.52	299.22	317.92	336.62
5	6	267.43	288.00	308.57	329.14	349.71	370.28
6		291.74	314.18	336.62	359.06	381.50	403.94
6	6	316.05	340.36	364.67	388.98	413.30	437.60
7		....	366.54	392.72	418.91	455.09	471.27
7	6	....	....	420.78	448.83	476.88	504.93
8		....	....	....	478.75	508.67	538.59
8	6	....	....	....	....	540.46	572.25
9		....	....	....	....	....	605.92

Capacity of Rectangular Tanks in U. S. Gallons for Each Foot in Depth — (*Continued*)

Width of tank		Length of tank					
		9 feet, 6 ins.	10 feet	10 feet, 6 ins.	11 feet	11 feet, 6 ins.	12 feet
Ft.	Ins.						
2		142.13	149.61	157.09	164.57	172.05	179.53
2	6	177.66	187.01	196.36	205.71	215.06	224.41
3		213.19	224.41	235.68	246.86	258.07	269.03
3	6	248.73	261.82	274.90	288.00	301.09	314.18
4		284.26	299.22	314.18	329.14	344.10	359.06
4	6	319.79	336.62	353.45	370.28	385.10	403.94
5		355.32	374.03	392.72	411.43	430.13	448.83
5	6	390.85	411.43	432.00	452.57	473.14	493.71
6		426.39	448.83	471.27	493.71	516.15	538.59
6	6	461.92	486.23	510.54	534.85	559.16	583.47
7		497.45	523.64	549.81	575.99	602.18	628.36
7	6	523.98	561.04	589.08	617.14	645.19	673.24
8		568.51	598.44	628.36	658.28	688.20	718.12
8	6	604.05	635.84	667.63	699.42	713.21	763.00
9		639.58	673.25	706.90	740.56	774.23	807.89
9	6	675.11	710.65	746.17	781.71	817.24	852.77
10		....	748.05	785.45	822.86	860.26	897.66
10	6	....	....	824.73	864.00	903.26	942.56
11		....	....	....	905.14	946.27	987.43
11	6	....	....	....	....	989.29	1032.3
12		....	....	....	....	....	1077.2

Number of Barrels (31.5 Gallons) in Cisterns and Tanks

1 Bbl. 31.5 Gallons 4.2109 Cubic Feet.

Depth in feet	Diameter in feet							
	5	6	7	8	9	10	11	12
1	4.663	6.714	9.139	11.937	15.108	18.652	22.659	26.859
5	23.3	36.6	45.7	59.7	75.5	93.3	112.8	134.3
6	28.0	40.3	54.8	71.6	90.6	111.9	135.4	161.2
7	32.6	47.0	64.0	83.6	105.10	130.6	158.0	188.0
8	37.3	53.7	73.1	95.5	120.9	149.2	180.6	214.9
9	42.0	60.4	82.3	107.4	136.0	167.9	203.1	241.7
10	46.6	67.1	91.4	119.4	151.1	186.5	225.7	268.6
11	51.3	73.9	100.5	131.3	166.3	205.2	248.3	295.4
12	56.0	80.6	109.7	143.2	181.3	223.8	270.8	322.3
13	60.6	87.3	118.8	152.2	196.4	242.5	293.4	349.2
14	65.3	94.0	127.9	167.1	211.5	261.1	316.0	376.0
15	69.0	100.7	137.1	179.1	226.6	289.8	338.5	402.9
16	74.6	107.4	146.2	191.0	241.7	298.4	361.1	429.7
17	79.3	114.1	155.4	202.9	256.8	317.1	383.7	456.6
18	83.9	120.9	164.5	214.9	271.9	335.7	406.2	483.5
19	88.6	127.6	173.6	226.8	287.1	354.4	428.8	510.3
20	93.3	134.3	182.8	238.7	302.2	373.0	451.4	537.2

NUMBER OF BARRELS (31.5 GALLONS) IN CISTERNS AND TANKS — (*Continued*)

Depth in feet	Diameter in feet								
	13	14	15	16	17	18	19	20	21
1	31.522	36.557	41.9	47.7	53.9	60.4	67.3	74.6	82.2
5	157.6	182.8	209.8	238.7	269.5	203.2	336.7	373.0	441.3
6	199.1	219.3	251.8	286.5	323.4	362.6	404.0	447.6	493.6
7	220.7	255.9	293.8	334.2	377.3	423.0	471.3	522.2	575.8
8	252 2	292.5	335.7	382.0	431.2	483.4	538.7	590.8	658.0
9	283.7	329.0	377.7	429.7	485.1	543.9	606.0	671.5	740.3
10	315.2	365.6	419.7	477.5	539.0	604.3	673.3	746.1	822.5
11	346.7	402.1	461.6	525.2	592.9	664.7	740.7	820.7	904.8
12	378.3	438.7	503.6	573.0	646.8	725.2	808.0	895.3	987.0
13	409.8	475.2	545.6	620.7	700.7	785.6	875.3	969.9	1069.3
14	441.3	511.8	587.5	668.5	754.6	846.0	942.6	1044.5	1151.5
15	472.8	548.4	629.5	716.2	808.5	906.5	1010.0	1119.1	1223.8
16	504.4	584.9	671.5	764.0	862.4	966.9	1077.3	1193.7	1316.0
17	535.9	621.5	713.4	811.7	916.4	1027.4	1144.6	1268.3	1398.3
18	567.4	658.0	755.4	859.5	970.3	1087.8	1212.0	1342.9	1480.6
19	598.9	694.6	797.4	907.2	1024.2	1148.2	1279.3	1417.5	1562.8
20	630.4	731.1	839.3	955.0	1078.1	1208.6	1346.6	1492.1	1645.1

Depth in feet	Diameter in feet								
	22	23	24	25	26	27	28	29	30
1	90.3	98.6	107.4	116.6	126.1	136.0	148.2	157.9	167.9
5	451.4	483.3	537.2	582.9	630.4	679.8	731.1	784.3	839.3
6	541.6	592.0	644.6	699.4	756.5	815.8	877.4	941.1	1007.2
7	631.9	690.7	752.0	816.0	882.6	951.8	1023.6	1098.0	1175.0
8	722.2	789.3	859.5	932.6	1008.7	1087.7	1169.8	1254.9	1342.9
9	812.5	888.0	966.9	1049.1	1134.7	1223.7	1316.0	1411.7	1510.8
10	902.7	986.7	1074.3	1165.7	1260.8	1359.7	1462.2	1568.6	1678.6
11	993.0	1085.3	1181.8	1282.3	1386.9	1495.6	1608.5	1725.4	1846.5
12	1083.3	1184.0	1289.2	1398.8	1513.0	1631.6	1764.7	1882.3	2014.0
13	1173.5	1282.7	1396.6	1515.4	1639.1	1767.6	1900.9	2039.2	2182.2
14	1263.8	1381.3	1504.0	1632.6	1765.2	1903.6	2047.2	2196.0	2350.1
15	1354.1	1480.0	1611.5	1748.6	1891.2	2039.5	2193.4	2352.9	2517.9
16	1444.4	1578.7	1718.9	1865.1	2017.3	2175.5	2339.6	2509.7	2685.8
17	1534.5	1677.3	1826.3	1981.7	2143.4	2311.5	2485.8	2666.6	2853.7
18	1624.9	1776.0	1933.8	2098.3	2269.5	2447.4	2632.0	2823.4	3021.5
19	1715.2	1874.7	2041.2	2214.8	2395.6	2583.4	2778.3	2980.3	3189.4
20	1805.5	1973.3	2148.6	2321.4	2521.7	2719.4	2924.5	3137.2	3357.3

Contents of Cylinders, or Pipes

Contents for one foot in length, in cubic feet, and in U. S. gallons of 231 cubic inches, or 7.4805 gallons to a cubic foot. A cubic foot of water weighs about 62⅓ lbs.; and a gallon about 8⅓ lbs. Diams. 2, 3, or 10 times as great give 4, 9, or 100 times the content.

Diameter in inches	Diameter in decimals of a foot	For 1 foot in length: Cubic feet. Also area in square feet	For 1 foot in length: Gallons of 231 cubic inches	Diameter in inches	Diameter in decimals of a foot	For 1 foot in length: Cubic feet. Also area in square feet	For 1 foot in length: Gallons of 231 cubic inches
¼	.0208	.0003	.0025	½	.6250	.3068	2.295
5/16	.0260	.0005	.0040	¾	.6458	.3276	2.450
⅜	.0313	.0008	.0057	8	.6667	.3491	2.611
7/16	.0365	.0010	.0078	¼	.6875	.3712	2.777
½	.0417	.0014	.0102	½	.7083	.3941	2.948
9/16	.0469	.0017	.0129	¾	.7292	.4176	3.125
⅝	.0521	.0021	.0159	9	.7500	.4418	3.305
11/16	.0573	.0026	.0193	¼	.7708	.4667	3.491
¾	.0625	.0031	.0230	½	.7917	.4922	3.682
13/16	.0677	.0036	.0269	¾	.8125	.5185	3.879
⅞	.0729	.0042	.0312	10	.8333	.5454	4.080
15/16	.0781	.0048	.0359	¼	.8542	.5730	4.286
1	.0833	.0055	.0408	½	.8750	.6013	4.498
¼	.1042	.0085	.0638	¾	.8958	.6303	4.715
½	.1250	.0123	.0918	11	.9167	.6600	4.937
¾	.1458	.0167	.1249	¼	.9375	.6903	5.164
2	.1667	.0218	.1632	½	.9583	.7213	5.396
¼	.1875	.0276	.2066	¾	.9792	.7530	5.633
½	.2083	.0341	.2550	12	1 foot	.7854	5.875
¾	.2292	.0412	.3085	½	1.042	.8522	6.375
3	.2500	.0491	.3672	13	1.083	.9218	6.895
¼	.2708	.0576	.4309	½	1.125	.9940	7.436
½	.2917	.0668	.4998	14	1.167	1.069	7.997
¾	.3125	.0767	.5738	½	1.208	1.147	8.578
4	.3333	.0873	.6528	15	1.250	1.227	9.180
¼	.3542	.0985	.7369	½	1.292	1.310	9.801
½	.3750	.1104	.8263	16	1.333	1.396	10.44
¾	.3958	.1231	.9206	½	1.375	1.485	11.11
5	.4167	.1364	1.020	17	1.417	1.576	11.79
¼	.4375	.1503	1.125	½	1.458	1.670	12.49
½	.4583	.1650	1.234	18	1.500	1.767	13.22
¾	.4792	.1803	1.349	½	1.542	1.867	13.96
6	.5000	.1963	1.469	19	1.583	1.969	14.73
¼	.5208	.2131	1.594	½	1.625	2.074	15.51
½	.5417	.2304	1.724	20	1.667	2.182	16.32
¾	.5625	.2485	1.859	½	1.708	2.292	17.15
7	.5833	.2673	1.999	21	1.750	2.405	17.99
¼	.6042	.2867	2.145	½	1.792	2.521	18.86

Contents of Cylinders, or Pipes — (*Continued*)

Diameter in inches	Diameter in decimals of a foot	For 1 foot in length		Diameter in inches	Diameter in decimals of a foot	For 1 foot in length	
		Cubic feet. Also area in square feet	Gallons of 231 cubic inches			Cubic feet. Also area in square feet	Gallons of 231 cubic inches
22	1.833	2.640	19.75	35	2.917	6.681	49.98
½	1.875	2.761	20.66	36	3.000	7.069	52.88
23	1.917	2.885	21.58	37	3.083	7.467	55.86
½	1.958	3.012	22.53	38	3.167	7.876	58.92
24	2.000	3.142	23.50	39	3.250	8.296	62.06
25	2.083	3.409	25.50	40	3.333	8.727	65.28
26	2.167	3.687	27.58	41	3.417	9.168	68.58
27	2.250	3.976	29.74	42	3.500	9.621	71.97
28	2.333	4.276	31.99	43	3.583	10.085	75.44
29	2.417	4.587	34.31	44	3.667	10.559	78.99
30	2.500	4.909	36.72	45	3.750	11.045	82.62
31	2.583	5.241	39.21	46	3.833	11.541	86.33
32	2.667	5.585	41.78	47	3.917	12.048	90.13
33	2.750	5.940	44.43	48	4.000	12.566	94.00
34	2.833	6.305	47.16				

Table Continued, but with the Diameters in Feet

Diam., feet	Cubic feet	U. S. gallons	Diam., feet	Cubic feet	U. S. gallons	Diam., feet	Cubic feet	U. S. gallons
4	12.57	94.0	8	50.27	376.0	20	314.2	2350
¼	14.19	106.1	½	56.75	424.5	21	346.4	2591
½	15.90	119.0	9	63.62	475.9	22	380.1	2844
¾	17.72	132.5	½	70.88	530.2	23	415.5	3108
5	19.64	146.9	10	78.54	587.5	24	452.4	3384
¼	21.65	161.9	½	86.59	647.7	25	490.9	3672
½	23.76	177.7	11	95.03	710.9	26	530.9	3971
¾	25.97	194.3	½	103.90	777.0	27	572.6	4283
6	28.27	211.5	12	113.1	846.1	28	615.8	4606
¼	30.68	229.5	13	132.7	992.8	29	660.5	4941
½	33.18	248.2	14	153.9	1152	30	706.9	5288
¾	35.79	267.7	15	176.7	1322	31	754.8	5646
7	38.49	287.9	16	201.1	1504	32	804.8	6017
¼	41.28	308.8	17	227.0	1698	33	855.3	6398
½	44.18	330.5	18	254.5	1904	34	907.9	6792
¾	47.17	352.9	19	283.5	2121	35	962.1	7197

Contents of Linings of Wells

For diameters twice as great as those in the table, for the cubic yards of digging, take out those opposite *one half* of the greater diameter; and multiply them by 4. Thus, for the cubic yards in each foot of depth of a well 31 feet in diameter, first take out from the table those opposite the diameter of 15½ feet; namely, 6.989. Then 6.989 × 4 = 27.956 cubic yards required for the 31 feet diameter. But for the stone lining or walling, bricks or plastering, multiply the tabular quantity opposite *half* the greater diameter by 2. Thus, the perches of stone walling for each foot of depth of a well of 31 feet diameter will be 2.073 × 2 = 4.146. If the wall is more or less than one foot thick, within usual moderate limits, it will generally be near enough for practice to assume that the number of perches, or of bricks, will increase or decrease in the same proportion.

The size of the bricks is taken at 8¼ × 4 × 2 inches; and to be laid dry, or without mortar. In practice an addition of about 5 per cent should be made for waste. The brick lining is supposed to be 1 brick thick, or 8¼ ins.

Caution. — Be careful to observe that the diameters to be used for the digging are greater than those for the walling, bricks, or plastering.

Diameter in feet	For each foot of depth: For this column use the diameter of the digging — Cubic yards of digging	For these three columns use the diameter in clear of the lining: Stone lining 1 foot thick. Perches of 25 cubic feet	No. of bricks in a lining 1 brick thick	Square yards of plastering	Diameter in feet	For each foot of depth: For this column use the diameter of the digging — Cubic yards of digging	For these three columns use the diameter in clear of the lining: Stone lining 1 foot thick. Perches of 25 cubic feet	No. of bricks in a lining 1 brick thick	Square yards of plastering
1	.0291	.2513	57	.3491	4	.4654	.6283	227	1.396
¼	.0455	.2827	71	.4364	¼	.5254	.6597	241	1.484
½	.0654	.3142	85	.5236	½	.5890	.6912	255	1.571
¾	.0891	.3456	99	.6109	¾	.6563	.7226	269	1.658
2	.1164	.3770	114	.6982	5	.7272	.7540	283	1.745
¼	.1473	.4084	128	.7855	¼	.8018	.7854	297	1.833
½	.1818	.4398	142	.8727	½	.8799	.8168	311	1.920
¾	.2200	.4712	156	.9600	¾	.9617	.8482	326	2.007
3	.2618	.5027	170	1.047	6	1.047	.8796	340	2.095
¼	.3073	.5341	184	1.135	¼	1.136	.9111	354	2.182
½	.3563	.5655	198	1.222	½	1.229	.9425	368	2.269
¾	.4091	.5969	212	1.309	¾	1.325	.9739	382	2.356

A cubic yard = 202 U. S. gallons.

Contents of Linings of Wells

Diameter in feet	For each foot of depth: For this column use the diameter of the digging — Cubic yards of digging	For these three columns use the diameter in clear of the lining — Stone lining 1 foot thick. Perches of 25 cubic feet	No. of bricks in a lining 1 brick thick	Square yards of plastering	Diameter in feet	For each foot of depth: For this column use the diameter of the digging — Cubic yards of digging	For these three columns use the diameter in clear of the lining — Stone lining 1 foot thick. Perches of 25 cubic feet	No. of bricks in a lining 1 brick thick	Square yards of plastering
7	1.425	1.005	396	2.444	16¼	7.681	2.168	919	5.673
¼	1.529	1.037	410	2.531	½	7.919	2.199	933	5.760
½	1.636	1.068	425	2.618	¾	8.161	2.231	948	5.847
¾	1.747	1.100	439	2.705	17	8.407	2.262	962	5.934
8	1.862	1.131	453	2.793	¼	8.656	2.293	976	6.022
¼	1.980	1.162	467	2.880	½	8.908	2.325	990	6.109
½	2.102	1.194	481	2.967	¾	9.165	2.356	1004	6.196
¾	2.227	1.225	495	3.054	18	9.425	2.388	1018	6.283
9	2.356	1.257	509	3.142	¼	9.688	2.419	1032	6.371
¼	2.489	1.288	523	3.229	½	9.956	2.450	1046	6.458
½	2.625	1.319	538	3.316	¾	10.23	2.482	1061	6.545
¾	2.765	1.351	552	3.404	19	10.50	2.513	1075	6.633
10	2.909	1.382	566	3.491	¼	10.78	2.545	1089	6.720
¼	3.056	1.414	580	3.578	½	11.06	2.576	1103	6.807
½	3.207	1.445	594	3.665	¾	11.35	2.608	1117	6.894
¾	3.362	1.477	608	3.753	20	11.64	2.639	1131	6.982
11	3.520	1.508	622	3.840	¼	11.93	2.670	1145	7.069
¼	3.682	1.539	637	3.927	½	12.22	2.702	1160	7.156
½	3.847	1.571	651	4.014	¾	12.52	2.733	1174	7.243
¾	4.016	1.602	665	4.102	21	12.83	2.765	1188	7.331
12	4.189	1.634	679	4.189	¼	13.14	2.796	1202	7.418
¼	4.365	1.665	693	4.276	½	13.45	2.827	1216	7.505
½	4.545	1.696	707	4.364	¾	13.76	2.859	1230	7.593
¾	4.729	1.728	721	4.451	22	14.08	2.890	1244	7.680
13	4.916	1.759	736	4.538	¼	14.40	2.922	1259	7.767
¼	5.107	1.791	750	4.625	½	14.73	2.953	1273	7.854
½	5.301	1.822	764	4.713	¾	15.06	2.985	1287	7.942
¾	5.500	1.854	778	4.800	23	15.39	3.016	1301	8.029
14	5.701	1.885	792	4.887	¼	15.72	3.047	1315	8.116
¼	5.907	1.916	806	4.974	½	16.06	3.079	1329	8.203
½	6.116	1.948	820	5.062	¾	16.41	3.110	1343	8.291
¾	6.329	1.979	834	5.149	24	16.76	3.142	1357	8.378
15	6.545	2.011	849	5.236	¼	17.11	3.173	1372	8.465
¼	6.765	2.042	863	5.323	½	17.46	3.204	1386	8.552
½	6.989	2.073	877	5.411	¾	17.82	3.236	1400	8.640
¾	7.216	2.105	891	5.498	25	18.18	3.267	1414	8.727
16	7.447	2.136	905	5.585					

A cubic yard = 202 U. S. gallons.

If perches are named in a contract, it is necessary, in order to prevent fraud, to specify the number of cubic feet contained in the perch; for stone-quarriers have one perch, stone-masons another, etc. Engineers, on this account, contract by the *cubic yard*. The perch should be done away with entirely; perches of 25 cubic feet × 0.926 = cubic yards; and cubic yards ÷ 0.926 = perches of 25 cubic feet.

CHAPTER III

NATURAL SINES, TANGENTS, ETC.

Sine

THE sine of any angle *acb* or the sine of any circular arc *ab* is the perpendicular distance, *as*, from one end of the arc *a* to the radius passing through the other end *b* of the arc. It is equal to one-half the chord of the arc *abn*, which is twice the arc *ab*; or the chord of the arc *abn* is equal to twice the sine of half the arc, or twice the sine of *ab*.

The sine of the angle *tcb*, if *tcb* equals 90°, is equal to the radius of the circle.

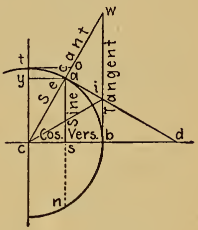


FIG. 36.

Cosine

The cosine of an arc *ab* is the distance *cs* from the center of the circle *c* to the intersection of the sine *as* with the radius *cb*, and is equal to *ya* or the sine of the arc *ta*. But the angle *tca* is equal to the difference between 90° and the angle *acb*; or the difference between the arcs *tab* and *ab*; and is the complement of *acb*. Hence the cosine of an angle or arc is equal to the sine of its complement, and vice versa.

Versed Sine

The versed sine of an arc is the distance *sb* from the foot *s* of the sine to the arc at *b*, measured on the radius *cb*.

Natural Sines, Tangents, etc.

The versed sine of an arc *ab* is equal to the rise of twice the arc; or equal to the rise of *abn*.

Tangent

The tangent *bw* of an arc *ab* is the perpendicular distance from the radius at one extremity of the arc *b* to the intersection *w* of the perpendicular *bw* with the prolongation of a radius drawn through the other extremity of the arc at *a*.

The Secant

The secant of an arc is the distance *cw* from the center of the arc to the intersection of the tangent at *w* of the prolonged radius *ca*.

If the angle *tcb* equals 90 degrees and *tca* be the complement of *acb*, the sine *ya* of this complement, its versed sine *ty*, tangent *to* and secant *co* become respectively the cosine, coversed sine, cotangent and cosecant of the angle *acb*, and vice versa.

When the radius *ab* is equal to unity the corresponding sines, cosines, tangents, etc., are called natural sines, cosines, etc.; and the table containing their lengths for different angles is the table of natural sines, etc.

The lengths of the sines, etc., for the arcs of any other circle, whose radius may be greater or less than 1, are found by multiplying the tabular values by such radius.

The following table contains only natural sines, tangents and secants; the other lengths may be found for any angle not exceeding 90 degrees as follows:

Cosine = sine of the complement of the given angle.

Versed sine = 1 − cosine.

Coversed sine = 1 − sine.

Cotangent = tangent of the complement.

Cosecant = 1 divided by natural sine.

Sine $= \frac{1}{\text{cosec}} = \frac{\cos}{\cot} = \sqrt{(1 - \cos^2)}.$

Tangent $= \frac{\sin}{\cos} = \frac{1}{\cot}.$

Secant $= \frac{1}{\cos} = \frac{\tan}{\sin} = \sqrt{R^2 + \text{tangent}^2}.$

Cosine $= \sqrt{(1 - \sin^2)} = \frac{\sin}{\tan} = \text{sine} \times \text{cotangent} = \frac{1}{\sec}.$

Cotangent $= \frac{\cos}{\sin} = \frac{1}{\tan}.$

Versed sine = radius − cosine.

Coversed sine = radius − sine.

Radius $= \text{tangent} \times \text{cotangent} = \sqrt{\text{sine}^2 + \text{cosine}^2}.$

The formulæ for the solution of the right-angled and the oblique-angled triangle are given; for further information the reader is referred to works on *Trigonometry*.

Solution of the Right-angled Triangle

Let A, B and C be the angles of the triangle and a, b and c the sides opposite those angles respectively.

Then (1) $\frac{a}{c} = \text{sine } A, \quad a = c \text{ sine } A.$

(2) $\frac{b}{c} = \text{cosine } A, \quad b = c \text{ cosine } A.$

(3) $\frac{a}{b} = \text{tangent } A, \quad a = b \text{ tangent } A.$

(4) $\frac{b}{a} = \cot A, \quad b = a \cot A.$

(5) $\frac{\text{Sin } A}{\text{Cos } A} = \text{tangent } A.$

(6) $\frac{\text{Cos } A}{\text{Sin } A} = \text{cotangent } A.$

(7) $\text{Sine } A + \cos^2 A = 1$

(8) $\text{Sine } A = \sqrt{1 - \cos^2 A}.$

(9) $\text{Cos } A = \sqrt{1 - \text{sine}^2 A}.$

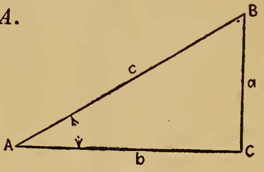


FIG. 37.

Solution of Oblique-angled Triangles

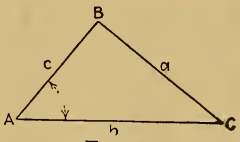


FIG. 38.

Value of any side c is:

$$c = \frac{a \sin C}{\sin A} = \frac{b \sin C}{\sin B}.$$

Value of any angle A:

$$\text{Sin } A = \frac{a \sin C}{c} = \frac{a \sin B}{b}.$$

$$\text{Cos } A = \frac{b - a \cos C}{c} = \frac{c - a \cos B}{b}$$

$$= \frac{c^2 + b^2 - a^2}{2bc}.$$

$$\text{Tan } A = \frac{a \sin C}{b - a \cos C} = \frac{a \sin B}{c - a \cos B}.$$

Natural Sines, Tangents and Secants

Advancing by 10 min.

Deg.	Min.	Sine	Tan-gent	Secant	Deg.	Min.	Sine	Tan-gent	Secant
0	00	.0000	.0000	1.0000		50	.1536	.1554	1.0120
	10	.0029	.0029	1.0000	9	00	.1564	.1584	1.0125
	20	.0058	.0058	1.0000		10	.1593	.1614	1.0129
	30	.0087	.0087	1.0000		20	.1622	.1644	1.0134
	40	.0116	.0116	1.0001		30	.1650	.1673	1.0139
	50	.0145	.0145	1.0001		40	.1679	.1703	1.0144
1	00	.0175	.0175	1.0002		50	.1708	.1733	1.0149
	10	.0204	.0204	1.0002	10	00	.1736	.1763	1.0154
	20	.0233	.0233	1.0003		10	.1765	.1793	1.0160
	30	.0262	.0262	1.0003		20	.1794	.1823	1.0165
	40	.0291	.0291	1.0004		30	.1822	.1853	1.0170
	50	.0320	.0320	1.0005		40	.1851	.1883	1.0176
2	00	.0349	.0349	1.0006		50	.1880	.1914	1.0181
	10	.0378	.0378	1.0007	11	00	.1908	.1944	1.0187
	20	.0407	.0407	1.0008		10	.1937	.1974	1.0193
	30	.0436	.0437	1.0010		20	.1965	.2004	1.0199
	40	.0465	.0466	1.0011		30	.1994	.2035	1.0205
	50	.0494	.0495	1.0012		40	.2022	.2065	1.0211
3	00	.0523	.0524	1.0014		50	.2051	.2095	1.0217
	10	.0552	.0553	1.0015	12	00	.2079	.2126	1.0223
	20	.0581	.0582	1.0017		10	.2108	.2156	1.0230
	30	.0610	.0612	1.0019		20	.2136	.2186	1.0236
	40	.0640	.0641	1.0021		30	.2164	.2217	1.0243
	50	.0669	.0670	1.0022		40	.2193	.2247	1.0249
4	00	.0698	.0699	1.0024		50	.2221	.2278	1.0256
	10	.0727	.0729	1.0027	13	00	.2250	.2309	1.0263
	20	.0756	.0758	1.0029		10	.2278	.2339	1.0270
	30	.0785	.0787	1.0031		20	.2306	.2370	1.0277
	40	.0814	.0816	1.0033		30	.2334	.2401	1.0284
	50	.0843	.0846	1.0036		40	.2363	.2432	1.0291
5	00	.0872	.0875	1.0038		50	.2391	.2462	1.0299
	10	.0901	.0904	1.0041	14	00	.2419	.2493	1.0306
	20	.0929	.0934	1.0043		10	.2447	.2524	1.0314
	30	.0958	.0963	1.0046		20	.2476	.2555	1.0321
	40	.0987	.0992	1.0049		30	.2504	.2586	1.0329
	50	.1016	.1022	1.0052		40	.2532	.2617	1.0337
6	00	.1045	.1051	1.0055		50	.2560	.2648	1.0345
	10	.1074	.1080	1.0058	15	00	.2588	.2679	1.0353
	20	.1103	.1110	1.0061		10	.2616	.2711	1.0361
	30	.1132	.1139	1.0065		20	.2644	.2742	1.0369
	40	.1161	.1169	1.0068		30	.2672	.2773	1.0377
	50	.1190	.1198	1.0072		40	.2700	.2805	1.0386
7	00	.1219	.1228	1.0075		50	.2728	.2836	1.0394
	10	.1248	.1257	1.0079	16	00	.2756	.2867	1.0403
	20	.1276	.1287	1.0082		10	.2784	.2899	1.0412
	30	.1305	.1317	1.0086		20	.2812	.2931	1.0421
	40	.1334	.1346	1.0090		30	.2840	.2962	1.0429
	50	.1363	.1376	1.0094		40	.2868	.2994	1.0439
8	00	.1392	.1405	1.0098		50	.2896	.3026	1.0448
	10	.1421	.1435	1.0102	17	00	.2924	.3057	1.0457
	20	.1449	.1465	1.0107		10	.2952	.3089	1.0466
	30	.1478	.1495	1.0111		20	.2979	.3121	1.0476
	40	.1507	.1524	1.0116		30	.3007	.3153	1.0485

NATURAL SINES, TANGENTS AND SECANTS — (*Continued*)

Deg.	Min.	Sine	Tan-gent	Secant	Deg.	Min.	Sine	Tan-gent	Secant
	40	.3035	.3185	1.0495		50	.4514	.5059	1.1207
	50	.3062	.3217	1.0505	27	00	.4540	.5095	1.1223
18	00	.3090	.3249	1.0515		10	.4566	.5132	1.1240
	10	.3118	.3281	1.0525		20	.4592	.5169	1.1257
	20	.3145	.3314	1.0535		30	.4617	.5206	1.1274
	30	.3173	.3346	1.0545		40	.4643	.5243	1.1291
	40	.3201	.3378	1.0555		50	.4669	.5280	1.1308
	50	.3228	.3411	1.0566	28	00	.4695	.5317	1.1326
19	00	.3256	.3443	1.0576		10	.4720	.5354	1.1343
	10	.3283	.3476	1.0587		20	.4746	.5392	1.1361
	20	.3311	.3508	1.0598		30	.4772	.5430	1.1379
	30	.3338	.3541	1.0608		40	.4797	.5467	1.1397
	40	.3365	.3574	1.0619		50	.4823	.5505	1.1415
	50	.3393	.3607	1.0631	29	00	.4848	.5543	1.1434
20	00	.3420	.3640	1.0642		10	.4874	.5581	1.1452
	10	.3448	.3673	1.0653		20	.4899	.5619	1.1471
	20	.3475	.3706	1.0665		30	.4924	.5658	1.1490
	30	.3502	.3739	1.0676		40	.4950	.5696	1.1509
	40	.3529	.3772	1.0688		50	.4975	.5735	1.1528
	50	.3557	.3805	1.0700	30	00	.5000	.5774	1.1547
21	00	.3584	.3839	1.0711		10	.5025	.5812	1.1566
	10	.3611	.3872	1.0723		20	.5050	.5851	1.1586
	20	.3638	.3906	1.0736		30	.5075	.5890	1.1606
	30	.3665	.3939	1.0748		40	.5100	.5930	1.1626
	40	.3692	.3973	1.0760		50	.5125	.5969	1.1646
	50	.3719	.4006	1.0773	31	00	.5150	.6009	1.1666
22	00	.3746	.4040	1.0785		10	.5175	.6048	1.1687
	10	.3773	.4074	1.0798		20	.5200	.6088	1.1707
	20	.3800	.4108	1.0811		30	.5225	.6128	1.1728
	30	.3827	.4142	1.0824		40	.5250	.6168	1.1749
	40	.3854	.4176	1.0837		50	.5275	.6208	1.1770
	50	.3881	.4210	1.0850	32	00	.5299	.6249	1.1792
23	00	.3907	.4245	1.0864		10	.5324	.6289	1.1813
	10	.3934	.4279	1.0877		20	.5348	.6330	1.1835
	20	.3961	.4314	1.0891		30	.5373	.6371	1.1857
	30	.3987	.4348	1.0904		40	.5398	.6412	1.1879
	40	.4014	.4383	1.0918		50	.5422	.6453	1.1901
	50	.4041	.4417	1.0932	33	00	.5446	.6494	1.1924
24	00	.4067	.4452	1.0946		10	.5471	.6536	1.1946
	10	.4094	.4487	1.0961		20	.5495	.6577	1.1969
	20	.4120	.4522	1.0975		30	.5519	.6619	1.1992
	30	.4147	.4557	1.0989		40	.5544	.6661	1.2015
	40	.4173	.4592	1.1004		50	.5568	.6703	1.2039
	50	.4200	.4628	1.1019	34	00	.5592	.6745	1.2062
25	00	.4226	.4663	1.1034		10	.5616	.6787	1.2086
	10	.4253	.4699	1.1049		20	.5640	.6830	1.2110
	20	.4279	.4734	1.1064		30	.5664	.6873	1.2134
	30	.4305	.4770	1.1079		40	.5688	.6916	1.2158
	40	.4331	.4806	1.1095		50	.5712	.6959	1.2183
	50	.4358	.4841	1.1110	35	00	.5736	.7002	1.2208
26	00	.4384	.4877	1.1126		10	.5760	.7046	1.2233
	10	.4410	.4913	1.1142		20	.5783	.7089	1.2258
	20	.4436	.4950	1.1158		30	.5807	.7133	1.2283
	30	.4462	.4986	1.1174		40	.5831	.7177	1.2309
	40	.4488	.5022	1.1190		50	.5854	.7221	1.2335

Natural Sines, Tangents and Secants — (*Continued*)

Deg.	Min.	Sine	Tangent	Secant	Deg.	Min.	Sine	Tangent	Secant
36	00	.5878	.7265	1.2361		10	.7092	1.0058	1.4183
	10	.5901	.7310	1.2387		20	.7112	1.0117	1.4225
	20	.5925	.7355	1.2413		30	.7133	1.0176	1.4267
	30	.5948	.7400	1.2440		40	.7153	1.0235	1.4310
	40	.5972	.7445	1.2467		50	.7173	1.0295	1.4352
	50	.5995	.7490	1.2494	46	00	.7193	1.0355	1.4396
37	00	.6018	.7536	1.2521		10	.7214	1.0416	1.4439
	10	.6041	.7581	1.2549		20	.7234	1.0477	1.4483
	20	.6065	.7627	1.2577		30	.7254	1.0538	1.4527
	30	.6088	.7673	1.2605		40	.7274	1.0599	1.4572
	40	.6111	.7720	1.2633		50	.7294	1.0661	1.4617
	50	.6134	.7766	1.2661	47	00	.7314	1.0724	1.4663
38	00	.6157	.7813	1.2690		10	.7333	1.0786	1.4709
	10	.6180	.7860	1.2719		20	.7353	1.0850	1.4755
	20	.6202	.7907	1.2748		30	.7373	1.0913	1.4802
	30	.6225	.7954	1.2778		40	.7392	1.0977	1.4849
	40	.6248	.8002	1.2808		50	.7412	1.1041	1.4987
	50	.6271	.8050	1.2837	48	00	.7431	1.1106	1.4945
39	00	.6293	.8098	1.2868		10	.7451	1.1171	1.4993
	10	.6316	.8146	1.2898		20	.7470	1.1237	1.5042
	20	.6338	.8195	1.2929		30	.7490	1.1303	1.5092
	30	.6361	.8243	1.2960		40	.7509	1.1369	1.5141
	40	.6383	.8292	1.2991		50	.7528	1.1436	1.5192
	50	.6406	.8342	1.3022	49	00	.7547	1.1504	1.5243
40	00	.6428	.8391	1.3054		10	.7566	1.1571	1.5294
	10	.6450	.8441	1.3086		20	.7585	1.1640	1.5345
	20	.6472	.8491	1.3118		30	.7604	1.1708	1.5398
	30	.6494	.8541	1.3151		40	.7623	1.1778	1.5450
	40	.6517	.8591	1.3184		50	.7642	1.1847	1.5504
	50	.6539	.8642	1.3217	50	00	.7660	1.1918	1.5557
41	00	.6561	.8693	1.3250		10	.7679	1.1988	1.5611
	10	.6583	.8744	1.3284		20	.7698	1.2059	1.5666
	20	.6604	.8796	1.3318		30	.7716	1.2131	1.5721
	30	.6626	.8847	1.3352		40	.7735	1.2203	1.5777
	40	.6648	.8899	1.3386		50	.7753	1.2276	1.5833
	50	.6670	.8952	1.3421	51	00	.7771	1.2349	1.5890
42	00	.6691	.9004	1.3456		10	.7790	1.2423	1.5948
	10	.6713	.9057	1.3492		20	.7808	1.2497	1.6005
	20	.6734	.9110	1.3527		30	.7826	1.2572	1.6064
	30	.6756	.9163	1.3563		40	.7844	1.2647	1.6123
	40	.6777	.9217	1.3600		50	.7862	1.2723	1.6183
	50	.6799	.9271	1.3636	52	00	.7880	1.2799	1.6243
43	00	.6820	.9325	1.3673		10	.7898	1.2876	1.6303
	10	.6841	.9380	1.3711		20	.7916	1.2954	1.6365
	20	.6862	.9435	1.3748		30	.7934	1.3032	1.6427
	30	.6884	.9490	1.3786		40	.7951	1.1311	1.6489
	40	.6905	.9545	1.3824		50	.7969	1.3190	1.6553
	50	.6926	.9601	1.3863	53	00	.7986	1.3270	1.6616
44	00	.6947	.9657	1.3902		10	.8004	1.3351	1.6681
	10	.6967	.9713	1.3941		20	.8021	1.3432	1.6746
	20	.6988	.9770	1.3980		30	.8039	1.3514	1.6812
	30	.7009	.9827	1.4020		40	.8056	1.3597	1.6878
	40	.7030	.9884	1.4061		50	.8073	1.3680	1.6945
	50	.7050	.9942	1.4101	54	00	.8090	1.3764	1.7013
45	00	.7071	1.0000	1.4142		10	.8107	1.3848	1.7081

Natural Sines, Tangents and Secants — (*Continued*)

Deg.	Min.	Sine	Tangent	Secant	Deg.	Min.	Sine	Tangent	Secant
	20	.8124	1.3924	1.7151		30	.8949	2.0057	2.2412
	30	.8141	1.4019	1.7221		40	.8962	2.0204	2.2543
	40	.8158	1.4106	1.7291		50	.8975	2.0353	2.2677
	50	.8175	1.4193	1.7362	64	00	.8988	2.0503	2.2812
55	00	.8192	1.4281	1.7434		10	.9001	2.0655	2.2949
	10	.8208	1.4370	1.7507		20	.9013	2.0809	2.3088
	20	.8225	1.4460	1.7581		30	.9026	2.0965	2.3228
	30	.8241	1.4550	1.7655		40	.9038	2.1123	2.3371
	40	.8258	1.4641	1.7730		50	.9051	2.1283	2.3515
	50	.8274	1.4733	1.7806	65	00	.9063	2.1445	2.3662
56	00	.8290	1.4826	1.7883		10	.9075	2.1609	2.3811
	10	.8307	1.4919	1.7960		20	.9088	2.1775	2.3961
	20	.8323	1.5013	1.8039		30	.9100	2.1943	2.4114
	30	.8339	1.5108	1.8118		40	.9112	2.2113	2.4269
	40	.8355	1.5204	1.8198		50	.9124	2.2286	2.4426
	50	.8371	1.5301	1.8279	66	00	.9135	2.2460	2.4586
57	00	.8387	1.5399	1.8361		10	.9147	2.2637	2.4748
	10	.8403	1.5497	1.8443		20	.9159	2.2817	2.4912
	20	.8418	1.5597	1.8527		30	.9171	2.2998	2.5078
	30	.8434	1.5697	1.8612		40	.9182	2.3183	2.5247
	40	.8450	1.5798	1.8699		50	.9194	2.3369	2.5419
	50	.8465	1.5900	1.8783	67	00	.9205	2.3559	2.5593
58	00	.8480	1.6003	1.8871		10	.9216	2.3750	2.5570
	10	.8496	1.6107	1.8959		20	.9228	2.3945	2.5949
	20	.8511	1.6213	1.9048		30	.9239	2.4141	2.6131
	30	.8526	1.6319	1.9139		40	.9250	2.4342	2.6316
	40	.8542	1.6426	1.9230		50	.9261	2.4545	2.6504
	50	.8557	1.6534	1.9323	68	00	.9272	2.4751	2.6695
59	00	.8572	1.6643	1.9416		10	.9283	2.4960	2.6888
	10	.8587	1.6753	1.9511		20	.9293	2.5172	2.7085
	20	.8601	1.6864	1.9606		30	.9304	2.5386	2.7285
	30	.8616	1.6977	1.9703		40	.9315	2.5605	2.7488
	40	.8631	1.7090	1.9801		50	.9325	2.5826	2.7695
	50	.8646	1.7205	1.9900	69	00	.9336	2.6051	2.7904
60	00	.8660	1.7321	2.0000		10	.9346	2.6279	2.8117
	10	.8675	1.7437	2.0101		20	.9356	2.6511	2.8334
	20	.8689	1.7556	2.0204		30	.9367	2.6746	2.8555
	30	.8704	1.7675	2.0308		40	.9377	2.6985	2.8779
	40	.8718	1.7796	2.0413		50	.9387	2.7228	2.9006
	50	.8732	1.7917	2.0519	70	00	.9397	2.7475	2.9238
61	00	.8746	1.8040	2.0627		10	.9407	2.7725	2.9474
	10	.8760	1.8165	2.0736		20	.9417	2.7980	2.9713
	20	.8774	1.8291	2.0846		30	.9426	2.8239	2.9957
	30	.8788	1.8418	2.0957		40	.9436	2.8502	3.0206
	40	.8802	1.8546	2.1070		50	.9446	2.8770	3.0458
	50	.8816	1.8676	2.1185	71	00	.9455	2.9042	3.0716
62	00	.8829	1.8807	2.1301		10	.9465	2.9319	3.0977
	10	.8843	1.8940	2.1418		20	.9474	2.9600	3.1244
	20	.8857	1.9074	2.1537		30	.9483	2.9887	3.1515
	30	.8870	1.9210	2.1657		40	.9492	3.0178	3.1792
	40	.8884	1.9347	2.1786		50	.9502	3.0475	3.2074
	50	.8897	1.9486	2.1902	72	00	.9511	3.0777	3.2361
63	00	.8910	1.9626	2.2027		10	.9520	3.1084	3.2653
	10	.8923	1.9768	2.2153		20	.9528	3.1397	3.2951
	20	.8936	1.9912	2.2282		30	.9537	3.1716	3.3255

Natural Sines, Tangents and Secants — (*Continued*)

Deg.	Min.	Sine	Tangent	Secant	Deg.	Min.	Sine	Tangent	Secant
	40	.9546	3.2041	3.3565		30	.9890	6.6912	6.7655
	50	.9555	3.2371	3.3881		40	.9894	6.8269	6.8998
73	00	.9563	3.2709	3.4203		50	.9899	6.9682	7.0396
	10	.9572	3.3052	3.4532	82	00	.9903	7.1154	7.1853
	20	.9580	3.3402	3.4867		10	.9907	7.2687	7.3372
	30	.9588	3.3759	3.5209		20	.9911	7.4287	7.4957
	40	.9596	3.4124	3.5559		30	.9914	7.5958	7.6613
	50	.9605	3.4495	3.5915		40	.9918	7.7704	7.8344
74	00	.9613	3.4874	3.6280		50	.9922	7.9530	8.0156
	10	.9621	3.5261	3.6652	83	00	.9925	8.1443	8.2055
	20	.9628	3.5656	3.7032		10	.9929	8.3450	8.4047
	30	.9636	3.6059	3.7420		20	.9932	8.5555	8.6138
	40	.9644	3.6470	3.7817		30	.9936	8.7769	8.8337
	50	.9652	3.6891	3.8222		40	.9939	9.0098	9.0652
75	00	.9659	3.7321	3.8637		50	.9942	9.2553	9.3092
	10	.9667	3.7760	3.9061	84	00	.9945	9.5144	9.5668
	20	.9674	3.8208	3.9495		10	.9948	9.7882	9.8391
	30	.9681	3.8667	3.9939		20	.9951	10.0780	10.1275
	40	.9689	3.9136	4.0394		30	.9954	10.3854	10.4334
	50	.9696	3.9617	4.0859		40	.9957	10.7119	10.7585
76	00	.9703	4.0108	4.1336		50	.9959	11.0594	11.1045
	10	.9710	4.0611	4.1824	85	00	.9962	11.430	11.474
	20	.9717	4.1126	4.2324		10	.9964	11.826	11.868
	30	.9724	4.1653	4.2837		20	.9967	12.251	12.291
	40	.9730	4.2193	4.3362		30	.9969	12.706	12.745
	50	.9737	4.2747	4.3901		40	.9971	13.197	13.235
77	00	.9744	4.3315	4.4454		50	.9974	13.727	13.763
	10	.9750	4.3897	4.5022	86	00	.9976	14.301	14.336
	20	.9757	4.4494	4.5604		10	.9978	14.924	14.958
	30	.9763	4.5107	4.6202		20	.9980	15.605	15.637
	40	.9769	4.5736	4.6817		30	.9981	16.350	16.380
	50	.9775	4.6382	4.7448		40	.9983	17.169	17.198
78	00	.9781	4.7046	4.8097		50	.9985	18.075	18.103
	10	.9787	4.7729	4.8765	87	00	.9986	19.081	19.107
	20	.9793	4.8430	4.9452		10	.9988	20.206	20.230
	30	.9799	4.9152	5.0159		20	.9989	21.470	21.494
	40	.9805	4.9894	5.0886		30	.9990	22.904	22.926
	50	.9811	5.0658	5.1636		40	.9992	24.542	24.562
79	00	.9816	5.1446	5.2408		50	.9993	26.432	26.451
	10	.9822	5.2257	5.3205	88	00	.9994	28.636	28.654
	20	.9827	5.3093	5.4026		10	.9995	31.242	31.258
	30	.9833	5.3955	5.4874		20	.9996	34.368	34.382
	40	.9838	5.4845	5.5749		30	.9997	38.188	38.202
	50	.9843	5.5764	5.6653		40	.9997	42.964	42.976
80	00	.9848	5.6713	5.7588		50	.9998	49.104	49.114
	10	.9853	5.7694	5.8554	89	00	.9998	57.290	57.299
	20	.9858	5.8708	5.9554		10	.9999	68.750	68.757
	30	.9863	5.9758	5.0589		20	.9999	85.940	85.946
	40	.9868	6.0844	6.1661		30	1.0000	114.589	114.593
	50	.9872	6.1970	6.2772		40	1.0000	171.885	171.888
81	00	.9877	6.3138	6.3925		50	1.0000	343.774	343.775
	10	.9881	6.4348	6.5121	90	00	1.0000	Infinite	Infinite
	20	.9886	6.5606	6.6363					

Approximate Measurement of Angles

(1) **The four fingers of the hand,** held at right angles to the arm and at arm's length from the eye, cover about 7 degrees; and an angle of 7 degrees corresponds to about 12.2 feet in 100 feet; or to 36.6 feet in 100 yards; or to 645 feet in a mile.

(2) **By means of a two-foot rule,** either on a drawing or between distant objects in the field. If the inner edges of a common two-foot rule be opened to the extent shown in the column of inches, they will be inclined to each other at the angles shown in the column of angles. Since an opening of ⅛ inch (up to 19 inches or about 105 degrees) corresponds to from about ½ degree to 1 degree, no great accuracy is to be expected, and beyond 105 degrees still less, for the liability to error then increases very rapidly as the opening becomes greater. Thus, the last ⅛ inch corresponds to about 12 degrees.

Angles for openings intermediate of those given may be calculated to the nearest minute or two, by simple proportion, up to 23 inches of opening, or about 147 degrees.

TABLE OF ANGLES CORRESPONDING TO OPENINGS OF A 2-FOOT RULE. (Original.) Trautwine.

Ins.	Deg.	Min.	Ins.	Deg.	Min.	Ins.	Deg.	Min.	Ins.	Deg.	Min.
¼	1	12	3½	16	46	6¾	32	40	10	49	15
	1	48		17	22		33	17		49	54
½	2	24	¾	17	59	7	33	54	¼	50	34
	3	00		18	35		34	33		51	13
¾	3	36	4	19	12	¼	35	10	½	51	53
	4	11		19	48		35	47		52	33
1	4	47	¼	20	24	½	36	25	¾	53	13
	5	23		21			37	3		53	53
¼	5	58	½	21	37	¾	37	41	11	54	34
	6	34		22	13		38	19		55	14
½	7	10	¾	22	50	8	38	57	¼	55	55
	7	46		23	27		39	35		56	35
¾	8	22	5	24	3	¼	40	13	½	57	16
	8	58		24	39		40	51		57	57
2	9	34	¼	25	16	½	41	29	¾	58	38
	10	10		25	53		42	7		59	19
¼	10	46	½	26	30	¾	42	46	12	60	00
	11	22		27	7		43	24		60	41
½	11	58	¾	27	44	9	44	3	¼	61	23
	12	34		28	21		44	42		62	5
¾	13	10	6	28	58	¼	45	21	½	62	47
	13	46		29	35		45	59		63	28
3	14	22	¼	30	11	½	46	38	¾	64	11
	14	58		30	49		47	17		64	53
¼	15	34	½	31	26	¾	47	56	13	65	35
	16	10		32	3		48	35		66	18

TABLES OF ANGLES CORRESPONDING TO OPENINGS OF A 2-FOOT RULE — (*Continued*)

Ins.	Deg.	Min.	Ins.	Deg.	Min.	Ins.	Deg.	Min.	Ins.	Deg.	Min.
13¼	67	1	16	83	37	18¾	102	45	21½	127	14
	67	44		84	26		103	43		128	35
½	68	28	¼	85	14	19	104	41	¾	129	59
	69	12		86	3		105	40		131	25
¾	69	55	½	86	52	¼	106	39	22	132	53
	70	38		87	41		107	40		134	24
14	71	22	¾	88	31	½	108	41	¼	135	58
	72	6		89	21		109	43		137	35
¼	72	51	17	90	12	¾	110	46	½	139	16
	73	36		91	3		111	49		141	1
½	74	21	¼	91	54	20	112	53	¾	142	51
	75	6		92	46		113	58		144	46
¾	75	51	½	93	38	¼	115	5	23	146	48
	76	36		94	31		116	12		148	58
15	77	22	¾	95	24	½	117	20	¼	151	17
	78	8		96	17		118	30		153	48
¼	78	54	18	97	11	¾	119	40	½	156	34
	79	40		98	5		120	52		159	43
½	80	27	¼	99	00	21	122	6	¾	163	27
	81	14		99	55		123	20		168	18
¾	82	2	½	100	51	¼	124	36	24	180	00
	82	49		101	48		125	54			

(3) **With the same table, using feet instead of inches.** — From any point measure 12 *feet* toward* each object and place marks. Measure the distance in *feet* between these marks. Suppose the first column in the table to be *feet* instead of inches. Then opposite the distance in *feet* will be the angle.

⅛ foot = 1.5 inches.

1 in. = .083 ft.	4 ins. = .333 ft.	7 ins. = .583 ft.	10 ins. = .833 ft.
2 ins. = .167 ft.	5 ins. = .416 ft.	8 ins. = .667 ft.	11 ins. = .917 ft.
3 ins. = .25 ft.	6 ins. = .5 ft.	9 ins. = .75 ft.	12 ins. = 1.0 ft.

(4) **Or, measure toward* each object** 100 or any other number of feet and place marks. Measure the distance in feet between the marks. Then

$$\text{Sine of } \textit{half} \text{ the angle} = \frac{\textit{half} \text{ the distance between the marks}}{\text{the distance measured toward one of the objects}}.$$

Find this sine in the table, etc.; take out the corresponding angle and multiply it by 2.

* If it is inconvenient to measure *toward* the objects, measure directly *from* them.

TAPERS PER FOOT AND CORRESPONDING ANGLES
Computed by E. M. Willson

Taper per foot	Included angle Deg.	Min.	Sec.	Angle with center line Deg.	Min.	Sec.	Taper per foot	Included angle Deg.	Min.	Sec.	Angle with center line Deg.	Min.	Sec.
1/64	0	4	28	0	2	14	2 3/8	11	18	10	5	39	5
1/32	0	8	58	0	4	29	2 1/2	11	53	36	5	56	48
1/16	0	17	54	0	8	57	2 5/8	12	29	2	6	14	31
3/32	0	26	52	0	13	26	2 3/4	13	4	24	6	32	12
1/8	0	35	48	0	17	54	2 7/8	13	39	42	6	49	51
5/32	0	44	44	0	22	22	3	14	15	0	7	7	30
3/16	0	53	44	0	26	52	3 1/8	14	50	14	7	25	7
7/32	1	2	34	0	31	17	3 1/4	15	25	24	7	42	42
1/4	1	11	36	0	35	48	3 3/8	16	0	34	8	0	17
9/32	1	20	30	0	40	15	3 1/2	16	35	40	8	17	50
5/16	1	29	30	0	44	45	3 5/8	17	10	40	8	35	20
11/32	1	38	22	0	49	11	3 3/4	17	45	40	8	52	50
3/8	1	47	24	0	53	42	3 7/8	18	20	34	9	10	17
13/32	1	56	24	0	58	12	4	18	55	28	9	27	44
7/16	2	5	18	1	2	39	4 1/8	19	30	18	9	45	9
15/32	2	14	16	1	7	8	4 1/4	20	5	2	10	2	31
1/2	2	23	10	1	11	35	4 3/8	20	39	44	10	19	52
17/32	2	32	4	1	16	2	4 1/2	21	14	2	10	37	1
9/16	2	41	4	1	20	32	4 5/8	21	48	54	10	54	27
19/32	2	50	2	1	25	1	4 3/4	22	23	22	11	11	41
5/8	2	59	42	1	29	51	4 7/8	22	57	48	11	28	54
21/32	3	7	56	1	33	58	5	23	32	12	11	46	6
11/16	3	16	54	1	38	27	5 1/8	24	6	28	12	3	14
23/32	3	25	50	1	42	55	5 1/4	24	40	42	12	20	21
3/4	3	34	44	1	47	22	5 3/8	25	14	48	12	37	24
25/32	3	43	44	1	51	52	5 1/2	25	48	48	12	54	24
13/16	3	52	38	1	56	19	5 5/8	26	22	52	13	11	26
27/32	4	1	36	2	0	48	5 3/4	26	56	46	13	28	23
7/8	4	10	32	2	5	16	5 7/8	27	30	34	13	45	17
29/32	4	19	34	2	9	47	6	28	4	2	14	2	1
15/16	4	28	24	2	14	12	6 1/8	28	37	58	14	18	59
31/32	4	37	20	2	18	40	6 1/4	29	11	34	14	35	47
1	4	46	18	2	23	9	6 3/8	29	45	18	14	52	39
1 1/16	5	4	12	2	32	6	6 1/2	30	18	26	15	9	13
1 1/8	5	21	44	2	40	52	6 5/8	30	51	48	15	25	54
1 3/16	5	39	54	2	49	57	6 3/4	31	25	2	15	42	31
1 1/4	5	57	48	2	58	54	6 7/8	31	58	10	15	59	5
1 5/16	6	15	38	3	7	49	7	32	31	12	16	15	36
1 3/8	6	33	26	3	16	43	7 1/8	33	4	8	16	32	4
1 7/16	6	51	20	3	25	40	7 1/4	33	36	40	16	48	20
1 1/2	7	9	10	3	34	35	7 3/8	34	9	50	17	4	55
1 9/16	7	26	58	3	43	29	7 1/2	34	42	30	17	21	15
1 5/8	7	44	48	3	52	24	7 5/8	35	15	2	17	37	31
1 11/16	8	2	38	4	1	19	7 3/4	35	47	32	17	53	46
1 3/4	8	20	26	4	10	13	7 7/8	36	19	54	18	9	57
1 13/16	8	38	16	4	19	8	8	36	52	12	18	26	6
1 7/8	8	56	2	4	28	1	8 1/8	37	24	22	18	42	11
1 15/16	9	13	50	4	36	55	8 1/4	37	56	26	18	58	13
2	9	31	36	4	45	48	8 3/8	38	28	16	19	14	8
2 1/8	10	7	10	5	3	35	8 1/2	39	0	16	19	30	8
2 1/4	10	42	42	5	21	21	8 5/8	39	31	52	19	45	56

TAPERS PER FOOT AND CORRESPONDING ANGLES — (*Continued*)

Taper per foot	Included angle			Angle with center line			Taper per foot	Included angle			Angle with center line		
	Deg.	Min.	Sec.	Deg.	Min.	Sec.		Deg.	Min.	Sec.	Deg.	Min.	Sec.
8¾	40	3	42	20	1	51	10⅜	46	45	24	23	22	42
8⅞	40	35	16	20	17	38	10½	47	15	32	23	37	46
9	41	6	44	20	33	22	10⅝	47	45	30	23	52	45
9⅛	41	38	28	20	49	14	10¾	48	15	24	24	7	42
9¼	42	9	18	21	4	39	10⅞	48	45	10	24	22	35
9⅜	42	40	26	21	20	13	11	49	14	48	24	37	24
9½	43	11	24	21	35	42	11⅛	49	44	20	24	52	10
9⅝	43	42	20	21	51	10	11¼	50	13	46	25	6	53
9¾	44	13	6	22	6	33	11⅜	50	43	4	25	21	32
9⅞	44	43	48	22	21	54	11½	51	12	14	25	36	7
10	45	14	22	22	37	11	11⅝	51	41	18	25	50	39
10⅛	45	44	52	22	52	26	11¾	52	10	16	26	5	8
10¼	46	15	46	23	7	53	11⅞	52	39	2	26	19	31

CHAPTER IV

DIFFERENT STANDARDS FOR WIRE GAUGES

Different Standards for Wire Gauges in Use in the United States

Dimensions of sizes in decimal parts of an inch

Number of wire gauge	H., S. & Co. "F. & G." steel music wire gauge	Screw gauge	U. S. standard for plate	American or Brown & Sharpe	Birmingham or English standard	Washburn & Moen Mfg. Co. Worcester, Mass.	Imperial wire gauge	Stubs' steel wire	Number of wire gauge
000000	......	......	.46875	......	.....	.....	.464	.....	000000
00000	......	......	.4375	......	.....	.....	.432	.....	00000
0000	......	......	.40625	.46	.454	.3938	.400	.....	0000
000	......	......	.375	.40964	.425	.3625	.372	.....	000
00	.0087	......	.34375	.3648	.38	.3310	.348	.....	00
0	.0093	.0578	.3125	.32486	.34	.3065	.324	.....	0
1	.0098	.0710	.28125	.2893	.3	.2830	.300	.227	1
2	.0106	.0842	.265625	.25763	.284	.2625	.276	.219	2
3	.0114	.0973	.25	.22942	.259	.2437	.252	.212	3
4	.0122	.1105	.234375	.20431	.238	.2253	.232	.207	4
5	.0138	.1236	.21875	.18194	.22	.2070	.212	.204	5
6	.0157	.1368	.203125	.16202	.203	.1920	.192	.201	6
7	.0177	.1500	.1875	.14428	.18	.1770	.176	.199	7
8	.0197	.1631	.171875	.12849	.165	.1620	.160	.197	8
9	.0216	.1763	.15625	.11443	.148	.1483	.144	.194	9
10	.0236	.1894	.140625	.10189	.134	.1350	.128	.191	10
11	.0260	.2026	.125	.090742	.12	.1205	.116	.188	11
12	.0283	.2158	.109375	.080808	.109	.1055	.104	.185	12
13	.0303	.2289	.09375	.071961	.095	.0915	.092	.182	13
14	.0323	.2421	.078125	.064084	.083	.0800	.080	.180	14
15	.0342	.2552	.0703125	.057068	.072	.0720	.072	.178	15
16	.0362	.2684	.0625	.05082	.065	.0625	.064	.175	16
17	.0382	.2816	.05625	.045257	.058	.0540	.056	.172	17
18	.04	.2947	.05	.040303	.049	.0475	.048	.168	18
19	.042	......	.04375	.03589	.042	.0410	.040	.164	19
20	.044	.3210	.0375	.031961	.035	.0348	.036	.161	20
21	.046	......	.034375	.028462	.032	.03175	.032	.157	21
22	.048	.3474	.03125	.025347	.028	.0286	.028	.155	22
23	.051	......	.028125	.022571	.025	.0258	.024	.153	23
24	.055	.3737	.025	.0201	.022	.0230	.022	.151	24
25	.059	......	.021875	.0179	.02	.0204	.020	.148	25
26	.063	.4000	.01875	.01594	.018	.0181	.018	.146	26
27	.067	......	.0171875	.014195	.016	.0173	.0164	.143	27
28	.071	.4263	.015625	.012641	.014	.0162	.0149	.139	28

Different Standards for Wire Gauges in Use in the United States — (*Continued*)

Number of wire gauge	H., S. & Co. "F. & G." steel music wire gauge	Screw gauge	U. S. standard for plate	American or Brown & Sharpe	Birmingham or English standard	Washburn & Moen Mfg. Co. Worcester, Mass.	Imperial wire gauge	Stubs' steel wire	Number of wire gauge
29	.074	......	.0140625	.011257	.013	.0150	.0136	.134	29
30	.078	.4520	0125	.010025	.012	.0141	.0124	.127	30
31	.082	......	.0109375	.008928	.01	.0132	.0116	.120	31
32	.086	......	.01015625	.00795	.009	.0128	.0108	.115	32
33	......	......	.009375	.00708	.008	.0118	.0100	.112	33
34	......	......	.00859375	.006304	.007	.0104	.0092	.110	34
35	......	......	.0078125	.005614	.005	.0095	.0084	.108	35
36	......	......	.00703125	.005	.004	.0090	.0076	.106	36
37	......	......	.006640625	.004453	.....	.....	.0068	.103	37
38	......	......	.00625	.003965	.....	.....	.0060	.101	38
39	......	......	....	.003531	.....	.....	.0052	.099	39
40	......	......	....	.003144	.....	.....	.0048	.097	40

Birmingham Gauge for Sheet Brass, Silver, Gold and all Metals except Steel and Iron

No.	Thickness, inch	No.	Thickness, inch	No.	Thickness, inch	No.	Thickness, inch	No.	Thickness, inch	No.	Thickness, inch
1	.004	7	.015	13	.036	19	.064	25	.095	31	.133
2	.005	8	.016	14	.041	20	.067	26	.103	32	.143
3	.008	9	.019	15	.047	21	.072	27	.113	33	.145
4	.010	10	.024	16	.051	22	.074	28	.120	34	.148
5	.012	11	.029	19	.057	23	.077	29	.124	35	.158
6	.013	12	.034	18	.061	24	.082	30	.126	36	.167

Gauges Generally used by Mills in the U. S. Rolling Sheet Iron. (Vary Slightly from Birmingham Gauge)

No.	Pounds per square foot	No.	Pounds per square foot	No.	Pounds per square foot	No.	Pounds per square foot
1	12.50	8	6.86	15	2.81	22	1.25
2	12.00	9	6.24	16	2.50	23	1.12
3	11.00	10	5.62	17	2.18	24	1.00
4	10.00	11	5.00	18	1.86	25	.90
5	8.75	12	4.38	19	1.70	26	.80
6	8.12	13	3.75	20	1.54	27	.72
7	7.50	14	3.12	21	1.40	28	.64

Band and Hoop Iron Weights per Lineal Foot

No. of gauge	Width in inches								
	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
6	.4231	.5078	.5924	.674	.762	.846	.931	1.016	1.10
8	.3581	.4296	.5013	.5729	.645	.716	.788	.859	.931
10	.2929	.3515	.4101	.4689	.527	.586	.645	.703	.762
11	......	......	......	......	.469	.521	.573	.625	.677
12	.2278	.2734	.3190	.3645	.41	.456	.501	.547	.592
13	......	......	......	......	.352	.391	.430	.469	.508
14	.1628	.1953	.2278	.2604	.293	.326	.358	.391	.423
15	......	......	......	......	.264	.293	.322	.352	.381
16	.1302	.1562	.1822	.2083	.234	.26	.286	.313	.339
17	.1139	.1367	.1595	.1822	.205	.229	.251	.273	.269
18	.0976	.1171	.1367	.1562	.176	.195	.215	.234	.254
19	.0895	.1074	.1253	.1432	.161	.179	.197	.215	.....
20	.0814	.0976	.1139	.1302	.146	.163	.179	.195	.....
21	.0731	.0877	.1023	.1169	......	......	......	......	.....
22	.0651	.0781	.0911	.1041	......	......	......	......	.....
23	.0588	.0705	.0822	.0939	......	......	......	......	.....

No. of gauge	Width in inches									
	1 3/4	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2	2 5/8	2 3/4	2 7/8
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
4	1.367	1.465	1.562	1.660	1.758	1.855	1.953	2.051	2.148	2.246
6	1.185	1.270	1.354	1.439	1.523	1.608	1.693	1.777	1.862	1.947
8	1.003	1.074	1.146	1.217	1.289	1.361	1.432	1.504	1.576	1.647
9	.914	.977	1.042	1.107	1.172	1.237	1.302	1.367	1.423	1.497
10	.820	.897	.938	.996	1.055	1.113	1.172	1.231	1.289	1.348
11	.729	.781	.833	.885	.938	.990	1.042	1.094	1.146	1.198
12	.638	.684	.729	.775	.820	.866	.911	.957	1.003	1.048
13	.547	.586	.625	.664	.703	.742	.781	.820	.859	.898
14	.456	.488	.521	.553	.586	.618	.651	.684	.716	.749
15	.410	.439	.469	.498	.527	.557	.586	.....	.....	.....
16	.365	.391	.417	.443	.469	.495	.521	.....	.....	.....
17	.319	.342	.365	.....	.....	.....	.....	.....	.....	.....
18	.273	.293	.313	.....	.....	.....	.....	.....	.....	.....

BAND AND HOOP IRON WEIGHTS PER LINEAL FOOT — (*Continued*)

No. of gauge	Width in inches									
	3	3¼	3½	3¾	4	4¼	4½	5	5½	6
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
4	2.344	2.539	2.734	2.930	3.125	3.321	3.516	3.906	4.297	4.688
5	2.188	2.370	2.552	2.734	2.917	3.099	3.281	3.646	4.011	4.375
6	2.031	2.201	2.370	2.539	2.708	2.878	3.047	3.385	3.724	4.063
7	1.875	2.031	2.188	2.344	2.500	2.656	2.813	3.125	3.437	3.750
8	1.719	1.862	2.005	2.148	2.292	2.435	2.578	2.864	3.151	3.438
9	1.563	1.693	1.823	1.953	2.083	2.214	2.344	2.604	2.865	3.125
10	1.406	1.523	1.641	1.758	1.875	1.992	2.109	2.344	2.578	2.813
11	1.250	1.354	1.458	1.563	1.667	1.771	1.875	2.083	2.292	2.500
12	1.094	1.185	1.276	1.367	1.458	1.549	1.641	1.823	2.005	2.188
13	.938	1.016	1.094	.....	.....	.....	.....	.....	.....	.....
14	.781	.846	.911	.....	.....	.....	.....	.....	.....	.....

Weights of Flat Rolled Iron per Lineal Foot

For thicknesses from 1/16 inch to 2 inches and widths from 1 inch to 12¾ inches.

Iron weighing 480 pounds per cubic foot.

Thickness in inches	1 inch	1¼ inches	1½ inches	1¾ inches	2 inches	2¼ inches	2½ inches	3¾ inches	12 inches
1/16	.208	.260	.313	.365	.417	.469	.521	.573	2.50
⅛	.417	.521	.625	.729	.833	.938	1.04	1.15	5.00
3/16	.625	.781	.938	1.09	1.25	1.41	1.56	1.72	7.50
¼	.833	1.04	1.25	1.46	1.67	1.88	2.08	2.29	10.00
5/16	1.04	1.30	1.56	1.82	2.08	2.34	2.60	2.86	12.50
⅜	1.25	1.56	1.88	2.19	2.50	2.81	3.13	3.44	15.00
7/16	1.46	1.82	2.19	2.55	2.92	3.28	3.65	4.01	17.50
½	1.67	2.08	2.50	2.92	3.33	3.75	4.17	4.58	20.00
9/16	1.88	2.34	2.81	3.28	3.75	4.22	4.69	5.16	22.50
⅝	2.08	2.60	3.31	3.65	4.17	4.69	5.21	5.73	25.00
11/16	2.29	2.86	3.44	4.01	4.58	5.16	5.73	6.30	27.50
¾	2.50	3.13	3.75	4.38	5.00	5.63	6.25	6.88	30.00
13/16	2.71	3.39	4.06	4.74	5.42	6.09	6.77	7.45	32.50
⅞	2.92	3.65	4.38	5.10	5.83	6.56	7.29	8.02	35.00
15/16	3.13	3.91	4.69	5.47	6.25	7.03	7.81	8.59	37.50
1	3.33	4.17	5.00	5.83	6.67	7.50	8.33	9.17	40.00
1 1/16	3.54	4.43	5.31	6.20	7.08	7.97	8.85	9.74	42.50
1⅛	3.75	4.69	5.63	6.56	7.50	8.44	9.38	10.31	45.00
1 3/16	3.96	4.95	5.94	6.93	7.92	8.91	9.90	10.89	47.50
1¼	4.17	5.21	6.25	7.29	8.33	9.38	10.42	11.46	50.00
1 5/16	4.37	5.47	6.56	7.66	8.75	9.84	10.94	12.03	52.50
1⅜	4.58	5.73	6.88	8.02	9.17	10.31	11.46	12.60	55.00
1 7/16	4.79	5.99	7.19	8.39	9.58	10.78	11.98	13.18	57.50
1½	5.00	6.25	7.50	8.75	10.00	11.25	12.50	13.75	60.00
1 9/16	5.21	6.51	7.81	9.11	10.42	11.72	13.02	14.32	62.50
1⅝	5.42	6.77	8.13	9.48	10.83	12.19	13.54	14.90	65.00
1 11/16	5.63	7.03	8.44	9.84	11.25	12.66	14.06	15.47	67.50
1¾	6.83	7.29	8.75	10.21	11.67	13.13	14.58	16.04	70.00
1 13/16	6.04	7.55	9.06	10.57	12.08	13.59	15.10	16.61	72.50
1⅞	6.25	7.81	9.38	10.94	12.50	14.06	15.63	17.19	75.00
1 15/16	6.46	8.07	9.69	11.30	12.92	14.53	16.15	17.76	77.50
2	6.67	8.33	10.00	11.67	13.33	15.00	16.67	18.33	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAL FOOT — (*Continued*)

Thickness in inches	3 inches	3¼ inches	3½ inches	3¾ inches	4 inches	4¼ inches	4½ inches	4¾ inches	12 inches
1/16	.625	.677	.729	.781	.833	.885	.938	.990	2.50
⅛	1.25	1.35	1.46	1.56	1.67	1.77	1.88	1.98	5.00
3/16	1.88	2.03	2.19	2.34	2.50	2.66	2.81	2.97	7.50
¼	2.50	2.71	2.92	3.13	3.33	3.54	3.75	3.96	10.00
5/16	3.13	3.39	3.65	3.91	4.17	4.43	4.69	4.95	12.50
⅜	3.75	4.06	4.38	4.69	5.00	5.31	5.63	5.94	15.00
7/16	4.38	4.74	5.10	5.47	5.83	6.20	6.56	6.93	17.50
½	5.00	5.42	5.83	6.25	6.67	7.08	7.50	7.92	20.00
9/16	5.63	6.09	6.56	7.03	7.50	7.97	8.44	8.91	22.50
⅝	6.25	6.77	7.29	7.81	8.33	8.85	9.38	9.90	25.00
11/16	6.88	7.45	8.02	8.59	9.17	9.74	10.31	10.89	27.50
¾	7.50	8.13	8.75	9.38	10.00	10.63	11.25	11.88	30.00
13/16	8.13	8.80	9.48	10.16	10.83	11.51	12.19	12.86	32.50
⅞	8.75	9.48	10.21	10.94	11.67	12.40	13.13	13.85	35.00
15/16	9.38	10.16	10.94	11.72	12.50	13.28	14.06	14.84	37.50
1	10.00	10.83	11.67	12.50	13.33	14.17	15.00	15.83	40.00
1 1/16	10.63	11.51	12.40	13.28	14.17	15.05	15.94	16.82	42.50
1⅛	11.25	12.19	13.13	14.06	15.00	15.94	16.88	17.81	45.00
1 3/16	11.88	12.86	13.85	14.84	15.83	16.82	17.81	18.80	47.50
1¼	12.50	13.54	14.58	15.63	16.67	17.71	18.75	19.79	50.00
1 5/16	13.13	14.22	15.31	16.41	17.50	18.59	19.69	20.78	52.50
1⅜	13.75	14.90	16.04	17.19	18.33	19.48	20.63	21.77	55.00
1 7/16	14.38	15.57	16.77	17.97	19.17	20.36	21.56	22.76	57.50
1½	15.00	16.25	17.50	18.75	20.00	21.25	22.50	23.75	60.00
1 9/16	15.63	16.93	18.23	19.53	20.83	22.14	23.44	24.74	62.50
1⅝	16.25	17.60	18.96	20.31	21.67	23.02	24.38	25.73	65.00
1 11/16	16.88	18.28	19.69	21.09	22.50	23.91	25.31	26.72	67.50
1¾	17.50	18.96	20.42	21.88	23.33	24.79	26.25	27.71	70.00
1 13/16	18.13	19.64	21.15	22.66	24.17	25.68	27.19	28.70	72.50
1⅞	18.75	20.31	21.88	23.44	25.00	26.56	28.13	29.69	75.00
1 15/16	19.38	20.99	22.60	24.22	25.83	27.45	29.06	30.68	77.50
2	20.00	21.67	23.33	25.00	26.67	28.33	30.00	31.67	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAL FOOT — (*Continued*).

Thickness in inches	5 inches	5¼ inches	5½ inches	5¾ inches	6 inches	6¼ inches	6½ inches	6¾ inches	12 inches
1/16	1.04	1.09	1.15	1.20	1.25	1.30	1.35	1.41	2.50
⅛	2.08	2.19	2.29	2.40	2.50	2.60	2.71	2.81	5.00
3/16	3.13	3.28	3.44	3.59	3.75	3.91	4.06	4.22	7.50
¼	4.17	4.38	4.58	4.79	5.00	5.21	5.42	5.63	10.00
5/16	5.21	5.47	5.73	5.99	6.25	6.51	6.77	7.03	12.50
⅜	6.25	6.56	6.88	7.19	7.50	7.81	8.13	8.44	15.00
7/16	7.29	7.66	8.02	8.39	8.75	9.11	9.48	9.84	17.50
½	8.33	8.75	9.17	9.58	10.00	10.42	10.83	11.25	20.00
9/16	9.38	9.84	10.31	10.78	11.25	11.72	12.19	12.66	22.50
⅝	10.42	10.94	11.46	11.98	12.50	13.02	13.54	14.06	25.00
11/16	11.46	12.03	12.60	13.18	13.75	14.32	14.90	15.47	27.50
¾	12.50	13.13	13.75	14.38	15.00	15.63	16.25	16.88	30.00
13/16	13.54	14.22	14.90	15.57	16.25	16.93	17.60	18.28	32.50
⅞	14.58	15.31	16.04	16.77	17.50	18.23	18.96	19.69	35.00
15/16	15.63	16.41	17.19	17.97	18.75	19.53	20.31	21.09	37.50
1	16.67	17.50	18.33	19.17	20.00	20.83	21.67	22.50	40.00
1 1/16	17.71	18.59	19.48	20.36	21.25	22.14	23.02	23.91	42.50
1⅛	18.75	19.69	20.63	21.56	22.50	23.44	24.38	25.31	45.00
1 3/16	19.79	20.78	21.77	22.76	23.75	24.74	25.73	26.72	47.50
1¼	20.83	21.88	22.92	23.96	25.00	26.04	27.08	28.13	50.00
1 5/16	21.88	22.97	24.06	25.16	26.25	27.34	28.44	29.53	52.50
1⅜	22.92	24.06	25.21	26.35	27.50	28.65	29.79	30.94	55.00
1 7/16	23.96	25.16	26.35	27.55	28.75	29.95	31.15	32.34	57.50
1½	25.00	26.25	27.50	28.75	30.00	31.25	32.50	33.75	60.00
1 9/16	26.04	27.34	28.65	29.95	31.25	32.55	33.85	35.16	62.50
1⅝	27.08	28.44	29.79	31.15	32.50	33.85	35.21	36.56	65.00
1 11/16	28.13	29.53	30.94	32.34	33.75	35.16	36.56	37.97	67.50
1¾	29.17	30.63	32.08	33.54	35.00	36.46	37.92	39.38	70.00
1 13/16	30.21	31.72	33.23	34.74	36.25	37.76	39.27	40.78	72.50
1⅞	31.25	32.81	34.38	35.94	37.50	39.06	40.63	42.19	75.00
1 15/16	32.29	33.91	35.52	37.14	38.75	40.36	41.98	43.59	77.50
2	33.33	35.00	36.67	38.33	40.00	41.67	43.33	45.00	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAL FOOT — (*Continued*)

Thickness in inches	7 inches	7¼ inches	7½ inches	7¾ inches	8 inches	8¼ inches	8½ inches	8¾ inches	12 inches
1/16	1.46	1.51	1.56	1.61	1.67	1.72	1.77	1.82	2.50
⅛	2.92	3.02	3.13	3.23	3.33	3.44	3.54	3.65	5.00
3/16	4.38	4.53	4.69	4.84	5.00	5.16	5.31	5.47	7.50
¼	5.83	6.04	6.25	6.46	6.67	6.88	7.08	7.29	10.00
5/16	7.29	7.55	7.81	8.07	8.33	8.59	8.85	9.11	12.50
⅜	8.75	9.06	9.38	9.69	10.00	10.31	10.63	10.94	15.00
7/16	10.21	10.57	10.94	11.30	11.67	12.03	12.40	12.76	17.50
½	11.67	12.08	12.50	12.92	13.33	13.75	14.17	14.58	20.00
9/16	13.13	13.59	14.06	14.53	15.00	15.47	15.94	16.41	22.50
⅝	14.58	15.10	15.63	16.15	16.67	17.19	17.71	18.23	25.00
11/16	16.04	16.61	17.19	17.76	18.33	18.91	19.48	20.05	27.50
¾	17.50	18.13	18.75	19.38	20.00	20.63	21.25	21.88	30.00
13/16	18.96	19.64	20.31	20.99	21.67	22.24	23.02	23.70	32.50
⅞	20.42	21.15	21.88	22.60	23.33	24.06	24.79	25.52	35.00
15/16	21.88	22.66	23.44	24.22	25.00	25.78	26.56	27.34	37.50
1	23.33	24.17	25.00	25.83	26.67	27.50	28.33	29.17	40.00
1 1/16	24.79	25.68	26.56	27.45	28.33	29.22	30.10	30.99	42.50
1⅛	26.25	27.19	28.13	29.06	30.00	30.94	31.88	32.81	45.00
1 3/16	27.71	28.70	29.69	30.68	31.67	32.66	33.65	34.64	47.50
1¼	29.17	30.21	31.25	32.29	33.33	34.38	35.42	36.46	50.00
1 5/16	30.62	31.72	32.81	33.91	35.00	36.09	37.19	38.28	52.50
1⅜	32.08	33.23	34.38	35.52	36.67	37.81	38.96	40.10	55.00
1 7/16	33.54	34.74	35.94	37.14	38.33	39.53	40.73	41.93	57.50
1½	35.00	36.25	37.50	38.75	40.00	41.25	42.50	43.75	60.00
1 9/16	36.46	37.76	39.06	40.36	41.67	42.97	44.27	45.57	62.50
1⅝	37.92	39.27	40.63	41.98	43.33	44.69	46.04	47.40	65.00
1 11/16	39.38	40.78	42.19	43.59	45.00	46.41	47.81	49.22	67.50
1¾	40.83	42.29	43.75	45.21	46.67	48.13	49.58	51.04	70.00
1 13/16	42.29	43.80	45.31	46.82	48.33	49.84	51.35	52.86	72.50
1⅞	43.75	45.31	46.88	48.44	50.00	51.56	53.13	54.69	75.00
1 15/16	45.21	46.82	48.44	50.05	51.67	53.28	54.90	56.51	77.50
2	46.67	48.33	50.00	51.67	53.33	55.00	56.67	58.33	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAL FOOT — (*Continued*)

Thickness in inches	9 inches	9¼ inches	9½ inches	9¾ inches	10 inches	10¼ inches	10½ inches	10¾ inches	12 inches
1/16	1.88	1.93	1.98	2.03	2.08	2.14	2.19	2.24	2.50
⅛	3.75	3.85	3.96	4.06	4.17	4.27	4.38	4.48	5.00
3/16	5.63	5.78	5.94	6.09	6.25	6.41	6.56	6.72	7.50
¼	7.50	7.71	7.92	8.13	8.33	8.54	8.75	8.96	10.00
5/16	9.38	9.64	9.90	10.16	10.42	10.68	10.94	11.20	12.50
⅜	11.25	11.56	11.88	12.19	12.50	12.81	13.13	13.44	15.00
7/16	13.13	13.49	13.85	14.22	14.58	14.95	15.31	15.68	17.50
½	15.00	15.42	15.83	16.25	16.67	17.08	17.50	17.92	20.00
9/16	16.88	17.34	17.81	18.28	18.75	19.22	19.69	20.16	22.50
⅝	18.75	19.27	19.79	20.31	20.83	21.35	21.88	22.40	25.00
11/16	20.63	21.20	21.77	22.34	22.92	23.49	24.06	24.64	27.50
¾	22.50	23.13	23.75	24.38	25.00	25.62	26.25	26.88	30.00
13/16	24.38	25.05	25.73	26.41	27.08	27.76	28.44	29.11	32.50
⅞	26.25	26.98	27.71	28.44	29.17	29.90	30.63	31.35	35.00
15/16	28.13	28.91	29.69	30.47	31.25	32.03	32.81	33.59	37.50
1	30.00	30.83	31.67	32.50	33.33	34.17	35.00	35.83	40.00
1 1/16	31.88	32.76	33.65	34.53	35.42	36.30	37.19	38.07	42.50
1⅛	33.75	34.69	35.63	36.56	37.50	38.44	39.38	40.31	45.00
1 3/16	35.63	36.61	37.60	38.59	39.58	40.57	41.56	42.55	47.50
1¼	37.50	38.54	39.58	40.63	41.67	42.71	43.75	44.79	50.00
1 5/16	39.38	40.47	41.56	42.66	43.75	44.84	45.94	47.03	52.50
1⅜	41.25	42.40	43.54	44.69	45.83	46.98	48.13	49.27	55.00
1 7/16	43.13	44.32	45.52	46.72	47.92	49.11	50.31	51.51	57.50
1½	45.00	46.25	47.50	48.75	50.00	51.25	52.50	53.75	60.00
1 9/16	46.88	48.18	49.48	50.78	52.08	53.39	54.69	55.99	62.50
1⅝	48.75	50.10	51.46	52.81	54.17	55.52	56.88	58.23	65.00
1 11/16	50.63	52.03	53.44	54.84	56.25	57.66	59.06	60.47	67.50
1¾	52.50	53.96	55.42	56.88	58.33	59.79	61.25	62.71	70.00
1 13/16	54.38	55.89	57.40	58.91	60.42	61.93	63.44	64.95	72.50
1⅞	56.25	57.81	59.38	60.94	62.50	64.06	65.63	67.19	75.00
1 15/16	58.13	59.74	61.35	62.97	64.58	66.20	67.81	69.43	77.50
2	60.00	61.67	63.33	65.00	66.67	68.33	70.00	71.67	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAL FOOT — (*Continued*)

Thickness in inches	11 inches	11¼ inches	11½ inches	11¾ inches	12 inches	12¼ inches	12½ inches	12¾ inches
1/16	2.29	2.34	2.40	2.45	2.50	2.55	2.60	2.66
⅛	4.58	4.69	4.79	4.90	5.00	5.10	5.21	5.31
3/16	6.88	7.03	7.19	7.34	7.50	7.66	7.81	7.97
¼	9.17	9.38	9.58	9.79	10.00	10.21	10.42	10.63
5/16	11.46	11.72	11.98	12.24	12.50	12.76	13.02	13.28
⅜	13.75	14.06	14.38	14.69	15.00	15.31	15.63	15.94
7/16	16.04	16.41	16.77	17.14	17.50	17.86	18.23	18.59
½	18.33	18.75	19.17	19.58	20.00	20.42	20.83	21.25
9/16	20.63	21.09	21.56	21.94	22.50	22.97	23.44	23.91
⅝	22.92	23.44	23.96	24.48	25.00	25.52	26.04	26.56
11/16	25.21	25.78	26.35	26.93	27.50	28.07	28.65	29.22
¾	27.50	28.13	28.75	29.38	30.00	30.63	31.25	31.88
13/16	29.79	30.47	31.15	31.82	32.50	33.18	33.85	34.53
⅞	32.08	32.81	33.54	34.27	35.00	35.73	36.46	37.19
15/16	34.38	35.16	35.94	36.72	37.50	38.28	39.06	39.84
1	36.67	37.50	38.33	39.17	40.00	40.83	41.67	42.50
1 1/16	38.96	39.84	40.73	41.61	42.50	43.39	44.27	45.16
1⅛	41.25	42.19	43.13	44.06	45.00	45.94	46.88	47.81
1 3/16	43.54	44.53	45.52	46.51	47.50	48.49	49.48	50.47
1¼	45.83	46.88	47.92	48.96	50.00	51.04	52.08	53.13
1 5/16	48.13	49.22	50.31	51.41	52.50	53.59	54.69	55.78
1⅜	50.42	51.56	52.71	53.85	55.00	56.15	57.29	58.44
1 7/16	52.71	53.91	55.10	56.30	57.50	58.70	59.90	61.09
1½	55.00	56.25	57.50	58.75	60.00	61.25	62.50	63.75
1 9/16	57.29	58.59	59.90	61.20	62.50	63.80	65.10	66.41
1⅝	59.98	60.94	62.29	63.65	65.00	66.35	67.71	69.06
1 11/16	61.88	63.28	64.69	66.09	67.50	68.91	70.31	71.72
1¾	64.17	65.63	67.08	68.54	70.00	71.46	72.92	74.38
1 13/16	66.46	67.97	69.48	70.99	72.50	74.01	75.52	77.03
1⅞	68.75	70.31	71.88	73.44	75.00	76.56	78.13	79.69
1 15/16	71.04	72.66	74.27	75.89	77.50	79.11	80 73	82.34
2	73.33	75.00	76.67	78.33	80.00	81.67	83.33	85.00

The weights for 12-inch width are repeated on each page to facilitate making the additions necessary to obtain the weights of plates wider than 12 inches. Thus, to find the weight of 15¼″×⅞″, add the weights to be found in the same line for 3¼×⅞ and 12×⅞=9.48 + 35.00 = 44.48 pounds.

Areas of Flat Rolled Iron

For thicknesses from 1/16 inch to 2 inches and widths from 1 inch to 12¾ inches.

Thickness in inches	1 inch	1¼ inches	1½ inches	1¾ inches	2 inches	2¼ inches	2½ inches	2¾ inches	12 inches
1/16	.063	.078	.094	.109	.125	.141	.156	.172	.750
⅛	.125	.156	.188	.219	.250	.281	.313	.344	1.50
3/16	.188	.234	.281	.328	.375	.422	.469	.516	2.25
¼	.250	.313	.375	.438	.500	.563	.625	.688	3.00
5/16	.313	.391	.469	.547	.625	.703	.781	.859	3.75
⅜	.375	.469	.563	.656	.750	.844	.938	1.03	4.50
7/16	.438	.547	.656	.766	.875	.984	1.09	1.20	5.25
½	.500	.625	.750	.875	1.00	1.13	1.25	1.38	6.00
9/16	.563	.703	.844	.984	1.13	1.27	1.41	1.55	6.75
⅝	.625	.781	.938	1.09	1.25	1.41	1.56	1.72	7.50
11/16	.688	.859	1.03	1.20	1.38	1.55	1.72	1.89	8.25
¾	.750	.938	1.13	1.31	1.50	1.69	1.88	2.06	9.00
13/16	.813	1.02	1.22	1.42	1.63	1.83	2.03	2.23	9.75
⅞	.875	1.09	1.31	1.53	1.75	1.97	2.19	2.41	10.50
15/16	.938	1.17	1.41	1.64	1.88	2.11	2.34	2.58	11.25
1	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	12.00
1 1/16	1.06	1.33	1.59	1.86	2.13	2.39	2.66	2.92	12.75
1⅛	1.13	1.41	1.69	1.97	2.25	2.53	2.81	3.09	13.50
1 3/16	1.19	1.48	1.78	2.08	2.38	2.67	2.97	3.27	14.25
1¼	1.25	1.56	1.88	2.19	2.50	2.81	3.13	3.44	15.00
1 5/16	1.31	1.64	1.97	2.30	2.63	2.95	3.28	3.61	15.75
1⅜	1.38	1.72	2.06	2.41	2.75	3.09	3.44	3.78	16.50
1 7/16	1.44	1.80	2.16	2.52	2.88	3.23	3.59	3.95	17.25
1½	1.50	1.88	2.25	2.63	3.00	3.38	3.75	4.13	18.00
1 9/16	1.56	1.95	2.34	2.73	3.13	3.52	3.91	4.30	18.75
1⅝	1.63	2.03	2.44	2.84	3.25	3.66	4.06	4.47	19.50
1 11/16	1.69	2.11	2.53	2.95	3.38	3.80	4.22	4.64	20.25
1¾	1.75	2.19	2.63	3.06	3.50	3.94	4.38	4.81	21.00
1 13/16	1.81	2.27	2.72	3.17	3.63	4.08	4.53	4.98	21.75
1⅞	1.88	2.34	2.81	3.28	3.75	4.22	4.69	5.16	22.50
1 15/16	1.94	2.42	2.91	3.39	3.88	4.36	4.84	5.33	23.25
2	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	24.00

Weights of Flat Rolled Steel per Lineal Foot

For thicknesses from 3/16 inch to 2 inches and widths from 1 inch to 12¾ inches.

Thickness in inches	1 inch	1¼ inches	1½ inches	1¾ inches	2 inches	2¼ inches	2½ inches	2¾ inches	12 inches
3/16	.638	.797	.957	1.11	1.28	1.44	1.59	1.75	7.65
¼	.850	1.06	1.28	1.49	1.70	1.91	2.12	2.34	10.20
5/16	1.06	1.33	1.59	1.86	2.12	2.39	2.65	2.92	12.75
⅜	1.28	1.59	1.92	2.23	2.55	2.87	3.19	3.51	15.30
7/16	1.49	1.86	2.23	2.60	2.98	3.35	3.72	4.09	17.85
½	1.70	2.12	2.55	2.98	3.40	3.83	4.25	4.67	20.40
9/16	1.92	2.39	2.87	3.35	3.83	4.30	4.78	5.26	22.95
⅝	2.12	2.65	3.19	3.72	4.25	4.78	5.31	5.84	25.50
11/16	2.34	2.92	3.51	4.09	4.67	5.26	5.84	6.43	28.05
¾	2.55	3.19	3.83	4.47	5.10	5.75	6.38	7.02	30.60
13/16	2.76	3.45	4.14	4.84	5.53	6.21	6.90	7.60	33.15
⅞	2.98	3.72	4.47	5.20	5.95	6.69	7.44	8.18	35.70
15/16	3.19	3.99	4.78	5.58	6.38	7.18	7.97	8.77	38.25
1	3.40	4.25	5.10	5.95	6.80	7.65	8.50	9.35	40.80
1 1/16	3.61	4.52	5.42	6.32	7.22	8.13	9.03	9.93	43.35
1⅛	3.83	4.78	5.74	6.70	7.65	8.61	9.57	10.52	45.90
1 3/16	4.04	5.05	6.06	7.07	8.08	9.09	10.10	11.11	48.45
1¼	4.25	5.31	6.38	7.44	8.50	9.57	10.63	11.69	51.00
1 5/16	4.46	5.58	6.69	7.81	8.93	10.04	11.16	12.27	53.55
1⅜	4.67	5.84	7.02	8.18	9.35	10.52	11.69	12.85	56.10
1 7/16	4.89	6.11	7.34	8.56	9.78	11.00	12.22	13.44	58.65
1½	5.10	6.38	7.65	8.93	10.20	11.48	12.75	14.03	61.20
1 9/16	5.32	6.64	7.97	9.30	10.63	11.95	13.28	14.61	63.75
1⅝	5.52	6.90	8.29	9.67	11.05	12.43	13.81	15.19	66.30
1 11/16	5.74	7.17	8.61	10.04	11.47	12.91	14.34	15.78	68.85
1¾	5.95	7.44	8.93	10.42	11.90	13.40	14.88	16.37	71.40
1 13/16	6.16	7.70	9.24	10.79	12.33	13.86	15.40	16.95	73.95
1⅞	6.38	7.97	9.57	11.15	12.75	14.34	15.94	17.53	76.50
1 15/16	6.59	8.24	9.88	11.53	13.18	14.83	16.47	18.12	79.05
2	6.80	8.50	10.20	11.90	13.60	15.30	17.00	18.70	81.60

WEIGHTS OF FLAT ROLLED STEEL PER LINEAL FOOT — (*Continued*)

Thick-ness in inches	3 inches	3¼ inches	3½ inches	3¾ inches	4 inches	4¼ inches	4½ inches	4¾ inches	12 inches
3/16	1.91	2.07	2.23	2.39	2.55	2.71	2.87	3.03	7.65
¼	2.55	2.76	2.98	3.19	3.40	3.61	3.83	4.04	10.20
5/16	3.19	3.45	3.72	3.99	4.25	4.52	4.78	5.05	12.75
⅜	3.83	4.15	4.47	4.78	5.10	5.42	5.74	6.06	15.30
7/16	4.46	4.83	5.20	5.58	5.95	6.32	6.70	7.07	17.85
½	5.10	5.53	5.95	6.38	6.80	7.22	7.65	8.08	20.40
9/16	5.74	6.22	6.70	7.17	7.65	8.13	8.61	9.09	22.95
⅝	6.38	6.91	7.44	7.97	8.50	9.03	9.57	10.10	25.50
11/16	7.02	7.60	8.18	8.76	9.35	9.93	10.52	11.11	28.05
¾	7.65	8.29	8.93	9.57	10.20	10.84	11.48	12.12	30.60
13/16	8.29	8.98	9.67	10.36	11.05	11.74	12.43	13.12	33.15
⅞	8.93	9.67	10.41	11.16	11.90	12.65	13.39	14.13	35.70
15/16	9.57	10.36	11.16	11.95	12.75	13.55	14.34	15.14	38.25
1	10.20	11.05	11.90	12.75	13.60	14.45	15.30	16.15	40.80
1 1/16	10.84	11.74	12.65	13.55	14.45	15.35	16.26	17.16	43.35
1⅛	11.48	12.43	13.39	14.34	15.30	16.26	17.22	18.17	45.90
1 3/16	12.12	13.12	14.13	15.14	16.15	17.16	18.17	19.18	48.45
1¼	12.75	13.81	14.87	15.94	17.00	18.06	19.13	20.19	51.00
1 5/16	13.39	14.50	15.62	16.74	17.85	18.96	20.08	21.20	53.55
1⅜	14.03	15.20	16.36	17.53	18.70	19.87	21.04	22.21	56.10
1 7/16	14 66	15.88	17.10	18.33	19.55	20.77	21.99	23.22	58.65
1½	15.30	16.58	17.85	19.13	20.40	21.68	22.95	24.23	61.20
1 9/16	15.94	17.27	18.60	19.92	21.25	22.58	23.91	25.24	63.75
1⅝	16.58	17.96	19.34	20.72	22.10	23.48	24.87	26.25	66.30
1 11/16	17.22	18.65	20.08	21.51	22.95	24.38	25.82	27.26	68.85
1¾	17.85	19.34	20.83	22.32	23.80	25.29	26.78	28.27	71.40
1 13/16	18.49	20.03	21.57	23.11	24.65	26.19	27.73	29.27	73.95
1⅞	19.13	20.72	22.31	23.91	25.50	27.10	28.69	30.28	76.50
1 15/16	19.77	21.41	23.06	24.70	26.35	28.00	29.64	31.29	79.05
2	20.40	22.10	23.80	25.50	27.20	28.90	30.60	32.30	81.60

WEIGHTS OF FLAT ROLLED STEEL PER LINEAL FOOT — (*Continued*)

Thickness in inches	5 inches	5¼ inches	5½ inches	5¾ inches	6 inches	6¼ inches	6½ inches	6¾ inches	12 inches
3/16	3.19	3.35	3.51	3.67	3.83	3.99	4.14	4.30	7.65
¼	4.25	4.46	4.67	4.89	5.10	5.31	5.53	5.74	10.20
5/16	5.31	5.58	5.84	6.11	6.38	6.64	6.90	7.17	12.75
⅜	6.38	6.69	7.02	7.34	7.65	7.97	8.29	8.61	15.30
7/16	7.44	7.81	8.18	8.56	8.93	9.29	9.67	10.04	17.85
½	8.50	8.93	9.35	9.77	10.20	10.63	11.05	11.48	20.40
9/16	9.57	10.04	10.52	11.00	11.48	11.95	12.43	12.91	22.95
⅝	10.63	11.16	11.69	12.22	12.75	13.28	13.81	14.34	25.50
11/16	11.69	12.27	12.85	13.44	14.03	14.61	15.20	15.78	28.05
¾	12.75	13.39	14.03	14.67	15.30	15.94	16.58	17.22	30.60
13/16	13.81	14.50	15.19	15.88	16.58	17.27	17.95	18.65	33.15
⅞	14.87	15.62	16.36	17.10	17.85	18.60	19.34	20.08	35.70
15/16	15.94	16.74	17.53	18.33	19.13	19.92	20.72	21.51	38.25
1	17.00	17.85	18.70	19.55	20.40	21.25	22.10	22.95	40.80
1 1/16	18.06	18.96	19.87	20.77	21.68	22.58	23.48	24.39	43.35
1⅛	19.13	20.08	21.04	21.99	22.95	23.91	24.87	25.82	45.90
1 3/16	20.19	21.20	22.21	23.22	24.23	25.23	26.24	27.25	48.45
1¼	21.25	22.32	23.38	24.44	25.50	26.56	27.62	28.69	51.00
1 5/16	22.32	23.43	24.54	25.66	26.78	27.90	29.01	30.12	53.55
1⅜	23.38	24.54	25.71	26.88	28.05	29.22	30.39	31.56	56.10
1 7/16	24.44	25.66	26.88	28.10	29.33	30.55	31.77	32.99	58.65
1½	25.50	26.78	28.05	29.33	30.60	31.88	33.15	34.43	61.20
1 9/16	26.57	27.89	29.22	30.55	31.88	33.20	34.53	35.86	63.75
1⅝	27.63	29.01	30.39	31.77	33.15	34.53	35.91	37.29	66.30
1 11/16	28.69	30.12	31.55	32.99	34.43	35.86	37.30	38.73	68.85
1¾	29.75	31.24	32.73	34.22	35.70	37.19	38.68	40.17	71.40
1 13/16	30.81	32.35	33.89	35.43	36.98	38.52	40.05	41.60	73.95
1⅞	31.87	33.47	35.06	36.65	38.25	39.85	41.44	43.03	76.50
1 15/16	32.94	34.59	36.23	37.88	39.53	41.17	42.82	44.46	79.05
2	34.00	35.70	37.40	39.10	40.80	42.50	44.20	45.90	81.60

WEIGHTS OF FLAT ROLLED STEEL PER LINEAL FOOT — (*Continued*)

Thickness in inches	7 inches	7¼ inches	7½ inches	7¾ inches	8 inches	8¼ inches	8½ inches	8¾ inches	12 inches
3/16	4.46	4.62	4.78	4.94	5.10	5.26	5.42	5.58	7.65
¼	5.95	6.16	6.36	6.58	6.80	7.01	7.22	7.43	10.20
5/16	7.44	7.70	7.97	8.23	8.50	8.76	9.03	9.29	12.75
⅜	8.93	9.25	9.57	9.88	10.20	10.52	10.84	11.16	15.30
7/16	10.41	10.78	11.16	11.53	11.90	12.27	12.64	13.02	17.85
½	11.90	12.32	12 75	13.18	13.60	14.03	14.44	14.87	20.40
9/16	13.39	13.86	14.34	14.82	15.30	15.78	16.27	16.74	22.95
⅝	14.87	15.40	15.94	16.47	17.00	17.53	18.06	18.59	25.50
11/16	16.36	16.94	17.53	18.12	18.70	19.28	19.86	20.45	28.05
¾	17.85	18.49	19.13	19.77	20.40	21.04	21.68	22.32	30.60
13/16	19.34	20.03	20.72	21.41	22.10	22.79	23.48	24.17	33.15
⅞	20.83	21.57	22.32	23.05	23.80	24.55	25.30	26.04	35.70
15/16	22.32	23.11	23.91	24.70	25.50	26.30	27.10	27.89	38.25
1	23.80	24.65	25.50	26.35	27.20	28.05	28.90	29.75	40.80
1 1/16	25.29	26.19	27.10	28.00	28.90	29.80	30.70	31.61	43.35
1⅛	26.78	27.73	28.68	29.64	30.60	31.56	32.52	33.47	45.90
1 3/16	28.26	29.27	30.28	31.29	32.30	33.31	34.32	35.33	48.45
1¼	29.75	30.81	31.88	32.94	34.00	35.06	36.12	37.20	51.00
1 5/16	31.23	32.35	33.48	34.59	35.70	36.81	37.93	39.05	53.55
1⅜	32.72	33.89	35.06	36.23	37.40	38.57	39.74	40.91	56.10
1 7/16	34.21	35.44	36.66	37.88	39.10	40.32	41.54	42.77	58.65
1½	35.70	36.98	38.26	39.53	40.80	42.08	43.35	44.63	61.20
1 9/16	37.19	38.51	39.84	41.17	42.50	43.83	45.16	46.49	63.75
1⅝	38.67	40.05	41.44	42.82	44.20	45.58	46.96	48.34	66.30
1 11/16	40.16	41.59	43.03	44.47	45.90	47.33	48.76	50.20	68.85
1¾	41.65	43.14	44.63	46.12	47.60	49.09	50.58	52.07	71.40
1 13/16	43.14	44.68	46.22	47.76	49.30	50.84	52.38	53.92	73.95
1⅞	44.63	46.22	47.82	49.40	51.00	52.60	54.20	55.79	76.50
1 15/16	46.12	47.76	49.41	51.05	52.70	54.35	56.00	57.64	79.05
2	47.60	49.30	51.00	52.70	54.40	56.10	57.80	59.50	81.60

WEIGHTS OF FLAT ROLLED STEEL PER LINEAL FOOT — (*Continued*)

Thickness in inches	9 inches	9¼ inches	9½ inches	9¾ inches	10 inches	10¼ inches	10½ inches	10¾ inches	12 inches
3/16	5.74	5.90	6.06	6.22	6.38	6.54	6.70	6.86	7.65
¼	7.65	7.86	8.08	8.29	8.50	8.71	8.92	9.14	10.20
5/16	9.56	9.83	10.10	10.36	10.62	10.89	11.16	11.42	12.75
⅜	11.48	11.80	12.12	12.44	12.75	13.07	13.39	13.71	15.30
7/16	13.40	13.76	14.14	14.51	14.88	15.25	15.62	15.99	17.85
½	15.30	15.73	16.16	16.58	17.00	17.42	17.85	18.28	20.40
9/16	17.22	17.69	18.18	18.65	19.14	19.61	20.08	20.56	22.95
⅝	19.13	19.65	20.19	20.72	21.25	21.78	22.32	22.85	25.50
11/16	21.04	21.62	22.21	22.79	23.38	23.96	24.54	25.13	28.05
¾	22.96	23.59	24.23	24.86	25.50	26.14	26.78	27.42	30.60
13/16	24.86	25.55	26.24	26.94	27.62	28.32	29.00	29.69	33.15
⅞	26.78	27.52	28.26	29.01	29.75	30.50	31.24	31.98	35.70
15/16	28.69	29.49	30.28	31.08	31.88	32.67	33.48	34.28	38.25
1	30.60	31.45	32.30	33.15	34.00	34.85	35.70	36.55	40.80
1 1/16	32.52	33.41	34.32	35.22	36.12	37.03	37.92	38.83	43.35
1⅛	34.43	35.38	36.34	37.29	38.25	39.21	40.17	41.12	45.90
1 3/16	36.34	37.35	38.36	39.37	40.38	41.39	42.40	43.40	48.45
1¼	38.26	39.31	40.37	41.44	42.50	43.56	44.63	45.69	51.00
1 5/16	40.16	41.28	42.40	43.52	44.64	45.75	46.86	47.97	53.55
1⅜	42.08	43.25	44.41	45.58	46.75	47.92	49.08	50.25	56.10
1 7/16	44.00	45.22	46.44	47.66	48.88	50.10	51.32	52.54	58.65
1½	45.90	47.18	48.45	49.73	51.00	52.28	53.55	54.83	61.20
1 9/16	47.82	49.14	50.48	51.80	53.14	54.46	55.78	57.11	63.75
1⅝	49.73	51.10	52.49	53.87	55.25	56.63	58.02	59.40	66.30
1 11/16	51.64	53.07	54.51	55.94	57.38	58.81	60.24	61.68	68.85
1¾	53.56	55.04	56.53	58.01	59.50	60.99	62.48	63.97	71.40
1 13/16	55.46	57.00	58.54	60.09	61.62	63.17	64.70	66.24	73.95
1⅞	57.38	58.97	60.56	62.16	63.75	65.35	66.94	68.53	76.50
1 15/16	59.29	60.94	62.58	64.23	65.88	67.52	69.18	70.83	79.05
2	61.20	62.90	64.60	66.30	68.00	69.70	71.40	73.10	81.60

WEIGHTS OF FLAT ROLLED STEEL PER LINEAL FOOT — (*Continued*)

Thickness in inches	11 inches	11¼ inches	11½ inches	11¾ inches	12 inches	12¼ inches	12½ inches	12¾ inches
3/16	7.02	7.17	7.32	7.49	7.65	7.82	7.98	8.13
¼	9.34	9.57	9.78	10.00	10.20	10.42	10.63	10.84
5/16	11.68	11.95	12.22	12.49	12.75	13.01	13.28	13.55
⅜	14.03	14.35	14.68	14.99	15.30	15.62	15.94	16.26
7/16	16.36	16.74	17.12	17.49	17.85	18.23	18.60	18.97
½	18.70	19.13	19.55	19.67	20.40	20.82	21.25	21.67
9/16	21.02	21.51	22.00	22.48	22.95	23.43	23.90	24.39
⅝	23.38	23.91	24.44	24.97	25.50	26.03	26.56	27.09
11/16	25.70	26.30	26.88	27.47	28.05	28.64	29.22	29.80
¾	28.05	28.68	29.33	29.97	30.60	31.25	31.88	32.52
13/16	30.40	31.08	31.76	32.46	33.15	33.83	34.53	35.22
⅞	32.72	33.47	34.21	34.95	35.70	36.44	37.19	37.93
15/16	35.06	35.86	36.66	37.46	38.25	39.05	39.84	40.64
1	37.40	38.25	39.10	39.95	40.80	41.65	42.50	43.35
1 1/16	39.74	40.64	41.54	42.45	43.35	44.25	45.16	46.06
1⅛	42.08	43.04	44.00	44.94	45.90	46.86	47.82	48.77
1 3/16	44.42	45.42	46.44	47.45	48.45	49.46	50.46	51.48
1¼	46.76	47.82	48.88	49.94	51.00	52.06	53.12	54.19
1 5/16	49.08	50.20	51.32	52.44	53.55	54.67	55.78	56.90
1⅜	51.42	52.59	53.76	54.93	56.10	57.27	58.44	59.60
1 7/16	53.76	54.99	56.21	57.43	58.65	59.87	61.10	62.32
1½	56.10	57.37	58.65	59.93	61.20	62.48	63.75	65.03
1 9/16	58.42	59.76	61.10	62.43	63.75	65.08	66.40	67.74
1⅝	60.78	62.16	63.54	64.92	66.30	67.68	69.06	70.44
1 11/16	63.10	64.55	65.98	67.42	68.85	70.29	71.72	73.15
1¾	65.45	66.93	68.43	69.92	71.40	72.90	74.38	75.87
1 13/16	67.80	69.33	70.86	72.41	73.95	75.48	77.03	78.57
1⅞	70.12	71.72	73.31	74.90	76.50	78.09	79.69	81.28
1 15/16	72.46	74.11	75.76	77.41	79.05	80.70	82.34	83.99
2	74.80	76.50	78.20	79.90	81.60	83.30	85.00	86.70

The weights for 12-inch width are repeated on each page to facilitate making the additions necessary to obtain the weights of plates wider than 12 inches. Thus to find the weight of 15½″×⅞″, add the weights to be found in the same line for 3½×⅞ and 12×⅞=10.41 + 35.70 = 46.11 pounds.

Weights and Areas of Square and Round Bars of Wrought Iron and Circumference of Round Bars.

One cubic foot weighing 480 lbs.

Thickness or diameter in inches	Weight of □ bar 1 foot long	Weight of ○ bar 1 foot long	Area of □ bar in square inches	Area of ○ bar in square inches	Circumference of ○ bar in inches
0					
1/16	.013	.010	.0039	.0031	.1963
1/8	.052	.041	.0156	.0123	.3927
3/16	.117	.092	.0352	.0276	.5890
1/4	.208	.164	.0625	.0491	.7854
5/16	.326	.256	.0977	.0767	.9817
3/8	.469	.368	.1406	.1104	1.1781
7/16	.638	.501	.1914	.1503	1.3744
1/2	.833	.654	.2500	.1963	1.5708
9/16	1.055	.828	.3164	.2485	1.7671
5/8	1.302	1.023	.3906	.3068	1.9635
11/16	1.576	1.237	.4727	.3712	2.1598
3/4	1.875	1.473	.5625	.4418	2.3562
13/16	2.201	1.728	.6602	.5185	2.5525
7/8	2.552	2.004	.7656	.6013	2.7489
15/16	2.930	2.301	.8789	.6903	2.9452
1	3.333	2.618	1.0000	.7854	3.1416
1/16	3.763	2.955	1.1289	.8866	3.3379
1/8	4.219	3.313	1.2656	.9940	3.5343
3/16	4.701	3.692	1.4102	1.1075	3.7306
1/4	5.208	4.091	1.5625	1.2272	3.9270
5/16	5.742	4.510	1.7227	1.3530	4.1233
3/8	6.302	4.950	1.8906	1.4849	4.3197
7/16	6.888	5.410	2.0664	1.6230	4.5160
1/2	7.500	5.890	2.2500	1.7671	4.7124
9/16	8.138	6.392	2.4414	1.9175	4.9087
5/8	8.802	6.913	2.6406	2.0739	5.1051
11/16	9.492	7.455	2.8477	2.2365	5.3014
3/4	10.21	8.018	3.0625	2.4053	5.4978
13/16	10.95	8.601	3.2852	2.5802	5.6941
7/8	11.72	9.204	3.5156	2.7612	5.8905
15/16	12.51	9.828	3.7539	2.9483	6.0868
2	13.33	10.47	4.0000	3.1416	6.2832
1/16	14.18	11.14	4.2539	3.3410	6.4795
1/8	15.05	11.82	4.5156	3.5466	6.6759
3/16	15.95	12.53	4.7852	3.7583	6.8722
1/4	16.88	13.25	5.0625	3.9761	7.0686
5/16	17.83	14.00	5.3477	4.2000	7.2649
3/8	18.80	14.77	5.6406	4.4301	7.4613
7/16	19.80	15.55	5.9414	4.6664	7.6576
1/2	20.83	16.36	6.2500	4.9087	7.8540
9/16	21.89	17.19	6.5664	5.1572	8.0503
5/8	22.97	18.04	6.8906	5.4119	8.2467
11/16	24.08	18.91	7.2227	5.6727	8.4430
3/4	25.21	19.80	7.5625	5.9396	8.6394
13/16	26.37	20.71	7.9102	6.2126	8.8357
7/8	27.55	21.64	8.2656	6.4918	9.0321
15/16	28.76	22.59	8.6289	6.7771	9.2284

WEIGHT OF SQUARE AND ROUND BARS — (*Continued*)

Thickness or diameter in inches	Weight of □ bar 1 foot long	Weight of ○ bar 1 foot long	Area of □ bar in square inches	Area of ○ bar in square inches	Circumference of ○ bar in inches
3	30.00	23.56	9.0000	7.0686	9.4248
1/16	31.26	24.55	9.3789	7.3662	9.6211
1/8	32.55	25.57	9.7656	7.6699	9.8175
3/16	33.87	26.60	10.160	7.9798	10.014
1/4	35.21	27.65	10.563	8.2958	10.210
5/16	36.58	28.73	10.973	8.6179	10.407
3/8	37.97	29.82	11.391	8.9462	10.603
7/16	39.39	30.94	11.816	9.2806	10.799
1/2	40.83	32.07	12.250	9.6211	10.996
9/16	42.30	33.23	12.691	9.9678	11.192
5/8	43.80	34.40	13.141	10.321	11.388
11/16	45.33	35.60	13.598	10.680	11.585
3/4	46.88	36.82	14.063	11.045	11.781
13/16	48.45	38.05	14.535	11.416	11.977
7/8	50.05	39.31	15.016	11.793	12.174
15/16	51.68	40.59	15.504	12.177	12.370
4	53.33	41.89	16.000	12.566	12.566
1/16	55.01	43.21	16.504	12.962	12.763
1/8	56.72	44.55	17.016	13.364	12.959
3/16	58.45	45.91	17.535	13.772	13.155
1/4	60.21	47.29	18.063	14.186	13.352
5/16	61.99	48.69	18.598	14.607	13.548
3/8	63.80	50.11	19.141	15.033	13.744
7/16	65.64	51.55	19.691	15.466	13.941
1/2	67.50	53.01	20.250	15.904	14.137
9/16	69.39	54.50	20.816	16.349	14.334
5/8	71.30	56.00	21.391	16.800	14.530
11/16	73.24	57.52	21.973	17.257	14.726
3/4	75.21	59.07	22.563	17.721	14.923
13/16	77.20	60.63	23.160	18.190	15.119
7/8	79.22	62.22	23.766	18.665	15.315
15/16	81.26	63.82	24.379	19.147	15.512
5	83.33	65.45	25.000	19.635	15.708
1/16	85.43	67.10	25.629	20.129	15.904
1/8	87.55	68.76	26.266	20.629	16.101
3/16	89.70	70.45	26.910	21.135	16.297
1/4	91.88	72.16	27.563	21.648	16.493
5/16	94.08	73.89	28.223	22.166	16.690
3/8	96.30	75.64	28.891	22.691	16.886
7/16	98.55	77.40	29.566	23.221	17.082
1/2	100.8	79.19	30.250	23.758	17.279
9/16	103.1	81.00	30.941	24.301	17.475
5/8	105.5	82.83	31.641	24.850	17.671
11/16	107.8	84.69	32.348	25.406	17.868
3/4	110.2	86.56	33.063	25.967	18.064
13/16	112.6	88.45	33.785	26.535	18.261
7/8	115.1	90.36	34.516	27.109	18.457
15/16	117.5	92.29	35.254	27.688	18.653
6	120.0	94.25	36.000	28.274	18.850
1/16	122.5	96.22	36.754	28.866	19.046
1/8	125.1	98.22	37.516	29.465	19.242
3/16	127.6	100.2	38.285	30.069	19.439

WEIGHT OF SQUARE AND ROUND BARS — (*Continued*)

Thickness or diameter in inches	Weight of □ bar 1 foot long	Weight of ○ bar 1 foot long	Area of □ bar in square inches	Area of ○ bar in square inches	Circumference of ○ bar in inches
6¼	130.2	102.3	39.063	30.680	19.635
5/16	132.8	104.3	39.848	31.296	19.831
⅜	135.5	106.4	40.641	31.919	20.028
7/16	138.1	108.5	41.441	32.548	20.224
½	140.8	110.6	42.250	33.183	20.420
9/16	143.6	112.7	43.066	33.824	20.617
⅝	146.3	114.9	43.891	34.472	20.813
11/16	149.1	117.1	44.723	35.125	21.009
¾	151.9	119.3	45.563	35.785	21.206
13/16	154.7	121.5	46.410	36.450	21.402
⅞	157.6	123.7	47.266	37.122	21.598
15/16	160.4	126.0	48.129	37.800	21.795
7	163.3	128.3	49.000	38.485	21.991
1/16	166.3	130.6	49.879	39.175	22.187
⅛	169.2	132.9	50.766	39.871	22.384
3/16	172.2	135.2	51.660	40.574	22.580
¼	175.2	137.6	52.563	41.282	22.777
5/16	178.2	140.0	53.473	41.997	22.973
⅜	181.3	142.4	54.391	42.718	23.169
7/16	184.4	144.8	55.316	43.445	23.366
½	187.5	147.3	56.250	44.179	23.562
9/16	190.6	149.7	57.191	44.918	23.758
⅝	193.8	152.2	58.141	45.664	23.955
11/16	197.0	154.7	59.098	46.415	24.151
¾	200.2	157.2	60.063	47.173	24.347
13/16	203.5	159.8	61.035	47.937	24.544
⅞	206.7	162.4	62.016	48.707	24.740
15/16	210.0	164.9	63.004	49.483	24.936
8	213.3	167.6	64.000	50.265	25.133
1/16	216.7	170.2	65.004	51.054	25.329
⅛	220.1	172.8	66.016	51.849	25.525
3/16	223.5	175.5	67.035	52.649	25.722
¼	226.9	178.2	68.063	53.456	25.918
5/16	230.3	180.9	69.098	54.269	26.114
⅜	233.8	183.6	70.141	55.088	26.311
7/16	237.3	186.4	71.191	55.914	26.507
½	240.8	189.2	72.250	56.745	26.704
9/16	244.4	191.9	73.316	57.583	26.900
⅝	248.0	194.8	74.391	58.426	27.096
11/16	251.6	197.6	75.473	59.276	27.293
¾	255.2	200.4	76.563	60.132	27.489
13/16	258.9	203.3	77.660	60.994	27.685
⅞	262.6	206.2	78.766	61.862	27.882
15/16	266.3	209.1	79.879	62.737	28.078
9	270.0	212.1	81.000	63.617	28.274
1/16	273.8	215.0	82.129	64.504	28.471
⅛	277.6	218.0	83.266	65.397	28.667
3/16	281.4	221.0	84.410	66.296	28.863
¼	285.2	224.0	85.563	67.201	29.060
5/16	289.1	227.0	86.723	68.112	29.256
⅜	293.0	230.1	87.891	69.029	29.452
7/16	296.9	233.2	89.066	69.953	29.649

WEIGHT OF SQUARE AND ROUND BARS — (*Continued*)

Thickness or diameter in inches	Weight of □ bar 1 foot long	Weight of ○ bar 1 foot long	Area of □ bar in square inches	Area of ○ bar in square inches	Circumference of ○ bar in inches
9½	300.8	236.3	90.250	70.882	29.845
9/16	304.8	239.4	91.441	71.818	30.041
⅝	308.8	242.5	92.641	72.760	30.238
11/16	312.8	245.7	93.848	73.708	30.434
¾	316.9	248.9	95.063	74.662	30.631
13/16	321.0	252.1	96.285	75.622	30.827
⅞	325.1	255.3	97.516	76.589	31.023
15/16	329.2	258.5	98.754	77.561	31.200
10	333.3	261.8	100.00	78.540	31.416
1/16	337.5	265.1	101.25	79.525	31.612
⅛	341.7	268.4	102.52	80.516	31.809
3/16	346.0	271.7	103.79	81.513	32.005
¼	350.2	275.1	105.06	82.516	32.201
5/16	354.5	278.4	106.35	83.525	32.398
⅜	358.8	281.8	107.64	84.541	32.594
7/16	363.1	285.2	108.94	85.562	32.790
½	367.5	288.6	110.25	86.590	32.987
9/16	371.9	292.1	111.57	87.624	33.183
⅝	376.3	295.5	112.89	88.664	33.379
11/16	380.7	299.0	114.22	89.710	33.576
¾	385.2	302.5	115.56	90.763	33.772
13/16	389.7	306.1	116.91	91.821	33.968
⅞	394.2	309.6	118.27	92.886	34.165
15/16	398.8	313.2	119.63	93.956	34.361
11	403.3	316.8	121.00	95.033	34.558
1/16	407.9	320.4	122.38	96.116	34.754
⅛	412.6	324.0	123.77	97.205	34.950
3/16	417.2	327.7	125.16	98.301	35.147
¼	421.9	331.3	126.56	99.402	35.343
5/16	426.6	335.0	127.97	100.51	35.539
⅜	431.3	338.7	129.39	101.62	35.736
7/16	436.1	342.5	130.82	102.74	35.932
½	440.8	346.2	132.25	103.87	36.128
9/16	445.6	350.0	133.69	105.00	36.325
⅝	450.5	353.8	135.14	106.14	36.521
11/16	455.3	357.6	136.60	107.28	36.717
¾	460.2	361.4	138.06	108.43	36.914
13/16	465.1	365.3	139.54	109.59	37.110
⅞	470.1	369.2	141.02	110.75	37.306
15/16	475.0	373.1	142.50	111.92	37.503

Weights and Areas of Cold Rolled Steel Shafting

Diameter, inches	Area, square inches	Circumference, inches	Weight per foot, pounds	Diameter, inches	Area, square inches	Circumference, inches	Weight per foot, pounds
3/16	.0276	.5890	.095	2 3/16	3.7583	6.8722	12.80
1/4	.0491	.7854	.167	2 1/4	3.9761	7.0686	13.52
5/16	.0767	.9817	.260	2 5/16	4.2000	7.2749	14.35
3/8	.1104	1.1781	.375	2 3/8	4.4301	7.4613	15.07
7/16	.1503	1.3744	.511	2 7/16	4.6664	7.6576	15.89
1/2	.1963	1.5708	.667	2 1/2	4.9087	7.8540	16.70
9/16	.2485	1.7671	.845	2 9/16	5.1572	8.0503	17.55
5/8	.3068	1.9635	1.05	2 5/8	5.4119	8.2467	18.41
11/16	.3712	2.1598	1.26	2 11/16	5.6727	8.4430	19.31
3/4	.4418	2.3562	1.50	2 3/4	5.9396	8.6394	20.21
13/16	.5185	2.5525	1.77	2 13/16	6.2126	8.8357	21.15
7/8	.6013	2.7489	2.05	2 7/8	6.4918	9.0321	22.09
15/16	.6903	2.9452	2.35	2 15/16	6.7771	9.2284	23.06
1	.7854	3.1416	2.68	3	7.0686	9.4248	24.05
1 1/16	.8866	3.3379	3.02	3 1/8	7.6699	9.8175	26.09
1 1/8	.9940	3.5343	3.38	3 3/16	7.9798	10.014	27.16
1 3/16	1.1075	3.7306	3.77	3 1/4	8.2958	10.210	28.22
1 1/4	1.2272	3.9270	4.17	3 3/8	8.9462	10.603	30.43
1 5/16	1.3530	4.1233	4.61	3 7/16	9.2806	10.799	31.58
1 3/8	1.4849	4.3197	5.05	3 1/2	9.6211	10.996	32.73
1 7/16	1.6230	4.5160	5.52	3 5/8	10.321	11.388	35.20
1 1/2	1.7671	4.7124	6.01	3 11/16	10.680	11.585	36.40
1 9/16	1.9175	4.9087	6.52	3 3/4	11.045	11.781	37.57
1 5/8	2.0739	5.1051	7.06	3 7/8	11.793	12.174	39.40
1 11/16	2.2365	5.3014	7.61	3 15/16	12.177	12.370	41.04
1 3/4	2.4053	5.4978	8.18	4	12.566	12.566	42.75
1 13/16	2.5802	5.6941	8.78	4 1/4	14.186	13.352	48.26
1 7/8	2.7612	5.8905	9.39	4 7/16	15.466	13.941	52.62
1 15/16	2.9483	6.0868	10.03	4 1/2	15.904	14.137	54.11
2	3.1416	6.2832	10.69	4 3/4	17.728	14.923	60.88
2 1/16	3.3410	6.4795	11.35	4 15/16	19.147	15.512	65.50
2 1/8	3.5466	6.6759	12.07	5	19.635	15.708	67.45

Sheet Iron

Weight of a superficial foot.

Number of gauge	Weight per foot	Number of gauge	Weight per foot
1	11.25	16=1/16	2.5
2	10.625	17	2.1875
3=1/4	10.00	18	1.875
4	9.375	19	1.7188
5	8.750	20	1.5625
6	8.125	21	1.4063
7	7.50	22=1/32	1.2500
8	6.875	23	1.120
9	6.250	24	1.000
10	5.625	25	.900
11=1/8	5.000	26	.800
12	4.375	27	.720
13	3.750	28	.640
14	3.125	29	.560
15	2.8125	30	.500

Galvanized Sheet Iron

Am. Galv. Iron Ass'n. B. W. G.

No.	Ounces avoir. per square foot	Square feet per 2240 pounds	No.	Ounces avoir. per square foot	Square feet per 2240 pounds	No.	Ounces avoir. per square foot	Square feet per 2240 pounds
29	12	2987	24	17	2108	19	33	1084
28	13	2757	23	19	1886	18	38	943
27	14	2560	22	21	1706	17	43	833
26	15	2389	21	24	1493	16	48	746
25	16	2240	20	28	1280	14	60	597

Corrugated Iron Roofing

B. W. gauge	Weight per square (100 square feet). Plain	Galvanized
Number	Pounds	
28	97	Weighs from 5 to 15 per cent heavier than plain, according to the number B. W. G.
26	105	
24	128	
22	150	
20	185	
18	270	
16	340	

Allow one-third the net width for lapping and for corrugations. From 2½ to 3½ pounds for rivets will be required per square.

Sizes and Weight of Sheet Tin

Mark	Number of sheets in box	Dimension		Weight of box, pounds
		Length, inches	Breadth, inches	
1C	225	13¾	10	112
11C	225	13¼	9¾	105
111C	225	12¾	9½	98
1X	225	13¾	10	140
1XX	225	13¾	10	161
1XXX	225	13¾	10	182
1XXXX	225	13¾	10	203
DC	100	16¾	12½	105
DX	100	16¾	12½	126
DXX	100	16¾	12½	147
DXXX	100	16¾	12½	168
DXXXX	100	16¾	12½	189
5DC	200	15	11	168
5DX	200	15	11	189
5DXX	200	15	11	210
5DXXX	200	15	11	231
1CW	225	13¾	10	112

A box containing 225 sheets, 13¾ by 10, contains 214.84 square feet; but allowing for seams it will cover only 150 square feet of roof.

A roof covered with metal should slope not less than 1 inch to the foot.

Weights of Sheet Metals per Square Foot

Thickness, inches	Wrought iron, pounds	Cast iron, pounds	Steel, pounds	Copper, pounds	Brass, pounds	Lead, pounds	Zinc, pounds
1/16	2.53	2.34	2.55	2.89	2.73	3.71	2.34
⅛	5.05	4.69	5.10	5.78	5.47	7.42	4.69
3/16	7.58	7.03	7.66	8.67	8.20	11.13	7.03
¼	10.10	9.38	10.21	11.56	10.94	14.83	9.38
5/16	12.63	11.72	12.76	14.45	13.67	18.54	11.72
⅜	15.16	14.06	15.31	17.34	16.41	22.25	14.06
7/16	17.68	16.41	17.87	20.23	19.14	25.96	16.41
½	20.21	18.75	20.42	23.13	21.88	29.67	18.75
⅝	25.27	23.44	25.52	28.91	27.34	37.08	23.44
¾	30.31	28.13	30.63	34.69	32.81	44.50	28.13
⅞	35.37	32.81	35.73	40.47	38.28	51.92	32.81
1	40.42	37.50	40.83	46.25	43.75	59.33	37.50

Weight of Copper and Brass Wire and Plates

Brown and Sharpe Gauge.

No. of gauge	Size of each no., inch	Weight of wire per 1000 lineal feet		Weight of plates per square foot	
		Copper, pounds	Brass, pounds	Copper, pounds	Brass, pounds
0000	.46000	640.5	605.28	20.84	19.69
000	.40964	508.0	479.91	18.55	17.53
00	.36480	402.0	380.77	16.52	15.61
0	.32476	319.5	301.82	14.72	13.90
1	.28930	253.3	239.45	13.10	12.38
2	.25763	200.9	189.82	11.67	11.03
3	.22942	159.3	150.52	10.39	9.82
4	.20431	126.4	119.48	9.25	8.74
5	.18194	100.2	94.67	8.24	7.79
6	.16202	79.46	75.08	7.34	6.93
7	.14428	63.01	59.55	6.54	6.18
8	.12849	49.98	47.22	5.82	5.50
9	.11443	39.64	37.44	5.18	4.90
10	.10189	31.43	29.69	4.62	4.36
11	.090742	24.92	23.55	4.11	3.88
12	.080808	19.77	18.68	3.66	3.46
13	.071961	15.65	14.81	3.26	3.08
14	.064084	12.44	11.75	2.90	2.74
15	.057068	9.86	9.32	2.59	2.44
16	.050820	7.82	7.59	2.30	2.18
17	.045257	6.20	5.86	2.05	1.94
18	.040303	4.92	4.65	1.83	1.72
19	.035890	3.90	3.68	1.63	1.54
20	.031961	3.09	2.92	1.45	1.37
21	.028462	2.45	2.317	1.29	1.22
22	.025347	1.94	1.838	1.15	1.08
23	.022571	1.54	1.457	1.02	.966
24	.020100	1.22	1.155	.911	.860
25	.017900	.699	.916	.811	.766
26	.01494	.769	.727	.722	.682
27	.014195	.610	.576	.643	.608
28	.012641	.484	.457	.573	.541
29	.011257	.383	.362	.510	.482
30	.010025	.304	.287	.454	.429
31	.008928	.241	.228	.404	.382
32	.007950	.191	.181	.360	.340
33	.007080	.152	.143	.321	.303
34	.006304	.120	.114	.286	.270
35	.005614	.096	.0915	.254	.240
36	.005000	.0757	.0715	.226	.214
37	.004453	.0600	.0567	.202	.191
38	.003965	.0467	.0450	.180	170
39	.003531	.0375	.0357	.160	151
40	.003144	.0299	.0283	.142	.135
Specific gravity............		8.880	8.386	8.698	8.218
Weight per cubic foot.......		555	524.16	543.6	513.6

Weight of Sheet and Bar Brass

Thickness, inches	Sheets per square foot, pounds	Square bars 1 foot long, pounds	Round bars 1 foot long, pounds	Thickness, inches	Sheets per square foot, pounds	Square bars 1 foot long, pounds	Round bars 1 foot long, pounds
1/16	2.7	.015	.011	1 1/16	45.95	4.08	3.20
1/8	5.41	.055	.045	1 1/8	48.69	4.55	3.57
3/16	8.12	.125	.1	1 3/16	51.4	5.08	3.97
1/4	10.76	.225	.175	1 1/4	54.18	5.65	4.41
5/16	13.48	.350	.275	1 5/16	65.85	6.22	4.86
3/8	16.25	.51	.395	1 3/8	59.55	6.81	5.35
7/16	19	.69	.54	1 7/16	62.25	7.45	5.85
1/2	21.65	.905	.71	1 1/2	65	8.13	6.37
9/16	24.3	1.15	.9	1 9/16	67.75	8.83	6.92
5/8	27.13	1.4	1.1	1 5/8	70.35	9.55	7.48
11/16	29.77	1.72	1.35	1 11/16	73	10.27	8.05
3/4	32.46	2.05	1.66	1 3/4	75.86	11	8.65
13/16	35.18	2.4	1.85	1 13/16	78.55	11.82	9.29
7/8	37.85	2.75	2.15	1 7/8	81.25	12.68	9.95
15/16	40.55	3.15	2.48	1 15/16	84	13.5	10.58
1	43.29	3.65	2.85	2	86.75	14.35	11.25

Weight of Round Bolt Copper per Foot

Diameter, inches	Pounds	Diameter, inches	Pounds	Diameter, inches	Pounds
3/8	.425	1	3.02	1 5/8	7.99
1/2	.756	1 1/8	3.83	1 3/4	9.27
5/8	1.18	1 1/4	4.72	1 7/8	10.64
3/4	1.70	1 3/8	5.72	2	12.10
7/8	2.31	1 1/2	6.81	....	....

Areas and Weights of Fillets of Steel, Cast Iron and Brass

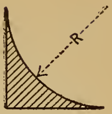


Fig. 39.

Calculations are based on the following weights:

Steel.................. ..... 489.6 pounds per cubic foot.
Cast iron...................... 450 " "
Cast brass.. .... 504 " "

Radius R	Area	Weight of steel		Weight of cast iron		Weight of cast brass	
		Per foot	Per inch	Per foot	Per inch	Per foot	Per inch
1/16	.0008	.0029	.00024	.0026	.00022	.0029	.00025
1/8	.0033	.0115	.00096	.0106	.0009	.0118	.0010
3/16	.0075	.0255	.0021	.0235	.0019	.0263	.0022
1/4	.0134	.0455	.0038	.0418	.0035	.0469	.0040
5/16	.0209	.0712	.0059	.0655	.0054	.0733	.0061
3/8	.0302	.1027	.0085	.0945	.0078	.1058	.0088
7/16	.0411	.1397	.0116	.1285	.0107	.1439	.0120
1/2	.0536	.1825	.0152	.1679	.0140	.1880	.0157
9/16	.0679	.2310	.0192	.2125	.0177	.2380	.0200
5/8	.0834	.2847	.0237	.2169	.0218	.2932	.0244
1 1/16	.1014	.3447	.0287	.3171	.0264	.3550	.0300
3/4	.1207	.4105	.0342	.3777	.0315	.4228	.0352
1 3/16	.1416	.4817	.0401	.4432	.0369	.4962	.0414
7/8	.1643	.5580	.0465	.5134	.0428	.5747	.0479
1 5/16	.1886	.6405	.0534	.5893	.0491	.6597	.0550
1	.2146	.7300	.0608	.6716	.0559	.7519	.0626
1 1/8	.2716	.9250	.0771	.8510	.0709	.9527	.0794
1 1/4	.3353	1.140	.0950	1.049	.0874	1.174	.0979
1 3/8	.4057	1.200	.1000	1.104	.0920	1.236	.1030
1 1/2	.4828	1.642	.1368	1.511	.1259	1.691	.1410
1 5/8	.5668	1.930	.1608	1.776	.1479	1.988	.1657
1 3/4	.6572	2.235	.1862	2.056	.1713	2.302	.1920
1 7/8	.7545	2.565	.2137	2 360	.1970	2.642	.2202
2	.8585	2.917	.2431	2.684	.2237	3.005	.2504
2 1/8	.9692	3.292	.2743	3.029	.2502	3.091	.2826
2 1/4	1.086	3.695	.3079	3.399	.2832	3.806	.3172
2 3/8	1.210	4.115	.3429	3.786	.3155	4.238	.3532
2 1/2	1.341	4.560	.3800	4.195	.3496	4.697	.3014
2 5/8	1.478	5.030	.4192	4.628	.3857	5.181	.4317
2 3/4	1.623	5.507	.4589	5.066	.4222	5.672	.4727
2 7/8	1.774	6.027	.5022	5.545	.4621	6.208	.5017
3	1.931	6.565	.5471	5.940	.4950	6.762	.5635
3 1/8	2.096	7.125	.5937	6.555	.5462	7.339	.6116
3 1/4	2.267	7.700	.6417	7.084	.5903	7.931	.6609
3 3/8	2.444	8.300	.6917	7.636	.6363	8.549	.7124
3 1/2	2.629	8.925	.7438	8.211	.6926	9.193	.7661
3 5/8	2.820	9.575	.7979	8.809	.7341	9.862	.8220
3 3/4	3.018	10.27	.8523	9.448	.7873	10.58	.8817
3 7/8	3.222	10.97	.9142	10.09	.8408	11.30	.9417
4	3.434	11.65	.9709	10.72	.8933	12.00	1.000
4 1/8	3.652	12.40	1.033	11.41	.9508	12.77	1.064
4 1/4	3.876	13.15	1.096	12.10	1.008	13.54	1.130
4 3/8	4.107	13.97	1.164	12.85	1.071	14.39	1.199
4 1/2	4.346	14.77	1.231	13.59	1.132	15.21	1.270
4 5/8	4.590	15.60	1.300	14.35	1.196	16.07	1.340
4 3/4	4.842	16.45	1.371	15.13	1.261	16.94	1.412
4 7/8	5.100	17.32	1.444	15.93	1.328	17.84	1.487
5	5.365	18.25	1.521	16.79	1.400	18.80	1.570

Contributed by Ernest J. Lees.

Gauges and Weights of Iron Wire

The sizes and weights from No. 20 to No. 40 are those of the Trenton Iron Co., Trenton, N. J.

No.	Diameter, inches	Lineal feet to the pound	No.	Diameter, inches	Lineal feet to the pound
21	.031	392.772	31	.013	2232.653
22	.028	481.234	32	.012	2620.607
23	.025	603.863	33	.011	3119.092
24	.0225	745.710	34	.010	3773.584
25	.020	943.396	35	.0095	4182.508
26	.018	1164.689	36	.009	4657.728
27	.017	1305.670	37	.0085	5222.035
28	.016	1476.869	38	.008	5896.147
29	.015	1676.989	39	.0075	6724.291
30	.014	1925.321	40	.007	7698.253

American Steel & Wire Company

Full sizes of plain wire	Gauge	Diameter of American Steel & Wire Co.'s gauge	Weight one mile, pounds	Feet to pound
	1	.2830	1128.0	4.681
	2	.2625	970.4	5.441
	3	.2437	836.4	6.313
	4	.2253	714.8	7.386
	5	.2070	603.4	8.750
	6	.1920	519.2	10.17
	7	.1770	441.2	11.97
	8	.1620	369.6	14.29
	9	.1483	309.7	17.05
	10	.1350	256.7	20.57
	11	.1205	204.5	25.82
	12	.1055	156.7	33.69
	13	.0915	117.9	44.78
	14	.0800	90.13	58.58
	15	.0720	73.01	72.32
	16	.0625	55.01	95.98
	17	.0540	41.07	128.6
	18	.0475	31.77	166.2
	19	.0410	23.67	223.0
	20	.0348	17.05	309.6

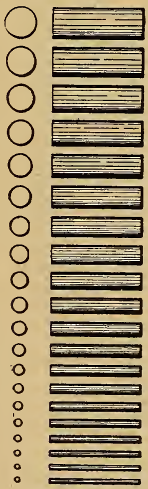


Fig. 40.

Iron Wire

Measured by Washburn & Moen gauge. List prices per pound.

No.	*Bright market wire	Galvanized market wire	Annealed stone wire, bright or black	Tinned market wire	Tinned stone wire
0000 to 9	$0.10	$0.10	....	$0.15	....
10 and 11	.11	.11	....	.16	....
12	.11½	.11½	....	.17	....
13 and 14	.12½	.12½	....	.17	....
15	.14	.14	....	.17½	....
16	.14	.14	$0.14	.17½	....
17	15	.15	.15	.18	....
18	.16	.16	.16	.18½	$0.18½
19	.19	.19	.19	....	.19
20	.20	.20	.20	....	.19
21	.21	.21	.21	....	.20
22	.22	.22	.22	....	.20
23	.23	.23	.23	....	.21
24	.24	.24	.24	....	.21
25	.25	.25	.25	....	.22
26	.26	.26	.26	....	.23
27	.28	.28	.28	....	.24
28	.29	.29	.29	....	.25
29	.30	.30	.30	....	.26
30	.32	.32	.32	....	.27
31	.33	.33	.33	....	.28
32	.35	.35	.35	....	.32
33	.37	.37	.37	....	.33
34	.40	.40	.40	....	.34
35	.45	.45	.45	....	.40
36	.55	.55	.55	....	.48

* Coppered Market Wire and Coppered Bessemer Spring Wire take same list prices as Bright Market Wire.

Nails and Tacks

Common Wire Nails

Measured by Washburn & Moen Gauge

Size	Length and gauge		Approx. no. to pound
	Inch	No.	
2d	1	15	876
3d	1¼	14	568
4d	1½	12½	316
5d	1¾	12½	271
6d	2	11½	181
7d	2¼	11½	161
8d	2½	10¼	106
9d	2¾	10¼	96
10d	3	9	69
12d	3¼	9	63
16d	3½	8	49
20d	4	6	31
30d	4½	5	24
40d	5	4	18
50d	5½	3	14
60d	6	2	11

Length and Number of Tacks to the Pound

Name, ounces	Length, inches	No. to the pound	Name, ounces	Length, inches	No. to the pound
1	⅛	16,000	10	11/16	1600
1½	3/16	10,666	12	¾	1333
2	¼	8,000	14	13/16	1143
2½	5/16	6,400	16	⅞	1000
3	⅜	5,333	18	15/16	888
4	7/16	40,000	20	1	800
6	9/16	2,666	22	1 1/16	727
8	⅝	2,000	24	1⅛	666

United States Standard Threads

Nominal diameter of screw, inches		No. of threads per inch	Diameter of tap at root of thread		Size of tap drill, giving a clearance of 1/8 the height of the original thread triangle		Area at root of thread, square inches	Safe load on threaded bolt on basis of 6000 pounds stress per sq. in. of section at root of thread, pounds
			Inches	Nearest 64ths	Inches	Nearest 64ths		
1/4	.250	20	.185	3/16 −	.196	13/64 −	.027	162
5/16	.312	18	.240	15/64 +	.252	1/4 +	.045	270
3/8	.375	16	.294	19/64 −	.307	5/16 −	.068	408
7/16	.437	14	.345	11/32 +	.360	23/64 +	.093	558
1/2	.500	13	.400	13/32 −	.417	27/64 −	.126	756
9/16	.562	12	.454	29/64 +	.472	15/32 +	.162	997
5/8	.625	11	.507	1/2 +	.527	17/32 −	.202	1,210
11/16	.687	11	.569	9/16 +	.589	19/32 −	.254	1,520
3/4	.750	10	.620	5/8 −	.642	41/64 +	.302	1,810
13/16	.812	10	.683	11/16 −	.704	45/64 +	.366	2,190
7/8	.875	9	.731	47/64 −	.755	3/4 +	.420	2,520
15/16	.937	9	.793	51/64 −	.817	13/16 +	.494	2,960
1	1.000	8	.838	27/32 −	.865	55/64 +	.551	3,300
1 1/16	1.062	8	.900	29/32 −	.927	59/64 +	.636	3,810
1 1/8	1.125	7	.939	15/16 +	.970	31/32 +	.694	4,160
1 3/16	1.187	7	1.002	1 +	1.032	1 1/32 +	.788	4,720
1 1/4	1.250	7	1.064	1 1/15 +	1.095	1 3/32 +	.893	5,350
1 3/8	1.375	6	1.158	1 5/32 +	1.215	1 7/32 −	1.057	6,340
1 1/2	1.500	6	1.283	1 9/32 +	1.345	1 11/32 +	1.295	7,770
1 5/8	1.625	5 1/2	1.389	1 25/64 −	1.428	1 27/64 +	1.515	9,090
1 3/4	1.750	5	1.490	1 31/64 +	1.534	1 17/32 +	1.746	10,470
1 7/8	1.875	5	1.615	1 39/64 +	1.659	1 21/32 +	2.051	12,300
2	2.000	4 1/2	1.711	1 23/32 −	1.760	1 49/64 −	2.302	13,800
2 1/4	2.250	4 1/2	1.961	1 61/64 +	2.010	2 1/64 −	3.023	18,100
2 1/4	2.500	4	2.175	2 11/64 +	2.230	2 15/64 −	3.719	22,300
2 3/4	2.750	4	2.425	2 27/64 +	2.480	2 31/64 −	4.620	27,700
3	3.000	3 1/2	2.629	2 5/8 +	2.691	2 11/16 +	5.428	32,500
3 1/4	3.250	3 1/2	2.879	2 7/8 +	2.941	2 15/16 +	6.510	39,000
3 1/2	3.500	3 1/4	3.100	3 3/32 +	3.167	3 11/64 −	7.548	45,300
3 3/4	3.750	3	3.317	3 5/16 +	3.389	3 25/64 −	8.641	51,800
4	4.000	3	3.567	3 9/16 +	3.639	3 41/64 −	9.963	59,700

United States Standard Bolts and Nuts

Bolt		Diameters				Thickness		Areas		Tensile strength			Shearing strength			
													Full bolt		Bot. of thread	
Diameter	Threads per inch				Bottom of thread			Bolt	Bottom of thread	At 10,000 lbs. per sq. in.	At 12,500 lbs. per sq. in.	At 17,500 lbs. per sq. in.	At 7500 lbs. per sq. in.	At 10,000 lbs. per sq. in.	At 7500 lbs. per sq. in.	At 10,000 lbs. per sq. in.
.25	20	.5	.578	.707	.1850	.25	.25	.0491	.0269	269	336	471	368	491	202	269
.3125	18	.5938	.686	.840	.2403	.3125	.2969	.0767	.0454	454	568	795	575	767	341	454
.375	16	.6875	.794	.972	.2938	.375	.3438	.1104	.0678	678	848	1,187	828	1,104	509	678
.4375	14	.7813	.902	1.105	.3447	.4375	.3906	.1503	.0933	933	1,166	1,633	1,127	1,503	700	933
.5	13	.875	1.011	1.237	.4001	.5	.4375	.1963	.1257	1,257	1,571	2,200	1,472	1,963	943	1,257
.5625	12	.9688	1.119	1.370	.4542	.5625	.4844	.2485	.1621	1,621	2,026	2,837	1,864	2,485	1,216	1,621
.625	11	1.0625	1.227	1.502	.5069	.625	.5313	.3068	.2018	2,018	2,523	3,532	2,301	3,068	1,514	2,018
.75	10	1.25	1.444	1.768	.6201	.75	.625	.4418	.3020	3,020	3,775	5,285	3,314	4,418	2,265	3,020
.875	9	1.4375	1.660	2.033	.7307	.875	.7188	.6013	.4193	4,193	5,241	7,338	4,510	6,013	3,145	4,193
1	8	1.625	1.877	2.298	.8376	1	.8125	.7854	.5510	5,510	6,888	9,643	5,891	7,854	4,133	5,510
1.125	7	1.8125	2.093	2.563	.9394	1.125	.9063	.9940	.6931	6,931	8,664	2,129	7,455	9,940	5,198	6,931
1.25	7	2	2.310	2.828	1.0644	1.25	1	1.2272	.8899	8,899	11,124	15,573	9,204	12,272	6,674	8,899
1.375	6	2.1875	2.527	3.093	1.1585	1.375	1.0938	1.4849	1.0541	10,541	13,176	18,447	11,137	14,849	7,906	10,541
1.5	6	2.375	2.743	3.358	1.2835	1.5	1.1875	1.7671	1.2938	12,938	16,173	22,642	13,253	17,671	9,704	12,938
1.625	5.5	2.5625	2.960	3.623	1.3888	1.625	1.2813	2.0739	1.5149	15,149	18,936	26,511	15,554	20,739	11,362	15,149
1.75	5	2.75	3.176	3.889	1.4902	1.75	1.375	2.4053	1.7441	17,441	21,801	30,522	18,040	24,053	13,081	17,441
1.875	5	2.9375	3.393	4.154	1.6152	1.875	1.4688	2.7612	2.0490	20,490	25,613	35,858	20,709	27,612	15,368	20,490
2	4.5	3.125	3.609	4.419	1.7113	2	1.5625	3.1416	2.3001	23,001	28,751	40,252	23,562	31,416	17,251	23,001
2.25	4.5	3.5	4.043	4.949	1.9613	2.25	1.75	3.9761	3.0213	30,213	37,766	52,873	29,821	39,761	22,660	30,213
2.5	4	3.875	4.476	5.479	2.1752	2.5	1.9375	4.9087	3.7163	37,163	46,454	65,035	36,815	49,087	27,872	37,163
2.75	4	4.25	4.909	6.010	2.4252	2.75	2.125	5.9396	4.6196	46,196	57,745	80,843	44,547	59,396	34,647	46,196

UNITED STATES STANDARD BOLTS AND NUTS — (*Continued*)

3	3.5	4.625	5.342	6.540	2.6288	3	2.3125	7.0686	5.4277	54,277	67,846	94,985	53,015	70,686	40,708	54,277
3.25	3.5	5	5.775	7.070	2.8788	3.25	2.5	8.2958	6.5092	65,092	81,365	13,911	62,219	82,958	48,819	65,092
3.5	3.25	5.375	6.202	7.600	3.1003	3.5	2.6875	9.6211	7.5491	75,491	94,364	132,109	72,158	96,211	56,618	75,491
3.75	3	5.75	6.641	8.131	3.3170	3.75	2.875	11.0447	8.6412	86,412	108,015	151,221	82,835	110,447	64,809	86,412
4	3	6.125	7.074	8.661	3.5670	4	3.0625	12.5664	9.9929	99,929	124,911	174,876	94,248	125,664	74,947	99,929
4.25	2.875	6.5	7.508	9.191	3.7982	4.25	3.25	14.1863	11.3302	113,302	141,628	198,279	106,397	141,863	84,977	113,302
4.5	2.75	6.875	7.941	9.721	4.0276	4.5	3.4375	15.9043	12.7405	127,405	159,256	222,959	119,282	159,043	95,554	127,405
4.75	2.625	7.25	8.374	10.252	4.2551	4.75	3.625	17.7205	14.2205	142,205	177,756	248,859	132,904	177,205	106,654	142,205
5	2.5	7.625	8.807	10.782	4.4804	5	3.8125	19.6350	15.7659	157,659	197,074	275,903	147,263	196,350	118,244	157,659
5.25	2.5	8	9.240	11.312	4.7304	5.25	4	21.6475	17.5745	175,745	219,681	307,554	162,356	216,475	131,809	175,745
5.5	2.375	8.375	9.673	11.842	4.9530	5.5	4.1875	23.7583	19.2678	192,678	240,848	337,187	178,187	237,583	144,509	192,678
5.75	2.375	8.75	10.106	12.373	5.2020	5.75	4.375	25.9672	21.2520	212,620	265,775	372,085	194,754	259,672	159,465	212,620
6	2.25	9.125	10.539	12.903	5.4227	6	4.5625	28.2743	23.0947	230,947	288,684	404,157	212,057	282,743	173,210	230,947

{ Diameters at bottom of thread.
{ Sharp V of 60° angle = diameter of bolt − (1.73205 × pitch of thread).
{ Sellers or .75 depth of thread = diameter of bolt − (1.2990375 × pitch of thread).

Flats of hexagon or square nuts = 1.5 diameter of bolt + .125.
Corners of hexagon nuts = 1.155 flats.
Corners of square nuts = 1.414 flats.
Thickness of nuts = diameter of bolt.
Thickness of heads × flats of heads and nuts ÷ 2.
Sizes of "Sellers" or "Franklin Institute" finished heads and nuts are (flats and thickness of U. S. rough and finished nuts) −.0625. Rough heads, same thickness as U. S. nuts.

Nuts and Washers, Number to the Pound

United States Standard Nuts

Approximate Number in One Hundred Pounds

Size of bolt, inches	Hot pressed				Cold punched			
	Blank		Tapped		Plain		Chamfered, trimmed and reamed	
	Square	Hexagon	Square	Hexagon	Square blank	Hexagon blank	Square blank	Hexagon blank
1/4	7200	8400	7500	9000	6700	7500	7400	8880
5/16	4010	5300	4500	5500	4100	4700	4000	4800
3/8	2540	3070	2720	3200	2400	2800	2730	3276
7/16	1750	2080	1900	2170	1550	1830	1700	2040
1/2	1175	1430	1250	1512	1100	1300	1160	1392
9/16	910	1030	980	1150	825	990	900	1080
5/8	655	798	700	850	580	700	653	784
3/4	387	479	408	528	348	438	386	463
7/8	260	315	264	332	228	290	260	312
1	172	216	176	230	156	198	170	204
1 1/8	133	155	139	180	122	140	122	146
1 1/4	98	114	101	129	88	103	90	108
1 3/8	73	91	77	96	65	77	69	83
1 1/2	58	73	61	77	54	63	54	65
1 5/8	44	57	49	60	42	50	43	52
1 3/4	38	41	40	44	33	39	35	42
1 7/8	31	39	33	40	27	31	29	35
2	25	32	27	33	23	28	24	29
2 1/8	20	25	21	26	19	24	20 1/4	26
2 1/4	18	21	18 1/2	22	17	20	17	23
2 3/8	15	20	15 3/4	20 1/2	......	......	15	20
2 1/2	12	16	12 1/2	16 1/2	......	......	12	16
2 3/4	9	11	9 1/2	11 3/4	......	......	......	......
3	7	8 1/2	7 3/4	9	......	......	......	......

Wrought Steel Plate Washers

Fig. 41.

In 200-pound Kegs. List prices per 100 pounds.

Size of bolt, inches	Outside diameter, inches	Size of hole, inches	Thickness, English standard wire gauge	Approximate number in 100 pounds	Per 100 pounds
			No.		
3/16	9/16	1/4	18	44,075	$14.00
1/4	3/4	5/16	16	13,845	12.20
5/16	7/8	3/8	16	11,220	11.40
3/8	1	7/16	14	6,573	10.50
7/16	1 1/4	1/2	14	4,261	9.70
1/2	1 3/8	9/16	12	2,683	9.20
9/16	1 1/2	5/8	12	2,249	9.10
5/8	1 3/4	11/16	10	1,315	9.00
3/4	2	13/16	10	1,013	8.80
7/8	2 1/4	15/16	9	858	8.80
1	2 1/2	1 1/8	9	617	8.80
1 1/8	2 3/4	1 1/4	9	516	8.80
1 1/4	3	1 3/8	9	403	9.00
1 3/8	3 1/4	1 1/2	8	320	9.00
1 1/2	3 1/2	1 5/8	8	278	9.20
1 5/8	3 3/4	1 3/4	8	247	9.20
1 3/4	4	1 7/8	8	224	9.50
1 7/8	4 1/4	2	8	200	9.50
2	4 1/2	2 1/8	8	180	9.50

In ordering, always specify size of bolt.

Fig. 42.
Showing Lock Washer on Bolt.

When the nut is screwed upon the bolt, it first strikes the rib on the lock washer, which, being harder than the nut, progressively upsets and forces some of the metal of the nut into the thread of the bolt, thereby preventing the nut from backing off or loosening.

Can be used on any make of bolt or nut. The same bolt, nut and lock washer can be used as often as required.

Prices upon receipt of specifications.

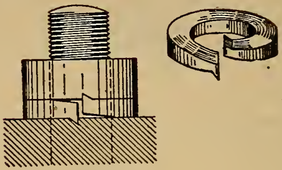


FIG. 43.

The positive lock washer is so constructed that the "body" of the washer carries the *load of compression* and the *tapered ends* are thus relieved and the spring is constant. The barbs, being free to move when subjected to vibration, force themselves deeply into the nut and metal backing.

Are reversible and can be used many times. Do not injure the nut, its thread, or the threads of the bolt.

Machine Bolts

Approximate Weight per 100 of Machine Bolts with Square Heads and Square Nuts

Length	¼ Pound	5/16 Pound	⅜ Pound	7/16 Pound	½ Pound	9/16 Pound	⅝ Pound
¾	2.55	4.4	7.71	10	....	....	....
⅞	2.64	4.65	8.04	10.53	....	....	....
1	2.73	4.9	8.36	11.03	15.5	19.8	28.95
1¼	2.9	5.4	9.01	11.9	16.7	21.6	30.89
1½	3.08	5.9	9.66	12.8	17.9	23.4	31.83
2	3.43	6.8	10.94	14.5	20.4	27	36.7
2½	4.45	7.8	12.74	17.25	24.91	31.5	41.55
3	5.45	8.7	14.37	18.75	27.64	33.1	45.4
3½	6.46	9.7	15.83	20.90	29.74	36.7	49.28
4	7.09	10.7	17.3	23.09	32.89	40.3	53.16
4½	7.7	11.7	18.76	25.27	34.98	43	57.04
5	8.3	12.7	20.2	27.50	36.01	47.3	61.9
5½	8.9	13.7	21.58	29.59	38.61	50.9	65.77
6	9.5	14.7	22.95	31.68	41.22	52.9	68.9
6½	10.2	15.7	24.42	33.9	43.82	56.5	72.77
7	10.8	16.7	25.9	35.73	46.42	60.7	76.71
7½	11.5	17.7	27.37	37.56	49.02	64.3	80.58
8	12.1	18.7	28.84	39	51.64	67.9	84.45
9	13.4	20.8	31.8	43.18	56.84	75.1	92.19
10	14.6	22.9	34.75	47.36	62.04	82.3	99.94
11	15.8	24.9	37.7	51.6	67.24	89.5	107.69
12	17	26.9	40.65	55.76	72.44	96.7	115.44
13	18.2	28.9	43.6	59.92	77.64	103.9	123.19
14	19.4	31.0	46.55	64.20	82.84	111.1	130.94
15	20.6	33	49.5	68.36	88.04	118.3	138.69
16	21.8	35	52.45	72.52	93.24	125.5	146.44
17	23	37	55.4	76.68	98.44	132.7	154.19
18	24.2	39	58.35	80.84	103.64	139.9	161.94
19	25.4	41	61.3	85	108.83	147.1	169.69
20	26.6	43	64.25	89.16	114.04	154.3	177.44
21	27.8	45	67.20	93.32	119.20	161.5	185.19
22	29	47	70.15	97.48	124.44	168.7	192.94
23	30.2	49	73.1	101.64	129.65	175.9	200.69
24	31.4	51	76.05	105.80	134.80	183.1	208.44
25	32.6	53	79	109.96	140.04	190.3	216.19
26	33.8	55	81.95	114.12	145.24	197.5	224.94
27	35	57	84.9	118.28	150.44	204.7	232.19
28	36.2	59	87.8	122.44	155.64	211.9	240.44
29	37.4	61	90.75	126.60	160.84	219.1	248.24
30	38.6	63	93.7	130.76	166.04	226.3	254.94

Approximate Weight per 100 of Machine Bolts with Square Heads and Square Nuts — (*Continued*)

Length	¾ Pound	⅞ Pound	1 Pound	1⅛ Pounds	1¼ Pounds	1½ Pounds
¾	....	....	....	....	....	....
⅞	....	....	....	....	....	....
1	47.63	....	....	....	....	....
1¼	50.10	....	....	....	....	....
1½	52.57	81.25	....	....	....	....
2	57.6	90.63	137.50	178.00	235.37	....
2½	63.44	98.63	149.10	192.87	253.75	....
3	69.84	106.3	160.75	207.75	272.12	458
3½	75.93	114.30	171.55	222.62	290.50	483
4	81.77	122.30	182.35	237.50	308.88	508
4½	87.61	130.30	193.15	252.38	327.25	533
5	93.45	138.30	203.90	267.25	345.62	558
5½	99.46	146.30	214.75	282.13	364.00	583
6	105.13	154.30	225.65	297.00	382.37	608
6½	111.14	162.30	236.35	311.87	399.22	633
7	117.15	170.30	247.15	316.75	416.07	658
7½	123.16	178.30	257.95	321.62	432.92	683
8	129.17	186.30	268.75	336.49	449.77	708
9	141.19	202.30	290.35	366.23	483.47	758
10	153.21	218.30	311.95	395.98	517.17	808
11	165.23	234.30	333.55	425.73	550.87	858
12	177.25	250.30	355.15	455.48	584.57	908
13	189.27	266.30	376.75	485.33	618.27	958
14	201.29	282.30	398.35	514.98	651.97	1008
15	213.31	298.30	419.95	544.73	685.67	1058
16	225.33	314.30	441.55	574.48	719.37	1108
17	237.35	330.30	463.15	604.23	753.07	1158
18	249.37	346.30	484.75	633.98	786.77	1208
19	261.39	362.30	506.35	663.73	610.47	1258
20	273.41	378.30	527.95	693.48	844.17	1308
21	285.43	394.30	549.55	723.23	877.17	1358
22	297.45	410.30	571.15	752.98	911.57	1408
23	309.47	426.30	592.75	782.73	945.27	1458
24	321.49	442.30	614.35	812.48	978.97	1508
25	333.51	458.30	635.95	842.23	1012.67	1558
26	345.53	464.30	657.55	871.98	1046.37	1608
27	357.55	480.30	679.15	901.73	1080.07	1658
28	369.57	496.30	700.75	931.48	1113.77	1708
29	381.59	512.30	722.35	961.23	1147.47	1758
30	393.61	528.30	743.95	990.98	1181.17	1808

These weights are for bolts with bolt size nuts, and with heads of diameter equal to 1½ times diameter of bolt, and thickness equal to ¾ times diameter of bolt.

Machine Bolts with Square or Button Heads, Square Nuts and Finished Points

Adopted Sept. 20, 1899, to take effect Oct. 1, 1899. List prices per 100.

Length, inches	Diameter, inches										
	¼	5/16	⅜	7/16	½	9/16 and ⅝	¾	⅞	1	1⅛	1¼
1½	$1.70	$2.00	$2.40	$2.80	$3.60	$5.20	$7.20	$10.50	$15.10	$22.50	$30.00
2	1.78	2.12	2.56	3.00	3.86	5.58	7.70	11.20	16.00	23.70	31.50
2½	1.86	2.24	2.72	3.20	4.12	5.96	8.20	11.90	16.90	24.90	33.00
3	1.94	2.36	2.88	3.40	4.38	6.34	8.70	12.60	17.80	26.10	34.50
3½	2.02	2.48	3.04	3.60	4.64	6.72	9.20	13.30	18.70	27.30	36.00
4	2.10	2.60	3.20	3.80	4.90	7.10	9.70	14.00	19.60	28.50	37.50
4½	2.18	2.72	3.36	4.00	5.16	7.48	10.20	14.70	20.50	29.70	39.00
5	2.26	2.84	3.52	4.20	5.42	7.86	10.70	15.40	21.40	30.90	40.50
5½	2.34	2.96	3.68	4.40	5.68	8.24	11.20	16.10	22.30	32.10	42.00
6	2.42	3.08	3.84	4.60	5.94	8.62	11.70	16.80	23.20	33.30	43.50
6½	2.50	3.20	4.00	4.80	6.20	9.00	12.20	17.50	24.10	34.50	45.00
7	2.58	3.32	4.16	5.00	6.46	9.38	12.70	18.20	25.00	35.70	46.50
7½	2.66	3.44	4.32	5.20	6.72	9.76	13.20	18.90	25.90	36.90	48.00
8	2.74	3.56	4.48	5.40	6.98	10.14	13.70	19.60	26.80	38.10	49.50
9	2.90	3.80	4.80	5.80	7.50	10.90	14.70	21.00	28.60	40.50	52.50
10	3.06	4.04	5.12	6.20	8.02	11.66	15.70	22.40	30.40	42.90	55.50
11	3.22	4.28	5.44	6.60	8.54	12.42	16.70	23.80	32.20	45.30	58.50
12	3.38	4.52	5.76	7.00	9.06	13.18	17.70	25.20	34.00	47.70	61.50
13	....	....	6.08	7.40	9.58	13.94	18.70	26.60	35.80	50.10	64.50
14	....	....	6.40	7.80	10.10	14.70	19.70	28.00	37.60	52.50	67.50
15	....	....	6.72	8.20	10.62	15.46	20.70	29.40	39.40	54.90	70.50
16	....	....	7.04	8.60	11.14	16.22	21.70	30.80	41.20	57.30	73.50
17	....	....	7.36	9.00	11.66	16.98	22.70	32.20	43.00	59.70	76.50
18	....	....	7.68	9.40	12.18	17.74	23.70	33.60	44.80	62.10	79.50
19	....	....	8.00	9.80	12.70	18.50	24.70	35.00	46.60	64.50	82.50
20	....	....	8.32	10.20	13.22	19.26	25.70	36.40	48.40	66.90	85.50
21	....	....	....	....	13.74	20.02	26.70	37.80	50.20	69.30	88.50
22	....	....	....	....	14.26	20.78	27.70	39.20	52.00	71.70	91.50
23	....	....	....	....	14.78	21.54	28.70	40.60	53.80	74.10	94.50
24	....	....	....	....	15.30	22.30	29.70	42.00	55.60	76.50	97.50
25	....	....	....	....	15.82	23.06	30.70	43.40	57.40	78.90	100.50
26	....	....	....	....	....	....	31.70	44.80	59.20	81.30	103.50
27	....	....	....	....	....	....	32.70	46.20	61.00	83.70	106.50
28	....	....	....	....	....	....	33.70	47.60	62.80	86.10	109.50
29	....	....	....	....	....	....	34.70	49.00	64.60	88.50	112.50
30	....	....	....	....	....	....	35.70	50.40	66.40	90.90	115.50

Bolts with hexagon heads or hexagon nuts, 10 per cent advance.

If both hexagon heads and hexagon nuts, 20 per cent advance.

Machine bolts with countersunk head, joint bolts with oblong nuts, bolts with tee heads, askew heads, and eccentric heads, 10 per cent advance.

Bolts with cube heads, 20 per cent advance.

Bolts requiring extra upsets to form the head, 20 per cent advance for each extra upset.

Special bolts with irregular threads and unusual dimensions of heads or nuts will be charged extra at the discretion of the manufacturer.

Bolts with cotter pin hole, prices upon application. In ordering bolts with cotter pin hole, state size of hole, and distance from end of bolt to center of hole.

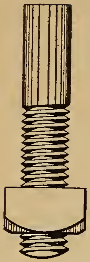


FIG. 44.

Bolt Ends and Lag Screws

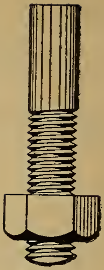


FIG. 45.

BOLT ENDS FITTED WITH SQUARE NUTS*

Adopted Jan. 30, 1895, to take effect Feb. 14, 1895.
List prices per pound.

Size of iron, inches	Length, inches	Length of thread, inches	Price per pound	Size of iron, inches	Length, inches	Length of thread, inches	Price per pound
5/16	6	1	$0.20	1 1/8	13	4 1/2	$0.10
3/8	7	1 1/4	.18	1 1/4	14	5	.11
7/16	7	1 1/2	.16	1 3/8	15	5 1/2	.11
1/2	8	2 1/2	.14	1 1/2	16	6	.11
5/8	9	3	.12	1 5/8	17	6 1/2	.12
3/4	10	3 1/2	.10	1 3/4	18	7	.12
7/8	11	3 1/2	.10	1 7/8	19	7 1/2	.12
1	12	4	.10	2	20	8	.12

* With hexagon nuts, 10 per cent advance.

Prices of bolt ends shorter than above standard lengths will be quoted upon application.

Coach Screws with *Square or Washer Heads; Gimlet Points

List prices per 100.

Length, inches	¼ and 5⁄16	⅜	7⁄16	½	9⁄16 and ⅝	¾	⅞	1
1½	$2.25	$2.70	$3.15	$3.75	......	....	....	......
2	2.45	2.96	3.47	4.11	$6.00	....	....	......
2½	2.65	3.22	3.79	4.47	6.50	$9.20	....	......
3	2.85	3.48	4.11	4.83	7.00	9.90	$15.00	......
3½	3.05	3.74	4.43	5.19	7.50	10.60	16.00	$22.00
4	3.25	4.00	4.75	5.55	8.00	11.30	17.00	23.30
4½	3.45	4.26	5.07	5.91	8.50	12.00	18.00	24.60
5	3.65	4.52	5.39	6.27	9.00	12.70	19.00	25.90
5½	3.85	4.78	5.71	6.63	9.50	13.40	20.00	27.20
6	4.05	5.04	6.03	6.99	10.00	14.10	21.00	28.50
6½	......	......	6.35	7.35	10.50	14.80	22.00	29.80
7	......	......	6.67	7.71	11.00	15.50	23.00	31.10
7½	......	......	6.99	8.07	11.50	16.20	24.00	32.40
8	......	......	7.31	8.43	12.00	16.90	25.00	33.70
9	......	......	7.95	9.15	13.00	18.30	27.00	36.30
10	......	......	......	9.87	14.00	19.70	29.00	38.90
11	......	......	......	10.59	15.00	21.10	31.00	41.50
12	......	......	......	11.31	16.00	22.50	33.00	44.10

* Coach screws with hexagon and tee heads, 10 per cent advance.

Weights of Nuts and Bolt Heads in Pounds. Kent

For calculating the weight of long bolts.

Diameter of bolt, in inches..........	....	¼	⅜	½	⅝	¾	⅞
Weight of hexagon nut and head.....	....	.017	.057	.128	.267	.43	.73
Weight of square nut and head......	....	.021	.069	.164	.320	.55	.88
Diameter of bolt in inches...........	1	1¼	1½	1¾	2	2½	3
Weight of hexagon nut and head.....	1.10	2.14	3.78	5.6	8.75	17	28.8
Weight of square nut and head......	1.31	2.56	4.42	7.0	10.50	21	36.4

Steel Set Screws

List Price per 100.

Diameter of screw, inch	¼	5/16	⅜	7/16	*½	9/16	⅝	¾	⅞	1	⅛	1¼
Threads per inch	20	18	16	14	*12 and 13	12	11	10	9	8	7	7
Length (inches) under head to extreme point: ¾	$2.50	$2.75	$3.10	$3.60	$4.25	$5.30	$6.25	....	....	....	....	....
1	2.65	2.90	3.30	3.90	4.50	5.30	6.25	$8.75	....	....	....	....
1¼	2.85	3.10	3.50	4.15	4.75	5.60	6.55	8.75	$14.10	....	....	....
1½	3.05	3.30	3.70	4.40	5.00	5.90	6.90	9.35	14.10	$18.60	....	....
1¾	3.25	3.50	3.90	4.65	5.25	6.25	7.25	10.00	15.00	19.80	$24.40	....
2	3.50	3.75	4.15	4.95	5.55	6.60	7.60	10.75	16.10	21.25	26.35	$31.60
2¼	3.80	4.05	4.45	5.30	5.90	7.05	8.00	11.60	17.25	23.00	28.60	34.25
2½	4.10	4.45	4.80	5.75	6.35	7.55	8.50	12.50	18.50	24.70	30.85	37.00
2¾	4.45	4.80	5.25	6.20	6.85	8.10	9.05	13.50	19.85	26.65	33.40	40.00
3	4.75	5.20	5.70	6.75	7.45	8.75	9.70	14.60	21.35	28.75	36.00	43.25
3¼	....	5.55	6.10	7.30	8.05	9.45	10.45	15.85	23.00	30.85	38.75	46.75
3½	....	....	6.55	7.90	8.70	10.15	11.20	17.10	24.60	33.25	41.50	50.25
3¾	....	....	....	8.50	9.35	10.85	11.95	18.35	26.25	35.15	44.30	53.75
4	....	....	....	....	9.95	11.50	12.70	19.60	27.85	37.25	47.00	57.25
4¼	....	....	....	....	....	12.20	13.45	20.85	29.50	39.40	49.75	60.75
4½	....	....	....	....	....	....	14.20	22.10	31.00	41.50	52.50	64.30
4¾	....	....	....	....	....	....	....	23.40	32.75	43.60	55.25	67.95
5	....	....	....	....	....	....	....	....	34.40	45.75	58.00	71.25
Add for each ¼ inch	.35	.40	.50	.60	.70	.80	.90	1.30	1.75	2.30	3.00	3.75

State whether V or U. S. Standard threads are wanted; also style of point. *When not specified*, cup points are sent (U. S. Standard).

* On ½-inch screws, state whether 12 or 13 threads are wanted. *When not specified*, 13 threads are sent (U. S. Standard).

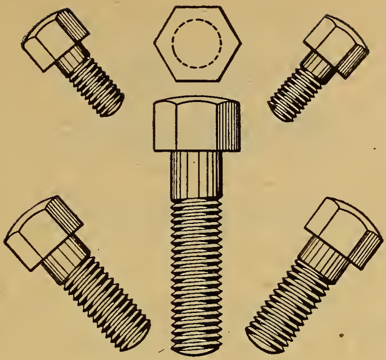


Fig. 46.

On all screws of one inch and less in diameter, and less than four inches long, threads are cut $\frac{3}{4}$ of the length. Beyond four inches, threads are cut half the length.

Regular cap screws are soft and have ground heads. Special prices on black heads, extra finished and case hardened screws.

Cap screws with over-sized heads take the list of regular cap screws with the same-sized heads.

Price of steel screws will be 25 per cent above the price of iron.

Drop-Forged Turn-Buckles

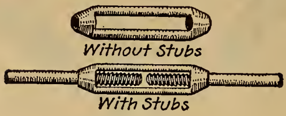


Fig. 47.

With right and left U. S. Standard thread.

List prices with and without stubs.

Diameter of stub, inches	Inside opening of buckle, inches	Length over all (including stubs), inches	Each
¼	3	14	$0.36
5/16	3	14	.38
⅜	5	19½	.40
7/16	5	19½	.42
½	6	21	.45
½	9	24	.56
9/16	6	22	.48
⅝	6	23	.50
⅝	9	26	.63
¾	6	23	.63
¾	9	26	.79
⅞	6	23	.75
⅞	9	26	.94
1	6	23	.88
1	9	26	1.10
1⅛	6	24	1.00
1⅛	9	27	1.25
1¼	6	25	1.25
1¼	9	28	1.56
1⅜	6	26	1.38
1⅜	9	29	1.73
1½	6	26	1.50
1½	9	29	1.88
1⅝	6	26	1.75
1¾	6	27	2.00
1⅞	6	28	2.25
2	6	29	2.65

Drop-Forged Turn-Buckles

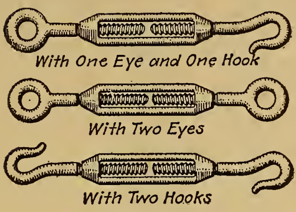


Fig. 48.

With right and left U. S. Standard thread.

List prices with either one hook and one eye, two eyes, or two hooks.

Diameter of threaded end, inches	Inside opening of buckle, inches										
	3	5	6	9	12	15	18	24	36	48	72
¼	$0.40	....	....	....	....	....	....	....	....	....	....
5/16	.45	....	....	....	....	....	....	....	....	....	....
⅜	....	$0.65	....	....	....	....	....	....	....	....	....
½	....	....	$0.72	$0.85	$0.95	$1.15	....	....	....	....	....
⅝	....	....	.80	.95	1.05	1.30	$1.55	$2.05	....	....	....
¾	....	....	1.10	1.25	1.00	1.70	2.00	2.65	....	....	....
⅞	....	....	1.35	1.55	1.70	2.10	2.45	3.20	....	....	....
1	....	....	1.65	1.85	2.05	2.50	2.95	3.80	$4.25	....	....
1⅛	....	....	2.10	2.35	2.55	3.05	3.55	4.55	5.05	....	....
1¼	....	....	2.65	2.95	3.25	3.90	4.50	5.75	6.40	$8.90	....
1⅜	....	....	3.15	3.45	3.80	4.50	5.20	6.60	7.25	10.00	....
1½	....	....	3.70	4.05	4.45	5.20	5.95	7.45	8.20	11.20	$14.20
1⅝	....	....	4.65	....	5.50	6.40	7.25	9.00	9.90	13.40	16.90
1¾	....	....	5.30	....	6.40	7.40	8.40	10.40	11.40	15.40	19.40
1⅞	....	....	6.50	....	7.60	8.75	9.85	12.10	13.25	17.75	22.25
2	....	....	7.75	....	9.10	10.40	11.75	14.40	15.75	21.00	26.30

Steel Spring Cotters

Fig. 49.

These cotters are made of the best quality, half round, spring wire. The length measurements given are from point to neck, or under the eye. Length, price per 1000.

Diameter	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	No. in a box
3/32	4.80	5.45	6.10	6.75	7.40	......	......	......	......	......	......	......	......	500
7/64	5.50	6.25	7.00	7.75	8.00	......	......	......	......	......	......	......	......	500
1/8	6.70	7.55	8.40	9.25	10.10	10.95	11.80	......	......	......	......	......	......	500
9/64	8.00	9.00	10.00	11.00	12.00	13.00	14.00	......	......	......	......	......	......	500
5/32	9.30	10.45	11.60	12.75	13.90	15.05	16.20	......	......	......	......	......	......	500
11/64	10.60	11.90	13.20	14.50	15.80	17.10	18.40	......	......	......	......	......	......	500 to 250
3/16	12.20	13.80	15.40	17.00	18.60	20.20	21.80	23.40	25.00	......	......	......	......	500 to 250
13/64	14.00	16.00	18.00	20.00	22.00	24.00	26.00	28.00	30.00	......	......	......	......	500 to 250
7/32	16.00	18.50	21.00	23.50	26.00	28.50	31.00	33.50	36.00	......	......	......	......	500 to 250
1/4	20.00	23.50	27.00	30.50	34.00	37.50	41.00	44.50	48.00	51.50	55.00	58.50	62.00	500 to 250
5/16	29.00	33.50	28.00	42.50	47.00	51.50	56.00	60.00	65.00	69.50	74.00	78.50	83.00	250 to 100

Thumb Screws, Drop-Forged Steel, Threaded, U. S. Standard

Fig. 50.

Can be furnished in styles A to F.

List prices per 100.

Diameter, inches	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4
Threads per inch	40	24	20	18	16	14	13	12	11	10
Length under head, inches: 1/4	$3.20	$3.60	$4.10	$4.80	$5.90	....	......	......	.....	....
1/2	3.40	3.80	4.30	5.00	6.10	$7.60	$9.50	$11.70	......	....
3/4	3.60	4.00	4.50	5.20	6.40	8.00	10.00	12.40	.....	....
1	3.80	4.20	4.70	5.50	6.80	8.50	10.60	13.10	$16.00	$23.10
1 1/4	4.00	4.40	4.90	5.80	7.20	9.00	11.20	13.80	16.80	24.40
1 1/2	4.20	4.60	5.10	6.20	7.60	9.50	11.90	14.60	17.80	25.80
1 3/4	....	4.80	5.40	6.60	8.10	10.10	12.60	15.50	18.80	27.20
2	....	5.00	5.70	7.00	8.60	10.70	13.30	16.40	19.90	28.60
2 1/4	....	....	6.10	7.40	9.20	11.40	14.10	17.30	21.00	30.10
2 1/2	....	....	6.50	7.90	9.80	12.10	14.90	18.30	22.10	31.60
2 3/4	....	....	6.90	8.40	10.40	12.80	15.80	19.30	23.30	33.10
3	....	....	7.40	8.90	11.00	13.50	16.70	20.30	24.50	34.70
3 1/2	....	....	....	10.00	12.30	15.10	18.50	22.50	27.00	38.10
4	...	....	....	11.20	13.80	16.90	20.50	24.80	29.70	41.50
4 1/2	....	....	....	....	15.40	18.70	22.70	27.40	32.70	45.20
5	....	....	....	....	17.00	20.70	25.20	30.30	36.00	49.60
5 1/2	....	....	....	....	18.80	22.90	27.80	33.30	39.60	54.30
6	....	....	....	....	....	....	30.40	36.60	43.60	60.00

Round Head Iron Rivets

Approximate number in one pound.

Length, inches	Diameter of wire													
	3/8	0	5/16	1	2	3	1/4	4	5	6	3/16	7	8	9
3/8	...	...	...	...	...	...	...	...	...	154	188	221	256	334
1/2	32	42	51	57	65	75	80	89	108	131	159	185	215	278
5/8	29	37	45	50	57	67	70	78	94	114	138	158	185	238
3/4	26	33	41	45	51	59	63	70	84	101	122	139	163	208
7/8	24	30	37	41	46	54	57	63	75	91	109	123	145	185
1	22	28	34	39	42	49	52	57	68	82	98	111	131	166
1 1/8	20	26	31	34	39	45	47	53	63	75	90	101	119	151
1 1/4	19	24	29	32	36	42	44	49	58	69	83	93	109	138
1 3/8	18	22	27	29	33	39	41	45	54	64	76	86	101	127
1 1/2	17	21	25	28	31	37	38	42	51	59	71	80	94	119
1 3/4	15	18	22	24	27	33	34	40	44	55	63	70	82	104
2	13	17	20	22	25	29	30	35	40	47	56	62	73	92
2 1/4	12	15	18	19	22	27	28	32	36	42	50	56	66	83
2 1/2	11	14	17	18	20	24	25	29	33	39	46	50	60	75
2 3/4	10	13	15	17	19	22	23	26	30	36	42	46	55	67
3	9	12	14	15	17	21	22	24	28	33	39	43	51	64
3 1/4	8 1/2	11	13	14	16	19	20	23	26	31	36	40	47	59
3 1/2	8	10 1/2	12	13 1/2	15	18	19	21	24	29	34	38	44	55
3 3/4	7 1/2	9 3/4	11 3/4	12 3/4	14	17	18	20	23	27	32	35	41	52
4	7 1/4	9 1/4	11	12	13	16	17	18	21	25	30	33	38	49
4 1/4	7	8 3/4	10 1/2	11 1/4	12 3/4	15	16	17	20	24	..	..	..	..
4 1/2	6 1/2	8 1/4	10	10 3/4	12	14	15	16	19	23	..	..	..	..
4 3/4	6 1/4	8	9 1/4	10	11 1/2	13 3/4	14 3/4	15 3/4	18	22	..	..	..	..
5	6	7 1/2	9	9 3/4	11	13	14	15	17	21	..	..	..	..
5 1/4	5 3/4	7 1/4	8 1/2	9 1/4	10 1/2	12 1/2	13 1/2	14 1/2	16 1/2	20	..	..	..	..
5 1/2	5 1/2	7	8 1/4	9	10	12	13	14	16	19	..	..	..	..
5 3/4	5 1/4	6 3/4	7 3/4	8 1/2	9 1/2	11 1/2	12 1/2	13 1/2	15	18	..	..	..	..
6	5	6 1/2	7 1/2	8 1/4	9 1/4	11	12	13	14	17	..	..	..	..

3 1/2 cents per pound, net.

Dimensions of Standard Wrot Pipe

Nominal inside diameter	Actual inside diameter	Actual outside diameter		Thickness	Number of threads per inch	Diameter at bottom of thread at end of pipe	Size of drill	Length of perfect thread	Diameter at top of thread at end of pipe	Internal diameter.
Ins.	Ins.		Ins.				Ins.			
1/8	.269	.405	3/8+1/32	.068	27	.334	21/64	.19	.393	.27
1/4	.364	.54	1/2+1/32	.088	18	.433	7/16	.29	.522	.36
3/8	.493	.675	11/16	.091	18	.567	9/16	.3	.658	.49
1/2	.622	.84	13/16+1/32	.109	14	.701	11/16	.39	.815	.62
3/4	.824	1.05	1 1/16	.113	14	.911	29/32	.4	1.025	.82
1	1.047	1.315	1 5/16	.134	11 1/2	1.144	1 5/32	.51	1.283	1.05
1 1/4	1.38	1.66	1 11/16	.140	11 1/2	1.488	1 15/32	.54	1.627	1.38
1 1/2	1.61	1.90	1 15/16	.145	11 1/2	1.727	1 23/32	.55	1.866	1.61
2	2.067	2.375	2 3/8	.154	11 1/2	2.2	2 7/32	.58	2.339	2.07
2 1/2	2.467	2.875	2 7/8	.204	8	2.62	2 5/8	.89	2.82	2.47
3	3.066	3.50	3 1/2	.217	8	3.24	3 1/4	.95	3.441	3.07
3 1/2	3.548	4.00	4	.226	8	3.738	3 23/32	1	3.938	3.55
4	4.026	4.50	4 1/2	.237	8	4.233	4 1/4	1.05	4.434	4.07
4 1/2	4.508	5.00	5	.246	8	4.733	4 3/4	1.1	4.931	4.51
5	5.045	5.563	5 9/16	.259	8	5.289	5 9/32	1.16	5.489	5.04
6	6.065	6.625	6 5/8	.280	8	6.347	6 11/32	1.26	6.547	6.06
7	7.023	7.625	7 5/8	.301	8	7.34	7 11/32	1.36	7.54	7.02
8	7.981	8.625	8 5/8	.322	8	8.332	8 11/32	1.46	8.534	7.98
9	8.937	9.625	9 5/8	.344	8	9.324	9 3/8	1.56	9.527	8.93
10	10.018	10.75	10 3/4	.366	8	10.445	10 7/16	1.68	10.645	10.02
11	11	11.75	11 3/4	.375	8	11.439	11 7/16	1.80	11.639	11
12	12	12.75	12 3/4	.375	8	12.433	12 27/64	1.90	12.633	12
13	13.25	14	14	.375	8	13.675	13 43/64	1.98	13.875	13.25
14	14.25	15	15	.375	8	14.668	14 21/32	2.15	14.869	14.25
15	15.25	16	16	.375	8	15.662	15 21/32	2.21	15.863	15.25
16	16.25	17	17	.375	8	16.656	16 21/32	2.30	16.856	16.25
17	17.25	18	18	.375	8	17.65	17 21/32	2.40	17.85	17.25
18	18.25	19	19	.375	8	18.644	18 41/64	2.50	18.844	18.25
19	19.25	20	20	.375	8	19.637	19 5/8	2.59	19.837	19.25
20	20.25	21	21	.375	8	20.631	20 5/8	2.72	20.831	20.25

Taper of conical tube ends 3/4 inch in diameter in 12 inches.

Contributed by Louis H. Frick. No. 74, Extra Data Sheet, Machinery, October, 1907.

Seamless drawn brass and copper tubes are made by American Tube Works, Boston, Mass.; Ansonia Brass and Copper Co., Ansonia, Conn., office 19 and 21 Cliff St., New York; Benedict & Burnham Mfg. Co., Waterbury, Conn., office 13 Murray St., New York; Randolph & Clowes, Waterbury, Conn., and Bridgeport Brass Co., Bridgeport, Conn. The following sizes are kept in stock, in 12 feet lengths, by Merchant & Co., 517 Arch St., Philadelphia. The five columns signify as follows:

A = outside diameter of tube in inches.

B = thickness of side by Stubs' (or Birmingham) gauge. When seamless tubes are ordered to gauge number, it is understood that *this* gauge is intended unless otherwise specified.

C = thickness of sides of tube in decimals of an inch.

D = weight, in pounds per lineal foot, of *brass* tube for columns *A*, *B* and *C*. (For copper, add one-nineteenth).

Tubes will be furnished hard, unless ordered annealed or soft.

A	*B*	*C*	*D*.	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
¼	18	.049	.11	1⅝	13	.095	1.68	2½	12	.109	3.02
5/16	18	.049	.15	1⅝	11	.120	2.10	2½	10	.134	3.68
⅜	17	.058	.22	1¾	15	.072	1.40	2⅝	14	.083	2.44
7/16	17	.058	.25	1¾	14	.083	1.61	2⅝	12	.109	3.18
½	17	.058	.29	1¾	13	.095	1.82	2⅝	10	.134	3.87
9/16	17	.058	.34	1¾	11	.120	2.27	2¾	14	.083	2.57
⅝	16	.065	.42	1⅞	15	.072	1.50	2¾	12	.109	3.37
¾	16	.065	.51	1⅞	14	.083	1.72	2¾	10	.134	4.07
⅞	16	.065	.61	1⅞	13	.095	1.96	2⅞	12	.109	3.50
1	16	.065	.70	1⅞	11	.120	2.44	2⅞	10	.134	4.26
1⅛	16	.065	.79	2	14	.083	1.84	3	10	.134	4.46
1¼	16	.065	.88	2	13	.095	2.10	3¼	10	.134	4.85
1¼	14	.083	1.12	2	10	.134	2.91	3½	10	.134	5.24
1¼	11	.120	1.57	2⅛	14	.083	1.97	3¾	10	.134	5.62
1⅜	15	.072	1.08	2⅛	13	.095	2.23	4	10	.134	6.00
1⅜	14	.083	1.25	2⅛	10	.134	3.10	4¼	10	.134	6.39
1⅜	11	.120	1.76	2¼	14	.083	2.08	4½	10	.134	6.78
1½	15	.072	1.19	2¼	13	.095	2.38	4¾	10	.134	7.17
1½	14	.083	1.36	2¼	10	.134	3.29	5	10	.134	7.56
1½	13	.095	1.55	2⅜	14	.083	2.20	5¼	10	.134	7.94
1½	11	.120	1.92	2⅜	13	.095	2.51	5½	10	.134	8.33
1⅝	15	.072	1.29	2⅜	10	.134	3.49	5¾	10	.134	8.72
1⅝	14	.083	1.48	2½	14	.083	2.33	6	10	.134	9.11

Merchant & Co. supply sizes up to 7 inches outside or inside diameter, and up to 16 inches inside diameter, of other gauges as well as those given in the table; also tubes of special shapes, such as square, triangular, octagonal, etc.; and bronze tubes.

They also have in stock, in lengths of 12 feet, the following sizes of seamless brass and copper tubing, made of same outside diameter as standard sizes of iron piping, so as to be used with the same fittings as the iron pipe.

A = *nominal* inside diameter of iron pipe, in inches. For *actual* inside diameters.

B = outside diameter of iron pipe and of seamless tube, in inches.

C = inside diameter of seamless tube, in inches.

D = weight per foot of *brass* pipe, cols. *B* and *C*. For copper, add one-nineteenth.

A	B	C	D	A	B	C	D	A	B	C	D
1/8	1 3/32	1/4	.28	3/4	1 1/16	2 7/32	1.15	2	2 3/8	2 1/16	4.15
1/4	1 7/32	1 1/32	.43	1	1 5/16	1 3/32	1.50	2 1/2	2 7/8	2 7/16	4.50
3/8	2 1/32	1 5/32	.58	1 1/4	1 5/8	1 11/32	2.25	3	3 1/2	3 1/16	8.00
1/2	1 3/16	3/8	.80	1 1/2	1 7/8	1 19/32	2.55	4	4 1/2	4 1/8	12.24

TIN AND ZINC

The pure metal is called block tin. — When perfectly pure (which it rarely is, being purposely adulterated, frequently to a large proportion, with the cheaper metals lead or zinc), its specific gravity is 7.29; and its weight per cubic foot is 455 pounds. It is sufficiently malleable to be beaten into tin foil, only 1/1000 of an inch thick. Its tensile strength is but about 4600 pounds per square inch; or about 7000 pounds when made into wire. It melts at the moderate temperature of 442° F. Pure block tin is not used for common building purposes; but thin plates of sheet iron covered with it on both sides constitute the *tinned plates*, or, as they are called, the *tin*, used for covering roofs, rain pipes and many domestic utensils. For roofs it is laid on boards.

The sheets of tin are united as shown in this Fig. First, several sheets are joined together in the shop, end for end, as at *tt*, by being first bent over, then hammered flat, and then soldered. These are then formed into a roll to be carried to the roof, a roll being long enough to reach from the peak to the eaves. Different rolls being spread up and down the roof are then united along their sides by simply being bent as at *a* and *s*, by a tool for that purpose. The roofers call the bending at *s* a *double groove*, or *double lock;* and the more simple ones at *t*, a *single groove*, or lock.

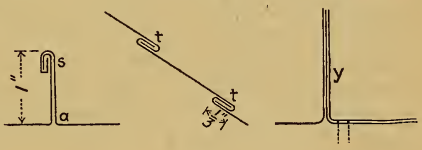


Fig. 51.

To hold the tin securely to the sheeting boards, pieces of the tin 3 or 4 inches long, by 2 inches wide, called cleats, are nailed to the boards at about every 18 inches along the joints of the rolls that are to be united, and are bent over with the double groove *s*. This will be understood from *y*, where the middle piece is the cleat, before being bent over. The nails should be 4-penny slating nails, which have broader heads than common ones. As they are not exposed to the weather, they may be of plain iron.

Much use is made of what is called leaded tin, or ternes, for roofing. It is simply sheet iron coated with lead, instead of the more costly metal tin. It is not as durable as the tinned sheets, but is somewhat cheaper.

The best plates, both for tinning and for ternes, are made of charcoal iron, which, being tough, bears bending better. Coke is used for cheaper plates, but inferior as regards bending. In giving orders, it is important to specify whether charcoal plates or coke ones are required; also whether *tinned* plates, or *ternes*.

Tinned and leaded sheets of Bessemer and other cheap steel are now much used. They are sold at about the price of charcoal tin and terne plates.

There are also in use for roofing, certain compound metals which resist tarnish better than either lead, tin, or zinc but which are so fusible as to be liable to be melted by large burning cinders falling on the roof from a neighboring conflagration.

A roof covered with tin or other metal should, if possible, slope not much *less* than five degrees, or about an inch to a foot; and at the eaves there should be a sudden fall into the rain-gutter, to prevent rain from backing up so as to overtop the double-groove joint *s*, and thus cause leaks. When coal is used for fuel, tin roofs should receive two coats of paint when first put up, and a coat at every 2 or 3 years after. Where wood only is used, this is not necessary; and a tin roof, with a good pitch, will last 20 or 30 years.

Two good workmen can put on, and paint outside, from 250 to 300 square feet of tin roof, per day of 8 hours.

Tinned iron plates are sold by the box. These boxes, unlike glass, have *not* equal areas of contents. They may be designated or ordered either by their names or sizes. Many makers, however, have their private brands in addition; and some of these have a much higher reputation than others.

SIZES AND WEIGHTS OF LEAD PIPES

Inner diameter, inches	Thickness, inches	Weight per foot, ounces	Inner diameter, inches	Thickness, inches	Weight per foot, pounds
3/8	.08	.10	1 1/2	.14	3.5
		Pounds			
3/8	.12	1.00	1 1/2	.17	4.25
3/8	.16	1.25	1 1/2	.19	5.00
3/8	.19	1.5	1 1/2	.23	6.5
1/2	.09	.75	1 1/2	.27	8.0
1/2	.11	1.0	1 3/4	.13	4.0
1/2	.13	1.25	1 3/4	.17	5.0
1/2	.16	1.75	1 3/4	.21	6.5
1/2	.19	2.0	1 3/4	.27	8.5
1/2	.25	3.0	2	.15	4.75
5/8	.09	1.0	2	.18	6.0
5/8	.13	1.5	2	.22	7.0
5/8	.16	2.0	2	.27	9.0
5/8	.20	2.5	2 1/2	3/16	8.0
3/4	.22	2.75	2 1/2	1/4	11.0
5/8	.25	3.5	2 1/2	5/16	14.0
3/4	.10	1.25	2 1/2	3/8	17.0
3/4	.12	1.75	3	3/16	9.0
3/4	.16	2.25	3	1/4	12.0
3/4	.20	3.0	3	5/16	16.0
3/4	.23	3.5	3	3/8	20.0
3/4	.30	4.75	3 1/2	3/16	9.5
1	.11	2.0	3 1/2	1/4	15.0
1	.14	2.5	3 1/2	5/16	18.5
1	.17	3.25	3 1/2	3/8	22.0
1	.21	4.0	4	3/16	12.5
1	.24	4.75	4	1/4	16.0
1 1/4	.10	2.0	4	5/16	21.0
1 1/4	.12	2.5	4	3/8	25.0
1 1/4	.14	3.0	4 1/2	3/16	14.0
1 1/4	.16	3.75	4 1/2	1/4	18.0
1 1/4	.19	4.75	5	1/4	20.0
1 1/4	.25	6.00	5	3/8	31.0

Proportions for Chain Hooks

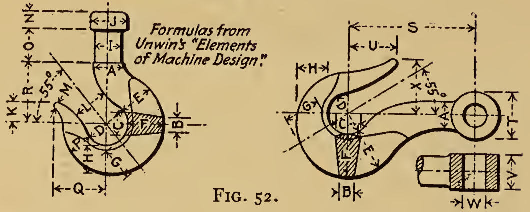


Fig. 52.

Tons	Lbs.	Common to both								Swivel hook										Plain hook					
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1/8	250	5/8	5/32	35/64	1 5/16	11/16	27/32	3/4	23/32	9/16	13/16	15/16	1	5/16	21/64	9/16	21/32	1 11/16	1 11/16	3	1 1/8	1 1/8	13/16	9/16	1 1/4
1/4	500	11/16	11/64	5/8	1 3/8	3/4	59/64	53/64	25/32	5/8	7/8	31/32	1 1/16	11/32	3/8	5/8	47/64	1 3/4	1 3/4	3 1/4	1 1/4	1 1/4	7/8	5/8	1 3/8
1/2	1,000	3/4	3/16	21/32	1 1/2	13/16	1	29/32	55/64	11/16	15/16	1 1/16	1 1/8	3/8	7/16	11/16	51/64	1 15/16	1 15/16	3 9/16	1 3/8	1 3/8	15/16	11/16	1 1/2
1	2,000	1 1/16	17/64	15/16	1 3/4	1 5/32	1 27/64	1 9/32	1 13/64	15/16	1 3/8	1 7/32	1 5/16	17/32	41/64	7/8	1 1/8	2 1/4	2 1/4	5	1 7/8	1 7/8	1 3/8	15/16	2 1/8
1 1/2	3,000	1 1/4	5/16	1 3/32	2	1 23/64	1 43/64	1 1/2	1 27/64	1 1/8	1 9/16	1 3/8	1 1/2	5/8	51/64	1 1/16	1 5/16	2 9/16	2 9/16	6	2 1/4	2 1/4	1 9/16	1 1/8	2 1/2
2	4,000	1 3/8	11/32	1 7/32	2 1/4	1 1/2	1 27/32	1 21/32	1 9/16	1 1/4	1 3/4	1 9/16	1 11/16	11/16	29/32	1 1/4	1 29/64	2 15/16	2 15/16	6 1/2	2 1/2	2 1/2	1 3/4	1 1/4	2 3/4
3	6,000	1 3/4	7/16	1 17/32	2 3/4	1 57/64	2 11/32	2 7/64	1 63/64	1 9/16	2 3/16	1 7/8	2	7/8	1 3/16	1 5/8	1 27/32	3 9/16	3 9/16	8 3/8	3 1/8	3 1/8	2 3/16	1 9/16	3 1/2
4	8,000	2	1/2	1 3/4	3 1/4	2 11/64	2 43/64	2 13/32	2 17/64	1 3/4	2 1/2	2 1/4	2 7/16	1	1 21/64	2	2 7/64	4 3/16	4 3/16	9 1/2	3 1/2	3 1/2	2 1/2	1 3/4	4
5	10,000	2 1/4	9/16	1 31/32	3 3/4	2 7/16	3	2 45/64	2 35/64	2	2 13/16	2 9/16	2 13/16	1 1/8	1 35/64	2 3/8	2 3/8	4 13/16	4 13/16	10	4	4	2 13/16	2	4 1/2
6	12,000	2 1/2	5/8	2 3/16	4 1/4	2 45/64	3 11/32	3	2 27/32	2 3/16	3 1/8	2 7/8	3 3/16	1 1/4	1 45/64	2 3/4	2 5/8	5 1/2	5 1/2	10 1/4	4 3/8	4 3/8	3 1/8	2 3/16	5
8	16,000	2 7/8	23/32	2 1/2	5 1/4	3 1/8	3 27/32	3 29/64	3 1/4	2 1/2	3 5/8	3 9/16	3 15/16	1 7/16	1 31/32	3 1/2	3 1/32	6 3/4	6 3/4	10 3/8	5	5	3 5/8	2 1/2	5 3/4
10	20,000	3 1/4	13/16	2 13/16	6 1/4	3 1/2	4 11/32	3 29/32	3 11/16	2 7/8	4	4 1/4	4 11/16	1 5/8	29/32	4 1/4	3 7/16	8	8	10 1/2	5 3/4	5 3/4	4	2 7/8	6 1/2

* Contributed by Walter Brown, Chicago, Ill. No. 33 Supplement to Machinery, June, 1904.

Chains and Cables

(United States Navy Standard.)

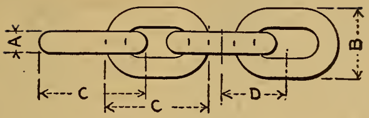


Fig. 53.

A	*B*	*C*	*D*	Pounds per foot	Load in pounds	
					Ultimate	Working
Inches	Inches	Inches	Inches			
¼	⅞	1 5/16	25/32	.875	3,360	670
5/16	1 1/16	1½	27/32	1.000	5,040	1,000
⅜	1¼	1¾	31/32	1.70	7,280	1,460
7/16	1⅜	2 1/16	1 5/32	2.00	10,080	2,020
½	1 11/16	2⅜	1 11/32	2.50	13,440	2,690
9/16	1⅞	2⅝	1 15/32	3.20	16,800	3,360
⅝	2 1/16	3	1 23/32	4.125	20,720	4,140
11/16	2¼	3¼	1 27/32	5.00	25,200	5,040
¾	2½	3½	1 31/32	5.875	30,240	6,050
13/16	2 11/16	3¾	2 3/32	6.70	35,280	7,060
⅞	2⅞	4	2 7/32	8.00	40,880	8,180
15/16	3 1/16	4⅜	2 15/32	9.00	47,040	9,410
1	3¼	4⅝	2 19/32	10.70	53,760	10,750
1 1/16	3 9/16	4⅞	2 23/32	11.20	60,480	12,100
1⅛	3¾	5⅛	2 27/32	12.50	68,320	13,660
1 3/16	3⅞	5 9/16	3 5/32	13.70	76,160	15,230
1¼	4⅛	5¾	3 7/32	16.00	84,000	17,000
1 5/16	4⅜	6⅛	3 15/32	16.50	91,840	18,400
1⅜	4 9/16	6⅜	3⅝	18.40	101,360	20,300
1 7/16	4¾	6 11/16	3 25/32	19.70	109,760	21,900
1½	5	7	3 31/32	21.70	120,960	24,200

CHAIN END LINK AND NARROW SHACKLE

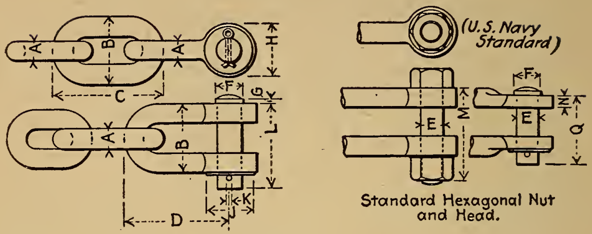


FIG. 54.

A	A_1	B	C	D	E	F	G	H	J	K	L	M	N	O
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
1/2	9/16	1 7/8	3 1/2	2 1/2	3/4	1 1/16	3/16	1 1/2	1 3/8	3/16	2 3/8	2 3/4	....	....
9/16	5/8	2 1/16	3 5/8	2 3/4	3/4	1 1/16	3/16	1 1/2	1 3/8	3/16	2 5/8	2 7/8	....	....
5/8	11/16	2 1/4	4 3/8	3	1	1 7/16	1/4	2	1 7/8	3/16	3	3 3/8	....	....
11/16	3/4	2 1/2	4 5/8	3 1/4	1	1 7/16	1/4	2	1 7/8	3/16	3 1/4	3 5/8	....	....
3/4	13/16	2 11/16	5	3 1/2	1 1/8	1 9/16	1/4	2 1/4	2 1/8	3/16	3 1/2	4	....	....
13/16	7/8	2 7/8	5 1/4	3 3/4	1 1/8	1 9/16	5/16	2 1/4	2 1/8	3/16	3 3/4	4 1/8	....	....
7/8	1	3 1/4	5 3/4	4 1/8	1 1/4	1 11/16	5/16	2 1/2	2 3/8	1/4	4 1/8	4 5/8	5/8	3 1/2
15/16	1 1/16	3 9/16	6	4 3/8	1 1/4	1 11/16	5/16	2 1/2	2 3/8	1/4	4 1/2	5	5/8	3 5/8
1	1 1/8	3 3/4	6 5/8	4 5/8	1 1/2	2 1/16	3/8	3	2 3/4	1/4	4 7/8	5 3/8	5/8	3 7/8
1 1/16	1 3/16	3 7/8	6 7/8	4 7/8	1 1/2	2 1/16	3/8	3	2 3/4	1/4	5	5 5/8	5/8	4
1 1/8	1 1/4	4 1/8	7 1/2	5 1/8	1 3/4	2 5/16	7/16	3 1/2	3 1/4	5/16	5 1/2	6	3/4	4 1/2
1 3/16	1 5/16	4 3/8	7 3/4	5 3/8	1 3/4	2 5/16	7/16	3 1/2	3 1/4	5/16	5 3/4	6 1/4	3/4	4 3/8
1 1/4	1 3/8	4 9/16	8 1/8	5 3/4	1 7/8	2 7/16	7/16	3 3/4	3 1/2	5/16	6	6 5/8	3/4	4 3/4
1 5/16	1 7/16	4 3/4	8 3/8	5 7/8	1 7/8	2 7/16	1/2	3 3/4	3 1/2	5/16	6 1/4	6 3/4	3/4	4 7/8
1 3/8	1 1/2	5	8 3/4	6 1/4	2	2 11/16	1/2	4	3 1/2	5/16	6 1/2	7 1/8	7/8	5 1/4
1 7/16	1 9/16	5 3/16	9	6 1/2	2	2 11/16	1/2	4	3 1/2	5/16	6 3/4	7 3/8	7/8	5 3/8
1 1/2	1 5/8	5 3/8	9 5/8	6 7/8	2 1/4	3 1/16	9/16	4 1/2	4	3/8	7	7 3/4	7/8	5 1/2
1 9/16	1 11/16	5 5/8	9 7/8	7 1/8	2 1/4	3 1/16	9/16	4 1/2	4	3/8	7 1/4	8	7/8	5 5/8
1 5/8	1 3/4	5 13/16	10 1/2	7 3/8	2 1/2	3 7/16	5/8	5	4 1/2	3/8	7 1/2	8 1/2	1	6 1/8
1 11/16	1 13/16	6	10 3/4	7 3/4	2 1/2	3 7/16	5/8	5	4 1/2	3/8	7 3/4	8 3/4	1	6 1/4
1 3/4	1 7/8	6 1/4	11 3/8	8	2 3/4	3 11/16	11/16	5 1/2	5	7/16	8	9 1/8	1	6 3/8
1 13/16	1 15/16	6 7/16	11 5/8	8 1/4	2 3/4	3 11/16	11/16	5 1/2	5	7/16	8 1/4	9 3/8	1	6 1/2
1 7/8	2	6 11/16	11 3/4	8 1/2	2 3/4	3 11/16	11/16	5 1/2	5	7/16	8 1/2	9 5/8	1 1/8	6 3/4
1 15/16	2 1/16	6 7/8	12	8 3/4	2 3/4	3 11/16	11/16	5 1/2	5	7/16	8 3/4	9 7/8	1 1/8	6 7/8

No. 33, Supplement to Machinery, June, 1904.

TABLE FOR EYE BOLTS

(Contributed by H. A. H.)

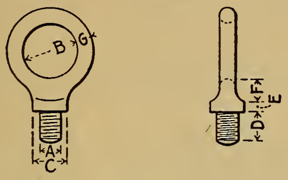


FIG. 55.

A	*B*	*C*	*D*	*E*	*F*	*G*	Number of threads per inch	Strength at bottom of thread S = 10,000 pounds	Strength of unstudded chain made from *G* size bar
.375	2	.75	.625	.1875	.375	.25	16	677	750
.5	2.125	1	.75	.25	.5	.3125	13	1,257	1,172
.625	2.25	1.25	1	.3125	.625	.4375	11	2,018	2,296
.75	2.375	1.4375	1.125	.3125	.6875	.5	10	3,020	3,000
.875	2.5	1.6875	1.375	.375	.75	.625	9	4,194	4,687
1	2.75	1.875	1.5	.4875	.875	.75	8	5,509	6,750
1.125	2.875	2.125	1.625	.5	1	.8125	7	6,931	7,921
1.25	3	2.375	1.75	.5	1.125	.875	7	8,899	9,188
1.375	3.125	2.625	1.875	.5625	1.1875	1	6	10,541	12,000
1.5	3.25	2.75	2	.625	1.25	1.0625	6	12,938	13,546
1.625	3.375	3	2.125	.6825	1.375	1.125	5.5	15,149	15,187
1.75	3.5	3.25	2.25	.75	1.5	1.25	5	17,441	18,750
1.875	3.625	3.5	2.375	.8125	1.625	1.3125	5	20,490	20,671
2	3.75	3.75	2.5	.875	1.75	1.375	4.5	23,001	22,686

SPROCKET WHEELS FOR ORDINARY LINK CHAINS

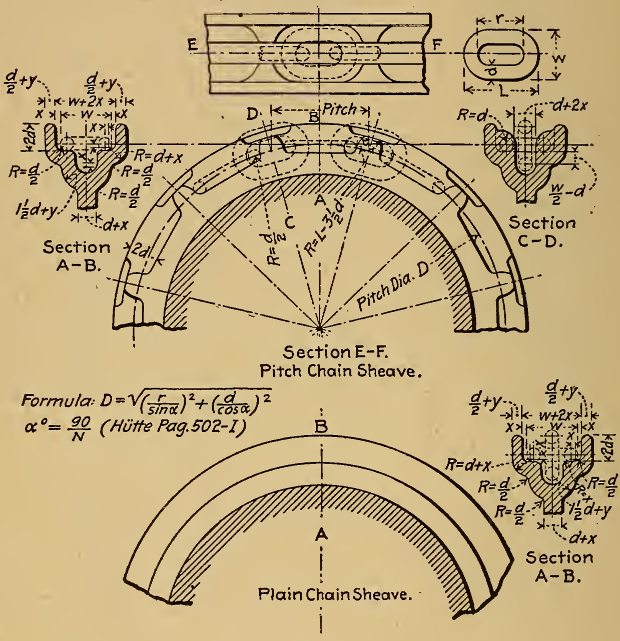


FIG. 56.

Sprocket Wheels for Ordinary Link Chains

No. of teeth = N =			5	6	7	8	9	10	11	12	13	14	15	16	17		
Angle $\alpha°$ =			18° 0′	15° 0′	12° 51.4′	11° 15′	10° 0′	9° 0′	8° 10.9′	7° 30′	6° 55.4′	6° 25.7′	6° 0′	5° 37.5′	5° 17.64′		
d = size of chain	L = length of link	W = width of link	D = pitch diameter													x	y
Ins.	Ins.	Ins.														Ins.	Ins.
3/16	1 3/8	1 3/16	3.24	3.87	4.50	5.13	5.76	6.40	7.03	7.66	8.29	8.93	9.57	10.20	10.84	1/16	3/32
1/4	1 1/2	1	3.25	3.87	4.50	5.13	5.76	6.40	7.03	7.66	8.29	8.93	9.57	10.20	10.84	3/32	3/32
5/16	1 3/4	1 3/16	3.65	4.35	5.06	5.77	6.48	7.18	7.91	8.62	9.33	10.05	10.76	11.47	12.19	3/32	3/32
3/8	2	1 3/8	4.06	4.85	5.63	6.42	7.21	8.00	8.79	9.59	10.38	11.17	11.96	12.76	13.56	3/32	3/32
7/16	2 1/4	1 9/16	4.49	5.31	6.18	7.06	7.74	8.79	9.67	10.53	11.41	12.28	13.16	14.03	14.90	3/32	3/32
1/2	2 1/2	1 3/4	4.86	5.80	6.76	7.71	8.65	9.61	10.55	11.49	12.45	13.40	14.35	15.30	16.26	3/32	1/16
9/16	2 7/8	1 15/16	5.69	6.79	7.88	8.97	10.08	11.19	12.30	13.41	14.52	15.63	16.74	17.85	18.97	1/8	1/16
5/8	3 1/4	2 1/8	6.51	7.75	9.01	10.27	11.53	12.80	14.07	15.33	16.60	17.90	19.14	20.41	21.68	1/8	1/16
11/16	3 1/2	2 5/16	6.91	8.25	9.58	10.91	12.26	13.61	14.95	16.29	17.65	18.99	20.34	21.69	23.04	1/8	1/16
3/4	3 3/4	2 1/2	7.32	8.73	10.14	11.56	12.98	14.40	15.83	17.26	18.68	20.06	21.54	22.97	24.40	1/8	1/16
13/16	4	2 11/16	7.73	9.21	10.71	12.20	13.72	15.21	16.71	18.20	19.72	21.23	22.74	24.24	25.75	1/8	1/16
7/8	4 1/4	3	8.17	9.70	11.27	12.85	14.43	16.01	17.55	19.17	20.76	22.35	23.93	25.52	27.11	1/8	1/16
15/16	4 1/2	3 1/4	8.54	10.19	11.84	13.50	15.15	16.81	18.47	20.13	21.80	23.46	25.13	26.80	28.47	1/8	1/16
1	4 3/4	3 1/2	8.96	10.68	12.40	14.13	15.87	17.61	19.35	21.09	22.84	24.58	26.33	28.08	29.83	1/8	....
1 1/8	5 1/2	3 7/8	10.58	12.61	14.66	16.71	18.76	20.81	22.87	24.93	26.99	29.05	31.11	33.18	35.25	1/8	....
1 1/4	6	3 1/4	11.40	13.58	15.78	17.99	20.20	22.41	24.63	26.84	29 06	31.28	33.51	35.73	37.95	5/32	....
1 3/8	6 1/2	4 3/4	12.22	14.56	16.91	19.27	21.64	24.01	26.39	28.75	31.14	33.52	35.90	38.37	40.67	5/32	....
1 1/2	7 1/4	5 1/4	13.85	16.49	19.16	21.84	24.52	27.21	29.91	32.52	35.29	37.99	40.69	......	......	5/32	....
1 5/8	7 7/8	5 3/4	15.06	17.95	20.85	23.77	26.62	29.61	32.54	35.47	38.41	41.34	....	......	......	5/32	....

No. 62, Supplement to Machinery, October, 1906.

Sprocket Wheels for Ordinary Link Chains — (*Continued*)

No. of teeth = N =			18	19	20	21	22	23	24	25	26	27	28	29	30		
Angle $\alpha°$ =			5° 0′	4° 44.22′	4° 30′	4° 17.14′	4° 5.45′	3° 54.78′	3° 45′	3° 36′	3° 27.69′	3° 20′	3° 12.85′	3° 6.18′	3° 0′		
d = size of chain	L = length of link	W = width of link	D = pitch diameter													x	y
Ins.	Ins.	Ins.														Ins.	Ins.
3/16	1 3/8	13/16	11.47	12.11	12.75	13.38	14.02	14.66	15.29	15.93	16.56	17.20	17.84	18.47	19.11	1/16	3/32
1/4	1 1/2	1	11.47	12.11	12.75	13.38	14.02	14.66	15.29	15.93	16.56	17.20	17.84	18.47	19.11	3/32	3/32
5/16	1 3/4	1 3/16	12.91	13.62	14.34	15.05	15.77	16.49	17.20	17.92	18.62	19.34	20.06	20.80	21.50	3/32	3/32
3/8	2	1 3/8	14.36	15.16	15.96	16.74	17.53	18.32	19.11	19.90	20.70	21.50	22.29	23.08	23.88	3/32	3/32
7/16	2 1/4	1 9/16	15.78	16.65	17.53	18.40	19.27	20.15	21.02	21.90	22.77	23.65	24.52	25.40	26.27	3/32	3/32
1/2	2 1/2	1 3/4	17.21	18.16	19.12	20.07	21.03	21.98	22.94	23.89	24.85	25.80	26.75	27.71	28.66	3/32	1/16
9/16	2 7/8	1 15/16	20.08	21.19	22.30	23.42	24.53	25.64	26.76	27.87	28.98	30.10	31.21	32.32	33.43	1/8	1/16
5/8	3 1/4	2 1/8	22.95	24.22	25.50	26.77	28.03	29.31	30.58	31.85	33.13	34.40	35.67	36.94	38.25	1/8	1/16
11/16	3 1/2	2 5/16	24.34	25.73	27.09	28.44	29.79	31.14	32.49	33.84	35.20	36.55	37.90	39.25	40.60	1/8	1/16
3/4	3 3/4	2 1/2	25.83	27.26	28.69	30.12	31.55	32.97	34.41	35.84	37.27	38.70	40.04	......	....	1/8	1/16
13/16	4	2 11/16	27.26	28.77	30.28	31.79	33.30	34.81	36.32	37.83	39.34	40.85	......	......	....	1/8	1/16
7/8	4 1/4	3	28.70	30.29	31.88	33.46	35.04	36.63	38.23	39.82	41.41	....	......	......	....	1/8	1/16
15/16	4 1/2	3 1/4	30.14	31.80	33.46	35.13	36.83	38.48	40.15	....	......	....	......	......	....	1/8	1/16
1	4 3/4	3 1/2	31.57	33.31	35.06	36.81	38.56	40.30	....	....	......	....	......	......	....	1/8	...
1 1/8	5 1/2	3 7/8	37.32	39.38	41.45	......	......	......	....	....	......	....	......	......	....	1/8	...
1 1/4	6	4 1/4	40.18	......	....	......	......	......	....	....	......	....	......	......	....	5/32	...
1 3/8	6 1/2	4 3/4	....	......	....	......	......	......	....	....	......	....	......	......	....	5/32	...
1 1/4	7 1/4	5 1/4	....	......	....	......	......	......	....	....	......	....	......	......	....	5/32	...
1 5/8	7 7/8	5 3/4	....	......	....	......	......	......	....	....	......	....	......	......	....	5/32	...

No. 62, Supplement to Machinery, October, 1906.

Pliable Hoisting Rope

With 6 strands of 19 wires each.

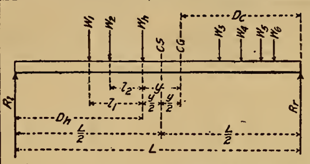
Trade number	Diameter	Circumference in inches	Weight per foot in lbs. with hemp center	Breaking strain in tons of 2000 pounds		Proper working load in tons of 2000 pounds		Circumference of Manila rope of equal strength		Minimum size of drum or sheave in feet	
				Iron	Steel	Iron	Steel	Iron	Steel	Iron	Steel
1	2¼	6¾	8.00	74.0	155.0	15.0	31.0	14.0	....	13.0	8.5
2	2	6.0	6.3	65.0	125.0	13.0	25.0	13.0	....	12.0	8.0
3	1¾	5.5	5.25	54.0	106.0	11.0	21.0	12.0	....	10.0	7.25
4	1⅝	5.0	4.10	44.0	86.0	9.0	17.0	11.0	15.0	8.5	6.25
5	1½	4.75	3.65	39.0	77.0	8.0	15.0	10.0	14.0	7.5	5.75
5½	1⅜	4.38	3.00	33.0	63.0	6.5	12.0	9.5	13.0	7.0	5.5
6	1¼	4.0	2.5	27.0	52.0	5.5	10.0	8.5	12.0	6.5	5.0
7	1⅛	3.5	2.0	20.0	42.0	4.0	8.0	7.5	11.0	6.0	4.5
8	1	3.13	1.58	16.0	33.0	3.0	6.0	6.5	9.5	5.25	4.0
9	⅞	2.75	1.20	11.5	25.0	2.5	5.0	5.5	8.5	4.5	3.5
10	¾	2.25	0.88	8.64	18.0	1.75	3.5	4.75	7.0	4.0	3.0
10¼	⅝	2.0	0.60	5.13	12.0	1.25	2.5	3.75	5.75	3.5	2.25
10½	9/16	1.63	0.44	4.27	9.0	0.75	1.5	3.5	5.0	2.75	1.75
10¾	½	1.5	0.35	3.48	7.0	0.5	1.0	3.0	4.5	2.25	1.5
10a	7/16	1.38	0.29	3.00	5.5	0.38	0.75	2.7	3.75	2.0	1.25
10⅞	⅜	1.25	0.26	2.50	4.5	0.25	0.5	2.5	3.5	1.5	1.0

Transmission or Standing Cables

With 6 strands of 7 wires each.

11	1.5	4.63	3.37	36.0	62.0	9.0	13.0	10.0	13.0	13.0	8.5
12	1.38	4.25	2.77	30.0	52.0	7.5	10.0	9.0	12.0	12.0	8.0
13	1.25	3.75	2.28	25.0	44.0	6.25	9.0	8.5	11.0	10.75	7.25
14	1.13	3.37	1.82	20.0	36.0	5.0	7.5	7.5	10.0	9.5	6.25
15	1.0	3.0	1.5	16.0	30.0	4.0	6.0	6.5	9.0	8.5	5.75
16	0.88	2.62	1.12	12.3	22.0	3.0	4.5	5.75	8.0	7.5	5.0
17	0.75	2.38	0.88	8.8	17.0	2.25	3.5	4.75	7.0	6.75	4.5
18	0.69	2.13	0.70	7.6	14.0	2.0	3.0	4.5	6.0	6.0	4.0
19	0.63	1.88	0.57	5.8	11.0	1.5	2.25	4.0	5.5	5.25	3.5
20	0.56	1.63	0.41	4.1	8.0	1.0	1.75	3.25	4.75	4.5	3.0
21	0.5	1.38	0.31	2.83	6.0	0.75	1.5	2.75	4.0	4.0	2.5
22	0.44	1.25	0.23	2.13	4.5	0.50	1.25	2.5	3.5	3.25	2.25
23	0.38	1.13	0.9	1.65	4.0	....	1.0	2.25	3.25	2.75	2.0
24	0.31	1.0	0.16	1.38	3.0	....	0.75	2.0	2.75	2.5	1.75
25	0.28	0.88	0.13	1.03	2.0	....	0.5	1.75	2.25	2.25	1.5

Location for Maximum Moment.

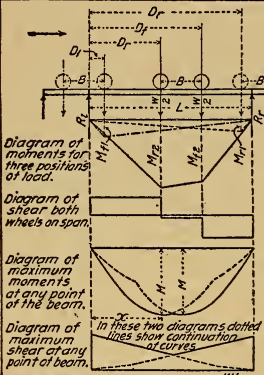


CS denotes center of span.
CG denotes center of gravity of loads.
W_h denotes heaviest load adjacent to CG.

Let W = total load and M = moment.

For M a maximum place CS midway between W_h and CG and find M under W_h. For reactions, $R_l = \frac{WD_c}{L}$ and $R_r = W - R_l$. For maximum moment $M = R_l D_h - (W_1 l_1 + W_2 l_2)$, or since $D_c = D_h$, $M = \frac{WD_c^2}{L} - (W_1 l_1 + W_2 l_2)$.

Two Wheels Equally Loaded.



Notation: All values in inches and pounds.
W = total load. $W/2$ = load on one wheel.
L = length of span. B = wheel base.
R_l = left reaction. R_r = right reaction.
V = vertical shear = reaction nearest to the point under consideration.
D_f = distance to front wheel, D_r = distance to rear wheel } the load coming on from the left. M_{f1} = moment under front wheel, one wheel on the span. M_{f2} = moment under front wheel with both wheels on the span. M_{r1} = moment under rear wheel, one wheel on the span. M_{r2} = moment under rear wheel, both wheels on the span.
x = value of D_r for M_{r2} a maximum.
M = maximum moment. Z = section modulus.
S_b = stress due to bending.

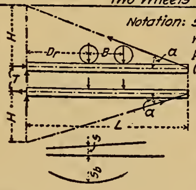
$M_{f1} = \frac{WD_f}{2L}(L - D_f)$. $M_{r1} = \frac{WD_r}{2L}(L - D_r)$. $M_{f2} = \frac{W}{L}(D_f - \frac{B}{2})(L - D_f)$.

$M_{r2} = \frac{WD_r}{L}(L - D_r - \frac{B}{2})$ For values of B less than $0.5858\,L$, $x = \frac{L}{2} - \frac{B}{4}$ and $M = \frac{WL}{4}(1 - \frac{B}{2L})^2$.

$Z = \frac{M}{S_b}$ or $S_b = \frac{M}{Z}$.

For B = or exceeds $0.5858L$, $M = \frac{WL}{8}$. For both wheels on the span, $R_l = \frac{W}{L}(L - D_r - \frac{B}{2})$ and $R_r = \frac{W}{L}(D_r + \frac{B}{2})$.

Two Wheels Equally Loaded, Oblique Reaction.



Notation: Same as above with addition of; a = angle of the reaction with beam. A = cross sectional area of beam. T = thrust or pull due to oblique reaction. S = direct stress due to T (tension or compression).

$T = \frac{W}{H}(D_r + \frac{B}{2})$, or $T = \frac{W}{L}(D_r + \frac{B}{2}) \cot a$

$S = \frac{T}{A} = \frac{W}{HA}(D_r + \frac{B}{2})$, or $S = \frac{W}{LA}(D_r + \frac{B}{2}) \cot a$.

M_{f2}, M_{r2}, x, M and S_b = same as above.

$S + S_b = W(\frac{D_r + \frac{1}{2}B}{HA} + \frac{D_r(L - D_r - \frac{1}{2}B)}{LZ})$, or

$S + S_b = \frac{W}{L}(\frac{(D_r + \frac{1}{2}B)\cot a}{A} + \frac{D_r(L - D_r - \frac{1}{2}B)}{Z})$.

$S + S_b$ = a maximum when $D_r = \frac{LZ}{2HA} + \frac{L}{2} - \frac{B}{4} = \frac{Z}{2A}\cot a + \frac{L}{2} - \frac{B}{4}$.

For light weight I-beams $\frac{Z}{A}$ = about $\frac{1}{3}$ depth of beam.

FIGS. 57, 58, 59.

Modulus of Elasticity

The modulus of elasticity of any body is the ratio, within the elastic limit, of the stress per unit of area to the stretch per unit of length.

Let S = stress per square inch, and
L = elongation per unit of length.
S' = total stress.
L' = total elongation.
O = original length.
A = area of cross section in square inches.
E = modulus of elasticity.

Then $E = \frac{S}{L}$, which is found to be practically constant, and is a measure of the resistance which a body can oppose to change of shape.

$$\frac{S'}{A} = S = \text{stress per square inch,} \qquad (1)$$

$$\frac{L'}{O} = L = \text{elongation per unit of length}$$

and
$$\frac{S}{L} = \frac{S'O}{AL'} = E. \qquad (2)$$

Hence the modulus of elasticity is equal to the total stress, multiplied by the original length, divided by the area in square inches, multiplied by the total elongation.

From equation (2),

$$S' = \frac{EL'A}{O}, \qquad (3)$$

and since

$$\frac{S'}{A} = S \quad \text{and} \quad \frac{L'}{O} = L, \text{ then } S = EL; \qquad (4)$$

or the stress per unit of area is equal to the modulus multiplied by the elongation per unit of length.

From (3),

$$L' = \frac{S'O}{EA} = \frac{SO}{E} \qquad (5)$$

and
$$L = \frac{S}{E}; \qquad (6)$$

or the elongation per unit of length equals the stress per unit of area divided by the modulus.

Table of Moduli of Elasticity and of Elastic Limits for Different Materials

The values here given are approximate averages compiled from many sources. Authorities differ considerably in their data on this subject.

Material	Modulus or coefficiency of elasticity	Stretch or compression in a length of 10 feet, under a load of		Approximate elastic limit
		1000 lbs. per sq. in.	1 ton per sq. in.	
	Lbs. per sq. in.	Ins.	Ins.	Lbs. per sq. in.
Ash	1,600,000	.075	.168	4,500
Beech	1,300,000	.092	.207	4,000
Birch	1,400,000	.086	.192	5,000
Brass, cast	9,200,000	.013	.029	6,000
Brass wire	14,200,000	.009	.019	16,000
Chestnut	1,000,000	.120	.269	4,500
Copper, cast	18,000,000	.007	.015	6,300
Copper wire	18,000,000	.007	.015	10,000
Elm	1,000,000	.120	.269	2,000
Glass	8,000,000	.015	.034	3,200
Iron, cast	12,000,000 to 23,000,000	.010 to .005	.022 to .012	4,500 to 8,000
Iron, cast, average	17,500,000	.007	.015	6,250
Iron, wrought, in either bars, sheets or plates	18,000,000 to 40,000,000	.006 to .003	.015 to .007	20,000 to 40,000
Iron bars, sheets, average	29,000,000	.004	.009	30,000
Iron wire, hard	26,000,000	.005	.010	27,000
Iron wire ropes	15,000,000	.008	.018	13,000
Larch	1,100,000	.109	.244	2,300
Lead, sheet	720,000	.167	....	1,100
Lead wire	1,000,000	.120	....	1,100
Mahogany	1,400,000	.086	.192	2,700
Oak	1,000,000 to 2,000,000	.120 to .060	.269 to .134	....
Oak, average	1,500,000	.080	.179	3,300
Pine, white or yellow	1,600,000	.075	.168	3,300
Slate	14,500,000	.008	.018	3,700
Spruce	1,600,000	.075	.168	3,300
Steel bars	29,000,000 to 42,000,000	.004 to .003	.009 to .006	34,000 to 44,000
Steel bars, average	35,500,000	.003	.007	39,000
Sycamore	1,000,000	.120	.269	4,000
Teak	2,000,000	.060	.134	5,000
Tin, cast	4,600,000	.026	....	1,500

Table of Deflections

The formulæ are based on the assumption that the increase of deflection is proportional to the increase of load.

The values of the letters in the table are as follows:

d = deflection of beam in inches.
W = weight of extraneous load in pounds.
w = weight of clear span of beam in pounds.
l = clear span of beam in inches.
E = modulus of elasticity in pounds per square inch.
I = moment of inertia of cross section of beam in inches.

Moduli of Elasticity of Various Materials

Materials	Moduli
Brass, cast	9,170,000
Brass wire	14,230,000
Copper	15,000,000 to 18,000,000
Lead	1,000,000
Tin, cast	4,600,000
Iron, cast	12,000,000 to 27,000,000 (?)
Iron, wrought	22,000,000 to 29,000,000
Steel	26,000,000 to 32,000,000
Marble	25,000,000
Slate	14,500,000
Glass	8,000,000
Ash	1,600,000
Beech	1,300,000
Oak	974,000 to 2,283,000
Pine, longleaf	1,119,000 to 3,117,000, 1,926,000
Walnut	306,000

Deflections of Beams of Uniform Cross Section Throughout

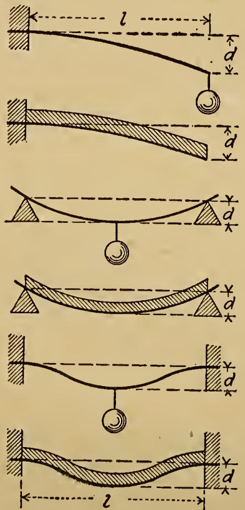


Fig. 60.

If the beam is	Deflection d, in inches, caused: By extraneous load	By weight of beam	By weight of beam and load	Extraneous load for a given deflection (weight of beam neglected)
Fixed at one end, loaded at the other	$\frac{1}{3}\frac{l^3W}{EI}$	$\frac{1}{8}\frac{l^3w}{EI}$	$\frac{1}{3}\frac{l^3(W+\frac{3}{8}w)}{EI}$	$3\frac{dEI}{l^3}$
Fixed at one end, loaded uniformly	$\frac{1}{8}\frac{l^3W}{EI}$	$\frac{1}{8}\frac{l^3w}{EI}$	$\frac{1}{8}\frac{l^3(W+w)}{EI}$	$8\frac{dEI}{l^3}$
Supported at both ends, loaded at the center	$\frac{1}{48}\frac{l^3W}{EI}$	$\frac{5}{384}\frac{l^3w}{EI}$	$\frac{1}{48}\frac{l^3(W+\frac{5}{8}w)}{EI}$	$48\frac{dEI}{l^3}$
Supported at both ends, loaded uniformly	$\frac{5}{384}\frac{l^3W}{EI}$	$\frac{5}{384}\frac{l^3w}{EI}$	$\frac{5}{384}\frac{l^3(W+w)}{EI}$	$\frac{384}{5}\frac{dEI}{l^3}$
Fixed at both ends, loaded at the center	$\frac{1}{192}\frac{l^3W}{EI}$	$\frac{1}{384}\frac{l^3w}{EI}$	$\frac{1}{192}\frac{l^3(W+\frac{1}{2}w)}{EI}$	$192\frac{dEI}{l^3}$
Fixed at both ends, loaded uniformly	$\frac{1}{384}\frac{l^3W}{EI}$	$348\frac{l^3w}{EI}$	$\frac{1}{384}\frac{l^3(W+w)}{EI}$	$384\frac{dEI}{l^3}$

From the table, it is found that for beams of similar cross section and of same material, and within the elastic limit, the load and deflections (neglecting the weight of the beam itself) are as follows:

DEFLECTIONS UNDER GIVEN EXTRANEOUS LOADS

With same span	Inversely as the breadths and as the cubes of the depths
With same span and breadth	Inversely as the cubes of the depths
With same span and depth	Inversely as the breadths
With same breadth and depth	Directly as the cube of the span

EXTRANEOUS LOADS FOR A GIVEN DEFLECTION

With the same span	Directly as the breadths and as the cubes of the depths
With the same span and breadth	Directly as the cubes of the depths
With the same span and depth	Directly as the breadth
With the same breadth and depth	Inversely as the cubes of the spans

Modulus of Rupture

The modulus of rupture is the total resistance, in pounds per square inch, of the fibres of a beam farthest from the neutral axis; and is 18 times the center breaking load in pounds, of a beam of the given material, 1 inch square by 1 foot span. The values of the modulus of rupture, which is usually denoted by "C," may be obtained from the following table of transverse strengths, by multiplying the values therein by 18.

One-third part of any of these constants (except those for wrought iron and steel) may be taken in ordinary practice as about the average constant for the greatest center load within the elastic limit. The loads here given for wrought iron and steel are already the greatest within elastic limits.

Transverse strengths, in pounds

In wooden beams in practice deduct one-third part to allow for knots, crooked grain, etc.

WOODS			
Ash:		*Hickory:*	
English	650	Amer.	800
Amer. White (Traut.)	650	Amer. Bitter nut	800
Swamp	400	*Iron Wood*, Canada	600
Black	600	*Locust*	700
Arbor Vitæ, Amer.	250	*Lignum Vitæ*	650
Balsam, Canada	350	*Larch*	400
Beech, Amer.	850	*Mahogany*	750
Birch:		*Mangrove:*	
Amer. Black	550	White	650
Amer. Yellow	850	Black	550
Cedar:		*Maple:*	
Bermuda	400	Black	750
Guadaloupe	600	Soft	750
Amer. White or Arbor Vitæ	250	*Oak:*	
Chestnut	450	English	550
Elm:		Amer. White (by Traut.)	600
Amer. White	650	Amer. Red, Black, Basket	850
Rock, Canada	800	Live	600
Hemlock	500	*Pine:*	
		Amer. White (by Traut.)	450
		Amer. Yellow* (by Traut.)	500

Transverse strengths, in pounds — (*Continued*)

Pine:	
Amer. Pitch* (by Traut.)	550
Georgia*	850
Poplar	550
Poon	700
Spruce:	
(By Traut.)	450
Black	550
Sycamore	500
Tamarack	400
Teak	750
Walnut	550
Willow	350
METALS	
Brass	850
Iron, cast:	
1500 to 2700, average	2100
Common pig	2000
Castings from pig	2300
Employed in our tables	2025
For castings 2½ or 3 ins. thick	1800?
Iron, wrought, 1900 to 2600, average	2250
Wrought iron does not *break;*	....
but at about the average of 2250	......
pounds its elastic limit is reached.	......
Steel, hammered or rolled; elasticity destroyed by 3000 to 7000.	5000
Under heavy loads hard steel snaps like cast iron, and soft steel bends like wrought iron.	
STONES, ETC.	
Blue stone flagging, Hudson River.	125
Brick:	
Common, 10 to 30, average	20
Good Amer. pressed, 30 to 50, average	40
Caen Stone	25
Cement, Hydraulic:	
English Portland, artificial, 7 days in water	30
1 year in water	50
Portland, Kingston, N. Y., 7 days in water	30

Cement Hydraulic:	
Saylor's Portland, 7 days in water	26
Common U. S. cements, 7 days in water	5
The following hydraulic cements were made into prisms, in vertical moulds, under a pressure of 32 pounds per square inch, and were kept in sea water for 1 year.	
Portland Cement, English, pure, 1 year old	64
Roman Cement, Scotch, pure	23
American Cements, pure, average about	25
Granite:	
50 to 150, average	100
Quincy	100
Glass, Millville, New Jersey, thick flooring (by Traut.)	170
Mortar:	
Of lime alone, 60 days old	10
1 measure of slacked lime in powder, 1 sand	8
1 measure of slacked lime in powder, 2 sand	7
Marble:	
Italian, White	116
Manchester, Vt., White	95
East Dorset, Vt., White	111
Lee, Mass., White	86
Montgomery Co., Pa., Gray	103
Montgomery Co., Pa., Clouded	142
Rutland, Vt., Gray	70
Glenn's Falls, N. Y., Black	155
Baltimore, Md., White coarse	102
Oolites, 20 to 50	35
Sandstones:	
20 to 70, average	45
Red of Connecticut and New Jersey	45
Slate, laid on its bed, 200 to 450, average	325

* Trautwine.

Moment of Inertia

The moment of inertia of the weight of a body, with respect to any axis, is the algebraic sum of the products obtained by multiplying the weight of each elementary particle by the square of its distance from the axis.

If the moment of inertia with respect to any axis be denoted by I; the weight of any elementary particle by w; and its distance from the axis by r; the sum of all the particles by Σ, then $I = \Sigma(wr^2)$.

The moment of inertia of a rod or bar of uniform thickness, with respect to an axis perpendicular to the length of the rod, is

$$I = W\left(\frac{l^3}{3} + d^2\right)$$

in which W equals the weight of rod, $2\,l$ equals length and d equals the distance of the center of gravity of the section from the axis.

For thin circular plates with the axis in its own plane, when r equals the radius of the plate,

$$I = W\left(\frac{r^2}{4} + d^2\right)$$

For circular plate, axis perpendicular to the plate,

$$I = W\left(\frac{r^2}{2} + d^2\right)$$

Circular ring, axis perpendicular to its own plane,

$$I = W\left(\frac{r^2 + r'^2}{2} + d^2\right)$$

r and r' being the exterior and interior radii of the ring.

Cylinder, axis perpendicular to the axis of the cylinder,

$$I = W\left(\frac{r^2}{4} + \frac{l^3}{3} + d^2\right)$$

r = radius of base and $2\,l$ = length of the cylinder.

By making d equal to 0 in any of the above formulæ, the moment of inertia for a parallel axis passing through the center of gravity is found.

The term moment of inertia is also used in respect to areas, as the cross section of beams under strain.

In this case, $I = \Sigma(ar)^2$, in which a is the elementary area and r its distance from the center.

General Formulæ for Transverse Strength of Beams of Uniform Cross Section

Beams	Rectangular beam: Breaking load	Rectangular beam: Deflection for load P or W	Beam of any section: Maximum moment of stress	Beam of any section: Moment of rupture	Beam of any section: Deflection
Fixed at one end, loaded at the other	$P \frac{1}{6} \frac{Rbd^2}{l}$	$\frac{4Pl^3}{Ebd^3}$	Pl	$\frac{RI}{C}$	$\frac{1}{3} \frac{Pl^3}{EI}$
Same with load distributed uniformly	$W \frac{1}{3} \frac{Rbd^2}{l}$	$\frac{3}{2} \frac{Pl^3}{Ebd^3}$	$\frac{1}{2} Wl$	$\frac{RI}{C}$	$\frac{1}{8} \frac{Pl^3}{EI}$
Supported at ends, loaded in the middle	$P = \frac{2}{3} \frac{Rbd^2}{l}$	$\frac{Pl^3}{4Ebd^3}$	$\frac{1}{4} Pl$	$\frac{RI}{C}$	$\frac{1}{48} \frac{Pl^3}{EI}$
Same, loaded uniformly	$W \frac{4}{3} \frac{Rbd^2}{l}$	$\frac{5}{32} \frac{Wl^3}{Ebd^3}$	$\frac{1}{8} Wl$	$\frac{RI}{C}$	$\frac{5}{348} \frac{Wl^3}{EI}$
Same, loaded at the middle and also uniform load.	$2P + W = \frac{4}{3} \frac{Rbd^2}{l}$	$\frac{1}{4}\left(P + \frac{1}{8} W\right) \frac{l^3}{Ebd^3}$	$\left(\frac{1}{4} P + \frac{1}{8} W\right) l$	$\frac{RI}{C}$	$\frac{1}{48}\left(P + \frac{5}{8} W\right) \frac{l^3}{EI}$
Fixed at both ends, loaded in the middle	$P \frac{4}{3} \frac{Rbd^2}{l}$	$\frac{1}{16} \frac{Pl^3}{Ebd^3}$	$\frac{1}{8} Pl$	$\frac{RI}{C}$	$\frac{P}{192} \frac{l^3}{EI}$
Same, Barlow's experiment	$P = \frac{Rbd^2}{l}$	....	$\frac{1}{6} Pl$	$\frac{RI}{C}$	....
Same, uniformly loaded	$W = \frac{2Rbd^2}{l}$	$\frac{1}{32} \frac{Wl^3}{Ebd^3}$	$\frac{1}{12} Wl$	$\frac{RI}{C}$	$\frac{W}{384} \frac{l^3}{EI}$
Fixed at one end, supported at the other at 0.634 l from fixed end	....	$\frac{.1148 Pl^3}{Ebd^3}$	$\frac{3}{8}(2\sqrt{3} - 3) Pl$	$\frac{RI}{C}$	$\frac{P}{105} \frac{l^3}{EI}$ nearly
Same, uniformly loaded	$W = \frac{4}{3} \frac{Rbd^2}{l}$	$\frac{.0648 Wl^3}{Ebd^3}$	$\frac{1}{8} Wl$	$\frac{RI}{C}$	$\frac{W}{185} \frac{l^3}{EI}$ nearly

(Kent, page 268.)

Formulæ for Transverse Strength of Beams

P = load at middle.
W = total load distributed uniformly.
l = length, b = breadth, d = depth in inches.
E = modulus of elasticity.
R = stress per square inch of extreme fibre.
I = moment of inertia.
C = distance between neutral axis and extreme fibre.

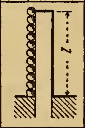
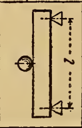
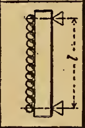
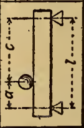
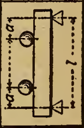
For breaking load of circular section replace bd^2 by 0.59 d^3.

For good wrought iron the value of R is about 80,000; for steel about 120,000. For cast iron the value of R varies greatly. Thurston found 45,740 for No. 2 and 67,980 for No. 1.

General Formulæ for Transverse Strength, Etc.

The following table gives the values of W, etc., without introducing the modulus of elasticity or the moment of inertia.

Formulæ for Round and Rectangular Solid Beams

Style of Loading and Support	Rectangular Solid Beams. b = breadth of beam in inches	h = height of beam in inches	f = stress per sq. in. in extreme fibers of beam	l = length of beam in inches	w = load in pounds	Round Solid Beams.	d = diameter of beam in inches	f = stress per sq. in. in extreme fibers of beam	l = length of beam in inches	w = load in pounds
	b	h	f	l	w		d	f	l	w
	Beam fixed at one end, loaded at the other.					Beam fixed at one end, loaded at the other.				
	$\frac{6lw}{fh^2}=b$	$\sqrt{\frac{6lw}{bf}}=h$	$\frac{6lw}{bh^2}=f$	$\frac{bfh^2}{6w}=l$	$\frac{bfh^2}{6l}=w$		$\sqrt[3]{\frac{10.18\,lw}{f}}=d$	$\frac{10.18\,lw}{d^3}=f$	$\frac{d^3f}{10.18\,w}=l$	$\frac{d^3f}{10.18\,l}=w$
	Beam fixed at one end, uniformly loaded.					Beam fixed at one end, uniformly loaded.				
	$\frac{3lw}{fh^2}=b$	$\sqrt{\frac{3lw}{bf}}=h$	$\frac{3lw}{bh^2}=f$	$\frac{bfh^2}{3w}=l$	$\frac{bfh^2}{3l}=w$		$\sqrt[3]{\frac{5.092\,wl}{f}}=d$	$\frac{5.092\,wl}{d^3}=f$	$\frac{d^3f}{5.092\,w}=l$	$\frac{d^3f}{5.092\,l}=w$
	Beam supported at both ends, single load in middle.					Beam supported at both ends, single load in middle.				
	$\frac{3lw}{2fh^2}=b$	$\sqrt{\frac{3lw}{2bf}}=h$	$\frac{3lw}{2bh^2}=f$	$\frac{2bfh^2}{3w}=l$	$\frac{2bfh^2}{3l}=w$		$\sqrt[3]{\frac{2.546\,wl}{f}}=d$	$\frac{2.546\,wl}{d^3}=f$	$\frac{d^3f}{2.546\,w}=l$	$\frac{d^3f}{2.546\,l}=w$
	Beam supported at both ends, uniformly loaded.					Beam supported at both ends, uniformly loaded.				
	$\frac{3lw}{4fh^2}=b$	$\sqrt{\frac{3lw}{4bf}}=h$	$\frac{3lw}{4bh^2}=f$	$\frac{4bfh^2}{3w}=l$	$\frac{4bfh^2}{3l}=w$		$\sqrt[3]{\frac{1.273\,wl}{f}}=d$	$\frac{1.273\,wl}{d^3}=f$	$\frac{d^3f}{1.273\,w}=l$	$\frac{d^3f}{1.273\,l}=w$
	Beam supported at both ends, single unsymmetrical load.					Beam supported at both ends, single unsymmetrical load.				
	$\frac{6wac}{fh^2l}=b$	$\sqrt{\frac{6wac}{bfl}}=h$	$\frac{6wac}{bh^2l}=f$	$a+c=l$	$\frac{bh^2fl}{6ac}=w$		$\sqrt[3]{\frac{10.18\,wac}{fl}}=d$	$\frac{10.18\,wac}{d^3l}=f$	$a+c=l$	$\frac{d^3fl}{10.18\,ac}=w$
	Beam supported at both ends, two symmetrical loads.					Beam supported at both ends, two symmetrical loads.				
	$\frac{3wa}{fh^2}=b$	$\sqrt{\frac{3wa}{bf}}=h$	$\frac{3wa}{bh^2}=f$	l, any length; $\frac{bh^2f}{3w}=a$	$\frac{bh^2f}{3a}=w$	$\frac{d^3f}{5.092\,w}=a$	$\sqrt[3]{\frac{5.092\,wa}{f}}=d$	$\frac{5.092\,wa}{d^3}=f$	l may be any length	$\frac{d^3f}{5.092\,a}=w$

CHAPTER V

ACCELERATION OF FALLING BODIES

THE change in velocity of a falling body which occurs in a unit of time is its acceleration.

That due to gravity is 32.16 feet per second, in one second and is denoted by g.

Let t = number of seconds during which a body falls.
v = velocity acquired in feet per second at the expiration of t seconds.
u = space fallen through in each second.
h = total space fallen through in t seconds.

Then $$v = gt = 32.16\, t = \sqrt{2\,gh} = 8.02\sqrt{h} = \frac{2\,h}{t};$$

$$h = \frac{vt}{2} = \frac{gt^2}{2} = 16.08\, t^2 = \frac{v^2}{2\,g} = \frac{v^2}{64.32};$$

$$t = \frac{v}{g} = \frac{v}{32.16} = \sqrt{\frac{2\,h}{8}} = \frac{2\,h}{v} = 0.24938\sqrt{h}.$$

The table below gives the values of h, v and u, for values of t up to ten seconds.

Time in seconds, t	Space fallen through in feet in time t, h	Velocity acquired in feet per second at end of time t, v	Space fallen through in feet in each second, u
1	16	32	16
2	64	64	48
3	145	96	80
4	257	129	113
5	402	161	145
6	580	193	177
7	789	225	209
8	1030	257	241
9	1303	290	273
10	1609	322	306

The graphical method of ascertaining the values of t, v, u and h is easily remembered and is often of service.

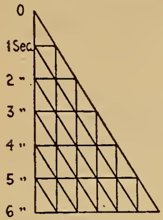


FIG. 61.

In the triangle, Fig. 61, let the vertical divisions on the left of the perpendicular represent the number of seconds through which the body falls $= t$.

Let the base of each small triangle equal the velocity at the end of the first second $= 32.16$. Then the number of bases on each of the horizontal lines at 1, 2, 3, etc., multiplied by 32.16 will equal the acquired velocity for the corresponding time $= v$.

Let the area of each small triangle $= 16.08$. Then the number of such areas between 0 and any horizontal line multiplied by 16.08 will equal the height in feet fallen through in the number of seconds corresponding to that line $= h$.

And the number of small triangles between each pair of horizontal lines, multiplied by 16.08 will equal the number of feet fallen through in each second $= u$.

Thus:

$$t = 1, 2, 3, 4, 5, 6.$$
$$v = 32.16 \times 1, 2, 3, 4, 5, 6.$$
$$h = 16.08 \times 1, 4, 9, 16, 25, 36.$$
$$u = 16.08 \times 1, 3, 5, 7, 9, 11.$$

Parallelogram of Forces

If two forces are applied to the same point, their resultant will be represented in intensity and direction by the diagonal of a parallelogram of which the adjacent sides represent the intensities and directions of the given forces.

Let AB and AC represent, in intensity and direction, any two forces applied to the point A; then AD will correspondingly represent their resultant.

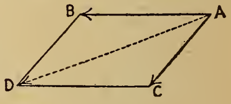


FIG. 62.

Conversely, if AD be the known force acting at A, it may be resolved into two components, in any direction in the same plane; which components will be the adjacent sides of a parallelogram having AD for its diagonal.

Parallelopipedon of Forces

If three forces, not in the same plane, act on the same point, they may be represented by the edges of a parallelopipedon and the diagonal through the point of application is their resultant.

Height Corresponding to a Given Acquired Velocity

Velocity, v	Height, h	Velocity, v	Height, h	Velocity, v	Height, h
Feet per second	Feet	Feet per second	Feet	Feet per second	Feet
.25	.0010	34	17.9	76	89.8
.50	.0039	35	19.0	77	92.2
.75	.0087	36	20.1	78	94.6
1.00	.016	37	21.3	79	97.0
1.25	.024	38	22.4	80	99.5
1.50	.035	39	23.6	81	102.0
1.75	.048	40	24.9	82	104.5
2.0	.062	41	26.1	83	107.1
2.5	.097	42	27.4	84	109.7
3.0	.140	43	28.7	85	112.3
3.5	.190	44	30.1	86	115.0
4.0	.248	45	31.4	87	117.7
4.5	.314	46	32.9	88	120.4
5.0	.388	47	34.3	89	123.2
6.0	.559	48	35.8	90	125.9
7.0	.761	49	37.3	91	128.7
8.0	.994	50	38.9	92	131.6
9.0	1.26	51	40.4	93	134.5
10.0	1.55	52	42.0	94	137.4
11.0	1.88	53	43.7	95	140.3
12.0	2.24	54	45.3	96	143.3
13.0	2.62	55	47.0	97	146.0
14.0	3.04	56	48.8	98	149.0
15.0	3.49	57	50.5	99	152.0
16.0	3.98	58	52.3	100	155.0
17.0	4.49	59	54.1	105	171.0
18.0	5.03	60	56.0	110	188.0
19.0	5.61	61	57.9	115	205.0
20.0	6.22	62	59.8	120	224.0
21.0	6.85	63	61.7	130	263.0
22.0	7.52	64	63.7	140	304.0
23.0	8.21	65	65.7	150	350.0
24.0	8.94	66	67.7	175	476.0
25.0	9.71	67	69.8	200	622.0
26.0	10.5	68	71.9	300	1,399.0
27.0	11.3	69	74.0	400	2,488.0
28.0	12.2	70	76.2	500	3,887.0
29.0	13.1	71	78.4	600	5,597.0
30.0	14.0	72	80.6	700	7,618.0
31.0	14.9	73	82.9	800	9,952.0
32.0	15.9	74	85.1	900	12,593.0
33.0	16.9	75	87.5	1000	15,547.0

The Lever

The lever is a solid bar of any form, supported at a fixed point, about which it may turn freely.

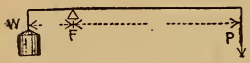


FIG. 63.

The fixed point is the fulcrum. There are three orders of levers. In those of the first order the points of application of the power and resistance are on opposite sides of the fulcrum.

In the second order the resistance is applied between the fulcrum and the power.

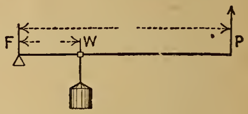


FIG. 64.

In the third order the power is applied between the fulcrum and the resistance.

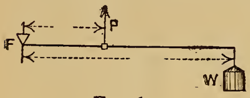


FIG. 65.

In any order the weight W multiplied by the distance WF from the fulcrum must equal the power P multiplied by PF, to establish equilibrium.

Whatever may be the shape of the lever, the power or resistance acts at the end of a line drawn through the fulcrum and perpendicular to the line of direction of the power or resistance. This perpendicular is called the *lever arm* of its corresponding force, and the product of the lever arm and its force is called the *moment* of that force. When the moments are equal the forces are in equilibrium.

If one moment exceeds the other, rotation will occur about the fulcrum in the direction of the force having the greater moment.

The Wheel and Axle

This is simply such an application of the lever of the first order, that the power and resistance may act through greater distances; the radius of the wheel is the lever arm of the power and that of the drum the lever arm of the resistance.

When the resistance is a weight, it will be raised if the moment of the power is the greater and vice versa.

The Inclined Plane

If a force P acts in the direction of AB, to overcome the resistance R, then $P : R :: a : b$.

$$\therefore \quad P = \frac{Ra}{b} \quad \text{and} \quad R = \frac{Pb}{a}$$

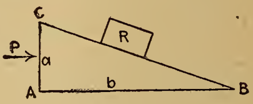


FIG. 66.

The Wedge

The wedge is simply a double inclined plane, placed back to back.

If the force applied to a wedge be represented by P and the resistance to be overcome by R, the base of the wedge by a and its length by b; then

$$P : R :: a : b \qquad P = \frac{Ra}{b} \text{ and } R = \frac{Pb}{a}$$

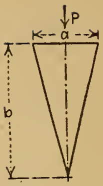


FIG. 67.

Center of Gravity

The center of gravity of a body is that point through which the effort of its weight always passes. If a body be suspended from any point, the direction of the line of suspension will pass through its center of gravity.

Therefore, the center of gravity of any body may be determined by finding the intersection of the lines of suspension passing through points not on the same vertical line.

The center of gravity of two bodies is on a line joining their respective centers of gravity and the distances from the center of gravity of either body to that of both of them (combined) are inversely proportional to the weights of the bodies respectively.

To find the center of gravity of any irregular plane surface, divide it into triangles of any convenient areas. Find the center of gravity and the area of each triangle. Then assuming any coördinate axes X and Y, multiply the area of each triangle by the abscissa of its center of gravity and divide the product by the sum of the areas of all the triangles. The quotient is the abscissa of the center of gravity of the entire figure. Find its ordinate in the same way; then the point determined by this abscissa and ordinate is the center of gravity of the figure.

This method is precisely that shown by Fig. 61, Machinery Supplement No. 5.

In addition to the formulæ taken from Machinery Supplement No. 5, others are given as follows:

Semiellipse

The center of gravity of a semiellipse is on the semiaxis perpendicular to the base and at a distance from the base equal to the product of that semiaxis and the decimal 0.4244.

The Center of Gravity of Solids of Uniform Density Throughout

Sphere and spheroid at center of the body.

Hemisphere on the radius perpendicular to the base and at ⅜ its length from the base.

Spherical Sector. — On the radius passing through the center of the circle cut from the sphere by the sector and at a distance from the center of the sphere, equal to three-fourths of the difference between the radius, and one-half the rise of the sector. Or G, representing the distance from center of sphere to center of gravity, R = radius of sphere and H the rise of the sector; then $G = \frac{3}{4}\left(R - \frac{H}{2}\right)$.

Spherical Segment

$$G = \frac{3}{4}\,\frac{(2R - H)^2}{3R - H}$$

Spherical Zone

Take the difference between the two segments whose difference is the zone. Find the center of gravity of each segment; then, by inverse proportion, find that of their difference.

Frustrum of a Cone

Let G = distance from base to center of gravity measured on the axis.

A = area of large end.

a = area of small end.

H = height of frustrum measured on the axis.

Then
$$G = \frac{H}{4}\left(\frac{A + 2\sqrt{Aa} + 3a}{A + \sqrt{Aa} + a}\right)$$

The center of gravity of a paraboloid is on the axis and at a distance from the vertex equal to two-thirds that from vertex to base.

A body suspended from center of gravity has no tendency to rotate.

Center of gravity of regular figures is at geometrical center; of a *triangle* two-thirds distance from any angle to middle of opposite side; of *semicircle* on middle radius, 4244 r from center; of *sector* $\frac{2\,cr}{3\,l}$ from center; of *segment*, $\frac{c^3}{12\,a}$ from center (where c = chord and a = area); of *cone* or *pyramid*, ¼ distance from center of base to apex a_1, a_2, a_3 = areas of respective triangles.

Center of gravity of two bodies, $x = \frac{wl}{w + W}$

General formulæ $x = \dfrac{a_1x_1 + a_2x_2 + a_3x_3}{a_1 + a_2 + a_3}$

$$y = \frac{a_1y_1 + a_2y_2 + a_3y_3}{a_1 + a_2 + a_3}$$

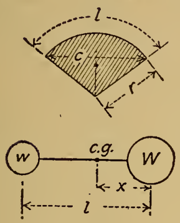


FIG. 68.

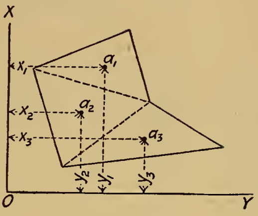


FIG. 69.

Volume of a solid generated by the revolution of a surface about an axis in the same plane with it = area of the surface × circumference described by its center of gravity.

Moment of Inertia

Moment of inertia of rotating body = products of weights of particles × squares of distances from the axis $= I = w_1r_1^2 + w_2r_2^2 + w_3r_3^2$, etc. w_1, w_2, etc. = weights of particles; r_1, r_2, etc. = distances from axis in same units as the volumes of the particles of which weights are taken.

Radius of Gyration

Center of gyration of rotating body is point at which weight may be assumed concentrated. Radius of gyration = k = distance from center of rotation to center of gyration. For circular disc, $k = \dfrac{r}{\sqrt{2}}$. For circular ring, $k = \sqrt{\dfrac{R^2 + r^2}{2}}$. (No. 5 Supplement to Machinery, Sept., 1899.)

Specific Gravity of Gases

Air = 1.

Hydrogen	0.069
Marsh gas	0.559
Steam	0.623
Carbonic oxide	0.968
Nitrogen	0.971
Olefiant gas	0.978
Oxygen	1.106
Sulphuretted hydrogen	1.191
Nitrous oxide	1.527
Carbonic acid	1.529
Sulphuric acid	2.247
Chlorine	2.470

Specific Gravity of Various Substances

Water = 1.

Substances	Average specific gravity	Average weight per cubic foot in pounds
Air at 60° F. under pressure of one atmosphere weighs 1/815 part as much as water at 60° F.	0.00123	0.0765
Alcohol	0.834	52.10
Ash, American, white, dry	0.61	38.0
Aluminum	2.6	162.0
Antimony	6.70	418.0
Asphaltum	1.4	87.3
Basalt	2.9	181.0
Bismuth	9.74	607.0
Brass:		
Copper and zinc, cast	8.1	504.0
Copper and zinc, rolled	8.4	524.0
Bronze, copper 8, tin 1	8.5	529.0
Brick, pressed	....	150.0
Brick, common, hard	....	125.0
Brick, soft	....	100.0
Box wood	0.96	60.0
Carbonic acid	0.00187	....
Charcoal, of pines and oaks	....	15 to 30
Chalk	2.5	156.0
Clay, dry, in lump, loose	....	63.0
Coke:		
Loose	....	23 to 32
A heaped bushel 35 to 42 pounds. A ton occupies from 40 to 43 cubic feet.		
Cherry, dry	0.672	47.0
Coal:		
Anthracite	1.5	93.5
Anthracite, broken, loose	....	52 to 56
Bituminous	1.35	84.0
Bituminous, broken, loose	....	47 to 52
A heaped bushel weighs from 70 to 78 pounds. A ton occupies from 43 to 48 cubic feet.		
Cement:		
Rosendale, ground, loose	....	56.0
Rosendale, struck bushel	....	76 to 81
English Portland	....	76 to 88
French Portland	....	76 to 88
Copper, cast	8.7	542.0
Copper, rolled	8.9	555.0
Diamond	3.53	....
Earth:		
Dry loam, loose	....	72 to 80
Dry loam, shaken	....	82 to 92
Dry loam, moderately rammed	....	90 to 100
Loam, moist, loose	....	70 to 76
Loam, moist, shaken	....	75 to 90
Soft mud	....	104 to 112
Elm, dry	0.56	35
Ebony	1.22	76.1

Specific Gravity of Various Substances — (*Continued*)

Substances	Average specific gravity	Average weight per cubic foot in pounds
Fat	.93	58.0
Flint	2.6	162.0
Feldspar	2.65	166.0
Glass	2.98	186.0
Glass, common window	2.52	157.0
Granite	2.72	170.0
Gneiss, common	2.69	168.0
Gypsum, plaster Paris	2.27	141.6
Greenstone, trap	3.0	187.0
Gravel	....	90 to 106
Gold, pure	19.258	1204.0
Gutta percha	.98	61.1
Hornblende, black	3.25	203.0
Hydrogen is 14½ times lighter than air and 16 times lighter than oxygen	....	.00527
Hemlock, dry	.4	25.0
Hickory, dry	.85	53.0
Iron, cast	7.218	450.0
Iron, pure	7.77	485.0
Iron, wrought, rolled	7.69	480.0
Iron, sheets	7.73	485.0
Ivory	1.82	114.0
Ice	.92	57.4
India rubber	.93	58.0
Lignum Vitæ, dry	1.33	83.0
Lard	.95	59.3
Lead	11.38	709.6
Limestones and marbles	2.7	168.0
Lime, quick	1.5	95.0
Lime, quick, ground loose, per struck bushel	....	53.0
Mahogany:		
Dry, San Domingo	.85	53.0
Dry, Honduras	.56	35.0
Maple, dry	.79	49.0
Marbles, see Limestone		
Masonry:		
Granite or limestone	....	165.0
Granite or limestone rubble	....	154.0
Brick, ordinary quality	....	125.0
Mercury at 32° F.	13.62	849.0
Mercury at 212° F.	13.38	836.0
Mica	2.93	183.0
Mortar, hardened	1.65	103.0
Mud:		
Dry	....	80 to 110
Moist	....	110 to 130
Wet, fluid	....	104 to 120
Naphtha	.848	52.9
Nitrogen	.001194	.0744
Oak live, dry	.95	59.3
Oak white	.77	48.0
Oak, red and black	....	32 to 45

SPECIFIC GRAVITY OF VARIOUS SUBSTANCES — (*Continued*)

Substances	Average specific gravity	Average weight per cubic foot in pounds
Oil:		
Whale	.92	57.3
Olive	.92	57.3
Linseed	.94	....
Palm	.969	....
Petroleum	.860	....
Turpentine	.87	54.3
Rape seed	.914	....
Sunflower	.926	....
Oolites	2.2	137.0
Ores:		
Copper, vitreous	4.129	....
Copper, pyrites	4.344	....
Copper, Cornish	5.452	....
Iron, chromate	4.057	....
Iron, pyrites	4.789	....
Iron, magnetic	4.9	....
Iron, red hematite	5.00	....
Iron, brown hematite	4.029	....
Iron, specular	5.218	....
Iron, spathic	3.81	....
Iron, ironstone	3.863	....
Lead, carbonate	7.20	....
Lead, galena	7.22	....
Tin, Cornish	6.45	....
Zinc, calamine	3.525	....
Oxygen	.00136	.0846
Peat, dry	....	20 to 30
Pine, white, dry	.40	25.0
Pine, yellow, northern	.55	34.3
Pine, yellow, southern	.72	45.0
Pitch	1.15	71.7
Plaster Paris	1.176	....
Powder, blasting	1.0	62.3
Porphyry	2.73	170.0
Platinum	21.5	1342.0
Quartz, pure	2.65	165.0
Ruby and sapphire	3.9	....
Rosin	1.1	68.6
Salt:		
Coarse, Syracuse struck bushel, 56 pounds	....	45.0
Coarse, Turk's Island struck bushel, 76 to 80	....	62.0
Coarse, Liverpool struck bushel, 50 to 55	....	42.0
Sand, dry and loose, average 98	....	90 to 106
Sand, wet	....	118 to 129
Sand stones	2.41	151.0
Serpentines	2.6	162.0
Snow:		
Freshly fallen	....	5 to 12
Wet and compacted	....	15 to 50
Sycamore, dry	.59	37.0
Shales, red or black	2.6	162.0
Slate	2.8	175.0

Specific Gravity of Various Substances — (*Continued*)

Substances	Average specific gravity	Average weight per cubic foot in pounds
Silver	10.5	655.0
Soapstone (steatite)	2.73	170.0
Steel	7.85	490.0
Sulphur	2.0	125.0
Spruce, dry	.4	25.0
Spelter, zinc	7.0	437.5
Tallow	.94	58.6
Tar	1.0	62.4
Trap	3.0	187.0
Topaz	3.55	....
Tin	7.35	459.0
Water:		
Distilled at 32° F., barometer 30″	....	62.417
Distilled at 62° F., barometer 30″	1.0	62.355
Distilled at 212° F., barometer 30″	....	59.7
At 60° F. a cubic inch of water weighs .03607 pounds or .57712 ounces, avoirdupois		
Sea	1.028	64.08
Dead Sea	1.240	....
Wax, bees	.97	60.5
Wines	.998	62.3
Walnut, black, dry	.61	38.0
Zinc	7.0	437.5
Zircon	4.45	....
Asbestos	.993	....
Acid:		
Acetic	1.063	....
Carbolic	1.065	....
Hydrochloric	1.270	....
Nitric	1.554	....
Sulphuric	1.970	....
Barytes	4.86	
Brick:		
Common	1.90	....
Fire	2.2	....
Clay, fire	2.16	....
Carbon, graphite	2.585	....
Manganese	8.01	499.0
Magnesium	2.04	....
Nickel	8.80	548.7
Potassium	.865	....
Phosphorus	1.863	....
Silicon	2.493	....
Stone (building)	2.9	....
Titanium	5.3	....
Tungsten	19.26	....
Uranium	18.4	....
Vanadium	5.5	....

Table of Physical Constants

Name	Symbol	Atomic weight	Specific heat, water = 1	Specific gravity, water = 1	Specific gravity, air = 1	Melting point	Latent heat of fusion
Aluminum....	Al	27.3	.214	2.6	....	1182° F.	28.5
Antimony.....	Sb	122.0	.0508	6.7	....	1973°–1134° F.	40.0
Arsenic........	As	74.9	.0814	5.95	....	774° F.	......
Bismuth......	Bi	207.5	.0308	9.74	....	497°–484° F.	23.25
Calcium.......	Ca	39.9	.170	1.578	....	....	......
Carbon........	C	11.97	.214	2.35	....	....	......
Chlorine......	Cl	35.36	....	2.43	....	....	......
Chromium....	Cr	52.4	....	6.8	....	>Pt.	......
Copper........	Cu	63.3	.0952	8.90	....	1994° F.	43.0
Gold..........	Au	196.2	.0324	19.258	....	2015° F.	16.0
Hydrogen.....	H	1.0	3.2963	....	.069	....	......
Iodine........	I	126.53	.0541	4.94	....	225° F.	......
Iron...........	Fe	55.9	.114*	7.80	....	1900°–2790° F.	88.69
Lead..........	Pb	206.4	.0314	11.38	....	617°–588° F.	11.0
Magnesium....	Mg	23.94	.25	1.70	....	1139° F.	......
Manganese....	Mn	54.8	.122	8.0	....	2240° F.	......
Mercury	Hg	199.8	.0317	13.62	....	39° F.	5.09
Molybdenum..	Mo	95.8	.0722	8.64	....	....	......
Nickel........	Ni	58.6	.109	8.90	....	2610° F.	68.0
Nitrogen......	N	14.01	.244	....	.971	....	......
Oxygen........	O	15.96	.218	....	1.106	....	......
Phosphorus...	P	30.94	.190	1.83	....	115° F.	9.06
Platinum......	Pt	196.7	.0324	21.53	....	3150° F.	24.00
Potassium.....	K	39.04	.166	.865	....	144.5°–136° F.	16.0
Silicon........	Si	28.0	.2029	2.49	....	2574° F.	128.0
Silver.........	Ag	107.66	.0570	10.50	....	1732° F.	23.0
Sodium.......	Na	23.0	.293	.972	....	207.7°–190° F.	32.0
Sulphur.......	S	31.98	.202	2.00	....	226° F.	16.86
Tellurium.....	Te	128.0	.0474	6.65	....	700° F.	19.0
Titanium.....	Ti	48.0	....	5.3	....	4000° F.	......
Tin...........	Sn	117.8	.0562	7.35	....	442°–417° F.	25.65
Tungsten.....	W	184.0	.0334	17.50	....	>Mn	......
Uranium......	U	180.0	....	18.40	....	....	......
Vanadium....	V	51.2	....	5.54	(5.50)	4300° F.	......
Zinc..........	Zn	64.9	.0955	7.00	....	773°–754° F.	48.36

* Cast iron specific heat at 212° F. is .109.
" " " 572° F. is .140.
" " " 2150° F. is .190.

Table of Physical Constants

Substances	Air = 1	Specific heat at constant pressure		Specific heat at constant volume	Pounds per cubic foot	Cubic feet per pound
	Specific gravity	For equal weight, water = 1	For equal volumes			
Air	1	.2377	.2377	.1689	.080728	12.387
Oxygen	1.1056	.2175	.2405	.1550	.089210	11.209
Nitrogen	.4713	.2438	.2368	.1730	.078420	12.752
Hydrogen	.0692	3.4090	.2359	2.4060	.005610	178.230
Carbon monoxide	.9670	.2450	.2370	.1730	.078100	12.804
Carbon dioxide	1.5210	.2169	.3307	.1710	.123430	8.102
Marsh gas	.5527	.5929	.3277	.4670	.044880	22.301
Olefiant gas (ethylene)	.9672	.4040	.4106	.3320	.079490	12.580
Aqueous vapor	.6220	.4805	.2989	....	....	....
Ammonia	.5894	.5084	.2996	....	....	....
Nitrous monoxide	1.5241	.2262	.0447	....	....	....
Nitrous dioxide	1.0384	.2317	.2406	....	....	....
Sulph. hydrogen	1.1746	.2432	.2857	....	....	....
Sulph. dioxide	2.2112	.1544	.3414	....	....	....
Chlorine	2.4502	.1210	.2965	....	....	....
Bromine vapor	5.4772	.0555	.3040	....	....	....
Carbon bisulphide vapor	2.6258	.1569	.4122	....	....	....
Hydrochloric acid	1.2596	.1882	.2333	....	....	....
Sulphuric acid	....	.335	....	....	....	....
Alcohol	....	.700	....	....	....	....
Glycerine	....	.450	....	....	....	....
Turpentine, oil	....	.426	....	....	....	....

Weight of Air Required for Combustion of Coal

Substances	Pounds of air	B.t.u. from combustion of one pound
Carbon	12.30	14,500
Hydrogen	35.00	61,524
Marsh gas	18.00	24,021
Olefiant gas	15.60	21,524
Acetylene	....	18,260

Boiling Points at Sea Level

Water	100 °C.
Alcohol	78.4 "
Ether	34.9 "
Carbon bisulphide	46.1 "
Nitric acid (strong)	120.0 "
Sulphuric acid	326.6 "
Oil turpentine	157.0 "
Mercury	350.0 "
Aldehyde	20.8 "

Combining Equivalents

Oxygen	8.0 °C.
Hydrogen	1.0 "
Nitrogen	14.0 "
Carbon	6.0 "
Sulphur	8.0 "
Phosphorus	10.33 "
Chlorine	35.5 "
Iodine	25.4 "
Potassium	39.1 "
Iron	28.0 "
Copper	31.7 "
Lead	103.5 "
Silver	108.0 "
Bromine	80 0 "
Sodium	23.0 "
Fluorine	19.0 "
Lithium	7.0 "
Rubidium	85.4 "

Lineal Expansion for Solids at Ordinary Temperature for 1° F.

Solids	From 1° F.	Coefficient of expansion from 32° to 212° F.
	Length	
Aluminum, cast	.00001234	.002221
Antimony, cryst.	.00000627	.001129
Brass, cast	.00000957	.001722
Brass, plate	.00001052	.001894
Brick	.00000306	.000550
Bronze (copper, 17; tin, 2½; zinc, 1)	.00000986	.001774
Bismuth	.00000975	.001755
Cement, Portland (mixed), pure	.00000594	.001070
Concrete: cement, mortar and pebbles	.00000795	.001430
Copper	.00000887	.001596
Ebonite	.00004278	.007700
Glass, English flint	.00000451	.000812
Glass, hard	.00000397	.000714
Glass, thermometer	.00000499	.000897
Granite (gray, dry)	.00000438	.000789
Granite (red, dry)	.00000498	.000897
Gold, pure	.00000786	.001415
Iron (wrought)	.00000648	.001166
Iron (cast)	.00000556	.001001
Lead	.00001571	.002828
Marbles, various { from	.00000308	.000554
Marbles, various { to	.00000786	.001415
Masonry, brick { from	.00000256	.000460
Masonry, brick { to	.00000494	.000890
Mercury (cubic expansion)	.00009984	.017971
Nickel	.00000695	.001251
Pewter	.00001129	.002033
Plaster, white	.00000922	.001660
Platinum	.00000479	.000863
Porcelain	.00000200	.000360
Silver, pure	.00001079	.001943
Slate	.00000577	.001038
Steel, cast	.00000636	.001144
Steel, tempered	.00000689	.001240
Stone, sand, dry	.00000652	.001174
Tin	.00001163	.002094
Wedgewood (ware)	.00000489	.000881
Wood, pine	.00000276	.000496
Zinc	.00001407	.002532
Zinc 8, Tin 1	.00001496	.002692

Cubical expansion or expansion of volume equals lineal expansion multiplied by 3.

The coefficient of expansion from 32° to 212° F. divided by 100 gives the lineal expansion for corresponding solid for 1° C.

The expansion of metals above 212° F. is irregular and more rapid.

Furnace Temperatures

M. Le Chatelier finds the melting heat of white cast iron 2075° F., and that of gray cast iron at 2228° F. Mild steel melts at 2687° F., semi-mild at 2651° F. and hard steel at 2570° F.

The furnace for hard porcelain at the end of the baking has a heat of 2498° F. The heat of a normal incandescent lamp is 3272° F., but it may be pushed beyond 3812° F.

The following are some of the temperatures determined by Professor Roberts-Austin.

Ten-ton Open-hearth Furnace (Woolwich Arsenal)

Temperature of steel, 0.3 per cent carbon, pouring into ladle	2993° F.
Temperature of steel, 0.3 per cent carbon, pouring into large mold	2876° F.
Reheating furnace, Woolwich Arsenal, temperature of interior	1706° F.
Cupola furnace, temperature of No. 2 cast iron pouring into ladle	2912° F.

Determinations by M. Le Chatelier. Bessemer Process. Six-ton Converter

Bath of slag	2876° F.
Metal in ladle	2984° F.
Metal in ingot mold	2876° F.
Ingot in reheating furnace	2192° F.
Ingot under the hammer	1976° F.

Open-hearth Furnace (Siemans) Semi-mild Steel

Fuel gas near gas generator	1328° F.
Fuel gas entering into bottom of regenerator chamber	752° F.
Fuel gas issuing from regenerator chamber	2192° F.
Air issuing from regenerator chamber	1832° F.

Chimney Gases

Furnace in perfect condition	590° F.

Open-hearth Furnace

End of the melting of pig charge	2588° F.
Completion of conversion	2732° F.

Fownes Elementary Chemistry gives relative conductivity of metals as follows:

Silver	1000
Copper	736
Gold	532
Brass	236
Tin	145
Iron	119
Steel	116
Lead	85
Platinum	84
German silver	63
Bismuth	18

MEASUREMENT OF HEAT

Unit of Heat

The British thermal unit (B.t.u.) is the quantity of heat required to raise the temperature of one pound of pure water one degree Fahrenheit at 39.1° F.

The French thermal unit, or calorie, is the quantity of heat required to raise the temperature of one kilogram of pure water one degree Centigrade at 4° C., which is equivalent to 39.1° F. The French calorie is equal to 3.968 British thermal units; one B.t.u. is equal to .252 calories.

Mechanical Equivalent of Heat

This is the number of foot pounds equivalent to one B.t.u. Joule's experiments gave the figure 772, which is known as Joule's equivalent. Recent experiments give higher figures and the average is now taken to be 778.

Heat of Combustion in Oxygen of Various Substances

Substance	Heat units	
	Cent.	Fahr.
Hydrogen to liquid water at 0° C.	34,462 33,808 34,342	62,032 60,854 61,816
Hydrogen to steam at 100° C.	28,732	51,717
Carbon (wood charcoal) to carbonic acid (CO_2); ordinary temperatures	8,080 7,900 8,137	14,544 14,220 14,647
Carbon graphite to CO_2	7,901	14,222
Carbon to carbonic oxide, CO	2,473	4,451
Carbonic oxide to CO_2 per unit of CO	2,403 2,431 2,385	4,325 4,376 4,293
CO to CO_2 per unit of C = $2\frac{1}{3} \times 2403$	5,607	10,093
Marsh gas, CH_4 to water and CO_2	13,120 13,108 13,063	23,616 23,594 23,513
Olefiant gas, C_2H_4 and water and CO_2	11,858 11,942 11,957	21,344 21,496 21,523

If one pound of carbon is burned to CO_2, generating 14,544 B.t.u., and the CO_2 thus formed is immediately reduced to CO in the presence of glowing carbon, by the reaction $CO_2 + C = 2\,CO$, the result is the same as if the two pounds of C had been burned directly to 2 CO, generating $2 \times 4451 = 8902$ heat units; consequently $14,544 - 8902 = 5642$ heat units have disappeared or become latent and the reduction of CO_2 to CO is thus a cooling operation.

Kent, 456.

RADIATION OF HEAT

Relative Radiating and Reflecting Power of Different Substances

Substances	Radiating or absorbing power	Reflecting power
Lampblack	100	0
Water	100	0
Writing paper	98	2
Ivory, jet, marble	93 to 98	7 to 2
Ordinary glass	90	10
Ice	85	15
Cast iron, bright polished	25	75
Mercury, about	23	77
Wrought iron, polished	23	77
Zinc, polished	19	81
Steel, polished	17	83
Platinum, polished	24	76
Tin	15	85
Brass, cast, dead polish	11	89
Brass, bright polished	7	93
Copper, varnished	14	86
Copper, hammered	7	93
Silver, polished, bright	3	97

Experiments of Dr. A. M. Mayer give the following: The relative radiations from a cube of cast iron, having faces rough, as from the foundry, planed, drawfiled and polished; and from the same surfaces oiled, are as below (Professor Thurston).

Surface	Oiled	Dry
Rough	100	100
Planed	60	32
Drawfiled	49	20
Polished	45	18

Relative Heat-Conducting Power of Metals

Metals	Conductivity	Metals	Conductivity
Silver	1000	Wrought iron	436
Gold	981	Tin	422
Copper, rolled	845	Steel	397
Copper, cast	811	Platinum	380
Mercury	677	Cast iron	359
Aluminum	665	Lead	287
Zinc	641	Antimony, cast, horizontal	215
Zinc, cast, horizontal	608	Antimony, cast, vertical	192
Zinc, cast, vertical	628	Bismuth	61

Relative Nonconducting Power of Materials

(Professor Ordway)

Substance 1 inch thick. Heat applied 310° F.	Pounds of water heated 10° F. per hour through 1 square foot	Solid matter in 1 square foot 1 inch thick, parts in 1000	Air included, parts in 1000
1. Loose wool	8.1	56	944
2. Live geese feathers	9.6	50	950
3. Carded cotton wool	10.4	20	980
4. Hair felt	10.3	185	815
5. Loose lampblack	9.8	56	944
6. Compressed lampblack	10.6	244	756
7. White-pine charcoal	13.9	119	881
8. Anthracite coal dust	35.7	506	494
9. Loose calcined magnesia	12.4	23	977
10. Compressed calcined magnesia	42.6	285	715
11. Light carbonate of magnesia	13.7	60	940
12. Compressed carbonate of magnesia	15.4	150	850
13. Loose fossil meal	14.5	60	940
14. Ground chalk	20.6	253	747
15. Dry plaster of Paris	30.9	368	632
16. Fine asbestos	49.0	81	919
17. Air, alone	48.0	0	1000
18. Sand	62.1	527	471
19. Best slag wool	13.0	....	....
20. Paper	14.0	....	....
21. Blotting paper, wound tight	21.0	....	....
22. Asbestos paper, wound tight	21.7	....	....
23. Straw rope, wound spirally	18.0	....	....
24. Loose rice chaff	18.7	....	....
25. Paste of fossil meal with hair	16.7	....	....
26. Paste of fossil meal with asbestos	22.0	....	....
27. Loose bituminous coal ashes	21.0	....	....
28. Loose anthracite coal ashes	27.0	....	....

Professor Ordway states that later experiments made with still air gave results which differ little from cotton wool, hair felt or compressed lampblack. Asbestos is one of the poorest conductors.

Heat-Conducting Power of Covering Materials

(J. J. Coleman)

Mineral wool	100	Charcoal	140
Hair felt	117	Sawdust	163
Cotton wool	122	Gas works breeze	230
Sheep's wool	136	Wood and air space	280
Infusorial earth	136		

Boiling Points at Atmospheric Pressure

Ether, sulphuric	100° F.	Average sea water	213.2° F.
Carbon bisulphide	118° F.	Saturated brine	226° F.
Ammonia	140° F.	Nitric acid	248° F.
Chloroform	140° F.	Oil of turpentine	315° F.
Bromine	145° F.	Phosphorus	554° F.
Wood-spirit	150° F.	Sulphur	570° F.
Alcohol	173° F.	Sulphuric acid	590° F.
Benzine	176° F.	Linseed oil	597° F.
Water	212° F.	Mercury	676° F.

The boiling points of liquids increase as the pressure increases.

Table of Equivalent Temperatures, Centigrade to Fahrenheit

Rule to change the values: Fahr. = $\frac{9}{5}$ C. + 32°.

Cent. = (F. − 32°) $\frac{5}{9}$.

Degrees		Degrees		Degrees		Degrees		Degrees	
Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
−10	+14.0	22	71.6	54	129.2	86	186.8	190	374
− 9	+15.8	23	73.4	55	131.0	87	188.6	195	383
− 8	+17.6	24	75.2	56	132.8	88	190.4	200	392
− 7	+19.4	25	77.0	57	134.6	89	192.2	205	401
− 6	+21.2	26	78.8	58	136.4	90	194	210	410
− 5	+23 0	27	80.6	59	138.2	91	195.8	215	419
− 4	+24.8	28	82.4	60	140.0	92	197.6	220	428
− 3	+26.6	29	84.2	61	141.8	93	199.4	225	437
− 2	+28.4	30	86.0	62	143.6	94	201.2	230	446
− 1	+30.2	31	87.8	63	145.4	95	203.0	235	455
0	+32.0	32	89.6	64	147.2	96	204.8	240	464
+ 1	33.8	33	91.4	65	149.0	97	206.6	245	473
2	35.6	34	93.2	66	150.8	98	208.4	250	482
3	37.4	35	95.0	67	152.6	99	210.2	255	491
4	39.2	36	96.8	68	154.4	100	212	260	500
5	41.0	37	98.6	69	156.2	105	221	265	509
6	42.8	38	100.4	70	158.0	110	230	270	518
7	44.6	39	102.2	71	159.8	115	239	275	527
8	46.4	40	104.0	72	161.6	120	248	280	536
9	48.2	41	105.8	73	163.4	125	257	285	545
10	50.0	42	107.6	74	165.2	130	266	290	554
11	51.8	43	109.4	75	167.0	135	275	295	563
12	53.6	44	111.2	76	168.8	140	284	300	572
13	55.4	45	113.0	77	170.6	145	293	305	581
14	57.2	46	114.8	78	172.4	150	302	310	590
15	59.0	47	116.6	79	174.2	155	311	315	599
16	60.8	48	118.4	80	176.0	160	320	320	608
17	62.6	49	120.2	81	177.8	165	329	325	617
18	64.4	50	122.0	82	179.6	170	338	330	626
19	66.2	51	123.8	83	181.4	175	347	335	635
20	68.0	52	125.6	84	183.2	180	356	340	644
21	69.8	53	127.4	85	185.0	185	365	345	653

Data Sheet No. 53, The Foundry, November, 1909.

TABLE OF EQUIVALENT TEMPERATURES, CENTIGRADE TO FAHRENHEIT — (*Continued*)

Degrees		Degrees		Degrees		Degrees		Degrees	
Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
350	662	510	950	670	1238	830	1526	990	1814
355	671	515	959	675	1247	835	1535	995	1823
360	680	520	968	680	1256	840	1544	1000	1832
365	689	525	977	685	1265	845	1553	1005	1841
370	698	530	986	690	1274	850	1562	1010	1850
375	707	535	995	695	1283	855	1571	1015	1859
380	716	540	1004	700	1292	860	1580	1020	1868
385	725	545	1013	705	1301	865	1589	1025	1877
390	734	550	1022	710	1310	870	1598	1030	1886
395	743	555	1031	715	1319	875	1607	1035	1895
400	752	560	1040	720	1328	880	1616	1040	1904
405	761	565	1049	725	1337	885	1625	1045	1913
410	770	570	1058	730	1346	890	1634	1050	1922
415	779	575	1067	735	1355	895	1643	1055	1931
420	788	580	1076	740	1364	900	1652	1060	1940
425	797	585	1085	745	1373	905	1661	1065	1949
430	806	590	1094	750	1382	910	1670	1070	1958
435	815	595	1103	755	1391	915	1679	1075	1967
440	824	600	1112	760	1400	920	1688	1080	1976
445	833	605	1121	765	1409	925	1697	1085	1985
450	842	610	1130	770	1418	930	1706	1090	1994
455	851	615	1139	775	1427	935	1715	1095	2003
460	860	620	1148	780	1436	940	1724	1100	2012
465	869	625	1157	785	1445	945	1733	1105	2021
470	878	630	1166	790	1454	950	1742	1110	2030
475	887	635	1175	795	1463	955	1751	1115	2039
480	896	640	1184	800	1472	960	1760	1120	2048
485	905	645	1193	805	1481	965	1769	1125	2057
490	914	650	1202	810	1490	970	1778	1130	2066
495	923	655	1211	815	1499	975	1787	1135	2075
500	932	660	1220	820	1508	980	1796	1140	2084
505	941	665	1229	825	1517	985	1805	1145	2093
.....	......	.....	......	.....	......	.....	......	1150	2102

Data Sheet No. 54, The Foundry, November, 1909.

Comparison of Thermometer Scales

Centigrade	Reaumur	Fahrenheit	Centigrade	Reaumur	Fahrenheit	Centigrade	Reaumur	Fahrenheit
−30	−24.0	−22.0	14	11.2	57.2	58	46.4	136.4
−28	−22.4	−18.4	16	12.8	60.8	60	48.0	140.0
−26	−20.8	−14.8	18	14.4	64.4	62	49.6	143.6
−24	−19.2	−11.2	20	16.0	68.0	64	51.2	147.2
−22	−17.6	− 7.6	22	17.6	71.6	66	52.8	150.8
−20	−16.0	− 4.0	24	19.2	75.2	68	54.4	154.4
−18	−14.4	− 0.4	26	20.8	78.8	70	56.0	158.0
−16	−12.8	3.2	28	22.4	82.4	72	57.6	161.6
−14	−11.2	6.8	30	24.0	86.0	74	59.2	165.2
−12	− 9.6	10.4	32	25.6	89.6	76	60.8	168.8
−10	− 8.0	14.0	34	27.2	93.2	78	62.4	172.4
− 8	− 6.4	17.6	36	28.8	96.8	80	64.0	176.0
− 6	− 4.8	21.2	38	30.4	100.4	82	65.6	179.6
− 4	− 3.2	24.8	40	32.0	104.0	84	67.2	183.2
− 2	− 1.6	28.4	42	33.6	107.6	86	68.8	186.8
0	0.0	32.0	44	35.2	111.2	88	70.4	190.4
2	1.6	35.6	46	36.8	114.8	90	72.0	194.0
4	3.2	39.2	48	38.4	118.4	92	73.6	197.6
6	4.8	42.8	50	40.0	122.0	94	75.2	201.2
8	6.4	46.4	52	41.6	125.6	96	76.8	204.8
10	8.0	50.0	54	43.2	129.2	98	78.4	208.4
12	9.6	53.6	56	44.8	132.8	100	80.0	212.0

No. 21, Supplement to Machinery, June, 1903.

Strength of Materials

(From notes on Machine Design, by permission of the author, Prof. Chas. H. Benjamin, Cleveland, O.)

Kind of metal	Ultimate strength			Elastic limit. tension	Modulus of rupture, transverse	Modulus of elasticity, tension
	Tensile	Compression	Shearing			
Wrought iron, small bars	55,000	38,000	45,000	28,000	40,000	26,000,000
Wrought iron, plates	50,000	......	40,000	25,000	......	25,000,000
Wrought iron, large forgings	45,000	......	35,000	22,500	30,000	25,000,000
Steel, O. H. plate	60,000	100,000	50,000	32,000	......	28,000,000
Steel, Bessemer	90,000	......	......	......	......	....
Steel, machinery	90,000	......	80,000	50,000	......	29,000,000
Steel, crucible or tool	120,000	......	......	60,000	......	40,000,000
Cast iron	18,000	75,000	25,000	Uncertain	36,000	18,000,000
Malleable castings	36,000	......	42,000	16,000	......	....
Steel castings	38,000	125,000	......	18,000	......	30,000,000
Brass castings	18,000	12,000	......	......	......	9,000,000
Copper castings	24,000	75,000	24,000	......	30,000	15,000,000
Bronze, gun metal	36,000	100,000	......	......	......	10,000,000
Bronze, 10 Al, 90 Cu	85,000	132,000	......	......	......	....
Bronze, phosphor	58,000	......	43,000	20,000	......	14,000,000
Aluminum castings	28,000	13,000	......	14,000	......	11,000,000

Material	Tension per square inch	Compression per square inch	Shear per square inch
Steel wire	103,272	...	...
	318,823	...	...
Iron wire	59,246	...	...
	97,908	...	...
Copper wire	37,607	...	...
	46,494	...	...
Brass wire	81,114	...	...
	98,578	...	...
Bronze wire	78,049	...	...
German silver	81,735	...	...
	92,224	...	...
Woods:			
Ash	11,000	6800	6280
	17,207	...	...
Beech	11,500	7000	5223
	18,000	...	...
Elm	13,500	7700	...
Hemlock	8,700	5300	2750
Hickory	12,800	8000	6045
	18,000	...	...
Maple	10,500	6800	7285
Oak (white)	10,250	7000	4425
	19,500	...	...
Oak (live)	...	6850	8480
Pine (white)	11,000	5400	2450
Pine (yellow)	15,900	8500	5735
Spruce	14,500	5700	5255
Walnut (black)	12,500	8000	4750
		Tons per square foot	
Brick (pressed)	...	40	...
	...	300	...
Granite	...	300	...
	...	1200	...
Limestone	...	250	...
	...	1000	...

Strength of Lime and Cement Mortar

TENSILE STRENGTH, POUNDS PER SQUARE INCH

Age	7 days.
Lime mortar	8
20 per cent Rosendale	8.5
20 per cent Roseland	8.5
30 per cent Rosendale	11
30 per cent Portland	16
40 per cent Rosendale	12
40 per cent Portland	39
60 per cent Rosendale	13
60 per cent Portland	58
80 per cent Rosendale	18.5
80 per cent Portland	91
100 per cent Rosendale	23
100 per cent Portland	120

Coefficient of Friction

If two bodies have plane surfaces in contact and the plane of contact be inclined so that one body just begins to slide upon the other, the angle made by this plane with a horizontal plane is called the angle of repose.

The coefficient of friction is the ratio of the ultimate friction to the pressure perpendicular to the plane of contact, and is equal to the tangent of the angle of repose.

Thus, if R denotes the friction between the surfaces, Q the perpendicular pressure and F the coefficient of friction. Then

$$F = \frac{R}{Q} \quad \text{and} \quad R = FQ.$$

Centrifugal Force

In a revolving body the force expended to deflect it from a rectilinear to a curved path is called centrifugal force and is equal to the weight of the body multiplied by the square of its velocity in feet per second, divided by 32.6 times the radius; or, if F equals centrifugal force, W equals weight of body, V equals velocity in feet per second and R equals the radius, then $F = \frac{WV^2}{32.16\,R}$. If N equals the number of revolutions per minute, the formula is reduced to $F = .000341\,WN^2R$.

Properties of Air

Air is a mechanical mixture of the gases, oxygen and nitrogen; 21 parts oxygen and 79 parts nitrogen by volume, or 23 parts oxygen and 77 parts nitrogen by weight. The weight of pure air at 32° F. and 29.9 barometer, or 14.6963 pounds per square inch; or 2116.3 pounds per square foot is .080728 pounds. The volume of one pound is 12.387 cubic feet.

Air expands 1/491.2 of its volume for every increase of 1° F., and its volume varies inversely as the pressure.

Volume, Density and Pressure of Air at Various Temperatures

(D. K. Clark.)

Fahr.	Volume at atmospheric pressure		Density, lbs. per cubic foot at atmospheric pressure	Pressure at constant volume	
	Cubic feet in 1 pound	Comparative volume		Pounds per square inch	Comparative pressure
0	11.583	.881	.086331	12.96	.881
32	12.387	.943	.080728	13.86	.943
40	12.586	.958	.079439	14.08	.958
50	12.840	.977	.077884	14.36	.977
62	13.141	1.000	.076097	14.70	1.000
70	13.342	1.015	.074950	14.92	1.015
80	13.593	1.034	.073565	15.21	1.034
90	13.845	1.054	.072230	15.49	1 054
100	14.096	1.073	.070942	15.77	1.073
110	14.344	1.092	.069721	16.05	1.092
120	14.592	1.111	.068500	16.33	1.111
130	14.846	1.130	.067361	16.61	1.130
140	15.100	1.149	.066221	16.89	1.149
150	15.351	1.168	.065155	17.19	1.168
160	15.603	1.187	.064088	17.50	1.187
170	15.854	1.206	.063089	17.76	1.206
180	16.106	1.226	.062090	18.02	1.226
200	16.606	1.264	.060210	18.58	1.264
210	16.860	1.283	.059313	18.86	1.283
212	16.910	1.287	.059135	18.92	1.287

Pressure of the Atmosphere per Square Inch and per Square Foot at Various Readings of the Barometer

Rule. — Barometer in inches × .4908 = pressure per square inch; pressure per square inch × 144 = pressure per square foot.

Barometer, inches	Pressure per square inch, pounds	Pressure per square foot, pounds	Barometer, inches	Pressure per square inch, pounds	Pressure per square foot, pounds
28.00	13.74	1978	29.75	14.60	2102
28.25	13.86	1995	30.00	14.72	2119
28.50	13.98	2013	30.25	14.84	2136
28.75	14.11	2031	30.50	14.96	2154
29.00	14.23	2049	30.75	15.09	2172
29.25	14.35	2066	31.00	15.21	2190
29.50	14.47	2083	....	....	....

Barometric Readings Corresponding with Different Altitudes (Kent.)

Altitude, feet	Reading of barometer, inches	Altitude, feet	Reading of barometer, inches
0	30.00	3763.2	25.98
68.9	29.92	4163.3	25.59
416.7	29.52	4568.3	25.19
767.7	29.13	4983.1	24.80
1122.1	28.74	5403.2	24.41
1486.2	28.35	5830.2	24.01
1850.4	27.95	6243.0	23.62
2224.5	27.55	6702.9	23.22
2599.7	27.16	7152.4	22.83
2962.1	26.77	7605.1	22.44
3369.5	26.38	8071.0	22.04

Horse Power Required to Compress One Cubic Foot of Free Air per Minute to a Given Pressure (Richards.)

Air not cooled during compression; also the horse power required, supposing the air to be maintained at constant temperature during the compression.

Gauge pressure	Air not cooled	Air at constant temperature
100	.22183	.14578
90	.20896	.13954
80	.19521	.13251
70	.17989	.12606
60	.164	.11558
50	.14607	.10565
40	.12433	.093667
30	.10346	.079219
20	.076808	.061188
10	.044108	.036944
5	.024007	.020848

Horse Power Required to Deliver One Cubic Foot of Air per Minute at a Given Pressure (Richards.)

Air not cooled during compression; also the horse power required, supposing the air to be maintained at constant temperature during the compression.

Gauge pressure	Air not cooled	Air at constant temperature
100	1.7317	1.13801
90	1.4883	.99387
80	1.25779	.8528
70	1.03683	.72651
60	.83344	.58729
50	.64291	.465
40	.46271	.34859
30	.31456	.24086
20	.181279	.14441
10	.074106	.06069
5	.032172	.027938

In computing the above tables an allowance of 10 per cent has been made for friction of the compressor.

Pressure of Water

Pressure in Pounds per Square Inch for Different Heads of Water (Kent.)

At 62° F. 1 foot head 0.433 pound per square inch, 0.433 × 144 = 62.352 pounds per cubic foot.

Head, feet	0	1	2	3	4	5	6	7	8	9
0	.....	0.433	0.866	1.299	1.732	2.165	2.598	3.031	3.464	3.897
10	4.330	4.763	5.196	5.629	6.062	6.495	6.928	7.361	7.794	8.227
20	8.660	9.093	9.526	9.959	10.392	10.825	11.258	11.691	12.124	12.557
30	12.990	13.423	13.856	14.298	14.722	15.155	15.588	16.021	16.454	16.887
40	17.320	17.753	18.186	18.619	19.052	19.485	19.918	20.351	20.784	21.217
50	21.650	22.083	22.516	22.949	23.382	23.819	24.248	24.681	25.114	25.547
60	25.980	26.413	26.846	27.279	27.712	28.145	28.578	29.011	29.444	29.877
70	30.310	30.743	31.176	31.609	32.042	32.475	32.908	33.341	33.774	34.207
80	34.640	35.073	35.506	35.939	36.372	36.805	37.238	37.671	38.104	38.537
90	38.970	39.403	39.836	40.269	40.702	41.135	41.568	42.001	42.436	42.867

Head in Feet of Water, Corresponding to Pressures in Pounds per Square Inch (Kent.)

1 pound per square inch 2.30947 feet head, 1 atmosphere 14.71 pounds per square inch 33.94 foot head.

Pressure	0	1	2	3	4	5	6	7	8	9
0	......	2.309	4.619	6.928	9.238	11.547	13.857	16.166	18.476	20.785
10	23.0947	25.404	27.714	30.023	32.333	34.642	36.952	39.261	41.570	43.880
20	46.1894	48.499	50.808	53.118	55.427	57.737	60.046	62.356	64.665	66.975
30	69.2841	71.594	73.903	76.213	78.522	80.831	83.141	85.450	87.760	90.069
40	92.3788	94.688	96.998	99.307	101.62	103.93	106.24	108.55	110.85	113.16
50	115.4735	117.78	120.09	122.40	124.71	126.02	129.33	131.64	133.95	136.26
60	138.5682	140.88	143.19	145.50	147.81	150.12	152.42	154.73	157.04	159.35
70	161.6629	163.97	166.28	168.59	170.90	173.21	175.52	177.83	180.14	182.45
80	184.7576	187.07	189.38	191.69	194.00	196.31	198.61	200.92	203.23	205.54
90	207.8523	210.16	212.47	214.78	217.09	219.40	221.71	224.02	226.33	228.64

Equivalent Values of Electrical and Mechanical Units

Units	Equivalent value in other units
1 kilowatt hour =	1,000 watt hours. 1.34 horse-power hours. 2,654,200 ft. lbs. 3,600,000 joules. 3,412 heat units. 367,000 kilogram metres. .235 lb. carbon, oxidized with perfect efficiency. 3.53 lbs. water evap. from and at 212° F. 22.75 lbs. of water raised from 62° F., to 212° F.
1 horse-power hour =	.746 K.W. hours. 1,980,000 ft. lbs. 2,545 heat units. 273,000 kilogram metres. .175 lb. carbon oxidized with perfect efficiency. 2.64 lbs. water evap. from and at 212° F. 17 lbs. of water raised from 62° F. to 212° F.
1 kilowatt =	1,000 watts. 1.34 horse power. 2,654,200 ft. lbs. per hour. 44,240 ft. lbs. per minute. 737.3 ft. lbs. per second. 3,412 heat units per hour. 56.9 heat units per minute. .948 heat unit per second. .2275 lb. carbon oxidized per hour. 3.53 lbs. water evap. per hour from and at 212° F.
1 horse power =	746 watts. .746 K.W. 33,000 ft. lbs. per minute. 550 ft. lbs. per second. 2,545 heat units per hour. 42.4 heat units per minute. .707 heat unit per second. .175 lb. carbon oxidized per hour. 2.64 lbs. water evap. per hour from and at 212° F.
1 joule =	1 watt second. .000000278 K.W. hour. .102 k.g.m. .0009477 heat units. .7373 ft. lbs.
1 foot pound =	1.356 joules. .1383 k.g.m. .000000377 K.W. hour. .001285 heat unit. .0000005 H.P. hour.

EQUIVALENT VALUES OF ELECTRICAL AND MECHANICAL UNITS — (*Continued*)

Units	Equivalent Value in Other Units
1 watt =	1 joule per second. .00134 H.P. 3.412 heat units per hour. .7373 ft. lb. per second. .0035 lb. of water evap. per hour. 44.24 ft. lbs. per minute.
1 watt per square inch =	8.19 heat units per sq. ft. per minute. 6,371 ft. lbs. per sq. ft. per minute. .193 H.P. per sq. ft.
1 heat unit =	1,055 watt seconds. 778 ft. lbs. 107.6 kilogram metres. .000293 K.W. hour. .000393 H.P. hour. .0000688 lb. of carbon oxidized. .001036 lb. water evap. from and at 212° F.
1 heat unit per square foot per minute =	.122 watts per square inch. .0176 K.W. per sq. ft. .0236 H.P. per sq. ft.
1 kilogram metre =	7.233 ft. lbs. .00000365 H.P. hour. .00000272 K.W. hour. .0093 heat unit.
1 pound carbon oxidized with perfect efficiency =	14,544 heat units. 1.11 lbs. of anthracite coal oxidized. 2.5 lbs. dry wood, oxidized. 21 cubic ft. illuminating gas. 4.26 K.W. hours. 5.71 H.P. hours. 11,315,000 ft. lbs. 15 lbs. water evap. from and at 212° F.
1 pound water evaporated from and at 212° F. =	.283 K.W. hour. .379 H.P. hour. 965.7 heat units. 103,900 k.g.m. 1,019,000 joules. 751,300 ft. lbs. .0664 lb. of carbon oxidized.

CHAPTER VI

ALLOYS

An alloy is a combination by fusion of two or more metals. The combination may be a chemical one; generally, however, there is an excess of one or more of the constituents.

Metals do not unite indifferently, but have certain affinities; thus zinc and lead do not unite, but either will mix with silver in any proportion.

Alloys are generally harder, less ductile and have greater tenacity than the mean of their components. The melting point of an alloy is as a rule below that of any of its components, and it is more easily oxidized.

The specific gravity of an alloy may be greater, equal to, or less than the mean of its components.

In alloys of copper and tin the maximum tensile and compressive strength is afforded by a mixture containing 82.7 per cent copper and 17.3 per cent tin. The minimum strength is shown by a composition of 62.5 per cent copper and 37.5 per cent tin.

Alloys of Copper and Tin

Mean composition by analysis		Tensile strength in pounds per square inch	Elastic limit in pounds per square inch	Crushing strength in pounds per square inch
Copper	Tin			
100	....	12,760	11,000	39,000
97.89	1.90	24,580	10,000	34,000
92.11	7.80	28,540	19,000	42,000
87.15	12.75	29,430	20,000	53,000
80.95	18.84	32,980	....	78,000
76.63	23.24	22,010	22,010	144,000
69.84	29.88	5,585	5,585	147,000
65.34	34.47	2,201	2,201	84,700
56.70	43.17	1,455	1,455	....
44.52	55.28	3,010	3,010	35,800
23.35	76.29	6,775	6,775	....
11.49	88.47	6,390	3,500	10,100
8.57	91.39	6,450	3,500	9,800
3.72	96.31	4,780	2,750	9,800
....	100.00	3,505	....	6,400

Alloys of Copper and Zinc

Mean composition by analysis		Tensile strength in pounds per square inch	Elastic limit per cent of breaking load in pounds per square inch	Crushing strength in pounds per square inch
Copper	Zinc			
97.83	1.88	27,240	....	....
82.93	16.98	32,600	26.1	....
76.65	23.08	30,520	84.6	42,000
71.20	28.54	30,510	29.5	....
66.27	33.50	37,800	25.1	....
60.94	38.65	41,065	40.1	75,000
55.15	44.44	44,280	44.00	78,000
49.66	50.14	30,990	54.5	117,400
47.56	52.28	24,150	100.0	121,000
43.36	56.22	9,170	100.0	....
32.94	66.23	1,774	100.0	....
20.81	77.63	9,000	100.0	52,152
12.12	86.67	12,413	100.0	....
4.35	94.59	18,065	100.0	....
0	100.00	5,400	75.0	22,000

Composition of Alloys in Common Use in Brass Foundries

(American Machinist.)

Alloys	Copper, lbs.	Zinc, lbs.	Tin, lbs.	Lead, lbs.	
Admiralty metal..	87	5	8	....	For parts of engines on naval vessels.
Bell metal.........	16	....	4	....	Bells for ships and factories.
Brass (yellow).....	16	8	....	5	For plumbers, ship and house work.
Bush metal........	64	8	4	4	Bearing bushes for shafting.
Gun metal........	32	1	3	....	For pumps and hydraulic work.
Steam metal......	20	1	1.5	1	Casting subjected to steam pressure.
Hard gun metal...	16	....	2.5	....	For heavy bearings.
Muntz metal......	60	40	....	....	For bolts and nuts, forged. Valve spindles, etc.
Phosphor bronze	92	....	8.0	....	Phos. tin for valves, pumps and general work.
Phosphor bronze	90	....	10.0	....	Phos. tin for cog and worm wheels, bushes and bearings.
Brazing metal....	16	3	....	....	Flanges for copper pipe.
Brazing solder...	50	50	....	....	Solder for above flanges.

Alloys of Copper, Tin and Zinc

Analysis original mixture			Tensile strength per square inch
Cu	Sn	Zn	
90	5	5	23,660
85	5	10	28,840
85	10	5	35,680
80	5	15	37,560
80	10	10	32,830
75	5	20	34,960
75	7.5	17.5	39,300
75	10.0	15.0	34,000
75	15.0	10.0	28,000
75	20.0	5.0	27,660
70	5.0	25.0	32,940
70	7.5	22.5	32,400
70	10.0	20.0	26,300
70	15.0	15.0	27,800
70	20.0	10.0	12,900
67.5	2.5	30.0	45,850
67.5	5.0	27.5	34,460
67.5	7.5	25.0	30,000
65.0	2.5	32.5	38,300
65.0	5.0	30.0	36,000
65.0	10.0	25.0	22,500
65.0	15.0	20.0	7,231
65.0	20.0	15.0	2,665
60.0	2.5	37.5	57,400
60.0	5.0	35.0	41,160
60.0	10.0	30.0	21,780
60.0	15.0	25.0	18,020
58.22	2.3	39.48	66,500
55.0	0.5	44.5	68,500
55.0	5.0	40.0	27,000
55.0	10.0	35.0	25,460
50.0	5.0	45.0	23,000

Above tables from report of U. S. Test Board, Vol. II, 1881.

Copper-Nickel Alloys

(German Silver.)

Constituents	Copper, lbs.	Nickel, lbs.	Tin, lbs.	Zinc, lbs.
German silver {	51.6	25.8	22.6	....
	50.2	14.8	3.1	31.9
Nickel silver	75.0	....	25.0	....

Useful Alloys of Copper, Tin and Zinc

Alloys	Copper, lbs.	Tin, lbs.	Zinc, lbs.	Other Metals
U. S. Navy Dept., journal boxes, and guide gibs	6	1	.25	....
	82.8	13.8	3.4	....
Tobin bronze	58.22	2.3	29.48	....
Naval brass	62.0	1.0	37.0	....
Composition, U.S. Navy	88.0	10.0	2.0	....
Gun metal	92.5	5.0	2.5	....
	91.0	7.0	2.0	....
	85.0	5.0	10.0	....
	83.0	2.0	15.0	....
Tough brass for engines	76.5	11.8	11.7	....
Bronze for rod boxes	82.0	16.0	2.0	....
Bronze subject to shock	83.0	15.0	1.5	.5 lead.
Bronze for pump castings	88.0	10.0	2.0	....
Red brass	87.0	4.4	4.3	4.3 lead.
Bronze, steam whistles	81.0	17.0	....	2.0 antimony.
Bearing metal	89.0	8.0	3.0	....
	86.0	14.0	....	....
	74.0	9.5	9.5	7.0 lead.
Gold bronze	98.5	2.1	5.6	2.8 lead.

Tobin Bronze

Constituents	Pig metal, per cent
Copper	59.00
Zinc	38.40
Tin	2.16
Iron	.11
Lead	.31

Tensile strength (cast) 66,000 pounds.

Delta Metal

Constituents	Per cent	Constituents	Per cent
Iron	.1 to 5	Iron	.1 to 5
Copper	50.0 to 65	Tin	.1 to 10
Zinc	49.9 to 30	Zinc	1.8 to 45
		Copper	98.0 to 40

This metal is said to be very strong and tough.

Aluminum Bronze

Aluminum, per cent	Copper, per cent	Tensile strength, pounds per square inch
11	89	89,600 to 100,800
10	90	73,920 to 89,600
7.5	92.5	56,000 to 67,200
5.0	95.0	33,600 to 40,320

Analysis of Bearing-Metal Alloys

Metal	Copper	Tin	Lead	Zinc	Antimony	Iron
Camelia metal	70.20	4.25	14.75	10.20	......	.55
Anti-friction metal	1.60	98.13	......	......	......	......
White metal	......	......	87.92	......	12.08	......
Salgee anti-friction	4.01	9.91	1.15	85.57	......	......
Graphite bearing metal	......	14.38	67.73	......	16.72	......
Antimonial lead	......	......	80.69	......	18.83	......
Cornish bronze	77.83	9.60	12.40	......	......	......
Delta metal	92.39	2.37	5.10	......	......	.07
Magnolia metal	Trace	......	83.55	Trace	16.45	Trace
American anti-friction metal	......	......	78.44	.98	18.60	.65
Tobin bronze	59.00	2.16	.31	38.44	......	.11
Graney bronze	75.80	9.20	15.06	......	......	......
Damascus bronze	76.41	10.60	12.52	......	......	......
Manganese bronze	90.52	9.58	......	......	......	......
Ajax metal	81.24	10.98	7.27	......	......	......
Anti-friction metal	......	......	88.32	......	11.93	......
Harrington bronze	55.73	.97	......	42.67	......	68
Hard lead	......	......	94.40	......	6.03	Phos.
Phosphor bronze	97.72	10.92	9.61	......	......	.94
Extra box metal	76.80	8.00	15.00	......	......	.20

Results of Tests for Wear

Metal	Composition					Rate of Wear
	Copper	Tin	Lead	Phos.	Arsenic	
Standard	79.70	10.00	9.50	.80	......	100
Copper-tin	87.50	12.50	......	......	......	148
Copper-tin, second experiment, same metal	......	......	......	......	......	153
Copper-tin, third experiment, same metal	......	......	......	......	......	147
Arsenic bronze	89.20	10.00	......	......	.80	142
	79.20	10.00	7.00	......	.80	115

Concerning the preceding table Dr. Dudley remarks: "We began to find evidences that wear of bearing metal alloys varied in accordance with the following law. That alloy which has the greatest power of distortion without rupture will best resist wear."

Alloys Containing Antimony

Various analyses of Babbitt metal.

Metal	Tin	Copper	Antimony	Zinc	Lead
Babbitt metal	50	1	5	......	......
Babbitt metal for light duty	89.3	1.8	8.9	......	......
Babbitt, hard	96.0	4.0	8.0	......	......
	88.9	3.7	7.4	......	......
	45.5	1.5	13.0	......	......
Britannia	85.7	1.0	10.1	2.9	......
	81.0	2.0	16.0	1.0	......
	22.0	10.0	62.0	6.0	......
White metal	85.0	5.0	10.0	......	......
Parson's metal	86.0	2.0	1.0	27.0	2.0
Richard's metal	70.0	4.5	15.0	......	10.5
Fenton's metal	16.0	5.0	......	79.0	......
French Navy	7.5	7.0	......	87.5	7.0
German Navy	85.0	7.5	7.5	......	......

Belting

Trautwine gives the ultimate strength of good leather belting at 3000 pounds per square inch.

Jones and Laughlin give the breaking strength per inch of width, 3/16 thick, of good leather belting as follows:

In the solid leather	675 pounds.
At the rivet holes of splices	362 pounds.
At the lacing holes	210 pounds.

Safe working load 45 pounds per inch of width for single belts, equivalent to speed for each inch of width of 720 feet per minute per horse power. The efficiency of the double belt compared to that of a single belt is as 10 is to 7.

Making D = diameter of pulley in inches.
R = number of revolutions per minute.
W = width of belt in inches.
H = horse power that can be transmitted by the belt;

then for single belts,

$$H = \frac{D \times R \times W}{2750};$$

and for double belts,

$$H = \frac{D \times R \times W}{1925}.$$

FOR WIDTH OF BELT IN INCHES

Single belt	Double belt
$W = \frac{H \times 2750}{D \times R}$	$W = \frac{H \times 1925}{D \times R}$
Revolutions per minute	
$R = \frac{H \times 2750}{D \times W}$	$R = \frac{H \times 1925}{D \times W}$
Diameter of pulley	
$D = \frac{H \times 2750}{W \times R}$	$D = \frac{H \times 1925}{W \times R}$

These formulæ are for open belts and pulleys of same diameter. If the arc of contact on the smaller pulley is less than 90 degrees, use the following constants for those given in above formulæ.

Degrees contact	Single belt	Double belt
90	6080	4250
112½	4730	3310
120	4400	3080
135	3850	2700
150	3410	2390
157½	3220	2250

Belt Velocity or Circumferential Speed of Pulleys

Pulley diameter in inches	Revolutions per minute												
	50	60	70	80	90	100	110	120	130	140	150	160	170
	Velocity in feet per minute												
6	78.5	94.2	110	126	141	157	173	188	204	220	235	251	267
7	91.7	110	128	146	165	183	201	220	238	256	275	293	312
8	105	126	146	167	188	210	230	251	272	293	314	335	356
9	118	141	165	188	212	236	259	282	306	330	353	377	400
10	131	157	183	209	235	262	288	314	340	366	392	419	445
12	157	188	220	252	282	314	346	377	408	440	471	502	534
14	183	220	256	293	330	366	403	440	476	513	550	586	623
16	209	251	293	335	377	419	460	502	544	586	628	670	712
18	230	282	330	377	424	471	518	565	612	659	707	754	801
20	262	314	366	419	471	524	576	628	681	733	785	838	890
22	288	345	403	460	518	576	634	691	749	806	864	921	979
24	314	377	440	502	565	628	691	754	817	880	942	1005	1068
26	340	408	476	545	622	681	749	817	885	953	1021	1089	1157
28	380	440	513	586	659	733	806	880	953	1026	1100	1173	1246
30	393	471	550	628	706	785	864	942	1022	1100	1178	1256	1335
32	419	502	586	670	754	838	921	1005	1089	1173	1257	1340	1424
34	445	534	623	712	801	890	979	1068	1157	1246	1335	1424	1513
36	471	565	659	754	848	942	1037	1131	1225	1319	1414	1508	1602
40	523	628	733	837	942	1047	1152	1256	1361	1466	1571	1675	1780
48	628	754	879	1005	1131	1257	1382	1508	1633	1759	1885	2010	2136
54	707	848	989	1131	1272	1414	1555	1696	1838	1979	2120	2262	2403
60	785	942	1099	1256	1414	1571	1728	1885	2042	2199	2356	2513	2670
66	864	1036	1209	1382	1550	1728	1900	2073	2246	2419	2592	2764	2937
72	942	1131	1319	1508	1696	1885	2073	2262	2450	2639	2827	3016	3204
78	1021	1225	1429	1633	1838	2042	2245	2450	2655	2859	3063	3267	3472
84	1099	1319	1539	1754	1978	2199	2419	2639	2859	3079	3298	3518	3738

Contributed by W. J. Phillips, No. 117, extra data sheet, Machinery, October, 1909.

Belt Velocity or Circumferential Speed of Pulleys — (*Continued*)

Pulley diameter in inches	Revolutions per minute												
	180	190	200	210	220	230	240	250	260	270	280	290	300
	Velocity in feet per minute												
6	282	298	311	330	346	361	377	392	408	424	440	455	471
7	330	348	367	385	403	421	440	458	477	495	513	531	550
8	377	398	419	440	461	481	503	523	545	565	586	607	628
9	424	447	471	495	518	542	565	588	613	630	660	683	707
10	471	497	524	549	576	602	628	654	681	707	733	759	785
12	560	597	628	659	691	722	754	785	817	848	880	911	942
14	659	696	733	769	806	843	880	916	953	989	1026	1063	1100
16	754	796	838	879	921	963	1005	1046	1089	1131	1173	1214	1257
18	848	895	942	989	1037	1084	1131	1178	1225	1272	1319	1366	1414
20	942	995	1047	1099	1152	1204	1256	1309	1361	1414	1466	1518	1571
22	1037	1094	1152	1209	1267	1325	1382	1440	1497	1555	1612	1670	1728
24	1131	1194	1257	1319	1382	1445	1508	1671	1633	1696	1759	1822	1885
26	1225	1293	1361	1429	1497	1565	1633	1701	1770	1838	1906	1974	2042
28	1319	1393	1466	1539	1613	1686	1759	1832	1906	1979	2052	2126	2199
30	1413	1492	1571	1649	1728	1806	1885	1963	2042	2120	2199	2277	2356
32	1508	1592	1675	1759	1843	1927	2010	2094	2178	2252	2345	2429	2513
34	1602	1691	1780	1869	1958	2047	2136	2225	2314	2403	2492	2581	2670
36	1696	1791	1885	1978	2073	2168	2262	2326	2450	2545	2639	2733	2827
40	1885	1989	2094	2199	2304	2513	2618	2723	2827	2932	3037	3141	3246
48	2262	2387	2513	2639	2765	2890	3016	3142	3267	3393	3518	3644	3769
54	2545	2686	2827	2969	3110	3251	3393	3534	3676	3817	3959	4100	4240
60	2827	2984	3141	3298	3456	3613	3770	3927	4084	4251	4398	4555	4712
66	3110	3283	3455	3628	3801	3974	4147	4319	4492	4665	4838	5010	5183
72	3392	3581	3770	3958	4147	4335	4524	4713	4900	5059	5278	5466	5654
78	3676	3880	4084	4288	4492	4696	4900	5059	5309	5513	5717	5921	6125
84	3958	4178	4398	4618	4838	5058	5277	5497	5717	5937	6157	6377	6597

Contributed by W. J. Phillips, No. 117, extra data sheet, Machinery, October, 1909.

Rules for Calculating Speeds and Diameters of Pulleys

Proposed speed of grinding spindle being given, to find proper speed of countershaft.

Rule. — Multiply the number of revolutions per minute of the grinding spindle by the diameter of its pulley and divide the product by the diameter of the driving pulley on the countershaft.

Speed of countershaft given, to find diameter of pulley to drive grinding spindle.

Rule. — Multiply the number of revolutions per minute of the grinding spindle by the diameter of its pulley and divide the product by the number of revolutions per minute of the countershaft.

Proposed speed of countershaft given, to find the diameter of pulley for the lineshaft.

Rule. — Multiply the number of revolutions per minute of the countershaft by the diameter of the tight and loose pulleys and divide the product by the number of revolutions per minute of the lineshaft.

Table of Grinding Wheel Speeds

Diameter of wheel, inches	Revolutions per minute for surface speed of 4000 feet	Revolutions per minute for surface speed of 5000 feet	Revolutions per minute for surface speed of 6000 feet
1	15,279	19,099	22,918
2	7,639	9,549	11,459
3	5,093	6,366	7,639
4	3,820	4,775	5,730
5	3,056	3,820	4,584
6	2,546	3,183	3,820
7	2,183	2,728	3,274
8	1,910	2,387	2,865
10	1,528	1,910	2,292
12	1,273	1,592	1,910
14	1,091	1,364	1,637
16	955	1,194	1,432
18	849	1,061	1,273
20	764	955	1,146
22	694	868	1,042
24	637	796	955
30	509	637	764
36	424	531	637

The revolutions per minute at which wheels are run is dependent on conditions and style of machine and the work to be ground.

Data Sheet, No. 52, The Foundry, October, 1909.

Rules for Obtaining Surface Speeds, etc.

To find surface speed in feet per minute, of a wheel.

Rule. — Multiply the circumference in feet by its revolutions per minute.

Surface speed and diameter of wheel being given, to find number of revolutions of wheel spindle.

Rule. — Multiply surface speed in feet per minute by 12, and divide the product by 3.14 times the diameter of wheel in inches.

Formulæ for Dimensions of Cast Iron, Flanged Fittings

To withstand Hydraulic Pressures of 50, 100 and 200 Pounds per Square Inch

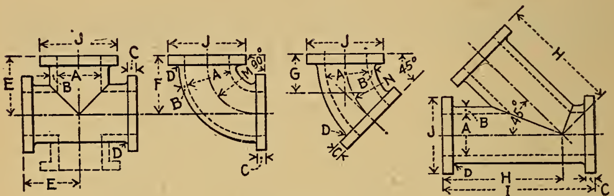


Fig. 70.

Diameter of opening . . . . . A

Thickness of pipe . . . . $B = \frac{A \text{ (pressure in lbs. per sq. inch)}}{3000} + 13.25$ in.

Thickness of flange . . . . . . $C = \frac{7B}{4}$ Radius of fillet $D = \frac{C}{2}$ approximately.

Center to face of flange,
tee and cross . . . . $E = \frac{J}{2} + 2C$, or next half-inch.

Center to face of flange;
bends, up to 90° . . . . . F and $G = \text{tang.} \left(\frac{\text{Ang.}}{2}\right)\left(\frac{J}{2}\right) + 2C$, or next half inch.

Center to face of flange,
45° Y . . . . $H = \text{tang. } 67\tfrac{1}{2}° \times \left(\frac{J}{2}\right) + 2C$, or next half-inch.

Face to face of flange,
45° Y . . . . $I = \text{tang. } 22\tfrac{1}{2}° \times \left(\frac{A}{2}\right) + 2C + H$, or next half inch.

Diameter of flange . . . . J = standard. Number and size of bolts . . . . K = standard.

Diameter of bolt circle. . . L = standard.

Radius on center line of bends, up to 90°. . . . . M and $N = \dfrac{\left(F \text{ or } G - \frac{3C}{2}\right)}{\left(\text{tang. } \frac{\text{Ang.}}{2}\right)}$. Use first quarter inch below.

Note.—J and L are alike for 50 and 100 lbs., as both are computed for 100 lbs. Contributed. No. 43, Data Sheet, Machinery, April, 1905.

CHAPTER VII

USEFUL INFORMATION

SHRINKAGE OF CASTINGS PER FOOT

(By F. G. Walker.)

Metals	Fractions of an inch	Decimals of an inch
Pure aluminum	13/64	.2031
Nickel aluminum casting alloy	3/16	.1875
"Special Casting Alloy," made by the Pittsburg Reduction Co.	11/64	.1718
Iron, small cylinders	1/16	.0625
Iron, pipes	1/8	.1250
Iron, girders, beams, etc.	1/64	.1000
Iron, large cylinders, contraction of diameter at top	5/8	.6250
Iron, large cylinders, contraction of diameter at bottom	5/64	.0830
Iron, large cylinders, contraction in length	3/32	.0940
Cast iron	1/8	.1250
Steel	1/4	.2500
Malleable iron	1/8	.1250
Tin	1/12	.0833
Britannia	1/32	.03125
Thin brass castings	11/64	.1670
Thick brass castings	5/32	.1500
Zinc	5/16	.3125
Lead	5/16	.3125
Copper	3/16	.1875
Bismuth	5/32	.1563

Data Sheet, No. 34, The Foundry, January, 1909.

This Table Has Been Arranged for the Rapid Conversion of Gross Tons and Fractions Thereof into Pounds

Equivalent of gross tons (2240 pounds) in pounds.

Tons	Pounds	Tons	Pounds	Tons	Pounds	Tons	Pounds
15	33,600	24	53,760	33	73,920	42	94,080
15¼	34,160	24¼	54,320	33¼	74,480	42¼	94,640
15½	34,720	24½	54,880	33½	75,040	42½	95,200
15¾	35,280	24¾	55,440	33¾	75,600	42¾	95,760
16	35,840	25	56,000	34	76,160	43	96,320
16¼	36,400	25¼	56,560	34¼	76,720	43¼	96,880
16½	36,960	25½	57,120	34½	77,280	43½	97,440
16¾	37,520	25¾	57,680	34¾	77,840	43¾	98,000
17	38,080	26	58,240	35	78,400	44	98,560
17¼	38,640	26¼	58,800	35¼	78,960	44¼	99,120
17½	39,200	26½	59,360	35½	79,520	44½	99,680
17¾	39,760	26¾	59,920	35¾	80,080	44¾	100,240
18	40,320	27	60,480	36	80,640	45	100,800
18¼	40,880	27¼	61,040	36¼	81,200	45¼	101,360
18½	41,440	27½	61,600	36½	81,760	45½	101,920
18¾	42,000	27¾	62,160	36¾	82,320	45¾	102,480
19	42,560	28	62,720	37	82,880	46	103,040
19¼	43,120	28¼	63,280	37¼	83,440	46¼	103,600
19½	43,680	28½	63,840	37½	84,000	46½	104,160
19¾	44,240	28¾	64,400	37¾	84,560	46¾	104,720
20	44,800	29	64,960	38	85,120	47	105,280
20¼	45,360	29¼	65,520	38¼	85,680	47¼	105,840
20½	45,920	29½	66,080	38½	86,240	47½	106,400
20¾	46,480	29¾	66,640	38¾	86,800	47¾	106,960
21	47,040	30	67,200	39	87,360	48	107,520
21¼	47,600	30¼	67,760	39¼	87,920	48¼	108,080
21½	48,160	30½	68,320	39½	88,480	48½	108,640
21¾	48,720	30¾	68,880	39¾	89,040	48¾	109,200
22	49,280	31	69,440	40	89,600	49	109,760
22¼	49,840	31¼	70,000	40¼	90,160	49¼	110,320
22½	50,400	31½	70,560	40½	90,720	49½	110,880
22¾	50,960	31¾	71,120	40¾	91,280	49¾	111,440
23	51,520	32	71,680	41	91,840	50	112,000
23¼	52,080	32¼	72,240	41¼	92,400	50¼	112,560
23½	52,640	32½	72,800	41½	92,960	50½	113,120
23¾	53,200	32¾	73,360	41¾	93,520	50¾	113,680

Data Sheet No. 2, The Foundry, September, 1907.

Window Glass

TABLE OF NUMBER OF PANES IN A BOX

Size in inches	Panes to a box	Size in inches	Panes to a box	Size in inches	Panes to a box	Size in inches	Panes to a box	Size in inches	Panes to a box
8×10	90	14×20	26	20×42	9	26×48	6	34×48	5
8×12	75	14×24	22	20×48	8	26×60	5	34×60	4
9×12	67	14×36	14	22×30	11	28×36	7	36×40	5
9×14	57	16×18	25	22×36	9	28×42	6	36×44	5
10×12	60	16×20	23	22×42	8	28×56	5	36×48	4
10×16	45	16×24	19	22×48	7	30×34	7	36×54	4
12×14	43	16×36	13	24×30	10	30×42	6	36×60	3
12×18	34	18×20	20	24×36	9	30×48	5	40×54	3
12×20	30	18×24	17	24×42	7	30×60	4	40×72	3
12×24	25	18×36	11	24×48	6	32×42	6	44×50	3
14×16	32	20×24	15	26×36	8	32×48	5	44×56	3
14×18	29	20×30	12	26×42	7	32×60	4	......	.....

Box Strapping

FIG. 71.

Improved Trojan Box Strapping

A soft steel *continuous* band, without rivets, which allows the nail to be driven anywhere. The surface is studded or embossed, as illustrated, which not only protects the head of the nail, but stiffens and strengthens the strap. Edges are perfectly smooth. Put up in reels of 300 feet.

Width..........................	½	⅝	¾	1 in.
Per reel..................	$1.00	1.25	1.50	2.00

Fire Brick and Fire Clay

An ordinary fire brick measures 9 by 4½ by 2½ inches, contains 101.25 cubic inches and weighs 7 pounds. Specific gravity, 1.93. From 650 to 700 pounds of fire clay are required to lay 1000 bricks. The clay should be used as a thin paste and the joints made as thin as possible.

Analysis of Fire Clays

New Jersey Clays:	*Per cent*	
Silica	56.80	
Alumina	30.08	
Peroxide of iron	1.12	
Titanic acid	1.15	
Potash	0.80	
Water and organic matter	10.50	
		100.45

Pennsylvania Clays:		
Silica	44.395	
Alumina	33.558	
Lime	trace	
Peroxide of iron	1.080	
Magnesia	0.108	
Alkalies	0.247	
Titanic acid	1.530	
Water and organic matter	14.575	
		95.493

Stourbridge Clays:		
Silica	40.00	
Alumina	37.00	
Magnesia	2.00	
Potash	9.00	
Water	12.00	
		100.00

Stourbridge Clays:		
Silica	70.00	
Alumina	26.60	
Oxide of iron	2.00	
Lime	1.00	
Magnesia	trace	
		100.00

Fire brick should have a light buff color and when broken present an uniform shade throughout the fracture. Bricks weighing over 7 to 7.5 pounds each contain too large a percentage of iron.

Useful Information

Velocity of light is 185,844 miles per second.
Velocity of sound at 60° F. is 1120 feet per second.
The semiaxis of the earth at the poles is 3949.555 miles.
The terrestrial radius at 45° latitude is equal to 3936.245 miles.
Radius of a sphere equal to that of the earth is 3958.412 miles.
Quadrant of the equator is equal to 6224.413 miles.

Quadrant of the meridian 6214.413 miles.

One degree of the terrestrial meridian is 69.049 miles.

One degree of longitude on the equator equals 69.164 miles.

A degree of longitude upon parallel 45 equals 48.988 miles.

A nautical mile equals 1.153 statute miles and is equal to one minute of longitude upon the equator.

Length of a pendulum beating seconds in vacuum at sea level at New York is 39.1012 inches.

Length of a pendulum beating seconds in vacuum at the equator is 39.01817 inches.

Mean distance of the earth from the sun is 95,364,768 miles.

Time occupied in transmission of light from the sun to the earth is 8 minutes, 13.2 seconds.

Force Required to Pull Nails from Various Woods

Kind of wood	Size of nail	Holding-power per square inch of surface in wood, pounds		
		Wire nail	Cut nail	Mean
White pine	8 d	....	450	....
	9 d	....	455	....
	20 d	167	477	405
	50 d	....	347	....
	....	....	363	....
	60 d	....	340	....
Yellow pine	8 d	....	695	....
	10 d	....	755	....
	50 d	318	596	662
	60 d		604	....
White oak	8 d	....	1340	....
	20 d	940	1292	1216
	60 d	....	1018	....
Chestnut	50 d	....	664	....
	60 d	....	702	683
Laurel	9 d	....	1179	....
	20 d	651	1221	1200

Trautwine gives the holding power of 6 d nail driven one inch into oak as 507 pounds; beech, 667 pounds; elm, 327 pounds; pine (white), 187 pounds; 3/8 inch square spike driven 4½ inches into yellow pine, 2000 pounds; oak, 4000 pounds; locust, 6000 pounds; ½ inch square spike in yellow pine, 3000 pounds; 9/16 square spike six inches in yellow pine, 4873 pounds. In all cases the nails or spikes were driven across the grain. When driven with the grain the resistance is about one half.

Weights per Cubic Inch of Metals

	Lbs.
Cast iron	0.263
Wrought iron	0.281
Cast steel	0.283
Copper	0.3225
Brass	0.3037
Zinc	0.26
Lead	0.4103
Mercury	0.4908

Temperatures Corresponding to Various Colors

(Taylor & White.)

Color	Temperature, degrees F.
Dark blood red, black red	990
Dark red, blood red, low red	1050
Dark cherry red	1175
Medium cherry red	1250
Cherry, full red	1375
Light cherry red, bright cherry red Scaling heat,* light red	1550
Salmon, orange, free scaling heat	1650
Light salmon, light orange	1725
Yellow	1825
Light yellow	1975
White	2200

* Heat at which scale forms and adheres, *i.e.*, does not fall away from the piece when allowed to cool in air.

Iron Ores

Iron is usually found as an ore in one of the following classifications, oxides, carbonates and sulphides.

The following table gives the subdivisions of these classes and an idea of the general composition and character of the different varieties.

Component parts	Oxides			Carbonates		Sulphides
	Anhydrous: Red hematite	Hydrated: Brown hematite	Magnetic	Spathic	Clay iron stone	Pyrites
Iron	....	....	....	....	....	44.28
Ferric oxide	60–95	50–90	30–70	0–50	0–10	....
Ferrous oxides	0– 5	Usually absent	15–55	20–60	30–45	....
Manganese oxide	0– 2	0– 2	0– 1	1–25	0– 2	....
Magnesia	0– 1	0– 2	0– 2	0–10	1–10	....
Alumina	0– 5	1–10	0–10	0– 5	1–10	....
Lime	0– 3	0– 5	0– 5	0–25	1–10	1.18
Silica	1–25	1–30	0–25	0– 5	2–25	2.34
Carbon dioxide	0– 2	0– 5	0– 5	35–40	20–35	....
Phosphoric anhydride.	0– 3	0– 3	0– 2	Usually absent	0– 3	....
Sulphur	0– 1	0– 1	0– 2	"	0– 2	49.07
Water	0– 5	5–20	0– 5	0– 5	0– 4	....
Copper	....	....	....	....	....	2.75
Arsenic	....	....	....	....	....	.38
Zinc	....	....	....	....	....	.22
Lead	....	....	....	....	....	....
	Includes: specular micaceous and kidney ores.	Includes: bog iron ore, lake ore and limonite	Includes: franklinite or spiegeleisen and load stone.		Black-band	

CHAPTER VIII

IRON

Physical Properties

Atomic weight	55.9	
Specific gravity	7.80	
Specific heat	0.11	
Melting point	2600° F.	
Coefficient of linear expansion	0.0000065 per 0° F.	
Thermal conductivity	11.9	Silver 100
Electric "	8.34	Mercury 1
Latent heat of fusion	88	B.t.u.

Pure iron is termed ferrite.

In the presence of manganese, chromium, etc., hard carbides (double carbides) are formed, known as cementite.

A mixture of ferrite and cementite is called pearlite.

Pearlite often consists of alternate layers of ferrite and cementite and in this condition, from its peculiar iridescence, is termed pearlite.

As carbon increases, ferrite is replaced by pearlite.

Pearlite is not found in hardened steels.

In steels saturated with carbon, a point fixed by Professor Arnold as .89 per cent carbon, the whole structure is represented by pearlite.

Steels containing less than .89 per cent carbon are known as unsaturated; those having over .89 per cent carbon as supersaturated. These degrees refer distinctly to iron-carbon steels; for the double carbides the point of saturation is slightly lowered.

Cementite is a hard and brittle compound, but when interspersed with ferrite in the form of pearlite, its brittleness is somewhat neutralized by the adjacent ferrite.

A steel containing well laminated pearlite possesses high ductility but less tenacity than when found unsegregated.

Pig Iron

Pig iron contains from 92 to 96 per cent metallic iron; the remainder is mostly composed of silicon, sulphur, phosphorus and manganese in greatly varying amounts. Cobalt, copper, chromium, aluminum, nickel, sodium, titanium and tungsten appear in some brands in minute quantities.

Specific gravity of cast iron is variously given at 7.08, 7.15 and 7.40.
Atomic weight, 54.5.
Specific heat from 32° to 212° F., 0.129 Bystrom.
" " " " at 572° F., 0.1407 "
" " " " at 2150° F., 0.190 Oberhoffer.
Latent heat of fusion, 88 B.t.u.*
Total heat in melted iron, 450 B.t.u.
Critical temperature, 1382° F., Stupakoff.
Coefficient of linear expansion for 32° F., 0.000006.
" " " " at 1400° F., 0.0000100.
Weight per cubic foot, 450 pounds.
Weight per cubic inch, 0.2604 pounds.
3.84 cubic inches, 1 pound.

Grading Pig Iron

The usual practice of furnaces has been to grade by fracture.

The grades are designated, Nos. 1, 2, 3, 4 or gray forge; mottled and white.

No. 1. — Soft; open grain; dark in color. Used for thin, light castings. Does not possess much strength; has great softening properties; is mixed advantageously with harder grades; carries large percentage of scrap.

No. 2. — Harder, closer, stronger and color somewhat lighter than No. 1.

No. 3. — Harder, closer, stronger and lighter in color than No. 2; and inclines to gray.

No. 4 (*Gray forge*). — Hard, strong, fine grained and light gray color.

Mottled. — Hard, very strong and close grained. Color presents mottled or imperfectly mingled gray and white colors.

White. — Hard and brittle, breaks easily under sledge but has high tensile strength; color white.

No. 1 iron running in the spout of the cupola displays few sparks. In the ladle its surface is lively and broken, sometimes flowery.

Nos. 2 and 3 present similar appearances but less marked.

Hard irons running from the cupola throw out innumerable sparks; in the ladle the surface is dull and unbroken; if disturbed the reaction is sluggish.

One cannot safely be guided by the appearance of the fracture of the pig; as when melted it may produce a casting of an entirely different character than that indicated.

* Harker and Oberhoffer have found that the specific heat of iron increases in about the same ratio up to within the region of the critical point (1382° F.). After this it remains practically constant.

This method of grading is entirely unreliable as to chemical constituents (and physical characteristics); the degree of coarseness of fracture, which affects the grade more than any other property, may be due entirely to the rate of cooling.

Two pigs from the same cast may produce two grades; pigs from different beds of the same cast may vary as much as 1 per cent in silicon and .05 in sulphur.

The character of pig iron is often greatly affected by the accidents of the furnace.

Irons produced from the same furnace at different times, from identical mixtures, may differ greatly in their constituents, by reason of different thermal conditions existing in the furnace at the time the ores were melted.

Grading by fracture is so unreliable that most foundrymen specify the characteristics required.

The following specifications are from Mr. W. G. Scott of the J. I. Case Threshing Machine Co., Racine, Wis.

No.	Si, not less than	S, not over	P, not over	Mn, not less	Total carbon
1	2.50	.03	.60	.50	....
2	1.95	.04	.70	.70	....
3	1.35	.05	.80	.90	....

Below these figures for silicon, or .005 above for sulphur means rejection.

Special pig irons	Silver gray	Ferro-silicon	Manganese pig
Silicon	3.00 to 5.50	7.00 to 12.50	Over 2.50
Sulphur (not over)	.04	.04	.04
Phosphorus (not over)	.90	....	.70
Manganese (not under)	.30	....	.90 to 2.50
Total carbon (not under)	2.50	....	....

In calling for charcoal irons, silicon is asked for from .30 to 2.75; sulphur not over .025; phosphorus not over .250; manganese not over .70; carbon with range of from 2.50 to 4.50.

Phosphoric pig irons, for small thin castings, silicon not under 1.50; phosphorus not under 1.00; sulphur not over .055; manganese from .30 to .90; carbon not under 3.00.

Based on a sliding scale for silicon and sulphur and a minimum for carbon. (Marshall.)

No. 1 Foundry Pig Iron

Silicon with sulphur	
1.70 to 3.00	.010 to .050

Carbon content	Silicon	Sulphur
Total carbon over .... 3.20 Graphitic carbon over .... 2.75 An increase of .10 silicon for every .003 sulphur.	1.70	.010
	1.80	.013
	1.90	.016
	2.00	.019
	2.10	.022
	2.20	.025
	2.30	.028
	2.40	.031
	2.50	.034
	2.60	.037
	2.70	.040
	2.80	.043
	2.90	.046
	3.00	.050

No. 2 Foundry Pig Iron

Silicon with sulphur	
1.20 to 2.20	.005 to .055

Carbon content	Silicon	Sulphur
Total carbon over .... 3.00 Graphitic carbon over .... 2.50 An increase of .10 silicon for every .005 sulphur.	1.20	.005
	1.30	.010
	1.40	.015
	1.50	.020
	1.60	.025
	1.70	.030
	1.80	.035
	1.90	.040
	2.00	.045
	2.10	.050
	2.20	.055

No. 3 Foundry Pig Iron

Silicon	with sulphur
.70 to 1.70	.005 to .055

Carbon content	Silicon	with sulphur
Total carbon over .... 2.75 Graphitic carbon over .... 2.00 An increase of .10 silicon for every .005 sulphur.	.70 .80 .90 1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70	.005 .010 .015 .020 .025 .030 .035 .040 .045 .050 .055

No. 4 Foundry Pig Iron — (Gray Forge)

Silicon	with sulphur
.50 to 1.50	.025 to .075

Carbon content	Silicon	with sulphur
Total carbon over .... 2.00 Graphitic carbon over .... 1.25 An increase of .10 silicon for every .005 sulphur.	.50 .60 .70 .80 .90 1.00 1.10 1.20 1.30 1.40 1.50	.025 .030 .035 .040 .045 .050 .055 .060 .065 .070 .075

The wide variation in silicon and sulphur which may occur in irons graded by fracture is shown in the Transactions of the American Foundrymen's Association, Cleveland Convention; wherein appears a statement as to the range of those elements, in the same grades of iron, made by the same furnace.

No. 1 X	varies in	silicon	from	1.13 to 3.40 per cent.
"	"	" sulphur	"	0.013 to 0.053 per cent.
No. 2 X	"	" silicon	"	0.67 to 3.30 per cent.
"	"	" sulphur	"	0.01 to 0.049 per cent.
No. 3 Plain	"	" silicon	"	1.05 to 3.21 per cent.
"	"	" sulphur	"	0.01 to 0.069 per cent

After long consideration, a committee of the American Foundrymen's Association, appointed to suggest a uniform system of grading, submitted the following report, which was adopted at the Cincinnati Convention, May, 1909.

AMERICAN FOUNDRYMEN'S ASSOCIATION

Standard Specifications for Foundry Pig Iron

Adopted by the American Foundrymen's Association in Convention, Cincinnati, May 20, 1909.

It is recommended that foundry pig iron be bought by analysis, and that when so bought these standard specifications be used.

Percentages and Variations

In order that there may be uniformity in quotations, the following percentages and variations shall be used. (These specifications do not advise that all five elements be specified in all contracts for pig iron, but do recommend that when these elements are specified that the following percentages be used.)

Silicon (.25 allowed either way)		Sulphur (maximum)		Total carbon (minimum)	
1.00	(La) Code.	0.04	(Sa) Code.	3.00	(Ca) Code.
1.50	(Le)	0.05	(Se)	3.20	(Ce)
2.00	(Li)	0.06	(Si)	3.40	(Ci)
2.50	(Lo)	0.07	(So)	3.60	(Co)
3.00	(Lu)	0.08	(Su)	3.80	(Cu)
		0.09	(Sy)		
		0.10	(Sh)		

Manganese (.20 either way)			Phosphorus (.150 either way)		
.20	(Ma)	Code.	.20	(Pa)	Code.
.40	(Me)		.40	(Pe)	
.60	(Mi)		.60	(Pi)	
.80	(Mo)		.80	(Po)	
1.00	(Mu)		1.00	(Pu)	
1.25	(My)		1.25	(Py)	
1.50	(Mh)		1.50	(Ph)	

Percentages of any element specified half way between the above shall be designated by addition of letter "X" to next lower symbol.

In case of phosphorus and manganese, the percentages may be used as maximum or minimum figures, but unless so specified they will be considered to include the variation above given.

Sampling and Analysis

Each car load, or its equivalent, shall be considered as a unit in sampling.

One pig of machine-cast, or one-half pig of sand-cast iron shall be taken to every four tons in the car, and shall be so chosen from different parts of the car, as to represent as nearly as possible the average quality of the iron.

An equal weight of the drillings from each pig shall be thoroughly mixed to make up the sample for analysis.

In case of dispute, the sample and analysis shall be made by an independent chemist, mutually agreed upon, if practicable, at the time the contract is made.

It is recommended that the standard methods of the American Foundrymen's Association be used for analysis. Gravimetric methods shall be used for sulphur analysis, unless otherwise specified in the contract.

The cost of the resampling and reanalysis shall be borne by the party in error.

Base or Quoting Price

The accompanying table may be filled out and may become a part of the contract: "B," or base, represents the price agreed upon for a pig iron running 2.00 in silicon (with allowed variation 0.25 either way), and under 0.05 sulphur. "C" is a constant differential to be determined upon at the time the contract is made.

Silicon percentages allow .25 variation either way. Sulphur percentages are maximum.

Silicon	3.25	3.00	2.75	2.50	2.25
Sulphur — .04......	B + 6 C	B + 5 C	B + 4 C	B + 3 C	B + 2 C
Sulphur — .05......	B + 5 C	B + 4 C	B + 3 C	B + 2 C	B + C
Sulphur — .06......	B + 4 C	B + 3 C	B + 2 C	B + C	B
Sulphur — .07......	B + 3 C	B + 2 C	B + C	B	B − C
Sulphur — .08......	B + 2 C	B + C	B	B − C	B − 2 C
Sulphur — .09......	B + C	B	B − C	B − 2 C	B − 3 C
Sulphur — .10......	B	B − C	B − 2 C	B − 3 C	B − 4 C

Silicon	2.00	1.75	1.50	1.25	1.00
Sulphur — .04......	B + C	B	B − C	B − 2 C	B − 3 C
Sulphur — .05......	Base	B − C	B − 2 C	B − 3 C	B − 4 C
Sulphur — .06......	B − C	B − 2 C	B − 3 C	B − 4 C	B − 5 C
Sulphur — .07......	B − 2 C	B − 3 C	B − 4 C	B − 5 C	B − 6 C
Sulphur — .08......	B − 3 C	B − 4 C	B − 5 C	B − 6 C	B − 7 C
Sulphur — .09......	B − 4 C	B − 5 C	B − 6 C	B − 7 C	B − 8 C
Sulphur — .10......	B − 5 C	B − 6 C	B − 7 C	B − 8 C	B − 9 C

(This table is for settling any differences which may arise in filling a contract, as explained under Penalties and Allowances, and may be used to regulate the price of a grade of pig iron which the purchaser desires, and the seller agrees to substitute for the one originally specified.)

Penalties

In case the iron, when delivered, does not conform to the specifications, the buyer shall have the option of either refusing the iron, or accepting it on the basis as shown in the table, which must be filled out at the time the contract is made.

Allowances

In case the furnace cannot for any good reason deliver the iron as specified, the purchaser may at his option accept any other analysis which the furnace can deliver. The price to be determined by the Base Table herewith, which must be filled in at the time the contract is made.

Machine-Cast Pig Iron

Pig iron is usually cast in sand beds. The casting machine has of late years been adopted by some furnaces and the statement is made that machine-cast pig, aside from the freedom from sand, possesses other important advantages. That it is more uniform in character; affords greater certainty as to its chemical composition; is cleaner and melts more readily.

Machine-cast pig presents a closer grain and is harder than iron cast in sand, by reason of the greater percentage of combined carbon.

Upon remelting, this difference disappears and the castings show the same analysis.

Mr. A. L. Colby, chemist of the Bethlehem Iron Co., gives the following statement regarding an experiment, made to determine the influence of the mould upon pig iron.

"One half of a cast was poured into sand moulds and the other half into iron. Equal quantities of drillings from six pigs, selected from different parts of that portion of the cast which had been cast in sand were taken; and similar drillings were obtained from that portion of the cast which had been taken to the casting machine; and each was carefully analyzed, with the following results:

Cast No. 7602	Sand-cast, per cent	Machine-cast, per cent
Silicon	3.00	2.99
Manganese	.95	.95
Phosphorus	.770	.773
Sulphur	.041	.041
Total carbon	3.460	3.380
Combined carbon	.250	.920
Graphitic carbon	3.210	2.460
Tensile strength per square inch	15,000	41,000

"The high tensile strength of the machine-cast iron is due almost entirely to the higher percentage of its combined carbon. Some of the sand-cast portion of this cast, and some of the machine-cast portion were melted separately in the same cupola, keeping all smelting conditions as nearly uniform as possible; and castings from each melt were made, which were proved by analysis, tensile strength, ability to machine and appearance of fracture to be as nearly alike as different things, made from the same iron, ever are."

Regarding this experiment, Mr. W. J. Keep in a communication to "The Foundry," remarks:

"The experiment shows that a pig iron cast in iron moulds with a very close grain and high combined carbon and the same iron cast in a sand pig mould with open grain and low combined carbon, will each, when remelted in a cupola, make castings exactly alike."

The following report on the test ingots, cast with the experimental castings, supports this statement.

Constituents	Sand-cast pig iron ingot 3½ inches square and 1½ feet long		Machine-cast pig iron ingot 3½ inches square and 1½ feet long	
	Cast horizontally, per cent.	Cast vertically, per cent	Cast horizontally, per cent	Cast vertically, per cent
Silicon	2.93	2.91	2.96	2.95
Manganese	.84	.85	.84	.84
Phosphorus	.766	.769	.772	.764
Sulphur	.071	.064	.077	.071
Total carbon	3.40	3.390	3.364	3.357
Combined carbon	.470	.368	.336	.257
Graphitic carbon	2.930	3.022	3.028	3.100
Tensile strength	18,000	16,300	17,000	17,000
Mark on ingot	G2 F1	G2 E1	G1 F1	G1 F1

The coarse open fracture presented by some pig irons, and which under the old system might cause them to be graded as No. 1, may be due to an excessive amount of manganese and the iron will be hard upon remelting. On the other hand, an iron may have a close grain, by reason of the graphitic carbon occurring in a finely divided condition and be graded low; when, since it is soft, it should have a much higher grading.

Charcoal Iron

Charcoal iron is graded according to fracture. The grades are designated by numbers and also as soft foundry; low carbon, 2.5 per cent total carbon; medium carbon, 3.5 per cent total carbon; and high carbon, 4.5 per cent carbon. Purchases are usually made on specifications.

Comparatively little charcoal iron is now used, since its valuable properties as regards chill and strength may be imparted to coke irons by use of the ferrometalloids and scrap steel.

Grading Scrap Iron

Machinery scrap should be free from burnt iron, wrought iron, steel, plow points, brake shoes, sash weights, sleigh shoes, chilled iron, stove plate and fine scrap; should be broken into pieces weighing not over 400 pounds.

Approximately, scrap iron varying in thickness from ¼ inch to 1 inch, may be compared with pig iron carrying from 1.5 per cent to 2 per cent silicon and .08 per cent sulphur.

From 1 inch to 3 inches thick, as compared with pig iron carrying from 1 per cent to 1.75 per cent silicon and .08 per cent sulphur. Above 3 inches thick, with an open gray fracture, as ranging in silicon from .75 to 2 per cent.

In white scrap, silicon is usually very low and sulphur very high.

Burnt iron is worthless except for sash weights and similar castings.

The successful grading of scrap iron can only be accomplished by experience.

CHAPTER IX

INFLUENCE OF THE CHEMICAL CONSTITUENTS OF CAST IRON

Carbon

Combined carbon increases strength, shrinkage, chill and hardness, and closes the grain.

Graphitic carbon reduces strength, shrinkage, chill, hardness, and tends to produce an open grain.

Silicon softens iron by promoting the formation of graphitic carbon. It decreases shrinkage and strength; increases fluidity and opens the grain.

Sulphur hardens iron, increases shrinkage and chill; causes it to set quickly in the ladle ("lose its life"); produces blow holes, shrinkage cracks and dirty iron.

Phosphorus weakens iron, imparts fluidity, decreases shrinkage and lowers the melting point.

Manganese in large percentages hardens cast iron. It increases shrinkage and chill, reduces deflection and tends to convert graphitic into combined carbon. In small amounts by reason of its power to remove sulphur and occluded gases, its tendency is to produce sound, dense castings, without increased hardness or shrinkage.

To raise the strength of castings, increase manganese and reduce silicon and phosphorus.

To soften iron, increase silicon and phosphorus.

To reduce shrinkage, increase silicon and phosphorus and reduce sulphur.

To prevent blow holes, reduce sulphur and increase manganese.

To prevent kish (excessive amount of free carbon), increase scrap or increase manganese.

[W. G. Scott.]

Properties of the Usual Constituents of Cast Iron

Carbon

Specific gravity (diamond)........	3.55
" " (graphite)........	2.35
Atomic weight....................	12.

Specific heat at	212° F.	0.198
" " "	1800° F.	0.459
" " "	3000° F.	0.525

Carbon exists in cast iron as combined and graphitic.

Professor Turner recognizes two different varieties under each of the general subdivisions, as follows:

Graphitic	Coarse-grained carbon or graphite. Fine-grained carbon, called amorphous carbon, or temper graphite.
Combined carbon	Combined carbon. "Missing" carbon, which usually occurs in relatively small quantities in cast iron.

The amount of carbon which may be absorbed by pure iron at high temperatures is stated differently by different authorities.

Turner places the limit of saturation at 4.25 per cent, and cites Saniter's experiments as follows:

"At cementation, heat about 1650° F., 2 per cent; by fusion, about 2550° F., 4.00 per cent."

Field states that pure iron at maximum temperatures absorbs 6½ per cent carbon.

Keep gives the saturation of charcoal iron when cold as 4 per cent and that of anthracite or coke irons as 3.50 per cent to 3.75 per cent.

The saturation point varies according to the temperature.

As iron cools below the temperature of saturation, carbon separates out in the form of graphitic carbon. At just what temperature this separation ceases is not definitely known; it is variously stated at 1300° F., 1650° F., and as high as 1800° F.

Since the specific heat of carbon is much greater than that of iron, it delays the rate of cooling as the temperature falls.

In a mixture containing 96 per cent of iron and 4 per cent of carbon, the heat evolved by the carbon, during the process of cooling, retards the rate of cooling one-seventh.

According to Field, an iron containing 6½ per cent carbon will dissolve no silicon; and one containing 23 per cent of silicon dissolves no carbon.

Iron having 3 per cent silicon contains approximately 0.3 per cent combined carbon.

With 2 per cent silicon the combined carbon is 0.6 per cent and with 1 per cent silicon 0.9 per cent.

As the carbon separates out in cooling, it changes from combined to graphitic, producing a softer, weaker iron and one having less shrinkage.

The total carbon in cast iron varies from 2 per cent to 4½ per cent, averaging about 3.4 per cent.

With silicon as high as 8 to 10 per cent, the total carbon falls to 2 per cent.

Under the same conditions, the higher the total carbon, the softer the iron. A very soft iron may contain as little as 1 per cent combined carbon with 3.4 to 3.5 per cent graphitic.

An increase of .25 per cent *total* carbon produces a marked increase in the softness, and a corresponding decrease in strength and shrinkage.

Combined carbon increases as the grades grow harder.

Ordinary soft iron contains from .3 to .5 per cent combined carbon.

Strong irons carry from .45 to .9 per cent.

The harder grades run from .6 to 1 per cent.

The proportion of combined to graphitic carbon is determined:

First. — By the total carbon present, as the greater the total carbon, the greater will be the proportion of graphitic to combined carbon.

Second. — By the rate of cooling. Rapid cooling increases the combined and slow cooling increases graphitic carbon.

Third. — By the temperature of the iron when it begins to cool.

The higher the temperature at which the iron is poured, the longer will be the time elapsed in cooling and the longer the period for conversion of combined to graphitic carbon.

Fourth. — By the amount and kind of other elements present.

Silicon decreases combined and increases graphitic carbon. With increased silicon all the combined carbon may be changed to graphitic.

An increase of 1 per cent silicon in cast iron, other conditions remaining the same, will convert from .35 to .47 per cent of combined into graphitic carbon; and under the same circumstances an increase of .47 per cent combined carbon will cause a corresponding decrease in silicon.

Sulphur increases combined carbon as also does manganese.

Phosphorus prolongs the cooling and thereby affords more time for the separation of graphitic carbon.

Loss or Gain of Carbon in Remelting

An iron may gain or lose carbon in passing through the cupola.

There is a tendency to loss of carbon in remelting where the carbon and silicon are high, with heavy blast and low percentage of fuel.

On the other hand, where the carbon and silicon are low, with low blast and high percentage of fuel, the tendency is to gain in carbon.

Hard irons melt more readily than soft; the higher the combined carbon, the lower the melting point.

Hard irons hold their shape in melting. The melted iron runs from bottom and sides of the pig freely, leaving smooth surfaces; while gray irons become soft and drop away in lumps presenting ragged surfaces.

Hard irons must be melted hotter than gray for pouring as they set much more rapidly.

In running from the spout of the cupola and in the ladle, hard irons throw off great quantities of sparks, and the surface of the iron in the ladle is dull and inactive when broken; on the other hand, the soft irons seldom emit sparks and present a lively surface in the ladle, breaking with innumerable checks, the soft Scotch irons showing peculiar flowery surfaces.

The diagram given below taken from the report of Prof. J. J. Porter, "shows the range of combined carbon, which should result for each

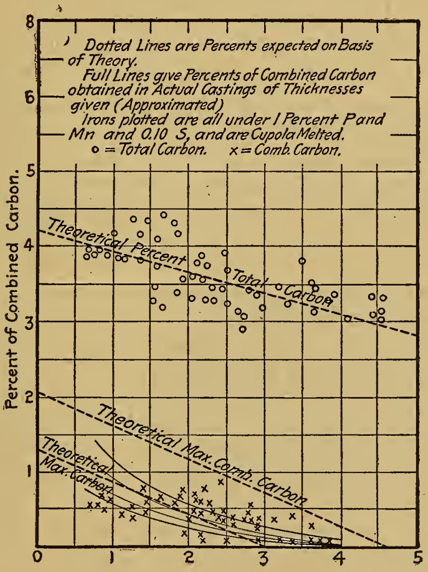


FIG. 72.

percentage of silicon (the cooling being normal, *i.e.*, the castings being neither chilled nor annealed)." The calculations are made on the theory that 1 per cent of silicon precipitates from solution .45 per cent carbon as graphitic carbon.

For specified purposes Prof. Turner gives the following percentages of combined carbon.

Character of iron	Combined carbon
Extra soft siliceous gray iron	.08
Soft cast iron	
Cast iron of maximum tensile strength	.47
Cast iron of maximum transverse strength	.47
Cast iron of maximum crushing strength	Over 1.00

Silicon

Full lines show approximately the relation existing between the thickness of section, per cent of silicon and per cent of combined carbon, and are plotted from the actual data there given.

Atomic weight	28.4
Specific gravity	2.49
Specific heat	.20 B.t.u.

Pig iron takes up its silicon in the furnace, and the amount so absorbed depends largely upon the working temperatures.

Pure iron dissolves about 23 per cent of silicon. By means of the electric furnace iron is made to absorb as much as 80 per cent. Those irons containing over 20 per cent are called ferrosilicons; where the silicon content runs from 5 to 10 per cent they are called high silicon irons.

Iron always loses silicon in passing through the cupola, and the amount lost depends upon three conditions.

First. — The amount of oxygen coming in contact with the metal in melting; oxidation increases with the blast.

Second. — Upon the composition of the iron as it is charged into the cupola, the loss being greater in irons having a high percentage of silicon than in those where the silicon content is low. An iron with 4 per cent silicon may lose as much as 2 per cent in melting, while with one very low in silicon, the loss may be inappreciable.

The affinity of iron for silicon decreases as the latter increases, hence the amount oxidized increases with increased silicon.

Third. — The loss of silicon varies also with the percentage of carbon present, being greater in high than in low carbon irons.

Silicon lowers the solvent power of cast iron for carbon, thereby reducing the amount of combined carbon and increasing the graphitic.

This influence is the more powerful with the lower percentages of silicon; the decrease in combined carbon being particularly rapid as the silicon rises from 0 to .75 per cent; then as the silicon continues to rise, the decrease in combined carbon grows less and less.

Silicon and carbon each reduce the solubility of iron for the other.

The influence of silicon is sometimes rendered less apparent by that of other variable elements.

Silicon is not of itself a softener of cast iron, nor does it, *per se*, lessen shrinkage; but it produces a softening effect and reduces shrinkage by changing combined into graphitic carbon; the amount used should be just sufficient to force from solution the amount of carbon desired in the free state for any particular mixture and to furnish the requisite fluidity.

For every rise of 1 per cent silicon in cast iron there will be a corresponding drop of .45 per cent in combined carbon and vice versa.

Where iron is melted, very hot silicon unites to some extent with sulphur, forming a very volatile sub-sulphide of silicon, thereby reducing the amount of sulphur absorbed by the iron.

By reason of its specific heat, silicon retards the cooling of iron to a certain extent. It can be made to overcome many difficulties in castings, and to control the quality and cost of mixtures, where scrap iron is largely used.

An increase of .2 per cent in silicon decreases shrinkage about .01 inch per foot.

Very high percentages of silicon decrease the fusibility of iron.

When the percentage of silicon in the casting is above 2 per cent, it has a weakening influence.

Ferrosilicon is mixed with iron in the ladle for softening and reducing shrinkage.

Carbide of silicon is sometimes charged with the iron in the cupola.

Regarding the use of silicon, Prof. Turner says: "That at one time its presence in cast iron, in all proportions, was regarded as injurious; that there was no accurate knowledge of its influence prior to 1885, when my first paper on 'The Influence of Silicon on the Properties of Cast Iron' was published in the 'Journal of the Chemical Society.'"

Summary of Prof. Turner's experiments in the use of silicon.

Characteristics	Per cent silicon
Cast iron yielding maximum hardness	.60
Cast iron yielding maximum crushing strength	.80
Cast iron yielding maximum density in mass	1.00
Cast iron yielding maximum crushing tensile and transverse strength	1.40
Cast iron yielding maximum tensile strength	1.80
Cast iron yielding maximum softness and general working qualities	2.50

The subjoined chart and table giving the effect of silicon on the properties of cast iron taken from Prof. Turner, show that the influence of silicon is of a uniform character as respects crushing, transverse and tensile strength.

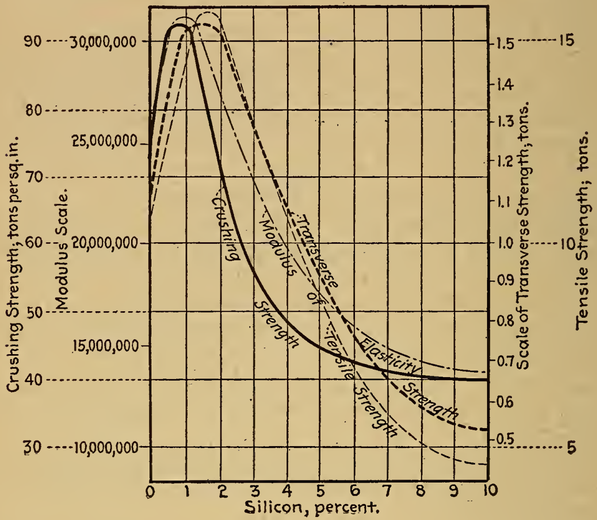


FIG. 73.

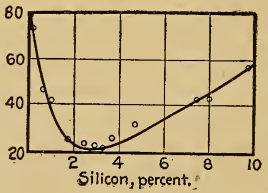


FIG. 74.

Chart No. II, showing the hardness of the same series of test bars, was determined by the "Sclerometer."

The hardness decreased continuously with the additions of silicon until 2.5 per cent was reached, when further additions caused an increase of hardness.

The addition of silicon to iron free from carbon increases the tensile strength and hardness. The influence resembles that of combined carbon on iron or steel, but is less energetic.

EFFECTS OF SILICON ON THE PROPERTIES OF CAST IRON

Silicon per cent (calculated)	Cylinders: Relative density at 20° C.	Relative hardness	Tensile strength per square inch	Modulus of elasticity	Crushing strength per square inch	Calculated* transverse strength	Chemical analysis: Total carbon	Graphite	Combined carbon	Silicon	Phosphorus	Manganese	Sulphur
			Lbs.		Lbs.	Lbs.							
0	7.560	72	22,720	25,790,000	168,700	2702	1.98	.38	1.60	.19	.32	.14	.05
.5	7.510	52	27,580	28,670,000	204,800	3280	2.00	.10	1.90	.45	.33	.21	.05
1.0	7.641	42	28,490	31,180,000	207,300	3370	2.09	.24	1.85	.96	.33	.26	.04
1.4	7.555	..	31,440	23,500,000	183,900	3498	2.21	.50	1.71	1.37	.30	...	.05
2.0	7.518	22	35,180	23,560,000	137,300	3446	2.18	1.62	.56	1.96	.28	.60	.03
2.5	7.422	22	32,760	25,450,000	172,900	3534	1.87	1.19	.68	2.51	.26	.75	.05
3.0	7.258	22	27,390	21,150,000	128,700	2850	2.23	1.43	.80	2.96	.34	.70	.04
4.0	7.183	27	25,280	15,640,000	105,900	2543	2.01	1.81	.20	3.92	.33	.84	.03
5.0	7.167	32	22,750	18,720,000	103,400	2342	2.03	1.66	.37	4.74	.30	.95	.05
7.5	7.128	42	11,950	14,750,000	111,000	1505	1.86	1.48	.38	7.33	.29	1.36	.03
10.0	6.978	57	10,630	13,930,000	76,380	1252	1.81	1.12	.69	9.80	.21	1.95	.04

* Bars one foot long, one inch square, loaded in the center.

Silicon added to hard iron affects the size of the graphite, since the freshly precipitated graphite resulting from such addition is smaller than that found in ordinary soft foundry irons. Consequently, the metal is closer and stronger.

Prof. Turner favors increasing silicon in a mixture of cast iron by the use of high silicon pig iron, rather than by that of ferrosilicon, as the latter differs both in fusibility and density from the iron, rendering the product of the mixture uncertain and irregular. "The ideal method is for the founder to have a fairly large stock, including several kinds of iron, each separate kind being a little too hard or a little too soft for the general run of work, but still not very different from what is required. By mixing these irons in suitable proportions, it is then easy to obtain any composition which may be desired, it being assumed, of course, that the composition of each variety is already known."

During the period from 1886 to 1888, Mr. Keep made an exhaustive study of the influence of silicon on cast iron. The results of his researches as summarized in "Cast Iron" are:

Silicon added to white iron changes it to gray; added to gray iron, low in silicon, makes the mixture darker.

It is the influence of silicon, not the percentage, which produces desirable qualities; and that influence is indirect, acting through the carbon which the iron contains.

The saturation point of iron for carbon is lowered by the addition of silicon, as the carbon is expelled in the graphitic form and caught between the grains of the iron producing a grayer color.

If the total carbon is high, or the combined carbon low, the amount of silicon required to produce a particular effect will be correspondingly low. Similar effects are produced by a small amount of silicon acting through a prolonged period, by reason of slow cooling of large castings, and by a large amount acting through a short period, as in the rapid cooling of small castings. By regulating the amount of silicon in the mixture the state of carbon as well as the depth of chill can be controlled. The diffusion of silicon is very irregular. Mr. Keep found in a number of experiments that the average variation in diffusion was from .09 to .24 per cent. This average increases and the diffusion is less and less complete as the silicon increases, so that any literal determinatives of silicon are rendered more or less approximative (as showing the percentage of silicon in a car load of iron) by the unequal diffusion.

As regards hardness, the addition of 2 to 3½ per cent of silicon will convert all the combined into graphitic carbon, which it is possible to change by the use of that element.

Silicon in itself hardens cast iron, but the softening effect caused by it in producing the change from combined to graphitic carbon, is such as to result in decreased hardness, until the amount of silicon added has reached from 2 to 3 per cent. Further additions are not advantageous. The beneficial influence resulting from the use of silicon in cast iron is not confined to decreased hardness. It imparts fluidity and also tends to produce clear, smooth surfaces on the castings, by reason of the liberated graphite, in part, interposing itself between the sand and the hot iron.

Sulphur

Atomic weight	32.
Specific gravity	2.03
Specific heat	0.2026
Melting point	226° F.
Latent heat of fusion	16.86 B.t.u.
Weight per cubic foot	125 pounds

The sulphur in pig iron is taken up in the furnace, from the fuel and flux. Its presence is most injurious and causes the foundryman more difficulty than any other element. It makes iron hard and brittle, increases shrinkage and chill, causes iron to congeal quickly and by preventing the ready escape of gases, makes blow holes and pin holes.

It increases the combined carbon and reduces silicon.

When pig iron is remelted, the percentage of sulphur is always increased, as it takes up from 20 to 40 per cent of the sulphur in the fuel. Mr. J. B. Neu found in some experiments that as much as 66 per cent of the sulphur in the fuel was absorbed by the iron in melting.

The sulphur content of the iron at each of three remeltings is given by Mr. Percy Longmuir as follows:

	First melt	Second melt	Third melt
Per cent sulphur.....	.04	.10	.20

The proportion between the total amount of sulphur present in the fuel, to that absorbed by the iron, is dependent on three conditions.

First. — The quality and quantity of flux used.

Second. — The temperature of the melted iron.

Third. — The composition of the fuel and iron.

In a hot working cupola, the proper quantity of flux will remove much of the sulphur. That present in the fuel as a sulphuretted hydrocarbon has no appreciable effect upon the percentage retained in the melted iron.

As sulphur combines with iron at low temperatures, a hot cupola tends to increase the amount carried away by the slag. Where the fuel contains 1 per cent or over of sulphur, it may add from .04 per cent to .06 per cent to the iron and a casting made from iron having only 2 per cent of sulphur may, when the iron is melted with high sulphur coke, show from .06 to .08 per cent.

A slow melting cupola with low temperature favors the absorption of sulphur.

An increase of sulphur, the other elements and the rate of cooling remaining constant, hardens iron by increasing the combined carbon and also causes greater shrinkage, contraction and chill.

Less change in the percentage of sulphur present is required to harden or soften cast iron than in that of any other element.

Sulphur shortens the time that iron will remain fluid in the ladle, "destroys the life of the iron," and if present to a large extent, makes the production of sound castings very difficult. The molten iron is sluggish and sets quickly, thereby enclosing escaping gases, dross, kish, etc., which cause blow holes and dirty castings.

Where sulphur is present to any considerable extent, the iron must be poured very hot.

Iron will absorb as much as .3 per cent sulphur with increasing fusibility and decreasing fluidity.

An increase of .01 per cent of sulphur can neutralize the effect of from .08 to .10 per cent silicon. In coke irons, usually, as the silicon decreases the sulphur increases. To maintain a uniform degree of hardness in castings the increase of silicon corresponding to successive increases of .01 per cent sulphur should be about as follows:

Sulphur, per cent......	.01	.02	.03	.04	.05	.06
Silicon, per cent.......	2.00	2.10	2.20	2.30	2.40	2.50

Sulphur may be largely expelled from cast iron by the use of manganese, passing off in the slag as sulphide of manganese; the greater the amount of manganese present, the less sulphur will the iron absorb and, it is possible, where the manganese is very high, for the iron to lose sulphur in melting.

From 1 to 2 per cent manganese, in addition to that carried by the pig iron, is sometimes used in the ladle, to effect the removal of sulphur; care must be exercised in this respect, however, as manganese in excess of that taken up by the sulphur tends to harden the iron.

When the fuel does not contain more than .08 per cent sulphur and the iron has about .5 per cent manganese, the sulphur in ordinary gray irons will increase about .025 per cent in melting.

The injurious effects of sulphur are largely counteracted by the use of phosphorus. Other elements remaining constant, an increase of .1 per cent phosphorus produces about the same results in counteracting the effects of sulphur as does an increase of .25 per cent silicon.

By the use of phosphorus instead of silicon for this purpose, the fluidity of the iron is greatly increased; gases, dross, etc., can come to the surface and greater freedom from blow holes, shrink holes, etc., results.

Irons with high combined carbon are usually high in sulphur. Longmuir gives the following as the result of examinations of the sulphur content for different amounts of combined carbon.

Grade	1	2	3	4	5	Mottled	White
Combined carbon.....	.50	.60	.80	1.10	1.30	1.80	3.00
Sulphur..............	.02	.02	.04	.08	.10	.15	.20
Silicon...............	2.50	2.30	1.80	1.50	1.20	.70	.30

The sulphur content of pig iron usually runs from .01 to .08 and sometimes higher.

Prof. J. J. Porter concludes his remarks on the effects of sulphur upon the physical properties of cast iron as follows: "Through the formation in the iron sulphide of eutectic films, it causes brittleness and weakness, especially to shock. Through its action on the carbon it increases hardness and may either increase or decrease strength according as the combined carbon is already too low or too high. It has a great tendency to cause blow holes, especially near the upper surface of thick castings. So marked is this effect in pig iron that high sulphur pig may nearly always be spotted by the presence of blow holes in the top surfaces.

"Sulphur probably has a more detrimental effect on low silicon, or chill iron, than on the ordinary foundry grades. All of these effects of sulphur are considerably lessened by the presence of sufficient manganese to insure its being in the form of MnS, but on the other hand, the segregation of MnS may cause bad places in the casting, apparently due to dirty iron."

The statements given above are those generally entertained as regards the deleterious influence of sulphur. They are not, however, entirely confirmed by the investigations of Prof. Turner and Mr. Keep. The former remarks that: "We are still in need of exact information as to the influence of sulphur in cast iron." After a long series of experiments to determine the injurious effect of sulphur on cast iron, Mr. Keep concludes that the presence of .05 per cent of that element will not exert any appreciable deleterious influence, and that what little ill effect results is corrected by a slight increase of silicon. Such small percentage of sulphur does not seem to influence the depth of chill, nor does there appear to exist any relation between the sulphur content and the strength of an ordinary casting.

"While there is no indication that sulphur is in any way beneficial, on the other hand, evidence is lacking to show that its influence is ever anything but injurious; and the suggestion arises from the records, that the prevailing opinions regarding the deleterious effects of sulphur are partly superstitious, due, largely, to laboratory experiments made under conditions never met with in the foundry."

Phosphorus

Atomic weight	31.00
Specific gravity	1.83
Specific heat	0.189
Melting point	112° F.
Latent heat of fusion	9.06 B.t.u.
Weight per cubic inch	.066

The phosphorus content in pig iron comes mostly from the ore, but also in part from the fuel and flux.

Phosphorus weakens cast iron, lowers its melting point, imparts fluidity, tends to soften and decreases shrinkage.

It has no direct effect on carbon, but since it prolongs the cooling of melted iron it gives more time for graphitic carbon to separate out.

Its influence in imparting fluidity is greater than that of any other element, hence its presence within moderate limits (1 to 1.25 per cent) is especially desirable for light, thin castings.

After it is once taken up by the iron very little of it escapes, but its percentage is frequently increased if it exists to any extent in the fuel or flux used in melting.

Phosphorus largely counteracts the influence of sulphur to increase combined carbon, shrinkage, contraction and chill. An increase of .1 per cent phosphorus in the iron will produce about the same physical results in counteracting the effects of sulphur, as an increase of .25 per cent silicon, all other elements remaining constant.

Where over .7 per cent phosphorus is present in the iron it tends to make the latter cold short and unless there is necessity for extreme fluidity the phosphorus content should not exceed 1 per cent.

By reason of its tendency to increase fusibility, it should be kept as low as possible in castings required to stand high temperatures.

In machinery castings containing 1.5 per cent phosphorus, the tools are quickly heated and worn.

Where great strength is required of castings, the phosphorus content should not exceed .02 per cent.

Where blow-holes are formed in castings, by reason of occluded gases, phosphide of iron is frequently extruded into them in the shape of globular masses or shot.

Ferrophosphorus may contain from 20 to 25 per cent phosphorus and is sometimes used in the ladle where prolonged fluidity is desired.

Prof. Turner states that the presence of 0.5 phosphorus in cast iron produces excellent results and that where fluidity and soundness are more important than strength, from 1 to 1.5 per cent may be permitted; it should not be allowed in excess of the higher limit. According to Prof. Porter, the addition of 1 per cent phosphorus to iron containing 3.5 per cent carbon and 2 per cent silicon approximately:

Lowers the temperature at which freezing begins from 2200° to 2150° F., or 50° F.

Lowers the temperature at which freezing ends from 2165° to 1740° F., or 425° F.

Increases the temperature range of solidification from 50° to 375° F.

Manganese

Atomic weight	55.00
Specific gravity	8.1
Specific heat	.12
Melting point	2250° F.
Latent heat of fusion	
Weight per cubic foot	506.25 pounds

Manganese is a white metal, having a brilliant crystalline fracture. It has a strong affinity for oxygen and sulphur, but none for iron; alloys with iron in all proportions.

The manganese in pig iron comes from the ores. Foundry irons contain from .2 to 2 per cent manganese.

Manganese pig from 2 to 10 per cent; spiegeleisen from 15 to 40 per cent; ferromanganese from 50 to 90 per cent.

There is always a loss of manganese in remelting. It escapes by volatilization; by oxidation, and if sulphur is present, by uniting with it to a greater or less extent. The amount of loss depends on the amount of blast and percentage of sulphur present in the fuel.

With 1 per cent manganese present in the iron the loss of Mn in remelting varies from .2 to .3 per cent.

A peculiarity of manganese is that it may impart to pig iron, or castings, a very open grain, rendering them apparently soft, even though they are quite hard.

It greatly affects the capacity of iron to retain carbon; where only .75 per cent Mn is present in the iron the carbon content may be as high as 4 per cent.

It decreases the magnetism of cast iron and when present to the extent of 25 per cent the magnetism disappears.

As the percentage of manganese in iron increases, that of sulphur decreases.

On the other hand, the higher the manganese, the greater the combined carbon.

Manganese hardens cast iron, promotes shrinkage, contraction and chill; but by reason of its affinity for sulphur and its removal of this element, it may produce effects precisely the opposite of those above stated. However, if the amount of manganese is greater than that required for the removal of the sulphur present, the excess causes the iron to take up more carbon in combination, and hardness results.

Increasing manganese above .75 per cent, the other elements remaining constant, causes greater contraction and chill on account of its hardening influence. These effects may be very pronounced in light castings.

On account of its strong affinity for oxygen it tends greatly to the removal of oxides and occluded gases, thereby preventing blow-holes.

Manganese pig iron is an ordinary iron, carrying somewhat more manganese than the ordinary foundry irons.

It is used to raise the combined carbon, to add strength to the mixture, to prevent blow-holes, to give life to the iron and for the removal of kish.

Ferromanganese comes to the foundry in a fine powder. It is used in the ladle in the proportion of about 1 pound to 600 pounds of iron and acts as a purifier, driving out sulphur, softening the iron where hardness is due to sulphur and reducing the chance of blow-holes.

When used in this way the iron must be very hot, as with dull iron it does little good. It should be thoroughly incorporated with the iron by stirring. It must be used with caution, as irons with low silicon and carbon and high manganese are hard and shrinky.

The use of manganese pig iron in the cupola gives better results, and is less expensive than that of ferromanganese in the ladles.

It is claimed for manganese that it makes hard iron soft and soft iron hard.

With respect to the influence of Mn upon chill, Mr. Keep's views are at variance with those above given. He states that manganese does not increase chill, but under certain conditions may aid in removing it.

Aluminum

Atomic weight	27.1
Specific gravity	2.65
Specific heat	0.212
Melting point	1182° F.
Latent heat of fusion	28.5 B.t.u.
Weight per cubic foot	165.6 pounds

Aluminum is a white metal, resembling silver; very soft and malleable; has a great affinity for oxygen; alloys with iron to an unlimited extent.

It does not occur in pig iron. When added to iron in the ladle it should be thoroughly mixed by stirring.

Its influence on cast iron resembles that of silicon, in producing a softening effect by the conversion of combined into graphitic carbon.

A white iron to which from .5 to .75 per cent of aluminum has been added becomes gray.

Aluminum decreases shrinkage and chill, and increases fluidity. By reason of its affinity for oxygen it tends to prevent the formation of blow-holes.

It closes the grain of irons high in graphitic carbon, but may render them sluggish and dirty. When used in amounts exceeding 1.5 to 2 per cent it has a weakening influence. Hard irons containing from 1.25 to 1.4 per cent combined carbon are made stronger by the addition of aluminum. The amount of aluminum which may be used varies from .25 to 1.25 per cent; its action is somewhat uncertain and its alloys with iron are erratic at times, producing results the reverse of those anticipated.

Nickel

Atomic weight	58.7
Specific gravity	8.8
Specific heat	.11
Melting point	2610° F.
Latent heat of fusion	
Weight per cubic foot	550 pounds

Nickel is a white metal having a silvery color; it is highly ductile and does not oxidize readily. Alloys with iron in all proportions. When used in quantities varying from .5 to 5 per cent, its tendency is to harden, render more dense and increase the tensile strength of cast iron. In large amounts it is said to have a softening influence.

Mr. A. McWilliams found that an alloy of white Sweeds iron with 50 per cent nickel gave a soft fine gray metal, even when cast in sections from 1 to 3 inches thick, in chills.

Cast iron containing from 25 to 30 per cent nickel resists corrosion.

Nickel is little used in cast iron, except where great strength is required. It imparts most valuable properties to steel.

Titanium

Atomic weight	48.00
Specific gravity	5.3
Specific heat	
Melting point	4000° F.
Latent heat of fusion	
Weight per cubic foot	330 pounds

Titanium is found in many brands of foundry and Bessemer irons, running in percentages from a trace to 1 per cent. It increases the strength of cast iron to a marked degree. An addition of from .01 to .06 per cent titanium has shown in test bars an increase of 40 per cent in transverse strength.

It has a strong affinity for oxygen and nitrogen.

Ferroalloys are made to contain from 10 to 30 per cent titanium.

When ferrotitanium is added to iron in the ladle, it unites with the oxygen and nitrogen, the resulting oxides and nitrides passing off in the slag; none of the titanium remains in the iron, except when used in large quantities; its effect then is to harden the iron.

Formerly titanic irons were carefully avoided and it does not appear that ferrotitanium has as yet been used to any great extent by foundrymen.

Investigations by Dr. Richard Moldenke and Mr. G. A. Rossi indicate, however, that the use of ferrotitanium promises a marked improvement as regards strength and the removal of nitrogen and oxygen from cast iron. Mr. Rossi found as the result of his experiments that the addition of 4 per cent of a 10 per cent ferrotitanium to cast iron increased the transverse and tensile strength from 25 to 30 per cent.

Dr. Moldenke gives the following summary of results obtained by him.

Mixtures	Gray		White	
	Tests	Lbs.	Tests	Lbs.
Original iron	9	2020	8	2030
plus .05 T.	4	3100	11	2400
" .10 T.	3	3030	....	....
" .05 T. and carb.	6	3070	9	2420
" .10 " " "	6	2990	10	2400
" .15 " " "	4	3190	10	2520
Average	....	3070	....	2430

Increase of strength of treated iron over original 52 per cent — 18 per cent.

From the above summary it appears that the greatest increase in strength was found in gray iron.

With vanadium and cast iron the Doctor found results directly contrary to the above. He calls attention to the fact that the improvement in strength is almost as marked with .05 per cent to .1 per cent titanium as with .15 per cent, showing that any excess of titanium over that required to produce oxidation is wasted; hence .05 per cent will be sufficient for foundry practice.

He found that titanium reduces chill but the chill produced is very much harder than that made in the usual way.

Titanium is of value as preventing blow-holes and producing sound castings.

Vanadium

Atomic weight	51.2
Specific gravity	5.5
Specific heat	
Melting point	4300° F.
Latent heat of fusion	
Weight per cubic foot	344 pounds

As a merchantable product this is obtained as ferrovanadium, containing from 10 to 15 per cent vanadium.

The investigations of Dr. Richard Moldenke furnish about all that is so far known as to the action of this element on cast iron. The following table gives a summary of his experiments.

Number of tests	Lump vanadium added	Ground vanadium added	Manganese added	Analyses of test bars: Silicon	Sulphur	Phosphorus	Manganese	Vanadium	Number of bar analyzed	Transverse strength	Deflection	Per cent gained in transverse strength
Burnt gray iron												
5	0	....	....	2.13	.094	.638	.35	....	2	1310	.090	....
3	.05	....	....	2.03	.095	....	.370	....	7	2220	.100	70
Burnt iron, white												
3	0	....	....	.41	.146	.423	.43	....	11	1440	.050	.....
12	.05	....	.50	...	....	....	.65	....	16	1910	.055	33
Machinery iron, gray. Melted pig iron. No scrap												
5	0	....	....	2.72	.065	.668	.54	....	24	1980	.105	.....
5	.05	....	....	...	....	....	....	....	....	2070	.105	5
19	.10	....	....	...	....	....	....	....	....	2200	.115	11
4	.15	....	....	...	....	....	....	....	....	2740	.130	40
3	0	....	.50	...	....	....	....	....	....	1970	.100	.....
5	....	.05	....	...	....	....	.54	.33	61	1980	.100	.....
4	....	.05	.50	...	....	....	.66	.25	66	2130	.100	7
5	....	.10	....	...	....	....	.59	.36	70	2372	.090	20
3	....	.10	.50	...	....	....	.59	.25	75	2530	.120	27
5	....	.15	....	...	....	....	.56	.27	78	2360	.100	20
Remelted car wheels, white. No pig iron												
...	....	....	....	.53	.122	.399	.38	....	82	....	...	.....
5	0	....	....	.60	.138	.374	.44	....	85	1470	.050	.....
5	.05	....	.....	...	....	....	....	....	....	2190	.050	50
7	.10	....	....	...	....	....	....	....	....	2050	.050	40
8	.15	....	....	...	....	....	....	....	....	2264	.060	54
4	0	.....	....	...	....	....	....	....	....	2790	.070	90
6	....	.05	.00	.45	.096	.423	.40	.36	113	3020	.060	105
6	.05	.05	.50	.66	.110	.591	1.150	.25	117	2970	.090	100
3	....	.10	.....	.45	.119	.414	.500	.31	123	2800	.055	91
4	....	.10	.05	.53	.084	.431	.74	.27	128	3030	.090	106
6	....	.15	....	.42	.112	.417	.40	.45	133	2950	.070	100
6	....	.15	.50	.50	.082	.374	.54	.22	137	3920	.095	166

The vanadium alloy used contained:

Vanadium 14.67 per cent; carbon 4.36 per cent; silicon 0.18 per cent.

The analyses of the test bars show much more vanadium than was used. This is attributed to errors arising from the difficulties experienced in making the experiments on too small a scale.

Dr. Moldenke concludes: "The results shown in the table speak for themselves, and the averages tallied off for each table show a remarkable progression of values. To increase the breaking strength of a test bar from 2000 up to 2500 for gray iron and 1500 up to 3900 for white iron, is sufficient to warrant further investigation on the part of every foundryman, who has special problems in strength to master."

Thermit

Thermit is a mixture of oxide of iron and aluminum, which when ignited burns at an intense heat (resulting temperature is said to be 5400° F.) in consequence of the great affinity of aluminum for oxygen. This compound is made by the Goldschmidt Thermit Co.

Its use in the foundry is to raise the temperature of dull iron; to keep the iron in risers fluid, and for the mending of broken castings. A titanium thermit is also made by same company.

This is used for the introduction of titanium, to remove nitrogen and oxygen, as well as for its heating effect. The claim is made, that cast iron can be advantageously used in place of steel castings, if titanium thermit is employed in connection with it. Nickel thermit is used for the introduction of nickel.

Oxygen

Atomic weight	15.96
Specific gravity (compared to atmospheric air 32°F. and one atmosphere)	1.1056
Weight per cubic foot	624.8 grains

No element, perhaps, causes the foundryman more trouble than oxygen. Iron oxidizes very rapidly at high temperatures, in presence of air. The oxides are readily dissolved in molten iron and the gases liberated from them in the castings are the frequent cause of cavities and blow-holes.

Ferrous oxides, produced in the process of smelting, are found to a greater or less extent in all pig irons. Those irons in which mill cinder has been largely used, often contain high percentages of dissolved oxides.

Frequently the ends of broken pigs present blow-holes in body of the pig, or worm-holes toward the upper surface. These are certain indications of the presence of oxygen or sulphur and such iron should be used carefully.

In remelting in the cupola, as the molten iron passes through the tuyere zone, more or less oxidation occurs, especially if the bed is high and the blast strong.

Rusty scrap (fine scrap particularly) furnishes ferrous oxides in large amounts.

The removal of ferrous oxides may be largely effected in the cupola by an abundance of hot slag.

Ferromanganese and aluminum are used in the ladle for same purpose.

The most effective deoxidizers are the metals in the order named below:

Titanium	Aluminum
Vanadium	Sodium
Magnesium	Manganese
Calcium	Silicon

Nitrogen

Atomic weight	14.01
Specific gravity (air 1)	.9713
Specific heat	.244
Weight per cubic foot	548.8 grains

Nitrogen is absorbed from the blast as a nitride, by iron in melting; and as the metal cools, the gas is liberated.

Very little is known as to the influence of nitrogen upon cast iron; its effect upon steel is very injurious; as little as .03 per cent causing a great loss in tensile strength and nearly eliminating ductility. Gray pig irons show only a trace of nitrogen from .007 to .009 per cent; in white iron it sometimes runs as high as .035 per cent.

So far as tests have been made it does not appear that, in gray iron, any relation exists between the quality of the iron and the nitrogen content.

It has a remarkably strong affinity for titanium, combining with it to form a nitride, which is insoluble in molten iron and passes off in the slag. Ground ferrotitanium previously heated is used in the ladle for removal of nitrogen.

Arsenic and copper are sometimes found in pig iron, but in amounts so small that the effects produced by them are inappreciable.

In concluding the subject of metalloids, the statement made by Prof. Porter as to the approximate influence of the more important ones on combined carbon must not be omitted.

1 per cent silicon decreases combined carbon....				.45 per cent.
1 per cent sulphur increases	"	"	....	4.50 per cent.
1 per cent manganese "	"	"	....	.40 per cent.
1 per cent phosphorus "	"	"	....	.17 per cent.

CHAPTER X

MIXING IRON

The mixing of iron for the cupola is done either by fracture or by chemical analysis.

Mixing by Fracture

The fracture of the freshly broken pig is taken as the index of its composition. A dark gray color, with coarse open crystalline grain indicates a soft iron, and, as a rule, one capable of carrying a large percentage of scrap. As the color becomes lighter and the grain closer, hardness increases and less scrap can be used. Very hard irons are mottled or white and are used for special work.

A broken pig may present a dark fracture with open grain, but with a fine white streak showing at the outer edges of the fracture. Such an iron will make hard castings, owing to the presence of too much manganese.

Blow holes and worm holes indicate sulphur or ferrous oxides. Iron showing these with frequency should be used carefully.

Segregations, much lighter in appearance than the rest of the fracture, frequently appear. These indicate higher percentages of carbon, sulphur or manganese at those particular spots and the iron should be used with care.

Mixing by fracture is uncertain and is liable to produce irregular and unsatisfactory results.

The foundryman must always proceed cautiously and can only arrive at the results desired by careful trial. The following mixtures are taken from West's "Foundry Practice."

Locomotive Cylinders

2600 pounds car wheel scrap.
600 pounds soft pig.

Marine and Stationary Cylinders

50 per cent No. 1 charcoal.
50 per cent good machinery scrap.
33 per cent car wheel scrap.
33 per cent good machinery scrap.
33 per cent No. 1 soft pig.

Rolling Mill Rolls

50 per cent car wheel scrap.
25 per cent No. 1 charcoal.
25 per cent No. 2 charcoal.

Small Chilled Rolls

1300 pounds old car wheels.
100 pounds No. 1 charcoal.
300 pounds steel rail butts.

Kettles to Stand Red Heat

1300 pounds No. 1 charcoal pig.
800 pounds car wheel scrap.
700 pounds good machinery scrap.

Chilled Castings to Stand Friction (no strain)

200 pounds white iron.
200 pounds plow points.
100 pounds No. 2 charcoal.
100 pounds car wheel scrap.

Ordinary Castings

33 per cent No. 1 soft pig.
67 per cent scrap.

Thin Pulleys

66 per cent No. 1 soft pig.
34 per cent scrap.

Sash Weight

67 per cent scrap tin.
33 per cent stove scrap.

The advent of the chemist into the foundry offers means to avoid many of the uncertainties coming from the selection of irons by fracture, and the more advanced foundrymen are now mixing their irons by analysis.

Mixing Iron by Analysis

This method of mixing iron is by no means entirely removed from uncertainties. The chemist is not yet able to insure the production, from irons of known chemical composition, of castings of definite physical characteristics. Analysis should be supplemented by physical tests.

Again, while the foundryman may have correct analysis of his pig iron, if scrap is used to any extent, especially foreign scrap, he must approximate the elements contained therein.

The statements made on page 307 offer some little assistance, but, in general, reliance must be placed on experience in this respect. Where the scrap comes entirely from previous casts, one can readily arrive at its constituents and much uncertainty is removed.

The qualities necessary for different grades of castings may be summarized as follows:

1. *Hollow Ware, Stove Plate, Sanitary Ware.* — Require fluidity, softness; must be high in silicon and phosphorus; low in combined carbon.

2. *Light Machinery Castings.* — Require fluidity, softness, strength and absence of shrinkage. Must be high in total carbon and manganese; low in sulphur and contain less silicon and phosphorus than grade No. 1.

3. *Heavy Machinery Castings.* — Require softness, strength and low shrinkage. Should be lower in silicon, phosphorus and graphitic carbon than No. 2. Higher in combined carbon and manganese; low in sulphur.

4. *Castings requiring great strength* should be low in silicon, graphitic carbon, sulphur and phosphorus. Combined carbon should be about .50 per cent; manganese .8 per cent to 1.0 per cent.

5. *Car Wheels and Chilled Castings.* — Require low silicon, phosphorus, graphitic carbon and sulphur. High combined carbon and manganese.

6. *Chilled Rolls.* — Require low silicon, graphitic carbon and phosphorus. High combined carbon.

The following table is abstracted from "Proceedings of the American Foundrymen's Association," Vol. X, Part II, which contains the results of a long series of tests made by their committee to standardize test bars. The mixtures are not given as being recommended by the committee for the several purposes, but simply to indicate the practice of some of the larger American foundries.

TABLE II

Character of work	Silicon	Sulph.	Phos.	Mang.	Graph. carb.	Total carb	Remarks
							Ton heat
Ingot moulds	1.67	.032	.095	......	......	......	60
Dynamo frames	1.95	.042	.405	......	......	......	60
Light machinery	2.04	.044	.578	......	......	......	40
Chilled rolls	.85	.070	.482	.15	.06	2.36	30
Sand rolls	.72	.070	.454	.17	.00	3.04	30
Car wheel iron	.97	.060	.301	.40	3.43	4.17	15
Stove plate	3.19	.084	1.160	.38	3.08	3.41	20
Heavy machinery	1.96	.081	.522	.48	2.99	3.32	30
Cylinder iron	2.49	.084	.839	.47	2.99	3.39	10
Novelty iron	4.19	.080	1.236	.67	.03	2.88	5
Gun iron	2.32	.044	.676	.43	2.62	3.12	10
Sash weights	0.91	.218	.441	......	......	......	15

TABLE III

Automobile cylinders	Silicon	Sulph.	Phos.	Mn.	Graph. carb.	Total carb.
25 per cent charcoal iron........	2.46	.063	.531	.063	......	......

Transverse strength, 2901.

At a later period Prof. J. J. Porter, at the request of the American Foundrymen's Association, undertook the investigation of the compositions used for various classes of castings, with a view to formulating standard mixtures. His report embraces every variety of work and contains tabulated analyses of several hundreds of mixtures in use. The averages of the mixtures in each class of work, together with those suggested by Prof. Porter, are subjoined.

Acid-resisting Castings

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	2.03	.033	.425	1.13	....	3.32
Suggested....	1.00–2.00	under .05	under .40	1.00–1.50	....	3.00–3.50

Agricultural Machinery, Ordinary

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	2.33	.072	.766	.62	.355	3.45
Suggested....	2.00–2.50	.06–.08	.60–.80	.60–.80	....	....

Agricultural Machinery, Very Thin

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	2.70	.065	.75	.65	.20	3.50
Suggested....	2.25–2.75	.06–.08	.70–.90	.50–.70	....	....

Air Cylinders

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	1.28	.084	.401	.69	.633	3.45
Suggested....	1.00–1.75	under .09	.30–.50	.70–.90	....	3.00–3.30

Ammonia Cylinders

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	1.55	under .095	under .70	.70	....	....
Suggested....	1.00–1.75	under .09	.30–.50	.70–.90	....	3.00–3.30

Annealing Boxes for Malleable Casting Work

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Suggested....	.650	.05	.10–.20	.20	2.75	2.75

Annealing Boxes, Pots and Pans

Average......	1.52	.043	.38	.69	.58	3.29
Suggested....	1.40–1.60	under .06	under .20	.60–1.00	....	low

Automobile Castings

Average......	1.93	.059	.52	.68	.52	3.50
Suggested....	1.75–2.25	under .08	.40–.50	.60–.80	....	....

Automobile Cylinders

Average......	2.15	.091	.643	.46	.45	3.14
Suggested....	1.75–2.00	under .08	.40–.50	.60–.80	.55–.65	3.00–3.25

Automobile Flywheels

Average......	2.73	.058	.475	.625	.335	....
Suggested....	2.25–2.50	under .07	.40–.50	.50–.70	....	....

Balls for Ball Mills

Average......	1.00	.10	.30	.50	....	low
Suggested....	1.00–1.25	under .08	under .20	.60–1.0	....	low

Bed-plates

Average......	1.815	.07	.535	.60	.53	3.52
Suggested....	1.25–1.75	under .10	.30–.50	.60–.80	....	....

Binders (see Agricultural Machinery)

Boiler Castings

Average......	2.38	.065	.41	.79	....	....
Suggested....	2.00–2.50	under .06	under .20	.60–1.00	....	....

Car Castings, Gray Iron (see Brake Shoes and Car Wheels)

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	2.03	.069	.65	.62	.52	3.50
Suggested....	1.50-2.25	under .08	.40-.60	.60-.80	....	....

Car Wheels, Chilled

Average......	.642	.094	.38	.44	.80	3.65
Suggested....	.60-.70	.08-.10	.30-.40	.50-.60	.60-.80	3.50-3.70

Car Wheels, Unchilled (see Wheels)

Chemical Castings (see Acid-resisting Castings)

Chilled Castings

Average......	1.04	.105	.40	.76	1.96	3.19
Suggested....	.75-1.25	.08-0.10	.20-.40	.80-1.20	....	....

Chills

Average......	2.07	.073	.31	.48	.23	2.64
Suggested....	1.75-2.25	under .07	.20-.40	.60-1.00	....	....

Collars and Couplings for Shafting

Average......	1.60	.04	.55	.55	.30	3.57
Suggested....	1.75-2.00	under .08	.40-.50	.60.-80	....	....

Cotton Machinery (see also Machinery Castings)

Average......	2.25	under .09	.70	.60	.45	3.45
Suggested....	2.00-2.25	under .08	.60-.80	.60-.80	....	....

Crusher Jaws

Average......	1.10	.127	.45	.92	3.00	3.125
Suggested....	.80-1.00	.08-.100	.20-.40	.80-1.20	....	....

Cutting Tools, Chilled Cast Iron

Average......	1.35	.117	.60	.54	.65	3.00
Suggested....	1.00-1.25	under .08	.20-.40	.60-.80	....	....

Cylinders

See Air Cylinders — Ammonia Cylinders
Automobile " — Gas Engine "
Hydraulic " — Locomotive "
Steam Cylinders

Cylinder Bushings, Locomotive (see Locomotive Castings)

Dies for Drop Hammers

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	1.40	.075	.25	.55	1.00	3.20
Suggested....	1.25-1.50	under .07	under .20	.60-.80	....	low

Diamond Polishing Wheels

Average......	2.70	.063	.30	.44	1.60	2.97

Dynamo and Motor Frames, Bases and Spiders, Large

Average......	2.025	.0655	.54	.49	.56	3.73
Suggested....	2.00-2.50	under .08	.50-.80	.30-.40	.20-.30	low

Dynamo and Motor Frames, Bases and Spiders, Small

Average......	2.66	.073	.73	.45	.30	3.45
Suggested....	2.50-3.00	under .08	.50-.80	.30-.40	.20-.30	low

Electrical Castings

Average......	2.30	.068	.62	.48	.48	3.61
Suggested....	2.00-3.00	under .08	.50-.80	.30-.40	.20-.30	low

Eccentric Straps (see Locomotive Castings and Machinery Castings)

Engine Castings

See Bed Plates — Engine Frames
Flywheels — Locomotive Castings
Machinery Castings — Steam Cylinders

Engine Frames (see also Machinery Castings)

Average......	1.72	.09	.48	.60	....	....
Suggested....	1.25-2.00	under .09	.30-.50	.60-1.00	....	....

Fans and Blowers. (see Machinery Castings)

Farm Implements

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	2.05	.078	.78	.455	.48	3.35
Suggested....	2.00–2.50	.06–.08	.50–.80	.60–.80	....	....

Fire Pots

Average......	2.50	under .07	under .20	.90	....	....
Suggested....	2.00–2.50	under .06	under .20	60–1.00	....	low

Flywheels (see also Automobile Flywheels and Machinery Castings)

Average......	1.85	.09	.525	.55	....	....
Suggested....	1.50–2.25	under .08	.40–.60	.50–.70	....	....

Friction Clutches

Average......	2.25	under .15	under .70	under .70	....	....
Suggested....	1.75–2.00	.08–.10	under .30	.50–.70	....	low

Furnace Castings

Average......	2.125	.082	.40	.51	....	....
Suggested....	2.00–2.50	under .06	under .20	.60–1.00	....	low

Gas Engine Cylinders

Average......	1.18	.082	.46	.63	.93	3.23
Suggested....	1.00–1.75	under .08	.20–.40	.70–.90	....	3.00–3.30

Gears, Medium

Average......	1.92	.075	.47	.576	.55	3.79
Suggested....	1.50–2.00	under .09	.40–.60	.70–.90	....	....

Gears, Small

Average......	2.72	.08	.91	.80	....	....
Suggested....	2.00–2.50	under .08	.50–.70	.60–.80	....	....

Gears, Heavy

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	1.38	.081	.39	.59	.92	3.33
Suggested....	1.00–1.50	.08–.10	.30–.50	.80–1.0	....	low

Grate Bars

Average......	2.38	.08	....	....	....	....
Suggested....	2.00–2.50	under 1.06	under .20	.60–1.0	under .30	low

Chilled Castings for Grinding Machinery

Average......	.50	.200	.45	1.50	3.00	3.00
Suggested....	.50–.75	.15–.20	.20–.40	1.5–2.0	....	....

Gun Carriages

Average......	.97	.05	.37	.46	.865	2.73
Suggested....	1.00–1.25	under .06	.20–.30	.80–1.0	....	low

Gun Iron

Average......	1.09	.053	.32	.62	.99	3.06
Suggested....	1.00–1.25	under .06	.20–.30	....	.80–1.0	low

Hangers for Shafting

Average......	1.60	.04	.55	.55	.30	3.57
Suggested....	1.50–2.00	under .08	.40–.50	.60–.80	....	......

Hardware, Light

Average......	2.30	.06	.74	.76	.32	3.39
Suggested....	2.25–2.75	under .08	.50–.80	.50–.70	....	....

Heat-resisting Iron

Average......	1.95	.056	.52	.68	.46	3.46
Suggested....	1.25–2.50	under .06	under .20	.60–1.00	under .30	low

Hollow Ware

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	2.51	1.10	.62	.41	.24	3.18
Suggested....	2.25–2.75	under .08	.50–.70	.50–.70	....	....

Housings for Rolling Mills

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	1.125	.085	.65	.75	....	low
Suggested....	1.00–1.25	under .08	.20–.30	.80–1.0	....	low

Hydraulic Cylinders, Heavy

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	1.19	.084	.39	.82	.99	3.12
Suggested....	.80–1.20	under .10	.20–.40	.80–1.0	....	low

Hydraulic Cylinders, Medium

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	1.67	.071	.375	.55	....	....
Suggested....	1.20–1.60	under .09	.30–.50	.70–.90	....	low

Ingot Moulds and Stools

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	1.43	.046	.095	.345	....	....
Suggested....	1.25–1.50	under .06	under .20	.60–1.0	....	....

Locomotive Castings, Heavy

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	1.55	.081	.50	.56	.60	3.50
Suggested....	1.25–1.50	under .08	.30–.50	.70–.90	....	....

Locomotive Castings, Light

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	1.725	.075	.53	.58	.50	3.50
Suggested....	1.50–2.00	under .08	.40–.60	.60–.80	....	....

Locomotive Cylinders

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
Average......	1.457	.084	.58	.60	.60	3.50
Suggested....	1.00–1.50	.08–.10	.30–.50	.80–1.0	....	....

Locks and Hinges (see Hardware, Light)

Machinery Castings, Heavy

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	1.335	.084	.43	.58	.33	3.21
Suggested....	1.00–1.50	under .10	.30–.50	.80–1.0	....	low

Machinery Castings, Medium

Average......	1.932	.078	.61	.53	.47	3.33
Suggested....	1.50–2.00	under .09	.40–.60	.60–.80	....	....

Machinery Castings, Light

Average......	2.57	.069	.74	.52	.27	3.49
Suggested....	2.00–2.50	under .08	.50–.70	.50–.70	....	....

Machine Tool Castings (see Machinery Castings)
Motor Frames, Bases and Spiders (see Dynamo)
Molding Machines (see Machinery Castings)
Mowers (see Agricultural Castings)
Niter Pots (see Acid-resisting Castings and Heat-resisting Castings)

Ornamental Work

Average......	2.95	.095	.84	.54	.135	3.03
Suggested....	2.25–2.75	under .08	.60–1.0	.50–.70	....	....

Permanent Moulds

Average......	2.085	.078	1.075	.35	.485	3.45
Suggested....	2.00–2.25	under .07	.20–.40	.60–1.0	....	....

Permanent Mould Castings

Average......	2.5	....	....	....	....	3.50
Suggested....	1.50–3.00	under .06	....	under .40	....	....

Piano Plates

Average......	2.00	low	.40	.60	....	....
Suggested....	2.00–2.25	under .07	.40–.60	.60–.80	....	....

Pillow Blocks

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	1.60	.04	.55	.55	.30	3.50
Suggested....	1.50–1.75	under .08	.40–.50	.60–.80	....	....

Pipe

Average......	2.00	.06	.60	.60	....	....
Suggested....	1.50–2.00	under .10	.50–.80	.60–.80	....	....

Pipe Fittings

Average......	2.36	.084	.51	.74	.70	3.68
Suggested....	1.75–2.50	under .08	.50–.80	.60–.80	....	....

Pipe Fittings for Superheated Steam Lines

Average......	1.57	.078	.49	.56	.17	2.90
Suggested....	1.50–1.75	under .08	.20–.40	.70–.90	....	low

Piston Rings

Average......	1.61	.073	.72	.45	.53	....
Suggested....	1.50–2.00	under .08	.30–.50	.40–.60	....	low

Plow Points, Chilled

Average......	1.15	.086	.30	.68	2.10	3.30
Suggested....	.75–1.25	under .08	.20–.30	.80–1.0	....	....

Printing Presses (see Machinery Casting)

Propeller Wheels

Average......	1.28	low	.26	.455	.60	....
Suggested....	1.00–1.75	under .10	.20–.40	.60–1.0	....	low

Pulleys, Heavy

Average	2.07	.05	.575	.575	.30	3.66
Suggested....	1.75–2.25	under .09	.50–.70	.60–.80	....	....

Pulleys, Light

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	2.55	.069	.695	.62	.35	3.48
Suggested....	2.25-2.75	under .08	.60-.80	.50-.70	....	....

Pumps, Hand

Average......	2.52	under .08	.80	.40	....	....
Suggested....	2.00-2.25	under .08	.60-.80	.50.-70	....	....

Radiators

Average......	2.30	low	.62	.425	.425	3.45
Suggested....	2.00-2.25	under .08	.60-.80	.50-.70	.50-.60	....

Railroad Castings

Average......	2.03	.065	.69	.64	.525	3.50
Suggested....	1.50-2.25	under .08	.40-.60	.60-.80	....	....

Retorts (see Heat-resisting Castings)

Rolls, Chilled

Average......	.73	.055	.534	.74	1.75	3.12
Suggested....	.60-.80	.06-.08	.20-.40	1.0-1.2	....	3.00-3.25

Rolls, Unchilled (Sand Cast)

Average......	.75	.03	.25	.66	1.20	4.10

Scales

Average......	1.83	....	1.05	1.43	....	....
Suggested....	2.00-2.30	under .08	.60-1.0	.50-.70	....	....

Slag Car Castings

Average......	1.88	.058	.67	.79	.56	3.68
Suggested....	1.75-2.0	under .07	under .30	.70-.90	....	....

Smoke Stacks, Locomotive (see Locomotive Castings)

Soil Pipe and Fittings

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	2.00	.060	1.00	.60	....	....
Suggested....	1.75–2.25	under .09	.50–.80	.60–80	....	....

Steam Cylinders, Heavy

Average......	1.20	.091	.36	.50	.81	3.35
Suggested....	1.00–1.25	under .10	.20–.40	.80–1.0	....	low

Steam Cylinders, Medium

Average......	1.658	.082	.55	.61	.62	3.43
Suggested....	1.25–1.75	under .09	.30–.50	.70–.90	....	....

Steam Chests (see Locomotive Castings and Machinery Castings)

Stove Plate

Average......	2.77	.076	.82	.59	.28	3.33
Suggested....	2.25–2.75	under .08	.60–.90	.60–.80	....	....

Valves, Large

Average......	1.34	.095	.43	.64	....	....
Suggested....	1.25–1.75	under .09	.20–.40	.80–1.0	....	....

Valves, Small

Average......	1.96	.067	.585	.705	1.16	4.18
Suggested....	1.75–2.25	under .08	.30–.50	.60–.80	....	low

Valve Bushings (see Locomotive Castings and Machinery Castings)

Water Heaters

Average......	2.15	.050	.40	.50	....	....
Suggested....	2.00–2.25	under .08	.30–.50	.60–.80	....	....

Weaving Machinery (see Machinery Castings)

Wheels, Large

Mixture	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Total carbon
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Average......	2.10	.04	.40	.70	....	....
Suggested....	1.50–2.00	under .09	.30–.40	.60–.80	....	....

Wheels, Small

Average......	1.85	.0665	.50	.45	....	....
Suggested....	1.75–2.00	under .08	.40–.50	.50–.70	....	....

Wheel Centers (see Locomotive Castings)

White Iron Castings

Average......	.70	.20	.45	.33	2.90	2.50

Wood Working Machinery (see Machinery Castings)

Brake Shoes

Average......	1.94	.125	.675	.556	.53	3.16
Suggested....	1.40–1.90	.08–.10	.30	.50–.70	....	low

Knowing the desired analysis for any class of casting to be made, the simplest way to arrive at the amounts of the different irons to be used is by percentage. For example, let the requirements be for an iron to produce machinery castings of which the analysis shall be:

Silicon	Sulphur	Phosphorus	Manganese
2.00	.084	.350	.625

As previously stated, the loss in silicon in remelting will be from 10 to 20 per cent, the same for manganese, and a gain of .03 in sulphur, phosphorus remaining constant. The mixture then must contain:

Silicon	Sulphur	Phosphorus	Manganese
2.22	.054	.350	.687

The irons then available are:

	Silicon	Sulphur	Phosphorus	Manganese
No. 2 Southern	2.25	.04	.280	.735
No. 2 Northern	2.10	.02	.350	.940
Silver gray	4.20	.025	.820	.820
Scrap	1.90	.080	.284	.540

After two or three trials it is found that the desired mixture may be obtained from

	Silicon	Sulphur	Phosphorus	Manganese
20 per cent No. 2 Southern, giving	.450	.008	.056	.147
20 per cent No. 2 Northern, giving	.420	.004	.070	.188
10 per cent silver gray, giving	.420	.0025	.082	.082
50 per cent scrap, giving	.950	.0400	.142	.270
	2.240	.0545	.350	.687

Example 2.—Required an iron for pulleys and light castings of following analysis: Silicon, 2.40; sulphur, .09; phosphorus, .700; manganese, .52, and to carry 50 per cent scrap.

Available irons:

	Silicon	Sulphur	Phosphorus	Manganese
No. 2 Southern	2.72	.070	.750	.48
No. 2 Northern	2.40	.020	.600	.56
Silver gray	5.00	.024	.960	.53
Scrap	2.20	.080	.660	.62

Correcting for losses of silicon and manganese and gain of sulphur the mixture must contain silicon, 2.66, sulphur, .06, phosphorus, .70, manganese, .577.

For reasons of economy no more than 10 per cent of the silver gray iron should be used. This with the 50 per cent scrap supplies:

	Silicon	Sulphur	Phosphorus	Manganese
10 per cent silver gray	.50	.0024	.096	.053
50 per cent scrap	1.10	.040	.330	.310
	1.60	.0424	.426	.363
To be supplied by remaining pig iron	1.066	.0176	.274	.214

By trial it is found that the remaining amounts of the different elements may be obtained by using:

	Silicon	Sulphur	Phosphorus	Manganese
25 per cent No. 2 Southern......	.68	.0175	.1875	.12
15 per cent No. 2 Northern......	.36	.0030	.0900	.084
Giving......................	1.04	.0205	.2775	.204

The slight discrepancies of .02 silicon, .0029 sulphur, .0035 phosphorus and .01 manganese may be neglected.

Where the scrap is very nearly of uniform quality, the analysis of the castings from any given heat furnishes data from which a very close approximation can be made of the scrap used in the previous heat.

Assuming such character of scrap, and knowing the mixture used in any heat as well as the analysis of the castings, *compute the analysis of scrap used in previous heat.*

Let the castings show the analysis of example 2, viz.: Si, 2.40, S, .09, P, .70, Mn, .52. Then the mixture must have been as before, Si, 2.66, S, .06, P, .70, Mn, .577.

The irons having the assumed analysis of example 2, then:

	Silicon	Sulphur	Phosphorus	Manganese
25 per cent No. 2 Southern gives.	.68	.0175	.1875	.12
15 per cent No. 2 Northern gives.	.36	.0030	.0900	.084
10 per cent silver gray gives......	.50	.0024	.0960	.053
	1.54	.0229	.3735	.257
Which subtracted from the mixture leaves....................	1.12	.0371	.3265	.320

As 50 per cent scrap was used, the analysis of scrap from previous heat is Si, 2.24, S, .0742, P, .653, Mn, .64, giving a very close approximation.

CHAPTER XI

USE OF STEEL SCRAP IN MIXTURES OF CAST IRON

STEEL scrap, when added to mixtures of cast iron in quantities varying from 10 to 40 per cent, closes the grain, increases the toughness and adds greatly to the tensile strength of the castings made from such mixture.

The steel should be low in carbon, such as boiler plate scrap, machine steel, rail ends, etc.

Turnings from machine steel are frequently used in the ladle. In this case the steel should be heated quite hot, placed in the ladle and the iron tapped out on it. The mixture should be thoroughly stirred until the steel is melted. In all cases the iron must be very hot.

Mixing steel in the ladle does not give as satisfactory results as mixing in the cupola.

As the steel is low in carbon the iron used should be high in total carbon, otherwise the castings will be hard with over 10 per cent steel scrap.

The following table by Mr. H. E. Diller presents the results of a series of tests, with mixtures made by varying in percentages of steel scrap from 12½ to 37½ per cent:

No.	Silicon	Sulphur	Phosphorus	Manganese	Comb. carbon	Graphitic carbon	Total carbon	Tensile strength	Transverse strength	Per cent steel
1	1.43	.047	.564	.82	.670	3.14	3.81	23,060	2550	0
2	1.50	.065	.532	.33	.640	3.44	3.08	30,500	2840	25
3	1.76	.062	.488	.53	.510	3.12	3.63	22,180	2440	0
4	1.76	.139	.515	.57	.430	2.94	3.37	37,090	2770	12½
5	1.77	.069	.339	.49	.560	2.87	3.43	32,500	3120	12½
6	1.83	.100	.610	.55	.510	2.44	2.95	36,860	3280	25
7	1.75	.089	.598	.35	.740	2.12	2.86	30,160	3130	37½
8	1.96	.104	.446	.44	.630	3.18	3.81	21,950	2230	0
9	2.12	.037	.410	.26	.380	3.26	3.64	21,890	3470	12½
10	2.16	.060	.315	.20	1.060	2.30	3.36	26,310	2670	12½
11	1.97	.093	.470	.48	.570	2.83	3.40	32,530	3050	37½
12	2.35	.061	.515	.56	.540	3.40	3.94	21,990	2200	0
13	2.53	.104	.490	.54	.600	2.56	3.16	33,390	2850	25
14	2.36	.064	.327	.24	1.080	2.15	3.23	31,560	3200	25

These tests were made with pig iron, ferrosilicon and steel scrap. No cast iron scrap was used. Mr. Diller concludes: "The tests given seem to indicate that 25 per cent of steel will add 50 per cent to the strength of the iron, and 12½ per cent of steel, approximately 25 per cent."

The tests containing 37½ per cent steel were hardly as much improved in strength as those with 25 per cent of steel; from which we may infer that the limit of the amount of steel it is beneficial to melt with iron in a cupola is between 25 and 37½ per cent.

Results of experiments made by Mr. C. B. McGahey are embodied below.

Mr. McGahey used test bars 1 in. by 1 in. by 24 in. (distance between supports not stated).

No.	Silicon	Sulphur	Phosphorus	Manganese	Per cent steel	Depth of chill	Transverse strength	Remarks
						In.		
1	.82	.097	.23	.54	7	.38	1800	Entirely gray when cast in sand.
2	.88	.081	.24	.67	20	.40	2200	Depth of chill ¾ in.
3	.58	.097	.25	.44	23	.48	2250	Steel scrap (structural shapes).
4	.79	.081	.239	.64	21.50	......	......	

"I find that to get the strongest bars I have to keep pretty close to these analyses and have made my strongest bar at 2350 pounds with .55 inch deflection. The iron had a fine grain, was low in graphite, but machined nicely.

When ferromanganese was used, about 1 per cent was found to be best. The above resulting compositions (the silicons of the mixtures being calculated to bring them about right) are intended for castings ranging from 1 inch to 2½ inches in section.

Should heavier work be required it is better to run the silicon in the pig up to 2.75 and manganese up to 2.00 and use 33⅓ per cent of steel scrap."

An addition of 10 per cent steel scrap to mixtures for engine cylinders gives excellent results affording a close-grained tough iron. Steel scrap increases shrinkage and causes the iron to set quickly; hence the irons used should be high in total carbon and must be melted and poured very hot.

Steel scrap promotes chill and is largely used with coke irons in making car wheels, obviating the use of the expensive charcoal mixtures.

The charges containing steel should be melted during the first part of the heat, and in each charge the steel should precede the iron.

Recovering and Melting Shot Iron

The shot from gangways and cupola bottom is usually recovered by riddling the gangway sand; picking over the dump and by grinding the bottom in the cinder mill. This is also done by magnetic or hydraulic separators. The amount recovered by machines is much greater than that obtained by hand.

After charging of the cupola is completed, the shot should be thrown on top of the last charge, using with it some of the coke picked from the dump. Each heat should take care of the shot from the previous one.

The melted iron coming from the shot can be poured into grate bars, sash weights, or other coarse castings; or it may be run into pigs and used as scrap.

Mr. W. J. Keep describes his method of recovery as follows: "After the blast has been shut off and all of the melted iron has been drained from the cupola, make a dam on the floor in front of the cupola spout about 4 inches high, enclosing a semicircular space, having a radius of about 4 feet. Let the melter lay a tapping bar across the spout and have three or four laborers with a piece of old 1½ inch shafting about 8 feet long ram in the breast. If the bottom and spout have been made right there will be no melted iron in the cupola, but ram back and forth to allow all to drain out.

All the liquid slag in the cupola will run into the enclosed space underneath the spout and if there is any iron in this, it will run through the slag and lie on the floor in the form of a slab which can be picked up the next morning.

When the cupola has been emptied of all slag and iron drop the bottom. I like to draw the refuse out from underneath the cupola, turning it over and cooling it down with water. The pieces of the sand bottom are thrown to one side and all the iron that can be seen is picked up. All the iron taken from the cupola dump, the pig bed, or from the gangways, which is not bad casting, is weighed up and charged as remelt or home scrap.

All remaining small pieces of coke, iron or slag are shoveled up from the bottom and from all parts of the foundry and placed in boxes on the cupola platform. This includes skulls from the ladles which contain more or less iron.

When the last charge of iron has been placed in the cupola and the heat is near enough to the end to show that there will be no shortage of iron, throw into the cupola any shot iron that may be left over, and all the refuse previously mentioned. The iron and slag will be melted at once and the small bits of coke will hold the blast down and insure hot iron.

All the finest shot iron is saved in this way, as well as all coke in the form of small pieces and nothing is lost."

The disposition on the part of many foundrymen is to neglect the saving of shot iron, preferring to sell to junk dealers what can be readily recovered. Such will not be the case, however, in a well-managed foundry, as by close attention to its recovery the loss in melt can be reduced from 1 to 2 per cent.

At one of the large western foundries, through mismanagement, shot had been allowed to accumulate until a portion of the yard was covered to a depth of from 12 inches to 20 inches. This was dug up, milled and melted; 1500 pounds, at each heat, were thrown on top of the last charge, without additional fuel; the melted iron was run into pigs.

Over 84 tons of No. 4 pig were recovered; 25 per cent of the scrap used in charging was replaced by this iron and the usual mixture was in no other respect changed.

Burnt Iron

This class of iron is of no use except for making sash weights. When used for ordinary purposes, the loss caused is greater than the gain. It makes iron hard, causes a great amount of slag and chokes up the cupola. It should be carefully selected and thrown out of the scrap.

Melting Borings and Turnings

Cast iron borings and turnings which are usually disposed of to junk dealers at a low price may be advantageously melted by packing them in wood or iron boxes, about 100 pounds to the box.

The boxes should be charged a few at a time, by throwing them into the center of the charge and covering them with scrap. These will descend to near the melting zone before they are burned or melted.

Mr. W. F. Prince has patented a process for melting borings, etc., which consists of packing them in sheet iron pipes, with or without bottoms. The pipes are of any convenient length, from 30 to 48 inches; the first one is placed on the coke bed and the others on top of it, with the charges surrounding them.

This differs little from the method of using boxes, where the latter are piled on each other. In either case the containers prevent the fine material from being blown out of the stack.

Many attempts have been made to render borings, etc., suitable for melting, by briquetting. So far, these efforts seem to have been only partially successful.

A process has recently been developed in Germany, by which the borings are made into briquettes under hydraulic pressure. It is claimed that the product successfully meets the purpose and preliminary tests made in America seem to warrant the statement.

CHAPTER XII

TEST BARS

This subject has been treated exhaustively by a Committee of the American Foundrymen's Association. Their report was adopted by the Association in June, 1901.

Extensive extracts from the report are given below.

The work covered the testing of 1229 bars by 1601 tests; the following table shows the character of the heats from which the bars were taken.

Series	Class of iron	Melted in	Pig iron used	Size of heat	Si	P	S
				tons			
A*	Ingot mould........	Cupola	Coke	60	1.67	.095	.032
B	Dynamo frame.....	Cupola	Coke and charcoal	60	1.95	.405	.042
C	Light machinery...	Air furnace	Coke and charcoal	40	2.04	.578	.044
D	Chilled roll	Air furnace	Cold-blast charcoal	30	.85	.482	.070
E	Sand roll...........	Cupola	Warm-blast charcoal	30	.72	.454	.070
F†	Sash Weight........	Cupola	Coke and charcoal	15	.91	.441	.218
G	Car wheel..........	Cupola	Coke and charcoal	10	.97	.301	.060
H	Stove plate.........	Cupola	Coke	20	3.19	1.160	.084
I	Heavy machinery..	Cupola	Coke	30	1.96	.522	.081
J	Cylinder...........	Cupola	Coke	10	2.49	.839	.084
K	Novelty............	Cupola	Coke	5	4.19	1.236	.080
L	Gun metal.........	O. H. furnace	Coke and charcoal	10	2.32	.676	.044

* All pig iron.

† Nearly all burnt scrap, originally from charcoal and coke iron.

"Throughout the whole line of operations only regularly constituted mixtures were used, the balance of the heats from which these test bars were cast going directly into commercial castings of the classes designated. The results are, therefore, entirely comparable with daily practice.

For purposes of comparison green sand and dry sand bars were made side by side.

It was felt that comparison records were wanted just as much as specifications for the separate lines of product. For this reason, we recommend one standard size of test bar for comparative purposes only, each class of iron being given its special treatment for the information wanted in daily practice in addition.

"Our studies on the shape of the test bar have resulted in the selection of the round form of cross section and this mainly on the score of greatest uniformity in physical structure. . . . There is still a further point of interest, in the preparation of test bars and that is, the making of coupons from which the quality of the castings to which they are attached is to be judged. This method is used extensively in government work and in the making of cylinder castings.

The idea of obtaining material from the same pour in the same mould as part of the casting itself is good enough in theory. Unfortunately, however, this direct connection introduces elements of segregation and temperature changes in the cast iron which make this test less valuable than is generally supposed. At best the iron which has passed through the different parts of a mold before entering the space for the coupon will not be representative of the whole body, but rather one portion of it only. We therefore recommend the method shown later on in Fig. 75. The metal can be poured from crane or hand ladle, clean and speedily, and possesses the temperature of the average iron in the casting more nearly than the coupon method now practiced.

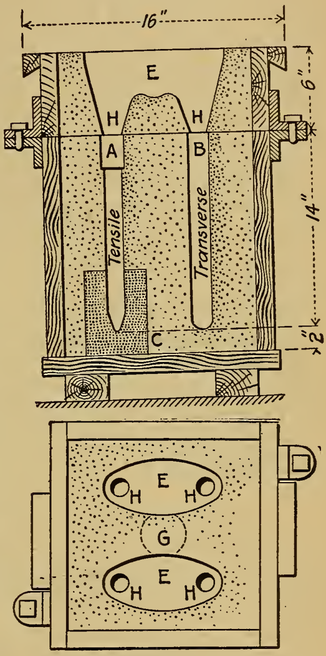


Fig. 75.

Your committee while giving specifications for the tensile test of cast iron is of the opinion that the transverse test is the more desirable and certainly within reach of even the smallest foundry.

In selecting the test bars for the purpose of specification, we have followed the cardinal principle of selecting the largest cross section for the iron consistent with a sound physical structure and within the range and structural limits of an ordinary testing machine.

The following are the sizes of bars selected for tests as a result of our investigations.

For all tensile tests, a bar turned to .8 inches in diameter, corresponding to a cross section of ½ square inch. Results, therefore, multiplied by two, give the tensile strength per square inch.

For transverse test, of all classes of iron for general comparison; a bar 1½ inches in diameter, on supports, 12 inches apart; pressure applied in the middle and deflection noted.

Similarly for ingot mould, light machinery, stove plate and novelty iron, a 1½-inch diameter bar; that is to say, for irons running from 2 per cent in silicon upward, or from 1.75 per cent silicon upward where but little scrap is in the mixture.

For dynamo frames, sash weights, cylinders, heavy machinery and gun metal irons; similarly, a 2-inch diameter bar is recommended, that is, for irons running from 1.5 per cent to 2 per cent in silicon or where the silicon is lower and the proportion of scrap is rather large.

For roll irons, whether chilled or sand, and car wheel metals, a 2½-inch diameter bar is recommended; that is, for all irons below 1 per cent silicon and which may, therefore, be classed as the chilling irons.

The method of moulding the test bar we would recommend is given herewith.

At least three bars of a kind should be made for a given test.

The sand should not be any damper than to mould well and stand the wash of the iron without cutting, blowing or scabbing. It should be rammed evenly to avoid swells and poured by dropping the metal from the top through gates, or from ladle direct into the open mould.

After the bars are cast they should remain in their moulds undisturbed until cool."

Proposed Standard Specifications for Gray Iron Castings

1. Unless furnace iron, dry sand, loam moulding, or subsequent annealing is specified, all gray iron castings are understood to be of cupola metal; mixtures, moulds and methods of preparation to be fixed by the founder to secure the results required by purchaser.

2. All castings shall be clean, free from flaws, cracks and excessive shrinkage. They shall conform in other respects to whatever points may be specially agreed upon.

3. When the castings themselves are to be tested to destruction, the number selected from a given lot and the tests they shall be subjected to are made a matter of special agreement between founder and purchaser.

4. Castings under these specifications, the iron in which is to be tested for its quality, shall be represented by at least three test bars cast from the same heat.

5. These test bars shall be subjected to a transverse breaking test, the load applied at the middle with supports 12 inches apart. The

breaking load and deflection shall be agreed upon specially on placing the contract, and two of these bars shall meet the requirements.

6. A tensile strength that may be added, in which case at least three bars for this purpose shall be cast with the others, in the same moulds respectively. The ultimate strength shall also be agreed upon specially before placing the contract and two of the bars shall meet the requirements.

7. The dimensions of the test bars shall be as given herewith. There is only one size for the tensile bar and three for the transverse. For the light and medium weight castings the 1½ inch □ bar is to be used; for heavy castings, the 2 inch □ bar; and for chilling irons the 2½ inch □ test bar.

8. When the chemical composition of the castings is a matter of specification, in addition to the physical tests, borings shall be taken from all the test bars made; they shall be well mixed and any required determination (combined and graphitic carbon alone excepted), made therefrom.

9. Reasonable facilities shall be given the inspectors to satisfy themselves that castings are being made in accordance with specifications, and if possible tests shall be made at the place of production prior to shipment."

Patterns for Test Bars of Cast Iron

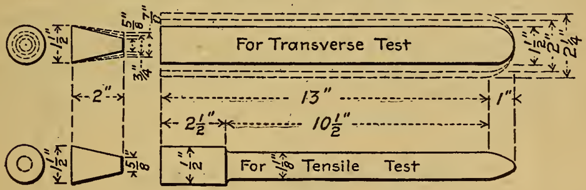
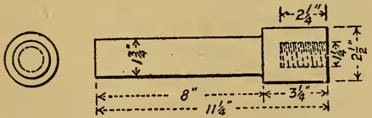
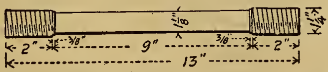


FIG. 76.



Steel Socket for Tensile Test of Cast Iron. — Two required



Standard Test Bar for Cast-iron Tensile Test. — Cross section equals ½ sq. in.; test piece should fit loosely in socket

FIG. 77.

Modulus of Rupture in Pounds Per Square Inch

The report of the committee is accompanied by a table giving the moduli of rupture per square inch for bars under the various conditions of the tests and from ¼ square inch to 16 square inches. It was found that, with few exceptions, the values decrease as the areas increase.

In the table on pages 299 and 300, which is extracted from their report, the moduli are given for bars having areas of 1 square inch, 2.25, 4, and 9 square inches.

"The results show that rough bars are stronger than machined and that there is practically no difference between bars made in green or dry sand.

An examination of the table shows that the transverse strength is greater in the rough than machined bars, except in two instances, viz.: □ bar, series *J*, in dry sand the rough bar broke with 178 pounds less load than the machined bar. ○ bar, series *L*, in dry sand, the rough bar broke with 115 pounds less load than did the machined bar. The average loss in transverse strength of the green sand bar by machining was 12 per cent; that of the dry sand bar 10 per cent.

The following articles are introduced as showing how little reliance can be placed on the results from test bars. It is shown that bars identical in chemical composition, but made from different brands, differ widely in physical properties; indicating the importance of using in mixtures, irons from different localities, as well as from different furnaces. The micrographs show clearly the variation in structure corresponding to the widely varying results, but it remains for the metallurgist to point out the causes for these differences."

Erratic Results — Test Bars

Mr. F. A. Nagle submitted to the American Society of Mechanical Engineers the following report of his investigation of test bars for castings used in the Baltimore Sewage pumps.

"In machinery castings as well as in cast pipes, separate bars are cast and subjected to tensile or transverse stress to the breaking point, these results being used as evidence of compliance with the contract specifications. The writer has examined a large number of such test bars for castings used in the Baltimore Sewage pumps and here reports the results of this examination and study.

Perhaps the most important conclusion is that the test bar is not to be regarded with too much confidence as indicative of the exact strength of the casting. All transverse bars were nominally 2 inches by 1 inch by

Area in square inches	Rough				Machined			
	Square		Round		Square		Round	
	Green sand	Dry sand	Green sand	Dry sand	Green sand	Dry sand	Green sand	Dry sand
Ingot Mould Iron. Series A. Silicon 1.67								
1.00	37,140	27,530	44,210	33,660	43,200	38,610	26,100	27,840
2.25	32,880	31,320	34,570	33,870	29,340	30,790	39,810	38,120
4.00	29,540	25,550	34,900	31,610	31,150	26,500	34,320	32,290
9.00	26,200	21,180	27,280	26,540	26,980	21,690	26,030	28,660
Dynamo Frame Iron. Series B. Silicon 1.95								
1.00	39,220	38,380	44,300	49,160	37,440	30,240	40,020	39,150
2.25	39,540	34,900	41,270	44,840	36,670	36,180	44,790	37,800
4.00	33,960	34,460	41,680	39,230	34,750	33,250	38,750	37,270
9.00	29,680	30,050	35,600	35,620	32,740	30,880	35,400	32,810
Light Machinery Iron. Series C. Silicon 2.04								
1.00	37,000	39,190	48,050	50,380	......	......	55,680	47,850
2.25	32,880	38,780	38,890	43,950	40,230	38,880	47,340	51,350
4.00	36,170	34,550	42,560	40,150	36,990	35,420	42,920	37,550
9.00	30,980	29,230	38,080	37,780	33,290	32,710	36,520	36,290
Chilled Roll (Furnace). *Series D. Silicon* 0.85								
1.00	44,120	44,010	49,440	49,850	......	......	......	......
2.25	47,760	67,680	69,130	59,010	......	......	......	......
4.00	46,710	43,260	65,940	75,000	......	......	......	......
9.00	52,700	54,910	65,850	51,660	......	......	......	......
Sand Roll Iron (Furnace). *Series E. Silicon* 0.72								
1.00	51,560	44,180	51,620	48,740	......	......	......	......
2.25	41,740	46,290	41,420	41,960	......	......	......	......
4.00	34,700	33,720	55,110	61,770	......	......	......	......
9.00	33,040	35,760	53,540	55,440	......	......	......	......
Sash Weight Iron. Series F. Silicon 0.91								
1.00	52,920	42,540	58,430	50,050	......	......	......	......
2.25	59,170	51,130	39,840	53,010	......	......	......	......
4.00	61,870	51,810	50,130	47,090	......	......	......	......
9.00	42,710	39,160	42,370	45,730	......	......	......	......

Area in square inches	Rough				Machined			
	Square		Round		Square		Round	
	Green sand	Dry sand	Green sand	Dry sand	Green sand	Dry sand	Green sand	Dry sand
Car Wheel Iron. Series G. Silicon 0.97								
1.00	47,110	44,810	52,600	61,720	43,200	46,080	64,380	52,200
2.25	32,120	28,200	45,880	39,740	44,640	40,680	43,200	46,170
4.00	35,460	32,190	45,970	39,330	27,520	32,760	41,590	37,350
9.00	32,050	32,140	37,610	35,150	28,730	28,960	33,930	28,040
Stove Plate Iron. Series H. Silicon 3.19								
1.00	27,980	29,360	42,570	36,920	48,960	43,200	78,300	68,600
2.25	24,960	30,710	42,160	41,420	22,500	24,480	33,250	31,550
4.00	27,980	28,930	40,540	36,940	23,400	28,810	32,290	21,910
9.00	25,620	25,020	33,350	33,550	23,710	24,100	25,540	23,000
Heavy Machinery Iron. Series I. Silicon 1.96								
1.00	36,000	44,060	53,210	54,180	43,200	46,080	52,200	55,680
2.25	35,290	35,040	43,860	47,100	33,120	39,060	44,900	43,200
4.00	36,120	33,580	42,290	41,330	30,400	32,970	41,670	42,420
9.00	23,850	20,880	33,040	34,970	37,040	30,410	36,030	38,020
Cylinder Iron. Series J. Silicon 2.49								
1.00	43,350	34,270	51,690	55,500	39,790	39,790	52,200	46,980
2.25	30,880	31,950	33,400	41,900	39,960	38,520	51,040	53,160
4.00	32,600	30,420	43,180	41,320	26,400	26,610	38,110	38,240
9.00	27,830	25,630	40,900	40,170	26,400	24,890	34,470	34,310
Novelty Iron. Series K. Silicon 4.19								
1.00	25,430	36,490	39,040	42,530	......	......	......	......
2.25	25,640	26,290	37,760	37,670	......	......	......	......
4.00	27,120	26,860	33,550	34,560	......	......	......	......
9.00	22,220	24,130	30,890	32,520	......	......	......	......
Gun Iron (Furnace). *Series L. Silicon* 2.32								
1.00	52,230	44,030	71,570	67,350	53,270	50,400	80,040	71,340
2.25	49,290	46,760	67,060	66,140	47,520	39,600	59,040	71,160
4.00	50,400	49,990	66,980	66,730	46,670	39,680	61,470	53,310
9.00	41,980	43,050	59,010	59,460	41,990	47,830	56,140	59,480

24 inch centers. . They were cast from two patterns in one mould and made in the same kind of sand as the main casting. The flask was inclined about 30 degrees. There was but one gate for the two bars with suitable risers. The iron for the bars was poured from a small ladle of iron taken as nearly as possible from the middle of the pour of the main casting.

The breaking loads were corrected for varying dimensions of the bars by the formula $W' = \frac{Wbd^2}{2}$, where b and d are the actual dimensions, W the actual breaking load and W' the corrected load of weight. These results are used throughout this paper. The deflections were not corrected.

The tensile bars, 1⅝ inches by 6 inches, were cast upright in the same mould as the main castings, within 3 or 4 inches thereof, and connected by an upper and lower gate. The tensile bars were turned to 1½ inches in diameter and threaded, and the middle portion reduced to 1.129 inches in diameter which is equal to 1 square inch area. Table I gives the results of the chemical analysis of the several bars tested.

TABLE I

	Total carbon	Graphitic carbon	Combined carbon	Manganese	Phosphorus	Sulphur	Silicon	Tensile strength, lbs. per sq. in.	Transverse, lbs. per sq. in.	Deflection, in.
Nov. 21, 1907....	3.580	2.830	.75	.79	.485	.081	1.59	24.900	2440	.49
Nov. 26, 1907....	3.396	2.736	.66	.38	.459	.124	1.91	22.000	2075	.40

From Aug. 5, 1907 to April 4, 1908 there were made 67 single tensile bars, and the same number of pairs of transverse bars; and the average of the latter was used in this record. From April 4 to Dec. 19, 1908, there were made 91 pairs of tensile bars and an equal number of transverse bars and each piece of the pair is recorded instead of the average.

Of these 249 tensile bars and their corresponding transverse bars, 32 sets — 26 flat and 6 round — were rejected for defects due to blow-holes and four tensile bars were too hard to bear threading, but the companion pieces were used in this record.

Of the 217 specimens here recorded, 42 were designated as abnormal; that is, the ratio between the tensile and the transverse bars was either considerably greater or smaller than the average.

By referring to Table II it will be seen that of the 175 specimens of cast iron running from 20,000 to 30,000 pounds tensile strength, the ratio of tensile to breaking loads is practically 10 to 1 and the deflection 0.45."

TABLE II

Number of specimens	Transverse	Tensile	Deflection	Ratio of tensile to transverse	
			Inch		
29	2065	21,630	.43	10.47	1
36	2289	22,940	.45	10.02	1
51	2523	24,880	.47	9.86	1
43	2756	26,500	.49	9.61	1
16	2894	28,460	.49	9.83	1
175	Average 2383	23,732	.45	9.96	1

Comparison of Test Bars

Table III gives 25 abnormal cases where this average ratio is as high as 12.56 to 1 with a deflection of 0.43 inch, also 17 abnormal cases where this average ratio is as low as 7.91 to 1, with a deflection of 0.44 inch; and yet the average of both normal and abnormal bars was again very nearly 10 to 1.

TABLE III

Above ratio 10 *to* 1

Number of specimens	Transverse	Tensile	Deflection	Ratio of tensile to transverse	
			In.		
10	2088	27,143	.41	12.95	1
10	2294	28,530	.43	12.44	1
4	2436	29,600	.49	12.15	1
......	......	......	......	......	1
1	2890	34,000	.45	11.76	1
25	Average 2258	28,365	.43	12.56	1

Below 10 *to* 1

1	2105	17,600	.50	8.36	1
4	2359	18,825	.41	7.98	1
7	2487	18,814	.43	7.57	1
3	2656	21,230	.45	8.00	1
2	2969	24,500	.47	8.25	1
17	2521	19,954	.44	7.91	1

Breaking loads, presumably alike, varied in pairs of transverse bars and also in pairs of tensile bars as follows:

Out of 65 pairs of flat or transverse bars, 14 or 22 per cent, average variation 18 per cent; 17 or 26 per cent, average variation 5.4 per cent; 34 or 52 per cent, average variation less than 2 per cent.

Out of 65 pairs of round or tensile bars 22 or 34 per cent, average variation 15 per cent; 20 or 31 per cent, average variation 5.5 per cent; 23 or 35 per cent, average variation less than 2 per cent.

61 other pairs of flat bars which had only one companion tensile bar varied in about the same ratios.

Two special flat bars and two special round bars, cast in one mould, one gate and at one pour varied as follows:

Two flat bars 12 per cent; two round bars 7 per cent.

In order to get some more definite information on these variations, if possible, I had a pair of transverse and a pair of tensile bars made and cast in the same mould and while the average was again nearly 10 to 1 as shown in Table III, the same type of bars again varied 12 and 7 per cent respectively.

TABLE IV

Comparison of Cast-iron Test Bars. Special. Two Sets Cast in Same Mould at Same Time

Number of specimens	Transverse	Tensile	Deflection	Ratio of tensile to transverse	
			Inch		
1	2350	23,000	.50	9.79	1
1	2100	21,470	.45	10.21	1
2	Average 2225	22,235	.47	10.04	1
217	All averages 2380	23,970	.45	10.07	1

I have no satisfactory explanation for the great variation of these test bars and we can only accept the fact that mathematical uniformity in strength of cast-iron bars is not found in the present state of the art.

To any one questioning the results, I can only say from my own knowledge of the circumstances, that the personal equation did not enter into them.

Careful observation of broken bars did not show that the so-called "skin of the metal" was of any appreciable thickness and the metal was remarkably homogeneous throughout.

The tensile bars being turned, the skin, if there was any, of course disappeared.

It is my opinion that the skin adds practically nothing to the strength in either transverse or tensile bars; other causes, though obscure, producing far greater deviations."

Casting Defects

Although many castings were condemned for physical defects not a single case of cold-shut was observed.

In one instance of defect, he says: "To remove all doubt that the test bars were truly representative of the iron in the main casting, two tensile bars were cut out of a large flange which had been at the bottom of the mould. These, from the most favored part of the casting, as will be seen, stood but about 17,350 pounds; 90 per cent of that revealed by the test bars. In this case there was a remarkable agreement between this pair of test bars.

It may be interesting to apply these results to the formula for the strength of cast-iron beams subjected to similar stress.

The formula commonly used is $R = \frac{3\,Pl}{2\,bd^2}$, where R is called the modulus of rupture, or stress per square inch of extreme fibre,

P = load at center,
l = length between supports in inches,
b and d = breadth and depth respectively in inches.

Make the proper substitutions and we have R = 42,840 pounds. This is not the correct figure, however, for the extreme fibre stress. We know this cannot exceed the tensile strength which we have found to be 23,732 pounds.

I think it is better to use D. K. Clarke's formula given on page 507 of his "Engine Tables." $S = \frac{WL}{1.155\,bd^2}$, where S = extreme fibre stress or tensile strength. If we use the tensile strength found in these tests as 23,732 pounds, the breaking load W would become 2284 pounds; the actual breaking load being 2383 pounds. As this is within 4.3 per cent of the average found in these tests, this formula, using the tensile strength for the extreme fibre stress, seems to me to be more intelligible and dispenses with the "coefficient of rupture."

Circular Test Bars

Since the foregoing was written I have had the opportunity to observe two circular test bars, nominally 1¼ inch diameter by 15 inches long, with 12-inch centers. These bars were cast from two separate patterns in one vertical dry sand mould, and poured from a small hand ladle, first one and then the other, with the result shown in Table V.

TABLE V. — CIRCULAR TEST BARS IN VERTICAL DRY SAND MOULDS

Bar mark	Transverse	Tensile	Deflection	Value W by formula	Original diameter
H.............	3344	23,070	.15	2948	1.305
H.............	3344	23,754	.15	3036	1.305
X.............	3026	24,670	.12	3153	1.300
I.............	2	3	4	5	6

The tensile bars were taken from the bottom ends of the broken test bars, but I do not know whether *H* or *X* was poured first.

The first tensile bar *H* had a small air-hole, which being allowed for, added 7 per cent to its tensile strength, and this is also given in the table. A second bar was then turned up from the immediate joining piece with the result recorded in the table first. The turned bars were 0.937 inch diameter.

Column six gives the original diameter. Column two was found by reducing the actual breaking loads in the ratio of the cubes of the diameters, and column three was reduced to the square inch area. Why the transverse breaking loads should vary 10 per cent and the tensile bars 4 to 7 per cent the opposite way, a total variation of 14 to 17 per cent, I leave to the reflection of the reader. If we apply Clarke's formula for the breaking weight for circular bars, $W = \frac{0.7854 \times d^3 \times S}{l}$, we find the values given in column five.

While the blow-holes seem to be more frequent in flat transverse bars than in round attached tensile bars, the latter seem liable to a greater abnormal hardness, for which I have no explanation.

Some indication of the toughness of cast iron may be seen in its deflection, which is not revealed in a direct pull. I would, therefore, be satisfied with two or three transverse test bars 2 in. by 1 in. by 24 in. centers, and a deflection record poured as near as may be from the middle of the pour of the main casting as giving a fair indication of the iron in the main casting, but mathematical exactness cannot be looked for as yet.

If we wish to know approximately the corresponding tensile strength of the iron, we can multiply the breaking load of the 2 in. by 1 in. by 24 in. flat bar by 10.

If the test bar is 1¼ inch diameter by 12-inch centers its breaking load should be multiplied by 8 to obtain the approximate tensile strength.

The general rule seems to be, that where both flat bars agree in breaking loads, the tensile strength is 10 to 1 of the breaking load, but where they differ the 10 to 1 ratio does not hold. A better practice, therefore, might be to cast three round transverse bars and accept the two that agree, if each is round, as a fair sample of the iron, dispensing with the tensile bars. This concession to the manufacturer, I believe, would entail not only no loss to the city's interests, but a positive gain.

EFFECT OF STRUCTURE OF CAST IRON UPON ITS PHYSICAL PROPERTIES

Microscopic Evidence of the Reason why Irons of Similar Chemical Composition have Different Relative Strengths

BY

F. J. Cook and G. Hailstone

"During daily foundry practice, with work made from mixtures of iron that have the same chemical composition and where tests are frequently taken, it is often found that widely different physical results are obtained. Instances of this have been brought to the notice of this association . . . but in neither case was an explanation of the phenomena given. Attempts have been made to give a satisfactory explanation of these differences, but on the whole the conclusions arrived at have not been generally accepted.

In the past the instances cited have generally been isolated ones, but a remarkable series of tests over a lengthy period has recently been met with by one of the authors.

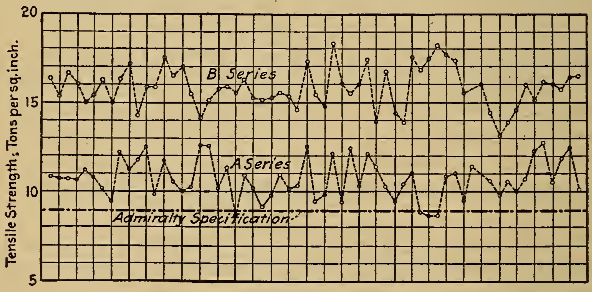


Fig. 78.

Fig. 78 is a diagram of tensile test results of two series of casts, each representing 60 consecutive days working with irons mixed to give the same chemical composition, but each series made up with different brands of pig iron.

That the chemical analysis was identical in each case was proved by analyses taken from time to time which, in each instance, for all practical purposes came out alike.

The diagram shows that the highest tensile result in the *A* series was lower than the lowest result in the *B* series. A summary of the whole of the tests is shown in Table I.

TABLE I. — RESULTS OF MECHANICAL TESTS

	Tensile test, tons per square inch		Transverse test, cwts. 1 in. sq. bar, 12 in. center		Transverse test, lbs. on ½ in. sq. bar, 12 in. centers, Keep's test		Shrinkage in inches ½ in. sq. bar, Keep's test		Hardness		Blast pressure in ounces	
Series..........	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Highest........	12.9	18.3	28.5	32.25	550	570	.182	.180	68	78	15	16
Lowest.........	8.7	13.1	19.0	25.0	390	375	.144	.140	48	56½	10	11
Average........	10.7	15.8	23.1	29.1	466	450	.140	.155	57½	64¼	12¾	13¼
No test taken..	60	60	33	30	58	59	58	58	60	56	44	39

Each tensile test bar was 1 inch square and transverse and hardness bars were cast relatively of the same size, and on the casting they were to represent; while the ½-inch transverse bars, which were also used for the shrinkage test, were cast separately by Keep's method.

The transverse bars were cast 1¼ inch square, machined down to 1 inch square and tested on 12-inch centers.

Referring to Table I, it will be seen that the results of the transverse tests on the 1 inch square bars also show a marked difference, as do the tensile tests. It will be noted, however, that the average result of the transverse test on the ½-inch square bars is slightly in favor of the series which gave the weakest tensile, and with the 1-inch square bar opposite results. This point will be referred to later.

As the method of manipulation and the chemical composition of the two series were the same, it was thought that a microscopical analysis would reveal a cause for the vast difference. For the first investigation a low bar of the *A* series, and the highest bar of the *B* series were examined. The chemical analysis of the two bars was first taken as shown in Table II.

TABLE II. — COMPARATIVE CHEMICAL ANALYSIS OF THE TWO SERIES

Series	*A*	*B*
Tensile test	9.1 tons per square inch, per cent	18.3 tons per square inch, per cent
Total carbon	3.250	3.092
Graphitic carbon	2.397	2.289
Combined carbon	.853	.903
Silicon	1.328	1.314
Sulphur	.095	.101
Phosphorus	.923	.909
Manganese	.290	.335
Iron by difference	94.114	94.149

Chemical Analyses

These analyses will be seen to be practically identical, even to the amount of the combined and graphitic carbon.

To insure the results being absolutely comparative, a number of micrographs were each taken from the same position at the center of the bars. Fig. 79 shows the polished, but unetched section of the low bar from the *A* series, Fig. 80 the high bar from the *B* series. These show the size of the graphite in each case, the one having it in the form of long flakes, the other in very small flakes.

FIG. 79.

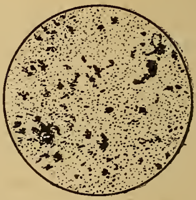


FIG. 80.

Figs. 81 and 82 show the same surfaces etched with iodine and magnified 120 diameters. In the one case the large flakes of graphite are plainly seen in a matrix of cementite, phosphorus eutectic, pearlite and ferrite; while in the other, the graphitic carbon is scarcely visible and a closer structure is observed. Otherwise, there is nothing very remarkable to account for such widely different physical results.

The same surfaces were then treated on the lines laid down by Mr. Stead at the 1909 convention, to bring into prominence the phosphorus eutectic. Fig. 83 shows the 9.1 ton bar, and Fig. 84 the 18.3 ton bar. In both cases not only is the phosphorus shown but the cementite as well.

In Fig. 83 the phosphorus and cementite are evenly distributed, and have not taken up any definite form of structure, the graphite being also shown intermixed with them, but in Fig. 84 a very remarkable arrangement of a net-like formation of phosphorus and cementite is shown. As

FIG. 81.—*A* Series; tensile strength 18,200 pounds per sq. inch; magnification 120 diameters.

FIG. 83.—*A* Series; tensile strength 18,200 pounds per sq. inch; magnification 30 diameters.

FIG. 82.—*B* Series; tensile strength 36,600 pounds per sq. inch; magnification 120 diameters.

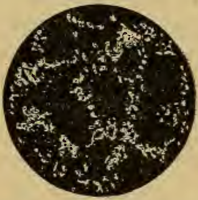


FIG. 84.—*B* Series; tensile strength 36,600 pounds per sq. inch; magnification 30 diameters.

it had been noticed with bars previously examined that those giving high test had also been associated with this particular net-like structure, we were lead to the conclusion that probably strength was associated with this structure independently of what the chemical composition might be; we, therefore, examined a series of bars made by one of the authors a few years ago to show the effect on strength of different rates of cooling. For this experiment four bars had been made in one box, cast from the same ladle of metal, which was ordinary No. 3 foundry pig iron.

Taken from "CASTINGS," Aug. 1909.

The rate of cooling was regulated by means of cast iron chills of different thicknesses placed in the moulds for three of the bars, the other having no iron chill. The bar without the chill gave a tensile test result of 8.1 tons per square inch, while the bar at the other end of the series broke at 15.2 tons per square inch. These two bars were selected, the chemical analyses of which are given in Table III.

TABLE III. — ANALYSIS OF MEDIUM BAR

Tensile strength	13.9 per cent
Total carbon	3.272
Graphitic carbon	2.740
Combined carbon	.532
Silicon	1.307
Sulphur	.111
Phosphorus	.948
Manganese	.330
Iron by difference	94.032

Chilled and Unchilled Bars

These results are identical, and as there is practically no combined carbon present, there must be an absence of cementite. The bars are also totally different in chemical composition from those previously examined.

Figs. 85 and 86 show unetched sections from the two bars, with the difference in the formation of the graphite as previously pointed out in

FIG. 85.

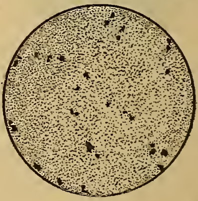


FIG. 86.

connection with the other bars; that is, elongated flakes of graphite in the unchilled bar, and finely divided graphite in that of the chilled one.

Figs. 87 and 88 show the formation of the phosphorus eutectic in the case of the weak bar to be broken up and having no distinct pattern, while in the case of the strong bar there is clearly shown that net-like formation which was the distinguishing feature of the strong bar from the *B* series, but with this difference, that the structure was rather smaller.

As there is no cementite present in this specimen, it is proof that the particular formation is not dependent upon cementite.

Fig. 87.

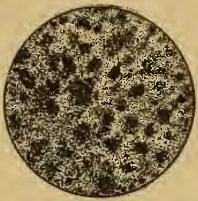


Fig. 88.

There was next examined another bar from *B* series. This had a tensile strength about half way between the two bars previously selected, and had given a tensile test result of 13.9 tons per square inch. The analysis of this bar is shown in Table III. This showed that while the total carbon and other elements were practically the same as the two bars previously taken, the graphitic carbon was higher by 0.35 per cent, and the combined carbon lower by 0.35 per cent. This was probably due to the fact that this bar had been cast on a much larger casting than the previous two.

The size of the graphite in this bar is illustrated by an unetched section in Fig. 89 which shows that although it is smaller than that shown in Fig. 79 of the 9.1 ton bar, it is larger and more elongated than that contained in the 18.3 bar, Fig. 80.

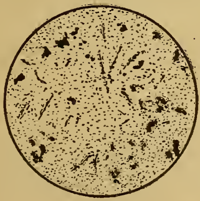


Fig. 89.

Fig. 90.

The phosphorus eutectic which is shown in Fig. 90 is the same net-like formation as associated with the previous strong bars, though rather less clearly defined and appears to be getting into the transition stage between the two.

The foregoing results, we think, have been sufficient to show that in each case, physical properties have been associated with this net-like formation of the phosphorus, also that the graphite, when in the elongated form, appears to split up phosphorus eutectic and prevent this formation, as clearly shown in Fig. 83. The question of the tendency of the graphite to take either an elongated or finely divided form, we think, is more a question of the way in which the pig iron has been made than of its subsequent treatment in the foundry. The statement of Mr. Pilkington in this respect is very interesting: "Furnace men have always been conversant with the fact that the temperature at which pig iron leaves the tapping hole of the furnace has a powerful effect on its physical characteristics. The temperature of a large modern blast furnace is very much higher and the metal, therefore, takes very much longer to cool than that which leaves the tapping hole of the smaller furnaces.

Pig iron from the extreme types could be made practically in a different manner altogether, and would show very different grades, grains and degrees of hardness.

On referring again to the summary of tests taken with the *A* and *B* series it will be seen that the results of the ½-inch transverse bars of the *A* series, which gave weak tensile results, are slightly higher than those of the *B* series, and from this, together with the evidence of the chilled and unchilled bars made from low grade iron, we are of the opinion that no matter what their chemical compositions may be, there is a rate of cooling which will give high physical properties; the structure of the iron then being associated with the net-like formation of the phosphorus eutectic and the cementite when present.

Tests reported to the International Association for Testing Materials show:

Circular bars showed greater bending and tensile strength than those of rectangular section.

Test pieces taken from castings showed lower strength figures than bars separately cast.

Extracts from Prof. Porter's Report

Prof. Porter's report contains so much information of value to the foundryman, that extensive extracts are made from those parts relating to the properties and mixtures of cast iron, notwithstanding they may comprise much which has already been considered.

In treating of the different forms of iron as occurring at different temperatures, they are designated as the "alpha," "beta" and "gamma."

The "alpha" form in the ordinary iron as known in unhardened steel at ordinary temperatures, is one of the constituents of slowly cooled gray pig iron, and is formed below 1140° F.

The "beta" form is that between 1440° F. and 1680° F.; it is harder than the "gamma." Prof. Howe suggests its identity with martensite, the chief constituent of hardened tool steels. It is non-magnetic and differs from "alpha" iron in specific heat and density.

The "gamma" form is the stable one above 1680° F., is very hard, non-magnetic, and differs in specific heat and density from both the "alpha" and "beta."

It is held that the "gamma" and "beta" forms may be preserved at ordinary temperatures by very rapid cooling, especially in the presence of carbon which is supposed to retard the change from one form into another.

TABLE I. — FORMS OF COMBINATION OF IRON AND CARBON

Name	Synonyms	Physical characteristics
Graphite	Free carbon	Very soft dark flakes of variable size. No strength.
Kish	Free carbon	Graphite in very large flakes.
Temper carbon	Free carbon	Graphite in form of very fine powder.
Ferrite	Iron	Soft, very ductile, low strength.
Cementite	Combined carbon. Iron carbide, FeC.	Very hard and brittle, high static strength, no ductility.
Austenite	Solution carbon in "gamma" iron.	Slightly softer than martensite. Also weaker and more brittle.
Martensite	Solution carbon in "beta" iron. Transition product austenite to pearlite.	Hard, but less brittle than cementite. Chief constituent of hardened tool steels.
Troostite	Transition product martensite to sorbite.	Softer than martensite, less brittle and more ductile.
Sorbite	Transition product. Troostite to pearlite.	Softer than troostite and more ductile. Strongest form.
Pearlite	An intimate mechanical mixture of cementite and ferrite.	Very strong. Harder than ferrite.

Prof. Porter classifies the more important physical properties of cast iron as follows:

Static strength, including: Tensile strength; compressive strength; transverse strength; torsional strength; shearing strength.

Dynamic strength, embracing: Resistance to repeated stress; resistance to alternating stresses; resistance to shock.

Elastic properties, embracing: Elastic limit; resilience or elasticity; rigidity; toughness; malleability.

Hardness, embracing: Hardness of mass; ability to chill; hardness of chill.

Grain structure, including: Fracture or grain size; porosity; specific gravity.

Shrinkage, embracing: Shrinkage of the liquid mass; shrinkage of the solid mass; stretch.

Fluid properties, embracing: Fusibility; fluidity.

Resistance to heat, embracing: Resistance to continued heat; resistance to alternate heating and cooling; resistance to very low temperatures.

Electrical properties, including: Electrical conductivity; magnetic permeability; hysteresis.

Miscellaneous properties, including: Resistance to various corrosive agencies; resistance to wear; coefficient of friction.

Properties of the mass: Soundness, or freedom from blow-holes and shrinkage cavities; cleanness, or freedom from inclusions of dross, etc.; freedom from pin-holes and porous places; homogeneity, or lack of segregation; crystallization; freedom from shrinkage strains; tendency to peel off sand and scale.

CHAPTER XIII

CHEMICAL ANALYSES

Strength

As regards chemical composition there are nine factors which influence strength of cast iron: (1) Per cent graphite; (2) size of individual graphite flakes; (3) per cent combined carbon; (4) size of primary crystals of solid solution Fe-C-Si; (5) amount of dissolved oxide; (6) per cent phosphorus; (7) per cent sulphur; (8) per cent silicon; (9) per cent manganese.

1. "*Per cent graphite.* — The weakening effect of graphite is due to its own extreme softness and weakness, and to the fact that it occurs in small flakes or plates and hence affords a multitude of cleavage planes through the metal. The size of the graphite particles is evidently important as well as the amount but this factor will be discussed under another head.

Theoretically, the simplest method of decreasing graphite is to lower the silicon, each decrease on 1 per cent in silicon lessening the graphite by 0.45 per cent, provided the total carbon remains the same. Practically, however, the fact that all the carbon not graphite becomes combined is an important objection, for when we lower the silicon too much the resulting increase in combined carbon increases the hardness and, beyond a certain point, decreases the strength. The minimum permissible silicon will depend chiefly on the hardness allowable,

The same objection applies to decreasing the graphite by increasing the sulphur and manganese, and in the case of sulphur there is also the objection that its direct effects are injurious. The rate of cooling is, of course, beyond the control of the foundryman in the majority of cases, while even if it were not, the graphite could not be reduced by rapid cooling without a corresponding increase in combined carbon.

Coming finally to the total carbon, we find here a means of reducing graphite without in any way affecting carbon, and hence, hardness. The only limitation to this is that as total carbon and graphite are reduced, shrinkage is increased and the metal becomes more liable to oxidation, blow-holes and other defects.

There are three ways of reducing total carbon in castings; first, by the use of low carbon pig iron; second, by melting in the air furnace; third, by the use of steel scrap in the cupola mixture.

In air furnace melting it is easy to reduce total carbon to almost any figure within reason. 2.75 per cent is commonly obtained in melting for malleable castings. Of course the silicon is also burnt out during this process, but were it desired, this could be readily replaced by suitable additions of ferrosilicon. From the standpoint of quality the air furnace is certainly the ideal method of melting, and hence, we find that many lines of castings which must be of particularly high quality are invariably made from air furnace metal.

The addition of steel scrap to the cupola has now become common practice, the product obtained being known as semi-steel and differing chemically from ordinary cast iron only in being somewhat lower in total carbon and graphite. Physically the metal so made is characterized by greater strength and total shrinkage, hardness remaining about the same. . . ."

The chief points to be watched in melting steel scrap in the cupola mixture are as follows:

"*Trouble with blow-holes.* — This is due to the fact that semi-steel being lower in carbon oxidizes more readily than cast iron. The trouble may usually be overcome by correct cupola practice and the use of ferromanganese or other deoxidizers in the ladle. Owing to the higher melting point of semi-steel mixtures, ferromanganese is much more efficient as a deoxidizer here than in the case of cast iron. . . .

High shrinkage. — This is due to the decrease in graphite and is hence inevitable. On work where this is an important factor a proper balance must be struck between shrinkage and strength. . . .

Imperfect mixture of steel and iron resulting in irregular quality of casting, hard spots, etc. — This results from the higher melting point of steel and consequent difficulty of getting perfect solution in the cast iron. It may be largely overcome by careful attention to the charging of the cupola, placing the *steel scrap on the coke* and the iron on top of the steel (so that the steel will reach the melting zone first and the molten pig will run down over the heated steel instead of away from it as would happen if the order were reversed). A large receiving ladle should, of course, be used also. Another point to be observed is in regard to the size of the steel scrap. Too large scrap is difficult to melt, but, on the other hand, very small scrap is also objectionable as being an abundant source of hard spots in the castings. Apparently very small pieces of steel are liable to be washed down through the coke bed and out of the cupola spout without being completely melted.

Regarding the amount of steel scrap to use, it has been found by trial that the best results are obtainable with about 25 per cent. Increase to 33⅓ per cent caused a slight falling off in strength. Probably these figures would not hold for every condition of practice, but, in general, 20 to 30 per cent steel is a sufficient amount to give the maximum results.

2. *Size of graphite flakes.* — The size of the graphite flakes is probably the most important factor of all those which influence strength, and is the one which most frequently upsets our calculations as to the relation between chemical composition and strength. . . . Recently, however, Messrs. F. J. Cook and G. Hailstone have brought out in a striking manner the great difference in irons in this respect. They give data showing that of two mixtures practically identical in composition the one was invariably much lower in strength (usually about one-half) than the other, this being the case for a great many heats extending over a long period of time."

Analyses and tests are given as typical of the series.

"Messrs. Cook and Hailstone have investigated and compared the micro-structure of the strong and weak bars and record two interesting facts: First, that the graphite flakes are invariably much larger in the weak bars; second, that when the polished specimens are treated so as to bring out the phosphide eutectic this eutectic is seen to be arranged in the customary heterogeneous manner in the weak bars but in a distinct meshwork structure in the strong iron.

These authors draw the conclusion that it is this meshwork structure which gives great strength to cast iron, but with this conclusion the writer cannot entirely agree. It seems more probable that the increase in strength is caused by the fine state of division of the graphite and that the same influences which have caused this have also caused the meshwork structure.

We may get some idea of the quantitative relationship between strength and size of graphite by considering the relative strength of malleable cast iron and a very open gray cast iron representing the smallest and largest graphite respectively. Malleable cast iron has a tensile strength of 40,000 pounds and upwards per square inch; open gray iron about 20,000 pounds per square inch. Apparently, then, the increase in the size of the graphite has caused a loss of at least 20,000 pounds in tensile strength.

It is one thing to find that to get strong iron we must have the graphite in finely divided state and another and much more difficult matter to formulate rules whereby we may secure this desired condition. . . ."

The factors which influence the size of the graphite flakes in cast iron are as follows:

A. Factors which certainly exert an influence.
- *a*. Rate of cooling.
- *b*. Pouring temperature.

B. Factors which may possibly exert an influence.
- *c*. Time which iron has remained in the molten state.
- *d*. Presence of dissolved oxide.
- *e*. Presence of steel scrap in the mixture.
- *f*. Mixture of different brands.
- *g*. Nature of ore from which iron is made and treatment in the blast furnace.
- *h*. Per cent metalloids.

a. The influence of rate of cooling is undoubted, and an example showing its effect on strength and structure is given by Cook and Hailstone. We have to distinguish here, however, between the rates of cooling through different ranges of temperature. Evidently the graphite which is separated within the semi-liquid iron will have a much better chance to grow large crystals owing to the greater mobility of the medium in which it is formed, while that graphite formed within the solid metal will necessarily be in small particles. Hence, we see that it is the rate of cooling through the solidification range 2200° to 2000° F., which is of prime importance, and if we can check the formation of graphite through this range and then allow it to form in the solid metal at lower temperatures we will have all the conditions for both the soft and strong iron. This is the principle of Custer's process of casting in permanent moulds and the making of malleable castings is based on the same theory."

b. The pouring temperature also undoubtedly exerts an influence on the size of the graphite flakes, and hence, on the strength. . . ."

Longmuir finds that iron poured at a medium temperature is stronger than when poured either very hot or very cold. Longmuir's experiments, by the way, are the only ones in which a pyrometer was used and the temperatures of pouring measured in degrees. . . . For this reason we may place the greatest faith in Longmuir's results.

It is probable that the pouring temperature affects the size of the graphite flakes indirectly through changing the rate of cooling through the solidification range. On this assumption the best results should be obtained from metal poured at as low a temperature as will suffice to give sound castings.

c. *Time which iron has remained in the molten state*. This might conceivably have an effect in the case of cast iron high in total carbon, since graphite separating in the liquid metal would remain in the metal if poured at once, and this graphite is in the form of large flakes known as kish.

d. Presence of dissolved oxide. — There is no direct proof that this affects the size of the graphite flakes. However, it is well known that addition of deoxidizing agents almost invariably improves the strength and it is barely possible that a portion of this may be due to change in the size of the graphite.

e. Presence of steel scrap in the mixture. — Although no exact data are at hand it is the common impression that the addition of steel scrap 'closes the grain,' which is equivalent to saying that it reduces the size of the graphite. . . .

f. Mixture of irons. — It is firmly believed by many foundrymen of the old school that a mixture of brands gives better results than a single brand of the same chemical composition as the average of the mixture. . . .

g. Cook and Hailstone believe that the difference in strength of the two mixtures quoted by them is due to some inherent quality of the pig iron derived from the ores used or their manner of treatment in the blast furnace. This inherent quality may have some connection with the presence of oxygen or nitrogen in the metal. . . ."

h. Per cent metalloids. — This, we know, has a certain effect. For example, high silicon is likely to cause larger graphite as well as more of it. Phosphorus should, theoretically, cause larger graphite since it prolongs the solidification period in which large flakes are free to separate. . . . Sulphur and manganese . . . close the grain, and probably diminish the size of the graphite, as well as its amount.

3. *Per cent combined carbon.* — According to Professor Howe the properties of cast iron are the properties of the metallic matrix modified by the presence of the graphite, but since this metallic matrix may be considered as a steel of carbon content equal to the combined carbon of the cast iron, we can predict accurately the effects of combined carbon by the use of the data on steel.

In the case of steel it is found that the strength increases regularly with the carbon up to about 0.9 per cent, then remains nearly stationary up to about 1.2 per cent, above which it falls off slowly.

In the case of cast iron the strength is dependent upon so many factors besides combined carbon that it is almost impossible to determine by direct experiment the percentage of combined carbon giving the maximum strength. All indications, however, are that the highest strength is obtained with somewhere between 0.7 per cent and 1 per cent combined carbon which is in sufficiently close accord with the corresponding value for steel. We may, therefore, state tentatively that the maximum strength is obtained with 0.9 per cent carbon, all other factors remaining constant.

This applies only to tensile strength (and approximately to transverse). For compressive strength a somewhat higher value, probably about 1.5 per cent combined carbon, would be found to give better results.

4. *Size of primary crystals of solid solution Fe-C-Si.* — There is absolutely no data as to the effect of this factor on the strength of cast iron and it is only from analogy with steel that we give it a place in the list of actors influencing strength. . . ."

5. *Effect of dissolved oxide.* — . . . It is probably a much more important factor than is generally supposed, but there is absolutely no data on which to base a quantitative estimate of its effect."

To reduce oxide in cast iron to the minimum, the following points may be observed:

First, get the best brands of pig iron. It is probable that pig made with charcoal fuel contains less oxygen than that made with coke fuel. Cold blast pig is better than hot blast. Pig iron made from easily reducible brown or carbonate ores is lower in oxygen than the pig made from red hematite or magnetic ores, *while iron made from mill cinder should never be used in foundries where strength is a prime consideration.* Moreover, a pig iron high in manganese is apt to be comparatively free from oxide because of the deoxidizing power of manganese at the high temperature of the blast furnace. It is noteworthy as confirming these observations that most brands of iron which have achieved a reputation for strength are high in manganese and many of them are charcoal irons. The Muirkirk and Salisbury brands which have been known for years as among the strongest irons made in this country answer to every one of these conditions. They are made from readily reducible ores using cold blast and charcoal fuel and contain from 1 to 2 per cent manganese."

Second, avoid oxidizing conditions in the cupola, particularly high-blast pressures and wrong methods of charging. Dr. Moldenke's system of using small charges is to be highly recommended in this connection."

Third, deoxidizing agents may be used, added either to the cupola or to the metal in the ladle. Of the commercially available deoxidizers, ferrotitanium, ferrosilicon and ferromanganese are, perhaps, the most successful, all things considered. Titanium thermite is also extremely valuable in this connection. . . ."

6. *Per cent phosphorus.* — Phosphorus lessens both the dynamic and static strength, but the former more than the latter. It weakens be-

cause it forms with iron a hard and brittle compound which has but little resistance to shock. The weakness produced is in nearly direct proportion to the amount of this compound present. The effects of phosphorus on strength do not become marked until upward of 1 per cent is present, but for great strength and particularly strength to shock it should be much lower. Ordinary strong irons may have up to 0.75 per cent, while iron which is to withstand shock should not exceed 0.50 per cent and is better even lower. . . ."

7. *Per cent sulphur.* — The action of sulphur in decreasing the strength of iron is explained in Chap. IX, page 261, and it is also explained there why it is so much less harmful in the presence of manganese. Many tests have been made showing that sulphur has no marked effect on strength and many foundrymen will use sulphur to harden iron and close the grain. It is true that an indirect strengthening effect can be obtained through the use of sulphur in some cases, *i.e.*, if too soft an iron is being used the strength will be increased by the addition of any element which will lessen the graphite, but the hardening is usually better obtained through decrease in silicon than through increase in sulphur. While increased sulphur may not always show in decreased strength of test bars, yet it is a frequent source of blow-holes, dirty iron and various defects caused by high shrinkage, hence, it often causes an indirect weakness in the iron.

8–9. *Per cent silicon and manganese.* — These elements act chiefly in an indirect manner and because of their effects on the condition of the carbon; their direct influence in the strength of the metallic matrix is unimportant. From analogy with steel it is probable that silicon in amounts of over 1 per cent causes weakness and brittleness in the metal. Similarly, manganese has probably a weakening effect due to its direct action when present in amounts of more than 1.5 per cent.

The preceding discussion is summarized in the following practical rules for making strong castings:

Use strong brands of iron. . . . Charcoal irons if cost will permit; irons made from easily reducible ores; irons high in manganese.

Avoid oxidation in melting. Look carefully after the details of cupola practice; avoid oxidized scrap; use deoxidizing agents in ladle if practicable. . . .

Keep the silicon down as low as possible and still have the necessary softness. About 1.50 per cent will be right for the ordinary run of medium castings; higher for small castings and lower for heavy ones. With low total carbon high silicon has less effect.

Keep the phosphorus low, especially when sulphur is high. 0.50 per cent or under is best.

Keep the sulphur low, especially if phosphorus is high. Under 0.10 per cent is all right for most castings."

Keep manganese high. 1 per cent for large castings, 0.7 per cent for medium, 0.5 per cent for small castings.

Use from 10 to 25 per cent steel scrap in the mixture.

Mr. Keep recommends using 10 per cent cast iron borings charged in wooden boxes. He states that this is very effective in closing the grain and strengthening the castings.

. . . .

For iron which is required to have the greatest possible resistance to shock, the points to be especially observed are as follows:

Keep the phosphorus as low as practicable, still having the necessary fluidity. It should best be below 0.30 per cent.

Keep the sulphur as low as possible.

If practicable add vanadium or titanium to the ladle either in the form of ferroalloy or as thermite. . . .

Elastic Properties

Of the elastic properties of metals, only toughness and its opposite, brittleness, and elasticity and its opposite, rigidity, are ordinarily considered in cast iron.

Toughness is defined as resistance to breaking after the elastic limit is passed.

Elasticity is the amount of yield under any stress up to the elastic limit.

It is unusual for these properties to be determined separately in cast iron, but their sum is given by the deflection which is determined in transverse testing. It is probably true that they nearly always vary together, and, hence, that deflection is a fairly good measure of either one as well as both.

Toughness is practically always a desirable quality in cast iron, but the same is not true of elasticity since in many machines great rigidity is a prime requisite.

The factors influencing toughness and elasticity are about the same as those influencing strength, *i.e.*, the chemical composition, presence of oxide and size of graphite. . . . In general, to get a tough elastic iron we should keep sulphur, phosphorus and combined carbon low; manganese, no higher than is necessary to take care of the sulphur; graphite and silicon, the less the better, *providing* that the combined carbon is not increased; and finally, use metal of good quality, melted carefully so as to be free from oxide.

In ordinary gray iron castings it is not practicable to attempt to control the graphite, since the combined carbon needs first attention and the graphite will necessarily be the difference between total carbon and combined carbon. The silicon also must be adjusted with a view to regulating the combined carbon. Practical rules for getting the maximum toughness and elasticity will then be about as follows:

Silicon, 1.5 to 2.0 per cent for castings of average thickness, more or less for very light and very heavy castings respectively.

Sulphur as low as practicable, best under 0.08 per cent.

Phosphorus as low as practicable considering the necessity for fluidity. Best under 0.50 per cent.

Manganese from three to five times the sulphur.

Use good irons and good cupola practice to insure freedom from dissolved oxide. . . .

"In case steel scrap can be used, *i.e.*, semi-steel made, the toughness may be considerably increased through decrease in the amount of graphite and in the size of the grain. The other elements may remain about as before except that it may be necessary to run the manganese a little higher to counteract the greater tendency of the semi-steel to become oxidized.

As previously noted, rigidity is desirable in some cases. This is the converse of elasticity and may be obtained by the direct opposite of the rules given for obtaining elasticity. However, to get rigidity with the least sacrifice of strength and toughness it is desirable to use manganese and combined carbon rather than to increase phosphorus and sulphur. That is, we would lower silicon as much as necessity for softness will allow and raise manganese to about 1 per cent (or less in very light work). It should be noted that manganese is particularly efficient in increasing rigidity since it accomplishes this end with comparatively little sacrifice of strength and toughness.

A few examples of very tough and elastic iron are as follows:

No.	Silicon	Sulphur	Phosphorus	Manganese	Combined carbon	Graphite carbon	Total carbon
1	2.50–2.75	.050	.30	....	....	....	....
2	.80	....	....	....	.87	2.34	3.21
3	2.45	.092	.063	.43	....	....	....
4	1.18	.084	.27	.30	....	....	....
5	2.36	.064	.33	.24	1.08	2.15	3.23

No. 1 represents iron which in thin sections can be punched and bent. No. 2 is an analysis of a gray cast iron which is exceedingly malleable. Nos. 3, 4 and 5 are gray irons showing deflections for the transverse test bars rather higher than usual.

Hardness

. . . It is generally stated that hardness in cast iron is due chiefly to the presence of combined carbon and is only indirectly or to a less extent caused by other elements. The writer believes that this is not altogether true and that there is another factor causing hardness which has not heretofore been generally considered in the case of cast iron."

It is well known that when steel is hardened by quenching from a temperature above its critical point its carbon is not in the combined state but rather in a form known as hardening or solution carbon, while the iron is retained in the 'gamma' allotropic form. It is the belief of the present writer that the same is true of cast iron and that many cases of hardness are to be explained in this way. For example, Keep describes a sample of cast iron which was too hard to drill and yet contained only 0.60 per cent combined carbon, and many analyses are on record of irons which have been quenched from comparatively low temperatures and are almost glass hard in spite of the fact that the combined carbons are under 1 per cent. I think it probable that the hardness of high manganese irons is due chiefly to this same cause since manganese is known to favor the retention of 'gamma' iron.

Granting for the present the truth of this theory, the presence of the 'gamma' or hard form of iron is controlled by the rate of cooling and the percentages of metalloids present; so that for all practical purposes we can say that there are six factors which influence hardness, *i.e.*, the rate and manner of cooling, the combined carbon, silicon, sulphur, manganese and phosphorus. The first two of these are of the greatest importance and we will then take up in reverse order, leaving the most important till the last.

Phosphorus has a slight hardening effect in large quantities but in amounts less than 1 per cent its effects are nearly imperceptible, and it does not become important until the amount exceeds commercial limits, or, say, 1.5 per cent. We may, therefore, usually neglect the effects of phosphorus in considering hardness.

Manganese, although usually regarded as a hardening agent may sometimes soften iron. This anomalous result is explained by the action of manganese on sulphur. If the iron is high in sulphur and low in manganese the first additions of manganese will unite with the sulphur forming the comparatively inert manganese sulphide and thus softening the iron. If, however, the manganese be increased beyond the amount necessary to care for the sulphur, increased hardness will result.

. . . A pig iron containing 3 per cent manganese may have a beautiful open gray fracture and yet be so hard as to be drilled only with great difficulty. In addition, the presence of manganese sometimes produces a peculiar kind of gritty hardness, the iron acting as if containing small hard grains. With regard to the amount of manganese required to produce hardness it will be evident that this depends largely on the per cent of sulphur present and also on the rate of cooling. In general, heavy castings will stand up to 1 per cent of manganese without noticeable increase of hardness, medium castings about 0.75 per cent and light castings 0.50 per cent.

Sulphur is an exceedingly energetic hardening agent acting, however, chiefly through the carbon. That is, sulphur has a strong tendency to keep the carbon in combined form and in that way to harden. . . . . Each 0.01 per cent sulphur will increase the combined carbon by about 0.045 per cent, other things being equal. It must be remembered, however, that this applies only to sulphur in the form of iron sulphide, and that in the form of manganese sulphide, *i.e.*, in the presence of about three times its weight of manganese, it acts much less energetically.

Sulphur also has a direct action in hardening, iron sulphide and manganese sulphide being quite hard substances. Usually this action is imperceptible, but occasionally one meets with hard spots which are due to the segregation of these sulphides.

Silicon is generally known as a softening agent and, within reasonable limits, has this effect due to its action in decreasing the combined carbon. The direct effect of silicon, however, is to harden since it forms with iron a compound which is harder than the iron itself.

When silicon is added to cast iron its first effect, as before stated, is to decrease the combined carbon. This, it does, at the rate of about 0.45 per cent for each per cent of silicon added. Actually the rate of decrease is more rapid than this, and, in consequence, by the time we have from 2 to 3 per cent silicon present (depending on the rate of cooling) we have practically all the combined carbon precipitated out as graphite and, hence, there is no further possibility of softening in this way. Now, any increase in silicon only increases the amount of the hard iron-silicon alloy, there is no more combined carbon to be decreased, and, hence, the hardness will now be increased again. In other words, it is possible to have too much of a good thing, the good thing in this case being silicon.

The actual percentage of silicon which is necessary to secure any given degree of softness will depend upon the size of the casting, the nature of the mold and the amount of sulphur and manganese present. It is, therefore, impossible to give definite silicon standards unless each of these factors is known. . . .

Combined carbon (or solution carbon) is the chief hardening agent of cast iron, and, under ordinary conditions, the hardness of the metal will be closely proportional to the percentage present. Of such relative unimportance are the effects of the other elements that it has been found practicable to use the amount of combined carbon as a measure of the hardness of castings and as a means of predicting their behavior in the machine shop. . . .

"To machine easily, cast iron should not contain over 0.75 per cent combined carbon. 1.00 per cent combined carbon gives a pretty hard casting and 1.50 per cent is about the upper limit for iron to be machined. The rate and manner of cooling of the casting are usually supposed to influence its hardness only as it affects the percentage of combined carbon. That it does affect the amount of combined carbon is a well-established fact. . . . However, we sometimes get hardness in the absence of any considerable amount of combined carbon. Hence, there must be some other factor at work, which, in the writer's opinion, is a solution of carbon in 'gamma' iron, the hard constituent of tool steel. According to this theory, combined carbon disappears in the temperature range 2200° F. to 1500° F., while 'gamma' or hard iron is not transformed into the 'alpha' or soft variety until the casting has cooled to about 1300° F. Evidently, then, ordinary rapid cooling of castings from the melted state results in both high combined carbon and high 'gamma' iron, and hence we have hardness due to both of these causes. The more rapid the cooling, the higher the combined carbon and the higher also the 'gamma' iron, therefore, since both vary together, the percentage of combined carbon is a satisfactory measure of the hardness produced by both factors.

"If, now, the conditions of cooling are changed, this need no longer be the case. For example, suppose we cool the casting slowly from the molten state down to 1600° and then quench it in water. In this case we would get nearly all combined carbon changed to graphite during the slow cooling through the upper range, while the rapid cooling through 1300° preserves the 'gamma' iron solution and hence gives hardness due to this cause. Some of the peculiar things noted in connection with Custer's process of casting in permanent moulds are to be explained on this basis. Also, the much greater softness of castings which have been allowed to cool in sand and thereby anneal themselves over those shaken out soon after being poured.

"Chilled iron is simply white iron, that is, iron in which graphite is absent and the carbon all in the combined or solution state. The same iron may be both gray and white, depending on rate of cooling and hence the exterior of the casting, if rapidly cooled, may be white while the interior which cools more slowly remains gray. Usually there is an intermediate zone having a mottled structure formed through the interlacing and the gradual merging of the gray and white. A chilling iron, then, is one which when rapidly cooled contains all of its carbon in the combined state. The factors which influence the depth and quality of chill are the temperature at which the iron is poured, and the amounts of silicon, sulphur and phosphorus, manganese and total carbon, besides some of the elements which are not normally present in cast iron, but which are occasionally added.

The higher the temperature at which iron is poured the deeper the chill, other things being equal, and it is usually considered advisable to pour chilled castings from hot iron. The quantitative effects of pouring temperature have been studied by Adamson, and while there are some conflicting results, it is in general indicated that in the case of the strongly chilling irons an increase of 50° in the pouring temperature causes an increase of from ⅛ to ¼ inch in the depth of the chill.

The most important element in its effects on chill is silicon, which has the strongest action in precipitating graphite. For chilling iron, silicon should be low, but how low depends on the thickness of the casting, the temperature of pouring and the depth of chill desired as well as on the percentage of other elements in the iron. Table I gives a very approximate relationship between the percentage of silicon and depth of chill, other elements being about normal.

Table I. — Approximate Relation Between Per Cent Silicon and Depth of Chill

Silicon, per cent	Depth of chill, inch	Silicon, per cent	Depth of chill, inch
1.50	1/16	.75	⅜
1.25	⅛	.50	¾
1.00	3/16	.40	1

Sulphur tends to increase the combined carbon, and, hence, the chill. So marked is its influence in this respect that it is sometimes added to cast iron to increase the depth of the chill. This, however, is not usually good practice since the chill imparted by sulphur is lacking in toughness and strength as well as in resistance to heat strains. Scott cites the case of stamp shoes for mining machinery where sulphur was used to increase the chill. The shoes were very hard at first, but soon went to pieces under the repeated blows. Johnson, also, has noted the great difference between high and low sulphur chilled iron as regards ability to withstand the strains of sudden cooling without cracking. On the other hand, West states that the chill produced by sulphur is very persistent to frictional wear, and, hence, it may be inferred that sulphur adds to the life of castings which are subject to abrasion. It has been stated that the presence of a small amount of sulphur is essential in order to get the best results in chilled rolls. This, however, is doubtful and it is believed that it is only rarely that sulphur is desirable in chilled castings. The presence of a moderate amount of manganese in cast iron greatly lessens the bad effects of sulphur in chilled as well as in gray iron castings.

"Phosphorus in the amounts ordinarily present in commercial cast iron has but slight influence on the depth of the chill but does have a more or less injurious effect on its strength. It is generally stated that high phosphorus has the effect of causing a sharp line of demarkation between the gray and chilled portions of the casting. . . . It is believed that it is best to limit the phosphorus in chilled iron to about 0.4 per cent.

Manganese, since it tends to increase the combined carbon, also tends to increase the chill. However, it must be remembered that the first effect of manganese is to neutralize sulphur, and, therefore, in small amounts it may indirectly decrease the chill. Manganese very greatly increases the hardness of the chill, and, to a less extent, its strength. It also increases the resistance of the chill to heat strain and hence diminishes the danger of surface cracks in such castings as chilled rolls and car wheels. Still another effect is the promotion of a more gradual merging of the gray and chilled portions of the castings. Manganese is usually considered a desirable constituent of chilled iron and the amounts used vary all the way from 0.40 up to 3.0 per cent. . . .

Of late years, semi-steel mixtures have been used to some extent for chilled castings, the total carbon being considerably lower than in the ordinary mixture. The effect of low total carbon is to give a deep and comparatively soft chill as compared with the shallow, hard chill obtained with high total carbon.

"It has been proposed to use nickel as a means of controlling chill, this element having an effect somewhat similar to silicon. Hence, by starting with a strong chilling iron and adding nickel, the depth of the chill would be lessened in some ratio to the amount of nickel added. Since the same results may be obtained by the use of less expensive silicon it is difficult to see any advantage in adding nickel.

The quality of chilled iron may be very greatly improved by the addition of small amounts of titanium or vanadium. The beneficial effects of these elements are probably due chiefly to their deoxidizing power. . . .

Grain Structure

"The fracture or grain size and the porosity are closely related and are both dependent primarily on the size of the graphite particles, and, to a less extent, on the percentage of graphite. . . .

Silicon should be kept just as low as possible and still have the castings soft enough to machine. The exact percentage will depend on the thickness of the casting, the character of the mould and whether the casting is allowed to anneal itself or is quickly shaken out after pouring. It may range from 0.75 per cent for very heavy work up to 2.0 per cent for small valves, etc. It is believed that the majority of founders use more silicon than is best in work of this character."

Combined carbon has a powerful action in closing the grain and giving a dense iron and should be just as high as possible and still have the iron machinable. . . .

Manganese had best be kept moderately high since it appears to have some beneficial effect in closing the grain.

Sulphur is a powerful agent in closing the grain and is frequently made purposely high for this end. It is, however, a dangerous agent since it may cause trouble in other directions, and as a general proposition it is better to keep the sulphur low and get necessary density by a proper regulation of silicon and manganese.

Finally, one of the best, if not the best, means of closing the grain of cast iron and securing the maximum density is by means of steel scrap in the mixture. This is now common practice with makers of hydraulic castings, and is very effective. . . .

Shrinkage

In considering the shrinkage of cast iron it is necessary to distinguish between the contraction of the fluid mass previous to and during the act of solidifying and the contraction of the solid mass. The first is that form of shrinkage which necessitates feeding in heavy castings, and which so often results in shrink holes or spongy places in heavy sections of castings which are not fed. West calls this contraction of the fluid mass 'shrinkage.'

"The contraction of the solid mass represents more nearly what is generally called shrinkage, this term as ordinarily used meaning the difference in size between the casting and its pattern. This contraction of the solid mass West calls 'contraction.'

" . . . It seems necessary to make some distinction between the total amount of fluid contraction and the tendency to form shrink holes in the heavy sections of small castings. At least there seems to be no very definite relation between chemical composition and this latter property and it is often the case that an iron low in graphite and, therefore, having a high fluid contraction, will give sounder castings than another iron high in graphite and which would, therefore, require less feeding in a large casting. . . ."

"Cook has found that two irons of practically identical chemical composition may give very different results as regards soundness when poured into small castings of heavy section and the writer can confirm this fact from his own experience. A convenient test has been developed by Cook to show the tendency of any particular brand of iron to trouble of this sort. This test consists in making a casting in the shape of a K, the branches having a cross section of one inch square. On breaking off the oblique branches any tendency to sponginess or shrink holes will at once be evident in the fracture."

"As before stated there has thus far been discovered no important relationship between this property and chemical composition. It rather appears to be something inherent in the brand of iron. . . . It is a curious fact that, in some instances at least, the addition of a small amount of steel scrap to the mixture will act as a partial corrective."

"The contraction of the solid mass does not take place uniformly as the casting cools but in stages which are separated by periods of less contraction or even of actual expansion. The total shrinkage which perhaps includes also a portion of the shrinkage in the fluid mass is conveniently obtained by Keep's test or by casting a test bar between iron yokes and determining the space between the end of the bar and the yoke after cooling."

"This, however, tells nothing as to the manner of shrinkage or the temperature at which it takes place. To get this latter information we must determine the shrinkage curve, or in other words, the length of the test bar at each instant of time during cooling, starting from the instant when the bar has solidified just enough to have some slight strength. West, Keep and Turner have described forms of apparatus for making these curves. Fig. 91 shows some typical shrinkage curves and illustrates the relationship between chemical composition and the form of these curves."

"It will be noted that there are three periods of expansion separated by intervals during which the shrinkage takes place. The first of these periods of expansion is due to the separation of graphite and hence is greatest in the softest irons. Note that in the case *A*, which is a white iron and contains no graphite, this expansion is entirely lacking. This expansion takes place within the temperature range 2200° to 1800° F., or immediately after the iron has solidified."

"The second expansion is due to the solidification of the phosphide eutectic with a consequent secondary precipitation of graphite at that time. Evidently, this expansion is only to be expected in high phosphorus irons and it will be noted that it is lacking in *C*, which is low in phosphorus, and is well marked in *D*, which is high in phosphorus. This expansion takes place within the temperature range 1800° to 1500° F."

"The third expansion is, in the writer's opinion, due to the change of the iron from the 'alpha' to the 'gamma' form, since it takes place

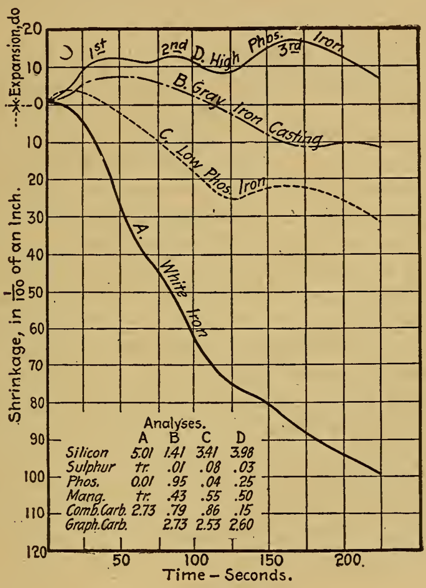


FIG. 91.

within the temperature range 1400° to 1200° F., or about where this change would be expected to take place. Note that this expansion is greatest in high silicon irons *C* and *D*, silicon having the effect of accelerating the 'gamma' to 'alpha' change. The point at which this third expansion occurs probably marks the lower limit below which iron cannot be hardened by quenching."

"The study of these curves is very interesting to the experimenter and it is believed that when we understand them better they may become of practical value to the foundryman. At present, however, the determination of total shrinkage gives information which is of more immediate value."

"The effect of composition on total shrinkage is given in concise form by the following tabular statement:

			Per cent
Silicon	Decreases by about .01	inch per foot for each	.20
Sulphur	Increases by about .01	inch per foot for each	.03
Phosphorus	Decreases by about .015	inch per foot for each	.10
Manganese	Increases by about .01	inch per foot for each	.20
Total carbon	Decreases.		

"To get the minimum shrinkage an iron should be high in silicon, from 2 to 3 per cent depending on the thickness, high in phosphorus, say, 0.75 to 1.25 per cent, as low as possible in sulphur, as high as possible in total carbon and with only enough manganese to care for the sulphur, or, say, 0.3 to 0.4 per cent. This will insure high graphite and hence low shrinkage in the casting. The iron will, however, be rather weak and it is something of a problem to get in one and the same iron considerable strength and at the same time very low shrinkage."

"By the term 'stretch' West describes the power of cast iron to stretch when placed under strain during the cooling process. This property is undoubtedly of much importance in cast iron since there are many castings which are called upon to exhibit it. An extreme case which is commonly cited is that of pulleys, the arms of which are placed in tension due to the quicker cooling of the rim and which must, therefore, either stretch or crack. There is no data regarding the effect of various metalloids of cast iron on its power of stretching but in general a soft iron will stretch more than a hard one. Almost the only data on this subject is given by West. He finds that the period of greatest stretching of cast iron is within the temperature range 1600° to 1200° F.

Fusibility

Fusibility, or the melting point of cast iron, must not be confounded with its fluidity, or ease of flow when molten. Fluidity is much the more important of these two properties, but fusibility is of some interest, particularly as it gives us a means of deciding intelligently in what order to charge metals in the cupola.

The investigations of Dr. Moldenke have shown that the fusibility of cast iron depends primarily on its combined carbon content, and, to a less extent, on the amount of phosphorus present. . . . We find that cast iron has a melting range varying from 2000° F. for a white iron up to 2300° F. for gray iron containing practically no combined carbon, this difference being due probably to the presence of silicon, sulphur, phosphorus and manganese.

Since the graphite in gray iron is only in mechanical mixture with the iron we should, perhaps, expect it to have no effect on the melting point. Moreover, it combines with the iron at temperatures below the melting point thus increasing the combined carbon and lowering the melting point. For this reason gray iron melts at a lower temperature than steel having the same percentage of combined carbon.

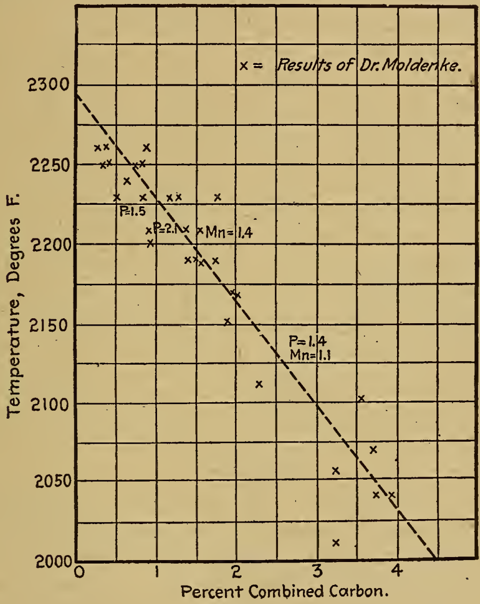


FIG. 92.

As previously noted, phosphorus also has the effect of lowering the melting point of cast iron but it is not nearly as powerful in its action as combined carbon. Iron containing 6.7 per cent phosphorus would melt at only 1740° F., but with less phosphorus than this the melting point rises rapidly so that the 1 or 2 per cent present in commercial high phosphorus irons makes very little difference in the melting point.

Fig. 92 gives in graphic form the data of Dr. Moldenke from which is drawn a line representing the approximate melting point of cast iron of any per cent combined carbon.

"Table I gives the melting points with analyses of some typical irons and ferroalloys selected from the above data. It will be noted that the metalloids other than carbon and phosphorus, *i.e.*, the silicon, sulphur and manganese, seem to have very little effect on the melting point."

TABLE I. — MELTING POINTS OF CAST IRONS

Melting point, degrees F.	Combined carbon, per cent	Graphite, per cent	Silicon, per cent	Manganese, per cent	Phosphorus, per cent	Sulphur, per cent
2030	3.98	....	.14	.10	.22	.037 pig iron
2100	3.52	.54	.47	.20	.20	.036 " "
2140	2.27	1.80	.45	1.10	1.46	.032 " "
2170	1.93	1.69	.52	.16	.76	.036 " "
2200	1.69	2.40	1.81	.49	1.60	.060 " "
2210	1.48	2.30	1.41	1.39	.17	.033 " "
2230	1.12	2.66	1.13	.24	.089	.027 " "
2210	.84	3.07	2.58	.47	2.12	.051 " "
2250	.80	3.16	1.29	.50	.22	.020 " "
2280	.13	3.43	2.40	.90	.08	.032 " "
2350	1.32	....	.21	.49	(?)	(?) steel
2210	6.48	(carbon)	.14	44.59	(?)	(?) ferromang.
2255	5.02	(carbon)	1.65	81.40	(?)	(?) ferromang.
2190	3.38	.37	12.30	16.98	(?)	(?) silicospiegel.
2040	1.82	.47	12.01	1.38	(?)	(?) ferrosilicon
2400	6.80	(carbon)	(chromium 62.70)	....	....	(?) ferrochrome
2280	....	....	(tungsten 39.02)	....	....	(?) ferrotungsten

Fluidity

"Fluidity may be defined as ease of flow. It is synonymous with mobility and opposed to viscosity. It is a property of far-reaching importance to the foundryman and especially to the manufacturer of small and intricate castings. Unfortunately, our means of measuring fluidity are not very satisfactory, and this makes it difficult to determine quantitatively the effect of composition upon this property. About the most satisfactory method is to pour fluidity strips or long strips of perhaps one square inch section (at one end) and tapering to nothing at the other. The distance which the iron runs in a mold of this form is a rough measure of its fluidity."

"The factors which govern fluidity are percentage of silicon, percentage of phosphorus, freedom from dissolved oxide and temperature above the melting point."

"Silicon perhaps aids fluidity by causing a separation of graphite at the moment of solidification, thus, according to Field, liberating latent heat and prolonging the life of the metal. On this basis, high total carbon would also aid fluidity by increasing the amount of graphite separated."

"Phosphorus is probably the most important element as regards fluidity, high phosphorus causing a marked increase in this property. The best results are obtained with about 1.5 per cent phosphorus, although for other reasons it is seldom desirable to use as much as that."

"Freedom from oxide is a very important point as its presence makes the metal sluggish and causes it to set quickly. It is a frequent and often unsuspected source of trouble. Dissolved oxide may be eliminated by any of the methods described."

"The temperature above the freezing point is probably the most important factor of all in connection with fluidity, and it should here be noted that a distinction is made between freezing point and melting point. The two may coincide in the case of white iron, but will not usually, especially with gray iron. This is because, as we have already seen, gray irons have a melting temperature corresponding to their percentage of combined carbon rather than total carbon. After they are in the molten state, however, all the carbon is in solution (combined as far as melting points are concerned), hence, the freezing point will correspond more nearly to the melting point of a white iron having the percentage of combined carbon equal to the total carbon of the original gray iron. This will be in general from 100° to 300° lower than its melting point. For this reason when gray irons are melted they are always considerably superheated above their solidifying points, and the greater this superheat, the more fluid the iron. Evidently, the superheat due to this cause will be the greater the lower the combined carbon in the iron going into the cupola."

Practical rules for getting fluid iron are as follows:

"Keep the phosphorus high, — up to 1.00 to 1.25 if possible."

"If the work will permit, use a soft iron of 2 per cent or over in silicon, and low in combined carbon."

"Avoid oxidizing conditions in melting and, if necessary, use deoxidizing agents."

"Use plenty of coke and good cupola practice."

Resistance to Heat

"Ability to withstand high temperatures is of paramount importance in several classes of castings such as grate bars, ingot moulds, annealing boxes, etc., and the factors which affect this ability are, the percentage of phosphorus, sulphur and combined carbon, and the density or closeness of grain."

"Phosphorus forms with iron an alloy which melts at only 1740° F., or about 400° lower than cast iron free from phosphorus, and each per cent of phosphorus present gives rise to 15 per cent of this easily fusible constituent. Now, it will be evident that the presence of a molten constituent in a piece of iron must greatly weaken it, and hence it is that the presence of much phosphorus decreases the resistance of cast iron to heat."

"Sulphur acts in a similar manner to phosphorus since it also forms with iron a constituent of low melting point (1780° F.). It is, therefore, detrimental to castings which have to stand high temperatures."

"As previously noted, combined carbon is the element which more than any other determines the melting point of cast iron, this melting point becoming lower with increase in this element. It would seem then, that combined carbon must be very detrimental in this class of castings. However, it should be remembered that the condition of the carbon in the solid iron changes readily at high temperatures, and, hence, after the casting has been in use for a while its combined carbon content will not in general be the same as when cast. This fact makes the question of combined carbon of much less practical importance than either phosphorus or sulphur."

"Density or close grain is commonly stated to render cast iron considerably more resistant to the effects of heat. . . ."

"One feature of the effect of heat on cast iron which deserves especial mention is the permanent expansion which it undergoes on repeated heatings. This peculiar behavior was first discovered by Outerbridge and has since been also investigated by Rugan and Carpenter."

"The extent to which this growth may take place is certainly surprising, the increase being in some cases as high as 46 per cent by volume and 1¾ inches in the length of a 15-inch bar. The strength of the metal is decreased proportionately to the expansion or to about one-half of the original strength. Both the expansion and the decrease in strength are explained by microscopic examination, which shows minute cracks throughout the interior of the metal. . . ."

"Two conditions are necessary for this growth. First, repeated heatings, and second, a proper composition of the metal."

"With regard to the heating, a minimum temperature of 1200° F. is necessary. At 1400° to 1600° the rate of growth is more rapid and an increase in temperature beyond 1700° produces no additional effect. Both heating and cooling are necessary to procure the growth, and the time of heating makes very little difference. No greater growth was produced by 17 hours continuous heating than by 4 hours. The number of heatings required to produce the maximum amount of growth varies with different irons, but usually lies somewhere between 50 and 100."

"Regarding the effects of composition, it appears that the growth is favored by the presence of graphite and silicon, and also by a large grain or open structure. White iron containing no graphite expands slightly when subjected to this treatment but not sufficiently to overcome its original shrinkage. In this case the expansion is due to the conversion of the combined carbon into the temper form, or in other words, to the malleableizing of the casting. Soft irons low in combined carbon and high in silicon show the greatest increase in volume. The effects of sulphur, manganese and phosphorus have not been investigated. Steel and wrought iron are not subject to this growth, but on the contrary undergo a slight permanent contraction when repeatedly heated."

"It is evident that this property of cast iron is of great importance in many of the applications of the metal and limits its use for many purposes. It is, no doubt, the reason why a close-grained iron gives better results when exposed to high temperatures and affords an explanation for the warping of grate bars, annealing boxes and similar castings. It also shows why chills and permanent molds must not be allowed to be heated to redness, such a degree of heat resulting in permanent expansion and the loss of their original dimensions."

The following is a summary of some of the published statements regarding the proper composition for castings exposed to high temperatures:

"Cast iron to withstand high temperatures should be low in phosphorus and combined carbon."

"In car wheels manganese increases the resistance to heat strain."

"For refractory castings choose a fine grained cast iron, best containing about 2 per cent manganese to retard the separation of amorphous carbon."

"Castings to resist heat should contain about 1.80 per cent silicon, 0.03 per cent sulphur, 0.70 per cent phosphorus, 0.60 per cent manganese and 2.90 per cent total carbon. Low sulphur is of chief importance, low silicon, carbon and manganese are also advisable."

"Close-grained cast iron having the greatest density will invariably be found best to withstand chemical influences and high temperatures."

"A chill which had given excellent service had the following composition: silicon, 2.07 per cent; sulphur, 0.073 per cent; phosphorus, 0.03 per cent; manganese, 0.48 per cent; combined carbon, 0.23 per cent; graphite carbon, 2.41 per cent; total carbon, 2.64 per cent.

"Two permanent moulds which had given excellent service analyzed as follows:

Silicon, per cent	Sulphur, per cent	Phosphorus, per cent	Manganese, per cent	Combined carbon, per cent	Graphite, per cent	Total carbon, per cent
2.15	.086	1.26	.41	.13	3.17	3.30
2.02	.070	.89	.29	.84	2.76	3.60

"Ingot moulds and stools are best made from medium soft iron low in phosphorus, or what is termed a regular Bessemer iron. . . . ."

Electrical Properties

"Of the three electrical properties, conductivity, permeability and hysteresis, the second only is of importance in connection with cast iron.

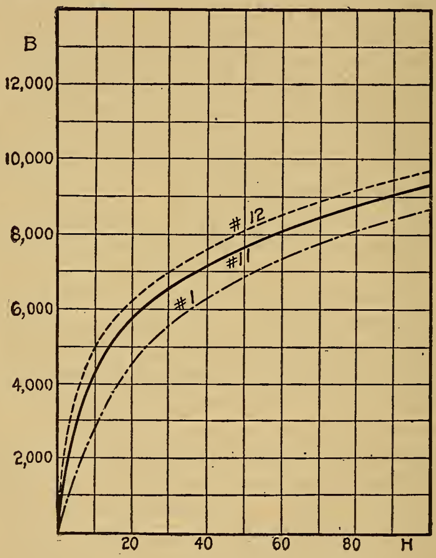
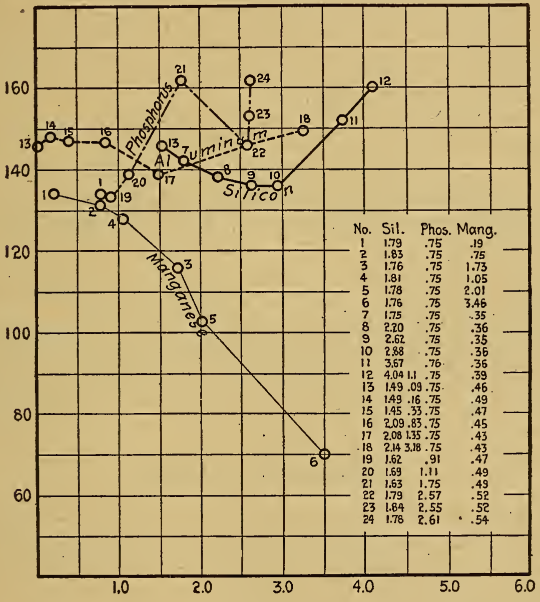


FIG. 93.

Little is known regarding the relation between chemical composition and conductivity of cast iron. In the case of steel it has been found that manganese is the element most injurious to this property with carbon a close second. Hence, by analogy, we may infer that to make iron castings of high conductivity we should keep both the manganese and combined carbon as low as possible.

Permeability may be defined as magnetic conductivity and is of importance in many castings used in the construction of electrical machinery. Permeability data are generally given in the form of a curve expressing the relation between the magnetizing force H and the resulting field strength or number of lines of magnetic force per unit area B. This is known as the permeability curve. The permeability is the ratio $\frac{H}{B}$ and it will be noted that it is different for each value of the magnetizing force, H, but approaches a constant or saturation value for high values of H. See Fig. 93.



No.	Sil.		Phos.	Mang.
1	1.79		.75	.19
2	1.83		.75	.75
3	1.76		.75	1.73
4	1.81		.75	1.05
5	1.78		.75	2.01
6	1.76		.75	3.46
7	1.75		.75	.35
8	2.20		.75	.36
9	2.62		.75	.35
10	2.88		.75	.36
11	3.67		.76	.36
12	4.04	1.1	.75	.39
13	1.49	.09	.75	.46
14	1.49	.16	.75	.49
15	1.45	.33	.75	.47
16	2.09	.83	.75	.45
17	2.08	1.35	.75	.43
18	2.14	3.18	.75	.43
19	1.62		.91	.47
20	1.69		1.11	.49
21	1.63		1.75	.49
22	1.79		2.57	.52
23	1.84		2.55	.52
24	1.78		2.61	.54

FIG. 94.

The effects of the various elements on permeability are not yet entirely clear although there are some published data along this line. The writer has recently done considerable work on the relation between permeability and chemical composition of cast iron, and the results, as yet unpublished, are summarized in Fig. 94. It will be noted that the effects of silicon, phosphorus and aluminum are not well marked and are probably not of any very great importance. On the other hand, manganese has a very detrimental effect on this property.

Silicon has the opposite effect from manganese in that it accelerates this change in the form of the iron, and we would, therefore, expect it to have a more or less beneficial influence. Silicon steel has achieved a wide reputation as a high permeability material for use in the construction of tran former cores, etc. According to the author's results high silicon is particularly effective in increasing *B* for low values of *H*.

An important element not considered in the diagram, Fig. 94, is carbon. For high permeability the lower the carbon the better, and excellent results are now being obtained through the use of semi-steel for electrical castings. In this connection, however, it must be remembered that manganese is undesirable and hence must be used cautiously as a deoxidizer in this class of work.

Some practical rules for obtaining high permeability iron are given herewith.

Keep the silicon high, best in the neighborhood of 3 per cent.

Keep the manganese low, preferably below 0.5 per cent.

If practicable keep the carbon low by the use of steel scrap or air furnace iron.

Allow the castings to anneal themselves, *i.e.*, cool completely in the sand before shaking out.

Hysteresis, like conductivity, is seldom or never of importance in cast iron. The property may be defined as the loss of energy due to molecular friction when magnetic polarity is reversed. The effect of composition upon hysteresis is in general about the same as in the case of permeability.

Resistance to Corrosion

Although there are a great many corrosive agencies it is not practicable, because of lack of information, to treat of each separately, and so far as we know the effects of composition would be relatively the same for the various corroding agents.

The following is a summary of most of the published information along this line:

Pig iron which best resists acids contains silicon, 1.0 per cent; phosphorus, 0.5 per cent; sulphur, 0.05 per cent; carbon, 3.0 per cent.

Excellent results with respect to resistance to corrosion by acids were obtained through the use of a mixture of three brands of pig iron *A*, *B* and *C* in the proportion, two parts of *A*, one part *B* and one part *C*. The analysis of the pig irons is thus given:

Fracture	Silicon, per cent	Manganese, per cent	Phosphorus, per cent	Total carbon, per cent
A Dark gray	3.50	.50	.20	3.80
B Light Gray	1.50	.40	.20	3.50
C Mottled	.70	.25	.20	3.50

The composition of acid-resistant castings should be about as follows:

Silicon, per cent	Sulphur, per cent	Phosphorus, per cent	Manganese, per cent	Total carbon, per cent
.8 to 2.0	.02 to .03	.40 to .60	1 0 to 2.0	3.0 to 3.5

and in addition, the metal should be as free as possible from oxide.

Cast iron to withstand the corrosive action of molten chemicals should be close grained and dense. The iron having the greatest density will invariably be found to best withstand chemical influences and high temperatures. The addition of deoxidizing agents is of great benefit.

Gray iron is attacked by acids about three times as fast as white iron. In cases where it is not practicable to use white iron castings it is sometimes possible to cast against chills in such a manner as to form a white iron surface to resist corrosion and still leave the body of the casting gray.

In a series of tests on the acid-resisting properties of some well-known English brands of iron, the No. 1 iron, presumably high in silicon, and the "hematite," low in phosphorus and probably high in silicon, gave the best results.

Ferrosilicons with high percentages of silicon, 20 per cent and over, are remarkably resistant to the effects of acids and are being made into vessels for use in the chemical industries.

Sulphur has been found to be a source of corrosion in steel in some instances, causing pitting at points where manganese sulphide has segregated.

It has been shown that the presence of small amounts of copper in steel and puddled iron diminish their tendency to rust.

Some practical rules for obtaining castings resistant to corrosion are as follows:

Use white iron if practicable.

If not practicable to use white iron casting, chill those surfaces which are to be in contact with the corrosive substances.

If gray iron must be used get dense, close-grained castings through the use of steel scrap or otherwise.

Avoid oxidized metal, use good cupola practice and good pig irons.

If possible use deoxidizing agents.

Keep the sulphur just as low as possible.

Resistance to Wear

We must first make some distinction between two cases of wear typified by a grinding roll and a brake shoe. The first case may be dismissed by the simple statement that the greater the hardness the better the wear, providing at the same time that the iron is sufficiently strong.

In the second case, however, it is necessary that the casting should not be so hard as to unduly wear the material with which it comes in contact. For example, the brake shoe must be softer than the tread of the car wheel. There is no theory to guide us in the matter and the rules given are the results of experiment chiefly with brake shoes.

Too much silicon gives an open, soft iron which does not wear well. The best results are obtained with silicon about 1½ per cent in castings of medium thickness.

Sulphur is claimed by many to be advantageous in castings for frictional wear because it closes the grain and hardens somewhat. Diller records a peculiar occurrence of a hard spot which could not be machined, a smooth surface being formed which wore the drill although it could be dented with a center punch. Analysis showed 0.20 per cent sulphur and 0.50 per cent combined carbon.

Phosphorus is best kept moderately low. Most specifications call for 0.75 per cent or under. It is injurious probably because it weakens the iron at the high temperature sometimes produced by friction.

Manganese is best kept moderately high to take care of the sulphur. Most brake shoe specifications call for under 0.70 per cent.

The addition of steel scrap to the mixture has been found to give excellent results for this class of work, probably owing to the reduction in the total carbon and to its action in closing the grain.

Coefficient of Friction

There are no data as to the relation between the composition of cast iron and its coefficient of friction. Since graphite is an excellent lubricant it is probable that the percentage of graphite is the controlling factor here, the friction decreasing with increase in this element. From theoretical considerations we should expect the best results to be obtained with a very soft iron low in sulphur, manganese and combined carbon and high in graphite.

Casting Properties

The properties which remain to be considered pertain more particularly to the casting as a whole and are chiefly influenced by the design, moulding and pouring of the casting, and to a very much less extent, by the composition of the metal.

Unsoundness due to the presence of blow-holes and shrinkage cavities, while usually resulting from bad practice in moulding may also be caused by poor quality of metal. Blowholes may be caused by oxidized metal or by excessive sulphur. . . . When caused by sulphur the remedy is to decrease this element. Raising the manganese is often effective in preventing blowholes since it acts both as a deoxidizer and desulphurizer. Scott states that manganese below 0.25 per cent often results in blowholes. High phosphorus sometimes acts as a corrective of blowholes due to its prolonging the fluidity, thus giving the iron more chance to release the dissolved gases.

Dirty castings are also caused chiefly by poor moulding, pouring or cupola practice. Occasionally, however, it may result from wrong composition of the metal, and the points chiefly to be watched are to keep the sulphur low; to avoid kish or segregated graphite and to avoid oxidized metal.

Sulphur tends to cause dirty castings because it makes the iron congeal more quickly, and hence any dirt present has less chance to separate. In addition, the sulphides of iron and manganese themselves form dirt spots when segregated. Kish is usually caused by too much silicon, or sometimes by too much total carbon. Oxidized metal is a prolific source of dirty castings, but the oxidization is usually due to bad cupola practice, or to the use of oxidized scrap. Moderately high manganese and phosphorus are conducive to clean castings, the first because it takes care of sulphur and oxidation, and the second because it increases the fluidity of the metal and thus gives the dirt a better chance to float out.

Porosity is usually caused by the presence of kish (see preceding paragraph). Pinholes, another form of porosity, are usually due to excessive sulphur in the form of iron sulphide. This compound retains gases in solution until the metal is partially frozen and then releases them in the form of tiny bubbles which give rise to this defect. Decrease in sulphur or increase in manganese or both is the remedy.

Segregation proper is caused by the difference in melting point and specific gravity of the several constituents of cast iron. The constituents of lowest melting point are the phosphorus and sulphur compounds, and it is, therefore, in these cases that we find the greatest tendency towards segregation. It is not unusual to find hard spots in heavy castings high in phosphorus which are caused by the phosphide being squeezed out into blow-holes formed during solidification. Frequently the phosphide does not completely fill the cavity, or fills it as a loose globule. The sulphides, owing to their low specific gravity, usually segregate in the top of the casting and it is not infrequent to find several times the normal amount of sulphur in the upper part of heavy castings. Manganese sulphide segregates more readily than iron sulphide.

Besides segregation proper we sometimes find cases of non-homogeneity due to other causes. Occasionally spots of white iron are found in the interior of castings. It has always been difficult to account for these but the clew is given by the fact that they are invariably found in castings poured from the first metal tapped.

Undoubtedly they are caused by the iron boiling on the sand bed and are connected in some way with the partial Bessemerizing of the metal. Again, hard spots in castings are sometimes due to small pieces of metal (for example, small steel scrap and shot iron) being incompletely melted in their passage through the cupola. Ferromanganese and other ferro-alloys may give rise to this same trouble through incomplete solution when stirred into the ladle.

Shrinkage strains are caused primarily by wrongly designed castings, but the trouble may be aggravated by the composition of the metal. High sulphur is a particularly prolific source of internal stresses, and, in general, the greater the total shrinkage, the greater the strains due to this cause.

As all foundrymen know, the fineness of finish and smoothness of skin of a casting depend chiefly on the sands and facings used and the skill of the moulder. High phosphorus in the iron, however, is a considerable aid in getting the fine skin desired in ornamental work. Another element affecting the skin is manganese which has the rather peculiar action of causing the sand to peel from the castings with extreme readiness. With 1 per cent manganese this tendency is evident and with 2 per cent it is very marked.

Bars, plates and hollow castings were treated, which were permitted to cool in the moulds. The plates cooled more slowly than the bar samples and the material proved somewhat softer, giving smaller values for the bending, tensile and compressive strength, but was better as regards flexure and strength to resist impact.

Tests reported to the Iron and Steel Institute showed:

The best tensile and transverse tests are obtained from bars which have been machined.

Transverse test bars cast on edge and tested with the "fin" in compression give the best results.

The transverse test is not so reliable or helpful as that of the moment of resistance.

Cast iron gives the best results when poured as hot as possible.

As in some measure explanatory of the conflicting results obtained in testing bars of precisely the same chemical combination, and as showing the importance of microscopical examinations of the structure of cast iron in pointing out the causes of difference in its physical properties, the paper of Mr. Percy Longmuir published in the Journal of the American Foundrymen's Association, June, 1903 is given in full.

Notes on the Micro-structure of Cast Iron

By Percy Longmuir, Sheffield, England

Journal of the American Foundrymen's Association, Vol. XII, June, 1903.

Instances are occasionally found where metal of the right chemical composition goes wrong in practice. It is in cases of this kind that the real value of microscopical examination is most evident, for very often such an examination will locate the trouble and at the same time suggest a remedy. Naturally an examination of diseased samples can only be undertaken after a thorough study of healthy ones, hence a foundation for the study of abnormal samples must necessarily be based on the knowledge gained from a wide series of normal ones, that is, samples of known chemical composition and known physical conditions.

The structure of cast iron is very complex — far more so than that of steel — a fact readily shown by the high content of elements present other than iron. By polishing and etching a sample of cast iron, several of the compounds of the elements with iron are, under suitable magnification, rendered visible. The structural features, such as the arrangement and distribution of the various compounds and their relationship to each other, can then be readily noted and the effect of this combination on the mass then becomes an estimable quantity.

If the metal under examination contain no impurities it is evident that its mass will be built up of pure crystals. A section cut from such a pure metal will, after polishing and etching, show only the crystal junctions. Crystal junctions of this type are shown in Fig. 95, which represents the structure of almost pure iron. Even here, although the metal is so pure, the very minute trace of carbon present can be readily detected in the dark knots of which about a dozen are to be seen. As foreign elements are added to pure iron the structure becomes more complex and a point is reached when all the pure crystals are replaced by more complex ones. It is to be remembered that all gray irons contain appreciable amounts of two varieties of carbon, silicon, manganese, sulphur and phosphorus.

FIG. 95. — Magnified 360 diameters.

Carbon	0.03	Sulphur	0.01
Silicon	0.02	Phosphorus	0.01
Manganese	0.07	Iron	99.86

Of these elements graphite is present in its elementary form, that is, as free carbon. The remaining constituents are present in compound form associated either with iron or with other elements. Thus sulphur may occur as sulphide of manganese or as iron sulphide. Carbon occurring

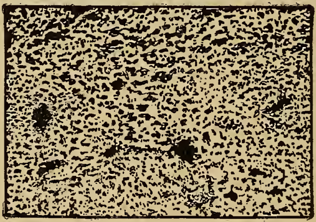


FIG. 96. — Magnified 60 diameters.

Combined Carbon	0.54	Manganese	0.63
Graphite	3.11	Sulphur	0.04
Silicon	1.77	Phosphorus	1.34

in the combined form is present as a definite carbide of iron; or under certain conditions as a double carbide of iron and manganese. Phosphorus is associated with iron as a definite phosphide. These compounds are all distinguishable under suitable magnification, but the association of silicon and iron is, so far as present knowledge goes, unrecognizable.

Microscopically these constituents have received other names — for instance pure iron is known as "ferrite," hence a structure similar to that of Fig. 96 consists almost entirely of ferrite. Combined carbon receives the term "cementite" and a mixture of cementite and ferrite

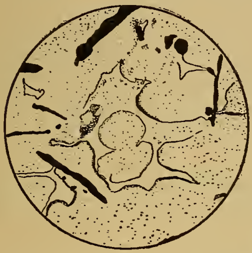


FIG. 97. — Magnified 460 diameters.

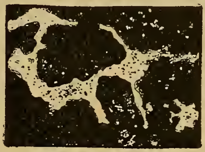


FIG. 98. — Magnified 360 diameters.

is known as "pearlite." Pearlite often consists of alternate striae of cementite and ferrite and in such a form gives a magnificent play of colors resembling those of mother-of-pearl, consequently this constituent was named by its discoverer, Dr. Sorby, the "pearly constituent," a term now contracted to "pearlite."

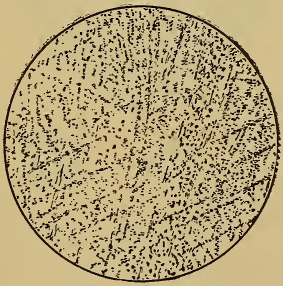


FIG. 99. — Magnified 50 diameters.

Combined Carbon	3.25	Sulphur	0.41
Silicon	0.78	Phosphorus	0.06
Manganese	0.09		

The classical researches of Professor Arnold have conclusively shown that iron containing 0.89 per cent carbon consists entirely of pearlite. As the content of carbon increases above 0.89 per cent, structurally free cementite appears increasing in quantity with each increment of carbon. It therefore follows that a white cast iron will consist essentially of cementite and pearlite. In the majority of gray irons used in the foundries the combined carbon is well below 0.89 per cent — cementite is, therefore, only present as a constituent of pearlite.

Sulphide globules when in the form of manganese sulphide show a light gray color, while iron sulphide shows a light brown tint.

In high sulphur irons the sulphide tends to envelop the crystals; a section cut from such an iron would show a network of sulphide following the crystal junctions and destroying their continuity. These sulphides have been thoroughly investigated by Professor Arnold whose researches have thrown much light on the behaviour of both iron and manganese sulphide.

The relations of iron and phosphorus have been very thoroughly studied by Mr. J. E. Stead. In September, 1900, Mr. Stead presented

FIG. 100. — Magnified 50 diameters.

Combined Carbon	0.82	Manganese	0.09
Graphite	2.07	Sulphur	0.37
Silicon	0.75	Phosphorus	0.07

before the Iron and Steel Institute a most exhaustive research on this subject. With ordinary pig irons the phosphide of iron appears to be rejected to a eutectic of uncertain composition. Eutectic may for our purpose be defined as that portion last to solidify. This phosphide eutectic may be readily distinguished in all gray irons by an ordinary etching medium, but in white irons containing structurally free cementite, Mr. Stead's "heat tinting" process becomes necessary to distinguish the eutectic from the cementite.

Fig. 96 reproduces a photo-microscope of an unetched section of gray iron at a magnification of 60 diameters.

This magnification gives, as it were, a general view only — to get at the ultimate structure higher powers must be used. Fig. 97 represents the structure of an ordinary gray iron magnified 460 diameters. The larger portion of this field consists of pearlite embedded in which are irregular areas of the phosphide eutectic and several notable black plates of graphite. The phosphide eutectic is recognizable by its irregular shape and broken up structure; an area in the center of the photograph enclosing an area of pearlite is worthy of notice.

Fig. 98 reproduces an area of phosphide eutectic from the same section as Fig. 96.

A typical white cast iron consisting essentially of pearlite and cementite is shown in Fig. 99. This is a type of iron used as a base for the production of malleable cast iron.

The influences of annealing are shown in Fig. 100, which represents the same iron as Fig. 99, after going through the ordinary malleable iron

FIG. 101. — Magnified 60 diameters.

annealing in ore. This section consists essentially of pearlite and graphite — the analyses appended to each figure showing the change in carbon condition. For the loan of the negatives illustrating Figs. 99 and 100, the writer is indebted to the courtesy of Mr. T. Baker, B. Sc.

Quite apart from the clear light thrown on what has been aptly termed the internal architecture of a metal, microscopical examination reveals many other features of profitable interest, one notable feature being the examination of minute flaws. Space will not permit of many illustrations under this head, but Fig. 101, reproduced from a photo-micrograph of a pin-hole in the same section as Fig. 96, will show the range of possibility in this direction. Obviously, a study of flaws of this character offers much to the founder producing castings which have to meet a hydraulic or high steam pressure test.

CHAPTER XIV

Standard Specifications for Cast Iron Car Wheels

Chemical Properties

The wheels furnished under this specification must be made from the best materials and in accordance with the best foundry methods. The following pattern analysis is given for information, as representing the chemical properties of a good cast iron wheel. Successful wheels, varying in some of the constituents quite considerably from the figures given, may be made:

Analysis	Per cent	Analysis	Per cent
Total carbon	3.50	Manganese	.40
Graphitic carbon	2.90	Phosphorus	.50
Combined carbon	.60	Sulphur	.08
Silicon	.70	....	....

1. Wheels will be inspected and tested at the place of manufacture.

2. All wheels must conform in general design and in measurements to drawings which will be furnished, and any departure from the standard drawing must be by special permission in writing. Manufacturers wishing to deviate from the standard dimensions must submit duplicate drawings showing the proposed changes, which must be approved.

Drop Tests

3. The following table gives data as to weight and tests of various kinds of wheels for different kinds of cars and service:

Wheel	33-inch diameter freight and passenger cars			36-inch diameter	
Kind of service	60,000 lbs. capacity and less	70,000 lbs. capacity	100,000 lbs. capacity	Passenger cars	Locomotive tenders
Number	1	2	3	4	5
Weight: Desired	600	650	700	700 lbs.	750 lbs.
Weight: Variation	Two per cent either way				
Height of drop, feet	9	12	12	12	12
Number of blows	10	10	12	12	14

Marking

4. Each wheel must have plainly cast on the outside plate the name of the maker and place of manufacture. Each wheel must also have cast on the inside double plate the date of casting and a serial foundry number. The manufacturer must also provide for the guarantee mark, if so required by the contract. No wheel bearing a duplicate number, or a number which has once been passed upon, will be considered. Numbers of wheels once rejected will remain unfilled. No wheel bearing an indistinct number or date, or any evidence of an altered or defaced number will be considered.

Measures

5. All wheels offered for inspection must have been measured with a standard tape measure and must have the shrinkage number stenciled in plain figures on the inside of the wheel. The standard tape measure must correspond in form and construction to the "Wheel Circumference Measure" established by the Master Car Builders' Association in 1900. The nomenclature of that measure need not, however, be followed, it being sufficient if the graduating marks indicating tape sizes are one-eighth of an inch apart. Any convenient method of showing the shrinkage or stencil number may be employed. Experience shows that standard tape measures elongate a little with use, and it is essential to have them frequently compared and rectified. When ready for inspection, the wheels must be arranged in rows according to shrinkage numbers, all wheels of the same date being grouped together. Wheels bearing dates more than thirty days prior to the date of inspection will not be accepted for test, except by permission. For any single inspection and test, only wheels having three consecutive shrinkage or stencil numbers will be considered. The manufacturer will, of course, decide what three shrinkage or stencil numbers he will submit in any given lot of 103 wheels offered, and the same three shrinkage or stencil numbers need not be offered each time.

Finish

6. The body of the wheels must be smooth and free from slag and blowholes, and the hubs must be solid. Wheels will not be rejected because of drawing around the center core. The tread and throat of the wheels must be smooth, free from deep and irregular wrinkles, slag, sand wash, chill cracks or swollen rims, and be free from any evidence of hollow rims, and the throat and tread must be practically free from sweat.

Material and Chill

7. Wheels tested must show soft, clean, gray iron, free from defects, such as holes containing slag or dirt more than one-quarter of an inch in

diameter, or clusters of such holes, honeycombing of iron in the hub, white iron in the plates or hub, or clear white iron around the anchors of chaplets at a greater distance than one-half of an inch in any direction. The depth of the clear white iron must not exceed seven-eighths of an inch at the throat and one inch at the middle of the tread, nor must it be less than three-eighths of an inch at the throat or any part of the tread. The blending of the white iron with the gray iron behind must be without any distinct line of demarcation, and the iron must not have a mottled appearance in any part of the wheel at a greater distance than one and five-eighths inches from the tread or throat. The depth of chill will be determined by inspection of the three test wheels described below, all test wheels being broken for this purpose, if necessary. If one only of the three test wheels fails in limits of chill, all the lot under test of the same shrinkage or stencil number will be rejected and the test will be regarded as finished so far as this lot of 103 wheels is concerned. The manufacturer may, however, offer the wheels of the other two shrinkage or stencil numbers, provided they are acceptable in other respects as constituents of another 103 wheels for a subsequent test. If two of the three test wheels fail in limits of chill, the wheels in the lot of 103 of the same shrinkage or stencil number as these two wheels will be rejected, and, as before, the test will be regarded as finished as far as this lot of 103 wheels is concerned. The manufacturer may, however, offer the wheels of the third shrinkage or stencil number, provided they are acceptable in other respects, as constituents of another 103 wheels for a subsequent test. If all three test wheels fail in limits of chill, of course the whole hundred will be rejected.

Inspection and Shipping

8. The manufacturer must notify when he is ready to ship not less than 100 wheels; must await the arrival of the inspector; must have a car, or cars, ready to be loaded with wheels, and must furnish facilities and labor to enable the Inspector to inspect, test, load and ship the wheels promptly. Wheels offered for inspection must not be covered with any substance which will hide defects.

9. One hundred or more wheels being ready for test, the inspector will make a list of the wheel numbers, at the same time examining each wheel for defects. Any wheels which fail to conform to specifications by reason of defects must be laid aside, and such wheels will not be accepted for shipment. As individual wheels are rejected, others of the proper shrinkage or stencil number may be offered to keep the number good.

Retaping

10. The inspector will retape not less than 10 per cent of the wheels offered for test, and if he finds any showing wrong tape-marking, he will tape the whole lot and require them to be restenciled, at the same time having the old stencil marks obliterated. He will weigh and make check measurements of at least 10 per cent of the wheels offered for test, and if any of these wheels fail to conform to the specification, he will weigh and measure the whole lot, refusing to accept for shipment any wheels which fail in these respects.

Drop Tests

11. Experience indicates that wheels with higher shrinkage or lower stencil numbers are more apt to fail on thermal test; more apt to fail on drop test and more apt to exceed the maximum allowable chill than those with higher stencil or lower shrinkage numbers; while, on the other hand, wheels with higher stencil or lower shrinkage numbers are more apt to be deficient in chill. For each 103 wheels apparently acceptable, the inspector will select three wheels for test — one from each of the three shrinkage or stencil numbers offered. One of these wheels chosen for this purpose by the inspector must be tested by drop test as follows: The wheel must be placed flange downward in an anvil block weighing not less than 1700 pounds, set on rubble masonry two feet deep and having three supports not more than five inches wide for the flange of the wheel to rest on. It must be struck centrally upon the hub by a weight of 200 pounds, falling from a height as shown in the table on page 350. The end of the falling weight must be flat, so as to strike fairly on the hub, and when by wear the bottom of the weight assumes a round or conical form, it must be replaced. The machine for making this test is shown on drawings which will be furnished. Should the wheel stand, without breaking in two or more pieces, the number of blows shown in the above table, the one hundred wheels represented by it will be considered satisfactory as to this test. Should it fail, the whole hundred will be rejected.

Thermal Test

12. The other two test wheels must be tested as follows: The wheels must be laid flange down in the sand, and a channel way one and one-half inches in width at the center of the tread and four inches deep must be molded with green sand around the wheel. The clean tread of the wheel must form one side of this channel way, and the clean flange must form as much of the bottom as its width will cover. The channel way must

then be filled to the top from one ladle with molten cast iron, which must be poured directly into the channel way without previous cooling or stirring, and this iron must be so hot, when poured, that the ring which is formed when the metal is cold shall be solid or free from wrinkles or layers. Iron at this temperature will usually cut a hole at the point of impact with the flange. In order to avoid spitting during the pouring, the tread and inside of the flange during the thermal test should be covered with a coat of shellac; wheels which are wet or which have been exposed to snow or frost may be warmed sufficiently to dry them or remove the frost before testing, but under no circumstances must the thermal test be applied to a wheel that in any part feels warm to the hand. The time when pouring ceases must be noted, and two minutes later an examination of the wheel under test must be made. If the wheel is found broken in pieces, or if any crack in the plates extends through or into the tread, the test wheel will be regarded as having failed. If both wheels stand, the whole hundred will be accepted as to this test. If both fail, the whole hundred will be rejected. If one only of the thermal test wheels fails, all of the lot under test of the same shrinkage or stencil number will be rejected, and the test will be regarded as finished, so far as this lot of wheels is concerned. The manufacturer may, however, offer the wheels of the other two shrinkage or stencil numbers, provided they are acceptable in other respects, as constituents of another 103 wheels for a subsequent test.

Storing and Shipping

13. All wheels which pass inspection and test will be regarded as accepted, and may be either shipped or stored for future shipment, as arranged. It is desired that shipments should be, as far as possible, in lots of 100 wheels. In all cases the inspector must witness the shipment, and he must give, in his report, the numbers of all wheels inspected and the disposition made of them.

Rejections

14. Individual wheels will be considered to have failed and will not be accepted or further considered, which,

First. Do not conform to standard design and measurement.

Second. Are under or over weight.

Third. Have the physical defects described in Section 6.

15. Each 103 wheels submitted for test will be considered to have failed and will not be accepted or considered further, if,

First. The test wheels do not conform to Section 7, especially as to limits of white iron in the throat and tread and around chaplets.

Second. One of the test wheels does not stand the drop test as described in Section 11.

Third. Both of the two test wheels do not stand the thermal test as described in Section 12.

Standard Specifications for Locomotive Cylinders

Process of Manufacture

Locomotive cylinders shall be made from a good quality of close-grained gray iron cast in a dry sand mould.

Chemical Properties

Drillings taken from test pieces cast as hereafter mentioned shall conform to the following limits in chemical composition:

Silicon..........	from 1.25 to	1.75 per cent
Phosphorus.......	not over	0.90 per cent
Sulphur..........	not over	0.10 per cent

Physical Properties

The minimum physical qualities for cylinder iron shall be as follows:

The "Arbitration Test Bar," 1¼ inches in diameter, with supports 12 inches apart, shall have a transverse strength not less than 3000 pounds, centrally applied, and a deflection not less than 0.10 of an inch.

Test Pieces and Method of Testing

The standard test-bar shall be 1¼ inches in diameter, about 14 inches long, cast on end in dry sand. The drillings for analysis shall be taken from this test piece, but in case of rejection the manufacturer shall have the option of analyzing drillings from the bore of the cylinder, upon which analysis the acceptance or rejection of the cylinder shall be based.

One test piece for each cylinder shall be required.

Character of Castings

Castings shall be smooth, well cleaned, free from blow-holes, shrinkage cracks or other defects, and must finish to blue-print size.

Each cylinder shall have cast on each side of saddle, the manufacturer's mark, serial number, date made and mark showing order number.

Inspector

The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy himself that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of the manufacturer.

Standard Specifications for Cast-Iron Pipe and Special Castings

Description of Pipes

The pipes shall be made with hub and spigot joints, and shall accurately conform to the dimensions given in tables Nos. I and II. They shall be straight and shall be true circles in section, with their inner and outer surfaces concentric, and shall be of the specified dimensions in outside diameter. They shall be at least 12 feet in length, exclusive of socket. For pipes of each size from 4-inch to 24-inch, inclusive, there shall be two standards of outside diameter, and for pipes from 30-inch to 60-inch, inclusive, there shall be four standards of outside diameter, as shown by table No. II.

All pipes having the same outside diameter shall have the same inside diameter at both ends. The inside diameter of the lighter pipes of each standard outside diameter shall be gradually increased for a distance of about 6 inches from each end of the pipe so as to obtain the required standard thickness and weight for each size and class of pipe.

Pipes whose standard thickness and weight are intermediate between the classes in table No. II shall be made of the same outside diameter as the next heavier class. Pipes whose standard thickness and weight are less than shown by table No. II shall be made of the same outside diameter as the class A pipes, and pipes whose thickness and weight are more than shown by table No. II shall be made of the same outside diameter as the class D pipes.

For 4-inch to 12-inch pipes, inclusive, one class of special castings shall be furnished, made from class D pattern. Those having spigot ends shall have outside diameters of spigot ends midway between the two standards of outside diameters as shown by table No. II, and shall be tapered back for a distance of 6 inches. For 14-inch to 24-inch pipes, inclusive, two classes of special castings shall be furnished, class B special castings with classes A and B pipes, and class D special castings with classes C and D pipes, the former to be stamped "AB" and the latter to be stamped "CD." For 30-inch to 60-inch pipes, inclusive, four classes of special castings shall be furnished, one for each class of pipe, and shall be stamped with the letter of the class to which they belong.

Allowable Variation in Diameter of Pipes and Sockets

Especial care shall be taken to have the sockets of the required size. The sockets and spigots will be tested by circular gauges, and no pipe will be received which is defective in joint room from any cause. The diameters of the sockets and the outside diameters of the bead ends of the pipes shall not vary from the standard dimensions by more than 0.06 of an inch for pipes 16 inches or less in diameter; 0.08 of an inch for 18-inch, 20-inch and 24-inch pipes; 0.10 of an inch for 30-inch, 36-inch and 42-inch pipes; 0.12 of an inch for 48-inch, and 0.15 of an inch for 54-inch and 60-inch pipes.

Allowable Variation in Thickness

For pipes whose standard thickness is less than 1 inch, the thickness of metal in the body of the pipe shall not be more than 0.08 of an inch less than the standard thickness, and for pipes whose standard thickness is 1 inch or more, the variation shall not exceed 0.10 of an inch, except that for spaces not exceeding 8 inches in length in any direction, variations from the standard thickness of 0.02 of an inch in excess of the allowance above given shall be permitted.

For special castings of standard patterns a variation of 50 per cent greater than allowed for straight pipe shall be permitted.

Defective Spigots may be Cut

Defective spigot ends on pipes 12 inches or more in diameter may be cut off in a lathe and a half-round wrought-iron band shrunk into a groove cut in the end of the pipe. Not more than 12 per cent of the total number of accepted pipes of each size shall be cut and banded, and no pipe shall be banded which is less than 11 feet in length, exclusive of the socket.

In case the length of a pipe differs from 12 feet, the standard weight of the pipe given in table No. II shall be modified in accordance therewith.

Special Castings

All special castings shall be made in accordance with the cuts and the dimensions given in the table forming a part of these specifications.

The diameters of the sockets and the external diameters of the bead ends of the special castings shall not vary from the standard dimensions by more than 0.12 of an inch for castings 16 inches or less in diameter; 0.15 of an inch for 18-inch, 20-inch and 24-inch castings; 0.20 of an inch for 30-inch, 36-inch and 42-inch castings; and 0.24 of an inch for 48-inch, 54-inch and 60-inch castings. These variations apply only to special castings made from standard patterns.

The flanges on all manhole castings and manhole covers shall be faced true and smooth, and drilled to receive bolts of the sizes given in the tables. The manufacturer shall furnish and deliver all bolts for bolting on the manhole covers, the bolts to be of the sizes shown on plans and made of the best quality of mild steel, with hexagonal heads and nuts and sound, well-fitting threads.

Table No. I. — General Dimensions of Pipes

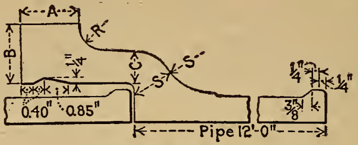


Fig. 102.

Nominal diam., inches	Classes	Actual outside diam., inches	Diameter of sockets		Depth of sockets		A	B	C
			Pipe, inches	Special castings, inches	Pipe, inches	Special castings, inches			
4	A–B	4.80	5.60	5.70	3.50	4.00	1.5	1.30	.65
4	C–D	5.00	5.80	5.70	3.50	4.00	1.5	1.30	.65
6	A–B	6.90	7.70	7.80	3.50	4.00	1.5	1.40	.70
6	C–D	7.10	7.90	7.80	3.50	4.00	1.5	1.40	.70
8	......	9.05	9.85	10.00	4.00	4.00	1.5	1.50	.75
8	C–D	9.30	10.10	10.00	4.00	4.00	1.5	1.50	.75
10	A–B	11.10	11.90	12.10	4.00	4.00	1.5	1.50	.75
10	C–D	11.40	12.20	12.10	4.00	4.00	1.5	1.60	.80
12	A–B	13.20	14.00	14.20	4.00	4.00	1.5	1.60	.80
12	C–D	13.50	14.30	14.20	4.00	4.00	1.5	1.70	.85
14	A–B	15.30	16.10	16.10	4.00	4.00	1.5	1.70	.85
14	C–D	15.65	16.45	16.45	4.00	4.00	1.5	1.80	.90
16	A–B	17.40	18.40	18.40	4.00	4.00	1.75	1.80	.90
16	C–	17.80	18.80	18.80	4.00	4.00	1.75	1.90	1.00
18	A–B	19.50	20.50	20.50	4.00	4.00	1.75	1.90	.95
18	C–D	19.92	20.92	20.92	4.00	4.00	1.75	2.10	1.05
20	A–B	21.60	22.60	22.60	4.00	4.00	1.75	2.00	1.00
20	C–D	22.06	23.06	23.06	4.00	4.00	1.75	2.30	1.15
24	A–B	25.80	26.80	26.80	4.00	4.00	2.00	2.10	1.05
24	C–D	26.32	27.32	27.32	4.00	4.00	2.00	2.50	1.25
30	A	31.74	32.74	32.74	4.50	4.50	2.00	2.50	1.15
30	B	32.00	33.00	33.00	4.50	4.50	2.00	2.30	1.15
30	C	32.40	33.40	33.40	4.50	4.50	2.00	2.60	1.32
30	D	32.74	33.74	33.74	4.50	4.50	2.00	3.00	1.50
36	A	37.96	38.96	38.96	4.50	4.50	2.00	2.50	1.25
36	B	38.30	39.30	39.30	4.50	4.50	2.00	2.80	1.40
36	C	38.70	39.70	39.70	4.50	4.50	2.00	3.10	1.60
36	D	39.16	40.16	40.16	4.50	4.50	2.00	3.40	1.80
42	A	44.20	45.20	45.20	5.00	5.00	2.00	2.80	1.40
42	B	44.50	45.50	45.50	5.00	5.00	2.00	3.00	1.50
42	C	45.10	46.10	46.10	5.00	5.00	2.00	3.40	1.75
42	D	45.58	46.58	46.58	5.00	5.00	2.00	3.80	1.95
48	A	50.50	51.50	51.50	5.00	5.00	2.00	3.00	1.50
48	B	50.80	51.80	51.80	5.00	5.00	2.00	3.30	1.65
48	C	51.40	52.40	52.40	5.00	5.00	2.00	3.80	1.95
48	D	51.98	52.98	52.98	5.00	5.00	2.00	4.20	2.20
54	A	56.66	57.66	57.66	5.50	5.50	2.25	3.20	1.60
54	B	57.10	58.10	58.10	5.50	5.50	2.25	3.60	1.80
54	C	57.80	58.80	58.80	5.50	5.50	2.25	4.00	2.15
54	D	58.40	59.40	59.40	5.50	5.50	2.25	4.40	2.45
60	A	62.80	63.80	63.80	5.50	5.50	2.25	3.40	1.70
60	B	63.40	64.40	64.40	5.50	5.50	2.25	3.70	1.90
60	C	64.20	65.20	65.20	5.50	5.50	2.25	4.20	2.25
60	D	64.82	65.82	65.82	5.50	5.50	2.25	4.70	2.60

TABLE NO. II. — STANDARD THICKNESSES AND WEIGHTS OF CAST IRON PIPE

Nominal inside diameter, inches	Class A 100 ft. head. 43 lbs. pressure			Class B 200 ft. head. 86 lbs. pressure		
	Thickness, inches	Weight per		Thickness, inches	Weight per	
		Foot	Length		Foot	Length
4	.42	20.0	240	.45	21.7	260
6	.44	30.8	370	.48	33.3	400
8	.46	42.9	515	.51	47.5	570
10	.50	57.1	685	.57	63.8	765
12	.54	72.5	870	.62	82.1	985
14	.57	89.6	1,075	.66	102.5	1,230
16	.60	108.3	1,300	.70	125.0	1,500
18	.64	129.2	1,550	.75	150.0	1,800
20	.67	150.0	1,800	.80	175.0	2,100
24	.76	204.2	2,450	89	233.3	2,800
30	.88	291.7	3,500	1.03	333.3	4,000
36	.99	391.7	4,700	1.15	454.2	5,450
42	1.10	512.5	6,150	1.28	591.7	7,100
48	1.26	666.7	8,000	1.42	750.0	9,000
54	1.35	800.0	9,600	1.55	933.3	11,200
60	1.39	916.7	11,000	1.67	1,104.2	13,250

Nominal inside diameter, inches	Class C 300 ft. head. 130 lbs. pressure			Class D 400 ft. head. 173 lbs. pressure		
	Thickness, inches	Weight per		Thickness, inches	Weight per	
		Foot	Length		Foot	Length
4	.48	23.3	280	.52	25.0	300
6	.51	35.8	430	.55	38.3	460
8	.56	52.1	625	.60	55.8	670
10	.62	70.8	850	.68	76.7	920
12	.68	91.7	1,100	.75	100.0	1,200
14	.74	116.7	1,400	.82	129.2	1,550
16	.80	143.8	1,725	.89	158.3	1,900
18	.87	175.0	2,100	.96	191.7	2,300
20	.92	208.3	2,500	1.03	229.2	2,750
24	1.04	279.2	3,350	1.16	306.7	3,680
30	1.20	400.0	4,800	1.37	450.0	5,400
36	1.36	545.8	6,550	1.58	625.0	7,500
42	1.54	716.7	8,600	1.78	825.0	9,900
48	1.71	908.3	10,900	1.96	1050.0	12,600
54	1.90	1,141.7	13,700	2.23	1341.7	16,100
60	2.00	1,341.7	16,100	2.38	1583.3	19,000

The above weights are for 12-feet laying lengths and standard sockets; proportionate allowance to be made for any variation therefrom.

Marking

Every pipe and special casting shall have distinctly cast upon it the initials of the maker's name. When cast especially to order, each pipe and special casting larger than 4-inch may also have cast upon it figures showing the year in which it was cast and a number signifying the order in point of time in which it was cast, the figures denoting the year being above and the number below, thus:

1901	1901	1901
1	2	3

etc., also any initials, not exceeding four, which may be required by the purchaser. The letters and figures shall be cast on the outside and shall be not less than 2 inches in length and ⅛ of an inch in relief for pipes 8 inches in diameter and larger. For smaller sizes of pipes the letters may be 1 inch in length. The weight and the class letter shall be conspicuously painted in white on the inside of each pipe and special casting after the coating has become hard.

Allowable Percentage of Variation in Weight

No pipe shall be accepted the weight of which shall be less than the standard weight by more than 5 per cent for pipes 16 inches or less in diameter, and 4 per cent for pipes more than 16 inches in diameter, and no excess above the standard weight of more than the given percentages for the several sizes shall be paid for. The total weight to be paid for shall not exceed, for each size and class of pipe received, the sum of the standard weights of the same number of pieces of the given size and class by more than 2 per cent.

No special casting shall be accepted the weight of which shall be less than the standard weight by more than 10 per cent for pipes 12 inches or less in diameter, and 8 per cent for larger sizes, except that curves, Y pieces and breeches pipe may be 12 per cent below the standard weight, and no excess above the standard weight of more than the above percentages for the several sizes will be paid for. These variations apply only to castings made from the standard patterns.

Quality of Iron

All pipes and special castings shall be made of cast iron of good quality and of such character as shall make the metal of the castings strong, tough and of even grain, and soft enough to satisfactorily admit of drilling and cutting. The metal shall be made without any admixture of cinder iron or other inferior metal, and shall be remelted in a cupola or air furnace.

Tests of Material

Specimen bars of the metal used, each being 26 inches long by 2 inches wide and 1 inch thick, shall be made without charge as often as the engineer may direct, and, in default of definite instructions, the contractor shall make and test at least one bar from each heat or run of metal. The bars, when placed flatwise upon supports 24 inches apart and loaded in the center, shall for pipes 12 inches or less in diameter support a load of 1900 pounds and show a deflection of not less than 0.30 of an inch before breaking, and for pipes of sizes larger than 12 inches shall support a load of 2000 pounds and show a deflection of not less than 0.32 of an inch. The contractor shall have the right to make and break three bars from each heat or run of metal, and the test shall be based upon the average results of the three bars. Should the dimensions of the bars differ from those above given, a proper allowance therefor shall be made in the results of the tests.

Casting of Pipes

The straight pipes shall be cast in dry sand moulds in a vertical position. Pipes 16 inches or less in diameter shall be cast with the hub end up or down, as specified in the proposal. Pipes 18 inches or more in diameter shall be cast with the hub end down.

The pipes shall not be stripped or taken from the pit while showing color of heat, but shall be left in the flasks for a sufficient length of time to prevent unequal contraction by subsequent exposure.

Quality of Castings

The pipes and special castings shall be smooth, free from scales, lumps, blisters, sand holes and defects of every nature which unfit them for the use for which they are intended. No plugging or filling will be allowed.

Cleaning and Inspection

All pipes and special castings shall be thoroughly cleaned and subjected to a careful hammer inspection. No casting shall be coated unless entirely clean and free from rust, and approved in these respects by the engineer immediately before being dipped.

Coating

Every pipe and special casting shall be coated inside and out with coal-tar pitch varnish. The varnish shall be made from coal tar. To this material sufficient oil may be added to make a smooth coating, tough and tenacious when cold, and not brittle nor with any tendency to scale off.

Each casting shall be heated to a temperature of 300° F., immediately before it is dipped, and shall possess not less than this temperature at the time it is put in the vat. The ovens in which the pipes are heated shall be so arranged that all portions of the pipe shall be heated to an even temperature. Each casting shall remain in the bath at least five minutes.

The varnish shall be heated to a temperature of 300° F. (or less if the engineer shall so order), and shall be maintained at this temperature during the time the casting is immersed.

Fresh pitch and oil shall be added when necessary to keep the mixture at the proper consistency, and the vat shall be emptied of its contents and refilled with fresh pitch when deemed necessary by the engineer. After being coated the pipes shall be carefully drained of the surplus varnish. Any pipe or special casting that is to be recoated shall first be thoroughly scraped and cleaned.

Hydrostatic Test

When the coating has become hard, the straight pipes shall be subjected to a proof by hydrostatic pressure, and, if required by the engineer, they shall also be subjected to a hammer test under this pressure.

The pressures to which the different sizes and classes of pipes shall be subjected are as follows:

Classes	20-inch diameter and larger, pounds per square inch	Less than 20-inch diameter, pounds per square inch
Class A pipe	150	300
Class B pipe	200	300
Class C pipe	250	300
Class D pipe	300	300

Weighing

The pipes and special castings shall be weighed for payment under the supervision of the engineer after the application of the coal-tar pitch varnish. If desired by the engineer, the pipes and special castings shall be weighed after their delivery and the weights so ascertained shall be used in the final settlement, provided such weighing is done by a legalized weighmaster. Bids shall be submitted and a final settlement made upon the basis of a ton of 2000 pounds.

Contractor to Furnish Men and Materials

The contractor shall provide all tools, testing machines, materials and men necessary for the required testing, inspection and weighing at the foundry, of the pipes and special castings; and, should the purchaser have no inspector at the works, the contractor shall, if required by the engineer, furnish a sworn statement that all of the tests have been made as specified, this statement to contain the results of the tests upon the test bars.

Power of Engineer to Inspect

The engineer shall be at liberty at all times to inspect the material at the foundry, and the moulding, casting and coating of the pipes and special castings. The forms, sizes, uniformity and conditions of all pipes and other castings herein referred to shall be subject to his inspection and approval, and he may reject, without proving, any pipes or other casting which is not in conformity with the specifications or drawings.

Inspector to Report

The inspector at the foundry shall report daily to the foundry office all pipes and special castings rejected, with the causes for rejection.

Castings to be Delivered Sound and Perfect

All the pipes and other castings must be delivered in all respects sound and conformable to these specifications. The inspection shall not relieve the contractor of any of his obligations in this respect, and any defective pipe or other castings which may have passed the engineer at the works or elsewhere shall be at all times liable to rejection when discovered until the final completion and adjustment of the contract, provided, however, that the contractor shall not be held liable for pipes or special castings found to be cracked after they have been accepted at the agreed point of delivery. Care shall be taken in handling the pipes not to injure the coating, and no pipes or other material of any kind shall be placed in the pipes during transportation or at any time after they receive the coating.

Definition of the Word "Engineer"

Wherever the word "engineer" is used herein it shall be understood to refer to the engineer or inspector acting for the purchaser and to his properly authorized agents, limited by the particular duties intrusted to them.

Volume and Weight of Piled, Bell and Spigot Cast Iron Pipe

Size of pipe, inches	Head in feet	Thickness of metal, inches	Weight of one pipe in pounds	No. of pipes in one ton of 2240 pounds	Cubic feet in one ton of 2240 pounds	No. of pipes in 40 cubic feet	Pounds of pipe in 40 cubic feet	Cubic feet in one pipe
3	100	.38	167	13.41	21.414	24.935	4164.121	1.604
3	200	.42	185	12.11	19.796	24.465	4523.320	1.635
3	300	.45	200	11.20	18.961	23.626	4724.224	1.693
3	400	.45	200	11.20	18.961	23.626	4724.224	1.693
4	100	.40	230	9.74	23.646	16.479	3787.720	2.428
4	200	.42	243	9.26	22.953	16.135	3920.034	2.479
4	300	.45	260	8.61	22.873	15.754	4004.480	2.539
4	400	.47	265	8.45	21.823	15.491	4104.372	2.582
5	100	.42	295	7.59	26.537	11.433	3376.136	3.495
5	200	.45	315	7.11	25.356	11.222	3534.332	3.565
5	300	.48	338	6.63	24.135	10.983	3712.000	3.642
5	400	.51	355	6.31	23.503	10.738	3811.172	3.725
6	100	.43	364	6.15	28.825	8.359	3008.000	4.684
6	200	.47	393	5.70	27.285	8.356	3283.240	4.787
6	300	.51	426	5.25	25.764	8.177	3477.224	4.900
6	400	.54	445	5.03	25.114	8.017	3567.092	4.990
8	100	.47	513	4.36	33.425	5.224	2680.164	7.656
8	200	.51	567	3.95	30.833	5.118	2906.196	7.804
8	300	.56	624	3.59	28.666	5.009	3129.392	7.985
8	400	.61	665	3.37	27.456	4.906	3262.730	8.152
10	100	.50	685	3.27	37.400	3.454	2366.256	11.579
10	200	.56	765	2.93	34.676	3.388	2587.484	11.826
10	300	.62	852	2.63	31.800	3.317	2826.248	12.058
10	400	.68	920	2.43	30.266	3.216	2959.172	12.435
12	100	.53	870	2.57	41.230	2.497	2172.492	16.018
12	200	.60	985	2.27	37.218	2.444	2407.236	16.367
12	300	.68	1110	2.02	33.858	2.384	2646.288	16.778
12	400	.75	1210	1.98	34.839	2.159	2612.892	17.549
14	100	.56	1074	2.08	44.310	1.882	2021.388	21.252
14	200	.65	1229	1.82	39.798	1.831	2250.592	21.843
14	300	.73	1399	1.60	35.699	1.794	2509.568	22.298
14	400	.82	1540	1.45	33.242	1.757	2969.184	22.847
16	100	.60	1293	1.73	47.325	1.464	1893.864	27.308
16	200	.69	1496	1.50	41.829	1.434	2145.788	27.886
16	300	.79	1723	1.30	37.095	1.401	2415.256	28.535
16	400	.89	1900	1.18	36.020	1.316	2490.308	30.578
18	100	.63	1532	1.46	48.274	1.211	1855.876	33.019
18	200	74	1788	1.28	44.456	1.157	2068.864	34.569
18	300	.85	2065	1.08	38.572	1.124	2321.284	35.583
18	400	.96	2300	.974	35.441	1.100	2532.076	36.338

VOLUME AND WEIGHT OF PILED, BELL AND SPIGOT CAST IRON PIPE (*Continued*)

Size of pipe, inches	Head in feet	Thickness of metal, inches	Weight of one pipe in pounds	No. of pipes in one ton of 2240 pounds	Cubic feet in one ton of 2240 pounds	No. of pipes in 40 cubic feet	Pounds of pipe in 40 cubic feet	Cubic feet in one pipe
20	100	.66	1,788	1.28	53.874	.945	1778.040	41.893
20	200	.78	2,104	1.06	45.596	.938	1963.836	42.854
20	300	.91	2,444	.916	39.900	.918	2240.272	43.559
20	400	.03	2,740	.814	36.508	.891	2443.188	44.850
24	100	.75	2,407	.931	55.122	.679	1626.132	59.207
24	200	.87	2,803	.799	49.463	.646	1811.112	61.906
24	300	1.02	3,299	.679	43.122	.630	2080.876	63.415
24	400	1.16	3,680	.600	38.783	.619	2277.256	64.639
30	100	.87	3,482	.649	59.733	.434	1513.268	92.039
30	200	1.01	4,027	.556	52.760	.421	1697.492	94.892
30	300	1.19	4,783	.468	45.550	.411	1965.660	97.337
30	400	1.37	5,420	.413	41.047	.402	2181.364	99.387
36	100	.98	4,699	.476	63.567	.299	1407.388	133.544
36	200	1.14	5,460	.410	55.586	.295	1610.884	135.577
36	300	1.36	6,543	.342	47.019	.291	1903.636	137.484
36	400	1.58	7,490	.300	42.566	.282	2111.516	141.888
40	100	1.09	5,807	.386	63.591	.242	1409.936	164.745
40	200	1.23	6,525	.343	56.997	.240	1570.636	166.174
40	300	1.48	7,858	.285	48.909	.233	1831.588	171.610
40	400	1.72	9,050	.247	43.413	.227	2059.372	175.763
42	100	1.10	6,147	.364	66.117	.225	1353.628	181.640
42	200	1.28	7,100	.315	58.179	.216	1537.664	184.695
42	300	1.54	8,563	.258	48.802	.211	1810.768	189.157
42	400	1.79	9,890	.248	48.002	.206	2043.812	193.559
48	100	1.25	7,982	.281	65.246	.171	1370.164	233.023
48	200	1.41	8,946	.250	59.800	.167	1496.000	239.200
48	300	1.71	10,857	.206	50.862	.166	1758.940	246.903
48	400	1.99	12,550	.179	44.767	.163	2007.856	250.097
60	100	1.40	11,000	.203	74.817	.108	1193.836	368.559
60	200	1.68	13,260	.169	63.188	.107	1418.568	373.897
60	300	2.05	16,040	.139	52.903	.105	1685.760	380.599
60	400	2.41	18,970	.118	46.253	.102	1938.820	391.978

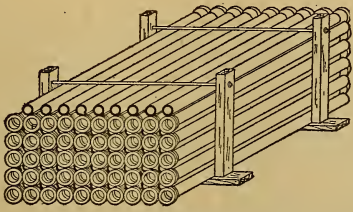


FIG. 103. — Pile of 100 Pipe.

Pattern Size and Weight of Cast Iron Pipe, 5/16 to 25/32 Inch Thick

	Thickness, inches	5/16	11/32	3/8	13/32	7/16	15/32	1/2	17/32	9/16	19/32	5/8	21/32	11/16	23/32	3/4	25/32
3-inch Pipe	Pattern size, inches	3 23/32	3 25/32	3 27/32	3 29/32	3 31/32	4 1/32	4 3/32	4 5/32	4 7/32	4 9/32	4 11/32	4 13/32	4 15/32	4 17/32	4 19/32	4 21/32
	Weight, pounds	132	147	162	177	193	208	224	240	256	272	288	306	324	342	360	378
4-inch Pipe	Pattern size, inches	4 23/32	4 25/32	4 27/32	4 29/32	4 31/32	5 1/32	5 3/32	5 5/32	5 7/32	5 9/32	5 11/32	5 13/32	5 15/32	5 17/32	5 19/32	5 21/32
	Weight, pounds	172	191	210	229	248	268	288	308	328	349	370	390	412	434	456	478
5-inch Pipe	Pattern size, inches	5 23/32	5 25/32	5 27/32	5 29/32	5 31/32	6 1/32	6 3/32	6 5/32	6 7/32	6 9/32	6 11/32	6 13/32	6 15/32	6 17/32	6 19/32	6 21/32
	Weight, pounds	212	235	258	281	304	328	351	376	400	425	450	474	500	525	551	577
6-inch Pipe	Pattern size, inches	6 3/4	6 13/16	6 7/8	6 15/16	7	7 1/16	7 1/8	7 3/16	7 1/4	7 5/16	7 3/8	7 7/16	7 1/2	7 9/16	7 5/8	7 11/16
	Weight, pounds	253	279	306	333	360	389	416	444	472	500	529	558	587	617	647	677
7-inch Pipe	Pattern size, inches	7 3/4	7 13/16	7 7/8	7 15/16	8	8 1/16	8 1/8	8 3/16	8 1/4	8 5/16	8 3/8	8 7/16	8 1/2	8 9/16	8 5/8	8 11/16
	Weight, pounds	292	323	354	385	416	448	479	513	545	577	610	643	676	709	743	777
8-inch Pipe	Pattern size, inches	8 3/4	8 13/16	8 7/8	8 15/16	9	9 1/16	9 1/8	9 3/16	9 1/4	9 5/16	9 3/8	9 7/16	9 1/2	9 9/16	9 5/8	9 11/16
	Weight, pounds	332	367	401	435	471	507	543	579	616	652	689	726	765	801	839	877
9-inch Pipe	Pattern size, inches	9 13/16	9 7/8	9 15/16	10	10 1/16	10 1/8	10 3/16	10 1/4	10 5/16	10 3/8	10 7/16	10 1/2	10 9/16	10 5/8	10 11/16	10 3/4
	Weight, pounds	371	411	449	488	528	567	607	648	688	728	769	810	851	893	935	977
10-inch Pipe	Pattern size, inches	10 13/16	10 7/8	10 15/16	11	11 1/16	11 1/8	11 3/16	11 1/4	11 5/16	11 3/8	11 7/16	11 1/2	11 9/16	11 5/8	11 11/16	11 3/4
	Weight, pounds	412	455	497	540	584	627	671	715	759	804	849	893	939	985	1032	1077
12-inch Pipe	Pattern size, inches	....	12 29/32	12 31/32	13 1/32	13 3/32	13 5/32	13 7/32	13 9/32	13 11/32	13 13/32	13 15/32	13 17/32	13 19/32	13 21/32	13 23/32	13 25/32
	Weight, pounds	....	542	594	644	695	747	799	851	903	956	1008	1062	1115	1168	1222	1277
14-inch Pipe	Pattern size, inches	....	....	15	15 1/16	15 1/8	15 3/16	15 1/4	15 5/16	15 3/8	15 7/16	15 1/2	15 9/16	15 5/8	15 11/16	15 3/4	15 13/16
	Weight, pounds	....	....	689	748	807	867	927	987	1047	1108	1159	1230	1291	1352	1414	1476
16-inch Pipe	Pattern size, inches	....	....	....	17 1/16	17 1/8	17 3/16	17 1/4	17 5/16	17 3/8	17 7/16	17 1/2	17 9/16	17 5/8	17 11/16	17 3/4	17 13/16
	Weight, pounds	....	....	....	852	919	987	1055	1123	1191	1259	1329	1397	1466	1536	1606	1676
18-inch Pipe	Pattern size, inches	....	....	....	....	19 1/8	19 3/16	19 1/4	19 5/16	19 3/8	19 7/16	19 1/2	19 9/16	19 5/8	19 11/16	19 3/4	19 13/16
	Weight, pounds	....	....	....	....	1031	1106	1182	1258	1335	1411	1488	1562	1642	1720	1798	1876
20-inch Pipe	Pattern size, inches	....	....	....	....	....	21 1/4	21 5/16	21 3/8	21 7/16	21 1/2	21 9/16	21 5/8	21 11/16	21 3/4	21 13/16	21 7/8
	Weight, pounds	....	....	....	....	....	1226	1310	1394	1479	1563	1648	1732	1818	1903	1987	2075
22-inch Pipe	Pattern size, inches	....	....	....	....	....	....	23 5/16	23 3/8	23 7/16	23 1/2	23 9/16	23 5/8	23 11/16	23 3/4	23 13/16	23 7/8
	Weight, pounds	....	....	....	....	....	....	1437	1529	1622	1715	1808	1901	1994	2088	2182	2276
24-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	25 3/8	25 7/16	25 1/2	25 9/16	25 5/8	25 11/16	25 3/4	25 13/16	25 7/8
	Weight, pounds	....	....	....	....	....	....	....	1666	1766	1867	1968	2069	2171	2271	2373	2475
30-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	31 1/2	31 9/16	31 5/8	31 11/16	31 3/4	31 13/16	31 7/8	31 15/16
	Weight, pounds	....	....	....	....	....	....	....	....	2198	2322	2447	2572	2697	2823	2948	3075
36-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	37 3/4	37 13/16	37 7/8	37 15/16	38
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	3072	3222	3372	3523	3674

Pattern Size and Weight of Cast Iron Pipe, 13/16 to 1 9/32 Inches Thick

	Thickness, inches	13/16	27/32	7/8	29/32	15/16	31/32	1	1 1/32	1 1/16	1 3/32	1 1/8	1 5/32	1 3/16	1 7/32	1 1/4	1 9/32
3-inch Pipe	Pattern size, inches	4 23/32	4 25/32	4 27/32	4 29/32	4 31/32	5 1/32	5 3/32	....	....	....	....	....	....	....	....	....
	Weight, pounds	396	415	434	453	472	491	511	....	....	....	....	....	....	....	....	....
4-inch Pipe	Pattern size, inches	5 23/32	5 25/32	5 27/32	5 29/32	5 31/32	6 1/32	6 3/32	6 5/32	6 7/32	....	....	....	....	....	....	....
	Weight, pounds	500	522	545	568	591	615	639	663	687	....	....	....	....	....	....	....
5-inch Pipe	Pattern size, inches	6 23/32	6 25/32	6 27/32	6 29/32	6 31/32	7 1/32	7 3/32	7 5/32	7 7/32	7 9/32	....	....	....	....	....	....
	Weight, pounds	604	631	657	684	711	734	767	795	823	851	....	....	....	....	....	....
6-inch Pipe	Pattern size, inches	7 3/4	7 13/16	7 7/8	7 15/16	8	8 1/16	8 1/8	8 3/16	8 1/4	8 5/16	8 3/8	....	....	....	....	....
	Weight, pounds	708	738	769	802	837	863	895	932	959	992	1025	....	....	....	....	....
7-inch Pipe	Pattern size, inches	8 3/4	8 13/16	8 7/8	8 15/16	9	9 1/16	9 1/8	9 3/16	9 1/4	9 5/16	9 3/8	9 7/16	....	....	....	....
	Weight, pounds	811	846	880	916	951	987	1023	1059	1095	1132	1168	1206	....	....	....	....
8-inch Pipe	Pattern size, inches	9 3/4	9 13/16	9 7/8	9 15/16	10	10 1/16	10 1/8	10 3/16	10 1/4	10 5/16	10 3/8	10 7/16	10 1/2	....	....	....
	Weight, pounds	916	954	993	1032	1071	1111	1151	1189	1230	1271	1312	1353	1395	....	....	....
9-inch Pipe	Pattern size, inches	10 13/16	10 7/8	10 15/16	11	11 1/16	11 1/8	11 3/16	11 1/4	11 5/16	11 3/8	11 7/16	11 1/2	11 9/16	11 5/8	....	....
	Weight, pounds	1019	1062	1105	1148	1191	1234	1278	1322	1366	1411	1456	1501	1547	1593	....	....
10-inch Pipe	Pattern size, inches	11 13/16	11 7/8	11 15/16	12	12 1/16	12 1/8	12 3/16	12 1/4	12 5/16	12 3/8	12 7/16	12 1/2	12 9/16	12 5/8	12 11/16	....
	Weight, pounds	1123	1170	1216	1263	1311	1358	1406	1454	1503	1551	1600	1649	1698	1747	1797	....
12-inch Pipe	Pattern size, inches	13 27/32	13 29/32	13 31/32	14 1/32	14 3/32	14 5/32	14 7/32	14 9/32	14 11/32	14 13/32	14 15/32	14 17/32	14 19/32	14 21/32	14 23/32	14 25/32
	Weight, pounds	1331	1385	1440	1495	1550	1606	1662	1718	1774	1831	1887	1944	2001	2059	2117	2175
14-inch Pipe	Pattern size, inches	15 7/8	15 15/16	16	16 1/16	16 1/8	16 3/16	16 1/4	16 5/16	16 3/8	16 7/16	16 1/2	16 9/16	16 5/8	16 11/16	16 3/4	16 13/16
	Weight, pounds	1538	1601	1664	1727	1790	1853	1917	1982	2046	2110	2175	2240	2305	2371	2437	2502
16-inch Pipe	Pattern size, inches	17 7/8	17 15/16	18	18 1/16	18 1/8	18 3/16	18 1/4	18 5/16	18 3/8	18 7/16	18 1/2	18 9/16	18 5/8	18 11/16	18 3/4	18 13/16
	Weight, pounds	1746	1817	1888	1958	2030	2101	2173	2245	2317	2380	2463	2536	2609	2683	2757	2831
18-inch Pipe	Pattern size, inches	19 7/8	19 15/16	20	20 1/16	20 1/8	20 3/16	20 1/4	20 5/16	20 3/8	20 7/16	20 1/2	20 9/16	20 5/8	20 11/16	20 3/4	20 13/16
	Weight, pounds	1954	2032	2111	2190	2269	2349	2429	2509	2589	2669	2750	2831	2913	2995	3076	3158
20-inch Pipe	Pattern size, inches	21 15/16	22	22 1/16	22 1/8	22 3/16	22 1/4	22 5/16	22 3/8	22 7/16	22 1/2	22 9/16	22 5/8	22 11/16	22 3/4	22 13/16	22 7/8
	Weight, pounds	2160	2246	2333	2420	2508	2596	2684	2778	2861	2949	3038	3127	3216	3306	3396	3486
22-inch Pipe	Pattern size, inches	23 15/16	24	24 1/16	24 1/8	24 3/16	24 1/4	24 5/16	24 3/8	24 7/16	24 1/2	24 9/16	24 5/8	24 11/16	24 3/4	24 13/16	24 7/8
	Weight, pounds	2370	2464	2558	2653	2748	2844	2940	3038	3132	3229	3326	3423	3520	3617	3715	3813
24-inch Pipe	Pattern size, inches	25 15/16	26	26 1/16	26 1/8	26 3/16	26 1/4	26 5/16	26 3/8	26 7/16	26 1/2	26 9/16	26 5/8	26 11/16	26 3/4	26 13/16	26 7/8
	Weight, pounds	2577	2679	2782	2883	2989	3092	3195	3299	3403	3507	3612	3717	3822	3928	4034	4140
30-inch Pipe	Pattern size, inches	32	32 1/16	32 1/8	32 3/16	32 1/4	32 5/16	32 3/8	32 7/16	32 1/2	32 9/16	32 5/8	32 11/16	32 3/4	32 13/16	32 1/8	32 15/16
	Weight, pounds	3201	3327	3453	3580	3707	3834	3962	4090	4218	4347	4476	4605	4734	4863	4993	5123
36-inch Pipe	Pattern size, inches	38 1/16	38 1/8	38 3/16	38 1/4	38 5/16	38 3/8	38 7/16	38 1/2	38 9/16	38 5/8	38 11/16	38 3/4	38 13/16	38 7/8	38 15/16	39
	Weight, pounds	3825	3976	4122	4279	4431	4583	4735	4887	5040	5193	5346	5499	5652	5806	5960	6114

Pattern Size and Weight of Cast Iron Pipe, 1 5/16 to 1 3/4 Inches Thick

Pipe	Thickness, inches	1 5/16	1 11/32	1 3/8	1 13/32	1 7/16	1 13/32	1 1/2	1 17/32	1 9/16	1 19/32	1 5/8	1 21/32	1 11/16	1 23/32	1 3/4
3-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
5-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
6-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
7-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
9-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
10-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
12-inch Pipe	Pattern size, inches	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
14-inch Pipe	Pattern size, inches	16 7/8	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	2569	....	....	....	....	....	....	....	....	....	....	....	....	....	....
16-inch Pipe	Pattern size, inches	18 7/8	18 15/16	19	....	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	2905	2979	3054	....	....	....	....	....	....	....	....	....	....	....	....
18-inch Pipe	Pattern size, inches	20 7/8	20 15/16	21	21 1/16	....	....	....	....	....	....	....	....	....	....	....
	Weight, pounds	3240	3322	3405	3488	....	....	....	....	....	....	....	....	....	....	....
20-inch Pipe	Pattern size, inches	22 15/16	23	23 1/16	23 1/8	23 3/16	23 1/4	....	....	....	....	....	....	....	....	....
	Weight, pounds	3576	3666	3757	3848	3939	4030	....	....	....	....	....	....	....	....	....
22-inch Pipe	Pattern size, inches	24 15/16	25	25 1/16	25 1/8	25 3/16	25 1/4	25 5/16	....	....	....	....	....	....	....	....
	Weight, pounds	3912	4010	4109	4208	4307	4406	4506	....	....	....	....	....	....	....	....
24-inch Pipe	Pattern size, inches	26 15/16	27	27 1/16	27 1/8	27 3/16	27 1/4	27 5/16	27 3/8	27 7/16	....	....	....	....	....	....
	Weight, pounds	4246	4352	4459	4566	4674	4782	4890	4998	5106	....	....	....	....	....	....
30-inch Pipe	Pattern size, inches	33	33 1/16	33 1/8	33 3/16	33 1/4	33 5/16	33 3/8	33 7/16	33 1/2	33 9/16	33 5/8	....	....	....	....
	Weight, pounds	5253	5384	5515	5646	5777	5908	6040	6172	6304	6436	6569	....	....	....	....
36-inch Pipe	Pattern size, inches	39 1/16	39 1/8	39 3/16	39 1/4	39 5/16	39 3/8	39 7/16	39 1/2	39 9/16	39 5/8	39 11/16	39 3/4	39 13/16	39 7/8	39 15/16
	Weight, pounds	6268	6428	6576	6731	6886	7041	7196	7351	7507	7663	7829	7985	8141	8298	8455

Pattern Size and Weight of Cast Iron Pipe, 3/4 to 1 19/32 Inches Thick

	Thickness, inches	3/4	25/32	13/16	27/32	7/8	29/32	15/16
40-inch	Pattern size, inches	42	42 1/16	42 1/8	42 3/16	42 1/4	42 5/16	42 3/8
Pipe	Weight, pounds	3910	4075	4240	4405	4737	4903	4903
42-inch	Pattern size, inches	....	....	44 1/8	44 3/16	44 1/4	44 5/16	44 3/8
Pipe	Weight, pounds	....	....	4440	4615	4790	4965	5140
48-inch	Pattern size, inches	....	....	....	....	....	....	50 7/16
Pipe	Weight, pounds	....	....	....	....	....	....	5969
60-inch	Pattern size, inches	....	....	....	....	....	....	....
Pipe	Weight, pounds	....	....	....	....	....	....	....

	Thickness, inches	31/32	1	1 1/32	1 1/16	1 3/32	1 1/8	1 5/32
40-inch	Pattern size, inches	42 7/16	42 1/2	42 9/16	42 5/8	42 11/16	42 3/4	42 13/16
Pipe	Weight, pounds	5070	5237	5404	5572	5740	5908	6077
42-inch	Pattern size, inches	44 7/16	44 1/2	44 9/16	44 5/8	44 11/16	44 3/4	44 13/16
Pipe	Weight, pounds	5316	5492	5668	5844	6021	6198	6375
48-inch	Pattern size, inches	50 1/2	50 9/16	50 5/8	50 11/16	50 3/4	50 13/16	50 7/8
Pipe	Weight, pounds	6068	6267	6467	6667	6867	7067	7268
60-inch	Pattern size, inches	....	....	....	62 7/8	62 15/16	63	63 1/16
Pipe	Weight, pounds	....	....	....	8282	8532	8782	9032

	Thickness, inches	1 3/16	1 7/32	1 1/4	1 9/32	1 5/16	1 11/32	1 3/8
40-inch	Pattern size, inches	42 7/8	42 15/16	43	43 1/16	43 1/8	43 3/16	43 1/4
Pipe	Weight, pounds	6246	6415	6585	6755	6925	7096	7267
42-inch	Pattern size, inches	44 7/8	44 15/16	45	45 1/16	45 1/8	45 3/16	45 1/4
Pipe	Weight, pounds	6552	6730	6908	7086	7264	7443	762
48-inch	Pattern size, inches	50 15/16	51	51 1/16	51 1/8	51 3/16	51 1/4	51 5/16
Pipe	Weight, pounds	7469	7670	7871	8073	8275	8477	8679
60-inch	Pattern size, inches	63 1/8	63 3/16	63 1/4	63 5/16	63 3/8	63 7/16	63 1/2
Pipe	Weight, pounds	9282	9532	9782	10,032	10,283	10,534	10,785

	Thickness, inches	1 13/32	1 7/16	1 15/32	1 1/2	1 17/32	1 9/16	1 19/32
40-inch	Pattern size, inches	43 5/16	43 3/8	43 7/16	43 1/2	43 9/16	43 5/8	43 11/16
Pipe	Weight, pounds	7438	7610	7782	7954	8127	8300	8473
42-inch	Pattern size, inches	45 5/16	45 3/8	45 7/16	45 1/2	45 9/16	45 5/8	45 11/16
Pipe	Weight, pounds	7801	7980	8160	8340	8520	8700	8881
48-inch	Pattern size, inches	51 3/8	51 7/16	51 1/2	51 9/16	51 5/8	51 11/16	51 3/4
Pipe	Weight, pounds	8882	9083	9288	9491	9695	9899	10,103
60-inch	Pattern size, inches	63 9/16	63 5/8	63 11/16	63 3/4	63 13/16	63 7/8	63 15/16
Pipe	Weight, pounds	11,086	11,337	11,588	11,839	12,091	12,343	12,545

Pattern Size and Weight of Cast Iron Pipe, 1⅝ to 2 9/32 Inches Thick

	Thickness, inches	1⅝	1 21/32	1 11/16	1 23/32	1¾	1 25/32
40-inch	Pattern size, inches........	43¾	43 13/16	43⅞	43 15/16	44	44 1/16
Pipe	Weight, pounds............	8647	8821	8995	9170	9345	9520
42-inch	Pattern size, inches........	45¾	45 13/16	45⅞	45 15/16	46	46 1/16
Pipe	Weight, pounds............	9062	9243	9424	9606	9788	9970
48-inch	Pattern size, inches........	51 13/16	51⅞	51 15/16	52	52 1/16	52⅛
Pipe	Weight, pounds............	10,307	10,512	10,717	10,922	11,127	11,333
60-inch	Pattern size, inches........	64	64 1/16	64⅛	64 3/16	64¼	64 5/16
Pipe	Weight, pounds............	12,847	13,099	13,357	13,603	13,856	14,109

	Thickness, inches	1 13/16	1 27/32	1⅞	1 29/32	1 15/16	1 31/32
40-inch	Pattern size, inches........	44⅛	44 3/16	44¼	.....	.....	.....
Pipe	Weight, pounds............	9688	9862	10,048	.....	.....	.....
42-inch	Pattern size, inches........	46⅛	46 3/16	46¼	46 5/16	46⅜	.....
Pipe	Weight, pounds............	10,152	10,335	10,518	10,700	10,885	.....
48-inch	Pattern size, inches........	52 3/16	52¼	52 5/16	52⅜	52 7/16	52½
Pipe	Weight, pounds............	11,539	11,745	11,951	12,158	12,365	12,572
60-inch	Pattern size, inches........	64⅜	64 7/16	64 1/16	64 9/16	64⅝	64 11/16
Pipe	Weight, pounds............	14,362	14,615	14,868	15,121	15,374	15,628

	Thickness, inches	2	2 1/32	2 1/16	2 3/32	2⅛
40-inch	Pattern size, inches........	......	....	....	....	....
Pipe	Weight, pounds............	......	....	....	....	....
42-inch	Pattern size, inches........	......	....	....	....	....
Pipe	Weight, pounds............	......	....	....	....	....
48-inch	Pattern size, inches........	52 9/16	52⅝	52 11/16	52¾	52 13/16
Pipe	Weight, pounds............	12,779	12,987	13,195	13,443	13,611
60-inch	Pattern size, inches........	64¾	64 13/16	64⅞	64 15/16	65
Pipe	Weight, pounds............	15,882	16,136	16,390	16,644	16,898

	Thickness, inches	2 5/32	2 3/16	2 7/32	2¼	2 9/32
40-inch	Pattern size, inches........	......	....	....	....	....
Pipe	Weight, pounds............	......	....	....	....	....
42-inch	Pattern size, inches........	......	....	....	....	....
Pipe	Weight, pounds............	......	....	....	....	....
48-inch	Pattern size, inches........	......	....	....	....	....
Pipe	Weight, pounds............	......	....	....	....	....
60-inch	Pattern size, inches........	65 1/16	65⅛	65 3/16	65¼	65 5/16
Pipe	Weight, pounds............	17,152	17,407	17,662	17,917	18,172

CHAPTER XV

MECHANICAL ANALYSIS

While chemical analysis is absolutely necessary for the determination of the constituents of iron and the fuels, and is of greatest importance to the foundryman as a guide in their purchase, chemists cannot, however, as yet predict with certainty the physical properties which will result from the mixture of irons possessing identical composition.

Test bars have shown, that of two irons, precisely the same in their chemical constituents, one may exceed the other in tensile strength by as much as 50 per cent. No satisfactory explanation of the discrepancy has been made. Various suggestions, attributing the cause to the ores, changes of temperature in the furnace, to difference in cooling, etc., are offered, but the problem is still unsolved.

Whatever may be the cause of these differences, the foundryman needs some means of quickly detecting and correcting them. He should have prompt information as to shrinkage, softness and strength of his castings.

During 1885, Mr. Keep made the important discovery that the shrinkage of test bars varied inversely as the silicon content, and that by measurement of shrinkage the silicon is practically determined.

His investigations resulted in pointing out the intimate relations which exist between shrinkage and the other properties of cast iron, both chemical and physical. Mr. Keep's conclusions as to the importance of mechanical analysis are summarized as follows:

The physical properties of the casting are not wholly dependent upon its chemical composition.

Mechanical analysis measures the physical properties of the iron, which are, shrinkage, strength, deflection, set and depth of chill. The measure of these properties shows the combined influence of each element in the chemical composition, and in addition thereto, it shows the influence of fuel and every varying condition attending melting.

These influences, particularly that of sulphur, are counteracted by the use of silicon.

The measurement of shrinkage tells whether more or less silicon is needed to bring the quality of the casting to an accepted standard of excellence.

Instead of calculating the chemical composition and predicting the physical properties, mechanical analysis ascertains the physical properties first, and determines from the shrinkage whether more or less silicon is required to produce castings of a given standard. Measurement of shrinkage is made quickly at a nominal cost and alone gives all necessary information.

It tells the founder exactly what physical properties his castings have and exactly what to do to bring each of those properties to standard. By this method a founder can determine whether a low-priced iron is suitable for his use.

Having fixed upon a standard, he can ascertain during the heat whether the mixture is of the desired quality, and if necessary can increase or decrease the silicon, according as the shrinkage should be reduced or increased.

Mechanical analysis answers all the requirements of the ordinary founder. Its simplicity renders the employment of an expert unnecessary.

Pig iron and coke, having been purchased upon guaranteed analysis, an occasional analysis of the castings is only required.

In a report to The American Society of Mechanical Engineers, Mr. Keep presents a Shrinkage Chart and Strength Table, which are given below with his directions for using them.

Shrinkage Chart

W. J. Keep

While the tensile tests show an increase of strength with an increase of phosphorus, yet the transverse tests seem to show that phosphorus reduces strength. This is also general shop experience.

Sulphur. — There is not in these tests enough uniformity between the percentage of sulphur and the strength to show any decided influence, but the indication is that sulphur decreases strength. In some cases sulphur might add to strength by causing the grain to be closer.

Manganese. — The percentage is too nearly the same in these series to show any influence on strength.

By comparing strengths and chemical composition of the irons nearest alike, with all chemical elements nearly alike, and no scrap, but with quite different strengths, it is very evident that strength is dependent upon something outside of the ordinary chemical composition.

Slow cooling decreases strength by making the grain of a casting coarse and more open. The larger the casting the weaker it becomes per square inch of section. The weakness is not caused by a decrease in combined carbon because a complete analysis of each size of test bar

(Transactions, American Society of Mechanical Engineers, Vol. XVI, p. 1100) shows the same combined carbon in all sizes of many series, but in all cases the strength per unit of section decreased as the size increased.

Strength of any size of test bar cannot be calculated by any mathematical formula from the measured strength of another size, because the grain changes by slow cooling.

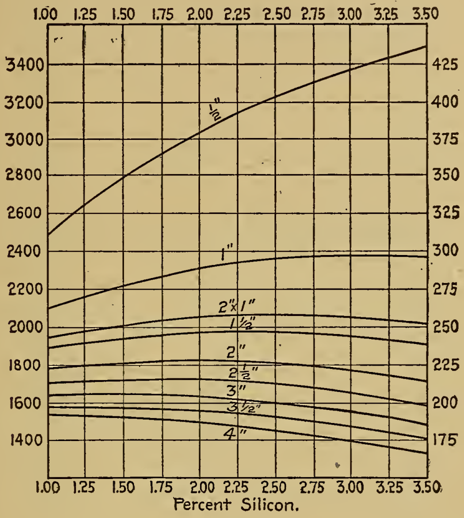


Fig. 104.

Tensile Strength Chart. — Fig. 105 shows this chart. The dotted line estimated.

"*Table for Obtaining the Strength of any Size of Test Bar from the Measured Strength of the Standard Test Bar.* — Table on p. 375 is calculated for a standard 1-inch square test bar. Measure the shrinkage per foot of the standard test bar, then on the shrinkage chart, Fig. 105, find this shrinkage on the left-hand margin and follow horizontally until you intersect the line of the measured test bar. Follow the vertical line at the intersection to the top of the chart, and you find the percentage of silicon that is expected to produce the shrinkage. Find this same percentage at the top of Table 1, and follow down to the size of test bar that you wish the strengths of. If you wish the actual strength use the lower figures as multiplier of the measured strength of the standard 1-inch bar. If you wish the strength of a section 1 inch square by 12 inches long of the required test bar use the upper number to multiply by."

"If you have the strength of any size of test bar other than a 1-inch bar and know the silicon percentage, divide such strength by the lower

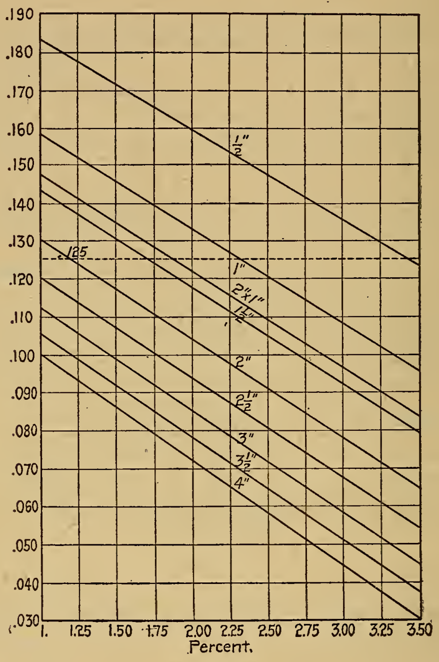


FIG. 105.

number for the bar, or if you have the strength of a section of the required test bar 1 inch square by 12 inches long, divide by the upper number, and the result in either case is the strength of the standard 1-inch bar."

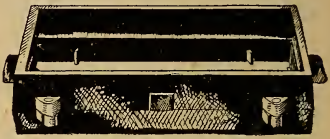
"*To find the Strength of any Casting.* — Divide the cubic contents of the casting by the square inches of cooling surface, and the quotient is the cooling ratio. If the casting has a large flat surface the edges may be neglected; for example, a casting 1 inch thick and 24 inches square.

Keep's Strength Table

Per cent of silicon	1.00 per cent	1.25 per cent	1.50 per cent	1.75 per cent	2.00 per cent	2.25 per cent	2.50 per cent	2.75 per cent	3.00 per cent	3.25 per cent	3.50 per cent
Size of test bar:											
½ inch square……	1.1790 .1473	1.2460 .1558	1.2530 .1567	1.2870 .1610	1.3180 .1648	1.3460 .1683	1.3700 .1713	1.3940 .1743	1.4180 .1772	1.4430 .1804	1.4710 .1839
1 inch square………	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2 × 1 inch square…	.9286 1.8570	.9188 1.8380	.9095 1.8190	.8982 1.7960	.8932 1.7870	.8860 1.7720	.8787 1.7570	.8750 1.7500	.8587 1.7170	.8586 1.7170	.8520 1.7040
1½ inch square……	.8976 3.0290	.8863 2.9910	.8733 2.9470	.8629 2.9120	.8562 2.8900	.8473 2.8600	.8383 2.8290	.8326 2.8100	.8228 2.7770	.8122 2.7410	.8055 3.1410
2 inch square………	.8429 6.7430	.8306 6.6450	.8167 6.5340	.8009 6.4070	.7908 6.3270	.7806 6.2450	.7681 6.1450	.7585 6.0680	.7447 5.9580	.7342 5.8730	.7225 5.7800
2½ inch square……	.8117 12.6800	.7935 12.4000	.7783 12.1600	.7611 11.8800	.7473 11.6800	.7365 11.4900	.7213 11.2700	.7098 11.0900	.6962 10.8800	.6857 10.7100	.6701 10.4700
3 inch square………	.7833 21.6400	.7610 20.5500	.7421 20.0400	.7235 19.5300	.7102 19.1800	.6968 18.8100	.6808 18.3800	.6695 18.0800	.6540 17.6600	.6413 17.3200	.6300 17.0100
3½ inch square……	.7524 32.6200	.7309 31.3400	.7104 30.4600	.6925 29.6900	.6776 29.0500	.6624 28.4000	.6468 27.7300	.6356 27.2500	.6224 26.6800	.6097 25.8400	.5962 25.5600
4 inch square………	.7654 46.7800	.7100 45.4400	.6900 44.1600	.6681 42.7600	.6493 41.5500	.6344 40.6000	.6191 39.6300	.6059 38.7800	.5907 37.8100	.5781 36.9900	.5646 36.1000

A strip one inch wide and 24 inches long would have 24 cubic inches contents and 48 square inches of cooling surface. 24 ÷ 48 = 0.5 ratio. Find this ratio at the top of the chart, Fig. 105, and follow down to the

Iron follow-board with yokes and brass pasterns for test bars ½ in. square × 12 in. long.



Iron Flask.

Fig. 106.

diagonal and we find that a 2-inch square test bar represents the strength of the casting."

"With the shrinkage of a standard 1-inch test bar, cast at the same time as the casting, find on the shrinkage chart the percentage of silicon in the casting. Then in the Table find the upper multiplier for a 2-inch test bar. This multiplied by the measured strength of the standard test bar gives the strength of a section of the casting 1 inch square and 12 inches long."

Taper steel scale which measures shrinkage.

Fig. 107.

Mechanical analysis covers tests for shrinkage, strength and hardness.

Figs. 106 and 107 show a device designed by Mr. Keep for determining shrinkage.

Determinations for strength are generally made by taking the transverse strength and deflection.

The Riehle Machine as shown in Fig. 108 is in common use for this purpose.

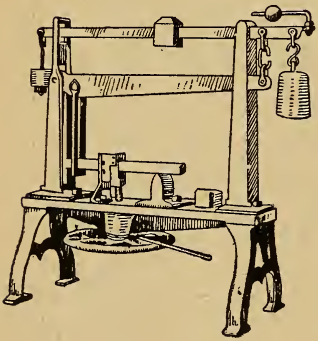


Fig. 108.

This illustration represents faithfully the general appearance of this machine. The specimen is shown in position. The weighing-beams and levers are all carefully sealed to the standard of the *United States Government*, and guaranteed to be accurate and reliable.

Operation

The weighing-beam must be balanced before the specimen is arranged for testing. The wheel shown must be moved from left to right, and, as the beam rises, the poise must be moved out to restore the equipoise. If more strain is required to break the specimen than can be weighed by the poise, move the poise back to zero and place the loose weight on the weight dish shown at the extreme left (small end) of weighing-beam, and move the poise out as before, until the test is completed. The calculations are made so that the beam registers the center load.

Dimensions

Extreme length	3 ft. 2 in.
Extreme height	3 ft. 1 in.
Extreme width	1 ft. 4 in.
Weight	200 lbs.
Shipping weight	230 lbs.

Adaptation

Transverse specimens	12 in. long

Hardness

This property may be measured by embedding steel balls in the casting to be tested, by Turner's Scleroscope (see cut, page 114, Turner's Lectures on "Founding"); or by Keep's Machine (see cut, page 187, "Cast Iron"). The latter method is the more simple and gives accurate results. A small high speed drill may be used for this purpose, but it must be so arranged that the load on the spindle will be constant.

Standard Methods for Determining the Constituents of Cast Iron

As reported by the Committee of the American Foundrymen's Association, Philadelphia Convention, May 21–24, 1907.

Determination of Silicon

Weigh one gram of sample, add 30 c.c. nitric acid (1.13 sp. gr.); then 5 c.c. sulphuric acid (conc.). Evaporate on hot plate until all fumes are driven off. Take up in water and boil until all ferrous sulphate is dissolved. Filter on an ashless filter, with or without suction pump, using a cone. Wash once with hot water, once with hydrochloric acid, and three or four times with hot water. Ignite, weigh and evaporate with a few drops of sulphuric acid and 4 or 5 c.c. of hydrofluoric acid. Ignite slowly and weigh. Multiply the difference in weight by 0.4702, which equals the per cent of silicon.

Determination of Sulphur

Dissolve slowly a three-gram sample of drillings in concentrated nitric acid in a platinum dish covered with an inverted watch glass. After the iron is completely dissolved, add two grams of potassium nitrate, evaporate to dryness and ignite over an alcohol lamp at red heat. Add 50 c.c. of a one per cent solution of sodium carbonate, boil for a few minutes, filter, using a little paper pulp in the filter if desired, and wash with a hot one per cent sodium carbonate solution. Acidify the filtrate with hydrochloric acid, evaporate to dryness, take up with 50 c.c. of water and 2 c.c. of concentrated hydrochloric acid, filter, wash and after diluting the filtrate to about 100 c.c. cool and precipitate with barium chloride. Filter, wash well with hot water, ignite and weigh as barium sulphate, which contains 13.733 per cent of sulphur.

Determination of Phosphorus

Dissolve 2 grams sample in 50 c.c. nitric acid (sp. gr., 1.13), add 10 c.c. hydrochloric acid and evaporate to dryness. In case the sample contains a fairly high percentage of phosphorus it is better to use half the above quantities. Bake until free from acid, redissolving in 25 to 30 c.c. of concentrated hydrochloric acid; dilute to about 60 c.c., filter and wash. Evaporate to about 25 c.c., add 20 c.c. concentrated nitric acid, evaporate until a film begins to form, add 30 c.c. of nitric acid (sp. gr., 1.20) and again evaporate until a film begins to form. Dilute to about 150 c.c. with hot water and allow it to cool. When the solution is between 70 degrees and 80 degrees C. add 50 c.c. of molybdate solution. Agitate the solution a few minutes, then filter on a tarred Gooch crucible having a paper disc at the bottom. Wash three times with a 3 per cent nitric acid solution and twice with alcohol. Dry at 100 degrees to 105 degrees C. to constant weight. The weight multiplied by 0.0163 equals the per cent of phosphorus in a 1-gram sample.

To make the molybdate solution add 100 grams molybdic acid to 250 c.c. water, and to this add 150 c.c. ammonia, then stir until all is dissolved and add 65 c.c. nitric acid (1.42 sp. gr.). Make another solution by adding 400 c.c. concentrated nitric acid to 1100 c.c. water, and when the solutions are cool, pour the first slowly into the second with constant stirring and add a couple of drops of ammonium phosphate.

Determination of Manganese

Dissolve one and one-tenth grams of drillings in 25 c.c. nitric acid (1.13 sp. gr.), filter into an Erlenmeyer flask and wash with 30 c.c. of the same acid. Then cool and add about one-half gram of bismuthate until a permanent pink color forms. Heat until the color has disappeared, with or without the precipitation of manganese dioxide, and then add either sulphurous acid or a solution of ferrous sulphate until the solution is clear. Heat until all nitrous oxide fumes have been driven off, cool to about fifteen degrees C.; add an excess of sodium bismuthate — about one gram — and agitate for two or three minutes. Add 50 c.c. water containing 30 c.c. nitric acid to the litre, filter on an asbestos filter into an Erlenmeyer flask, and wash with fifty to one hundred c.c. of the nitric acid solution. Run in an excess of ferrous sulphate and titrate back with potassium permanganate solution of equal strength. Each c.c. of N-10 ferrous sulphate used is equal to 0.10 per cent of manganese.

Determination of Total Carbon

This determination requires considerable apparatus; so in view of putting as many obstacles out of the way of its general adoption in cases of dispute, your committee has left optional several points which were felt to bring no chance of error into the method.

The train shall consist of a pre-heating furnace, containing copper oxide (Option No. 1) followed by caustic potash (1.20 sp. gr.), then calcium chloride, following which shall be the combustion furnace in which either a porcelain or platinum tube may be used (Option No. 2). The tube shall contain four or five inches of copper oxide between plugs of platinum gauze, the plug to the rear of the tube to be at about the point where the tube extends from the furnace. A roll of silver foil about two inches long shall be placed in the tube after the last plug of platinum gauze. The train after the combustion tube shall be anhydrous cupric sulphate, anhydrous cuprous chloride, calcium chloride, and the absorption bulb of potassium hydrate (sp. gr., 1.27) with prolong filled with calcium chloride. A calcium chloride tube attached to the aspirator bottle shall be connected to the prolong.

In this method a single potash bulb shall be used. A second bulb is sometimes used for a counterpoise being more liable to introduce error than correct error in weight of the bulb in use, due to change of temperature or moisture in the atmosphere.

The operation shall be as follows: To 1 gram of well-mixed drillings add 100 c.c. of potassium copper chloride solution and 7.5 c.c. of hydrochloric acid (conc.). As soon as dissolved, as shown by the disappearance of all copper, filter on previously washed and ignited asbestos. Wash thoroughly the beaker in which the solution was made with 20 c.c. of dilute hydrochloric acid [1 to 1], pour this on the filter and wash the carbon out of the beaker by means of a wash bottle containing dilute hydrochloric acid [1 to 1] and then wash with warm water out of the filter. Dry the carbon at a temperature between 95 and 100 degrees C.

Before using the apparatus a blank shall be run and if the bulb does not gain in weight more than 0.5 milligram, put the dried filter into the ignition tube and heat the pre-heating furnace and the part of the combustion furnace containing the copper oxide. After this is heated start the aspiration of oxygen or air at the rate of three bubbles per second, to show in the potash bulb. Continue slowly heating the combustion tube by turning on two burners at a time, and continue the combustion for 30 minutes if air is used; 20 minutes if oxygen is used. (The Shimer crucible is to be heated with a blast lamp for the same length of time.)

When the ignition is finished turn off the gas supply gradually so as to allow the combustion tube to cool off slowly and then shut off the oxygen supply and aspirate with air for 10 minutes. Detach the potash bulb and prolong, close the ends with rubber caps and allow it to stand for 5 minutes, then weigh. The increase in weight multiplied by 0.27273 equals the percentage of carbon.

The potassium copper chloride shall be made by dissolving one pound of the salt in one litre of water and filtering through an asbestos filter.

Option No. 1. — While a pre-heater is greatly to be desired, as only a small percentage of laboratories at present use them, it was decided not to make the use of one essential to this method; subtraction of the weight of the blank to a great extent eliminating any error which might arise from not using a pre-heater.

Option No. 2. — The Shimer and similar crucibles are largely used as combustion furnaces and for this reason it was decided to make optional the use of either the tube furnace or one of the standard crucibles. In case the crucible is used it shall be followed by a copper tube 3/16 inch inside diameter and ten inches long, with its ends cooled by water jackets. In the center of the tube shall be placed a disk of platinum gauze, and for three or four inches in the side towards the crucible shall be silver foil and for the same distance on the other side shall be copper oxide. The ends shall be plugged with glass wool, and the tube heated with a fish tail burner before the aspiration of the air is started.

Graphite

Dissolve one-gram sample in 35 c.c. nitric acid [1.13 sp. gr.], filter on asbestos, wash with hot water, then with potassium hydrate [1.1 sp. gr.] and finally with hot water. The graphite is then ignited as specified in the determination of total carbon.

CHAPTER XVI

MALLEABLE CAST IRON

The process of rendering iron castings malleable was discovered by Réaumur in 1722 and is essentially the same as that pursued at the present day.

McWilliams and Longmuir divide malleable castings into two classes.

1. Black Heart

Black heart has a silvery outside and black inside, with a silky lustre. This is made of a hard white iron, containing from 3 to 4 per cent carbon, as hard carbide of iron.

By the process of annealing, to be described later, the carbide of iron is decomposed into free carbon (annealing carbon) and iron; leaving a soft malleable iron, which contains nearly all of the initial carbon but in the free state finely divided and intermixed with the iron.

Black heart is mostly made in America. The process is conducted much more rapidly than that of the ordinary (or Réaumur process), but requires more skill and scientific information. The iron used must be low in silicon and sulphur but need not necessarily be a white iron.

The analysis should approximate to, silicon, 1 per cent to 0.5 per cent; sulphur, .05 per cent as a maximum; phosphorus, .1 per cent maximum; manganese, .5 per cent maximum and carbon 3 per cent.

The principle involved is that of taking white iron castings of suitable composition, heating them to high temperature and converting them to the malleable condition by precipitating the carbon in a fine state of division, as annealing carbon. High temperature shortens the process, but it has been found more desirable to use a lower temperature and longer anneal, as the desired change is more readily secured.

The method of molding is the same as for gray iron, with same allowance for shrinkage. The amount of feeder required varies from 12.5 to 25 per cent of the weight of casting. Skill is required to make solid castings with minimum amount of metal.

After cleaning in the usual manner the castings are packed in cast iron boxes of varying sizes to suit their character, with iron scale or sand, bone dust or fire clay; the boxes are covered with lids and luted, then stacked in the annealing oven (to be described later). The temperature of the oven is gradually raised to about 1100° C., maintained at that point for two days and then allowed to drop slowly until sufficiently cool to permit removal of the boxes.

The composition of the castings after annealing is only altered in the carbon, the total amount being somewhat less but practically all present in the free state. The composition of castings made by one of the largest English makers is as follows:

Si 0.5; S 0.04; P. 0.07; Mn 0.4; graphitic carbon 2.5; combined carbon 0.05. A test piece ½-inch square bent 180° — cold; tensile strength 40,000 pounds per square inch, elongation 6 per cent in 2 inches, reduction of area 9 per cent.

Black heart is more reliable for light than for heavy work. To avoid the introduction of sulphur, the pig iron is usually melted in an air furnace.

Messrs. Charpy & Grenet's experiments on irons of the following compositions are given herewith.

No.	Silicon	Sulphur	Phosphorus	Manganese	Carbon
1	.70	.01	trace	.03	3.60
2	.27	.02	.02	trace	3.40
3	.80	.02	.03	trace	3.25
4	1.25	.01	.01	.12	3.20
5	2.10	.02	.01	.12	3.30

These irons were poured into cold water and contained no appreciable amount of graphite, excepting the last which had 20 per cent. Samples of these were subjected to various reheatings and to ascertain as nearly as practicable the condition at any one temperature, the samples were quenched at that temperature and then analyzed.

1. Heated at 1100° C. or any low temperature for long periods gave no graphitic carbon; but at 1150° C. the separation of graphitic carbon was produced.

2. Heated for four hours each at 700°, 800°, 900° and 1000° C. showed no free carbon; but it appeared in heating to 1100° C.

3. Showed traces at 800° C.

4, 5. Showed traces at 650° C.

In the case of No. 5, after heating at 650° C. for 6 hours, the content of graphitic carbon had increased from 0.10 to 2.83 per cent.

The separation of graphite, once commenced, continues at temperatures inferior to those at which the action begins.

Thus: A sample of No. 1, heated at 1170° C. and quenched, contained only 0.50 graphitic carbon and 2.6 combined carbon, while another sample of the same cast iron, heated at the same time to 1170° C., cooled slowly to 700° C. and then quenched contained 1.87 graphitic carbon and 0.43 combined carbon.

Again a fragment of No. 3, heated to 1170° C. and quenched, contained 1.42 graphitic carbon and 1.69 combined carbon, while another fragment heated to 1170° C. cooled slowly to 700° C. and then quenched contained 2.56 graphitic carbon and 0.38 combined carbon.

At a constant temperature the separation of the graphite is effected progressively, at a rate that is the more gradual, the lower the temperature or the less the silicon content.

The authors show that these cast irons, with regard to the critical points, have the usual carbon change point, about 700° C., but that there is another well-marked arrest in heating at 1140°, 1165°, 1137° and 1165° C., for numbers 1, 2, 3, 4 and 5, respectively; and similarly in cooling at 1120°, 1130°, 1137° and 1145° C.

In an experiment made by W. H. Hatfield, with six bars, all containing: Si 1.0; S 0.04; P 0.04; Mn 0.22; graphitic carbon 2.83; combined carbon 0.08, all white irons as cast; variously heat-treated so as to give the same composition to analysis, but to have the free carbon in all states of division from fine in No. 1 to coarse in No. 6.

Bars 1 inch square by 18 inches long were tested transversely on knife edges 12 inches apart and gave

No.	Inches deflection	No.	Inches deflection
1	2¼	4	1 5/16
2	1⅝	5	1 3/16
3	1 9/16	6	⅝

before fracture; the gradually decreasing deflections given being due entirely to the increasing coarseness of the free carbon.

Another set of four test bars, containing 0.45, 0.90, 1.10–1.88 per cent silicon but otherwise similar in composition to the above; heat-treated so that all should have the same type of free or annealing carbon, gave 95°, 98°, 94° and 89°, respectively, when subjected to the ordinary bending test.

The microstructure of these bars consisted of ferrite or silicon ferrite speckled with annealing carbon, which if kept of suitable structure affects the malleability little more than does the slag in the case of wrought iron.

Pearlite, when present, after heat-treating white irons, greatly increases the tenacity, one sample having a tenacity of 32.6 tons per square inch, with an elongation of 6 per cent on 2 inches, and a bending angle of 90°, when treated so as to leave 0.35 per cent of carbon in the combined form and present as pearlite in the structure.

Another sample of the same general composition, but treated to leave only 0.06 per cent as combined carbon had a tenacity of 21.2 tons per square inch, elongation 11 per cent on two inches and a bending angle of 180° unbroken.

2. Ordinary or Réaumur Malleable Cast Iron

In this class of castings the carbon is completely eliminated, leaving a soft material similar in analysis to wrought iron.

It is stated that irons containing as much as 0.5 sulphur may be used in this class of castings. The irons employed are mottled or white, analyzing as follows: Si 0.5 to 0.9; S 0.25 to 0.35; P 0.05 to 0.08; Mn 0.1 to 0.2, total carbon 3½ per cent

It may be melted in the crucible, in the cupola, or in the air furnace. The cupola is more in general use in England than the air furnace.

The table below shows approximately the influence of remelting by the several processes.

Original pig iron	Crucible	Cupola	Reverb.	Siemens
C......3.5	3.4	3.4	3.2	3.2
Si...... .85	.82	.75	.65	.70
S....... .25	.30	.31	.27	.26
Mn..... .20	.10	.10	.10	.10
P...... .05	.05	.054	.052	.05

Whichever furnace is used it is necessary to have the metal fluid enough to fill the most intricate parts of the molds to be poured in any one batch. Molding operations are the same as for green sand, except that provision must be made for the narrow range of fluidity and the high contraction of white iron.

Allowance for shrinkage is ¼ inch to the foot. The castings after proper cleaning are packed in cast-iron boxes of suitable sizes, with red hematite ore broken up finely. New ore is not used alone but one part new is mixed thoroughly with four parts that have been used before; the castings are carefully packed in this mixture so that no two are in contact.

The oxygen from the ore oxidizes the carbon in the castings, gradually eliminating it. The ore, previous to use, is red oxide of iron (Fe_2O_3), but after the annealing process is found to be black oxide corresponding to the formula Fe_3O_4.

After stacking the boxes in the annealing oven, the temperature is gradually raised during 48 to 72 hours; maintained at the annealing temperature from 12 to 24 hours, then allowed from 48 to 72 hours to cool.

The length of time during which the high temperature is maintained varies with the thickness of the castings. For thick work the high temperature may have to be continued for a period increasing with the thickness of the castings up to 96 hours.

TYPICAL TEMPERATURE CURVE FOR ANNEALING OVEN

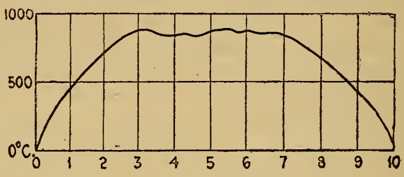


FIG. 109.

Some makers anneal at as low a temperature as 850° C. (see P. Long, "Metallurgy, Iron and Steel," page 130). Within reasonable limits, chemical composition of the castings in this process has little bearing on the result provided they are white iron as cast.

The silicon may run from 0.3 to 0.9; sulphur 0.05 to 0.5; phosphorus should be under 0.1; manganese causes trouble if over 0.5.

Castings made by this process give a tensile strength of 18 to 22 tons; an elongation of 2½ to 6 per cent on 2 inches and a reduction of area of 5 to 8 per cent, with a cold bend on ½-inch square, of 45° to 90°.

Mr. P. Longmuir obtained the following results from a commercial casting: Tensile strength, 27 tons; elongation, 5.7 per cent on 2 inches; reduction of area 10 per cent; it analyzed Si 0.65; S 0.3; P 0.04; Mn 0.15.

In the process of annealing the carbon only is affected, being considerably reduced in amount; what remains is partly free and partly combined. An annealed sample containing 0.6 per cent free carbon and 0.4 combined is considered good.

Mr. Percy Longmuir places the average silicon for good malleable castings at 0.6, sulphur 0.3, phosphorus 0.05, and combined carbon 3 to 3.5 per cent.

ANALYSES BEFORE AND AFTER ANNEALING

Constituents	Iron as cast	After prolonged annealing in iron ore
Total carbon	3.43	.10
Silicon	.45	.45
Sulphur	.06	.06
Phosphorus	.31	.32
Manganese	.53	.53

Interesting experiments were made by Mr. W. H. Hatfield of Sheffield, and results published in "The Foundry," Oct., 1909, by Mr. G. B. Waterhouse.

"Three converted bars of identical composition analyzing:

Constituents	Per cent	Constituents	Per cent
Total carbon	1.64	Manganese	trace
Combined carbon	1.64	Sulphur	.01
Silicon	.03	Phosphorus	.01

One was packed in charcoal, another in pure quartz sand, the third in a red hematite ore mixture, consisting of two parts old and one part new. The pots were placed close together in the annealing oven and slowly raised to about 800° C. This required about three days. They were held at this temperature for 24 hours, then raised to 900° C., held there for two days, then cooled slowly. Upon removal and breaking the following results appeared.

No. 1, from charcoal, broke short and gave a coarsely crystalline structure showing under the microscope absolutely no free carbon.

Its carbon was 1.63 per cent, the other elements remaining unchanged.

No. 2, from sand, was fairly tough but broke without bending. Fracture crystalline and steely. Its carbon was 0.74 per cent and again no free carbon was found.

No. 3, from the ore mixture, bent considerably before breaking and was fairly ductile. Its carbon was 0.15 per cent and again no free carbon could be found, the structure being of ferrite crystals. The experiments appearing to prove conclusively the possibility of carbon being removed without previous formation of free or temper carbon.

For the second series of experiments, an ordinary white iron was taken containing:

Constituents	Per cent	Constituents	Per cent
Combined carbon..........	3.5	Manganese.................	Trace
Free carbon................	none	Sulphur.....................	.35
Silicon......................	.50	Phosphorus................	.05

The packing was the ore mixture previously referred to.

Samples were heat-treated and sections were given a careful microscopical examination, with the following results:

Decarburization began 54 hours after commencement of heating and at 770° C., showing a thin skin of ferrite; the remaining portion of the casting retained the typical structure of white iron. 40 hours later, during which time the temperature gradually raised to 980° C., the decarburized skin increased in thickness to 3/16 inch.

Fourteen hours later, at a temperature of 970° C., the interior had broken down and free or temper carbon was apparent. During the next interval of 60 hours, at 950° C. very little change occurred. The center showed pearlite, with a little cementite and containing temper carbon, merging gradually into the skin of ferrite.

During the following 72 hours, the temperature was dropped to 140° C., resulting in the production of a really good sample of English malleable cast iron of the following analysis:

Constituents	Per cent	Constituents	Per cent
Combined carbon..........	.65	Sulphur.....................	.35
Temper carbon............	1.10	Phosphorus................	.05

The author's conclusion is, that carbon is eliminated while still in combination with the iron.

It (the elimination) begins to take place at the comparatively low temperature of 750° C., and increases in activity with the temperature until such a temperature is reached that free or temper carbon is precipitated.

Previous to this change the interior consists of white iron, with the original quantity of combined carbon.

As the operation proceeds the temper carbon is gradually taken back into combination to replace that removed by the oxidizing influences.

American Practice

The mixtures of iron vary as the castings are thick or thin. The iron is melted either in the cupola, the air furnace or the open hearth furnace. The latter produces the best castings, but can only be used advantageously where the output is large enough to permit of running the furnace continuously.

The air furnace is most frequently used.

The castings may or may not be packed in an oxidizing material. Sand or fire clay are frequently used.

Dr. Moldenke, who is recognized as an authority on malleable cast iron, states: "That it is absolutely necessary to have the hard castings free from graphite." He advises the following:

Contents:	Per Cent
Carbon	3 –3.5
Silicon, heavy work, not over	0.45
Silicon, ordinary work, not over	0.65
Silicon, agricultural work, not over	0.80–1.25
Sulphur, not over	0.05
Phosphorus, not over	0.225
Manganese, not over	0.40

"In annealing, the temperature of the furnace should be run up to 'heat' in the shortest safe time possible; the limit is the danger of injury to furnace. Then the dampers should be closed and the temperature evenly maintained for 48 hours. The furnace should then be gradually cooled to a black heat before dumping. 36 hours are usually required to bring the oven up to heat.

The entire process occupies about seven days. The annealing temperature is 1350° F. and this must obtain at the coldest part of the furnace, usually the lower part of the middle of the front row of pots.

A difference of 200° F. in temperature is often found at different parts of the furnace.

Cupola iron requires an annealing temperature 200° F. higher than that from an air furnace.

The fuel ratio of an air furnace runs from 1 to 2 to 1 to 4.

Loss in silicon about 35 points.

Temperatures should be carefully watched and measured with a Le Chatelier pyrometer."

The Doctor has much to say about the danger of injury to the melted iron in the bath, from oxidation. His practice was to have three tapping spouts at different levels, so that for an 18-ton furnace, three taps of 6 tons each may be made at intervals, tapping at the upper hole first and then in order from upper to bottom hole.

Mr. H. E. Diller, in the Journal of The American Foundrymen's Association, Vol. XI, Dec., 1902, says:

The hard casting should have its carbon practically all in the combined state, while the annealing process should convert this to the so-called *temper*, or annealing carbon.

In the manufacture of malleable castings the special make of iron called 'Malleable Bessemer' or 'Malleable Coke Iron' is the principal material used. The charcoal irons, while unequalled for value, are confined to the regions where they can compete with the cheaper coke irons.

The composition required is as follows:

	Per cent
Silicon	0.75 to 1.50
Sulphur, below	0.04, if possible
Phosphorus, under	0.20

With the pig iron, hard sprues (unannealed scrap), steel and also malleable scrap are charged. The latter two materials are very good to add to the mixture, as they raise the strength of the casting very considerably.

Too much must not be added, as it would reduce the carbon to a point where fluidity and life in the melted metal is sacrificed.

The most serious objection to cupola iron is its poor behavior under bending test, the deflection being very slight. Test bars from this class of iron seldom run above 40,000 pounds per square inch in tensile strength, while with furnace iron, there is no difficulty in getting a few thousand pounds more.

The metal may be tapped from the furnaces into hand ladles; or it may be caught in crane ladles, carried to the distributing point and there emptied into the hand ladles.

When tapped into hand ladles, time is a serious item, for the beginning and the end of the heat will be two different things. The latter iron will be inferior as it was subjected to the oxidizing effect of the flame much longer than the first part. This difficulty is somewhat remedied by pouring the light work first, the heavier pieces coming later, when the silicon has been lowered too much for good light castings.

The gating should be done to avoid the shrinkage effects as much as may be. The little tricks that can be applied make a surprising difference in the molding loss. Some malleable works seldom lose more than 10 per cent, while in others 20 per cent and over is the rule.

After the castings have been tumbled they go to the annealing room, where they are packed in mill cinder or iron ore, in cast-iron boxes. These are carefully luted up and heated in suitably constructed ovens, for five or six days.

It usually takes from 36 hours to 48 hours to get the oven up to heat, the temperature ranging from 1600° to 1800° F. in the oven, the boxes having a somewhat lower temperature at the coldest point.

When the fires are extinguished, the dampers are closed tight, all air excluded, and the oven allowed to cool very gradually; often only 400° F. the first day.

After the castings come from the annealing oven, they are again tumbled to remove the burnt scale; then chipped and ground for shipment.

A well-annealed casting should not have much over 0.06 to 0.12 per cent combined carbon remaining in it. There is a material difference between the strength of an over-annealed casting and a normal one.

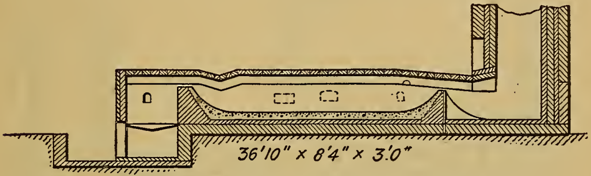


FIG. 110. — Typical American Air Furnace.

Two bars were taken from each of five heats. One from each set was given the usual anneal and the others reannealed. The average tensile strength of those annealed as usual, was 50,520 pounds per square inch, and the average elongation 6¾ per cent in six inches.

The reannealed set had an average tensile strength of 43,510 pounds per square inch; the average elongation was 6¼ per cent in six inches. Over annealing had therefore cost the metal some 7000 pounds of its strength.

'Malleable' can be made up to 60,000 pounds per square inch, though this is not advisable as the shock resisting qualities are sacrificed.

Prof. Ledebur determined by experiment that the higher the silicon the lower the annealing temperature required, and the higher the temperature and silicon the quicker the change. He used five samples:

1 with 0.07 silicon. Could not be annealed.
2 with 0.27 silicon. Required temperature almost at melting point.
3 with 0.80 silicon. Began to anneal at 1675° F.
4 with 1.25 silicon. Began to anneal at 1200° F.
5 with 2.10 silicon. Began to anneal at 1200° F.

Specifications for Malleable Castings of J. I. Case Co.

Tensile strength per sq. in., 35,000 to 50,000.

Elongation, 1.5 in 4 in.

Transverse test for ○ bar .8 inch diameter on supports 12 inches apart, must show 1750 pounds to 2,400 pounds breaking strength and deflection of not less than 0.31 inch.

Drop Test. — A bar .8 inch diameter on supports 12 inches apart must not break under less than 1650 inch pounds, the drop being 22 pounds and the first drop through 3 inches, second 4 inches and so on until rupture occurs.

Tortional test should closely approximate the tensile strength.

Bending Test. — Pieces from 3/16 to 9/16 inch thick and from 1 to 3 inches wide, should bend over on themselves, around a circle equal

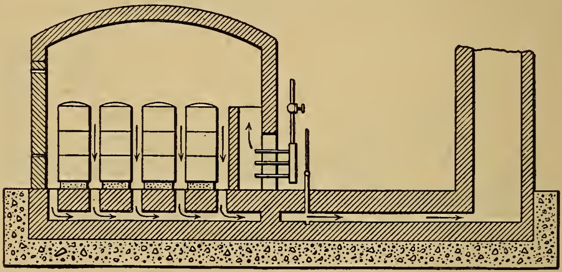


FIG. 111. — Annealing-Oven equipped for Gas.

in diameter to twice the thickness of the piece and bend back again without break.

The anneal is specified at not less than 72 hours for light and 120 hours for heavy work.

Comparison of Tests made in 1885 with those made in 1908
1885 By Prof. Ricketts

3/4-inch □ bar, tensile strength, 30,970 to 44,290 per square inch.

Elongation, 1.8 inches in 5 inches.

Bars 1 by .33, tensile strength, 32,750 to 36,990 per square inch.

Round bars, 1/2 inch diameter, tensile strength, 36,200 to 44,680 per square inch.

Round bars, 3/4 inch diameter, tensile strength, 26,430 to 34,600 per square inch.

Compression, 108,900 to 160,950 pounds per square inch.

1908

Bars ½-inch □, tensile strength, 52,000 to 59,000 per square inch.
Larger sections, tensile strength, 42,000 to 47,000 per square inch.
Dr. Moldenke states that the tensile strength should run from 40,000 to 44,000.
The Iron Trade Review gives the production of malleable castings in 1903 for the United States and Canada as 750,000 tons.
Combined output of the rest of the world 50,000 tons.

CHAPTER XVII

STEEL CASTINGS IN THE FOUNDRY

There is a great demand on the part of foundrymen for an appliance to successfully melt steel in small quantities; permitting small steel castings, or castings for which the demand is immediate, to be made in the gray iron foundry. Many efforts have been made to realize this desire, but so far have met with indifferent success. There are several appliances offered to manufacturers, some employing the Bessemer converter, others the electric furnace in connection with the cupola.

Men especially skilled are required to manipulate steel furnaces. The processes of mixing and melting the metal and annealing castings differ so radically from those of the gray iron foundry, that in the present undeveloped state of steel founding on a small scale, steps on the part of the foundryman in that direction should be taken with extreme caution.

Mr. Percy Longmuir defines ordinary steel "as iron containing from 0.1 to 2 per cent of carbon in the combined form, which has been submitted to complete fusion and poured into an ingot, or mould, for the production of a malleable or forgeable metal."

"Mild steel contains about 0.2 per cent carbon; the element increasing as the harder varieties are approached, being highest of all in the tool steels."

"The mechanical effect of this carbon is shown in the following table."

Material	Carbon	Silicon	Sulphur	Phosphorus	Tenacity in tons per square inch	Extension per cent on two inches	Contraction per cent of area
Mild steel....	.10	.03	.02	.02	20.00	50.0	70.0
Tool steel....	1.00	.03	.02	.02	60.00	5.0	10.0

"Within limits, an increase of carbon is accompanied by an increase in tenacity and a decrease in ductility, each increment of carbon showing distinctly these increases."

"The following classification embraces the most familiar tempers of Bessemer, Siemens and crucible steel."

Class of steel	Content of carbon	Purpose
Bessemer steel	.20	Ship and boiler plates, sheets, etc.
	.25	Axle steel.
	.03	Tire steel.
	.03	Rail steel.
	.50	Spring steel.
Siemens or open hearth	.20	Boiler plate.
	.65	Spring steel.
	1.30	Tool steel.
Crucible steel	.90	Chisel steel.
	1.10	Large files, drills and similar tool steels.
	1.20	Turning tool steels.
	1.40	Saw file steels.
	1.50	Razor steels.

A steel containing 0.10 per cent carbon is unaffected in hardness by quenching, while one containing 1 per cent carbon becomes so hard under same conditions that it will scratch glass.

Manganese is present in all commercial steels, varying from traces up to 1 per cent. It promotes soundness and neutralizes the effect of sulphur.

Silicon tends to the production of sound metal; while it is present in insignificant quantity in forging steel, in casting steels it may exist to the extent of 0.3 per cent.

Phosphorus produces an exceedingly brittle, cold short metal. Pure steels contain 0.02 to 0.03 per cent.

Usual specifications limit the phosphorus content to 0.06; at 0.1 the danger limit is reached.

Steels containing appreciable amounts of sulphur are red short. In high quality of steels the sulphur content runs about 0.01 per cent. Ordinary specifications place the limit at 0.04 per cent.

The variations in the carbon content to suit various requirements are shown in the following table:

Content of carbon in steel	Purpose for which the steel, in the form of a hardened or tempered tool, is suitable
.50	Springs.
.60	Stamping dies.
.65	Clock springs.
.75	Hammers, shear blades, axes, mint dies.
.80	Boiler punches, screw dies, cold sets.
.90	Edge tools, slate saws.
.95	Circular saws, pins.
1.00	Cold chisels, cross-cut saws.
1.10	Drills, large files, hand saws, mill picks.
1.20	Granite and marble saws, mill chisels.
1.30	Harder files, cutters, spindles, turning tools.
1.40	Saw files.
1.50	Turning tools for chilled rolls, razors and surgical instruments.

The following table is taken from Prof. J. O. Arnold's "Influence of Carbon on Iron."

MECHANICAL PROPERTIES "NORMAL STEELS"

Carbon	Elastic limit, tons per square inch	Maximum stress, tons per square inch	Elongation	Reduction of area
.08	12.19	21.39	46.6	74.8
.21	17.08	25.39	42.1	67.8
.38	17.95	29.94	34.5	56.3
.59	19.82	42.82	19.9	22.7
.89	24.80	52.40	13.0	15.4
1.20	35.72	61.64	8.0	7.8
1.47	32.27	55.71	2.8	3.3

"Normal steels" represent the rolled bars heated to 1000° C. and cooled in air.

"Comparing this table with the foregoing statements, it appears that as pearlite replaces ferrite, the maximum stress increases, continuing to do so until a structure consisting of pearlite and very thin meshes of cementite is reached. Further increase in carbon resulting in greater dispersal of free cementite is associated with a decrease in maximum stress."

Bessemer Process

The Bessemer process consists in blowing a large volume of compressed air through a bath of molten pig iron; the oxygen of the air combining with carbon, silicon and manganese to form oxides. That combined with carbon passes off as gas while with silicon and manganese slags are formed.

On removal of carbon, silicon and manganese, assuming that sulphur and phosphorus are low, a product resembling wrought iron is obtained. Meantime during the process of oxidation, there is a rise in temperature sufficient to maintain mild steel in a fluid condition. The oxidation of silicon has the greatest effect in producing the rise in temperature. The irons must be low in sulphur and phosphorus, as these elements are not removed. An average content of 2.5 per cent silicon in the pig iron gives the best results. Higher than this, the heats are liable to require scrapping; while with a lower content of silicon there is danger of "cold blows." The melted metal is taken directly from the cupola, led by runners to the converter.

The Baby Converter (Robert)

This consists of a steel shell mounted on trunnions, so that it may be properly rotated. It is flattened on the back and lined with silica brick or ganister. On the flattened side the tuyeres are introduced horizontally.

The surface of the metal lies approximately at the bottom of the tuyeres so that the blast may impinge upon it. The blast is from 3 to 4 pounds per square inch and means are provided for regulating it. The tuyeres being inclined radially, a rotary motion is imparted to the molten metal by the blast.

In some cases the surface of the metal may be above the tuyere level, but seldom exceeds that by more than three or four inches. The high tuyere level permits some of the air to escape and burn on the surface of the bath; carbon monoxide is formed in the bath by the oxidation of the carbon.

The combustion of carbon monoxide gives rise to considerable heat, which is absorbed by the bath. To this reaction is due the higher temperature of the side blow converter.

The Tropenas converter has a double row of tuyeres which are horizontal when the converter is vertical. They are not radially inclined as in the Robert. The surface of the metal is at the bottom edge of the lower row of tuyeres; the blast is always on the surface of the metal.

When blowing the converter is slightly inclined, causing the direction of the tuyeres to slope towards the surface of the metal. During the early stage of the blow the lower tuyeres only are used; but on the appearance of the carbon flame the upper row is opened. The carbon monoxide, partly consumed by air from the lower tuyeres, is supplied with sufficient oxygen for complete combustion by that from the upper row, generating additional heat.

Recarbonization is effected in the converter or in the ladles according to the character of the composition required.

The chemical changes taking place in a two ton Tropenas converter are given as follows:

Constituents	Cupola metal	After 5 minutes blowing	After 12 minutes blowing	After 14 minutes blowing	After 18 minutes blowing	End of blow	Finished metal
Graphite.......	3.180	2.920	....	....	....	....	....
Combined carbon..........	.350	.340	2.900	2.300	.860	.100	.240
Silicon.........	2.310	1.620	.466	.382	.084	.074	.326
Sulphur........	.037	.037	.035	.036	.038	.038	.037
Phosphorus.....	.054	.053	.054	.054	.051	.050	.058
Manganese.....	.610	.600	.101	.040	.040	.042	1.080

Theoretically the feeder on a steel casting should sink due to shrinkage. If, however, instead of sinking, a rise is shown, this is clear evidence of internal unsoundness or sponginess. To prevent this result one of the first essentials lies in having the steel thoroughly dead melted or "killed" before casting. A properly "killed" steel pours quietly and settles down gently in the mould. "Wild metal" acts in the opposite way and in some cases is represented by an over-oxidized metal.

A distinction must be drawn between a "pipe" and a blow hole.

The former is due entirely to contraction or shrinkage in passing from the liquid to the solid state and must be obviated by feeding.

"Blow-holes" are entirely different from "pipes" and are formed by the liberation of gases absorbed during the melting process.

In considering the character of these gases, oxygen naturally arises first, owing to the strong affinity between iron and oxygen. There is every reason to suppose, however, that the oxygen absorbed when the iron is molten, remains stable at low temperatures as an oxide, and in the absence of a deoxidizing agent this ferrous oxide is intermingled with the iron. Oxygenated steel is "dry" under the hammer and this condition is not necessarily due to blow-holes, but to "red-short" metal. Further, if free oxygen were present in quantity in the gas contained in a blow-hole, its skin would show an oxide film.

The majority of blow-holes have bright surfaces; comparatively few show colored tints, ranging from a straw to a blue, due to oxidation. These colored blow-holes owe their oxidized film, not to free oxygen liberated by the iron, but to air mechanically trapped during casting. Analyses of the gases seldom show more than traces of oxygen. Mr. E. Munker reports sixty-seven analyses of gases evolved by molten pig iron; the highest content of oxygen in the series is found at 0.8 per cent. Average analyses of gases in blow-holes give results of the following order:

	Per cent
Hydrogen	75
Nitrogen	23
Carbon monoxide	2

The actual amount of these gases absorbed depends to some extent on the temperature and composition of the bath. While fluid the gases are retained; but with a fall in temperature after casting they are evolved. Those set free by a fall in temperature bubble through the pasty mass, the trapped bubbles representing blow-holes in the casting. As the temperature continues to fall less movement is offered and the gases cannot force passages through the stiffening metal. Hence more bubbles are trapped. Finally a stage is reached at which the mass becomes rigid and the further formation of blow-holes becomes impossible.

The author's conclusions from the investigations of Wahlberg are:

"1. If no internal movement is possible in the solidifying steel, the gas cannot disengage itself and so leads to the formation of blow-holes."

"2. The presence of silicon and manganese lead to the retention of the gases until solidification is complete, hence preventing the formation of blow-holes."

Methods of prevention include:

"1. Liquid compression.

"2. Additions to the steel of silicon, manganese or aluminum. Each of these elements acts powerfully on the oxygen or the oxides of iron, combining with the oxygen to form slag."

"Aluminum will remove carbonic oxide. There is, however, no reason to suppose that it will remove either hydrogen or nitrogen."

"There are grounds for the belief that silicon, manganese and aluminum increase the solvent power of the steel for hydrogen and nitrogen and that these gases remain dissolved."

Brinell found that to produce an ingot of perfect density in the absence of silicon, 1.66 per cent of manganese is necessary. In the absence of manganese 0.32 per cent silicon is required; and with no manganese or silicon 0.0184 per cent of aluminum is sufficient to produce a perfectly sound ingot. Or expressed in another way he states that aluminum is 90 times as effective as manganese and 17.3 times as much so as silicon, in removal of gases.

Metallic borides are suggested by Weber for removal of oxygen; these in conjunction with ferrotitanium tend to removal of nitrogen.

The casting temperature exercises a great influence upon the properties of the metal. These are found to rise and fall with the temperature above and below the casting heat, as shown by the following table:

Analyses						Maximum stress, tons per square inch	Elongation, per cent in 2 inches	Reduction of area, per cent
No.	Carbon	Si	Mn	S	P			
80 A....	.29	.07	.16	.07	.06	24.2	9.5	18.0
81 A....	.29	.07	.16	.07	.06	27.2	24.0	32.3
82 A....	.29	.07	.16	.07	.06	27.0	12.5	17.5
83 A....	.29	.07	.16	.07	.06	25.5	8.0	12.0

These steels were poured from one large ladle at intervals of a few minutes. They are exactly of the same analysis; the bars were annealed together, each bar receiving exactly the same treatment, and apart from variation of casting temperatures, the conditions were the same for all. These results have been repeated many times. When the steel is poured at an excessive temperature, similar ones are always obtained.

Annealing

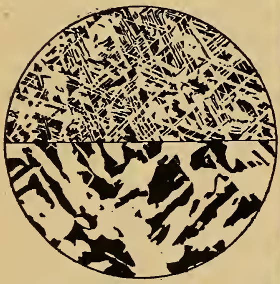
The following is extracted from McWilliams and Longmuir's "General Foundry Practice."

Steel castings are usually annealed in the reverberatory gas furnace. The annealing recommended by Prof. Arnold for general work is to heat the castings up to about 950° C. keeping them at that temperature for about 70 hours, then luting the furnace and allowing them to cool slowly for 100 hours.

The Clinch-Jones annealing furnace is highly spoken of, the controlling idea being that while the castings are heated in a muffle, by keen flames outside the walls of the muffle, virgin gas from the producer is allowed to come into the muffle and combine with all the oxygen that may enter, thus preventing it from getting to the castings to scale them by oxidizing at their surfaces. A cut of this oven is shown on page 266 (McW. & L.).

The micrographs (McW. & L.) show the structural changes produced by annealing. It should be remarked that the unannealed bar, Fig. 112, (McW. & L.) ¾-inch diameter when bent over a ⅜-inch radius broke at 43°. After annealing, same bar bent double without fracture.

AS CAST



AFTER ANNEALING

Fig. 112.

Fig. 113.

Fig. 113 (McW. & L.) shows the structure of a portion of a large open hearth casting, having originally the same structure as the unannealed part of Fig. 112 after insufficient annealing. When thoroughly annealed the structure was as shown in Fig. 114.

A test bar 1 inch square as shown in Fig. 113 broke at 40°; while one as per Fig. 114 bent at 101° without fracture, showing tensile strength of 33 tons per square inch; elongation 30 per cent; reduction of area 41 per cent. The composition of the casting was C.C. 0.24, Si 0.15, Mn 0.8, P 0.04, S 0.05.

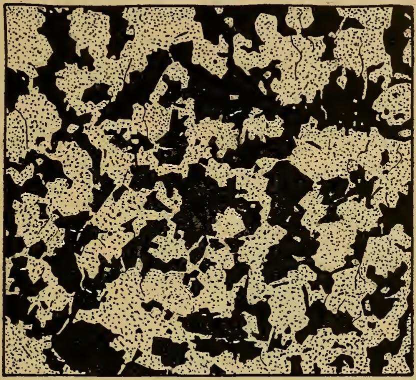


FIG. 114.

Other micrographs of most interesting character are shown on pages 293 to 297 and 338 to 354 (McW. & L.).

The process of annealing must be varied to suit different compositions and purposes for which the steel is provided.

Tropenas Process

This process was patented by Alex. Tropenas of Paris in 1891; the first converter, 800 pounds capacity, was erected at the works of Edgar Allen & Co., Ltd., Sheffield, Eng., and introduced into the United States in 1898.

It produces hotter steel than any other process. The steel may be carried for considerable distances in hand ladles or shanks and poured into small castings.

The Tropenas process consists in melting a calculated mixture in the cupola, transferring the metal to a special type of converter and its conversion to steel therein. The reactions are identical with those of the Bessemer and open hearth furnaces; the difference lies in the manner of producing these reactions. The converter is designed to conserve and increase the heat as much as possible and by preventing evolution in the bath, to keep out any gases not necessary for or caused by the decarburization, mechanical disturbance, gyration or ebullition of the bath is reduced to a minimum.

The converter is in general similar to the Bessemer converter, the particular difference being in the location and construction of the tuyeres.

Figs. 215 and 216, pages 307 and 308 McW. & L. give fair illustrations of the device. The operation consists in melting the iron in the cupola precisely as for gray iron castings, except that enough for the charge must be gathered at the first tapping. The melted iron is then transferred to the converter and skimmed clear of slag. The converter is so adjusted that the level of the metal reaches exactly to the lower edge

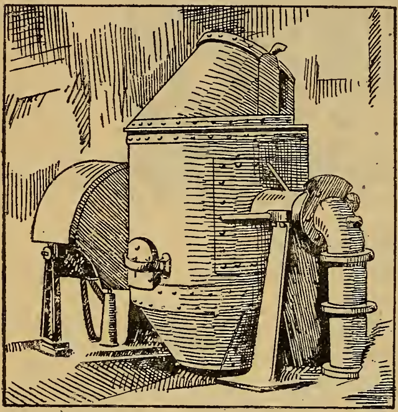


FIG. 115.

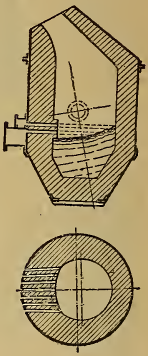


FIG. 116.

of the bottom tuyeres, so that the blast will strike exactly upon the surface of the metal. The longitudinal axis of the converter should make an angle of from 5° to 8° with the vertical. This is a matter of importance and extreme care must be taken to obtain the correct position before applying the blast. The upper tuyeres are closed and the blast turned on with about 3 pounds pressure.

If the composition of the iron is correct and it has been melted hot, sparks and smoke will be emitted from the converter for about four minutes, then flame appears which gradually increases in volume and brilliancy. After about ten minutes, what is known as "the boil" appears. In a few minutes this dies down considerably, and the blow remains quiescent for a time. Then the flame increases again, attains the maximum brilliancy and finally dies down for the last time.

This is the end of the blow, the carbon, silicon and manganese having been reduced to the lowest limits.

The converter is now turned down, the blast shut off and a weighed amount of ferrosilicon, ferromanganese or silicon speigel added to recarbonize the steel to the desired point. The steel is now ready for casting. On account of its great fluidity and thin slag it may be poured over the lip of an ordinary ladle, instead of from one with a bottom pour.

Claims made for this process.

1. The form of the bottom of the converter gives a greater depth in proportion to the surface area and cubic contents than any other pneumatic process, preventing the disturbance of the bath when blowing.

2. The symmetrical position of the tuyeres with respect to the center tuyere prevents any gyrating or churning of the bath. This is directly opposed to all other processes.

3. The special position of the bottom tuyeres during blowing, so that they are never below the surface of the bath, reduces the power necessary for blowing; as only enough air is introduced to make the combustion and not to support or agitate the bath.

4. The oxidation of the metalloids takes place at the surface only, the reaction being transmitted from molecule to molecule without any mechanical disturbance.

5. The addition of a second row of tuyeres completely burns the CO and H produced by the partial combustion of carbon and the decomposition of moisture introduced with the blast and this increases the temperature of the bath by radiation.

6. Very pure steel is obtained, as the slag and the iron are not mixed together.

7. There is a minimum of waste on account of the bath being kept comparatively quiet.

8. Less final addition is required on account of the purity of the steel and its freedom from oxides.

Chemistry of the Process

No fuel is needed in the converter. The increase in temperature after the melted metal is introduced is occasioned by the combustion of the metalloids during their removal.

These elements are carbon, silicon and manganese. The oxidation of the silicon furnishes by far the greatest part of the useful heat. Prof. Ledebur has calculated that the rise in temperature of the bath due to the combustion of 1 per cent of each of the constituents is as follows: Silicon 300° C.; phosphorus 183° C.; manganese 69° C.; iron 44° C.; carbon 6° C.

It is necessary that the composition of the bath before blowing should be that which has been found to give the best results.

Sulphur and phosphorus are as unaffected here as in any other acid-lined furnace and the content of those elements in the finished steel will depend on how much the stock melted contained.

The cupola mixture generally consists of low phosphorus pig iron and steel scrap, composed of runners, risers and waste from previous heats. As much as 50 per cent scrap may be carried successfully. The mixture must be made in such proportions that the analysis after melting will be:

	Per cent
Silicon	1.90–2.25
Manganese	0.60–1.00
Carbon, about	3.00

The result of low silicon is to make the blows colder; that of high silicon to make the blows unduly long and to increase the wear on the lining.

Manganese should be kept within the limits specified. Low manganese tends to make the slag thick. High manganese makes the blow sloppy and corrodes the lining.

During the first period of the blow, the silicon chiefly is oxidized and the carbon changed from graphitic to combined. The manganese is the most active element in the middle of the blow, being most rapidly eliminated at the boil. The last period brings the carbon flame, and the indications are so plain that it is feasible to stop the blow before all the carbon is burned out, thereby reducing the amount of carburiser needed. In addition to these elements a certain amount of iron is unavoidably oxidized and the total loss of all elements included is about 12 per cent.

Converter Linings

The converter is generally lined with an acid or silica lining. Successful experiments have been made with a basic lining (dolomite), but it has not been developed commercially. Special shaped blocks to fit the converter or the regular standard shapes may be used.

The material must be of the highest grade silica stock, burnt at the highest possible kiln temperature. It usually contains from 95 to 97 per cent SiO_2, and is practically free from lime and magnesia.

Another method in frequent use is to run ground ganister around a collapsible form. This probably is the cheapest method. Before making the first blow, the converter is made white hot by a coke or oil fire.

Mr. J. S. Whitehouse of Columbus, Ohio, in a paper read before the American Foundrymen's Association, states that the claims which were made for the side blow converter, when first introduced into America were, to say the least, absurd. Many failures were made by employing inexperienced workmen, who had only limited instructions from experts sent out with the apparatus and the results were frequently disastrous.

A year's experience, at least, under proper instruction is required before a man can become a competent blower. He must be able to tell the temperature of the metal soon after the flame starts and to judge the silicon by the first period. He must tell when the blow is finished from the slag as well as by the flame. He must know how to keep the lining in the best shape to get all the heat possible from the process, and the hundred little kinks of the trade, which, as a rule, the expert will never impart, but are obtained only from experience.

A man with the above qualifications will blow with a loss of less than 17 per cent — about 15 per cent.

With proper blowing the main loss comes from the silicon in the charge, usually 2 per cent, which is oxidized together with iron and manganese to form the slag.

Mr. Whitehouse learned to blow with 2 per cent silicon, but for the past few years has been blowing iron, analyzing from 0.90 to 1.25 per cent silicon from the cupola, and often has been obliged to use scrap while blowing.

There is an advantage in the increased amount of scrap which can be carried, as it cuts down the cupola loss by increasing the amount of carbon in the charge. For example: He charges 50 per cent pig carrying about 3.75 per cent carbon and 50 per cent scrap having 0.25 per cent carbon. Tests from such iron from the cupola give 3.25 to 3.50 per cent carbon, showing a gain of 1.25 to 1.50 per cent carbon, taken from the coke, instead of purchased in the pig iron. 50 per cent scrap can be melted in the cupola, using only 12½ per cent coke, but the blower must have a complete knowledge of cupola practice. Most blowers use too much volume and too high pressure of blast to get the best results. With low silicon the volume and pressure of blast must be low. No two blows will act alike and require different treatment, which can be determined by the flame, but which he is unable to describe.

It is as necessary for the blower to regulate the air valve to get proper combustion as it is for the melter to adjust air and gas valves. With ordinary care the steel produced in a converter is very uniform in carbon and silicon; more so, he thinks, than in the open hearth. The greatest variation seems to be in manganese. The temperature of the metal and the condition of the slag cause more variation in the converter than in the acid open hearth. It is possible to run several weeks without taking an analysis and find at the end of the run very little variation in the elements.

While this is possible with the open hearth, it is not practiced on account of the risk. It is, however, frequently done in converter practice. The method of making the molds is identical with that followed in the open-hearth practice.

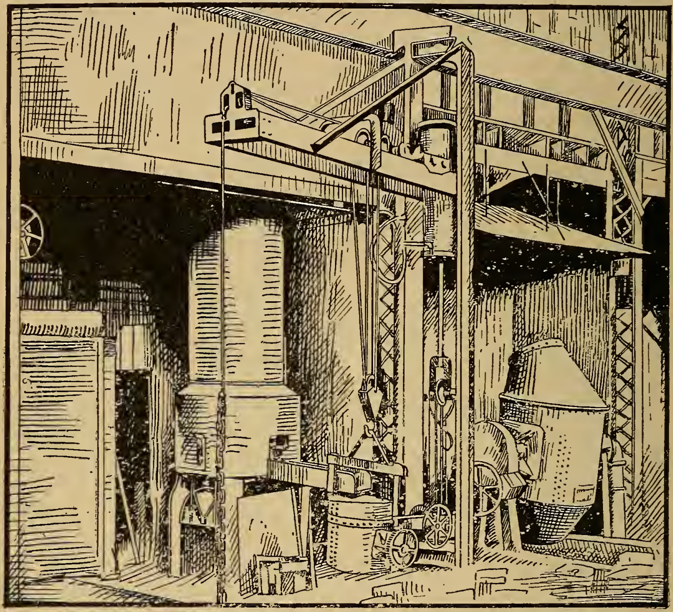


FIG. 117.—Arrangement of the Cupola and Converter. The Metal is Handled by a Four-ton Pneumatic Jib Crane.

An ordinary converter shop, with one two-ton converter is capable of producing between 100 and 150 tons of good castings per month, blowing three times a week. He concludes with saying that the management must be good and the salaries paid the officers as reasonable as possible, otherwise the shop is fore-doomed to failure, regardless of the quality of the product.

At the Cincinnati Meeting of the American Foundrymen's Association, Mr. Whitehouse, in reply to various inquiries, made the following statements:

When the flames show that the blow is getting very hot, scrap is thrown in at the top of the converter until it cools down. The scrap is as small as can be conveniently handled and is not preheated.

The blast pressure averages from 2.25 to 2.50 pounds.

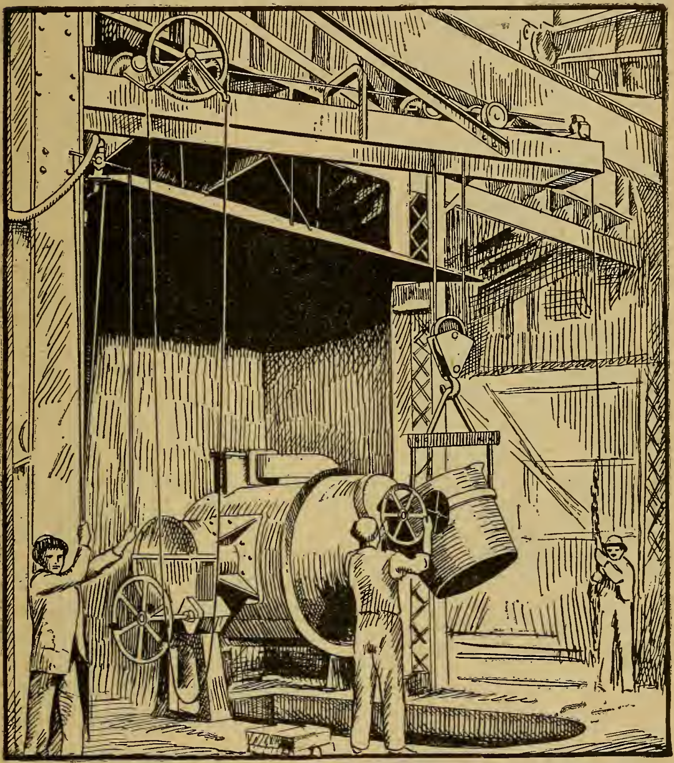


FIG. 118. — Pouring the Iron into the Converter before the Blow.

Sometimes, after the silicon is reduced and during the blow, steel scrap is thrown into the converter.

The carbon can be varied by the final additions.

It is usual and customary to blow the heat down till the flame drops; the carbon is then about 0.10 per cent. The carbon is then raised by the addition of melted pig iron or pulverized coke. The carbon can be raised as much as desired. If more than 0.40 or 0.50 per cent carbon is required, the blow is stopped before completion. It is customary to blow down to .09 or 0.10 per cent carbon, then to recarbonize with ferromanganese, melted pig iron and spiegeleisen. I usually use coke. If ferromanganese is melted in a small cupola, as has been done in the East, the loss is very heavy. The most economical practice is to throw the ferromanganese into the converter at the end of the blow. The usual custom is to add ferromanganese and then pig iron.

"My practice is never to reline entirely. At the end of the heat day, the converter is cooled off, patched up, dried out and is then ready for the next day. Where the converter is used until it is cut out, the lining removed and then renewed, there is a great loss of iron."

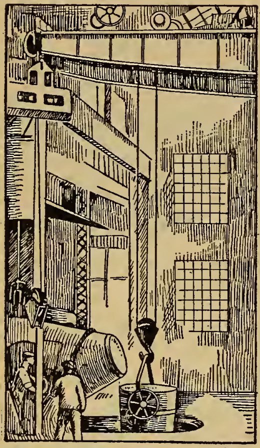


FIG. 119.—View of One End of the Foundry, Showing the Converter Discharging Steel into a Ladle.

The practice is to blow just at the surface, with the blast impinging slightly on the metal. During the blow the tuyeres are submerged, and if the pressure is suddenly stopped for any cause the iron will run into the wind box. The converter is so placed that the blast will strike the surface of the metal at an angle of 175° to 171°. He does not use a second row of tuyeres. Upon starting to use the converter, there was an upper row of tuyeres, but they were subsequently discarded. The lower tuyeres furnish all the blast required.

Formerly he used bull ladles in pouring small castings and experienced no trouble. At the present time, the entire heat, sometimes consisting of castings weighing less than thirty pounds, is poured with a thousand-pound ladle.

The following extract is from the Foundry, Jan., 1910, describing the equipment of the recently erected steel foundry of the Vancouver Engineering Works, Ltd., Vancouver, B.C.

The cupola is the Standard Whiting type, having a rated capacity of six to seven tons per hour.

Iron is tapped from the cupola into a six-thousand-pound ladle, carried by a pneumatic crane. Two taps are made to obtain a full charge for the converter.

The composition of the iron is as follows: Si. 1.80 to 2.00; S. 0.04;

Phos. 0.04; Mn. 0.60 to 1.50. The cupola charge is so proportioned as to give about one per cent manganese. Steel scrap is available as desired.

The converter, of two-tons capacity, is of the standard Whiting type (Tropenas) and is lined with ganister, sand and fireclay. This lining, if cared for, will give from 180 to 200 blows. The air pressure of blast to converter ranges from three to five pounds per square inch, regulated by valve on operator's platform.

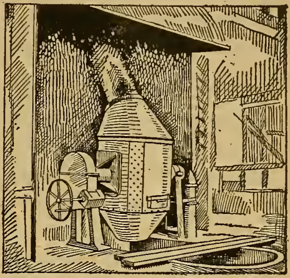


FIG. 120. — The Converter in Operation.

The blowing operation requires from 15 to 20 minutes, varying with the percentage of metalloids in the iron. The temperature of the bath depends upon the rapidity of the blow.

Reduction in the weight of metal is about 18 per cent.

The steel comes from the converter at 1700° C., insuring sufficient fluidity to give sharp, sound castings of light section.

Standard Specifications for Steel Castings Adopted by American Association for Testing Materials

Process of Manufacture

1. Steel for castings may be made by the open hearth, crucible or Bessemer process. Castings to be annealed or unannealed as specified.

Chemical Properties

2. Ordinary castings, those in which no physical requirements are specified, shall contain not over 0.40 per cent carbon, nor over 0.08 per cent of phosphorus.

3. Castings which are subject to physical test shall contain not over 0.05 per cent of phosphorus, nor over 0.05 per cent of sulphur.

Physical Properties

4. Tested castings shall be of three classes, *hard*, *medium* and *soft*. The minimum physical qualities required in each class shall be as follows:

Properties	Hard castings	Medium castings	Soft castings
Tensile strength, pounds per inch	85,000	70,000	60,000
Yield point, pounds per inch	38,250	31,500	27,000
Elongation per cent in 2 inches	15	18	22
Contraction of area	20	25	30

5. A test to destruction may be substituted for tensile test in the case of small or unimportant castings, by selecting three castings from a lot. This test shall show the material to be ductile, free from injurious defects, and suitable for the purposes intended.

A lot shall consist of all castings from the same melt, or blow annealed in the same furnace charge.

6. Large castings are to be suspended and hammered all over. No cracks, flaws, defects, nor weakness shall appear after such treatment.

7. A specimen one inch by one-half inch (1″ × ½″) shall bend cold around a diameter of one inch (1″) without fracture on outside of bent portion, through an angle of 120° for the "soft," and 90° for "medium" castings.

Test Pieces and Methods of Testing

8. The standard turned test specimen, one-half inch (½″) diameter and two inch (2″) gauged length, shall be used to determine the physical properties specified in paragraph No. 4. It is shown in the following sketch.

9. The number of standard test specimens shall depend upon the character and importance of the castings. A test piece shall be cut cold from a coupon to be molded and cast on some portion of one or more castings from each blow or melt, or from the sink heads (in case heads of sufficient size are used). The coupon, or sink head, must receive the same treatment as the casting, or castings, before the specimen is cut out and before the coupon, or sink head, is removed from the casting.

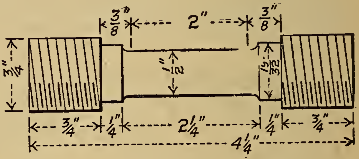


Fig. 121.

10. One specimen for bending test, one inch by one-half inch (1″ × ½″) shall be cut cold from the coupon, or sink head, of the casting, or castings, as specified in paragraph No. 9. The bending test may be made by pressure or by blows.

11. The yield point specified in paragraph No. 4 shall be determined by careful observation of the drop of the beam, or halt in the gauge of the testing machine.

12. Turnings from the tensile specimen, drillings from the bending specimen or drillings from the small test ingot, if preferred by the inspector, shall be used to determine whether or not the steel is within the limits, in phosphorus and sulphur, specified in paragraphs Nos. 2 and 3.

Finish

13. Castings shall be true to pattern, free from blemishes, flaws or shrinkage cracks. Bearing surfaces shall be solid, and no porosity shall be allowed in positions where the resistance and value of the casting for the purpose intended will be seriously affected thereby.

Inspection

14. The inspector, representing the purchaser, shall have all reasonable facilities afforded him by the manufacturer to satisfy himself that the finished material is furnished in accordance with these specifications.

All tests and inspections shall be made at the place of manufacture, prior to shipment.

The following paper, by Mr. W. M. Carr, on the manufacture of steel castings in small quantities by the open-hearth process is given herewith in full.

Open-Hearth Methods for Steel Castings

With Remarks on the Small Open-Hearth Furnace

By W. M. Carr, New York City

It is a fact that the open-hearth process for the manufacture of steel is gradually gaining ground, as can be proved by statistics. The reason for its supplanting other methods is mainly one of quality. Further, the basic open-hearth process permits a mixture of pig iron and miscellaneous steel scrap of a lower grade and cheaper price than raw material necessary to other processes.

With the foregoing facts in mind the author presents this article for the consideration of prospective investors in the manufacture of steel castings in small, moderate and large tonnages; to be more explicit, small tonnages are capacities of melting units in one-half, one and two tons per heat. Moderate tonnages are capacities of furnaces of two to five tons per heat, and large tonnages are capacities from ten to twenty-five tons per heat. There are thus offered possible outputs to meet almost any requirements.

In presenting the claims, it is with the recognition of the following advantages:

1. The small capacity furnaces cost less to install than any other steel making devices excepting only crucible melting furnaces.

2. The economy in operation of open-hearth furnaces in any capacity over that of any other steel-making process.

3. The certainty of results, the greater degree of control in operation and the reduction of the *personal equation* to the lowest possible expression.

It is generally known to the foundrymen that the largest production of steel castings comes through open-hearth furnaces of capacities of five to twenty-five tons per heat. Such practice is established and requires constant demand to be profitable, and investment of considerable capital varying with the size of the plant. It has been thought that capacities of less than five tons per heat are not possible by open-hearth methods, and engineers generally have dissuaded those who wish to

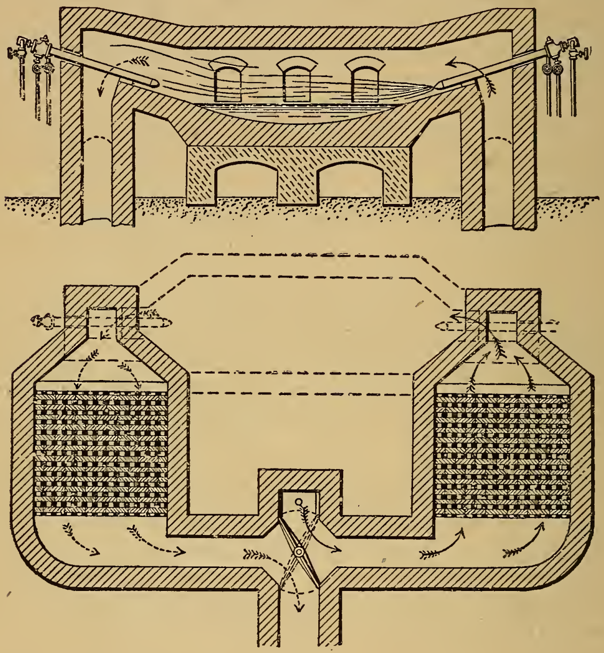


Fig. 122.

engage in the manufacture of steel castings either for their own consumption or the trade from using open-hearth methods, since up till quite recently the tendency has been rather to increase the capacity of the open hearth, supposedly for economical reasons rather than to build small units with less capacities.

The author, however, has had the opportunity to demonstrate the possibilities of the miniature open hearth and has found from actual practice that it is economical, and comparing operation costs with standard capacity furnaces, bears equally well in economy. This fact is somewhat of an innovation, but nevertheless true, and it can be said that the operating cost of the miniature open hearth is less than that of any type of steel-producing unit or process, making steel in equal quantity.

To assist those who may not be familiar with an open-hearth furnace and its operation, a study of the diagram herewith, (Fig. 122) given may be instructive. The upper part of the furnace is represented in sectional elevation. The structure is built of refractory bricks and bound securely with structural steel beams and plates at certain points not shown in the diagram. The lower part of the furnace, usually below the charging floor level or carried below the shop level, consists of the chambers, connecting flues leading to a reversing valve and thence to a regenerator stack. Referring again to the main body of the furnace it will be noticed that the hearth, which is practically a shallow dish lined with "silica" sand is fused into one solid mass at a high temperature at the time of what is known as "making bottom." This is the laboratory where the raw material is melted and refined to steel of any desired composition. In outline the practice is as follows and refers to the operation of a miniature open hearth fired with fuel-oil being recommended in preference to producer gas in capacities of less than five tons per heat.

After the furnace has been brought up to a working temperature — white heat — a mixture of acid pig iron and low phosphorus steel scrap usually in the proportions, one-third pig and two-thirds scrap, is charged into the furnace, adding the pig iron first, and when that becomes molten, following with the scrap. The whole mass subsequently becomes liquid by means of the oil flame passing above it. At this stage the temperature of the furnace has been lessened through the addition of the cold stock, but it will still be at a temperature above that required to melt pig-iron. But in order to elevate the temperature above that required to melt steel and have it in condition to pour, the advantage of the principle of regeneration is available. This consists in returning to the furnace waste heat which in other types of furnaces escapes to the stack. Without a system of regeneration it is not possible to reach a proper steel casting temperature; that is to say, a reverberatory furnace without regeneration gives a temperature, (where the combustion of the fuel is supported by *cold* air), less than that required to properly liquefy steel, but with the principle of regeneration applied to such a furnace, high temperatures are readily reached.

To understand this principle we will follow the course of the flame of the burning oil as indicated by the arrows in the diagram. Beginning at the right hand end oil is delivered to the burner which is shown surrounded with a water cooled casing to protect the burner fittings. The oil is delivered either by gravity or pump pressure, but before reaching the end of the burner it is atomized or vaporized by air under pressure. This air is designated as primary air and performs little or no part in supporting combustion of the oil vapor, and the quantity of air delivered in excess above the amount necessary to promote combustion of the oil is known as secondary air. The secondary air enters the reversing valve shown at the stack connection, passes through the right hand regenerator, enters the uptakes below the water cooled burner casing, performs its function and passes along the roof of the furnace, in part, and the remainder, mixed with the products of combustion with the strata of flame playing above the bath, enters the downtake at the left hand end of the furnace and in its passage to the stack gives up the major portion of its heat to a large quantity of brick work piled within the chamber. When the waste gases have passed through the reversing valve and entered the stack they have just about enough heat to induce the necessary draft. Now, after an interval of twenty to thirty minutes the right hand burner may be shut off, but not withdrawn from the furnace; the reversing valve is thrown and the oil and primary air turned on at the left hand end of the furnace. The secondary air will then be diverted by the reversing valve to flow through the left hand regenerator or checker chamber, and passing through innumerable passages in that set of checkers absorbs a large quantity of heat radiating from the glowing bricks which became heated in the first instance by the outgoing gases during a previous cycle of operation. This radiated heat regenerating the secondary air will be added to the temperature generated by the burning fuel and the products of combustion will accordingly have an increased quantity of heat to impart to the checker work at the outgoing or right hand end. In other words, whatever temperature may be carried in by the secondary air will be equivalent to an increase in efficiency of the burning fuel. Successive reversals of the fuel, primary and secondary air produce constantly increasing increments in flame temperatures below the melting points of the refractory brick works.

We have seen what can be accomplished by storing up and restoring to the furnace waste heat from the products of combustion, producing the effect of a higher possible temperature than in any type of melting furnace. In addition to this effect another one is quite active and that is reflection of heat from the walls and roof of the furnace upon the surface of the bath of metal. This latter effect, known as radio-activity, is more pronounced in a narrow melting chamber than in a wider one and consequently the result will be two factors, one a decreasing fuel consumption and the other the possibility of superheating steel in a miniature open-hearth. This fact has not been recognized heretofore because most open-hearth furnaces are fired with producer gas, and since that fuel requires peculiar furnace construction to get the best results in burning it, it has not been found possible to make use of such fuel in a comparatively short furnace hearth and therefore all furnaces designed to use that fuel must have a comparatively long hearth tending mainly in the direction of increased capacities rather than decreased. On the other hand, the length of the hearth is not restricted where oil can be substituted for producer gas and therefore it has been found possible to operate an open-hearth furnace as small as 350 pounds capacity per heat. Thus a new field is opened to make steel by the open-hearth process.

Referring again to the operating method, we saw where the bath of metal was molten and at a moderate temperature. This temperature was due to the fact that the metal was highly carburized, since the presence of carbon lowers the melting point of iron. We saw how it was possible to gradually increase the temperature of the furnace by the regeneration of the secondary air, and with that constant elevation of temperature, dormant chemical actions will be set up. The first effect will be an oxidization of the silicon occurring mostly on the surface of the metal by the oxidizing action of the flame. The product would be silica, which combines with whatever oxide of iron might be present in the bath of metal. The combination would form a slag of comparatively light weight that would rise to the surface and cover the bath. The slag is shown in the diagram by the heavy black line. This layer of slag prevents the metal below from direct contact with the flame. After the removal of the silicon the next action will be the removal of the carbon. This action is a gas-forming one and will cause a bubbling or boil throughout the bath. The action can be augmented from time to time by the addition of iron oxide in the form of iron ore. As the decarburization progresses test plugs are taken from time to time, the operator judging the amount of carbon in the bath by their fracture and malleability. When the carbon has decreased to a predetermined point, the boil may be stopped or killed by deoxidizing agents such as ferrosilicon and ferromanganese in properly weighed amounts. The metal can then be transferred to molds. This method as outlined refers to the acid process. In it the elements sulphur and phosphorus are not removed. The basic process consists of a hearth lining made of magnesite. Such a lining permits an addition of limestone to form a slag which will absorb the two elements and make a purer steel, chemically speaking, than the acid process, and at the same time allow the use of cheaper and irregular raw materials against the acid process with strictly limited chemical composition concerning the two elements mentioned.

With open-hearth furnaces designed to use producer gas and which rarely go below five tons capacity it is not possible to adapt them to intermittent operation. Even in the smaller producer-gas fired furnaces the roof span is considerable, resulting in heavy stresses on the side walls. These stresses will vary as the furnace is heated and cooled, and if such alternations are frequent there is danger of collapse of the furnace. It becomes necessary then to maintain them continuously at a steady temperature. Unless there should be demand for regular tonnage the fuel consumption during idle periods would be a constant expense.

In miniature open-hearth furnaces, owing to the comparatively narrow hearth chamber, the roof span is of course lessened and therefore whatever expansion or contraction therein following heatings and coolings, will result in comparatively slight stresses, and these results decrease in effect with the lessened capacity furnaces, and they therefore lend themselves to intermittent operation with greater ease and lessened liability of repairs. The miniature open hearth is most satisfactory in the rolling type with the body cylindrical, so that the stresses even though slight will be evenly distributed, whereas in a rectangular form the roof will always rest and thrust upon the inside walls. In fact the miniature open hearth is not recommended to be built in the stationary type.

In conclusion the miniature open hearth is not costly to install, is comparatively simple to operate, gives results equal to standard open-hearth practice, makes hotter steel than the regular open hearth and can show costs equally as low per pound of molten metal in the ladle.

Comparative Cost of Steel made by Different Processes

From paper presented to the American Foundrymen's Association by Mr. Bradley Stoughton.

Table I. — Acid Open Hearth

Raw materials	Per 2000 pounds of steel in ladle				
	Price of raw materials per 2000 pounds	Weight used, pounds	Per cent used	Cost	Cost
Pig iron	$14.00	300	15	$2.10	
Heads, gates, etc.	14.00	660	33	4.62	
Foreign scrap	14.50	1080	54	7.83	
Defective castings* (account bad metal)	50.00	20	1	.50	
Ferro-alloys	40.60	29	1	.59	
Total metal	....	2089	104	$15.64	$15.64
Operating costs	....	......	......	5.50†	8.85†
Cost of steel in ladle	....	......	......	$21.14	$24.49

Cost of Steel in Castings

Cost of steel in ladle ÷ 65 per cent‡ =	....	....	....	$32.52	$37.68
Less credit for heads, etc., as scrap =	....	....	....	4.62	4.62
Net cost of steel in castings	....	....	....	$27.90	$33.06

* The price given for defective castings is over and above their value as scrap See the text following for further discussion of this charge.

† The charge of $5.50 for operating costs is the figure for a 25-ton furnace and large tonnage; that of $8.85 is for a small furnace and small production.

‡ Of the steel in the ladle, 65 per cent goes into castings, 33 per cent goes into heads, gates, etc. and 2 per cent is lost in spattering, etc.

TABLE II. — BASIC OPEN HEARTH

Raw materials	Per 2000 pounds of steel in ladle: Price of raw materials per 2000 pounds	Weight used, pounds	Per cent used	Cost	Cost
Pig iron	$12.75	1040	52	$6.63	
Heads, gates, etc.	14.00	660	33	4.62	
Foreign scrap	11.15	350	17½	1.95	
Defective castings*	50.00	40	2	1.00	
Ferro-alloys	40.60	33	1½	.67	
Total metal	....	2123	106	$14.87	$14.87
Operating costs	....	......	......	6.10†	9.55†
Cost of steel in ladle	....	......	......	$20.97	$24.42

Cost of Steel in Castings

Cost of steel in laddle ÷ 65 per cent ‡ =	....	....	....	$32.26	$37.57
Less credit for heads, etc. as scrap =	....	....	....	4.62	4.62
Net cost of steel in castings	....	....	....	$27.64	$32.95

* See footnote under Hearth, Table I.
† See footnote under Table I.
‡ Of the steel in the ladle, 65 per cent goes into castings, 33 per cent goes into heads, gates, etc., 2 per cent is lost in spattering in pouring.

Acid Open Hearth and Basic Open Hearth [When Together in One Plant]

Raw materials	Acid open hearth per 2000 pounds of steel in ladle: Price of raw materials per 2000 pounds	Weight used, pounds	Per cent used	Cost	Basic open hearth per 2000 pounds of steel in ladle: Price of raw materials	Weight used, pounds	Per cent used	Cost
Pig iron	$14.00	300	15	$2.10	$12.75	1040	52	$6.63
Heads, gates, etc., from both furnaces	14.00	1320	66	9.24	....	....	....	....
Foreign scrap	14.50	420	21	3.05	11.15	1010	15½	5.63
Defective castings	50.00	20	1	.50	50.00	40	2	1.00
Ferroalloys	40.60	29	1	.59	40.60	33	1½	.67
Total metal	......	2089	104	$15.48		2123	71	$13.93
Operating costs	......		....	5.50	....	....	....	6.10
Cost of steel in ladle	......	....	....	$20.98	....	....	....	$20.03

Cost of Steel in Castings	Acid: Cost	Basic			Basic: Cost
Cost of steel in ladle ÷ 65 per cent	$32.28	....	....	....	$30.81
Less credit for heads, etc., as scrap	4.62	....	....	....	4.62
Net cost of steel in castings	$27.66	....	....	....	$26.19

TABLE IV. — CONVERTER

Raw materials	Per 2000 pounds of steel in ladle: Price of raw materials per 2000 pounds	Weight used, pounds	Per cent used	Cost	Cost
Pig iron	$14.00	300	15	$2.10	
Pig iron	17.40	1280	64	11.14	
Heads, gates, etc.	14.00	660	33	4.62	
Defective castings (account bad metal)	80.00*	20	1†	.80†	
Ferroalloys	40.60	35	2	.71	
Total metal	....	2295	115	$19.37	$19.37
Operating costs	....	......	......	3.50‡	5.50‡
Cost of steel in ladle	....	......	......	$22.87	$24.87

Cost of Steel in Castings

Cost of steel in ladle ÷ 65 per cent	....	....	....	$35.18	$38.26
Less credit for heads, etc., as scrap	....	....	....	4.62	4.62
Net cost of steel in castings	....	....	....	$30.56	$33.64

* See footnote under Table I.

† The percentage of defective castings in converter practice will actually be less than this, so that the cost is a little higher than justice to average converter practice demands. In the absence of average figures, we have charged it the same as acid open hearth, with this correction.

‡ Operating cost, $3.50, is for one 2-ton converter making 150 tons per week. The $5.50 per ton is a 2-ton converter with small production.

TABLE V. — CONVERTER, WITH LARGE WASTE

Raw materials	Per 2000 pounds of steel in ladle				
	Price of raw materials per 2000 pounds	Weight used, pounds	Per cent used	Cost	Cost
Pig iron	$14.00	300	15	$2.10	
Pig iron	17.40	1360	68	11.83	
Heads, gates, etc.	14.00	660	33	4.62	
Defective castings account bad metal.	80.00	20	1	.80	
Ferroalloys	40.60	38	2	.77	
Total metal	....	2378	119	$20.12	$20.12
Operating costs	....	......	......	3.50	5.50
Cost of steel in ladle	....	......	......	$23.62	$25.62

Cost of Steel in Castings

Cost of steel in ladle ÷ 65 per cent	....	....	....	$36.34	$39.42
Less credit for heads, etc., as scrap	....	....	....	4.62	4.62
Net cost of steel in castings	....	....	....	$31.72	$34.80

TABLE VI. — ACID OPEN HEARTH [MAKING SMALL CASTINGS]

Raw materials	Per 2000 pounds of steel in ladle				
	Price of raw materials per 2000 pounds	Weight used, pounds	Per cent used	Cost	Cost
Pig iron	$14.00	300	15	$2.10	
Heads, gates, etc.	14.00	660	33	4.62	
Foreign scrap	14.50	980	49	7.11	
Defective castings account bad metal.	50.00	120	6	3.00	
Ferroalloys	40.60	29	1	.59	
Total metal	....	2089	104	$17.42	$17.42
Operating costs	....	......	......	5.50	8.85
Cost of steel in ladle	....	....	....	$22.92	$26.27

Cost of steel in castings

Cost of steel in ladle ÷ 65 per cent*	$35.26	$40.41
Less credit for heads, etc., as scrap	4.62	4.62
Net cost of steel in castings	$30.64	$35.79

* Of the steel in the ladle, 65 per cent goes into castings, 33 per cent goes into heads, gates, etc., 2 per cent is lost in spattering during pouring. In making small castings, the loss in pouring from a bottom-poured ladle would be much larger than this, and the cost of steel in castings would be increased $1 to $3 per ton, but data is lacking for exact estimates.

TABLE VII. — BASIC OPEN HEARTH [MAKING SMALL CASTINGS]

Raw materials	Per 2000 pounds of steel in ladle: Price of raw materials per 2000 pounds	Weight used, pounds	Per cent used	Cost	Cost	Per 2000 pounds of steel in ladle: Weight used, pounds	Per cent used	Cost	Cost
Pig iron	$12.75	1040	52	$6.63		1040	52	$6.63	
Heads, gates, etc.	14.00	660	33	4.62		660	33	4.62	
Foreign scrap	11.15	190	9½	1.06		350	17½	1.95	
Defective castings	50.00	200	10	5.00		300	15	7.50	
Ferroalloys	40.60	33	1½	.67		33	1½	.67	
Total metal	......	2123	106	$17.98	$17.98	2124	106	$19.93	$19.93
Operating costs	......	....	....	6.10	9.55	....	....	6.10	9.55
Cost of steel in ladle	......	....	....	$24.08	$27.53	....	....	$26.03	$29.48

Cost of Steel in Castings

Cost of steel in ladle ÷ 65 per cent	$37.05	$42.35	....	....	$40.05	$45.85
Less credit for heads, etc., as scrap	4.62	4.62	....	....	4.62	4.62
Net cost of steel in castings	$32.43	$37.73	....	....	$35.43	$40.73

TABLE VIII. — CRUCIBLE CASTINGS

Raw materials	Per 2000 pounds steel in ladle: Price of raw materials per 2000 pounds	Weight used, pounds	Per cent used	Cost	Weight used, pounds	Per cent used	Cost
Wrought iron	$25.50	1360	68	$17.34	......	......	......
Foreign steel scrap	14.50	......	......	......	1330	66½	$9.64
Heads, gates, etc.	14.00	660	33	4.62	660	33	4.62
Defective castings	125.00	10	½	.63	10	½	.63
Ferroalloys	40.60	12	½	.24	12	½	.24
Total metal	......	2042	102	$22.83	2012	100½	$15.13
Operating costs	......	......	......	35.00	......	......	35.00
Cost of steel in ladle	......	......	......	$57.83	......	......	$50.13

Cost of Steel in Castings

Cost of steel in ladle ÷ 66 per cent*	$87.62	......	......	$75.95
Less credit for heads, etc., as scrap	4.62	......	......	4.62
Net cost of steel in castings	$83.00	......	......	$71.33

* Of the steel in the ladle, 66 per cent goes into castings, 33 per cent goes into heads, gates, etc. and 1 per cent is lost in pouring.

TABLE IX. — ELECTRIC FURNACE

Raw materials	Per 2000 pounds of steel in ladle			
	Price of raw materials per 2000 pounds	Weight used, pounds	Per cent used	Cost
Steel scrap	$9.50	1330	66½	$6.32
Heads, gates, etc.	14.00	660	33	4.62
Defective castings	125.00	10	½	.63
Ferroalloys	40.60	12	½	.24
Total metal	....	2012	100½	$11.81

Cost of netting steel	In ladle	
Electric power at 1 cent per kilowatt hour	$28.81	$39.03
" " " 2 cents " " "	37.96	52.89
" " " 3 " " " "	47.11	66.76
" " " 4 " " " "	56.26	80.62
" " " 5 " " " "	65.41	94.49

CHAPTER XVIII

FOUNDRY FUELS (Cupola)

THE fuels available for melting iron in the cupola are anthracite coal and coke.

Anthracite Coal

Lehigh lump is the best coal for the purpose. It produces a hot iron and melts it rapidly. On account of the cost as compared with coke, it is now little used in districts removed from the anthracite region.

A mixture of anthracite and coke, particularly for the bed, gives most excellent results, especially for prolonged heats.

Coke

When bituminous coal is exposed to a red heat for a prolonged period with total or partial exclusion of air, the volatile matter is driven off and the residuum is coke, containing more or less impurities. The coal used is of the coking variety and to produce good foundry coke should be low in sulphur and ash. Seventy-two hour Bee Hive Coke is most generally used by foundrymen. This has a hard, cellular, columnar structure, with a gray, silvery surface. The smooth, glistening appearance found in much of it is due to quenching in the furnace. (Weight about 25 pounds to cubic foot.) There will be found in each carload of coke "black-tops" and "black-butts"; the appearance of the former is due to deposits of carbon from the imperfect combustion of the gases at the top of the furnace. They in no way affect the value of the fuel. Black butts, however, come from incomplete burning and contain unconverted coal. These should be accepted only in limited quantities.

The following are analyses from different sections:

Localities	Fixed carbon	Volatile matter	Moisture	Ash	Sulphur
Connellsville	89.58	.46	.03	9.11	.81
Pocahontas	92.58	.49	.20	6.05	.68
Chattanooga	80.51	1.10	.45	16.34	1.59
New River	92.38	....	....	7.21	.56
Birmingham	87.29	....	....	10.54	1.19

Specific gravity averages 1.272. Coke will absorb from 10 to 30 per cent of its weight in moisture, depending on exposure. After exposure to a hard storm the increase in weight may easily be 15 per cent.

Less pressure of air, more volume and larger tuyere area are required when melting with coke than with anthracite coal.

The following specifications for coke from the J. I. Case Co. are given by Mr. Scott.

Good clean 72-hour coke, massive and free from granulation, dust and cinder.

	Per cent
Moisture not over	1.50
Volatile matter not over	3.50
Fixed carbon not under	86.00
Sulphur not over	0.75
Ash not over	11.50

Coke which has over 0.85 sulphur, 0.05 phosphorus, less than 85 fixed carbon or less than 5.00 ash will be rejected.

Good foundry coke should be high in carbon, low in sulphur, have good columnar structure, and there should not be a large percentage of small pieces in a carload. The product should be uniform.

By-Product Coke

Certain chemical works, in the distillation of bituminous coal for ammonia, manufacture coke as a by-product. This, when especially prepared for foundry purposes, gives excellent results. It is darker, harder and more irregular in form than beehive coke. It is high in carbon and low in sulphur, makes a very hot fire and will melt more iron than an equal weight of beehive. The short description of the process of making this coke by Mr. W. J. Keep is given herewith.

"The retort oven is a closed chamber from 15 to 24 inches in width, 5 to 8 feet in height and from 25 to 45 feet long. From 25 to 50 of these ovens are placed in a battery.

"The coal is charged through three or more openings in the top and levelled off to within a foot of the roof, after which the oven is carefully closed and sealed, in order to exclude the air. The oven is heated by a portion of the gas driven off in the process of coking. This is not burned in the oven itself, but in flues constructed in their walls. The heat is conducted through the walls of these combustion flues to the charges of coal and distillation thereof is started immediately.

"The gas which is driven off is conducted through an apparatus in which the tar and ammonia are recovered; after which a portion of the gas is returned to be burned in the oven flues, and the balance disposed of as local conditions determine.

"Distillation proceeds from the side walls toward the middle of the oven and the gas is probably driven toward the center of the oven, where it rises, forming a cleavage plane the whole length of the oven. When the process is completed, which takes place in from 20 to 36 hours, depending upon the width of the oven and the temperature maintained, the whole charge is pushed out by a steam or electric ram and is immediately quenched. The oven is at once closed and, without any loss of heat from the oven itself, is again charged with coal.

"On account of the cleavage plane through the center of the charge, no piece of coke can be longer than half the width of the oven."

"Owing to the complete exclusion of air, there is no combustion in the oven; and as the temperature of the oven, when the coal is charged, is very high, there is a considerable decomposition of volatile matter with consequent deposition of carbon upon the coking charge. As a result the yield of coke is a little higher than the theoretical yield, as calculated from the analysis of the coal. Quenching the coke outside the ovens mars its appearance somewhat, destroying its bright, silvery lustre, but probably results in carrying off an appreciable quantity of sulphur."

"Coke made from the same coal will have a slightly higher percentage of fixed carbon and a slightly lower percentage of ash than if made in a retort oven."

"The quality of retort oven coke depends upon the skill of the operator, upon the method of preparing the coal and more than all, upon the quality of the coal used.

He further says that after having satisfied himself that it was good coke, "in spite of its very bad appearance," by the use of several carloads, "from that time to this we have never had a pound of other coke. All through 1902 the coke was so uniform and satisfactory that we melted 9 pounds of iron with 1 pound of coke."

Effect of Atmospheric Moisture upon Coke

Under normal conditions, at a temperature of 70° F., 1000 cubic feet of air, equal in weight to about 75 pounds, contains 1 pound of moisture. Each pound of moisture requires the use of 0.10 additional pounds of coke. Therefore, every additional 1.0 per cent to the moisture of the atmosphere requires 0.03 additional pounds of coke to melt one ton of iron.

From 20 to 40 per cent of the sulphur in the coke is taken up by the iron in melting. This may be largely reduced by the liberal use of limestone.

Specifications for Foundry Coke Suggested by Dr. Richard Moldenke

Coke bought under these specifications should be massive, in large pieces and as free as possible from black ends and cinders.

Sampling

Each carload or its equivalent shall be considered as a unit, and sampled by taking from the exposed surface at least one piece for each ton, so as to fairly represent the shipment. These samples, properly broken down and ground to the fineness of coarse sawdust, well mixed and dried before analysis, shall be used as a basis for the payment of the shipment. In case of disagreement between buyer and seller an independent chemist, mutually agreed upon, shall be employed to sample and analyze the coke, the cost to be borne by the party at fault.

Base Analysis

The following analysis, representing an average grade of foundry coke capable of being made in any of the districts supplying foundries, shall be considered the base, premiums and penalties to be calculated thereon as determined by the analysis on an agreed base price:

Volatile matter.......	1.00	Ash...............	12.00
Fixed carbon.........	85.50	Sulphur............	1.10

Penalties and Bonuses

Moisture. — Payment shall be made on shipments on the basis of "dry coke." The weight received shall, therefore, be corrected by deducting the water contained. (Note. — Coke producers should add sufficient coke to their tonnage shipments to make up for the water included, as shown by their own determinations.)

Volatile Matter. — For every 0.50 or fraction thereof, above the 1.00 allowed, deduct .. cents from the price. Over 2.50 rejects the shipment at the option of the purchaser.

Fixed Carbon. — For every 1.00 or fraction thereof, above 85.50 add, and for every 1.00 or fraction thereof below 85.50, deduct .. cents. Below 78.50 rejects the shipment at the option of the purchaser.

Ash. — For every 0.50 or fraction thereof below 12.00, add, and for every 0.50 or fraction thereof above 12.00 deduct .. cents from the price. Above 15.00 rejects the shipment at the option of the purchaser.

Sulphur. — For every 0.10 or fraction thereof below 1.10 add, and for every 0.10 or fraction thereof above, deduct .. cents from the price. Above 1.30 rejects the shipment at the option of the purchaser.

Shatter Test

On arrival of the shipment the coke shall be subjected to a shatter test, as described below. The percentage of fine coke thus determined, above 5 per cent of the coke, shall be deducted from the amount of coke to be paid for (after allowing for the water), and paid at fine coke prices previously agreed upon. Above 25 per cent fine coke rejects the shipment at the option of the purchaser. Fine coke shall be coke that passes through a wire screen with square holes 2 inches in the clear.

The apparatus for making the shatter test should be a box capable of holding at least 100 pounds coke, supported with the bottom 6 feet above a cast-iron plate. The doors on the bottom of the box shall be so hinged and latched that they will swing freely away when opened and will not impede the fall of the coke. Boards shall be put around the cast iron plate so that no coke may be lost.

A sample of approximately 50 pounds is taken at random from the car, using a 1¼ inch tine fork, and placed in the box without attempt to arrange it therein. The entire material shall be dropped four times upon the cast iron plate, the small material and the dust being returned with the large coke each time.

After the fourth drop the material is screened as above given, the screen to be in horizontal position, shaken once only, and no attempt made to put the small pieces through specially. The coke remaining shall be weighed and the percentage of the fine coke determined.

If the sum of the weights indicates a loss of over 1 per cent the test shall be rejected and a new one made.

Rejection by reason of failure to pass the shatter test shall not take place until at least two check tests have been made.

Fluxes

The object of a flux is to render fusible the ash from the fuel, sand and rust from the iron, and dirt of any sort, found in the cupola, into slag and to put it in condition for easy removal.

Slag always forms to a greater or less extent where iron is melted, but unless a flux is present, it will not be sufficient in volume to give clean iron. Limestone and fluor spar are the most common fluxes in use. There are many compounds furnished for the purpose, but a limestone containing 90 per cent or more carbonate of lime, or oyster shells, furnish as good fluxing material as can be procured.

The following is copied from a paper by Mr. N. W. Shed, presented to the Cleveland meeting of the American Foundrymen's Association at June, 1906.

"The value of fluxes in the cupola is not generally appreciated by foundrymen. Hundreds of cupolas are not slagged at all and the cinder dumps show an immense amount of iron actually wasted. Not only is iron lost by the large amount combined with the cinders, but the more or less variable cinder encloses small masses and shots of iron which cannot be separated. It is a fact that the cinder dumps of many foundries contain more iron than many workable deposits of iron ore, and if these accumulations could be obtained by the German blast furnaces they would be quickly utilized.

Another value of fluxes is their cleansing action on the cupola. A well slagged cupola has no hanging masses of iron and cinder which require laborious chipping out. The time and labor saved in consequence is an item that is well worth considering. In the running of heavy tonnage from a single cupola, fluxes are indispensable. It would be well nigh impossible to run large heats in the same cupolas without using a good flux.

The value of fluxes being generally admitted, the question arises, what flux is best to use and how much?

There are two available fluxes for the cupola. These are limestone and fluor spar.

Fluor spar is much advertised as a flux and the promoters claim that it gives marvellous properties to the iron. The glowing advertisements have evidently deceived the U. S. Geological Survey, for the reports of the Survey speak of its great use and value in foundry practice."

The practical test of fluor spar, made by the writer showed it to be an inferior flux. It did not remove sulphur and the properties of the iron were not improved in the least by its use. There is no doubt of the value of fluor spar in certain branches of metallurgy, but the writer has failed to find a single supporter of its value in the foundry.

Limestone is far cheaper than fluor spar and far better as a flux. It makes little difference what form the limestone has so long as it is pure. It may be marble, soft limestone, hard limestone, oyster shells, or mussel shells, but it must be good. A limestone containing over 3 per cent silica is poor stuff, and one containing any considerable amount of clay should be rejected. There should be at least 51 per cent of lime present. The sulphur should be below 1 to 2 per cent. The phosphorus is unimportant. A magnesian limestone would do as well as an ordinary limestone for the cupola.

The amount of limestone to be used is variable, depending:

First: on the amount of silica in the coke ash.

Second: on the amount of silica or sand adhering to the pig or scrap.

Third: on the amount of silica to be carried by the slag.

The amount of limestone required to flux the coke ash can be figured according to the ordinary method of calculating blast furnace charges.

The amount of sand on the pig and scrap is so variable that it is difficult to know just the additional amount of limestone to add.

The most practical and easily fusible slag has been found to be a monosilicate, which means having equal amounts of silica and alkaline bases. Having these variables in mind, we find it a good rule to figure the limestone on the weight of the coke, using 25 per cent limestone.

For example, if the charge of coke on the bed is 4000 pounds, we use 1000 pounds of limestone. If the next charge of coke is 1000 pounds, we would use 250 pounds of limestone. This amount of limestone will flux any ordinary coke ash with the average amount of sand on pig and scrap. If we know the amount of sand on the pig to be excessive we figure 30 per cent limestone on the weight of the coke.

With a low coke ash, machine pig and clean scrap, the limestone may be reduced to 20 per cent and make a good cinder. Many foundry-men are afraid to use limestone, fearing some injury to the iron. This is a superstition for lime has no effect on the iron.

There is usually a slight reduction in the amount of sulphur, but owing to the great amount of iron present, the iron absorbs a large amount of sulphur from the coke.

If more than 30 per cent is required to make a good cinder and clear the cupola it is evident that either the coke is very high in ash, or else the limestone is high in silica. In the latter case a large amount of lime is used in fluxing its own silica.

On account of the frequent variations in the stock, it is a good plan to have coke, limestone and cinder analyzed occasionally.

The cinder usually tells about the condition of the furnace. A light brown indicates a small amount of iron and the iron unoxidized. A black cinder indicates a large amount of iron and some oxidation. A shiny metallic lustre shows an excess of oxide of iron due to over-blowing or lack of coke. Practically all the lime cinders from a cupola are glossy in appearance, while the cinders with no lime are usually dull and earthy. Occasionally a cinder is found full of bubbles, the color is usually black and shots of iron are found through the frothy slag. This is called foaming cinder, and is made when the last few charges are at the bottom of the cupola. This cinder often rises to the charging door and flows out over the floor. The iron cast at this time is hard and is low in manganese, silica and carbon.

With foaming slag a dense smoke of reddish brown color pours out of the stack.

Analysis of the foaming slag shows the iron to be in an oxidized condition and in large amount. Sometimes the iron will run 30 per cent in frothy cinder, sometimes only 12 per cent. The oxidized cinder and the red smoke show that iron is being rapidly burned in the cupola, and the action going on is very much like the action in a Bessemer converter when it is tilted back a little and blown to gain heat by burning the iron. The cinder is oxidized and the red smoke is produced in the same way. In both cases the iron is burnt to oxide, which is quickly taken up by the slag. The oxide in the slag acts upon the carbon in the iron forming a large amount of carbonic oxide, which rises through the cinder blowing it to a frothy condition.

There are two ways of avoiding this troublesome condition. If possible, reduce the blast. If the blast cannot be reduced, add more coke. The presence of a good body of coke will stop the burning of the iron, and frothing does not take place. In some cases the loss of silicon is very serious, and to insure good castings it is necessary to add crushed silicon metal and ferro-manganese to the stream of iron as it runs from the spout.

Analysis of cupola slags where no flux is used show from 14 to 28 per cent ferrous oxide. These slags contain 2 to 4 per cent of shot iron mingled with the cinder. This proves that some of the iron must be lost in order to flux the coke ash and sand. If we use limestone as a flux the amount of iron in the cinder is rarely over 3 per cent, showing that the lime fluxes the ash and sand leaving the iron for the ladle. And the question is simply whether we will use iron as a flux at $18.00 per ton or limestone at $1.50 per ton.

Another point in favor of the limestone is the clean cupola mentioned in the first part of this paper.

Following will be found an analysis of cupola cinder using lime."

Comparison of Analyses of Slags, Made With and Without Lime

Constituents	Using lime	Without lime
CaO	34.60	6.60
FeO	4.10	21.76
Al_2O_2	11.02	11.80
SiO_3	48.20	58.44
MnO	1.40	1.30
S	.20	.10
Total	99.52	100.00

The following analyses are extracted from "The Foundry," Dec. 1909.

Analysis of Slag from a Cupola Melting Car Wheel Iron, in the South

	Per cent		Per cent
Silica	48.77	Oxide of iron	13.18
Aluminum	10.90	Metallic iron	9.23
Lime	13.79	Manganese	4.84
Magnesia	6.05	Sulphur	0.81

Analysis of Slag from a Cupola Melting Gray Iron, No Fluor spar Being Used

	Per cent		Per cent
Silica	42.84	Magnesia	13.28
Alumina	.....	Manganese	2.34
Oxide of iron	21.32	Manganese oxide	3.01
Lime	21.16		

Analysis of Slag from a Cupola Melting Gray Iron, Fluor spar Being Used

	Per cent		Per cent
Silica	39.50	Magnesia	11.05
Alumina	.....	Manganese	2.24
Oxide of iron	22.82	Manganese oxide	2.89
Lime	24.50		

Analysis of Slag from a Cupola Melting Malleable Iron

	Per cent		Per cent
Silica	41.72	Magnesia	15.06
Oxide of iron	.....	Manganese	3.20
Alumina	22.24	Metallic iron	5.82
Lime	17.84	Manganese oxide	4.12

Analysis of Slag from a Cupola Melting Car Wheel Iron, in the North

	Per cent		Per cent
Silica	44.00	Magnesia	7.27
Oxide of iron	13.16	Metallic iron	9.21
Alumina	9.76	Manganese	5.70
Lime	15.99	Sulphur	0.78

Cupola Slag from a Western Foundry

	Per cent		Per cent
Silica	37.16	Oxide of iron	13.73
Alumina	9.16	Metallic iron	9.61
Lime	8.98	Manganese oxide	2.77
Magnesia	8.44	Sulphur	0.36

Sufficient flux must be used to obtain a fluid slag to carry off the silica from the iron and ashes and to reduce the oxidation as much as possible.

With low blast pressure the slag must be thin, to run off readily.

When slag wool is freely produced, the indication is that the slagging is satisfactory.

A good slag contains approximately 40 per cent of silica and from 28 to 30 per cent lime. If the slag is thin, the metallic iron will fall through it readily and an increase of lime tends to decrease the oxide of iron.

Rusty scrap produces a dark-colored slag caused by the oxide of iron.

A large body of slag is favorable to desulphurization, as the amount of sulphur which can be taken up by the slag is limited. At high temperatures sulphur tends to combine with the slag and under these conditions it has not its greatest affinity for iron.

Fire Brick and Fire Clay

A good brick has a light yellow color, a coarse and open structure, uniform throughout. It should be burned to the limit of contractility. The clay from which it is made should contain as little iron, lime, potash and soda as possible.

Analyses of Fire Clays Used for Making Fire Brick

Clay loses its plasticity at a temperature above 100° C., and it cannot again be restored.

Localities	Water	Silica	Alumina	Oxide of iron	Lime	Magnesia	Potash	Soda
Stourbridge, Eng.	17.34	45.25	28.77	7.72	.47	....	....	....
Mt. Savage, Md.	12.74	50.45	35.90	1.50	.13	.20	....	....
Mineral Point, Ohio	11.70	49.20	27.80	....	.40	.10	....	....
Port Washington, Ohio	5.34	59.95	33.85	....	2.05	.55	....	....
Springfield, Ohio	5.45	70.70	21.70	....	.40	.37	....	....
Springfield, Pa.	.....	55.62	38.55	4.17	.24	.24	.95	.24
Springfield, Pa.	.....	56.12	37.48	4.43	.36	.29	.99	.23

Pure silicate of alumina melts at 1830° C.

Fire bricks should stand continuous exposure to high temperatures of the furnace without decomposition or softening; should stand up under considerable pressure without distortion or fracture; should be unaffected by sudden and considerable variations of temperature; should not be affected by contact with heated fuel.

Fire brick should be regular in shape and uniform in character. The size of the ordinary straight fire brick is 9 by 4½ by 2½ inches, and the weight is 7 pounds.

Cupola brick are usually 4 inches thick and 6 inches wide radially.

Slabs and blocks are made in sizes up to 12 by 48 by 6 inches.

Silica Brick

Silica brick are used for resisting very high temperatures. They are composed mostly of silica in combination with alkaline matter. They are somewhat fragile and need careful handling.

ANALYSIS OF SILICA BRICK

Silica	Alumina	Ferric oxide	Lime	Magnesia	Potash
97.5	1.4	.55	.15	.10	....
90.0	3.0	.80	.20	.10	.6

Ganister

Ganister is made from an argillaceous sandstone, is a close-grained dark-colored rock containing no mica. There is present sufficient clay to cause the particles to become adherent under ramming, after the rock has been ground. The rock is ground to a coarse powder and sometimes if the binding properties are insufficient a little milk of lime is added during the grinding process. The composition of ganister will fall in the limits as given below.

Constituents	Per cent	
	From	To
Silica	87.00	95.00
Alumina	4.00	5.00
Ferric oxide	....	1.50
Lime and Magnesia	.25	.75
Alkalies	....	1.00

Fire Sand

An exceedingly refractory sand containing sometimes as much as 97 per cent silica. It is used in the setting of silica brick and in making the hearths of furnaces.

Pure silica melts at 1830° C.

Magnesite

Magnesite contains a small percentage of lime and ferrous silicates with serpentine. The ferrous silicates are separated out; thereupon calcining, magnesia is obtained. The calcined material is then mixed with from 15 to 30 per cent of the raw material, and from 10 to 15 per cent water, then moulded into bricks, dried and burned in the ordinary manner.

Bauxite

This is a hydrated aluminous ferric oxide, containing usually about 60 per cent of alumina, 1 to 3 per cent of silica, 20 per cent ferrous oxide and from 15 to 20 per cent water. It is very refractory and, notwithstanding the large amount of ferrous oxide contained, is practically infusible.

Calcined bauxite is mixed with from 6 to 8 per cent of clay, or other binding material and plumbago, then molded into bricks.

When heated the plumbago reduces the iron of the bauxite, producing a most refractory substance.

Such bricks are far more durable than the best fire bricks. They resist the action of the basic slags, as well as that of intense heat.

They become extremely hard after exposure to continued heat.

CHAPTER XIX

THE CUPOLA

The cupola is used in ordinary foundry practice in preference to the air furnace, not only on account of its simplicity, but because it melts more rapidly and economically. There are many forms manufactured. All of them are good, but it is doubtful if any furnishes better results than have been obtained from the ordinary old-fashioned cupola so commonly in use, such as is shown in the sketch below.

For the advantages of the various styles offered for sale, the reader is referred to the manufacturers' catalogues.

The cupola is essentially a vertical hollow cylinder, lined with refractory material, having the top open and the bottom closed, with provision for admission of the charges of fuel and iron part way up on the side, also for admission of air below the charges and for drawing off the melted metal at the bottom.

The cupola is divided into five zones.

First: The Crucible, extending from sand bottom to the tuyeres.

Second: The Tuyere Zone, extending from the crucible to melting zone.

Third: The Melting Zone, reaching from the tuyere zone to a point about 20 inches above the tuyeres.

Fourth: The Charging Zone, extending from melting zone to charging door.

Fifth: Stack, from charging door to top of furnace.

The Lining

The lining is usually made of two thicknesses of arch brick placed on end with the flat sides in radial planes. Several standard rectangular brick are placed in each ring or course to facilitate the removal of the rings when necessary. Angle iron rings are riveted to the shell at intervals of about six feet, to support the upper sections, when a lower one is removed for repairs.

The outer lining is kept about ¾ inch away from the shell to provide for expansion, and the interval is filled in loosely with sand and broken brick.

The distance from the sand bottom to the charging door should be about 3½ to 4 times the inside diameter of the lining. For cupolas

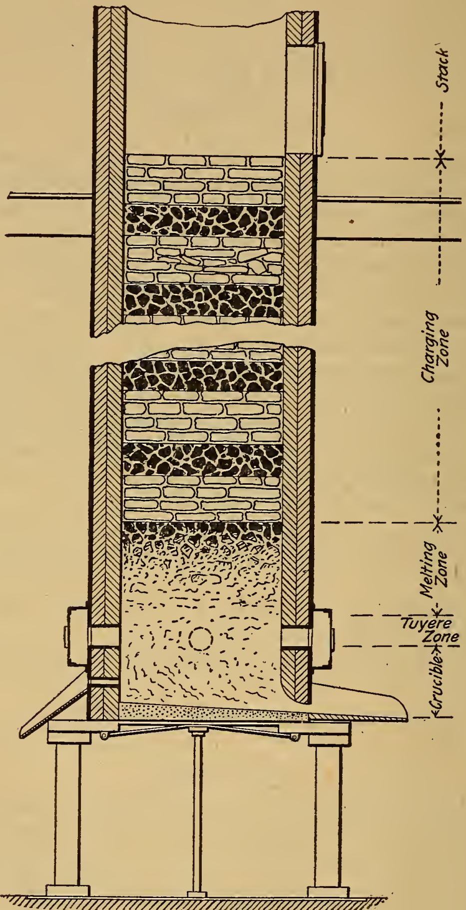


FIG. 123.

under 48 inches, one door is sufficient; for larger sizes two are more convenient. The doors may be hung on hinges or slide on a circular track above the openings. It is not necessary that they should be lined.

At the level of the charging door the lining should be covered with a cast-iron ring to protect it during the charging.

The bricks are laid with very close joints in mortar composed of fire clay and sand. The interior lining is daubed with a mixture of one-half fire clay and three-fourths sharp sand for a thickness of three-fourths inch. Any joints are well filled. A handful of salt to a pail of daubing will cause the interior of the shell to be glazed over and will reduce the amount of chipping required. Washing the daubing with strong brine and fire clay serves the same purpose.

Tuyeres

The tuyeres may be circular or rectangular in section with the bottoms inclining slightly toward the interior of the shell so that the drippings may not run into the wind box. Castings for tuyeres should not be over ⅝ inch thick.

The area of the tuyeres is made from 10 to 25 per cent that of the inside lining at the tuyeres; 20 per cent gives good results. As a matter of fact the tuyeres cannot be made too large. A continuous tuyere having an opening about 2 inches in height and extending all around the lining is frequently used.

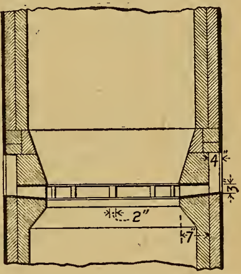


Fig. 124.

An excellent plan is to have an air chamber all around the outer lining and inside of the shell in the vicinity of the tuyeres; at the level of the bottom of the tuyeres place a cast-iron ring, in sections, on top of the double lining. On this, at intervals of from 7 to 10 inches, so as to divide the circumference of the interior of the lining into equal parts, place hollow iron blocks 2 inches wide, 3 inches high and 7 inches long. On top of the blocks place another segmental ring, which should be kept 3 or more inches away from the interior of the shell. Upon this ring the upper courses of the lining are built. This forms a nearly continuous tuyere, broken only by the iron blocks.

This construction involves a contraction of the lining at the tuyeres of about 8 inches. The bottom of the tuyeres should be from 10 to 20 inches above the sand bottom, depending upon the quantity of melted iron to be collected before tapping. Where the iron is allowed to run continuously from the spout, as in stove and other foundries doing light work, the tuyeres may be even lower than 10 inches.

Frequently an additional row of tuyeres, having about one-eighth of the main row in area, is placed just below the melting zone. These upper tuyeres should be arranged so that the admission of air through them may be regulated. The object is to supply the necessary air to convert whatever carbonic oxide is formed in the tuyere zone into carbonic acid at the melting zone. The heat developed at these upper tuyeres is such that the lining near them is often badly cut, therefore, care must be exercised as to the admission of air at this point.

A row of adjustable tuyeres about 10 inches above the melting zone is most effective in producing the combustion within the charges of carbonic oxide, forced above that zone, effecting thereby not only a saving of fuel, but the suppression of flame at the charging doors. The admission of air above the melting zone must be carefully regulated so that only enough will enter to burn the carbonic oxide.

The "Castings" for September, 1908, illustrates a cupola designed by Mr. J. C. Knoeppel, which presents an admirable arrangement of tuyeres and provides for the object above outlined.

Two or more of the lower tuyeres, should have slight depressions in the bottoms, to permit the slag or iron, should either reach that level, to run out upon sheet lead plates placed in the wind box in the line of these depressions. By the melting of these plates, and the discharge through the resulting holes, warning is given to the cupola tender, and the accumulation of slag or iron in the wind box avoided.

Unless the blast is much higher than good management permits, it will not penetrate the fuel in the cupola for more than 30 inches radially. Therefore, where the inside diameter of the cupola is over 60 inches, it should be contracted at the tuyeres to 60 inches or less diameter; or in place of this a center blast may be used. Large cupolas are frequently made oval in section with the same object in view.

In the wind box directly opposite each tuyere there should be a small door 5 inches in diameter, fastened with a thumb screw, for access to the tuyeres, to remove any stoppages in front of them; each door should be provided with a peek hole 1½ inches in diameter covered with mica.

The Breast

The breast is made by taking a mixture of one-half fire clay and one-half molding sand, thoroughly mixed and just moist enough to be kneaded. A quantity of this is placed around a bar 1¼ inches in diameter and made into cylindrical shape, 4 or 5 inches in diameter and about 6 inches long. This is placed in the opening for the breast, and the bar, while held in a nearly horizontal position, forced down until its bottom is on a line with the sand bottom, and ¾ inch above the upper side of lining to trough. The inner end of the clay cylinder should be flush with the inside of the cupola lining.

Ram hard around this cylinder with molding sand and fill opening for breast completely. Care must be taken that this clay cylinder is well secured in place. Remove the forming bar and enlarge the hole toward inside of cupola, leaving only about 3 inches in length of the original diameter from the front.

The slag hole is made up in same way, but should be only one and a half inches long. A core about 2½ inches in diameter may be inserted for the slag hole, and this dug out, when tapping for slag, until opening is sufficiently large, say about 1 inch diameter.

It sometimes happens that the breast gives way during the heat. In such an event, the blast is shut off and the cupola drained of iron and slag. The defective part of the breast is removed, and replaced with stopping clay, which is hammered with the side of a bar, well against the surrounding portion of the breast. The remaining hole is then filled with clay, carefully packed so as not to be driven to the interior of the cupola. Through this clay a tap hole is made by gently inserting the tapping bar and enlarging the hole after the ball of clay has been penetrated. In from fifteen to twenty minutes the clay will have been baked hard. The blast can then be turned on and melting resumed. This operation must be conducted with great care, as the operator is in danger of being severely burned.

Swab the lining from the bottom to 2 feet above the tuyeres with clay wash and salt, and black wash the tapping hole formed as above described.

Sand Bottom

The sand bottom is made from gangway sand passed through a No. 4 riddle. This bottom should be about 8 inches thick. It must be well rammed, especially next to the lining, where it should join with a liberal fillet. It must not be too wet. Care must be taken not to ram the bottom so hard that the iron will not lie on it quietly. The bottom should slope in all directions towards the tapping hole, the slope being one inch in four feet, and it should reach the tapping hole exactly on a level with its lower surface.

Black wash the bottom, build a light wood fire and dry out the lining thoroughly. The bottom doors should have a dozen or more ¾-inch holes drilled through them to allow any moisture in the bottom to escape. The doors are held in place by an iron post under the center, which can readily be knocked out to drop the bottom. The breast should be made up before the bottom.

Zones of Cupola

The crucible zone extends from the sand bottom to the tuyeres. The object of this zone is to hold the melted iron and slag. If the tap hole is kept open continuously, this zone may not be over 4 to 6 inches in depth from sand bottom to bottom of tuyeres. If it is to hold a large quantity of melted iron, the tuyeres must be correspondingly high. Metal can be melted at a higher temperature with low tuyeres, (collecting it in a ladle), than by holding it in the cupola.

Tuyere Zone

This is where the blast enters in contact with the fuel. Here combustion begins. This zone is confined to the area of the tuyeres. The combined area of the tuyeres should be about one-fifth that of a section of the cupola at this point, and should also largely exceed that of the outlet of the blower. It is important to keep the tuyeres as low as the conditions of the foundry, as to amount of melted iron to be collected at one tap, will permit. With low tuyeres the iron is hotter, there is less oxidation and the fuel required on the bed is less.

Melting Zone

The melting zone is the space immediately above the tuyeres. It extends upward from 20 to 30 inches, depending upon the pressure and volume of the blast, increasing in height with increased pressure. No iron is melted above or below it. The melting occurs through the upper 4 to 6 inches of that zone.

Charging Zone

This zone is that part containing the charges of iron and coke, and extends from the melting zone to charging door.

The stack is the continuation of the cupola from charging door through the roof. Contracting the stack above the charging door has no influence upon the efficiency of the cupola.

The spouts should be lined with fire brick. Above the fire brick bottom at center of trough, there should be 1½ inches of moulding sand. From the center the sand should slope rapidly each way to sides. The sand lining of trough at center should be ¾ inch below the tap hole. After lining, trough should be black washed and dried. Stopping material is made of one-half fire clay and one-half moulding sand.

It is the common practice to leave the top hole open until iron begins to run freely, in order to prevent freezing at the hole. This causes the oxidizing of considerable metal, and is unnecessary. The following method may be pursued. Just before the blast goes on, close up the inner end of the tap hole with a ball of greasy waste, then ram the remainder of the hole full of moulding sand. This is easily removed with the tapping bar, and does away with all the annoyance of escaping blast and sparks.

Chemical Reactions in the Ordinary Cupola with Single Row of Tuyeres

When the air blast comes in contact with the burning coke, its oxygen unites with the carbon of the coke to form carbonic acid (CO_2), as the result of complete combustion. As the temperature above the tuyeres increases to that necessary for melting iron, part of the CO_2 seizes upon the incandescent coke, takes up another equivalent of carbon and is converted into carbonic oxide (CO). If the supply of air is in excess of that required, the CO, being combustible gas, takes up another equivalent of oxygen and is burned to CO_2.

Again some of the CO_2, parting with an equivalent of oxygen to the iron for such oxidation as occurs, or by the acquisition of another equivalent of carbon from the coke; or by both, is reconverted into CO. These reactions take place at or near the melting zone.

After passing that zone, no more air is supplied, and the products of combustion, consisting of CO and CO_2 pass up the stack without further change until reaching the charging door. Here air is admitted, the CO is supplied with oxygen and is burned to CO_2.

If the air supplied at the tuyeres is insufficient for complete combustion, the evolution of CO is increased and the efficiency of the furnace reduced. On the other hand, an excessive supply of air is objectionable, as a reducing flame (that from CO) is desirable to prevent oxidation of the metal.

For the complete combustion of one pound of carbon, there is required 12 pounds, or about 150 cubic feet of air, developing 14,500 B.t.u.; but the combustion of one pound of carbon to CO requires only one-half the air, and the resulting heat is 4500 B.t.u.; hence for whatever portion of the fuel is burned to CO, there is a loss of over two-thirds its heat-producing value.

For the purpose of saving this waste heat, an upper row of tuyeres, just below the melting zone, is employed; and to utilize the heat which escapes above the melting zone, tuyeres have been introduced with good results, at from 5 to 10 inches above that zone. By the use of the latter tuyeres the heat developed is absorbed by the charges in the stack, and the flames at charging door are suppressed. Where such tuyeres are used, they must be provided with means for easily regulating the admission of air.

The following table taken from West's Moulders' Text Book gives the quantity of air required for the combustion of one pound each of coke and coal.

Combustibles, 1 pound weight	Weight of oxygen consumed per pound of combustible, pounds	Quantity of air consumed per pound of combustible		Total heat of combustion of 1 pound of combustible, units of heat
		Pounds	Cubic feet at 62° F.	
Coke, desiccated........	2.51	10.9	143	13,550
Coal, average............	2.46	10.7	141	14,133

By reason of the contact of the molten iron with the fuel, changes in atmospheric conditions, the amount of air used, and other conditions, the same mixture may produce different kinds of castings at different times; and there may also be variations in the same heat.

Chemical Reactions in the Cupola

The complete combustion of one pound of carbon to CO_2 requires:

2.66 pounds of oxygen
or 12.05 pounds of air
and develops 14,500 B.t.u.

The burning of one pound of carbon to CO requires:

1.33 pounds of oxygen
or 6.00 pounds of air
and develops 4500 B.t.u.

Therefore one pound of coke, having 86 per cent fixed carbon requires for complete combustion

$2.66 \times 0.86 = 2.29$ pounds oxygen
or $12.00 \times 0.86 = 10.32$ pounds air
and develops $14{,}500 \times 0.86 = 12{,}470$ B.t.u.

The 10.32 pounds of air less 2.29 pounds oxygen leave 8.03 nitrogen.

Taking the specific heat of oxygen at 0.218, carbon at 0.217, nitrogen at 0.244. The temperature resulting from the complete combustion of one pound of coke to CO_2 is

$$\frac{12,470}{0.217 \times 0.86 + 0.218 \times 2.28 + 0.244 \times 8.03} = 4718° \text{ F.}$$

That resulting from the combustion of one pound of coke to CO is

$$\frac{3870}{0.217 \times 0.86 + 0.218 \times 1.15 + 0.244 \times 4.015} = 2731° \text{ F.}$$

Hence for every pound of coke burned to CO, instead of CO_2, there is a loss of 8600 B.t.u., and a reduction of the resulting temperature of 1983° F. Taking the specific heat of cast iron at the average of temperatures between 2120° and 2650° F. as 0.169, and the latent heat of fusion as 88 B.t.u., and assuming the temperature of the escaping gases at 1330°, then the heat wasted is $(1330°–70°) \times (0.217 \times 0.86 + 0.218 \times 2.28 + 0.244 \times 8.03)$ equals 3330 B.t.u.; and the heat available for melting iron is $12,470 - 3330 = 9140$ B.t.u. for each pound of coke having 86 per cent fixed carbon.

For 1 pound of iron melted at 2650° F. (or 2580° F. above atmosphere) the number of heat units required is $2580 \times 0.17 = 439$ to which must be added the latent heat of fusion giving $439 + 88 = 527$ B.t.u.

Therefore, $\frac{9140}{527} = 17.34$ pounds of iron, which should be melted by one pound of coke, if all the carbon was converted into CO_2 and the gases escaped at 1330° F.; also neglecting the heat lost in the slag and by radiation.

Wind Box

The area of cross section of the wind box should be three or four times that of the combined area of the tuyeres, in order that there may be sufficient air reservoir to permit a steady pressure. There should be two or more doors in the box for ready access in cleaning out when necessary; and also for admission of air when the wood fire is started. As before stated, there should be small doors opposite each tuyere.

The blast pipe ought, if the situation will permit, to enter the box on a tangent, and box should be continuous. If it is necessary to divide it into two boxes, on account of the tapping or slag holes, there must, then, of course, be a blast pipe for each box and they should enter the boxes vertically.

The bottom of the box should be provided with at least two small openings opposite the alarm tuyeres, which are covered with sheet lead. These should be so placed that slag or iron running through them will be at once seen by the tapper.

The manufacturing of cupolas for the trade has become an important industry, and although the designs of the various makers differ largely in details, the essential features in all are the same.

Perhaps the names best known to the foundry industry are: Colliau, Calumet, Newten, Whiting.

All of these give good results. For special information reference should be made to the manufacturers' catalogues.

The melting capacities based on 30,000 cubic feet of air per ton of iron are given in the following table.

BUILDERS' RATING

Diameter inside of lining, inches		Colliau	Calumet	Newten
24	Melting capacity, tons per hour	1– 1½	1– 2	1¼– 2½
30		3– 4	2– 3	3 – 5
36		4– 6	4– 5	4 – 6
42		6– 8	6– 7	8 – 9
48		8–10	8– 9	9 –11
54		10–11	10–11	11 –12
60		12–14	12–14	12 –14
66		15–16	15–17	14 –18
72		17–20	18–20	18 –20
78		25–27	21–24	20 –24
84		....	24–27	....

A wind gauge should be attached to the wind box at a convenient place. The charging platform should not be more than 24 inches below the bottom of charging door for sizes up to the 48 inch; for the larger sizes not over 6 to 8 inches.

The Blast

The air for the blast is supplied by centrifugal blowers of the Sturtevant type, or by Positive Pressure Blowers of the Root type. Both are efficient, and it does not appear that either has any special advantage not possessed by the other.

For successful melting a large volume of air at low pressure is required. From 8 to 10 ounces pressure will usually be found sufficient; in no case should it be allowed to exceed 14 ounces.

As a rule 30,000 cubic feet of air per ton of iron are allowed. This is somewhat too small, especially if the air contains much moisture; 35,000 cubic feet per ton is better practice.

With blast at low pressure and with high temperature in the furnace, iron may gain in carbon during the process of melting. The reverse may occur, however, under contrary conditions. Oxidation increases with the intensity of the blast.

The castings produced by low blast pressure are softer and stronger, the loss by oxidation is less, there is less slag, less expenditure of power and less injury to the lining of the cupola.

Coke requires less pressure and more volume of air, as well as greater tuyere area than coal.

Low pressure, large volume, large tuyere area and good fluxing tend to prevent choking at the tuyeres. However, too much air must be avoided as it reduces the temperature of the furnace and may produce dull iron.

The main blast pipe should be as short, and the tuyeres as few as possible. Its diameter should be greater than the outlet of the blower. For each turn allow three feet in length of pipe. The minimum radius of the turn should not be less than the diameter of the pipe. It should be provided with a wind gate, and, where a pressure blower is used, an escape valve, both under control of the melter. The wind gate should be kept closed until after the blower is started to prevent gas from collecting in the blast pipe. For the same reason, the blower should, if possible, be located lower than the wind box.

At the commencement, the blast should be low, and gradually increased to the maximum as the heat progresses, then dropped toward its close.

The friction of air in pipes varies inversely as their diameters, directly as the squares of the velocities, and as the lengths. The table below shows the loss in pressure and the loss in horse power by friction of air in pipes 100 feet long; corresponding losses for other lengths can readily be calculated therefrom.

LOSS IN PRESSURE IN OUNCES AND HORSE POWER IN FRICTION OF AIR IN PIPES 100 FEET LONG

Diameter of cupola inside of lining, inches	Tons of iron melted per hour	Cubic feet of air per minute	Velocity of air in feet per minute	Diameter of blast pipe, inches	Diameter of outlet of blower	Loss of pressure in ounces per square inch	Horse power lost in friction
24	1.5	875	1600	10	8	.313	.099
30	3.0	1,750	2200	12	9	.448	.211
36	4.5	2,600	2400	14	11	.457	.320
42	6.0	3,500	2500	16	12	.434	.405
48	8.0	4,700	2600	18	14	.417	.523
54	10.0	5,800	2700	20	15	.406	.653
60	12.5	7,300	2300	22	18	.246	.485
66	15.0	8,750	2400	24	20	.246	.594
72	18.0	10,500	2500	26	22	.231	.582
78	22.0	12,800	2500	28	23	.202	.507
84	25.0	14,560	2600	30	24	.190	.498

Computed from catalogue of B. F. Sturtevant & Co., and from Foundry Data Sheet No. 5.

The following tables give the capacities of centrifugal and pressure blowers. As these are based on 36,000 cubic feet of air per ton of iron, the selection of sizes somewhat larger than those given in the tables is desirable, as the allowance of air is too small.

The Sturtevant Steel Pressure Blower Applied to Cupolas

No. of blower	Diameter of inside of cupola lining	Melting capacity per hour in pounds	No. of square inches of blast	Cubic feet of air per minute	Speed	Pressure in ounces of blast	Horse power required
1	22	1,200	4.0	324	4135	5	0.5
2	26	1,900	5.7	507	3756	6	1.0
3	30	2,880	8.0	768	3250	7	1.8
4	35	4,130	10.7	1102	3100	8	3.0
5	40	6,178	14.2	1646	2900	19	5.5
6	46	8,900	18.7	2375	2820	12	9.7
7	53	12,500	24.3	3353	2600	14	16.0
8	60	16,560	32 0	4416	2270	14	22.0
9	72	23,800	43.0	6364	2100	16	35.0
10	84	33,300	60.0	8880	1815	16	48.0

The Sturtevant Steel Pressure Blower Applied To Cupolas

(Power saved by reducing the speed and pressure of blast.)

Speed	Pressure, ounces	Horse power	Speed	Pressure, ounces	Horse power
3445	5	.8	3100	4	.6
3000	6	1.5	2750	5	1.1
2900	7	2.5	2700	6	2.0
2560	8	4.0	2390	7	3.3
2550	10	7.4	2260	8	5.3
2380	12	12.7	2150	10	9.4
2100	12	16.7	1900	10	12.7
1960	14	28.4	1800	12	22.5
1700	14	39.6	1566	12	31.7

Kent, page 519.

Buffalo Steel Pressure Blowers Speeds and Capacities as Applied to Cupolas

Square inches in blast	No. of blower	Diameter inside of cupola, inches	Pressure in ounces	Speed, No. of revs. per min.	Melting capacity, pounds per hour	Cubic feet of air required per min.	Horse power required
4	4	20	8	4793	1,545	412	1.0
6	5	25	8	3911	2,321	619	1.2
8	6	30	8	3456	3,093	825	2.05
11	7	35	8	3092	4,218	1125	3.1
14	8	40	8	2702	5,425	1444	3.9
18	9	45	10	2617	7,818	2085	7.1
26	10	55	10	2139	11,295	3012	10.2
46	11	73	12	1639	21,978	5861	23.9
68	12	88	12	1639	32,395	8626	36.2

Pressure in ounces	Speed, no. of revs. per min.	Melting capacity in pounds per hour	Cubic feet of air required per minute	Horse power required
9	5095	1,647	438	1.3
10	4509	2,600	694	2.2
10	3974	3,671	926	3.1
10	3476	4,777	1274	4.25
10	3034	6,082	1622	5.52
12	2916	8,598	2293	9.36
12	2353	12,378	3301	12.0
14	1777	23,838	6357	30.3
14	1777	35,190	6384	43.7

Kent, page 950.

The Root Positive Rotary Blowers

Size number	Cubic feet per revolution	Revolutions per minute for cupola melting iron	Size of cupola, inches inside lining	Will melt iron per hour, tons	Horse power required
2	5	275–325	24–30	2½–3	5½
3	8	200–300	30–36	3–4⅔	8
4	13	185–275	36–42	4⅔–7	11½
5	23	170–250	42–50	8–12	17¾
6	42	150–200	50–60	12½–16⅔	27
7	65	137–175	72 or ⅖5	17⅔–22⅔	40

Kent, page 526

Diameter of Blast Pipes for Pressure Blowers for Cupolas

B. F. Sturtevant & Co.

The following table has been constructed on this basis, namely, allowing a loss of pressure of one-half ounce in the process of transmission through any length of pipe of any size as a standard; the increased friction due to lengthening the pipe has been compensated for by an enlargement of the pipe, sufficient to keep the loss still at ½ ounce.

THE BLAST

Cubic feet of air transmitted per minute	Lengths of blast pipe in feet: 50	100	150	200	300
	Diameter in inches				
Blower No. 1					
360	5⅝	6¼	6¾	7¼	7⅞
515	6⅜	7⅛	7¾	8¼	8⅞
635	6¾	7¾	8½	9	9⅝
740	7¼	8½	9	9½	10¼
Blower No. 2					
504	6¼	7⅛	7¾	8¼	8⅞
721	7¼	8¼	9	9½	10¼
889	7⅞	9	9¾	10⅜	11
1036	8⅜	9½	10⅜	11	11¾
Blower No. 3					
720	7¼	8¼	9	9½	10¼
1030	8¾	9½	10⅜	11	11¾
1270	9⅛	10¾	11¼	11⅞	12¾
1480	9⅝	11	12	12⅝	13½
Blower No. 4					
1008	8¼	9⅝	10¼	10⅞	11⅝
1442	9½	10⅛	11⅞	12½	13⅜
1778	10⅜	11⅞	12⅞	13⅝	14⅝
2072	11	12⅝	13¾	14½	15½
Blower No. 5					
1440	9½	10⅞	11⅞	12½	13⅜
2060	11	12⅝	13¾	14½	15½
2540	11⅞	13⅝	14⅞	15⅝	16⅞
2960	12¾	14½	15⅞	16⅝	18

Cubic feet of air transmitted per minute	Lengths of blast pipe in feet: 50	100	150	200	300
	Diameter in inches				
Blower No. 6					
1,872	10⅝	12⅛	13¼	13⅞	15
2,679	12¼	14	15⅛	16	17¼
3,302	13¼	15⅛	16½	17½	18⅞
3,848	14⅛	16⅛	17½	18½	20⅛
Blower No. 7					
2,592	12	13¾	15	15⅞	17⅛
3,708	13⅞	15⅞	17¼	18¼	19¾
4,572	15⅛	17⅜	18⅞	19⅞	21⅝
5,238	16	18½	20	21¼	23
Blower No. 8					
3,312	13¼	15⅛	16½	17½	18⅞
4,738	15¼	17⅝	19⅛	20⅛	21⅞
5,842	16⅝	19⅛	20¾	22	23⅞
6,808	17⅝	20¼	22⅛	22⅜	25⅜
Blower No. 9					
4,320	14¾	17	18⅜	19⅜	21⅛
6,180	17	19½	21¼	22½	24⅜
7,620	18⅜	21⅛	23⅛	24⅜	26½
8,880	19½	22½	24½	26	28½
Blower No. 10					
5,760	16½	19	20⅝	21⅞	23¾
8,240	18⅞	21¾	23¾	25⅛	27¼
10,160	20⅝	23¾	25⅞	27⅜	29⅝
11,840	22⅛	25¼	27½	29⅛	31½

Kent, page 520.

The quantities of air in the left-hand column of each division indicate the capacity of the given blower when working under pressures of 4, 8, 12 and 16 ounces. Thus a No. 6 blower will force 2678 cubic feet of air at 8 ounces pressure through 50 feet of 12¼-inch pipe with a loss of ½ ounce pressure. If it is desired to force the air 300 feet without an increased loss by friction, the pipe must be enlarged to 17¼ inches diameter.

The table below gives the important dimensions, distribution of charges and melting capacities of cupolas from 24 inches to 84 inches diameter inside of lining. The table is based upon the consumption of 35,000 cubic feet of air per ton of iron and represents the best average practice.

Higher fuel ratios are frequently realized and the foundrymen must vary the fuel and air supply as the conditions indicate. It is unwise, however, to strive for high fuel ratio at the risk of a dull heat. The loss on castings from one melt may far outweigh the saving on coke, as between the ratios of 10 to 1 and 9 to 1, for many heats. Coke is one of the cheapest articles about the foundry; while hot, clean iron is an item of the highest importance.

In general the cupola should furnish 20 pounds of melted iron per minute per square foot of area of the melting zone.

Dimensions, Etc., of Cupolas

Diameter of cupola inside of lining, inches	Height from bottom-plate to charging door, feet	Height from sand bottom to underside of tuyeres, inches	Area of tuyeres, sq. in.	Pounds of coke on bed, pounds	First charge of iron, pounds	Succeeding charges of coke, pounds	Succeeding charges of iron, pounds	Pressure of blast, ounces
24	9.0	8–10	90	225	320	40	320	5– 7
30	10.0	8–10	142	370	560	62	560	6– 8
36	10.6	8–12	204	460	850	85	850	6– 8
42	10.6	10–12	277	530	1200	110	1200	6– 8
48	12.0	10–12	362	820	1500	140	1500	8–10
54	13.0	10–15	458	1100	1900	180	1900	8–10
60	15.0	10–18	565	1400	2500	225	2500	10–12
66	16.0	10–18	684	1900	3000	275	3000	10–12
72	18.0	10–20	814	2400	4000	320	4000	12–14
78	19.0	10–20	955	3000	5000	400	5000	12–14
84	19.0	10–22	1108	3600	6000	500	6000	14–16

DIMENSIONS, ETC., OF CUPOLAS. — (*Continued*)

Volume of air per minute, cu. ft.	Diameter of blast pipe not over 100 feet long, inches	Size of Root blower required, no.	Number of revolutions per minute, revs.	Horse power required H.P.	Size of Sturtevant blower required, no.	Number of revolutions per minute, revs.	Horse power required, H.P.	Melting capacity per hour, pounds
875	10	1	300	2	3	3500	2	3,000
1,750	12	2	300	5	5	2900	5.5	6,000
2,600	14	4	175	8	6	2800	10	9,000
3,500	16	4	230	12	7	2600	15	12,000
4,700	18	5	200	20	8	2300	22	16,000
5,800	20	5½	190	25	8	2500	25	20,000
7,300	22	6	180	33	9	2200	35	25,000
8,700	24	6½	170	45	10	1800	45	30,000
10,500	26	7	150	55	10	2000	55	36,000
12,800	28	7½	150	70	2–8	2500	60	44,000
14,500	30	7½	170	80	2–9	2200	70	50,000

Charging and Melting

In preparing the cupola for melting, a bed of shavings is spread evenly over the bottom; on this a layer of kindling wood; then enough cord wood cut in short lengths to come well above the tuyeres. The doors in the wind box or, two or more of those covering the tuyeres, should be left open to admit air to the fire. The wood should be covered with coke for a depth of from 12 to 15 inches. Where wood is scarce or expensive, the coke may be lighted directly with a kerosene oil blow torch. To use the torch place two strips of boards 3″ × 1″ on edge from the tap hole to center of cupola. Then place other strips of same size crosswise of the bottom forming a shallow trough about 6 inches wide in the shape of a T. Large pieces of coke are placed over the trough to form a cover, and on top of this coke is spread uniformly for a depth of about 15 inches. The torch is then applied at the tap hole.

After the fire is lighted and the top of the coke bed becomes red, enough coke is added to bring the top of the bed 20 inches above the tuyeres when the wood has burned out.

The necessary amount of coke for bottom is determined by gauging from the charging door. The proper depth of bed is a matter of great importance. Too much is as bad as too little. With too much coke, the melting will be slow and dull; with too little the iron after commencement of heat becomes dull, the cupola is bunged up and the bottom may have to be dropped.

There should be sufficient coke to locate the top of the melting zone about 20 inches above the tuyeres, and the subsequent charges of coke should be just enough to maintain this position.

With proper depth of bed, the molten iron will appear at the spout in from 8 to 10 minutes after the commencement of the blast. The first and subsequent charges of iron should be of the same weight, and these should be small.

The amount of coke between each charge of the iron and the preceding one should be 10 per cent of the iron. In many foundries the coke between the charges is made less than this, but 10 per cent is good practice. It is not the best policy to run the risk of making a poor heat by cutting down the coke. The charges should be continued as indicated until the cupola is filled to the charging door.

In charging care must be taken to distribute both iron and coke uniformly.

The pig iron (broken) should be charged first, beginning at the lining and proceeding toward the center, pigs should be placed sidewise to the lining. Next comes the scrap; if there are large pieces, they should be placed in the center of the cupola with the pig surrounding them.

The iron must be kept well around the lining and care exercised to avoid cavities. If the scrap is fine, it must not be charged so closely as to impede the blast. After the iron comes the coke, which must be evenly distributed throughout. After the second or third charge, limestone, broken into pieces about 1½ cube, is added. From 25 to 40 pounds of limestone per ton of iron is used according to the character of pig and scrap as to sand and rust, and to that of coke as to ash.

The top of the bed should not be permitted to drop more than 6 or 8 inches during the heat. This determines the weight of iron for each charge as well as that of the coke, the latter having a depth of 6 or 8 inches. The weights of all the materials going into the cupola should be kept separately. The melter should be furnished each day with a charging schedule giving the composition and the weight of each charge.

The fire should be started about two hours before the blast is put on, to allow the charges in the stack to become well heated. The openings in the wind box are closed immediately after starting the blast.

The egg-shaped section at the melting zone, which the cupola gradually assumes by use, should be maintained.

The Charging Floor

The charging floor should be large enough, if circumstances permit, to accommodate all the materials for the heat. Each charge of pig iron and scrap, after weighing, should be piled by itself and in the order in which it is to be used. The proper amount of coke for each charge is placed in cans or baskets. In larger works where the material is brought to the platform on charging cars, the cars are arranged so as to reach the cupola in proper order.

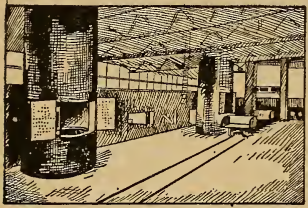


Fig. 125. — Charging Floor.

The cuts show two different methods of charging at large foundries. At one the charging is done by hand and at the other by machine.

While the material is handled more rapidly and at less expense by the latter method, it is doubtful if the saving effected compensates for irregular melting and lack of uniformity in product, which is likely to result from unequal distribution of the charges.

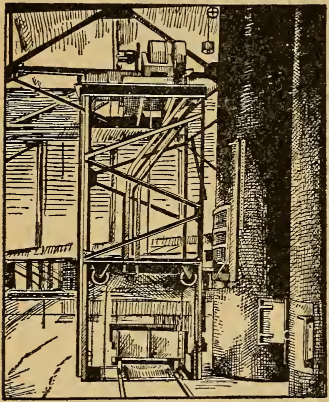


Fig. 126. — Cupola Charging Machine in Normal Position.

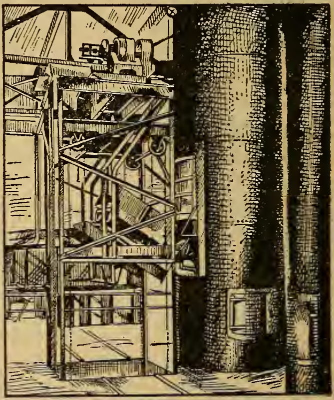


Fig. 127. — Cupola Charging Machine in Charging Position.

Melting Losses

Melting losses in a well-managed cupola should not exceed 4 per cent for the annual average. Instances are known where the losses for long periods were not over 2 per cent. The following records are taken from the report of the secretary of the American Foundrymen's Association, and cover the results from 41 cupolas. The percentage of castings made and the returns are calculated from the quantities given and added to each table.

TABLE I. — GENERAL JOBBING

Numbers	1	2	3	4	5
Usual tonnage	10	3	3	3	20
Time melting	1 hr. 15 m.	1 hr.	1 hr. 15 m.	2 hrs.	....
Blast pressure	8 oz.	....	....	8 oz.	8 oz.
Fan or blower	Fan	Fan	Fan	Blower	Fan
Pig iron	Coke	Coke	Coke	Coke	....
Per cent southern	None	....	None	None	....
Fuel used, lbs	Coke	Coke	Coke	Coke	....
Scrap bought	Mach.	Med. mach	Mach.	Stove	Mach.
Pig iron used	10,400	3200	2657	2685	20,000
Scrap used	9,600	3200	2886	3885	20,000
Castings made	16,495	5504	3916	4057	35,200
Scrap made	1,352	620	872	1873	2,200
Per cent melting lost	10.7	4.3	13.6	9.7	6.5
Per cent melt in returns	66	97	15.7	28.5	6.5
Per cent in good castings	82.4	86	70.6	61.7	88

Average melting loss .... 7.6 per cent
Average of melt in returns .... 8.8 per cent
Average of melt in good castings .... 83.0 per cent

TABLE II. — LIGHT JOBBING

Numbers	6	7	8	9
Usual tonnage	72	6	16	2.5
Time of melting	3 hrs. 30 m.	1 hr. 30 m.	2 hrs. 30 m.	1 hr.
Blast pressure, oz	13	6.5	....	....
Fan or blower	Blower	Fan	Fan	Fan
Pig iron	Coke	Coke	Coke	Coke
Per cent southern	None	None	None	None
Fuel used	Coke	Coke & coal	Coke	Coke
Scrap bought	....	Stove	Lt. mach.	Med. mach.
Pig iron used, lbs	102,000	4,500	19,200	3200
Scrap used, lbs	42,000	7,500	12,800	1800
Castings made	108,300	10,300	21,000	4000
Scrap made	27,500	1,200	9,100	800
Per cent melting loss	5.7	4.2	6	4
Per cent melt in returns	19.1	10	28.4	16
Per cent in good castings	75.2	85.8	65.6	80

Average melting loss .... 25.5 per cent
Average of melt in returns .... 20.8 per cent
Average of melt in good castings .... 73.6 per cent

TABLE III. — LIGHT MACHINERY

Numbers	10	11	12
Usual tonnage	10	6	3.5
Time of melting	1 hr. 10 m.	2 hrs.	1 hr. 30 m.
Blast pressure, oz.	....	....	7
Fan or blower	Fan	Fan	Blower
Pig iron	Coke	Coke & ch. coal	Coke
Per cent southern	....	....	None
Fuel used	Coke & coal	Coke	Coke
Scrap bought	None	Med. mach.	Lt. mach.
Pig iron used, lbs.	16,000	6,000	3900
Scrap iron used, lbs.	4,000	6,000	2750
Castings made	13,220	10,000	3738
Scrap made	4,500	900	2762
Per cent melting loss	6.5?	9.2	2.3
Per cent melt in returns	22.6	7.5	41.5
Per cent melt in good castings	66.1	83.3	56.20

Numbers	13	14	15
Usual tonnage	5	15	40
Time of melting	1 hr. 30 m.	2 hr.	6 hrs. 40 m.
Blast pressure, oz.	5	7	....
Fan or blower	Fan	Blower	Fan
Pig iron	Coke	Coke	Coke
Per cent southern	50	35	50
Fuel used	Coke & coal	Coke	Coke
Scrap bought	Med. mach.	Lt. mach.	Stove
Pig iron used, lbs.	4500	14,000	56,000
Scrap iron used, lbs.	4280	16,000	24,000
Castings made	7640	20,500	60,000
Scrap made	800	6,000	16,000
Per cent melting loss	3.9	11.6	5
Per cent melt in returns	9.1	20	2,000
Per cent melt in good castings	87	68.3	75

There is an error in this record. The loss should be 11.3 if the statement as to castings and scrap are correct.

Average melting loss	7.33 per cent
Average of melt in returns	19.55 per cent
Average of melt in good castings	73.0 per cent

Table IV. — Heavy Machinery

Numbers	16	17	18	19
Usual tonnage	13	15	21	15
Time of melt	2 hrs.	2 hrs.	4 hrs.	2 hrs.
Blast pressure, oz.	6	10	9	14
Fan or blower	Blower	Blower	Blower	Blower
Pig iron	Coke	Coke	Coke & coal	Coke
Per cent southern	50	70	17	20
Fuel used	Coke	Coke	Coke	Coke
Scrap bought	Mach.	H'vy mach.	Mach.	....
Pig iron used, lbs.	14,720	20,000	25,740	15,500
Scrap used, lbs.	11,130	10,000	16,270	11,500
Castings made	18,845	21,300	37,760	19,000
Scrap made	4,870	7,200	7,560	6,000
Per cent melting loss	8.4	5	4	7.4
Per cent melt in returns	18.8	24	18	22.2
Per cent melt in good castings	72.9	71	78	70.4

Average melting loss .... 5.8 per cent
Average of melt in returns .... 20.6 per cent
Average of melt in good castings .... 73.6 per cent

Table V. — Stove Plate

Numbers	20	21	22
Usual tonnage	20	15	10
Time of melt	2 hrs. 15 min.	1 hr. 30 min.	....
Blast pressure, oz.	14	11	13
Fan or blower	Blower	....	Blower
Pig iron	Coke	Coke	Coke
Per cent southern	100	50	25
Fuel used	Coke and coal	Coke	Coke and coal
Scrap bought	Stove	Stove	....
Pig iron used, lbs.	20,000	18,000	11,863
Scrap used, lbs.	20,000	12,000	7,906
Castings made	24,000	20,192	11,750
Scrap made	14,200	9,000	7,624
Per cent melting loss	4.5	2.7	2
Per cent melt in returns	35.5	30	38.5
Per cent melt in good castings	60	67.3	59.4

Average melting loss .... 3.3 per cent
Average of melt in returns .... 34.3 per cent
Average of melt in good castings .... 62.3 per cent

TABLE VI. — SANITARY WARE

Numbers	23	24	25	26
Usual tonnage	12	32	38	16
Time of heat	2 hrs.	3 hr. 15 m.	3 h. 15 m.	2 h. 30 m.
Blast pressure, oz.	5	14	14	50
Fan or blower	Fan	Blower	Blower	Fan
Pig iron	Coke	Coke	Coke	Coke
Per cent southern	None	....	60	....
Fuel used, lbs.	Coal and coke	Coke	Coke	Coal and coke
Scrap bought	Medium	....	None	Med. mach.
Pig iron used, lbs.	11,800	51,000	56,000	9,875
Scrap used, lbs.	12,200	12,000	20,000	22,625
Castings made	17,228	46,660	51,614	23,276
Scrap made	6,048	12,234	18,386	8,055
Per cent melting loss	3	6.5	7.9	3.6
Per cent melt in returns	25.4	19.4	24.1	24.7
Per cent in melt good castings	71.7	74	67.9	71.6
Numbers	**27**	**28**	**29**	**30**
Usual tonnage	25	26	40	23
Time of heat	3 h. 45 m.	3 h. 45 m.	3 h. 45 m.	3 h.
Blast pressure, oz.	14	....	5	....
Fan or blower	Blower	Blower	Fan	Blower
Pig iron	Coke	Coke	Coke	Coke
Per cent southern	....	....	None	....
Fuel used	Coke	Coke	Coal and coke	Coke
Scrap bought	None	....	Medium	None
Pig iron used, lbs.	31,470	33,000	35,560	29,000
Scrap used, lbs.	17,960	19,850	47,210	17,500
Castings made	35,956	37,250	59,400	33,385
Scrap made	11,270	11,300	21,960	11,500
Per cent melting loss	4.1	8.1	1.7	3.5
Per cent melt in returns	22.9	21.3	26.5	24.7
Per cent melt in good castings	73	70	71.7	71.8

Average melting loss .... 4.84 per cent
Average of melt in returns .... 23.60 per cent
Average of melt in good castings .... 71.50 per cent

Table VII. — Agricultural

Numbers	31	32	33	34	35
Usual tonnage	80	45	41	9	9.5
Time of heat	4 h. 20 m.	3 h. 15 m.	3 h. 30 m.	2 hrs.	1 h. 20 m.
Blast pressure, oz.	15	12	13	12	9
Fan or blower	Blower	Blower	Blower	Blower	Blower
Pig iron	Coke	Coke	Coke	Coke	Coke
Per cent southern	50	....	50	50	None
Fuel used	Coke	Coke	Coke	Coke & coal	Coke & coal
Scrap bought	Ag. No. 1	Ag. No. 1	Med. Mach.	Stove	Stove
Pig iron used, lbs.	80,000	45,000	45,700	7,071	7,500
Scrap used, lbs.	80,000	45,000	35,800	10,674	11,600
Castings made	108,800	61,200	62,960	11,845	7,450
Scrap made	42,700	24,300	15,600	5,200	10,650
Per cent melting loss	5.3	5.2	3.6	4	5.3
Per cent melt in returns	26.7	27	19.2	29.3	55.7
Per cent melt in good castings	67.5	67.7	77.2	67	39

Average loss in melt .... 4.77 per cent
Average of melt in returns .... 26.73 per cent
Average of melt in good castings .... 68.4 per cent

Table VIII. — Railroad Castings

Numbers	36	37	38
Usual tonnage	47	32	6.5
Time of heat	5 hrs. 20 m.	3 hrs. 45 m.	2 hrs.
Blast pressure, oz.	16	4	9
Fan or blower	Blower	Fan	....
Pig iron	Coke	Ch., coal and coke	Coke
Per cent southern	None	60	None
Fuel used	Coke	Coke and coal	Coke
Scrap bought	None	None	....
Pig iron used	66,500	25,000	6,765
Scrap used	28,500	39,000	6,235
Castings made	60,400	54,000	10,000
Scrap made	28,900	7,500	2,385
Per cent melting loss	6.1	3.9	4.7
Per cent of melt in returns	30.3	11.7	18.3
Per cent melt in good castings	63.5	84.3	76.9

Note. — No. 37 is an average of 27 heats. No. 38 is an average of 25 heats.

Average melting loss .... 5.64 per cent
Average of melt in returns .... 22.43 per cent
Average of melt in good castings .... 72.22 per cent

TABLE IX. — FLOOR PLATES, GRATE BARS, ETC.

Numbers	39	40
Usual tonnage	30	3
Time of heat	3 hrs. 40 m.	1 hr.
Blast pressure, oz.	16	....
Fan or blower	Blower	Fan
Pig iron	Coke	Coke
Per cent southern	None	....
Fuel used	Coke	Coke and coal
Scrap bought	Med. mach.	Light mach.
Pig iron used, lbs.	20,000	None
Scrap used, lbs.	40,000	6,000
Castings made	47,400	5,100
Scrap made	8,200	525
Per cent melting loss	7.3	6.2
Per cent melt in returns	13.7	8.8
Per cent melt in good castings	79	85

Average melting loss .... 7.23 per cent
Average of melt in returns .... 8.88 per cent
Average of melt in good castings .... 85 per cent

TABLE X. — CAR WHEELS

Number	41	Number	41
Usual tonnage	200	Scrap bought	Wheel
Time of heat	7 hrs.	Per cent melting loss	2.1
Blast pressure, oz.	10	Per cent melt in returns	....
Fan or blower	Blower	Per cent melt in good castings	....

From the above tables, the following table showing the average results for each class of work is compiled.

TABLE XI

Percentage	General jobbing	Light jobbing	Light machinery	Heavy machinery	Stove plate	Sanitary ware	Agricultural	Railroad cast	Floor plates, grate bars	Car wheel
Number of records	4	4	6	4	3	8	5	3	2	No data
Per cent melt in castings	83.9	73.6	73.01	73.6	62.3	71.5	68.5	72.3	79.5	
Per cent melt in returns	8.2	20.8	19.55	20.6	34.3	23.6	26.7	22.43	13.2	
Per cent melt lost	7.7	5.5	7.33	5.8	3.3	4.84	4.77	5.24	7.2	

NOTE. No. 12 was omitted in obtaining these averages. Evidently there was something wrong about this heat as shown by the excessive returns.

The figures in the preceding table are to be taken as approximations. The loss may be reduced in practice by careful management.

When the weight of the coke on the bed, and the weights of the iron and coke in each charge are known, to determine the necessary amount of iron which must be melted to produce a desired melting ratio:

Let X = the total iron;
Y = the total coke;
A = weight of coke on bed;
B = weight of coke in each charge;
C = weight of iron in each charge;
D = the desired melting ratio.

(1) Then $\frac{X}{Y} = D,$ $Y = \frac{X}{D}$ total coke (2)

(3) and $\frac{X}{C}$ = the number of charges.

The total coke is found in equation (4)

(4) $$Y = \left(\frac{X}{C} - 1\right) B + A.$$

From equations (2) and (4) $X = \frac{CD(A - B)}{C - DB}.$ (5)

Having found the total amount of iron, the total coke and number of charges are found from (2) and (3).

By applying these formulas to a 54-inch cupola as given in table on pp. 451–2 the required weight of iron to be melted to produce a melting ratio of 9 to 1 may be found.

Melting Ratio

Weight of coke on bed	A = 1100 pounds
Weight of coke to each charge	B = 180 pounds
Weight of iron to each charge	C = 1900 pounds
Required melting ratio	D = 9 to 1 pounds

From equation (5)

$$X = \frac{1900 \times 9\,(1100 - 180)}{1900 - 9 \times 180} = 56{,}185,$$

$$Y = \frac{56{,}185}{9} = 6243 \text{ pounds.}$$

And the number of charges

$$\frac{56{,}185}{1900} = 29.57.$$

Coke may be charged from dumps, as it can be uniformly spread.

The cupola should be kept full to the charging door until all the iron is in. Later the sweepings from the charging platform may be thrown on. The platform should, if possible, be large enough to accommodate the materials for the entire melt. Each charge of pig and scrap should be weighed and piled by itself; the coke kept in convenient charging buckets, and the broken limestone in a bin from which it may be charged by measure, above the coke.

Appliances about Cupola

The conditions will indicate the necessity for elevator and charging cars. In every foundry yard there should be a cinder mill and scrap breaker. In many foundries the cinders are frequently ground in the tumbling barrel. It is purely a matter of convenience; but locating the cinder mill in the yard promotes cleanliness, especially when broken fire brick are ground.

The cinder mill is made up of cast-iron staves from 8 to 10 inches wide and of convenient length, placed about polygonal heads; the latter mounted on trunnions, and the whole rotated slowly by any suitable means. The staves are so placed that there is not over an eighth of an inch opening at the joints, in order that the shot iron may not escape. Magnetic and hydraulic separators are frequently used to recover the shot, and they effect large savings.

The scrap breaker is located conveniently to the cars, or placed where heavy scrap is received. It consists of a derrick and ball with hoisting apparatus. The height of the derrick should be from 30 to 40 feet and the ball should weigh 2500 to 3000 pounds, both depending on the probable dimensions of the largest scrap.

The sketch below shows a simple and effective device for tripping the ball.

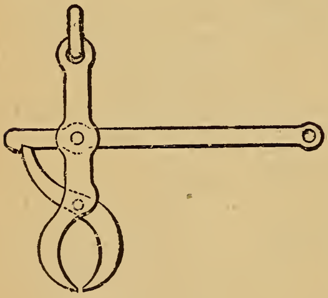


FIG. 128.

Ladles

Hand ladles, and shank ladles holding 200 pounds or less, are best made of sheet steel, as they are much lighter and are easily repaired. These, as well as larger sizes, to be handled by cranes, are furnished by the foundry supply houses.

It is usually best to tap into a fore ladle. This is kept under the spout, and has sufficient capacity to hold one entire charge. From it the smaller ladles are filled. By making large tappings, the various grades of iron in the cupola become thoroughly mixed in the fore ladle. The iron in the ladle is kept hot by covering the surface with charcoal or slacked lime.

In English practice the Fore Hearth is largely used instead of the fore ladle, but its use has not met with favor in the United States. An illustration of this arrangement is shown on page 248 of McWilliams and Longmuir's General Foundry Practice.

Lining of Ladles

The ladles are lined with a mixture of one-half fire clay and one-half sharp sand. With small ladles the lining is from ¾ inch to 1¼ inches thick on the bottom and gradually tapers to ¼ to ⅜ inch thick at the top.

Large ladles have first a lining of fire brick, then the clay daubing.

After the linings are completed they must be thoroughly baked either by placing the ladles in an oven or by building wood fires in them. It is customary to reline the small ladles after each heat. The larger ones, if completely drained of iron, may, by chipping out and patching, be made to last over many heats. The skulls from ladles are rattled with the cinders. Shanks for ladles holding 100 pounds and upwards are commonly made with single and double ends. The better practice is to make both ends double, the helper's end having a swivel joint. With this type of shank the helper can use both hands in carrying and two men can handle a 200-pound ladle easily. The iron bottoms of the larger ladles should have 10 or 12-¾-inch holes through them to permit the escape of moisture.

Tapping Bar

The tapping bar is usually made of 1-inch gas pipe, having a long tapered point (24 inches in length) welded to it at one end. Frequently the tapper stands along one side of the spout, and opens the tap hole with a single-handed bar. He carefully picks away the center of the bod, until a hole is made through it, then enlarges the hole to ⅝ inch, or an inch, according to the stream desired.

The Bod Stick

The bod stick is an iron bar about 1 inch in diameter, having at one end a flat disc 2½ inches in diameter. To this disc is attached the clay bod, used in stopping up the tap hole. In stopping the stream of iron, the bod, placed above the stream at the tap hole, is forced down-

Table Showing Capacities of Ladles with Bottom Diameters

Depth	Diameter of ladle at bottom, inches								
	20	22	24	26	28	30	32	34	36
Ins.									
2	157	191	227	267	309	356	403	455	510
4	318	334	459	538	624	717	812	917	1,026
6	483	585	696	815	945	1084	1228	1,385	1,550
8	652	788	938	1096	1272	1457	1651	1,860	2,085
10	825	997	1185	1383	1604	1836	2080	2,342	2,625
12	1002	1210	1436	1676	1942	2221	2516	2,830	3,172
14	1183	1427	1693	1973	2286	2612	3142	3,326	3,726
16	1368	1648	1954	2276	2606	3009	3408	3,829	4,288
18	1557	1873	2221	2585	2992	3412	3863	4,339	4,856
20	1749	2102	2492	2900	3353	3821	4325	4,855	5,432
22	1946	2337	2769	3221	3720	4237	4793	5,378	6,016
24	2149	2576	3050	3548	4093	4660	5268	5,911	6,608
26	......	2821	3337	3880	4472	5089	5750	6,451	7,208
28	......	......	3630	4218	4807	5525	6238	6,998	7,816
30	......	......	......	4560	5248	5968	6734	7,552	8,432
32	......	......	......	......	5645	6417	7237	8,114	9,054
34	......	......	......	......	......	6871	7747	9,682	9,694
36	......	......	......	......	......	7329	8261	9,258	10,332
38	......	......	......	......	......	......	8781	9,840	10,978
40	......	......	......	......	......	......	......	10,428	11,630
42	......	......	......	......	......	......	......	......	12,288
44	......	......	......	......	......	......	......	......	......
46	......	......	......	......	......	......	......	......	......
48	For steel add 5%								
50	......	......	......	......	......	......	......	......	......
52	......	......	......	......	......	......	......	......	......
54	......	......	......	......	......	......	......	......	......
56	......	......	......	......	......	......	......	......	......
58	......	......	......	......	......	......	......	......	......
60	......	......	......	......	......	......	......	......	......
62	......	......	......	......	......	......	......	......	......
64	......	......	......	......	......	......	......	......	......
66	......	......	......	......	......	......	......	......	......
68	......	......	......	......	......	......	......	......	......

wards into the hole squeezing off the stream. Many severe burns have been caused by stopping directly against the stream.

The spout is sometimes made with a side opening to carry off slag running on the stream of iron. This opening is made about the middle of the spout, and the trough in that vicinity is somewhat increased in width. About 2 inches below the side opening a fire brick is placed across the trough, leaving room below it for the iron to pass, but being low enough to skim off the slag, which runs out of the side at the opening. A swinging spout is occasionally used. This is hung on a pivot below the spout proper, and in a transverse direction.

Varying from 20 to 54 Inches, Slope of Sides 1½ to 1 Foot

Depth	Diameter of ladle at bottom, inches								
	38	40	42	44	46	48	50	52	54
Ins.									
2	568	630	694	762	832	906	984	1,064	1,146
4	1,144	1,268	1,396	1,600	1,672	1,820	1,978	2,138	2,302
6	1,728	1,914	2,106	2,310	2,522	2,774	2,982	3,222	3,469
8	2,330	2,568	2,824	3,096	3,380	3,678	3,996	4,316	4,829
10	2,930	3,330	3,552	3,892	4,248	4,622	5,019	5,420	6,063
12	3,538	3,900	4,288	4,696	5,124	5,576	6,052	6,334	7,308
14	4,154	4,578	5,032	5,510	6,012	6,540	7,095	7,659	8,564
16	4,776	5,264	5,784	6,332	6,910	7,514	8,149	8,784	9,831
18	5,406	5,958	6,546	7,154	7,816	8,498	9,213	9,930	10,711
20	6,044	6,660	7,316	7,994	8,730	9,492	10,287	11,086	11,936
22	6,690	7,370	8,094	8,844	9,654	10,496	11,371	12,253	13,212
24	7,344	8,088	8,880	9,702	10,588	11,510	12,465	13,422	14,479
26	8,006	8,816	9,676	10,570	11,532	12,533	13,569	14,623	15,757
28	8,676	9,552	10,480	11,446	12,486	13,566	14,683	15,826	17,046
30	9,354	10,296	11,294	12,334	13,450	14,609	15,808	17,038	18,346
32	10,040	11,048	12,116	13,232	14,424	15,663	16,943	18,261	19,657
34	10,734	11,810	13,943	14,140	15,408	16,727	18,089	19,495	20,979
36	11,436	13,580	13,788	15,059	16,402	17,801	19,249	20,740	22,312
38	12,146	13,358	14,618	15,988	17,406	18,885	20,412	21,996	23,657
40	12,864	14,144	15,496	16,927	18,420	19,998	21,591	23,263	25,014
42	13,590	14,940	16,364	17,876	19,443	21,083	22,782	24,541	27,070
44	14,322	15,712	17,240	18,835	20,476	22,197	23,985	25,830	27,761
46	......	16,550	18,122	19,802	21,519	23,322	25,197	27,130	29,152
48	For steel add 5%		19,014	20,776	22,573	24,557	26,420	28,441	30,555
50	......	......	......	22,198	23,637	25,703	27,654	29,763	31,920
52	......	......	......	......	24,711	26,859	28,899	31,096	33,397
54	......	......	......	......	......	28,032	30,155	32,441	34,336
56	......	......	......	......	......	29,223	31,422	33,798	36,287
58	......	......	......	......	......	30,256	32,690	35,166	37,750
60	......	......	......	......	......	......	33,979	36,545	39,225
62	......	......	......	......	......	......	35,279	37,941	40,712
64	The foundry						......	39,343	42,211
66							......	42,312	43,729
68	......	......	......	......	......	......	......	......	46,011

While the stream is running it can be tipped so as to let the iron run into a ladle at either side. In rapid melting this obviates stopping up when ladles are changed.

Applying Metalloids in Ladle

Where metalloids are added to the iron, if the amount to be used is sprinkled into the stream as it flows through the spout, a more intimate mixture is obtained than results from placing the material in the ladle and drawing the iron on to it.

Cranes

The equipment of cranes as to size, style and motive power is indicated entirely by the character and volume of production. Ample and convenient hoisting facilities are absolutely essential. A mistake is seldom made in providing cranes of too great capacity.

Most of the modern foundries are fitted with electric traveling cranes, which not only have access to the cupola, but sweep over the moulding floors. In addition to the electric crane, post and wall cranes are supplied for special requirements. There should be a small jib crane attached to the cupola for handling the fore ladle.

The manufacture of cranes has become a specialty, and the reader is referred to manufacturers' catalogues for special information.

Spill Bed

In many foundries the excess iron, and iron on the bench floor, is frequently dumped into holes in the sand heaps or floors. This is a slovenly practice and greatly injures the sand.

A very convenient and simple spill bed is shown in Fig. 129. This is so made that the iron is collected in pieces weighing from 60 pounds to 80 pounds, of convenient size to be handled in charging.

A small bed of same character serves an excellent purpose when placed near the snap floors.

Dumping Spill Bed

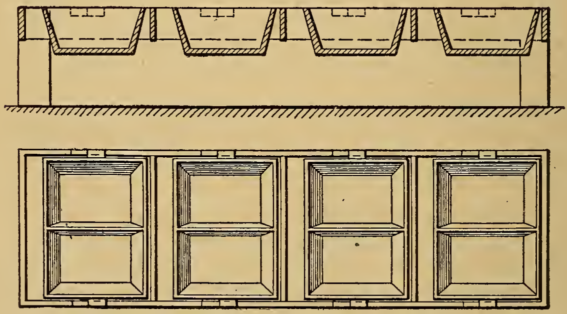


Fig. 129.

Gagger Mould

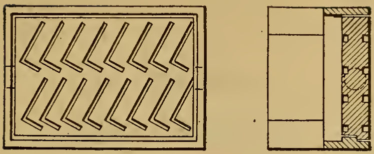


FIG. 130.

By a little care all the excess iron may be put through beds as above and sent to the cupola in good shape for melting.

The usual practice is to allow the bottom to remain where it drops until the next morning, simply wetting it thoroughly.

Below is shown a sketch of a large rake. If the bottom is dropped on this and the mass pulled out from under the cupola (by means of a

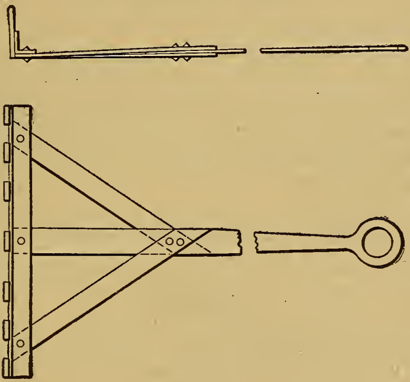


FIG. 131.

chain passing through a snatch block to the crane) and then wetted down, it will be found in much better shape for picking over in the morning.

The pieces of unconsumed coke should be picked out and used in core ovens, or as part of the last charge of coke, in the cupola. Little savings of this kind, although small of themselves, amount to an important item in the course of the year, particularly if the operations are extensive.

CHAPTER XX

MOULDING SAND

Moulding sand contains from 75 to 85 per cent silica, with varying proportions of alumina, magnesia, lime and iron.

The essential properties are:

Cohesion,	Refractoriness,
Permeability,	Durability,
Porosity,	Texture.

Cohesion or Bonding Power

Moulding sand must possess sufficient cohesion, not only to remain in position after ramming, but to resist the pressure of the molten metal, and its abraiding action while being poured.

Pure sand has no cohesive strength, but clay (double silicate of alumina) has, and as moist sands cohere more strongly than dry, the bonding power must depend on the amount of clayey matter and water contained. The moisture must not be in excess, otherwise the sand will pack too densely.

Permeability and Porosity

Permeability is the property which sand possesses of allowing liquids or gases to filter through it, and depends on the size of the pores.

By porosity is meant the volume of pore space.

These properties are not the same. A sand may contain a few large openings through which the liquids or gases may readily escape and yet have a small pore space. On the other hand, the total pore space may be large, but by reason of the small size of the pores, permeability by either liquids or gases might be difficult.

The permeability of sand may be influenced:

By the tightness of packing;
By the size of the grains;
By the fluxing elements in the sand.

By tamping or packing, the space occupied by a given weight of sand may be reduced, as the grains are forced into their closest arrangement producing the minimum pore space. Fine-grained sands have larger pore space than coarse-grained.

If silt or clay are present, and segregated, the sand will pack more closely than if the grains are cemented together in the form of compound grains. In the latter case the permeability and porosity would be larger than if the grains were separate.

The decreased permeability under increased tamping explains why some good sands behave badly. Permeability of sand is also influenced by the amount of water present. The relation between permeability and fluxing impurities is shown in the process of casting. If the clayey particles filling the interstices of the sand fuse when heated by the metal, their coalescence in melting will close up the pores to some extent. For this reason, in part, a high percentage of fluxing impurities is undesirable.

The proper permeability of a moulding sand is a matter of vital importance. A pathway must be opened for the escape of the gases to avoid blowing. The finer the sand the lower its permeability.

Refractoriness

A moulding sand must be sufficiently refractory to prevent complete fusion in contact with molten metal. Highly siliceous sands are, therefore, the more desirable. At the same time a high percentage of silica is gained at the expense of alumina and a consequent loss of bonding power. Generally silica should not exceed 85 per cent. Silica is refractory, does not shrink when heated, but has no cohesive nor bonding power.

Alumina, a most important component, is present in moulding sands in amounts varying from 4 to 12 per cent. It is refractory, has great bonding power, but shrinks greatly when heated. Too high a percentage of alumina makes the sand impermeable.

Durability

Sands begin to lose some of their desirable qualities after one or more heats and become dead or rotten. The injury to the sand arises from its dehydration, or loss of combined water by the heat of the molten metal, whereby its bonding power is destroyed. The water of combination cannot be restored.

The amount of sand burned is a layer of varying thickness next to the casting.

Texture

By texture is meant the percentage of grains of different sizes. This is determined by passing the sand through a series of sieves of decreasing mesh and noting the percentage remaining on each sieve. Mr. W. G. Scott pursues the following method:

"Ten grams of sand are placed on the 100-mesh sieve, together with ten 7/16 steel balls, and shaken with a circular motion for one minute.

Grades of Various Sands

(Mechanical analysis)

Locality	20 Mesh, per cent	40 Mesh, per cent	60 Mesh, per cent	80 Mesh, per cent	100 Mesh, per cent	Clay	Fineness	Per cent of space	Remarks
Albany, N. Y.	4.80	22.54	.22	33.74	27.60	9.78	62.5	......	Good for general foundry and heavy castings.
	.10	.14	.98	.12	66.12	30.76	......	42	Fine.
	.94	3.28	19.38	4.42	68.88	12.18	......	39	Medium.
	8.66	10.24	32.58	4.12	31.49	11.70	51.8	34	Coarse.
Metuchen, N. J.	3.44	12.40	25.84	6.60	43.62	7.28	59.0	39	Much fine quartz and angular grains.
	24.20	22.50	14.36	2.78	15.44	19.20	66.1	33	Coarse quartz and angular grains.
Florida Grove, N. J.	32.92	37.66	23.84	.44	1.34	3.76	......	38	Core sand, fine quartz with mica.
Zanesville, Ohio	.02	.45	2.02	.42	81.22	15.06	125.9	43	Fine yellow, brass, stove-plate, etc.
	.19	.60	8.08	4.75	66.43	19.12	......	37	Heavy, lining cupolas and ladles.
	1.32	11.18	33.40	4.29	16.48	32.82	67.3	35	Car wheels, heavy machinery.
Massillon, Ohio	3.40	1.36	12.52	11.98	63.82	6.50	74	......	Heavy castings.
Dye's Special, Ind.	......	.06	.10	.04	47.10	52.64	174	......	Brass and gray iron.
New Albany, Ind.	......	.10	.20	.10	76.34	22.80	139	......	Brass stove-plate and malleable.
Valparaiso, Ind.	.26	3.56	26.08	10.06	32.81	27.12	83	......	Large pipe and structural work.
Waterford, Ill.	.04	.06	.12	.06	80.24	19.22	137	......	Brass, gray and malleable iron No. 4.
Rocton, Ill.	......	1.12	10.68	1.86	53.20	32.86	134	......	Medium castings.
	......	.90	2.30	.70	75.86	18.50	129	......	Light gray castings.
Waterford, Ill.	.04	.42	3.90	1.92	62.84	33.02	131	......	Agricultural implements and malleable castings, No. 3.
Newport, Ky.	......	.06	.84	1.00	61.88	35.52	137	......	Light machinery and malleable No. 3.
	......	.02	.04	.02	77.68	22.12	140	......	Stove-plate and brass.
Ottawa, Ill.	......	40.28	41.28	2.92	13.28	1.48	40	......	Steel castings.
St. Charles, Mo.	......	4.54	41.98	13.78	36.88	.66	73	......	
St. Joe, Mich.	......	.54	11.68	2.78	68.00	24.52	110	......	Light gray iron, malleable, brass.
Grand Rapids, Mich.	......	1.98	21.76	6.56	44.22	24.96	93	......	
Kerrick, Minn.	6.00	8.20	19.96	4.92	42.76	10.30	49	......	Heavy and general castings.
Racine, Wis.	......	.70	3.54	1.38	56.68	37.44	136	......	Small castings.
	......	1.04	11.74	5.80	74.56	6.60	86	......	Fine core sand.
Milwaukee, Wis.	3.56	5.47	28.41	10.61	50.57	Tr.	62	......	Core sand.
South Milwaukee, Wis.	6.90	11.44	27.76	8.76	26.51	18.52	54	......	
Berlin, Wis.	......	.36	6.56	3.52	86.06	2.56	105	......	
Racine, Wis.	......	.72	24.68	11.78	45.80	16.30	86	......	Heavy castings.
Janesville, Wis.	.40	16.54	56.24	5.60	7.80	13.34	40	......	Heavy castings.

The sand passing through is weighed and credited to the 100-mesh sieve. That which remains, together with the balls, is emptied on the 80-mesh sieve and the operation repeated. In like manner sieves of varying size up to 20 mesh are used. The preceding table shows the texture or sand from different localities."

Lime is a fluxing element. If present as a carbonate, it loses its carbonic acid under heat, and in excessive amount the gas causes the mould to flake or crumble. Caustic lime fluxes and forms slag on surface of castings.

Magnesia is also a flux, and to a modified extent has the effect of lime.

Iron, as a carbonate or an oxide, if present in the mould near the casting, is converted into ferrous oxide, which is a flux.

Combined water is present in all sands containing clay, carbonate of lime or gypsum. It is driven off at a low red heat and increases the porosity of the sand.

Moulding sands are not always used alone. One or more grades are frequently mixed together. Blending is extensively practiced at the pit as well as at the foundry. In addition to blending to increase certain physical properties, foreign substances, such as ground coal, graphite, molasses, flour, beer, linseed oil or cinders are used, either to increase the bonding power or permeability of the material. A sand deficient in its natural condition may be greatly improved by "doctoring." The sand from any one deposit does not always run uniformly, and without previous careful examination of the shipments, unfavorable results may appear in the foundry.

The following table, taken from "The Iron Age," gives the analysis of eight different samples.

Constituents	1	2	3	4	5	6	7	8
Silica	92.08	91.90	92.91	90.62	81.50	84.86	82.90	79.81
Alumina	5.41	5.68	5.85	6.66	9.88	7.03	8.21	10.00
Ferric oxide	2.49	2.17	1.24	2.70	3.14	2.18	2.90	4.44
Lime	....	.41	....	....	1.04	.62	.62	.70
Magnesia	....	....	....	....	.65	.98	....	....
Potash	....	....	....	....	....	....	....	....
Soda	....	....	....	....	....	....	....	....
Water	....	....	....	....	3.00	3.20	2.85	2.89
Organic matter	....	....	....	....	....	....	....	....

Sands which contain the largest percentage of silica, sufficient alumina to impart cohesiveness and plasticity, with from 1 to 3 per cent of magnesia are the best for facing. Such sand should be entirely free from lime.

Specifications of W. G. Scott, Racine, Wis.

"Moulding sand for iron work generally contains from 75 to 85 per cent of silica; 5 to 13 per cent of alumina; less than 2.5 per cent lime and magnesia; not over 0.75 per cent soda and potash and generally less than 5 per cent oxide of iron; not more than 4 per cent of water."

Sand for Brass

Sand for brass may contain a much higher percentage of iron and lime without detriment.

All moulding sands contain more or less organic matter. Carbonate of lime must not exceed 1.5 per cent for iron sands, nor 2¼ per cent for brass. Iron oxide must not exceed 5.5 per cent for iron nor 7 per cent for brass sand; organic matter not to exceed 1 per cent. Any sand showing an excess of 13 per cent alumina will be rejected.

ANALYSIS

Constituents	For light iron work	For medium iron work	For heavy iron work	For light brass
Silica	82.21	85.85	88.40	78.86
Alumina	9.48	8.27	6.30	7.89
Iron oxide	4.25	2.32	2.00	5.45
Lime	....	.50	.78	.50
Lime carbonate	.68	.29	....	1.46
Magnesia	.32	.81	.50	1.18
Soda	.09	.10	....	.13
Potash	.05	.03	....	.09
Manganese	....	Trace	.25	Trace
Combined water	2.64	1.68	1.73	3.80
Organic matter	.28	.15	.04	.64
Specific gravity	2.652	2.654	2.63	2.64
Fineness	85.18	66.01	46.86	94.88

Any of these sands would answer very well so far as their chemical composition is concerned, for any class of work; but it is absolutely necessary that they should possess the proper degree of fineness.

The finer sands are less siliceous and as a rule carry higher percentages of alumina and fluxes than coarser grades, as shown by the following table.

Size	60	80	100	100
Silica	95.92	94.35	94.66	91.06
Alumina	1.29	1.47	1.47	4.57
Ferric oxide	.56	.56	.40	.80
Lime	.10	.04	.34	.72
Alkalies	2.13	3.58	3.13	2.85
Total	97.87	96.42	96.87	97.15

The greater the average fineness, the lower the permeability.

Prof. Ries, from whose paper the above notes are extracted, concludes that the chemical analysis of moulding sands are not of as much importance as their physical properties.

To test the "temper" and strength of sand, the moulder squeezes a handful into a ball. If it takes the impression of his hand readily and leaves the hand clean, it is considered sufficiently damp. Its strength or binding power is tested by lifting the lump from one end, or by carefully breaking it apart; or he may squeeze a ball of sand about a little stick or nail and see if it can be lifted by the stick. He then blows through it to test its porosity. Such crude tests are in constant use and, conducted by experienced moulders, serve the purpose.

A. E. Outerbridge instituted a series of experiments to determine these characteristics more definitely. The following is extracted from a paper read before A.S.M.E., at their New York meeting in 1907.

"A number of test bars of green sand 6″ × 1″ × 1″ were made under uniform conditions of pressure, dampness and quality of material used in forming the ordinary mould. These little test bars were placed upon a smooth metal plate with sharp square edges. The bars were then pushed over the edge of the plate until they broke, when the amount of the overhang was measured. It was soon found that there was a great difference in the length of the overhang, which was regarded as a quantitative measure of the toughness of the sand. These differences were not even noticeable in the crude ball test.

Samples taken from different parts of a small sand heap that had been uniformly dampened, or tempered, varied greatly in this respect, owing no doubt to the irregular distribution of the alumina or clay binder; and the correctness of this inference was subsequently confirmed by simple analytical tests. After a sufficient number of these test bars had been made and broken to prove the reliability of the method, further tests were devised to ascertain whether the usual methods of riddling and mixing the sand for the moulder's use affected its quality either by increasing or decreasing its toughness, as shown by the amount of overhang of similar test bars of green sand. It was proved that the more thoroughly the sand was worked, the greater the overhang, due, as already stated to the more uniform distribution of the binder.

"The ideal moulding sand is a material in which the individual grains of silex, constituting approximately 90 per cent of the mass, are completely covered with an overcoat of alumina or clay and the more uniform the grains are in size and shape, the better is the sand with respect to porosity in relation to the average size of the grain.

"It was found on passing a sample of sand a number of times through a handriddle, and making test bars from the sample after each riddling, that the overhang was increased measurably. Thus, a sample of sand, which, after tempering and mixing by hand with a shovel, showed an overhang of less than two inches of the test bar, increased to nearly three inches after a dozen riddlings. It would not be practicable to treat large masses of sand in this manner, nevertheless, the information thus obtained was quite valuable and led to important practical results.

"Another novel observation was concurrently made, viz., that the increased toughness and porosity noticed in these tests might be partly due to "aëration" or to the separation of the grains of sand when falling from the sieve to the floor. In order to discover the truth or falsity of this view, a quantity of sand was shaken in a box with a closed lid for several minutes and test bars were made before and after shaking. The correctness of the theory was quickly shown, for the shaking without sieving proved to be more effective than the sieving without shaking. Tests for porosity were also made, but these were not very satisfactory owing possibly to lack of suitable means of controlling and measuring the compressed air."

Using one of Wm. Seller's & Co.'s centrifugal sand mixers, the development of which was largely due to Mr. Outerbridge's experiments, a series of tests were made with facing sand prepared as follows:

Strong Sand

	Parts
Strong Lumberton sand (new)	14
Gravel (new)	7
Flour sand (old)	6
Coal dust	2

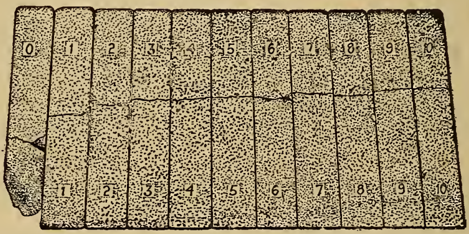


FIG. 132.—Green Sand Test Bars made from One Sample of Sand.

"Fig. 132 is from a photograph showing eleven bars 6″ × 1″ × 1″, made from strong sand under uniform conditions of quantity, temper (dampness) and pressure.

"The bar labeled o was pressed from a sample of the sand after having been dampened and turned over several times, with a shovel, and only partly mixed. The object of such preliminary mixing is simply to prevent the coal dust from flying out of the centrifugal machine on subsequent treatment.

"The other bars were made from the same pile of strong sand, after passing through the centrifugal machine from one to ten times. These bars were laid side by side upon the smooth metal plate, resting upon a table, and were slowly pushed over the edge of the plate until they broke."

The following table gives the measurements of the overhang of each bar as nearly as the somewhat irregular shape of the break permitted.

	Inches
No. o length of overhang	2¼
No. 1 " " "	3
No. 2 " " "	3¼
No. 3 " " "	3⅛
No. 4 " " "	3½
No. 5 " " "	3½
No. 6 " " "	3½
No. 7 " " "	3⅝
No. 8 " " "	3⅝
No. 9 " " "	3¾
No. 10 " " "	3¾

"It will be observed that the first treatment increased the overhang ¾ inch, the subsequent treatments increased the overhang in some cases ¼ inch, and in some cases not measurably. The first treatment was, therefore, the most effective, and for practicable purposes one treatment is often sufficient to insure good mixing of the materials and thorough disintegration of any lumps.

"The strain tending to break the sand beam is increased by the additional weight of the increasing length of the overhanging portion, and also by the increased moment of its center gravity. It is readily seen, therefore, that an increase in length of the overhang of ¾ inch on the first treatment in the centrifugal machine means an increased tenacity of 75 per cent. In like manner an increase in overhang of 50 per cent means an increase in strength of sand of 225 per cent.

The illustration, Fig. 133, shows the fractured surfaces of the same bars.

"Bar No. o shows the heterogeneous components of the partly mixed sand, while the other fractures show increasing uniformity due to more thorough mixing, and disintegration of lumps up to No. 3, after which no further increase in uniformity is observable to the eye.

The illustrations convey a very fair impression of the actual appearance of the bars. The appearance of the fractured surfaces coincides with the tests for overhang, and shows that a single treatment in this machine is in many cases sufficient, and two treatments are all that are usually needed with any sand mixtures.

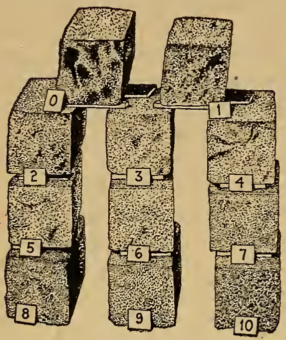


FIG. 133.—End View of the Test Bars in Fig. 132.

In mixing core sand containing flour, the effectiveness of this method is still more strikingly evident, owing to the almost total disappearance of the white flour, due to its thorough commingling with the sand and coal in one treatment.

The centrifugal machine is especially efficient in mixing sharp sand with linseed oil for cores. When so used it is run at a lower speed than when used for tempering and mixing moulding sand. Two treatments are sufficient to insure thorough mixing of sharp sand and oil for cores.

There are many other devices for tempering and mixing sand mechanically, such as, shakers, revolving reels, etc., which are effective.

The amount of cohesive matter, or binder, in moulding sand should be limited to that which will permit good ramming, without destroying its porosity, so that the gases will escape readily, without allowing the iron to penetrate.

The sand in a mould next to the casting is burned and loses much or all of its cohesion. This is due to driving off the water of combination in the alumina which cannot be restored. The thickness of the layer of burned sand depends upon the size of the casting and temperature of same.

It is impossible to separate all of this burned sand after the removal of the castings. Much of it gets mixed in the sand heaps, which must be strengthened from time to time with new sand.

Aside from the loss of combined water and increase in iron content, chemical analysis shows little difference in the composition of new and burned sand. This is shown in the table on page 437, made by analyzing the same sand before and after using.

In general, moulding sand must possess the following requirements.

It must be sufficiently porous to allow the free passage of air and the gases generated in casting.

It must resist high temperature without fusing.

It must permit of easy removal from the cold castings.

When rammed into shape it must be firm and sufficiently compact to resist the pressure of the liquid metal.

It must be strong enough to resist the abraiding action of the stream of metal entering the mould.

Constituents	New	Burned
Silica	83.49	82.32
Alumina	7.25	7.80
Ferric oxide	4.71	3.98
Lime	.36	.54
Magnesia	.35	.41
Potash	1.30	1.64
Soda	.41	.81
Titanic oxide	.30	.22
Water	1.66	.19
Ferrous oxide	....	2.38
Total	99.86	100.28
Fineness	64.50	60.80

For Dry Sand Moulding

Any sand which, when rammed, will permit of drying into a compact, coherent but porous mass, will answer the purpose of a dry sand mixture. Many green sands dry into friable masses.

Such sands must be mixed with some substance to give them strength. For such purpose, flour, stale beer, molasses-water, or clay-wash may be used. When flour is used, it is mixed in the proportion of one to twenty or thirty, depending upon the character of the sand.

With some sands the flour may be dispensed with and the sand strengthened sufficiently with molasses-water or clay wash. In dry sand moulds, only one or two inches of the sand next the pattern are of the prepared mixture. The remainder of the flask is filled with ordinary heap sand. This should be as open as possible to permit the ready escape of the gases. The facing should likewise be as open as can be safely worked. The amount of moisture should be about the same as is used in green sand. Dry sand facings must be thoroughly well mixed.

Mr. West gives the following mixtures for dry sand facings.

For Large Spur Gears

	Parts
Lake sand	12
Strong loam sand	12
Moulding sand	4
Coke, amount	1–10
Flour	1¼

Wet with water.

Or

	Part
Moulding sand	1
Jersey sand	1
Fire sand	1
Sea coal	1–16

Wet with thin clay wash.

For Close Facing

	Parts
Moulding sand	6
Lake or bank sand	1½
Flour	1–50

Wet with clay wash.

This mixture may be used for blacking, using flour 1–40.

For Cylinders

	Parts
Fair loam	4
Lake sand	1
Sea coal or coal dust	1–14

Wet with clay wash.

General Work

	Part
Moulding sand	1
Bank sand	1
Flour	1–30
Sea coal	1–20

Wet with clay wash.

Or

	Parts
Strong loam sand	6
Lake sand	6
Old dry sand	2
Flour	1–40
Sea coal	1–14

Wet with water.

For Rolls

	Parts
Dry sand	2
Lake sand	1
Sea coal	1–12
Flour	1–18

Wet with clay wash.

For Renewing Old Dry Sand for Body of Moulds

	Parts
Old sand	16
Lake sand	8
New loam	4

Wet with water.

Dry Sand Moulds

Old dry sand becomes very close. It should be passed through a No. 8 riddle to remove the dust and very fine particles. The coarse material mixed with new sand works well.

Skin Drying

Instead of making dry sand moulds which are baked in the oven, moulds are more frequently "skin dried." Skin dried moulds are essentially the same as "dry sand" except that the drying does not extend to as great depths and the facing is not as strong.

For skin dried moulds mix with ordinary heap sand about 1 to 30 flour. After the mould is finished sprinkle with molasses water. The mould is dried either with the kerosene blow torch, or fire of wood, coke or charcoal, built in iron baskets which are placed in the mould. Often the mould is covered with sheet iron and fires are built on top of the iron. In drying copes, they are suspended and fires built under them.

Before drying, the moulds are brushed with black wash, made of plumbago and water, to which a little molasses water or clay wash is added. Sometimes moulds are black washed after drying.

Core Sand

Core sand should be high in silica and low in alumina. A sand containing much alumina does not permit the ready escape of gases after baking.

Analyses of Core Sands
(W. G. Scott)

Constituents	Good quality core sand	Fair quality core sand
Silica	94.30	69.31
Alumina	1.95	4.76
Iron oxide	.33	1.58
Lime carbonate	1.63	3.50
Lime sulphate	....	8.19
Magnesia	.54	7.77
Alkalies	.05	.12
Combined water	1.05	2.95
Organic matter	.15	1.82

"Since the greater portion of a core is to be entirely surrounded by metal, the sand of which it is composed encounters conditions much more severe than those met with by facing sands. Three conditions must be noted.

First. — The core is subjected to much handling.

Second. — The gases generated in casting must find egress through the core and not through the metal.

Third. — The core has finally to be removed from the casting.

"All cores, before entering the mould, are dried, and in this condition must be hard enough to permit handling, and porous enough to admit the free escape of gases. Yet the sand must not be burned or converted into a compact mass by the heat; if so, it will be extremely difficult to remove from the casting.

"A sand high in silica should yield the best results. To such a sand the necessary bond must be added. An ideal core sand is one in which the silica is given bond by the addition of an organic substance, which produces a firm core, capable of withstanding high temperatures and resisting the penetrating action of fluid metal. Such a core is friable in the cold casting, and is, therefore, easily removed.

"If bond is given to silica by clayey matter alone, then the metal bakes the cores hard, and renders their removal difficult.

"A hard surface imparted to the sand by ramming is fatal, as fluid metal will not lie on it, but a hard surface resulting from the binder does not necessarily represent an impervious one, and fluid metal will usually lie quietly on it. Heat tends to loosen a sand made hard in this way, instead of fusing it.

Core Mixtures

"There should be just enough bonding material in a core mixture to coat each individual grain of sand, without filling the interstices between the grains, and the value of the core depends greatly upon the thoroughness with which the mixture is incorporated. Too much attention cannot be given to this feature. As a rule mechanical mixers give the best results. The binders in common use are

Flour,	Linseed oil,
Glue,	Rosin,
Molasses,	Rosin oil.

In addition to these there are many commercial binders of more or less value, all of them designed to offer a binder cheaper than those above mentioned.

Cores made with flour, glue or molasses soften quickly when exposed to dampness. Therefore they must be kept in a dry place, or used soon after they are made. The moulds in which they are placed should be poured shortly after the cores are set. If allowed to stand for a period of 24 hours, the cores should be taken out and dried.

Cores made with glue are very friable when hot and must be handled with great care. Less gas is given off by them than by those made with any other binder. Glue cores leave a smoother hole and do not require to be blackened as do flour cores.

Flour is mixed with sand in proportions varying from 1 to 18, to 1 to 30, depending upon the strain which the core is to resist. The weaker the mixture, the more readily the gas escapes.

Glue is first soaked in warm water and then boiled until entirely dissolved. Glue water should consist of 2 pounds of glue to 3 gallons of water. This mixture is sufficient to treat 100 pounds sand.

Rosin must be first pulverized; it is then mixed with sand in proportions of 1 to 20, or 1 to 30, as required.

Rosin oil is used 1 to 18, or 1 to 24 as the requirements of the case indicate.

Molasses, mixed 1 to 20 water is used more for spraying cores to give a hard surface, than for entire mixtures.

Linseed oil with sharp sand, mixed about 1 to 30 furnishes the best core of all binders. It is strong, porous and is easily removed from the casting. For light, delicate cores, such as gas engine and automobile work it is unequaled.

Large percentages of old cores, gangway sand and moulding sand may be used in the core mixtures.

Core sand should be quite damp for use, but not so wet as to adhere to the core box. Wet sands require much less binder than dry.

A saving may be made in the use of flour by boiling it thoroughly and then using the paste (very thin) to wet the sand. As already mentioned, the more thoroughly the binder is incorporated with the sand, the better will be the cores.

Mr. A. M. Loudon made an extensive series of experiments to determine the comparative values of various core binders, and published the results in a most interesting paper presented to the American Foundrymen's Association at the Cleveland meeting 1906. From it the following extensive extracts are made.

Dry Binders

Test No. 1. — Flour sand core mixture.

	Parts
New moulding sand	2
New fire sand	1
Flour	1 to 12 and 1 to 18

Wet down with thick clay wash.

Cores from this mixture are usually very strong. If not thoroughly dried or if slightly burned or scorched, cause great trouble by blowing or scabbing. Cores were removed from castings with difficulty. Became damp in mould quickly, especially small cores.

Test No. 2. — Syracuse dry core compound mixture.

Old flour sand	⅓
New moulding	⅓
Sharp or beach	⅓

One part binder to 35 parts sand thoroughly tempered with water. Cores made from this mixture dried quickly, were clean and sharp and left good surface on castings. Resisted dampness well.

Mr. Loudon states that the dampness test for each mixture was to dip a core partly in water, allowing it to stand after removal from the water for two or three days to air dry only. Iron was then cast in an open mould around the end which had been immersed.

Test No. 2. — Included the water test as did all the other tests for dry and oil binders, the conditions being the same for all.

The binder used in Test No. 2 stood the water test in a manner entirely satisfactory. The hot iron came in contact with the core without any disturbance.

This binder in Mr. Loudon's judgment is best suited to large plain work, or small round and square cores.

Test No. 3. — Dextrin or British gum mixture.

	Per cent
Old flour sand	50
New moulding sand	25
Beach or sharp sand	25

1 part binder to 150 parts sand, tempered with water.

This mixture was valuable for large cores, strong, with sharp edges and easily dried.

If the cores are burned in the oven, wash with some of the binder dissolved in water, and dry in oven for ten minutes. They are thus completely restored. For small intricate cores the following mixture was used.

	Per cent
Old sand	33
New moulding sand	33
Sharp sand	33

1 part dextrin to 100 parts sand.

A core from this mixture was treated by the water test, and allowed to stand for two days. It resisted the action of melted iron better than cores from many mixtures, when fresh from the oven.

Test No. 4. — Wago core-compound mixture.

	Per cent
Old sand	33
New moulding sand	33
Sharp sand	33

1 part Wago to 30 parts sand.

Made a good core; did not gum the box, and gave off very little smoke.

A second mixture made from Wago:

	Per cent
New moulding sand	50
Sharp sand	50

1 part Wago to 35 parts sand.

Unusually strong, true and sharp, but not as easily removed from casting as the first mixture with Wago.

One of these cores was dipped in water and left for two days to air dry. The melted iron was perfectly quiet when poured around it.

Test No. 5. — Cleveland core-compound mixture.

	Per cent
Old sand	33
Sharp sand	33
New moulding sand	33

1 part binder to 30 parts sand tempered with warer.

Strong core, easily removed from casting, very satisfactory for general use.

A mixture 1 part binder to 40 sand was tried, but cores were too soft. Cores from the 1 to 30 mixture when submitted to the water test gave excellent results.

Test No. 6. — Peerless core-compound mixture.

	Per cent
Old sand	33
Sharp sand	33
New moulding	33

1 part binder to 30 parts sand.

The mixture as above given was unsatisfactory, therefore, the following mixture was tried.

1 part binder to 20 parts sand.

This was satisfactory, being strong and true to box, but harder to remove from castings than most of those previously tested. It gave good results when submitted to the water test. The iron showed no signs of blowing.

Tests Nos. 7, 8, 9 were made from samples of flour submitted. Sand mixed in same proportions as before.

Thus, the first sample of flour was mixed with 15 sand,
the second sample of flour was mixed with 18 sand,
the third sample of flour was mixed with 20 sand.

These were made as comparative tests of the different samples of flour.

1. Made the strongest core, but was the most difficult to remove from the casting.
2. Good for general work.
3. Was too soft.

A mixture of 1 to 18 from 3 to 9 was good, better than Nos. 2 to 8 in same proportion. Each of the above mixtures was subjected to water test and failed. When withdrawn from the water and held in horizontal position, they broke at the line of submersion. Nos. 2 and 3 were not as good in this respect as No. 1.

The cores from the peerless compound and most of the others resisted the water so that it could be wiped off with a rag without injuring the cores.

Test No. 10. — Paxton dry compound mixture.

	Per cent
Sharp sand	33
New moulding sand	33
Old sand	33

1 part compound to 30 parts sand, made a very soft core.

When mixed 1 to 20 it made a very strong core.

One of these when subjected to the water test went to pieces, while the last mixture made a strong open core. It is readily affected by moisture.

Liquid Core Binders

Test No. 11. — Holland linseed mixture.

	Parts
Sharp sand	30
Oil	1

Made a strong core for small and medium shapes, but required venting. A core from this mixture immersed in water for half an hour was returned to the oven and dried. It was then as good as any which had not been immersed.

Test No. 12. — Syracuse core oil mixture.

	Parts
Sharp sand	35
Oil	1

Tempered with water and well mixed. These cores were excellent; without vents were not satisfactory.

A core from this mixture was immersed for 15 hours, taken out and dried in the oven for 15 minutes. Molten iron when cast about it showed no disturbance.

Tests Nos. 13, 14, 15. — Sterling oil samples from each of above were mixed at same time.

Mixture

	Parts
Sand	35
Oil	1

Nos. 1 and 2 of these samples showed too much oil. No. 3 was about right.

Another mixture was then made.

	Parts
Sand	45
Oil	1

Nos. 1 and 2 dried out quickly and made good strong cores, but when subjected to the water test the moisture acted quickly upon them, more so than on the other sand and oil mixtures. The cores were strong and were easily cleaned from the castings, but moulds which were left over night, and poured the next day blew very badly.

Test No. 16. — Gluten or Esso mixture.

	Per cent
New sand	33
Sharp sand	33
Old sand	33
Gluten	1 part to 30 parts sand

Cores were so hard that the iron would not lay to them.

One part gluten to 50 parts sand, — cores were good, sharp and strong. Iron somewhat disturbed. The gluten was mixed with water and the sand tempered with water.

One part gluten to 70 parts sand.

These cores were soft and did not stand the fire as well as the others. When subjected to water as before

1 to 30 stood very well,
1 to 50 became soft,
1 to 70 melted like sugar,

showing that for a free core, one not inclined to blow, 1 to 70 took moisture very quickly.

Test No. 17. — Glue melted in hot water mixture.

	Per cent
New moulding sand	25
Sharp sand	25
Old sand	50

1 pound of glue to 100 pounds of sand for small cores.
1 pound of glue to 150 pounds of sand for large cores.

Lump or granulated glue, the cheaper the better.

The glue water was made by dissolving two pounds of glue in three gallons of water.

Cores from the first of the glue mixture when submitted to the water test absorbed water but held their shape. After redrying were as good as when first made. Should such cores be burned in the oven, washing them with a mixture of plumbago and glue water restores them.

Mr. Loudon highly recommends the first of the above glue mixtures, using it for cores without vents for small port cores.

Cores made from it can safely be used for all purposes, taking care to have them thoroughly dried.

Cores for large beds have remained in the mould three and four days without causing trouble.

Test No. 18. — Glucose melted with hot water mixture.

	Per cent
Sharp sand	33
New moulding sand	33
Old sand	33

1 pound of glucose to 100 pounds of sand.

Cores of every description were first class, easily dried, easily cleaned from casting, emitting no smoke. They acted like green sand cores, dried and gave good results in every respect.

Parting Sand

The particles of burned sand, having been deprived of combined moisture will not cohere. Such sand, taken from the cleaning room, is used to separate the parts of the moulds and is also dusted on patterns to prevent the moulding sand from adhering to them.

A most excellent parting sand for intricate work is made by saturating very fine burned sand with kerosene or crude oil, and setting fire to the mixture.

Lycopodium is also used for parting in particular work, but the high price subjects it to adulteration.

Facings

When molten iron comes in contact with a sand mould it tends to penetrate the pores of the sand and to fuse the particles in immediate contact, leaving a rough surface or scale, varying in thickness from 1/64 to 1/8 of an inch, depending on the weight of the casting.

Facing sands containing large percentages of carbonaceous material are used to prevent this difficulty and to leave smooth surfaces on the castings. The carbon of the facing is decomposed by the heat, and the gases generated prevent the hot iron from attacking the sand. Facing sand which is composed of ground coal (sea coal), and sand in the proportions of from 1 coal to 8 sand, and 1 coal to 20 sand, depending upon the character of the work, is placed next to the pattern in a layer from ½ to 1½ inches in thickness. Back of this and completely filling the flask is the heap, or floor sand. By the continued use of facing the floor sand becomes black with it.

The term facing includes

Sea coal,	Coal dust,
Plumbago,	Charcoal.
Talc (or soapstone),	

It must adhere to the surface of the mould and cause the casting to peel when shaken out.

Sea coal is a ground bituminous gas coal, free from sulphur and slate. It is mixed mechanically with new moulding sand in the proportion of 1 to 10, usually, and used generally on all work. For the purpose of obtaining smoother and brighter surfaces than result from the use of sea coal alone as a facing, the moulds are finished with plumbago or some mixture of which plumbago is the base. Plumbago is the best of all materials for this purpose.

Soapstone is used largely in connection with plumbago as an adulterant, as also are coke dust and the dust of anthracite coal.

The facing is applied to the mould either by hand, with a camel's hair brush, or it is mixed with molasses water and applied by a spray or with a brush. The latter method is usually used on dry sand moulds.

Mr. W. G. Scott gives the analysis of Yougheogheny gas coal, from which the best "sea coal" facing is made as follows:

			Per cent
Moisture	1.00	Sulphur	0.33
Volatile matter	35.00	Ash	5.60
Fixed carbon	58.07	Specific gravity	1.28

Cannel coal is also used as facing and analyzes as follows:

Moisture	3.30	Sulphur	0.20
Volatile matter	48.50	Ash	6.00
Fixed carbon	42.00	Specific gravity	1.229

"Sulphur and ash are the two constituents of sea coal to be guarded against. If sulphur exceeds 0.75 the coal is inferior, and if sulphur is in excess of 1.5, the coal is unsuitable for facing.

"Facing containing over 11 per cent ash ought not to be used.

"Slack and culm are often ground and used as adulterants, but are readily detected by the amount of ash present.

Graphite Facing

"Pure graphite contains about 99 per cent carbon, but this degree of purity is not found in the natural product. A high grade natural graphite contains 75 per cent carbon; inferior grades contain from 15 to 65 per cent.

"As the regulation method of determining carbon in facings is to burn off a weighed amount of sample and call the loss carbon, an unscrupulous dealer may add coke or anthracite dust sufficient to raise the carbon content to any desired point.

"Adulterations of this sort may be determined in several ways.

"If several small beakers are filled with water and pure graphite, coke dust, anthracite dust, soft coal dust or charcoal are carefully sprinkled on the surface of the water, each in a separate glass, none of the powder will settle except the coke dust and some charcoals. This test eliminates coke dust and non-greasy charcoals. By shaking in a test tube ¼ gram of the sample with 15 c.c. of acetone and allowing the mixture to stand 10 or 15 minutes, it will be seen that the pure graphite settles clear, leaving the liquid colorless. Coke imparts a gray to the solution and remains in suspension a long time; anthracite coal imparts a faint brown color and settles more rapidly; soft coal dust imparts a deep brown color.

"The above tests are qualitative only. Equal parts of glacial acetic acid and sulphuric ether answer as well as acetone for this test."

The following analyses from Scott of graphite, coke dust, coal and charcoal give a general idea as to the character of the different forms of carbon.

Chemically Pure Graphite

	Per cent		Per cent
Moisture	0.02	Sulphur	0.00
Volatile matter	0.09	Ash	0.10
Fixed carbon	99.79		

Commercially Pure Graphite

	Per cent		Per cent
Moisture	0.15	Sulphur	trace
Volatile matter	0.79	Ash	4.46
Fixed carbon	94.60	Specific gravity	2.293

Stove-plate Graphite Facing

	Per cent		Per cent
Moisture	0.75	Sulphur	0.20
Volatile matter	5.29	Ash	37.66
Fixed carbon	56.10	Specific gravity	2.363

The Composition of Ash in Above Sample is

	Per cent		Per cent
Silica	25.60	Lime	1.07
Alumina	5.25	Magnesia	0.80
Iron oxide	4.94		

Cheap "Green Sand" Facing

	Per cent		Per cent
Moisture	0.45	Of which the ash analyzed.	
Volatile matter	5.75	Silica	32.13
Fixed carbon	41.49	Alumina	2.77
Sulphur	0.62	Iron oxide	6.78
Ash	51.69	Lime	1.64
Specific gravity	2.489	Magnesia	8.32

This sample was said to contain 25 per cent soapstone.

The following analyses are given for comparison.

Coke Dust

	Per cent		Per cent
Moisture	0.19	Sulphur	0.98
Volatile matter	1.40	Ash	10.54
Fixed carbon	86.89	Specific gravity	1.886

Anthracite Coal Dust

Constituents	Selected lump, per cent	Screenings, per cent
Moisture	.05	3.50
Volatile matter	4.40	8.99
Fixed carbon	92.00	68.70
Sulphur	.57	.86
Ash	2.98	17.95
Specific gravity	1.565	1.590

Analysis of Soft Coal

Constituents	Selected lump, per cent	Screenings, per cent
Moisture	1.39	4.44
Volatile matter	33.82	32.79
Fixed carbon	58.68	37.61
Sulphur	.96	3.10
Ash	5.15	22.06
Specific gravity	1.321	1.486

ANALYSIS OF WOOD CHARCOAL

Constituents	Common variety, per cent	Medicinal, per cent
Moisture	3.83	3.66
Volatile matter	26.57	33.15
Fixed carbon	66.63	58.52
Sulphur	None	None
Ash	2.97	4.67
Specific gravity	1.362	1.412

ANALYSIS OF SOAPSTONE AND TALC

Constituents	Vermont soapstone, per cent	French talc, per cent
Silica	51.20	61.85
Iron oxide	8.45	.25
Alumina	5.22	2.61
Lime	1.17	Trace
Magnesia	26.79	34.52
Water	7.17	.77

Mr. Scott gives the following as a test for the presence of anthracite coal in graphite.

"Treat 0.5 gram of sample with 50 c.c. of strong nitric acid, boiling about 10 minutes. Then add 0.5 grams of pulverized potassium chlorate and boil until most of the chlorine is off. Dilute with 30 c.c. of cold water and filter, reserving the filtrate for examination.

The filtrate from pure graphite treated in this manner should be clear and colorless unless iron is present, in which case it may be somewhat yellow in color.

The filtrate from any kind of coal and charcoal will have a distinct amber brown color, the soft coals giving a deeper color than the hard coals or charcoal.

To confirm the test add 30 c.c. of stannous chloride solution and note the change in color. The graphite filtrate will be reduced to a colorless liquid if iron is present, or remain unchanged if free from iron; whereas the filtrate from the coal having an amber color will be much deeper in color and in some cases nearly black. The only caution to be observed in this test is sufficient boiling to remove all of the hydrocarbon coloring matter in the coal.

The determination of magnesia is the only method to be relied upon for detecting the addition of soapstone to graphite. Mixed with graphite or anthracite dust, it answers very well for certain classes of work.

Facing made entirely of anthracite or mixed with a low grade of natural graphite is termed Mineral Facing and is represented by one or more letters X to designate the fineness. Such facings may be added to wet blacking; or mixed with graphite, may be used on heavy work.

All facings should be kept in a dry place as they readily absorb moisture. A high grade of plumbago makes the most suitable facing for producing bright clean castings. A good plumbago must not only have the proper chemical analysis, be of such refractory nature as to withstand the hot iron from cutting into the mould, but must also be of such a nature as will not retard the flow of the molten metal."

CHAPTER XXI

THE CORE ROOM AND APPURTENANCES

The important relation which the core room bears to the foundry product demands the most careful consideration as to location, construction and equipment. Unfortunately for the core maker, such considerations have been neglected in many foundries. Whatever could, has been made to serve so long as the imperative demands were satisfied. Good castings cannot be made without good cores. Their production requires the same attention and forethought as the making of good moulds.

Constant intercommunication between the moulding floors and core room, the handling of sand, fuel and ashes, etc., point to a location affording the greatest accessibility to the moulding floors and to the storage for sand and fuel.

The core room should be well lighted and ventilated. The space allotted should be ample, not only for the convenience of the workmen but for storage of supplies, movable equipment, core plates, etc., so that the place may be kept neat and orderly. The arrangement of the work benches, machinery, cranes, racks, etc., must be governed by circumstances.

The oven is the important feature in the core room. Where the cores are not very large and the demand for them not very great, some form of portable oven may answer the purpose. Many varieties are made, adapted to small and medium work. The convenience offered by them in placing and removing cores before and after baking, the small floor space occupied and the small fuel consumption commend them for light work. Most large foundries have one or more of these ovens. Where great quantities of small cores are required, some form of continuous oven is frequently used. An oven with a revolving reel is very desirable for medium-sized work.

The sketch below is taken from West's "American Foundry Practice," page 133.

"The oven is round, with an upright cast-iron shaft, having five flanges on which to bolt plates or arms *XX*, the shape of which is shown at *B*. This oven is built with an 8-inch brick wall to form the outside and a cast-iron plate for the top, on which plate is a box *D*, to which a cap can be bolted to hold the top of the shaft, the bottom of which rests in a cast iron seat.

"The fireplace should be outside of the circle, as shown, so that the cores will not get the direct heat from the fire. In building the walls, hinges *HH*, should be built in for hanging the oven door.

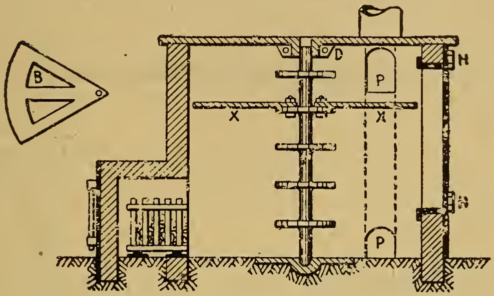


FIG. 134.

"This door should be made in two pieces, so as to open to the right and left, and should be the full height of oven, to provide for putting cores on the top shelves.

"The chimney should have a top flue, as well as a bottom one, as shown at *PP* and dampers in both, so as to throw the heat down or up, as required.

"When starting a fire, both dampers should be open, and when the cores to be dried are on the top shelf, the bottom damper may be closed, and vice versa.

"This style of oven is very handy for drying cores that can be lifted by hand, and will hold and dry more cores with less fuel than any oven I know of. Should you want to dry a single core quick, put it on the top shelf and turn it round to the fire.

"This oven can be filled with cores and they can be taken out again without going farther than the door, which alone is of great value to the core maker.

"The size of this oven was about 8 feet in diameter and 7 feet high." The oven was heated with a cast-iron fire basket.

On page 135 of same book is shown a sketch for a small oven of which Mr. West speaks very highly. The advisability of building such an oven is somewhat doubtful, however, in view of the great variety of portable ovens on the market which can be purchased at a reasonable price.

For large cores the dimensions of the oven are governed entirely by the requirements of the foundry.

Unless the drying of large moulds is comtemplated, it is not advisable to make an oven more than 12 feet wide by 20 feet long. Where greater capacity is required, it is better to duplicate it, on account of the greater loss of fuel in large ovens, which are not stored to their full limits.

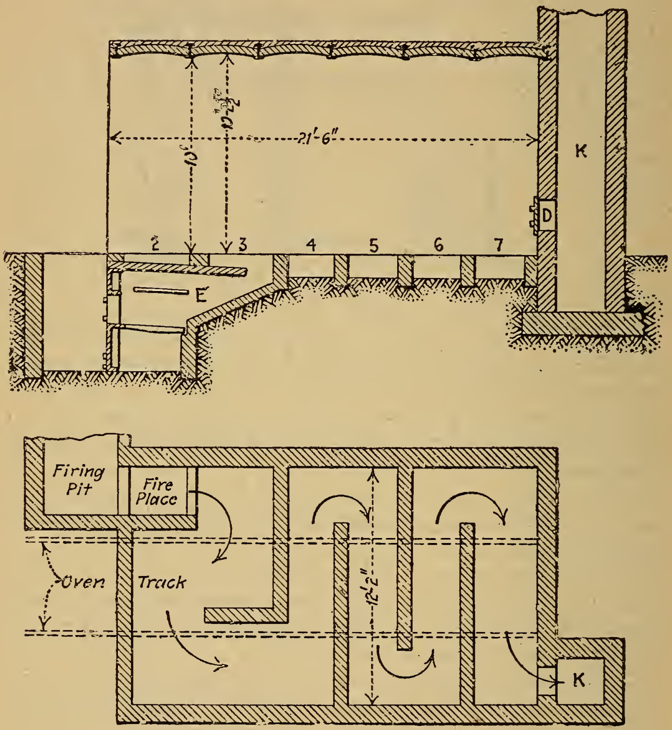


FIG. 135. — Core Oven.

Among the sketches of large ovens shown by Mr. West, that on page 227, "Moulders' Text Book," presents a most excellent design. An enlarged sketch is given above. The dimensions may of course be varied to suit the requirements.

Mr. West in describing ovens of this design says: "They surpass any I know of for properly drying moulds or cores. Although we use slack or soft coal for the fires, a mould or core will when dry, be almost as clean as when first put into the oven. Another important feature is that the ovens will dry rapidly and still not burn a mould or core."

Three ovens are fired from one pit, the draft flues being at the extreme ends of the oven and the channel for heat to travel being diverted from side to side. There is but a small chance for heat to escape entering through the joints and thickness of the boiler plate up into the oven, before it can enter the flue at *F*, *H* and *K*. The arrow-like lines represent the heat passing from the fires to the flue. The partitions *X* divert the direction of the heat and also support the covering plates and carriage tracks.

The covering plates, 2, 3, 4, 5, 6 and 7 are boiler iron ¼ inch thick, cut into sections the width of the flue partitions.

The plates on the outside of the track are free at any time to be lifted in order to clean out the soot. Where the fire enters the first flue or partition, the boiler plates are left out, and in their place a cast-iron plate ½ inch thick, having prickers 2 inches long (on underside) and daubed up with fire clay is used.

This is to prevent the direct flame from buckling and burning out the plates.

There are no holes whatever in any of the plates, the heat passing through them and their joints, which of course are not air tight, heat up the oven.

Were there holes in the plates, they would seriously injure the draught of the under flues, and also let much of the smoke into the ovens, thereby destroying essential points to be overcome in using slack for firing.

To be able to fire with slack or soft coal, and still keep moulds and cores free from soot is something that will be appreciated by all moulders and core makers that work around ovens. Not only does soot make everything look dirty, but it is more or less productive of rough castings.

"Another arrangement which I doubt being found in any other foundry oven is that for preventing smoke. Upon each side of the fireplaces, about on a level with the fire, are ⅜-inch openings, seen at *E* in elevation. In the rear of these openings the brick is left open about 4″ × 6″, running the entire length of the fireplace. This opening gives a reservoir in which the air becomes heated before being drawn into the fireplace. This is, I believe, claimed to be beneficial in assisting 'smoke burning' or combustion."

The grate surface for the fire contains an area equal to about 32″ × 38″.

"The fireplaces are all faced with one thickness of fire bricks, and the tops of fireplaces are arched over with fire bricks. Under the large oven are two fireplaces. The one nearest core oven is used for heating the same, and is so constructed with damper arrangement, that should an extra heat be required in the large oven, both of the fires can be turned on to it.

"As shown at *D* in elevation of oven, each one has a small manhole door, whereby the flue leading to the chimney *K* can be readily cleaned.

"The tops of the ovens are covered with a series of arches.

"Upon the tops of these ovens we store and keep shop tools, etc. The way the tops are formed, tons of weight can be laid upon them and do no harm; and the combined area of the tops makes a splendid storeroom for systematically keeping foundry tools."

"Altogether the ovens are a success, and a credit to their designer, the late Mr. Halloway."

NOTE. — Only one of the ovens is shown in the sketch. The other two are in all respects the same as the one shown.

Another excellent design for a large oven is shown on page 129, West's "American Foundry Practice." A description of one good oven is all that can be permitted here.

The essential requirements for an oven are good draught and means for regulating it. Where the fire is made directly in the oven, as is frequently the case, there should be openings into the chimney at the top and bottom, with dampers for changing the direction and regulating the draught. There should also be a damper on top of the chimney so as to retain the heat when the fire is not urged. Aside from coal and coke, crude oil and natural gas are used for heating.

The temperature of the ovens should range from 450° to 900° F. and must be varied somewhat according to the core sand mixtures.

Flour sand requires a higher temperature than rosin or oil. The workmen soon learn the part of the oven in which the drying is most rapid and place the cores where they will dry quickly or slowly as required.

A pyrometer is a most valuable attachment and will often prevent the destruction of cores by overheating.

The doors to these ovens are usually made in one piece of sheet iron and are provided with counter weights, so as to permit of being raised or lowered easily. In some cases they are made of overlapping, plain or corrugated strips, which are wound upon rollers.

Core Oven Carriages

These are mounted on wheels having anti-friction bearings. The top of the carriage extends over on each side as far as convenient. The carriages have usually three or more decks as required. The whole is made up of bars and angles properly trussed, and left as open as possible, for the passage of hot air to the cores.

The track should be evenly laid, so that there may be no jarring as the car passes over it.

Mixing Machines

Machines for this purpose are of greatest value to the core room. The worth of a binder and that of a core depends largely upon the thorough incorporation of the components of the core. Each individual grain of sand should receive a coating of the binding material, but the latter should not be present in such quantity as to fill up the pores of the sand. To accomplish this result requires long-continued manipulation. The best results are obtained by a mechanical mixer, driven by power or by hand, as the conditions permit. A machine of this sort is indispensable in a well-appointed core room. There are many different kinds on the market. The centrifugal machine is, perhaps, the most desirable.

Sand Conveyors

Many of the large foundries are provided with sand elevators and conveyors, whereby the sand after mixing is carried to the bench of each core maker and delivered through spouts. The necessity for appliances of this sort will be indicated by the extent and character of the work, simply bearing in mind that the core maker should have the sand delivered to him.

Rod Straighteners

Core wires and rods by use become crystallized, and bent in all manner of shapes; so that it is not unusual to find about core rooms, large heaps of material of this kind, which are picked over by the core maker in search of what he requires. In this condition it is practically worthless; therefore the expense for wire and rods is not inconsiderable. By annealing they may be softened, and if then passed through a straightener are rendered serviceable. Both hand and power machines for this purpose are made.

Wire Cutter

A machine for this purpose is very useful where there are many small cores of a kind to be made. Otherwise the common hand cutter serves the purpose.

Sand Driers

A sand drier is frequently very desirable. A simple one can be made by taking a sheet-iron cylinder from 15 to 20 inches in diameter, and say 5 feet long. Surround this by an inverted sheet-iron frustum of a cone, having a diameter at the base such that the space between it and the cylinder may contain any desired amount of sand. Near the intersection of the cone and cylinder there should be two or more small sliding doors. Mount the cylinder on a grate for coke; provide a cover for the top for checking the fire. This costs little and will dry sand very rapidly. The cut below shows a drier in frequent use.

The Champion Sand Dryer

Capacity, 20 tons daily.

Requires less fuel and has greater capacity than any of the dryers now in use, and being made of cast iron throughout, will outlast any made partially of sheet iron.

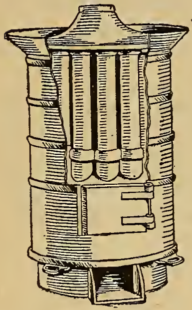


FIG. 136.

The parts, being made interchangeable, can be replaced at any time.

Set the dryer upon a solid foundation, and first placing casting No. 1. in position, follow up with the other casting as numbered.

No. 1. Ash pan and base.
" 2. Flat rings, with slides.
" 3. Wide ring of outside casing.
" 4. Fire box.
" 5. Rings with which to form casing.
" 6. Center pipe.
" 7. Outside pipes.
" 8. Plates to secure top of pipes.
No. 9. Cover for pipes and seat for stove pipe.
" 10. Flaring ring.
" 11. Slide.
" 12. Door.
Nos. 13 and 14. Grates.

Fire lightly, being careful not to get the dryer too hot. Never leave the dryer full of sand with a fire in it; and do not attempt to use it for heating purposes, as it radiates no heat outside the casing.

Core Plates and Driers

A great variety of core plates, varying in sizes, is required. These plates are usually rectangular and for sizes less than 12 × 20 are ½ inch thick. Larger plates are thicker. Each must be smooth and true on one side; on the opposite side are cast stiffening strips. Larger plates are of sizes and shapes required. For work of extreme accuracy, the plates should be planed on one side. The exposure of these plates to frequent heating and cooling finally warps them to such an extent that they become unserviceable. There should be racks for the storage of these plates so that any size desired may be quickly found.

Irregular shaped cores which cannot be turned out on flat plates, or which must be supported in drying, require iron shapes made to conform to one of the surfaces of the core. The shapes are in reality portions of the core boxes. The cores are baked on them, thereby retaining the original form when dried.

The expense for driers is often great, therefore they should be handled carefully, and put away with the core boxes to which they belong.

Core Machines

Where great numbers of small cores of uniform cross section, round, square, oval, polygonal or rectangular are used, a core machine is of the greatest value. One of these machines will make 200 or 300 linear feet of small core in an hour. The cores are pushed out of a former as sausage from a sausage machine, on to metal drying trays. The cores are cut up into lengths as required and pointed to fit the prints.

There are several different machines of this kind made, but the differences are not important.

Machines

Moulding machines are used in making cores for plain work, where the demand for the product warrants.

Machines for making straw rope. These are little used except in pipe foundries. It occasionally happens in a jobbing foundry that a rope body for a core is required. In such a case the rope is made by hand. Straw rope is furnished by supply houses at low cost.

Cranes and Hoists

The requirements and location of these implements are regulated by the character of, and demand for, the work. Where the work is large there should be a traveling crane covering the track and the "big floor." Circumstances will dictate in such cases.

Other appliances are screw clamps, spike claws, glue heaters, clay tubs, horses, etc. In view of the great number of implements needed about a core room, the necessity for adequate room, that the place may be kept neatly, orderly, and as cleanly as possible, will be apparent; and as the production of good castings depends upon the character of the cores, as well as upon that of the moulds, the neglect to provide proper facilities for the core maker is inexcusable.

CHAPTER XXII

THE MOULDING ROOM

Too much attention cannot be given, in selecting a location for a foundry, to the character of the ground; good drainage is a primary requisite. Gravelly subsoil is altogether desirable. If the natural features of the situation do not permit proper drainage, the surface should be raised by proper filling so that the floor may be at least one foot above the ground exterior to the foundry. Much damage often results from the flooding of the floor during severe storms.

Pits of greater or less depth have frequently to be made in the floor for heavy castings, and if the ground is not well drained great expense may be involved in keeping the pits dry.

In preparing the moulding floor the surface soil should be removed and replaced with coarse sandy loam. After this is leveled it should be covered with from 2 to 3 inches of moulding sand, rammed and leveled.

Provide gangways of liberal width, one leading from the cupola and others perpendicular to it. The number and location of the gangways and the subdivisions of the floor are dependent on the character of the business.

The main gangways, particularly the one leading out of the foundry, should be supplied with railroad tracks of standard gauge, connected to the switching system.

Where it will best serve the purpose, ample space should be set aside for the Foundry Office and Pattern Loft. In the selection of this space regard should be had for access to the pattern storage. If at one end of the shop, it may be overhead.

The proper lighting of a foundry is a matter of the greatest importance. The windows should be large and close together, and all light possible admitted through the roof. The monitor roof is generally adopted, but the saw tooth or weaving shed roof serves well. Whatever style is adopted, it should carry provisior for good ventilation. No investment can make larger returns than that expended in procuring a well lighted foundry floor.

Lavatories and closets are located where most convenient.

Cranes

Unless the shop is small, or all the work light, a traveling crane is indispensable. The capacity and span of the crane is governed by the conditions. Electric cranes are most commonly used and are probably the best for the purpose. The necessity for wall and post cranes will be indicated by the requirements of the business. Liberality in supplying cranes of lifting power in excess of the probable needs is never misplaced. Occasions arise in every foundry which tax the cranes to their utmost capacity. Wire cables, instead of chains, for cranes are altogether preferable. Warning is always given of weakness in a cable, whereas a link in a chain may break at any moment.

Abundant head room is a matter of great importance. Too frequently the inability to raise a heavy weight a few inches higher than the head room permits, occasions the greatest annoyance.

Hooks and Slings

For the strength and dimensions of hooks, see Table, page 172.

For chains, see Table, page 173.

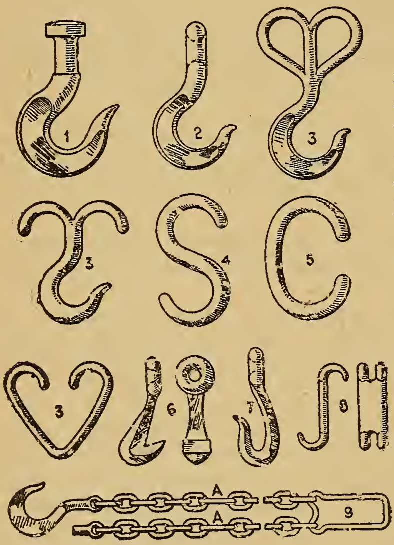


Fig. 137.

Chains and hooks should be frequently annealed. They are liable to give way at any time and seldom give warning of weakness. There is an endless variety of chains and hooks devised by the ingenuity of the moulder to meet exigencies which continually arise. Fig. 137 furnishes examples of those in ordinary use.

Hooks and Chains

Figs. 1, 2, 3, 4 and 5 show heavy hooks for the crane.

No. 1 is the type of heavy hook for crane block.

No. 2 is an unattached hook which is often found very convenient.

Nos. 3, 3, 3 show different forms of change hooks. They are used in shifting a load from one crane to another.

Nos. 4 and 5 "S. & C." hooks, made very heavy, are in frequent demand in connection with heavy lifting.

No. 6 is the form of hook usually attached to slings for lifting iron flasks. They are made with flat or chisel points from 1½ to 3 inches wide.

No. 7 is the ordinary chain hook.

No. 8 is a claw hook for shortening hitches and adjusting chain lengths.

No. 9 represents beam slings for hoisting copes, rolling flasks, etc. The hooks should be flat and thin, so as to engage easily in the long links *A*, *A*. There should be two or more of these long links in each chain, spaced at equal distances. Several pairs of these slings about every foundry where the lifting is by cranes are most convenient.

No. 10 shows a most serviceable sling. It is usually fitted with grab hooks like No. 6.

No. 11 is a rigid beam sling used on flasks with trunnions. There should be two or more pairs of this type of sling. Another form of trunnion sling is made of a large strap ring to which is attached a short chain with hook or ring for engaging the crane chains.

No. 12 is the ordinary turn-buckle, an invaluable implement; of which there should be several pairs of varying strength.

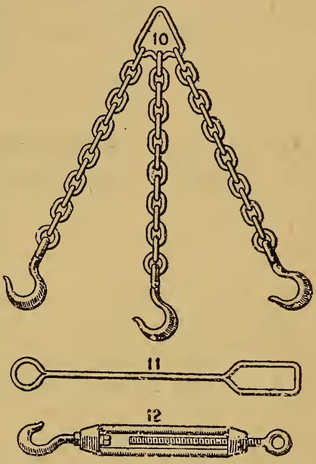


Fig. 138.

Lifting Beams

No. 13 shows a light forged beam, or spreader. This is most convenient especially for light work.

The usual lifting beam is made of cast iron with notches for slings. While such a beam is very serviceable, it is too heavy to handle for moderate weights and unsafe for heavy loads.

No. 14 shows a beam made of oak reinforced with iron straps. Such a beam is light and may be used for moderately heavy loads.

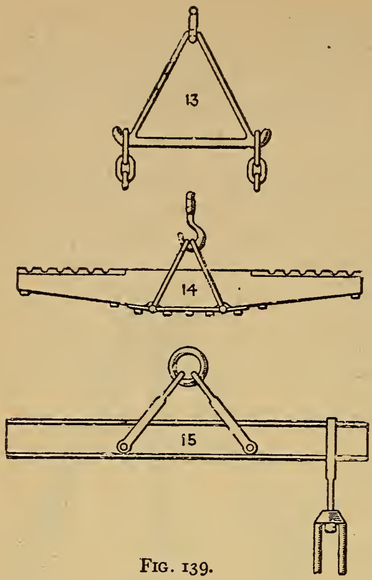


Fig. 139.

No. 15 for heavy loads. The beam should be made of steel I beams, or channels, and to carry any load to the full capacity of the crane.

Where very large and heavy copes are to be lifted, the beam is frequently made in the form of a cross, so that attachment can be made in four or more places, distributing the strain on the cope as desired.

The following table gives the dimensions of I beams and loads they may safely carry. The table is calculated for an extreme fibre stress of 12,000 pounds per square inch.

Safe Loads for Lifting Beams

Distance between slings	Depth of I beam, inches	Weight per foot, pounds	Area of section, square inches	Thickness of web	Width of flange, inches	Safe load for extreme fibre stress of 12,000 pounds per square inch, pounds
8	6	16	4.7	.26	3.63	4,772
10	6	16	4.7	.26	3.63	3,818
8	8	22	6.5	.27	4.5	8,982
10	8	22	6.5	.27	4.5	7,185
10	10	33	9.7	.37	5.0	12,900
12	10	33	9.7	.37	5.0	10,750
10	12	40	11.7	.39	5.50	18,753
12	12	40	11.7	.39	5.50	15,627
14	15	80	23.5	.77	6.41	29,937
16	15	80	23.5	.77	6.41	26,200
16	20	80	23.5	.60	7.00	36,225
18	20	80	23.5	.60	7.00	32,200
18	24	80	23.5	.50	6.95	38,136
20	24	80	23.5	.50	6.95	34,323

No. 16 shows a cross with detachable arms. This is frequently used for large copes or rings, where the points of attachment must be distributed equally. It does not answer for very great weights. Crosses with shorter arms cast in one piece are often of great service.

The foundry supplies itself with such appliances as occasion requires.

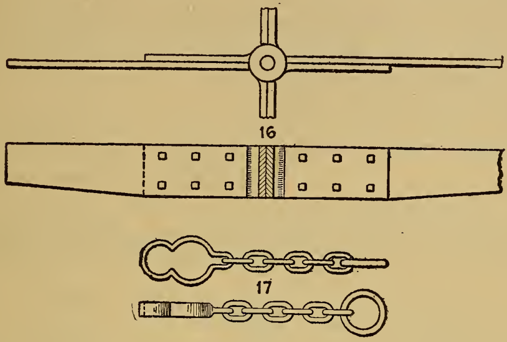


FIG. 140.

Binder Bars

Binder bars are usually made of cast iron, except for very heavy work, when steel beams are used. The binders are ordinarily made in open sand with the ends slotted for bolts. For heavy work holes are made in the ends instead of slots.

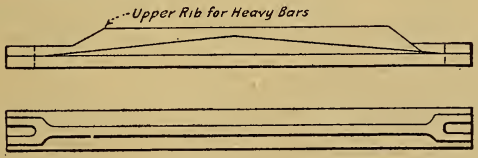


FIG. 141.

The binders are held by bolts to similar bars under the bottom board of flask, or are fastened to anchors in the floor. For safe loads on steel I beams employed as binders, multiply the loads given in the table on page 504.

Binder bars for supporting sides of flasks are of same character as those for holding down copes, except that they are shorter and not as heavy.

Clamps

There are many types of clamps on the market. Adjustable, steel and malleable iron, but it is extremely doubtful if anything has been found to take the place of the common, old fashioned, cast-iron clamp and wooden wedge.

A large assortment of the sizes in ordinary use should be kept on hand. Where very long ones are required □ wrought iron bars are bent to shape. It is the better practice, however, to use binders in place of exceedingly long clamps.

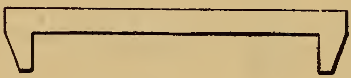


FIG. 142.

FIG. 143.

Iron flasks are frequently held together by short clamps on the flanges.

Flasks

The wood flask has been used for ages and has served its purpose most admirably. Wood, however, is becoming so expensive that the iron or steel flask is rapidly superseding it.

Cast-iron flasks are so durable and so easily made, that an assortment covering the ordinary range of work is almost indispensable.

The ordinary wooden flask is nothing more than a plain box. For light work it is made of 2-inch plank, of width and other dimensions to suit the requirements.

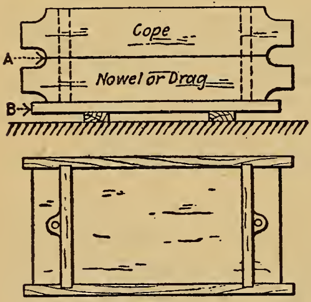


FIG. 144.

Fig. 144 shows the ordinary wood flask for light work; the ends are gained into the sides ½ inch and spiked. The upper part is called the cope and the bottom the nowel or drag. The depth of these parts depends entirely on the pattern.

It is essential that the joint at "*A*" should be a plane surface, or as the workmen say, "out of wind."

Each flask is provided with a bottom board *B*. This is made of boards one inch thick, nailed to battens.

The limit for copes made with no support for the sand except that of the wood sides is about 20 × 20 depending largely upon the character of the moulding sand.

For larger flask-bars, boards 1¼ inch thick are placed crosswise of the cope and about 6 or 8 inches apart. The cope is also strengthened by rods at the end *s* running from side to side. The rods should have large washers under the nuts. There should be one or more rods at each end depending upon the depth of the cope. The lower edges of the bars are chamfered to sharp edges, and the edges are kept from ¾ to 1 inch away from the pattern, the bars having been cut to conform to the general shape of the pattern. Where the distance between the edges of the bars and the surface of the pattern is more than ¾ inch, nails are driven slantwise into the bars so that their heads may come within three-quarters inch of pattern.

The cope is coated with thick clay wash before placing it in position to receive the sand. The ordinary medium-sized wood cope is generally made as shown in sketch below.

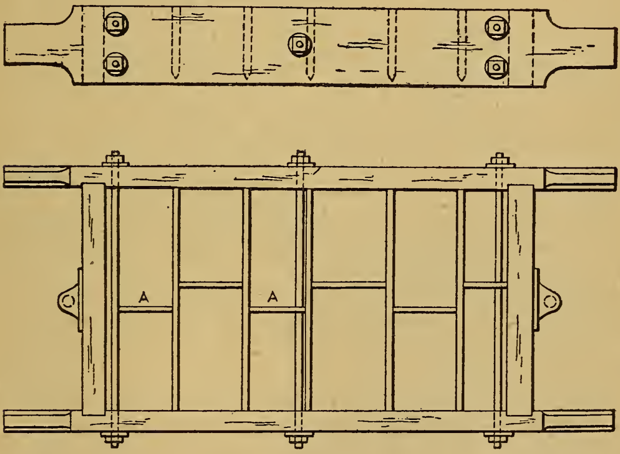


Fig. 145.

The short bars *A*, *A* are used where the copes are over 24 inches wide.

The following table showing the thickness of plank desirable for flasks of different dimensions is copied from the Transactions of the American Foundrymen's Association. The table is based on a depth of 6 inches for copes and drags. For each additional depth of 6 inches, the thickness should be increased 25 per cent.

Square flasks, inches	Sides, inches	Bars, inches
24 and under	1½	1
24-36	2	1¼
36-48	2½	1½
48-60	3	1½
Rectangular flasks		
18×48	2	1
18×60	2	1
18×72	2½	1
18×84	2½	1
24×48	2	1¼
24×60	2	1¼
24×72	2½	1¼
24×84	2½	1¼
36×48	2½	1¼
36×60	2½	1½
36×72	2½	1½
36×84	2½	1½
48×48	3	1½
48×60	3	1½
48×72	3	1½
48×84	3	1½

Bars should not be over 8 inches apart, center to center.

Square flasks, from 24 to 36 inches square should have one row of short cross bars running through center of flask, connecting the long bars that extend from side to side.

Sizes from 36 to 48 inches square should have at least one cast-iron bar, preferably two, and should also have one row of short cross bars.

Sizes from 48 to 60 inches square should have two iron bars and two rows of short cross bars.

With rectangular flasks, the statement that connecting bars are not needed until the flasks are 36 inches wide does not accord with the usual practice. Ordinarily connecting bars are used in flasks over 18 inches wide.

Rectangular flasks over 60 inches wide should have one cast bar crosswise in the center. Flasks over 48 inches wide should have two rows of cross bars and two cast bars at equal distances from the end of the flask.

All copes should have a ½-inch bolt running from side to side at each end, and where the cope is longer than three feet it should have a bolt in the center. Where copes are over 6 feet long, the bolts should be spaced every two feet apart. All bolts should have large washers at each end.

Drags should also have bolts at each end, but as conditions often prevent their use in the center, long-nosed clamps placed crosswise every 18 to 24 inches and securely wedged are recommended.

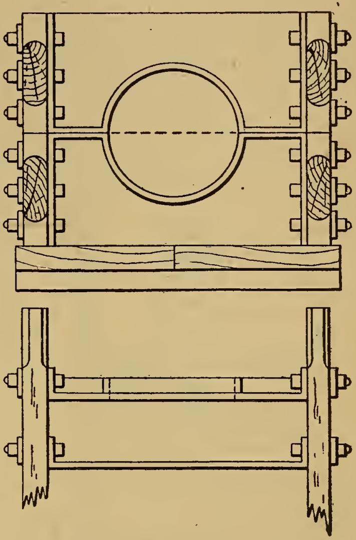


FIG. 146.

The form of flask shown above is that most commonly used when they are made of wood. It is a short-lived affair, being quickly knocked and racked out of shape, and soon goes to the cupola for kindling wood. Such flasks may be greatly strengthened and their durability increased by bolting cast-iron angles in the corners or even reinforcing the corners with blocks of wood, well spiked to sides and ends. Without greatly increasing the cost a far better flask is made by making the ends of cast iron. Such flasks are in common use for making cylinders or other castings, requiring large circular cores as per following sketch.

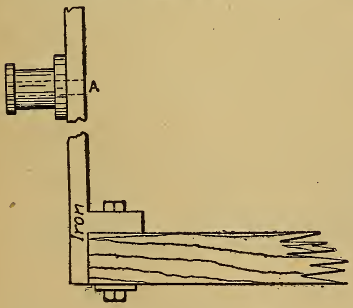


FIG. 147.

Flasks of similar construction are often used for cylinders as large as 20 inches diameter of bore. The sides of the flask must be made of plank from 3 to 4 inches thick depending on the size. For rectangular flasks made of wood and iron, the construction shown below, offered by Mr. P. R. Ramp, is excellent.

The suggestion to core the trunnion, as at *A*, is also valuable, as it greatly reduces the chance of unsoundness at that point.

Flasks that are heavy enough to require trunnions should have iron ends. The trunnions may be cast on the ends or on trunnion plates, which are bolted to the ends.

Iron Flasks

Although the first cost is somewhat greater, iron flasks soon pay for themselves by durability. They are stronger, more rigid and reduce the liability to swells and run-outs.

The copes and drags of small iron flasks are usually made each in one piece. At the joints for flasks with straight sides, flanges extend all the way around the inside.

The handles may be of wrought iron cast in place, or, of cast iron, for sizes requiring two men to lift the cope.

Some are made with sides turned up edgewise like troughs, so that the greatest length and breadth will be at the middle of the section.

These are more expensive to mould and present no advantages over the flask with flat sides as shown in fig. 148.

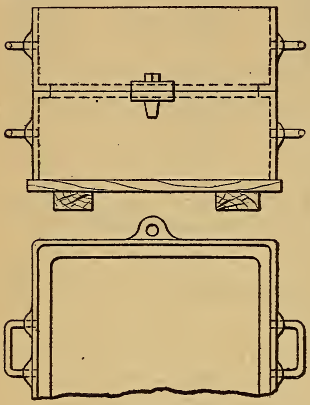


Fig. 148.

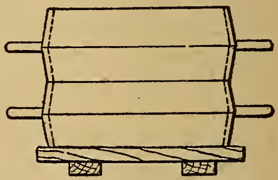


Fig. 149.

An assortment of small flasks of this description, ranging from 12 × 14 to 16 × 18 is of great value to any foundry.

Iron flasks of medium and large sizes are best made in sections and bolted together.

Flasks of this style are made and fitted up very quickly. A few patterns answer for a large assortment. With proper stop-offs, the ends and sides can be lengthened or shortened as desired.

Where the copes are too large to be lifted off by hand, bosses are cast on the end. These are drilled to receive a yoke and the cope may then be lifted by crane and turned.

If the flask is heavier than can be safely lifted with such a yoke, trunnions may be made on the ends and heavier lifting gear employed.

The requirements for heavy flasks are so varied that it is impossible to specify any general type.

By making them in standard sections as much as possible, having the parts interchangeable, a rectangular flask of almost any required dimensions may be constructed. By so doing the number of flasks is greatly reduced.

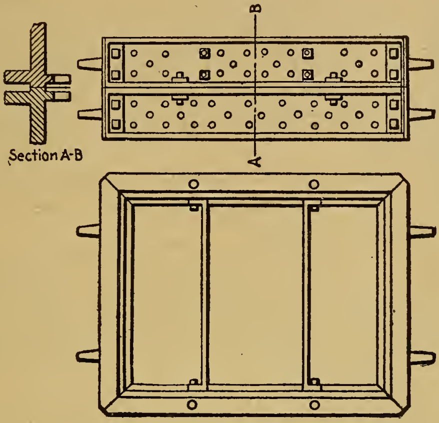


FIG. 150.

Care must be taken to number and store the parts systematically so that they may be readily accessible.

It is seldom that a large flask will need to be less than 6 feet by 8 feet, and 12 inches deep. Starting with the end pieces 6 feet × 1 foot, and having four distance pieces, each 1, 2, 3 and 4 feet long, ends can be assembled 6, 8, 10, 12, 14, 16 and 18 feet long; by duplicating the parts, the depth of cope or drag can be made any number of even feet.

Where the depth of cope or drag is over one foot, it is desirable to break joints in lapping the sections.

It is better to have the trunnion plates loose, so that they may be bolted to any of the 4 or 6 feet lengths.

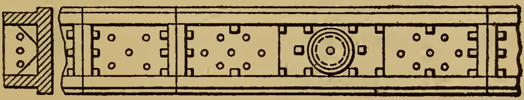


FIG. 151.

The top and bottom edges must be planed and the holes in ends and sides drilled to templets.

Flanges top and bottom must be from 3½ to 4 inches wide, and the 4 and 6 feet sections drilled at the center of flanges for pins. The planed surface need only be ¾ inch wide; the flanges should drop away from edges from ⅛ to 3/16 inch.

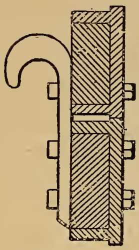


FIG. 152.

The web of sections should be ⅝ inch thick and the flanges 1¼ inches.

The lifting is in most cases done by attaching to the flanges, but where the weight is too great to be safely borne by these flanges, heavy wrought-iron loops are bolted to the sections, for points of attachment.

On page 98, "American Foundry Practice," Mr. West shows an admirable form of extension flask for moderate sizes.

"The handles *W*, *W*, are of wrought iron cast into the flask. They are placed on a slant so as to be in line with the chains when lifting. Guides *X*, *X* should be cast on for driving stakes along the side. The plate Y forms the end of flask. Should it be desired to make the flask longer, distance pieces may be bolted in between the flask proper and the plate Y.

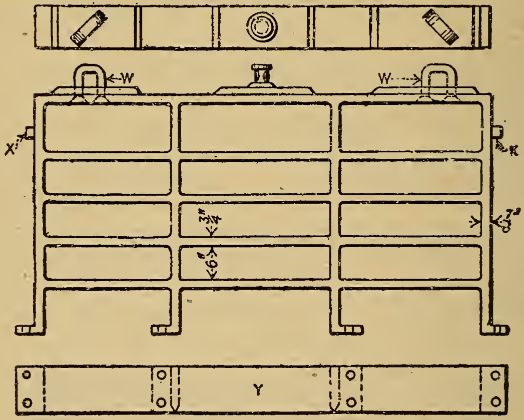


FIG. 153.

"To accomplish the same purpose, the whole flask may be cast in one piece, and the bottom edge of Y cut out ¾ of an inch so there may be no bearing on the joints. When a longer flask is wanted a section may be bolted to it. This is not as desirable as the form shown in sketch."

Flasks of this style are commonly used as copes to cover bedded work.

Where the conditions do not warrant the extension flask as above described special flasks are more or less in demand.

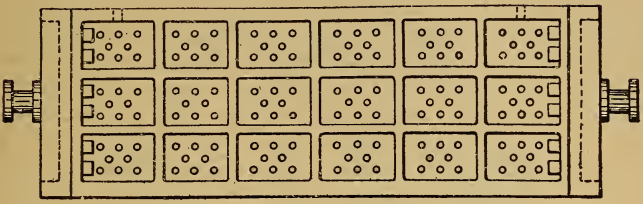


Fig. 154.

The above sketch represents an ordinary heavy flask (cope) say 6′ × 12′ × 3′.

In making large door frames, where the interior of the flask is not used, or for similar work, it is customary to have the flask follow the outline of the pattern and leave the interior vacant as shown in sketch below.

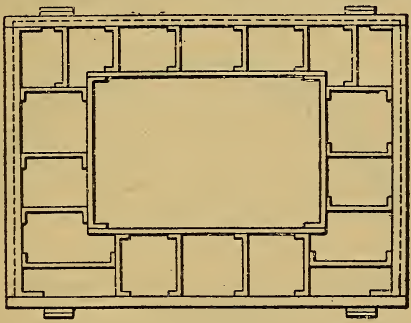


Fig. 155.

Flasks are made in all sorts of irregular shapes both in plan and elevation, as necessitated by the patterns. The bottom plates of heavy flasks are made of cast iron. These are fastened to the bottom flange of the drag by short heavy clamps. Thus.

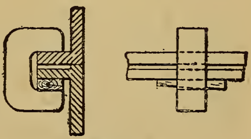


Fig. 156.

Circular flasks are in common use. They serve as copes to wheels cast in the floor and for other purposes. For large wheels which are swept up, instead of sweeping out the face in a pit, large rings are used for the cheek. The arms and hub are made with cores and interior of wheel swept up and not disturbed subsequently.

The cheek is rammed up against segments, and when lifted gives free access to all parts for finishing.

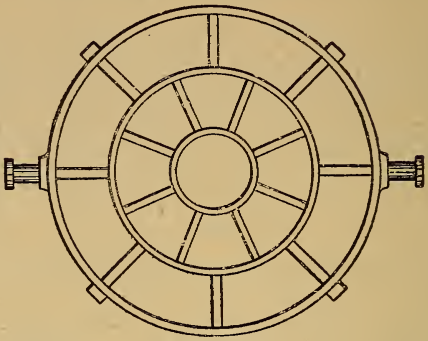


FIG. 157.

For wheels 16 to 18 feet in diameter the cheeks are commonly made in six segments, which are bolted together.

FIG. 158.

Flasks made of sheet steel pressed to shape are light and convenient. They are, however, much more expensive. They are not as durable as cast-iron flasks, and when worn out are of no value; whereas with the cast flasks, nothing is lost but the labor. The cuts following from a manufacturer's catalogue show standard types of light and heavy flasks.

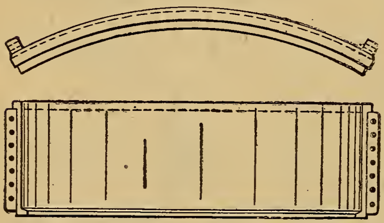


FIG. 159.

Sterling Steel Flasks

The scarcity and increased cost of good flask lumber is making it necessary for foundrymen to consider other flasks than wooden ones.

The line of steel flasks shown herewith combine strength, durability, lightness and efficiency. They will give splendid service. They have in many instances entirely supplanted wooden flasks, to the advantage of the user in every instance.

Style "A" Square Ribbed Tight Flask

Sheet Steel with Malleable Trimmings

Stock Sizes

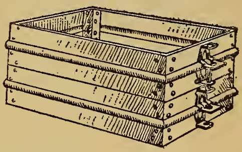


Fig. 160.

Height cope and drag, 2½, 3, 3½, 4, 4½ and 5 inches.

Length cope and drag, 12, 14, 16 and 18 inches.

Width cope and drag, 12, 14 and 16 inches.

Weight less than one-half as much as cast flasks and practically indestructible.

A complete small square-ribbed steel flask for general work in all foundries, made in above standard sizes, from which innumerable combinations can be made.

Can be made in special sizes when it is required and a sufficient number ordered to warrant the extra work in manufacturing.

Style "B" Round Ribbed Tight Flask

Sheet Steel with Malleable Trimmings

Stock Sizes

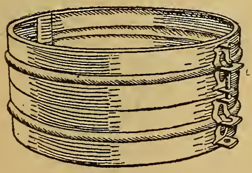


Fig. 161.

Height cope or drag, 2½, 3, 3½, 4, 4½, and 5 inches.

Diameter, 12, 14, 16, and 18 inches.

From the above dimensions many combinations can be made.

The illustration gives a clear idea of round-ribbed steel flask for general circular work, when the snap flask is not desirable.

Weighs less than half as much as a cast flask, and is unbreakable.

Style "C" Square Convex Tight Flask

Sheet Steel with Malleable Trimmings

Stock Sizes

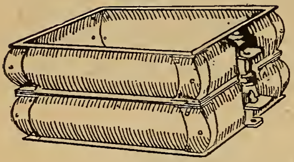


Fig. 162.

Height cope or drag, 2½, 3, 3½, 4, 4½ and 5 inches.

Length cope or drag, 12, 14, 16 and 18 inches.

Width cope or drag, 12, 14 and 16 inches.

Made in the above stock sizes, which admit of countless combinations of sizes.

This flask is particularly adapted to brass, bronze, or any special metal foundry work. It is a new departure, having convex sides and ends for holding the sand. It does nice work, and while not half as heavy as the cast flask, is much more durable.

Style "F" Channel Iron Floor Flask

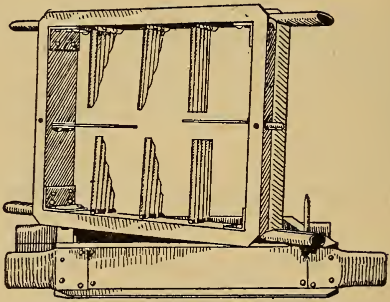


Fig. 163..

Stock Sizes

Size, inches	Depth, inches	Cope, inches	Drag, inches	Price
20×24	10	5	5	....
20×28	10	5	5	....
24×30	12	6	6	....
24×36	12	6	6	....
30×36	14	7	7	....
30×42	14	7	7	....

This is a decided departure in flask manufacture. It is constructed of structural channel steel with flanges to the outside, having a smooth wall on the inside. The interior is provided with staples arranged at intervals to permit of inserting corrugated swivel gaggers for sand supports.

This type of flask does away with the flask maker entirely, as each moulder arranges his gaggers or sand supports to suit the necessity.

An equipment of these flasks is an excellent investment.

1. They cut out the use of expensive material (lumber).
2. They practically do away with the flask maker.
3. They eliminate expense of handling flasks.
4. They will remain in foundry and save storage.
5. And the most important feature to be considered is the increased output, better castings, less scrap, all of which will appeal directly to the proprietor.

These floor flasks are furnished with a complete equipment of corrugated swivel gaggers for sand supports which the moulder arranges easily to suit requirements.

Snap Flasks

Snap flasks are used by bench molders for light work. They must be easily and quickly handled, although snaps are sometimes made so large as to require two men. The flask is removed from the mould, hence one flask serves for an entire floor.

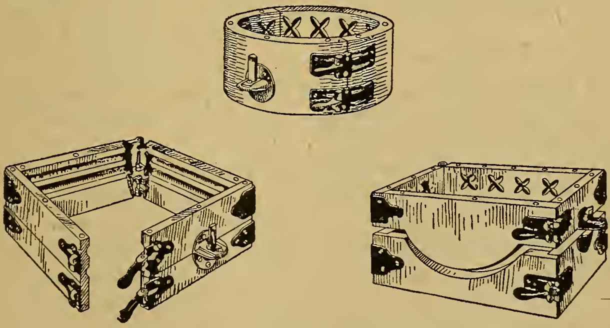


FIG. 164.

They are usually made of cherry or mahogany; the hinges should lock and unlock quickly and be rigid when locked. The corners are strengthened with iron corner bands, and the cope is faced on top with iron. For special work the joint may be made to conform with the parting. Rectangular snap flasks 3 feet long by 14 to 16 inches wide are not uncommon. For some classes of work round snaps are required.

In the hands of a rapid, skillful moulder the snap flask is an indispensable implement for a foundry having large quantities of small work.

Pieces weighing as much as 100 pounds may be made in the snap flask.

The cuts herewith illustrate the construction of the different kinds of snaps referred to.

Snap flasks of standard dimensions from 12 × 12 to 12 × 20 can be purchased of most of the foundry supply houses.

Where many moulds are to be made from one pattern, a match board, on which the patterns are placed, and upon which the parting is made, is practically a necessity. If these matches are not to be preserved, and are only to be used for a moderate number of moulds, they are made of moulding sand and fine sharp sand, half and half, stiffened with molasses water, or linseed oil, and dried; but if a permanent match board is desired, a mixture composed of one-half new moulding sand, one-half parting sand, 1/40 litharge, mixed with linseed oil and thoroughly dried will serve admirably. The match should be varnished with shellac and kept with the pattern. Such a match board is shown in Fig. 165..

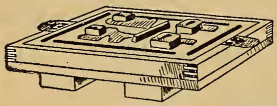


Fig. 165.

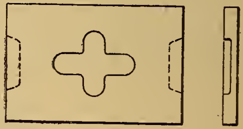


Fig. 166.

The moulds made in snap flasks must be covered with weights before they are poured. The weight should be about 1½ inches thick and should cover the cope entirely.

Where the contents of the flask are quite heavy, or where the patterns approach the sides of the flask closely, the moulds require to be supported by boxes, as well as to be weighted. For this purpose wood boxes of 1-inch lumber are made so that the interior shall have the same dimensions as the interior of the whole flask (cope and drag); this is shoved down over the mould and supports it against lateral pressure. Care must be taken that the boxes are not so small as to shave the mould nor so large as not to support it; they should just fit all around.

These boxes are sometimes made of cast iron. Very serviceable ones made of sheet iron can be purchased at moderate prices.

GALVANIZED IRON SLIP BOXES

Straight Taper

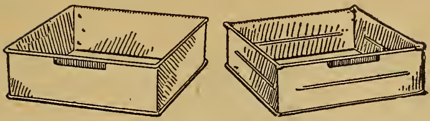


FIG. 167.

The above are undoubtedly the best slip boxes on the market. They are more durable than wood or cast-iron boxes, are lighter and will not break by falling. They are made either straight or tapered, of No. 22 iron with a No. 9 wire in top and bottom and creased.

In ordering, state whether straight or tapered and give the exact size of inside of flasks.

These boxes are for light handling and will not stand careless run-outs, as the hot iron will warp them. They are very rigid, however, and with the ordinary one-inch margin outside of pattern there will be no run-outs.

When ordering taper jackets, give taper or degree per foot on side, or make sketch giving size of top and bottom, also depth of drag.

Pins, Plates and Hinges

In order that the cope of a flask, when lifted from the drag after ramming, may be returned exactly to its original position, so that the two parts of the mould may match perfectly, guides must be provided which will insure correct closing.

These are frequently made of wood, and if kept in good shape, serve the purpose admirably. Wooden guides are especially advantageous for long lifts.

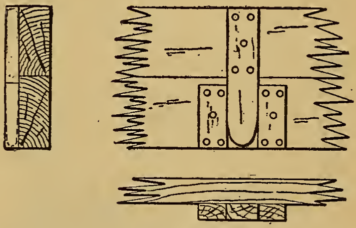


FIG. 168.

Fig. 168 shows a wood guide, of which there should be at least three on the flask. The moulder must exercise care when preparing to ram up a flask, to see that the guides and pins are securely nailed, that there is no lateral play and that the cope may be lifted and returned to its place without sticking at the pins.

Guides of this kind, while chiefly in use on wood, are sometimes employed on large iron flasks. In the latter case wooden blocks are securely fastened in the pockets between flanges, and the guides nailed to the blocks.

The usual guide for the ordinary wood flask is a common cast-iron plate and pin.

These are continually getting loose and furnish no end of trouble to the moulder as well as causing many castings to be scrapped. It is the most worthless appliance of its kind.

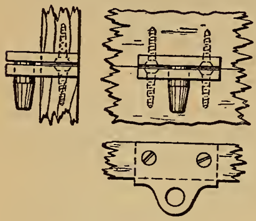


FIG. 169.

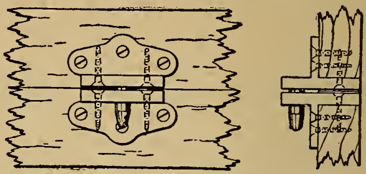
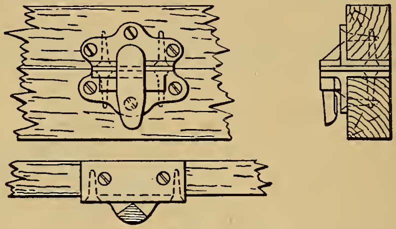


FIG. 170.

A very good iron guide may be made as per sketch. (Fig. 170.)



HEAVY HINGE
FIG. 171.

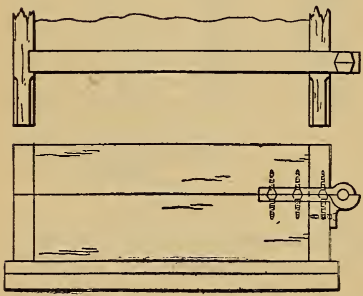


FIG. 172. — Light Hinges.

Such a guide may be fastened to the flask with very little more work, and the flanges give good support. An excellent pin and guide is made triangular in shape.

Cast-iron flasks either have lugs to receive the pins and holes, or where the flanges are wide, pin holes are put in them.

Pins for iron flasks should be accurately turned, the sizes should be standard, and those of each size interchangeable. An assortment of such pins should always be kept on hand.

FIG. 173.—Ball and Socket Hinge.

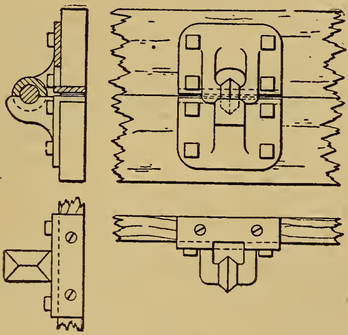


FIG. 174.—Heavy Hinge.

STANDARD IRON FLASK PIN NO. 2

For Iron Flasks

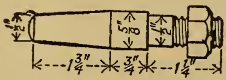


FIG. 175.

This is a nicely turned pin, with thread chased and hexagon nut, designed especially for cast-iron flasks.

SWEEPS

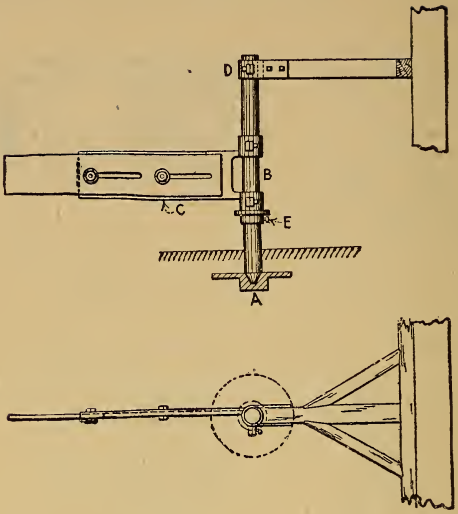


FIG. 176.

The above sketch shows the ordinary sweep used for making large pulleys, fly wheels, etc. A large class of work, circular in horizontal section, can be made with the sweep, thereby saving largely in the expense for patterns.

To obtain accurate work by the use of the sweep, the stepping *A* must be firmly placed, so that the axis of the spindle *B* shall be vertical. The upper support *D* must be held rigidly, either by braces to wall of foundry or otherwise as most convenient. The box *D* may be made with a flange surrounding it from which three or four rods lead away to any suitable anchorages. These rods are provided with turnbuckles so that the spindle may be held rigidly in a vertical position.

E is an adjustable collar fastened in position by a set screw.

C is an iron arm carrying the wood strikes. The bearings by which this arm is supported should be farther apart than the width of the arm, so as to avoid any sagging of the latter.

If these bearings are split in a direction parallel to the spindle and drawn up with clamp screws, lost motion can be taken up at any time. Any play in the supports for the arm, or neglect to maintain the spindle in a vertical position, will result in a distorted casting. Sweeps are often constructed with elaborate mechanical attachments for making gears, spiral wheels, spiral cones, etc.

Sometimes the steppings are placed permanently on concrete piers, where there are many wheels, etc., to be made.

The strikes are cut in any desired shape and are used for inside or outside sweeping. Swept moulds are usually skin dried.

Anchors, Gaggers and Soldiers

These devices are used for supporting the sand where the ordinary bars are insufficient or inapplicable.

Fig. 177 shows an anchor used for making pulleys. It consists of six cast-iron segmental plates about ¾ inch thick, which are so placed between the arms of the pulley as to leave a space for sand, ¾ inch wide, all around them. The upper sides of the plates are on the parting line of the arms.

The plates are held together by wrought iron loops, passing over the arms, and cast in place. All the plates are poured at once, and in open sand.

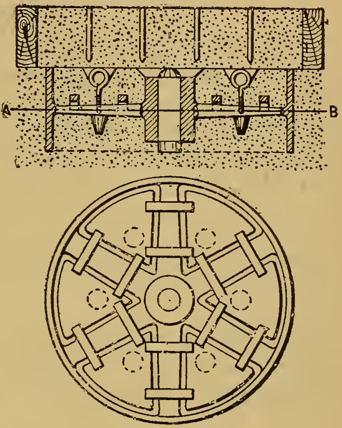


Fig. 177.

Instead of wrought-iron loops, these connections may be made by cast-iron loops, furnishing a much stiffer anchor. On the under side of each plate are cast one or more long conical projections, which serve as guides by which to replace the anchor. Each plate is provided with an eye bolt long enough to reach to the joint of flask.

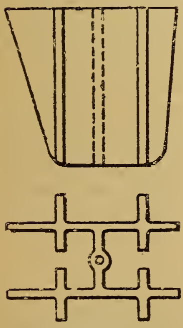


Fig. 178.

The interior parting is made on center line of arms, sand is rammed on top of the anchor and another parting made flush with the rim upon which the cope is rammed.

After the cope is removed, the sand covering the arms is lifted out by hooking to the eye bolts in anchor.

Fig. 178 shows an anchor for lifting out a deep pocket.

Where the anchor cannot rest on the bottom, but must permit iron to run under it, it is bolted to the cope and lifted out with it.

The necessities of the situation indicate the size and shape of anchors. Frequently, the pocket is such that the anchor must be broken to remove it from the casting. It is well to keep down the weight of the anchors as much as possible, relieving the cope to that extent.

Very many cores, as well as moulds, require to be supported in this manner.

Gaggers

In the use of gaggers it should be borne in mind, that they are heavier than the sand; it is simply due to the cohesion of the sand, holding them up to the sides of the flask or bars, that they are of assistance in supporting the cope. The gagger is of use just in proportion to the length that is surrounded with packed sand. All that part which projects above the cope is a detriment. They are first immersed in thick clay wash, and placed flat up against the bars or sides of flask, having about ⅜ inch sand under them. They are made in the gagger mould, already described, which is kept near the cupola. Costing practically nothing, they may be used freely. A good supply should always be kept on hand.

Many shops use gaggers made of ½ inch square bar iron bent to shape. They are not as serviceable, however, as they do not offer as good a surface to which the sand can adhere, and are more expensive.

Soldiers

Soldiers are simply pieces of wood about one inch square, cut from boards, with clay washed and placed around the mould instead of gaggers, where the latter cannot be used; or to assist the gaggers in deep lifts. The sand adheres to soldiers better than to gaggers.

The free use of either gaggers or soldiers is to be encouraged, as it is better to place too many of them in a mould than to have a drop. At the same time care must be exercised to have the ends well protected by sand, so that the hot iron will not come in contact with them, as there will surely be a "blow" in that event.

Sprues, Risers and Gates

The following tables, giving the equivalent areas of round gates, also of square and rectangular gates as compared with round ones, are taken from West's "Moulder's Text Book," pp. 245 and 246.

Table of Equivalent Areas of Round Gates

One	1½	inch	is equal	in area	to	two	1 1/16,	three	⅞,	or four	¾-inch gate
"	1¾	"	"	"	"	"	1¼	"	1	"	⅞
"	2	"	"	"	"	"	1 7/16	"	1 3/16	"	1
"	2¼	"	"	"	"	"	1⅝	"	1 5/16	"	1⅛
"	2½	"	"	"	"	"	1¾	"	1 7/16	"	1¼
"	2¾	"	"	"	"	"	1 15/16	"	1⅝	"	1⅜
"	3	"	"	"	"	"	2⅛	"	1¾	"	1½
"	3¼	"	"	"	"	"	2 5/16	"	1⅞	"	1⅝
"	3½	"	"	"	"	"	2½	"	2	"	1¾
"	3¾	"	"	"	"	"	2 11/16	"	2 3/16	"	1⅞
"	4	"	"	"	"	"	2 15/16	"	2 5/16	"	2
"	4¼	"	"	"	"	"	3	"	2 7/16	"	2⅛
"	4½	"	"	"	"	"	3 3/16	"	2⅝	"	2¼
"	4¾	"	"	"	"	"	3⅜	"	2¾	"	2⅜
"	5	"	"	"	"	"	3 9/16	"	2⅞	"	2½

Note. "The fractional parts of an inch as seen by the table are not carried out any further than 1/16, for the reason that the subject does not call for any closer figures. Therefore, the figures given will be understood as being 'nearly' equal in area. As given, the sizes can be readily discerned, and are also applicable to measurements by the shop pocket rules commonly used."

Table of Equivalent Areas in Square and Rectangular Gates to That of Round Gates

(See note above)

Round gates, inches	Square gates	Rectangular gates 1 inch thick	Rectangular gates 1½ inch thick	Rectangular gates 2 inches thick	Rectangular gates 2½ ins. thick
1	⅞	....	....	....	....
1¼	1⅛	....	....	....	....
1½	1 5/16	....	....	....	....
1¾	1 9/16	1×2⅜	....	....	....
2	1¾	1×3⅛	1½×2 1/16	....	....
2¼	2	1×4	1½×2 11/16	....	....
2½	2 3/16	1×5	1½×3 5/16	....	....
2¾	2 7/16	1×6	1½×4	2×3	....
3	2 11/16	1×7 1/16	1½×4¾	2×3 9/16	....
3¼	2⅞	1×8 5/16	1½×5½	2×4 3/16	2½×3 5/16
3½	3⅛	1×9⅝	1½×6 7/16	2×4⅝	2½×3⅞
3¾	3 5/16	1×11 1/16	1½×7⅜	2×5½	2½×4 7/16
4	3 9/16	1×12 9/16	1½×8⅜	2×6¼	2½×5
4¼	3¾	1×14 3/16	1½×9½	2×7⅛	2½×5⅝
4½	4	1×15 15/16	1½×10⅝	2×8	2½×6⅜
4¾	4 3/16	1×17¾	1½×11 13/16	2×8⅞	2½×7⅛
5	4 7/16	1×19⅝	1½×13 1/16	2×9 13/16	2½×7⅞

"The term 'equivalent' used does not imply that two or more small gates having a combined area equal to one large gate, all having like 'head pressure,' will deliver the same amount of metal per second."

"The flow of metal is retarded by friction in proportion to the surface area with which it comes in contact. Now although four 2½-inch round gates are of equal area to one 5-inch round gate, we find the frictional resistance to the flow of a like 'head pressure' through four 2½-inch round gates to be double that generated in one 5-inch round gate, simply because the combined circumferences of four 2½-inch round gates are 31.416 inches, whereas the circumference of one 5-inch round gate is 15.708 inches. As gates are generally combined under varying complicated conditions, the tables as given can be better practically used than where they are lumbered with the question of frictional resistance."

Risers are generally double the diameter of the pouring sprue. The function of the riser is twofold. It serves to catch and carry away any dirt entering the mould from the pouring sprue and also to furnish a supply of liquid metal to provide for shrinkage. Risers are placed either in connection with the gate, or on some part of the mould whence the deficiency from shrinkage can be most readily supplied. When located on the gate the latter is usually so cut as to impart a whirling motion to the metal ascending the riser. The metal enters the riser near the bottom and flows to the mould through a channel opened above the entrance.

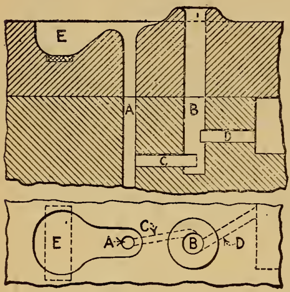


Fig. 179.

In the sketch *A* represents the pouring sprue, *B* is the riser, *C* the gate from sprue to riser which is cut tangential to *B*. *D* is the gate from riser to casting. The gates should be somewhat smaller in area than the pouring sprue so that the pouring basin *E* may always be kept full.

Top Pouring Gates

The advantage of this form of gate for large castings is that the dirt is kept at the top of the pouring basin, allowing the clean iron to flow into the mould from beneath.

The first dash of iron may carry some dirt, but the greater portion of it will flow with the stream over the gates; the runner being quickly filled, no dirt can enter subsequently if kept full. See West's "Moulder's Text Books," page 129.

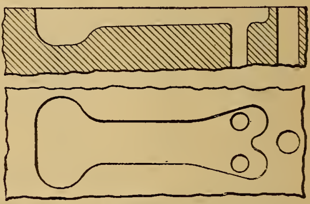


Fig. 180.

Whirl Gates

The object of the whirl gate is to impart a rotary motion to the iron in the basin and riser *B*, *B*.

By centrifugal force the metal is kept in contact with the exterior of the riser, and the dirt is carried up in the middle of it.

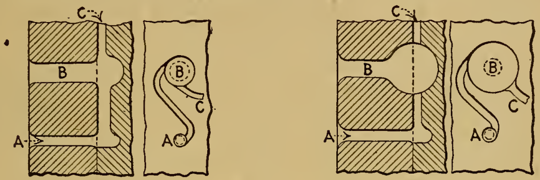


FIG. 181.

The riser *B* should be larger than the pouring sprue *A*, and *A* should be larger than *C*, in order that the pouring basin may be kept full.

It is best to have patterns made for whirl gates; they can be used in either cope or drag.

The "Cross" Skim Gate

This as shown in Fig. 182 is an excellent device and is largely used.

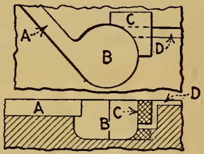


FIG. 182.

A is the gate leading from pouring sprue to basin *B*, *C* is a core in which is the gate *D*, leading to casting. The iron enters *B*, tangentially, a whirling motion is imparted to it carrying the dirt to the riser, while the clean iron flows out through *D*.

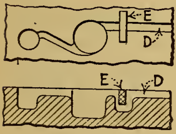


FIG. 183.

Another form of same gate is made as shown in fig. 183.

It differs from the first form simply in having a flat core *E* placed across the gate *D*, instead of forming a part of it.

Horn Gates

FIG. 184.

These are principally used for bottom pouring, leading from the parting of flask to the casting below.

They are made smaller at the point joining the casting to permit of easy removal and to choke the stream of metal.

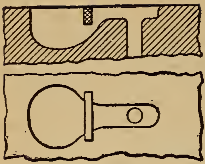


FIG. 185.

Pouring basins have frequently skimming cores placed between the basin and the down sprue to hold the dirt in basin. A pattern is usually made for them.

Strainers and Spindles

Thin perforated plates from 1/16 to 3/32 inch thick, and wide enough to cover the entrance to pouring gate are frequently placed in the runner basin over the gate. When the iron strikes the strainer it is held back until the latter is melted allowing the basin to fill partly, raising the dirt to the surface and furnishing clean iron to the gate. Spindle gates consisting of many small gates serve the same purpose.

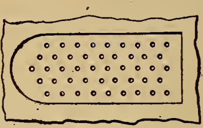
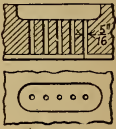


FIG. 186.



Spindle gate

Weights

For medium castings, weighting the copes will be found more convenient than the use of binding bars. There should be about every foundry a large assortment of weights depending on the class of work. Weights to be handled by the crane will be found more convenient, if made square in cross section and of whatever length desired. Holes are cast in the ends into which bars are inserted for lifting. Weights made in this way are more readily piled than if provided with eye bolts.

Chaplets

Chaplets are properly anchors, and should come under that heading. They are used mostly for securing cores in place in moulds. Except for special requirements the foundryman can procure chaplets from the supply houses far cheaper than he can make them. Cuts and sizes of the various chaplets in use are given below.

THE PEERLESS PERFORATED CHAPLET

FIG. 187.

Manufacturers of all classes of castings requiring small cores will readily observe the advantage in using a chaplet, such as is illustrated above.

Made from perforated tin-plated sheet metal, insuring perfect ventilation of the chaplet, eliminating all possibilities of blow holes, air pockets, chills, etc., forming a perfect union with the molten metal, thereby insuring an absolute pressure tight joint; something not obtained with any other chaplet on thin work. Through its use, not only are time and labor of the workman saved in adjusting the cores to the matrix of the mould, particularly on water backs or fronts, radiators, gas burners, pipe fittings, gas and gasoline engine work, and similar castings, but it also greatly lessens the liability of flaws, defects and consequent losses in castings, such as commonly result from the ordinary chaplets or anchors now in use.

Liquid Pressure on Moulds

The pressure of the liquid metal at any point of the mould is determined by multiplying the distance in inches from that point to the top of the metal in pouring basin by .26 pounds. The product is the pressure in pounds per square inch.

To overcome this pressure laterally, reliance is placed on the rigidity of the flask, supported, if necessary, in deep castings by binding bars.

The binding bars are of same character as those already described for holding down copes. They are tied across top and bottom of flask by rods, or otherwise.

The static pressure on the cope is ascertained by multiplying the area of the casting in square inches, at the joint of the flask by the height in inches from the joint of the flask to level of iron in pouring basin and by .26 pounds.

In addition to this there is the pressure due to resistance in overcoming the velocity of the rising iron, which pressure is measured by one-half the product of the weight of the rising iron by the square of the velocity. While this pressure may be accurately calculated with sufficient data, it is usually difficult to get them, and the results are, therefore, only approximate.

However, when the mould is nearly full, the pouring is slackened as much as possible without letting the dirt into the sprue, thereby reducing the head and velocity, and greatly lessening the shock as the iron reaches the cope.

The formulæ given for determining holding down weights for copes are empirical. The moulder will not be led astray by calculating the lifting area of the mould in square inches, multiplying this by the head measured to pouring basin, in inches, and this product by .26 pounds. Add 20 per cent to the result, this will make ample provision for the lift due to the blow of the rising iron.

The Peerless Perforated Chaplet

The following list will give an idea of the approximate number of the various sized chaplets required to make a pound.

Length	Breadth	Thickness	No. to the pound
3/8	1/4	1/8	1600
1/2	1/4	1/8	1400
1/2	1/2	1/8	1200
1/2	1/2	3/16	1100
3/4	3/4	3/16	600
1	1	1/4	300
3/4	3/4	1/4	250
1	1	3/8	130
1	1	3/8	100
1 1/4	1 1/4	1/2	80
1	1	1/2	90
1 1/4	1 1/4	3/4	80
1	1	3/4	45
2 1/4	1	1	35
1	1	1	40
1 1/4	1 1/4	1	30

Over two thousand different shapes, sizes and styles of these chaplets are made. Many hundred standard sizes and shapes are kept in stock.

The prices depend upon the sizes and number required to make a pound.

THE PEERLESS PERFORATED CHAPLET. — (*Continued*)

(Net prices per pound.)

No. to the pound	Price per pound	No. to the pound	Price per pound
20– 40	$0.35	200– 250	$0.85
40– 50	.35	250– 300	.90
50– 60	.40	300– 350	.95
60– 70	.45	350– 400	1.00
70– 80	.50	400– 500	1.05
80– 90	.55	500– 600	1.10
90–100	.60	600– 700	1.15
100–125	.65	700– 800	1.20
125–150	.70	800– 900	1.25
150–175	.75	900–1000	1.30
175–200	.80	1000–1100	1.35

Double Head Chaplet Stems

Plain or Tinned

Fig. 188.

Made of ⅜-inch round iron, ⅝ to 1¼ inches long (measuring from face to shoulder).

Price per hundred, from ⅝ to 1⅜ inches . . .	$4.00
Price per hundred, from 1½ to 2½ inches . . .	5.00

Double Head Chaplets with Forged Heads

Plain or Tinned

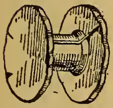


Fig. 189.

Made of ⅜-inch round iron, from ¾ to 2½ inches long, with head above ¾-inch diameter.

Price per hundred, from ⅝ to 1⅜ inches . .	$5.00
Price per hundred, from 1½ to 2½ inches.	6.00

With Square or Round Plates Fitted

Plain or Tinned

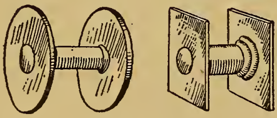


Fig. 190.

Square plates always furnished unless otherwise ordered.
Stems made of 3/16 inch round iron from ⅜ to 1½ inches long.

Price per hundred, ⅜ to ⅝ inch with plates any size.	$4.00
Price per hundred, ¾ to 1 inch with plates any size.	4.50
Price per hundred, 1⅛ to 1½ inch with plates any size. . .	5.00

Stems made from ¼-inch round iron from ½ to 2½ inches long.

Price per hundred, ½ to 1 inch with plate any size	$6.00
Price per hundred, 1 to 1½ inches with plate any size. . .	"
Price per hundred, 1½ to 2 inches with plate any size. . . .	"
Price per hundred, 2 to 2½ inches with plate any size. . . .	"

Price List of Douple Head Chaplet Stems

(Plain or tinned with square plates fitted, heavy stem and plate.)

Diameter of stem	Length	Per 100	Diameter of stem	Length	Per 100
½	⅞	$8.00	¾	⅞	$10.00
½	1	8.00	¾	1	10.00
½	1¼	9.00	¾	1¼	11.00
½	1½	10.00	¾	1½	12.00
½	1¾	11.00	¾	1¾	13.00
½	2	12.00	¾	2	14.00
½	2¼	13.00	¾	2¼	15.00
½	2½	14.00	¾	2½	16.00
½	2¾	15.00	¾	2¾	17.00
½	3	16.00	¾	3	18.00
½	3¼	17.00	¾	3¼	19.00
½	3½	18.00	¾	3½	20.00
½	3¾	19.00	¾	3¾	21.00
½	4	20.00	¾	4	22.00
½	4¼	21.00	¾	4¼	23.00
½	4½	22.00	¾	4½	24.00
½	4¾	23.00	¾	4¾	25.00
½	5	24.00	¾	5	26.00
⅝	⅞	9.00	⅞	⅞	11.00
⅝	1	9.00	⅞	1	11.00
⅝	1¼	10.00	⅞	1¼	12.00
⅝	1½	11.00	⅞	1½	13.00
⅝	1¾	12.00	⅞	1¾	14.00
⅝	2	13.00	⅞	2	15.00
⅝	2¼	14.00	⅞	2¼	16.00
⅝	2½	15.00	⅞	2½	17.00
⅝	2¾	16.00	⅞	2¾	18.00
⅝	3	17.00	⅞	3	19.00
⅝	3¼	18.00	⅞	3¼	20.00
⅝	3½	19.00	⅞	3½	21.00
⅝	3¾	20.00	⅞	3¾	22.00
⅝	4	21.00	⅞	4	23.00
⅝	4¼	22.00	⅞	4¼	24.00
⅝	4½	23.00	⅞	4½	25.00
⅝	4¾	24.00	⅞	4¾	26.00
⅝	5	25.00	⅞	5	27.00

Wrought-Iron Chaplet Stems with Square or Round Plates Fitted

Plain or Tinned

FIG. 191.

Square plates always furnished unless otherwise specified.

Price per Hundred

Diameter of plates.. Thickness of plates. Diameter of stem...	1¼ ins. 1/16 in. ¼ in.	1½ ins. 7/64 in. 5/16 in.	1¾ ins. ⅛ ins. ⅜ in.	2 ins. 11/64 in. ½ in.	2½ ins. 3/16 in. ⅝ in.	3 ins. ¼ in. ¾ in.
Length, inches						
3	$3.10	$5.10	$6.70	$11.30	$20.00	$31.25
3½	3.15	5.15	6.80	11.45	20.25	31.62
4	3.20	5.20	6.90	11.60	20.50	32.00
4½	3.25	5.25	7.00	11.75	20.75	32.37
5	3.30	5.30	7.10	11.90	21.00	32.75
5½	3.35	5.35	7.20	12.05	21.25	33.12
6	3.40	5.40	7.30	12.20	21.50	33.50
6½	3.45	5.45	7.40	12.35	21.75	33.87
7	3.50	5.50	7.50	12.50	22.00	34.25
7½	3.55	5.55	7.60	12.65	22.25	34.62
8	3.60	5.60	7.70	12.80	22.50	35.00
9	3.70	5.70	7.90	13.10	23.00	35.75
10	3.80	5.80	8.10	13.40	23.50	36.50
11	3.90	5.90	8.30	13.70	24.00	37.25
12	4.00	6.00	8.50	14.00	24.50	38.00
Net prices for curving plates to suit diameter of core	.35	.50	.60	.75	.90	1.25

Wrought-Iron Chaplet Stems

Plain or Tinned

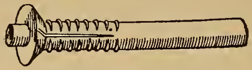


FIG. 192.

Price per Hundred

Length, measuring from face to stem, inches	Diameter					
	¼	5/16	⅜	½	⅝	¾
3	$2.40	$3.65	$4.50	$ 8.25	$13.00	$19.20
3½	2.45	3.70	4.60	8.40	13.25	19.60
4	2.50	3.75	4.70	8.55	13.50	20.00
4½	2.55	3.80	4.80	8.70	13.75	20.35
5	2.60	3.85	4.90	8.85	14.00	20.85
5½	2.65	3.90	5.00	9.00	14.25	21.20
6	2.70	3.95	5.10	9.15	14.50	21.60
6½	2.75	4.00	5.20	9.30	14.75	21.95
7	2.80	4.05	5.30	9.45	15.00	22.30
7½	2.85	4.10	5.40	9.60	15.25	22.65
8	2.90	4.20	5.50	9.85	15.50	23.00
9	2.95	4.25	5.70	10.20	16.00	23.75
10	3.00	4.30	5.90	10.55	16.50	24.50
11	3.05	4.35	6.10	10.90	17.00	25.25
12	3.10	4.40	6.30	11.25	17.50	26.00

Gray Iron Chaplets

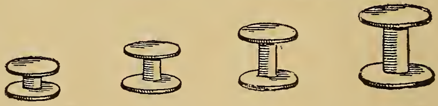


FIG. 193.

Length, inches...	¼	⅜	½	⅝	¾	⅞	1
Per hundred....	$0.72	$0.78	$0.84	$0.90	$1.00	$1.10	$1.20
Length, inches...	1⅛	1¼	1⅜	1½	1¾	2	
Per hundred....	$1.40	$1.60	$1.70	$1.80	$2.20	$3.00	

Double Head Water Back Chaplets

FIG. 194.

Made of 3/16-inch round iron, from ¼ to 2½ inches long, with heads about ⅜ inch in diameter.

Price per hundred, from ¼ to 1⅜ inches.... $5.00
Price per hundred, from 1½ to 2½ inches... 6.00

Wrought-Iron Chaplets with Forged Heads

Plain or Tinned

FIG. 195.

Price per Hundred

Diameter of head...	½, 1 1/16 and 1 3/16	1⅛	1¼	1½	1¾	2
Diameter of stem...	⅛, 3/16 and ¼	5/16	⅜	½	⅝	¾
Length, inches						
3	$2.40	$3.65	$4.50	$ 8.25	$13.00	$19.20
3½...............	2.45	3.70	4.60	8.40	13.25	19.60
4	2.50	3.75	4.70	8.55	13.50	20.00
4½...............	2.55	3.80	4.80	8.70	13.75	20.35
5	2.60	3.85	4.90	8.85	14.00	20.85
5½...............	2.65	3.90	5.00	9.00	14.25	21.20
6	2.70	3.95	5.10	9.15	14.50	21.60
6½...............	2.75	4.00	5.20	9.30	14.75	21.95
7	2.80	4.05	5.30	9.45	15.00	22.30
7½...............	2.85	4.10	5.40	9.60	15.25	22.65
8	2.90	4.20	5.50	9.85	15.50	23.00
9	2.95	4.25	5.70	10.20	16.00	23.75
10	3.00	4.30	5.90	10.55	16.50	24.50
11	3.05	4.35	6.10	10.90	17.00	25.25
12	3.10	4.40	6.30	11.25	17.50	26.00
Net price for pointing...............	.40	.60	.75	1.00	1.25	1.50

Single Head Water Back Chaplets

Head ½ inch, stem 3/16 inch, length to order. For price list see Wrought-iron Chaplets with Forged Heads.

FIG. 196.

Radiator Chaplets

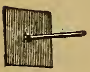


FIG. 197.

Head ¾ × ¾, stem and length to order.

Special chaplets and plates made to order.

Round and Square Head Chaplets

FIG. 198.

Stems made of 3/16-inch round iron, from 3/8 to 1½ inches long.

Plates ½ inch round and ¾ inch square, 5/16, 3/8, ½, 5/8, ¾, 7/8 and 1 inch long.

Price per hundred, all sizes.......................... $3.00

Tinned Clout Nails

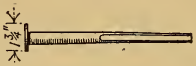


FIG. 199.

An indispensable article in the foundry. Do not rust like the ordinary black cut nail. Shipped in 100-pound kegs. All lengths from 5/8 inch to 2 inches, inclusive.

List Prices

Inches	Per pound
3-8	$0.70
3½-8	.60
1-2	.50
4½-8	.45
5-8	.43
5½-8	.41
3-4	.40
6½-8	.39
7-8	.38
1 and longer	.36

Pressed Tin Shell Chaplets

For certain classes of work these chaplets are invaluable. They form perfect union with the cast metal.

Sizes 1/8 inch to 5/8 inch inclusive are made in both two and three prongs, 11/16 inch to 1 inch inclusive are three prong only.

FIG. 200.

Price List

Size, inches	Two prong, per thousand	Three prong, per thousand
1/8	$3.00	$3.50
1/4	3.00	3.50
5/16	3.20	3.70
3/8	3.50	4.00
7/16	3.50	4.00
1/2	4.00	4.50
9/16	4.00	4.50
5/8	4.50	5.00
11/16	....	5.00
3/4	....	5.00
13/16	....	5.00
7/8	....	5.25
15/16	....	5.25
1	....	5.25

Steel Sprue Cutters

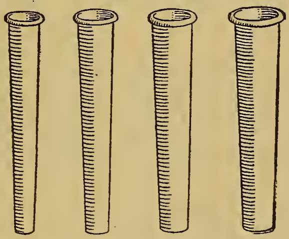


FIG. 201.

These sprue cutters are all 6 inches in length. They are made of steel and in four sizes, viz.:

No. 1. — 1/2 inch at bottom, 7/8 inch at top.
No. 2. — 5/8 inch at bottom, 1 inch at top.
No. 3. — 3/4 inch at bottom, 1 1/8 inches at top.
No. 4. — 7/8 inch at bottom, 1 1/4 inches at top.
Price.................................... 50 cents each

Brass Sprue Cutter

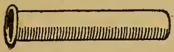


FIG. 202.

Made in one size only.

3/4-inch diameter, 10 inches long...$4.80 per dozen

CHAPTER XXIII

MOULDING MACHINES

The moulding machine has become of such importance that no foundry can afford to be without it. The reduction of cost in the production of the classes of work for which it is adapted and the superiority of the product as compared with hand work render the machine absolutely indispensable to the successful conduct of a foundry engaged in competitive work.

While the moulding machine is in some respects invaluable, it must not be supposed that its value can be realized without the exercise of a high order of intelligence.

To produce accurate work by machine requires the utmost care and accuracy in fitting up patterns and flasks. Appliances which may be used successfully in hand moulding would entail disastrous results in machine moulding. Again, no particular machine is adapted to all kinds of work. It has a certain range for a certain character of production. Without those limits its use is not warranted.

There are many kinds of machines, operated in various ways; by compressed air, hydraulic pressure, mechanical pressure, gravity and impact.

It is not the purpose of this book to discuss the merits of the different machines. The various types have been in service long enough to indicate the particular class of work to which each is best adapted. One type of machine is best suited for light, small work; another to stove-plate; another to car castings, etc.

In choice of machines the foundryman should profit by the experience of those who have preceded him in this field, and must be especially cautious in not attempting to extend the range of any one type beyond that for which it is particularly fitted.

There are machines which simply perform the operation of ramming; others which only draw the pattern, the ramming having been done by hand; while others perform both operations. In many instances the character of the work determines the function of the machine.

It is doubtful, however, if hand ramming for deep pockets, etc., can be dispensed with by use of the machine. In fact, except in cases where the plainest character of work is produced, it is a mistake to believe that the moulding machine does not require the services of an experienced moulder.

Mr. S. H. Stupakoff, in his comprehensive paper on the moulding machine, referring to the object of the machine as one to save labor, to increase the output, to decrease cost of production, to produce uniform and better castings, etc., says:

"It is obvious that it would require a complicated mechanism to perform successively and successfully all the necessary operations to make a complete mould, even if it were only the mould of a simple pattern. In consequence the general equipment of a foundry which accomplishes this object must be necessarily quite an elaborate and expensive matter. The majority of designs of moulding machines run in this direction, whereas in most cases it would have been better if the energy expended had been directed to their simplification.

"Such tendencies lead to complications which are altogether unsuited for foundry practice; they meet with little favor and machines built upon these principles are of short life."

"Only the simpler moulding machines have a chance of meeting with more or less success, even if they perform but a few operations, providing they perform these well."

"The first step in the evolution of the moulding machine was a device for withdrawing patterns from the sand. The next was to employ stripping plates, then an attempt to ram the mould by machinery."

In these three operations lie the basic principles of all moulding machines: all subsequent improvements and additions have been matters of detail; but to these improvements and to superior workmanship is due the real success of the modern moulding machine.

In the chart (p. 549), given by Mr. Stupakoff, moulding machines are divided into two classes — hand and power machines. The chart gives the variations of each class.

The selection and arrangement of machines, etc., is a matter governed entirely by the specific circumstances. Only hand machines are portable. They effect a great saving in the cost of carrying sand, but their use is limited by their size and weight. Mr. Stupakoff discusses the advantages and use of pattern plates as follows:

"At first sight it may appear that the construction and manipulation of pattern plates has but little connection with moulding machines, but I hope that I will succeed in showing in the course of this work, that they are not only intimately connected with each other, but that they are in fact the principal parts of all moulding machines. The lack of intimate knowledge of how to make use of them to the best advantage, the want of proper means to effect this purpose and the wretchedly little effort which is made to catch the right spirit of their nature, is generally the reason why a moulding machine becomes an elephant on the hands of the moulder and an eyesore to its owner."

The recommendations given by Mr. Stupakoff for the adoption of plate moulding by hand apply equally well to machine moulding.

1. Plated patterns give the best service when used continuously.

2. Castings which are to be produced in quantities are perferably moulded with plated patterns.

3. Standard patterns are preferably plated for economic production in the foundry.

4. Plated patterns should be made of metal to give good service."

5. When plated patterns are used good flasks only will insure good castings.

6. Accurate workmanship is one of the main requisites in plated patterns.

7. The use of wood patterns on plates is not excluded.

8. All patterns when placed on plates should be provided with plenty of draft.

9. Plated metal patterns are preferably made hollow.

10. Rapping is destructive of plates and patterns."

The chapter on jigs is regarded of such importance that it is given here in full.

The Moulding Machine

By S. H. Stupakoff, Pittsburgh, Pa.

Journal of the American Foundrymen's Association, Vol. XI, June, 1902, Part 1.

Jigs

The deduction arrived at in the foregoing chapter might make it appear that plated patterns are not likely to find extensive use in jobbing foundries, whereas this is really not altogether the case. There is no doubt that plate moulding as now practiced, or rather as ordinarily applied, is practically excluded from jobbing shops. But, if a plate is used in connection with a suitable jig, specially prepared for the purpose, objections are not only overcome, but the application and use of plates offer excellent advantages, even in such cases where only a small number of castings of the same pattern are required at one time. At best, the economic use of plated patterns is limited by the shape and size of the castings. The fundamental principle involved in their construction and application must be fully understood by the user, if satisfactory results are expected.

Irrespective of its relation to the moulding machine, it would seem that this subject — on its own merits — is of such importance, that it should be investigated by all foundrymen. It should specially interest the majority of our members. I have therefore somewhat enlarged the scope of this treatise on the moulding machine by including a detailed study of the construction and *modus operandi* of this particular contrivance.

To begin with, it should be understood that all plates are provided with guide-pin holes, which are accurately fitted to corresponding guide pins forming part of the flasks. Unless special flasks are used in connection with such plates the customary flask pins should not be confounded with these guide pins, as they will never answer the purpose. In order that misconceptions in this respect may be avoided, this term will be adhered to in what follows, and strict distinction will be made between flask pins and guide pins wherever they may be mentioned in the course of this work.

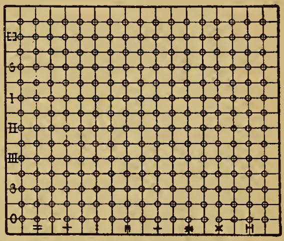


Fig. 203.

The guide-pin holes, *G* and *G′*, Fig. 205, are preferably arranged on opposite ends of the plate, in even multiples of an inch, and equidistant from its center and on a line dividing the plate into two equal rectangles. There are exceptional cases, in which three or four guide pins must be used. The most serious objection against this arrangement is the greater difficulty experienced in locating the patterns correctly.

Accuracy in preparing the plates becomes of the utmost importance, as the magnitude of all errors occurring in the original laying out is doubled by each subsequent operation. The guide-pin holes should be drilled and reamed out at right angles to the surface of the plate, and it is advisable to provide them with hardened and ground steel bushings.

Fig. 204.

All guide pins should be of uniform diameter irrespective of the size of the plate. A pair of test pins should be kept on hand, which snugly fit the guide-pin holes; one-half of one of their ends should have been cut down to about ¾ inch in length, leaving as remainder *exactly* one-half of the cylindrical portion (Fig. 204). If these test pins are inserted into their respective holes and a straight edge is placed against their flattened faces, it will serve for locating the base or the center line of the plate, for marking off and laying out the dowel pin holes, arranging the patterns and checking off all work relating to it.

The exact location of the center of the plate, and likewise the center of the flask, is found by dividing the base line from center to center guide-pin hole into two equal parts. Let us drill a hole *C* in this place (Fig. 205), and let this hole serve as the starting point for future operations. Now we will assume that we have procured a tri-square with a row of holes drilled in each of its legs; these holes are spaced equally — say

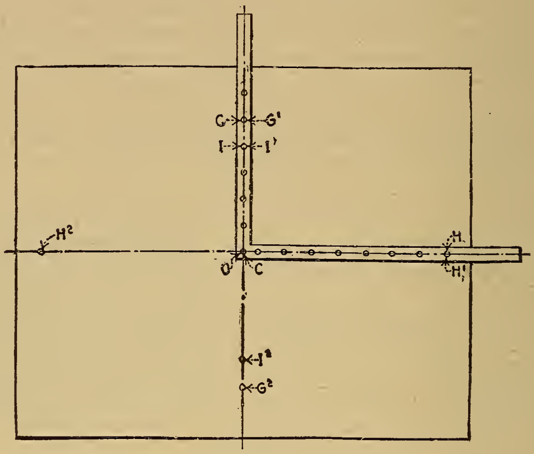


FIG. 205.

1 inch apart — care being taken that each row stands exactly in a straight line, and that both rows include an exact angle of 90 degrees. We place this square in such a manner on our plate that the hole in its apex corresponds with the center hole *C* of our plate, and insert a good fitting dowel pin through both. Thus we are able to shift the square over the whole surface of the plate by turning it around the center pin. Next we bring one leg of the square over the base line of the plate and insert a second dowel pin (which may be shouldered if necessary) through *G* into the corresponding hole of our square. Secured in this manner the square should be absolutely rigid and should not shake to right or left on the surface of the plate. We now drill one hole each into the plate through the guides *H* and *I* of the square, then we remove the pin from *G*, turn the square around the center pin over 90 degrees, so that one of its legs points upward and the other one to the left, insert a dowel through the hole in the leg pointing upward into the top hole *I′* of the plate, and drill the hole H^2; finally we turn it again over 90 degrees, secure it in the same manner as before, and drill the hole I^2. Fig. 205

illustrates the square in the first position as located on the plate; the holes H^2 and I^2, which are drilled subsequently, are shown in faint lines. In the future, we shall call these holes "pilot holes," in order to distinguish them from others in the same plate. These four pilot holes include an exact rectangle or square, and each opposite pair is located at uniform distances from the center of plate and flask. It will be understood that it is not absolutely necessary to employ the square for drilling the pilot holes. For instance, after one plate has been prepared in this manner, this plate can serve as a jig for drilling any number of additional plates in the same manner by a single setting. Such an original or master plate is especially serviceable, if all holes are provided with good steel bushings. The pilot holes in connection with the center hole will serve us hereafter as guides for locating pattern dowels.

Our object in view is to use this plate as a base for any and all suitable patterns, and as an illustration we will arrange it for the reception of patterns of a globe valve and a bib cock. We will assume that the patterns are all in good shape and properly parted. However, they shall originally not have been intended for use with either moulding machine or drawplate. Our plate and flasks are of a suitable size, but the job is in a hurry — as all jobs are — and we must get out quite a number of these castings to-day. What are we going to do about it? Take my advice and make it in the old fashioned way, unless you are provided with a suitable jig plate and an inexpensive, but a good small drill press, which was never used by your blacksmiths or yard laborers, but was expressly reserved for this purpose only, was always under the care of a mechanic who understood *how* to handle it, and who took pride in keeping it in good shape.

This jig plate (Fig. 205) should be provided with a number of holes, two rows of which, at least, are drilled exactly in the same manner as those in the above-mentioned square; the balance is laid out preferably, but not necessarily so, in straight and parallel lines, all equidistant from each other. Its dimensions should be sufficient to cover one corner, or one-fourth of your pattern plate.

If these things are part of your equipment you will have easy sailing, and you will be better fitted to tackle the job than your competitor.

Place this jig in such a manner in one corner of your draw plate that the hole *O* (Fig. 205) corresponds with the hole *C* in its center; hold both together with dowel pins inserted into the pilot holes, and drill the holes through the jig into your plate, which are required for securing the patterns in the predetermined places. To avoid mistakes be sure that the hole in that particular corner of the jig, which corresponds to the one described as located in the apex of the square is distinctly marked on both sides of the jig plate — in our figure marked *O* — and note carefully which holes in the jig were used for drilling the dowel holes into the pattern plate. Thereafter turn the jig upside down on the pattern plate, insert the dowel pins again through the same holes *O* and *OI* into *C* and *I′*, and the third one through *OH* into H^2, and then, as before, drill through the same guide holes of the jig the corresponding dowel holes into the second quarter of the pattern plate. Repeat the same process at the lower half of the plate, being always careful that *C* and *O* remain together and your plate is ready to receive the patterns.

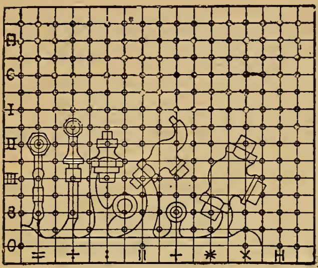


Fig. 206.

That there may be no doubt as to the method of operation, I suggest that you will refer to the two plates which are attached hereto, one of which (Fig. 206) is made on transparent — so-called "onion skin" paper. The cut on the latter represents the jig. In faint lines thereon is shown the outline of the position of patterns, which corresponds to the arrangement of the same on the pattern plate (Fig. 207). Horizontal and vertical

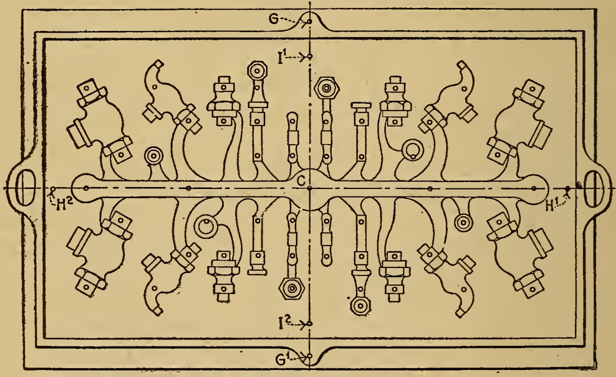


Fig. 207.

lines, which are provided with identification marks, cross all the holes in the jig plate. The holes which are to be used in this special case as guides for drilling the necessary dowel pin or screw holes in the pattern plate are indicated by circles drawn in heavy. Thus, the holes *II* × and 8* are used for securing the globe valve body pattern, *II* + and

III || for the body of the bib cock, and so forth. By placing the onion skin in such a manner over the drawing of the pattern plate, that its hole *O* corresponds with the center hole *C* of the latter, and *OI* and *OH* respectively with *I'* and *H'*, it will be noticed that the outlines representing the patterns cover each other in both cuts. The jig placed in this position over the pattern plate, and secured to it by the pilot pins at *O*, *OI* and *OH* is used in this manner for drilling all dark lined holes in the right-hand upper corner of the draw plate. This being done, the pilot pins are withdrawn and the jig plate is reversed and turned into the upper left-hand corner of the pattern plate, just as if it were hinged at the line *OI*; the pilot pins are replaced into the same holes of the jig as before and in this position they will secure it to the pattern plate by entering its pilot holes *C*, *I'* and H^2. It will be observed that in this position also, and equally well, the outlines of the patterns in both cuts fall exactly together. The jig is used in this position as before, the same guide holes which were used in the first position in the upper right hand corner serve again as guides for drilling the second quarter of the pattern plate. Identically the same process is then repeated at the lower left hand and lower right-hand corners of the plate, by first turning the jig plate around the imaginary hinge center *OH*, and then around *OI*.

In order to prepare the patterns to suit the above conditions, we proceed exactly in the same manner, by securing one-half of each separately, and always the one which has the dowel holes, at the previously determined place on the jig plate and drilling clear through them the holes which coincide with those drilled previously into the pattern plate. The second halves of these patterns are then placed in position against the first (drilled) halves; they are prevented from moving sideways by their original dowel pins, and they may be held together by suitable clamps. These clamps are preferably made of a universal type which adapts them for use with all kinds of patterns, their lower portion being constructed in the shape of a frame which rests on the table of the drill press without rocking and which is adapted for fastening the patterns in such a manner that their parting faces stand parallel to the drill table. The half of the pattern which has been drilled first with the aid of the jig occupies the upper position in this clamp or drill frame, and the holes in this one will now serve as guides for the drill to drill the holes in the second half which stands directly underneath. Finally, have the original dowel pins of the patterns removed and fasten all parts separately in place on the pattern plate by either dowels or screws, or both, whichever may be preferable and most convenient in your particular case.

If I may call your attention again to the drawings, you will observe that we have prepared the pattern plate in this manner with four complete sets of patterns; yet we have used only two. The castings resulting from the use of these plates should be perfect as to match. The amount of labor required to withdraw the patterns from the sand is reduced to a minimum; additional time is saved by the use of a stationary gate or runner on the plate, and double the quantity of castings can be produced in this manner with the same number of patterns and in the same number of flasks. All this can be accomplished by making an effort of no longer duration than it took to describe.

If you have followed the above description carefully, you may have noticed that it is not necessary to have an individual plate prepared for each set of patterns. Yet I thought it better to describe this method of preparing pattern plates and patterns for plate moulding in detail, than to leave room for any doubt or error. You can easily see that much of the time which it apparently took to get the plate and patterns ready for the moulder, can be saved by providing the entire surface of the plate with dowel holes before putting it into use. This should be done with the aid of the jig and in identically the same manner as has been sufficiently explained in the foregoing. Thus, only new patterns have to be prepared for the purpose, and all others, which once have been fitted, are easily replaced and secured to their correct positions on the plate, providing their dowel holes were promptly provided with specific numbers, letters or identification marks. The additional holes in the plate will not impair its working qualities, but they could be easily closed up with bees-wax if objectionable. Finally, it is well to note that each plate can be used in connection with all patterns within its range, and that it can be kept in continuous service, while the patterns may be changed at will, and as often as desirable.

While the above description may appear somewhat too extended, I assure you that a serious mistake would have been made had the subject been slighted merely for the sake of brevity. At the same time I will say in justification of my apparent digression, that my original subject has not been sidetracked. At first sight, it may appear, that the construction and the manipulation of pattern plates has but little connection with moulding machines, but I hope that I will succeed in showing in the course of this work, that they are not only intimately connected with each other, but that they are in fact the principal parts of all moulding machines. The lack of intimate knowledge of how to make use of them to the best advantage, the want of proper means to effect this purpose and the wretchedly little effort which is made to catch the right spirit of their nature is generally the reason why a moulding machine becomes an elephant on the hands of a moulder and an eyesore to its owner.

Flasks

Good flasks are especially important in machine or plate moulding. To insure good results from moulding machines the flasks must be practically perfect. They must be constructed to insure firm holding of the moulding sand; must be stiff, light and durable.

"The pins must be accurately fitted. The flasks, if made in sets, must be absolutely interchangeable. The pins should be square with the flask surface, must not bind and still must not fit too loosely.

Copes and drags when assembled, must not rock or shake sideways.

Wooden flasks, such as are used in most foundries, are not likely to give good results in moulding machine practice. However, if carefully and substantially made, there is no reason why their application in machine moulding should be absolutely condemned.

Iron flasks are always preferable, especially since they do not shrink, warp or get out of joint."

Pressed steel flasks are still more desirable.

If wooden flasks are used they should be faced with an iron ring, this ring serving not only to maintain alignment, but also as a base for securing flask pins. Taper steel pins secured to lugs by nuts give best satisfaction. The holes in lugs on drags may be reamed tapering and the lower ends of pins turned to fit, and tapped lightly into place. After the flask is closed and clamped these pins may be removed, thus making a few pins serve for any number of flasks. When not in use they should be removed from the flasks and properly taken care of. The pins are sometimes cut away so as to give them a triangular cross section, so that sand adhering to them may not interfere with readily inserting them in the holes.

FIG. 208.

By continued use the pins and sockets are so worn as to be unserviceable. The pins, of course, are replaced by new ones, but the sockets must be bushed by steel thimbles. The old holes are drilled out to standard size, so that the thimbles may be interchangeable. It is advisable to have the pin holes bushed when the flasks are made, so as to avoid subsequent annoyance.

"The makers of moulding machines are undoubtedly very well aware of all the requirements which are covered by the observance of these little details. They will appreciate their importance and must admit that they are essential to make their machines a success. Yet to my knowledge these facts have never been mentioned. Is this information kept from the foundryman purposely, that he may not be scared from the purchase of machines? If he should be told all this he might in the first place think of the expense, and next that his moulders cannot get used to refinement of this kind, which by the way is not a very creditable opinion. But if he buys one or more of the machines offered, he cannot help finding all this out before long, to his own chagrin. He may throw the machines away, or persist in the use of them and pay dearly for his experience. All this vexation could have been prevented in the first place and at a reasonable cost, had he been furnished in connection with the machine, with jigs, sample flasks, pins, etc., and above all with the necessary information to which he was entitled." Many failures to introduce and maintain labor-saving devices can be traced to the lack of intelligent instructions sent with them.

Mr. Stupakoff further discusses in detail the different kinds of machines remarking: "It is a grievous mistake to think that a moulding machine of any description will replace a skilled moulder. There is no less ingenuity required to produce good castings on a machine than to make them by hand.

"A moulder is aided by his experience and by his good judgment. A machine hand (customarily selected from unskilled labor) has nothing to offer but his muscle and good will. These qualities . . . are but poor substitutes for the dexterity of an expert. Therefore, under ordinary circumstances the chances are but slight to obtain good castings and good results by mechanical means which are imperfectly understood and subject to reckless abuse by hands which are unquestionably green in the business.

Owners of moulding machines should not expect marvels from an inert piece of mechanism, but it is safe to say they will seldom fail in their calculations if they are satisfied with a reasonable increased production, provided they are willing to pay the best possible attention to their manipulation."

Messrs. McWilliams and Longmuir in discussing the advantages of moulding machines conclude their remarks as follows:

"With ordinary small work, such as is usually included in boxes up to 14 inches by 16 inches, the greatest time consumers are (1) ramming, (2) jointing , and (3) setting cores. Jointing is largely obviated with a good odd-side, and altogether so with a plate. Ramming by the aid of a press reduces the time occupied to that required for the pulling forward of a lever.

Obviously, then, the greatest time consumers, with one exception, may be very considerably reduced by the simple and inexpensive aid offered by plate moulding and the hand press."

The exception referred to is that of setting cores, which holds good with all forms of mechanical moulding. Pattern drawing does not take up so much time as is usually supposed. With machines, jointing and

Moulding Operations. (Stupakoff.)

- Moulding.
  - Bench Moulding.
  - Floor Moulding.
    - Loam.
    - Dry Sand.
    - Green Sand.
      - Hand Moulding.
      - Machine Moulding.
        - Machine Operated by Hand.
          - Stationary.
          - Portable.
            - Mechanical Principles.
              - Lever.
              - Screw.
              - Geared.
                - Single Action.
                  - Squeezer.
                    - Single plain presser board.
                    - Single shaped presser board.
                    - Double, plain and shaped presser board.
                  - Drawplate.
                  - Stripping Plate.
                    - Withdrawing downwardly.
                    - Withdrawing upwardly.
                    - Lifting flask.
                    - Rapping.
                    - Combination.
                - Double Action.
                  - Squeezer and Drawplate.
                  - Squeezer and Stripping Plate
                    - Stripping plate stationary.
                    - Turnover machine.
                    - Rapping or vibrating.
        - Machines Operated by Power (Stationary).
          - Single Action.
          - Double Action.
          - Multiple Action.
            - Mechanical Principles.
              - Belt Driven. — — Steam. —
              - Pneumatic. — — Electric. —
              - Hydraulic. — — Vacuum. —
              - Used singly or Combined.
                - Ramming.
                  - Pressing.
                  - Jarring.
                - Drawing.
                  - Drawplate.
                  - Stripping Plate.
                    - Plated Patterns.
                    - Loose Patterns.
                      - Stationary.
                      - Rotating.
                - Ramming and Drawing.
                - Ramming and Stripping.
                - Ramming and Feeding Sand.
            - Ramming, Drawing stripping, rapping vibrating, feeding sand, etc. (3 or more of the above operations).
- Core Making.
  - Hand Made.
  - Machine Made.
    - Hand Operated Machine.
    - Power Driven Machine

Accessories.

Rammers.
Vibrators.
Sand Sifters.
Sand conveyers.
Mould conveyors.
Rapping arrangements.
Venting arrangements.

Combined Machines

Special moulding machine — (pulley, brake shoe, journal bed, etc.).
Single and double flask. Turnover machines. Revolving table machines.
Truck table machines. Universal moulding machines.
Dividing head moulding machines (gear moulding). Automatic moulding machines.

pattern drawing are eliminated and in certain cases, the initial outlay is comparatively small.

On standard, but changing work, our best results in machine practice have been obtained from the hand press supplemented, in case of deep patterns, such as flanged valve bodies, etc., by the hand rammed pattern drawing machine. Accessories in either case are not costly; the output is high and the quality good. Our best results on standard work, in which one plate could be run for at least 300 moulds, have been obtained from a pneumatic vibrator machine.

If the same plate could be run over a period of four or five days without changing, then production costs fall very considerably. . . .

Whatever may be said to the contrary, stripping plate machines involve costly accessories, but this outlay is warranted if the patterns are of a sufficiently standard character. These machines are especially good on intricate patterns, such as small spur wheels or others having little or no taper on the sides. While hand machines of any type represent a low first cost, the cost of subsequent accessories must not be forgotten.

Power machines represent a higher initial and maintenance cost, but if they can be maintained in constant operation, they give a low production cost. Finally, the chief drawback to the further development of machine moulding of any type occurs in core making and core setting.

An improvement in the mechanical production of irregular cores will result in a very considerable advance in machine practice."

The following remark is quoted from page 131, same book:

"As a rule we have found that while the initial cost of the machine is not considered, the after cost of the accessories is cut down to the narrowest possible margin. This is short sighted for if mechanical aids are adopted, there must be no half measures, or failure will inevitably follow. It cannot be too strongly urged that the cost of a machine represents only the beginning of expenditure."

CHAPTER XXIV

CONTINUOUS MELTING

There are some large shops where the processes of melting and moulding are carried on continuously. In some instances the moulds are made in one department, taken on trucks to the neighborhood of cupola, where they are filled; then to the dumping floor where the flasks are knocked out, and sent along on same truck to moulding floor. The manner of conducting this operation at the Westinghouse Foundry is described by Mr. Sheath, and is given in substance further on. In other shops, where work of the character of iron bedsteads is produced, the operation is also continuous, but the pouring is done in the ordinary way.

The management of the cupola is practically the same as in the ordinary foundry, except that the melter must have means for controlling the blast, so that he may increase or decrease the supply of air as the demand for melted iron may be greater or less. The cupola is run continuously from 7 A.M. to 6 P.M. with an interval of one hour at noon.

In respect to the cupola Mr. Sheath's advice is: "See that the coke bed is burning evenly all around, then charge just as you would for an ordinary run, allowing an extra amount of coke for the dinner hour. After running about an hour open the slag hole and keep it open, except during the dinner hour. Use about 40 to 50 pounds of limestone to the ton of molten metal — better use too much than too little. Have the cupola shell large enough, as it is easy to put in an extra lining for smaller heats."

"The Westinghouse Company have in their foundry at Wilmerding, Pa., three cupolas, one 60 inches, two 70 inches, inside lining. When running full, *i.e.*, night and day, we melt 280 tons, running each cupola about ten hours. We have operated one cupola from Friday night at 6 o'clock, until Saturday noon the following day, closing down at 11 P.M. for one-half hour for lunch, and again at 6.30 in the morning for three-quarters of an hour for breakfast. This is rather hard on the lining so we do not make a practice of it. We have tried a great many experiments with cupolas, but as yet have been unable to find any that will give better results than the double row of tuyeres. It is not necessary to keep the upper ones open all the time. Our blast pressure is about 11 ounces in the cupola bustle. When running full we melt ten to eleven pounds of iron to one pound of coke. . . .

All charges are the same from beginning to the end of the heat.

As the iron must come very soft and uniform we do not charge more than 4000 pounds at one time.

In the discussion of his paper at the Cincinnati meeting of the American Foundrymen's Association, May, 1910, Mr. Sheath gave much interesting information, which is summarized briefly.

Blast pressure, 11 ounces.

Little metal is held in cupola, consequently tuyeres are very low.

We are ready to tap almost after the whistle blows in the morning.

The melting is fast or slow as the moulds appear for pouring.

More coke is used for a small heat and slow melting, than with a large heat and rapid melting."

The sand is conveyed to the moulding machines by overhead reciprocating conveyors. Mr. Sheath's description of the pouring table is as follows:

"I might describe how we handle what we call our No. 2 table for No. 2 work. On that table there are castings, a great many of them measuring only a few inches. Notwithstanding the small size of the castings, we were running 52 tons off that table alone on a 10-hours run, showing what a great amount of metal can be used up under the continuous process in pouring small castings. We move the table at the rate of 20 feet per minute. A drag is put on. There are cores in it. As it passes up the core setters set the cores. Then the cope is put on. It then goes around to the casters in front of the cupola, which is connected with an endless control system. The casters have a ladle which can be raised or lowered by hand. They step on the table and travel with it, pouring anywhere from two moulds to a half dozen or a dozen, and by the time they are poured off, they are off at that end, and they can ride back to the cupola."

They do that all day long. The table is not supposed to stop, but just goes right straight ahead. It moves at the rate of about 21 feet a minute, which allows them to core up, cast, cover down and all. The core-setters walk with the platform and become very expert.

In some moulds we put in eight cores and two or three anchors at the same time, and it would take more than one man to do the coring.

Sometimes one man will core it, sometimes it takes two. The casters move right along with the table, take their ladle, and travel with it, the same as if they were on the floor.

One man handles a ladle that holds from 60 to 70 pounds.

The sand does not ball up, because we do not carry it very far with the conveyor. In the iron foundry from the time we make the mould and pour, until the mould is shaken out, that same sand is back again in twenty minutes. The sand is not touched by the men in any way. It simply goes down through the conveyor. The sand drops through the grating and is wet there and then taken overhead to the machine.

The lowest we have ever run was 40 to 50 tons. We have run as low as 5 tons an hour. This takes a little more lining up.

The economy comes in the room occupied by the moulds and the handling of the sand. The sand that we pour into, is back to the machine again in twenty minutes. We get the sand, the flasks and everything back empty every twenty minutes. There is a very little jarring about the platform. We have rebuilt one after running it nineteen years.

There is very little shake to it if it is working right. We use both the hydraulic and pneumatic moulding machines. . . .

The cutting of the cupola lining as compared with ordinary practice varies in proportion to the length of time in blast. We do not have any trouble from slag. At 12 o'clock all the metal is tapped out. We tap for slag twenty minutes before twelve and run it all out. The blast is shut off and metal run out before twelve. All the openings are stopped up. Very little iron comes down after the blast is stopped.

The cupola is drained before starting to work again and the blast put on at full pressure so as to heat up quickly. Perhaps 300 pounds metal is pigged before operations are resumed.

The smallest output any one day was 50 tons. I do not consider that the continuous process would pay if the production was as low as 20 or 30 tons per day. If there were no moulding machines the process would be economical upon a basis of two tons per hour."

When asked as to injury from jarring, Mr. Sheath replied:

"We make some moulds that have thirteen pockets hanging down in our smooth moulds; but there are much larger moulds which we have not put on the table at all, because our green sand cores are just held by a few fingers, and we would not risk putting them on. But we make lots of moulds that have quite deep pockets hanging down, and there is very little jarring to it. The table has a slow movement which eliminates jarring.

The displacing of the sand in the mould gives very little trouble.

The continuous system is adapted only for heats where the metal is of same character throughout. If two grades of metal are used they should be melted in separate cupolas.

The moulds may be made by machine or on the floor, and the table used for pouring anything placed on it.

Our conveyor makes a complete revolution in twenty minutes. We find in our line of work that the moulds and castings will be cold enough by the time they travel to the shaking out end.

The flasks are all iron and when shaken out are immediately put back on the table and carried to the moulding machine. They are carried entirely by the conveyor.

Our castings are not heavy. The sand is hot when it is shaken out, but when it is wet and elevated and shaken back and forward in the reciprocating conveyor, by the time it gets to the machine and iron patterns it is all right. We have to keep the patterns warm to prevent the sand from sticking to them.

Cores placed in hot sand will draw dampness. This feature was provided for. Our heaviest work is with flasks containing two castings which together weigh 45 pounds. Other flasks contain from thirty-two to forty castings, weighing a few ounces each.

I am familiar with a foundry where the cupola is 36 inches inside the lining. It is run from 7 A.M. to 5.30 P.M., continuously. The product is 60 tons per day. The sand is conveyed from the shaking out stand to the machines. Casting is continuous.

I am unable to say how small an output could be economically produced by this system. My experience is on a production from 50 to 280 tons. With us the casters do nothing but cast, the machine men do nothing but mould and the shakers-out do nothing but shake out.

We have had no trouble with freezing at the tap hole during the noon shut down."

As regards melting losses, Mr. Sheath was uncertain whether there were records or not. His opinion was that it runs from three to four per cent. The gates and sprues are returned to the cupola without cleaning.

"The pouring is done by a man moving with the table. The table is large enough for a man to stay on it with the mould. There is an overhead traveler, which travels with him as he is pouring. As soon as he has poured off and is at the end of his trolley line, he steps off the table and comes right back to the cupola. The coring is done by men standing and dropping in the cores as the moulds pass, or maybe taking a couple of steps, depending on the number of cores. The table does not stop from 7.15 A.M. until 12 M. unless for some special cause."

Mr. G. K. Hooper, in the discussion on Mr. Sheath's paper, remarked in response to the inquiry as to the minimum production for which the continuous process can be economically employed:

"That it was not so much a question of tonnage as of the number of moulds to be poured." The handling of a smaller tonnage than that mentioned by Mr. Sheath, if distributed over a large number of moulds would unquestionably be productive of great economy if performed mechanically and continuously. The mould is the unit which must be employed in determining whether the continuous system can be applied to any particular production."

Mr. Hooper also states that 20 minutes are not necessary for the manipulation and cooling of the sand. He had experience with a plant where the sand was returned in six minutes.

His further experience is that the foundry losses are less than are met with in the same class of work made on the floor.

Belts are more desirable than conveyors for moving sand. Rubber belts are better suited for the purpose than canvas. Flat belts are better than those which are troughed, and wide belts moving slowly are better than narrow ones at high speed.

A drag or scraper conveyor is the best for distributing sand to the hoppers over the moulding machines. It is preferably made of wooden troughs and flights.

Nettings, riddles, sieves, bolts and nuts are best made of phosphor bronze.

It is possible to handle all the sand required by productions up to 100 tons of castings per day, or more, with two men; even though as much as 100 tons of sand per hour may be passing through the system.

He has subjected moulds to very rough treatment to determine the liability of injury from jarring and confirms Mr. Sheath's statement that no trouble arises from this cause.

Mr. Hooper commends a system wherein the moulds are carried by an overhead trolley and allowed to swing freely except at the point where the pouring was done. Less power is required, less wear entailed, and the expense is less.

The continuous system is in no sense experimental. Its worth is demonstrated by use through many years in many large shops. . . . By means of mechanical handling systems in the foundry, the efficiency of the workman is increased from 10 to 50 per cent. The average wage can often be reduced somewhat; the foundry loss is decreased; the floor space reduced; in fact by such appliances only can the full capacity of moulding machinery be realized.

Multiple Moulds

When several moulds are stacked one on top of another and poured from a common sprue connecting to each mould, the process is styled multiple moulding.

The top and bottom sections are like the cope and drag of the ordinary mould; each intermediate section forms the drag for that immediately above and the cope for the one directly below.

A number of these sections, perhaps eight or even nine, are piled on top of each other and the pouring gate extends from the top cope to the

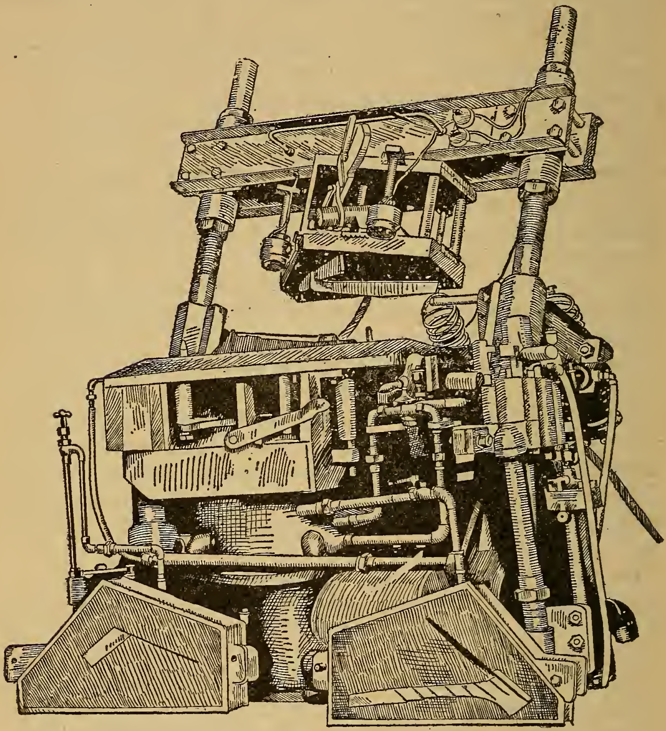


Fig. 209. — Rathbone Multiple Moulding Machine.

bottom drag. The special advantages of the system result from the reduction of floor space, the amount of sand used; the number of flasks required, and the labor of pouring off.

Mr. E. H. Mumford, in a paper presented to the American Foundrymen's Association, stated: "That the reduction in the amount of sand used and in the number of flasks is 37 per cent; and in floor space 88 per cent below that required for ordinary floor moulding."

The pouring may be done with a crane ladle; therefore, one of the great difficulties encountered in pouring off machine floors is eliminated. The great weight of sand, together with good clamping overcomes the tendency of straining.

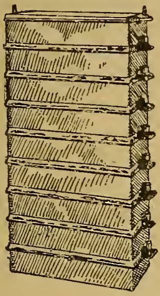


FIG. 210.

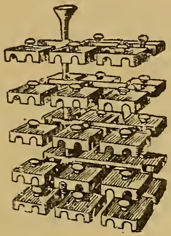


FIG. 211.

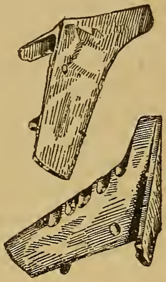


FIG. 212.

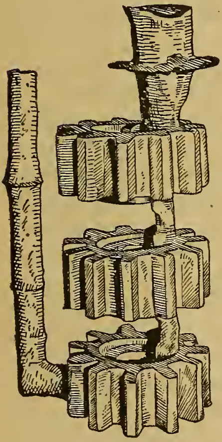


FIG. 213.

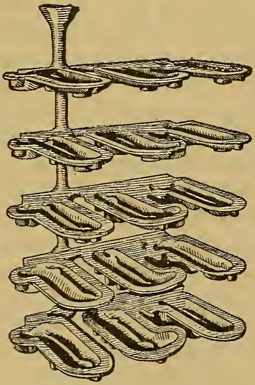


FIG. 214.

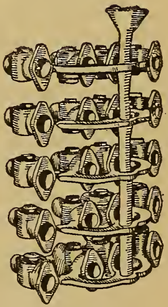


FIG. 215.

As originally practiced this method of moulding covered the piling of ordinary moulds, one above the other, and pouring from a common gate. The advantages were confined to reduced floor space and reduction of pouring difficulties. Subsequently each intermediate section was made to serve as a cope and drag; but the process was confined to patterns having plane bases, the drag having simply a flat surface. This limitation arose from the difficulty encountered in obtaining good moulds by pressing the patterns into the sand to form the drag. Later it was found that by bringing the drag up suddenly against the presser head, the sand was made by its inertia to take the impression of the pattern equally as well as when pressed from above. The scope of the process was immediately enlarged and although the method is not as yet extensively employed there seems to be a reasonable probability that it may be extended to cover the range of moderately small work now made by mechanical processes.

The cut above (Fig. 209) shows a machine of this character designed for making chilled plow points.

The moulds in position for clamping, and samples of castings made are shown in cuts above (Fig. 210–215).

Permanent Moulds

Moulds of more or less permanency made in loam, and moulds for chilled work, such as car wheels, etc., have long been in use, but moulds of a permanent character have only recently been used for extended lines of castings which are not chilled.

The management of the cupola, melting and pouring are very much the same as pursued in the continuous process already described.

The moulds are either mounted on frames near the cupola or are placed on revolving tables.

The iron from which the moulds are made must be soft enough for machining; it must be strong and of suitable composition to stand repeated heating without warping; it must also have a close structure to withstand the abraiding action of hot metal. The moulds are very heavy so that the mass of iron may carry away the heat rapidly from the casting and at the same time not permit its temperature to rise above 300° or 400° F. Keeping the temperature within these limits reduces the frequency with which the mould may be used. The moulds are machined at the joints and preferably hinged; the outside of the lower half of mould is also machined on the bottom.

Mr. Richard H. Probert of Louisville, Ky., in a paper read at the Cincinnati meeting of the American Foundrymen's Association gave the following analysis for moulds which had given good results:

Si	S	Phos.	Mn	C. C.	G. C.
2.02	.07	.89	.29	.84	2.76

He also states that he had used moulds made from high carbon steels for castings having sharp thin projections. In constant use these moulds become roughened, but are not burnt or eaten away, as with cast-iron moulds.

He likewise suggests that pressure applied to the moulds immediately after pouring would result in castings presenting sharp clean lines of great density and strength.

Mr. Edgar A. Custer of Tacony, Pa., presented at the same meeting a most interesting paper on the same subject and also submitted many sample castings, made by this process. Without giving definite information as to sizes of moulds with respect to patterns, he impressed the necessity for great mass in them. For instance, a mould for a 2-inch soil pipe **T**, weighs 500 pounds; one for a 3-inch trap 1700 pounds. In a mould for 4-inch soil pipe weighing 65 pounds, there were 6500 pounds iron. Castings were made in this mould every seven minutes without raising its temperature over 300° F.

He found that it is unnecessary to coat the moulds, but that their temperature must be sufficiently high to prevent the condensation of moisture before casting. If the castings are removed from the moulds immediately upon setting, there is little trouble about sticking after 60 to 100 castings have been made. The moulds improve by continued use, but how long they will last is unknown. He has now in use a mould in which 6000 castings have been made and it shows no signs of deterioration. The life of a mould depends not so much on the number of castings made in it as upon the number of times it has been allowed to become entirely cold and then reheated. Continuous pouring, when correctly timed so as to preserve a generally even temperature, has but very slight tendency to crack the mould. If the castings are removed from the mould as soon as they have set sufficiently to handle, there is with proper mixture no appearance of chill when cold. This was shown by a number of samples which had been machined. The iron was soft, and was readily filed on the parts not machined.

Cores are made of cast iron, and if straight, or curved in circular shape, can easily be removed from the castings, if taken out quickly while the casting is at a bright red. It is altogether probable that the time to remove the castings is at any period after setting and prior to the third expansion, and that the core should be removed during the third expansion. See Keep's "Cast Iron," Chapter VIII. The iron must be melted very hot. Mr. Custer's view is that the percentage of silicon may range between 1.75 and 3 per cent. The mixture in use by him is as follows:

Si	Phos.	S	Mn	G. C.	C. C.
2.24	1.12	.01	.38	3.02	1.54

Mr. Custer summarizes as follows:

"Any casting that can be poured in a sand mould can be poured in an iron mould. If the iron is hot enough to run in green sand mould it will surely run in an iron mould.

Iron that is suitable for radiator fittings, or brake shoes, or any other class of duplicate work that is made in sand, will be suitable for the use of permanent moulds. The same experience that shows the foundryman what is best for sand moulding can be applied in permanent mould work.

It is true that a somewhat wider range of iron can be used in permanent moulds for the same class of work than is the case in sand moulding, but any change from the general practice in selecting irons for any particular class of work must be made with a great deal of care. It is of course a subject that demands close and incessant study, and every manufacturer who wishes to use permanent moulds must give the same care and thought to this method that he has given to those previously employed."

Interesting information was brought out in the discussion of Mr. Custer's paper which is summarized below.

Temperature of moulds is not allowed to exceed 300° F.; the pouring is proportioned at intervals so as not to exceed that temperature.

It takes 25 seconds to make a 4-inch soil pipe T. No sand used in the core. The core for this mould was shown, which had been in constant use for thirteen months.

The mould for a 2-inch T weighed 500 pounds, the T itself weighs 8½ pounds.

The core with which the T was made was shown. It had been in use seven months during which period 3500 castings were made.

A casting can be made from it every forty-five seconds throughout the day.

No precaution is taken against shrinkage. Chilling quickly to point of set makes castings homogeneous, reducing shrinkage strains to a minimum. A trap weighing 42 pounds made on a sand core was shown. One is made every seven minutes. The mould weighs 1900 pounds. The casting is taken out within four seconds after pouring.

No special care is taken to keep the moulds from dampness. They are simply wiped out carefully before using. The core, upon which a four-inch pipe, 5 feet 3 inches long was made, was shown. The pipe was ¼ inch thick and weighed 65 pounds. The core had 1/16 inch taper in the whole length.

The pouring table revolves once in 7½ minutes. There are on it 35 pipe moulds, and a casting is produced every fifteen seconds.

In a ten-hour run at this rate of production, the temperature of the moulds never exceeds 250° F. The operations are automatic. With a 2-inch pipe, the casting can be taken from the mould within three seconds; it must not be allowed to remain in mould over six seconds. With a six-inch pipe, the time of removal is from five to sixteen seconds.

One man operates the table, pouring and removing the pipe, cleaning out the moulds, and setting the cores. The iron is white hot as it comes from the cupola. No attention is paid to coating the moulds; they are wiped out from time to time with a greasy rag if any dirt is present. The heaviest castings made are 6-inch pipes weighing 110 pounds each.

Gates are made larger than in green sand practice.

Mr. Custer did not consider the phosphorus content of importance. He prefers iron 0.5 to 1.0 per cent phosphorus on account of fluidity.

Chilling occurs so quickly that there is no segregation. The tensile strength of castings made in iron moulds is about 30 per cent greater than that of same character made in sand.

Brake shoes are left in the mould seven seconds. It takes about a minute to make a brake shoe. The castings do not warp.

Six-inch pipes can be laid on the pile within 20 seconds after casting.

The silicon content should not be lower than 1.75 per cent, sulphur should be below 0.05 per cent, total carbon high as possible not below 2.65.

Has used 70 per cent scrap with pig carrying 3 per cent silicon.

Centrifugal Castings

In 1809, Anthony Eckhardt of Soho, England, was granted a patent for making castings in rotating moulds, procuring in this manner either hollow or solid castings. Nothing favorable seems to have resulted from the scheme.

In 1848, Mr. Lovegrove attempted to make pipes in this manner. Subsequently a Mr. Shanks patented the same method in England. Sir Henry Bessemer endeavored to remove the gases from steel castings by a similar process.

About the same time a Mr. Needham endeavored to apply the method to making car wheels. So far as can be learned nothing of practical value resulted from these efforts. It is said that car wheels are now made in Germany in this way using a high carbon steel for the rim and soft material for the center. The mould is made to revolve about 120 times per minute while pouring. The principle is used by dentists successfully, and there seems to be no good reason why it could not be applied to some classes of iron castings where difficulty is encountered in running delicate parts, or to obtain increased density at the periphery.

Castings under Pressure

Attempts have been made to submit the liquid iron to pneumatic or hydraulic pressure in order to eliminate porosity or shrinkage cavities. So far these have been entirely experimental; the successful application of the idea would remove all doubt as to shrinkage in rims of fly wheels or in similar castings, where undiscoverable defects may exist.

Direct Casting

Making castings directly from the furnace has been practiced more or less since the discovery of reducing iron from the ores. But by reason of the presence of impurities and gases, which are to a greater or less extent eliminated in the process of refining in the cupola, the production of castings by the direct process has never been followed to any extent. In fact, except for quantities of large coarse castings, or an occasional piece required at the furnace, it may be said that the process has been entirely disregarded. The presence of kish in large quantity has been the greatest obstacle to contend with. The use of a receiver with reheating provision, in connection with manganese would seem to indicate a solution of this difficulty, especially for pipes and other coarse castings, where the physical characteristics are not matters of vital importance.

In view of the advancement in modern metallurgy, it is more than probable that commercial competition will turn manufacturers of products for which such iron is suitable to further efforts in this direction.

Carpenter Shop and Tool Room

In every foundry the services of a carpenter and machinist are more or less in demand. In the larger works it is found most convenient to devote separate space to each.

The carpenter shop should be given sufficient room for construction and repair of wood flasks, bottom boards, etc., and with its equipment of benches, trestle, etc., should be provided with a cut-off saw.

The tool room should have a drill press and small lathe. Unless there is a laboratory connected with the works, the testing machines are conveniently located in the tool room.

The Cleaning Room

The cleaning room should be adjacent to the moulding room, but separated from it by a wall or partition to exclude the dust and dirt from the foundry.

Where the work is heavy there should be proper facilities in the way of tracks and cranes. The necessary equipment comprises tumbling barrels, brushes, chipping (either hand or pneumatic) and grinding apparatus.

The sand blast is also of the greatest value.

Tumblers

The shape, size and number of tumblers depend entirely upon the character and volume of the work. Tumblers are made to revolve about inclined or horizontal axes. Those having inclined axes are used for very light castings, brass, forgings, etc. They are seldom found in the ordinary foundry. The barrel may be tilted for loading or discharging. The following cut shows the general character of this type. They vary in size as required.

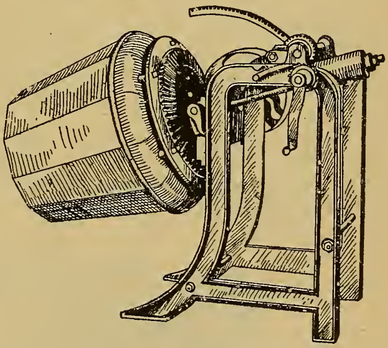


FIG. 216.

Fig. 216 shows the No. 2 machine mounted with 28-inch cast-iron barrel in partially lowered position preparatory to dumping.

This machine is designed along the same lines as the No. 1 tumbler excepting that it is much heavier and the crank shaft is back geared 2 to 1, making the raising and lowering of the barrel when heavily loaded quick and easy. It is driven by tight and loose pulleys 16 inches in diameter by 3¾-inch face, and will take barrels from 22 to 36 inches diameter, of wood, cast iron, steel, wrought brass and cast brass. The tumbling process may be wet or dry as desired, and the design of the machine is such that the barrel may be located at any required angle while in motion, to suit quantity of work being operated upon, and lowered to empty by means of the crank, ratchet and pawl. It has a belt shifter not shown in cut.

Floor space, with barrel, 42 by 60 inches.
Weight, without barrel, 600 pounds.
Speed of tight and loose pulleys, 147 to 168 rev. per min.
Speed of barrel, 35 to 40 rev. per min.

The ordinary horizontal tumbler is from 30 to 36 inches in diameter and from 4 to 6 feet long. It may revolve on trunnions or on friction rollers.

The barrel is made up of cast-iron staves securely bolted to the heads, and with closely fitting joints. The peripheral speed should be about 90 feet per minute. They are used singly, in pairs, or in batteries. The castings, large and small, are packed as closely as possible in the barrels, together with a quantity of shot, sprues or stars. Any unoccupied space is filled by pieces of wood. If any of the castings are delicate they are tumbled by themselves, so as to avoid breakage. It is not uncommon to tumble castings weighing 600 to 800 pounds; they must be packed very closely, however. The length of time that castings must be rattled to clean them depends entirely upon the intricacy of the shapes. While ten minutes may answer for some, others may require 30 minutes or even an hour.

The injury to castings from grinding away sharp corners or angular projections arises from the improper packing or too long continued tumbling. Since the dust comes from the tumblers in great volume, as an act of humanity, they should either be enclosed, or provided with exhaust fans. The dust may be carried to a water seal, or discharged outside the shop.

The cuts following show several varieties of tumblers manufactured. Usually each shop makes its own tumblers, so that the patterns may be at hand for repairs.

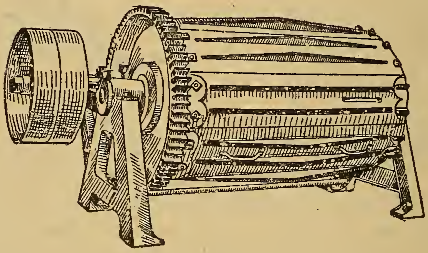


Fig. 217.

"The Falls" Friction-driven Tumbling Mill

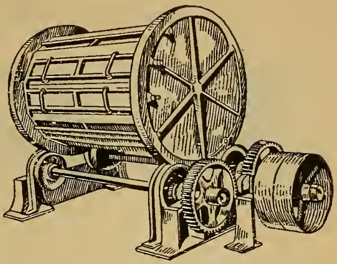


FIG. 218.

This mill was designed by an expert foundryman. It is of the very best workmanship throughout, and is guaranteed to give splendid satisfaction.

Made in six sizes as follows:

No.	Diameter, inches	Length, inches
1	26	48
2	32	54
3	38	60
4	42	54
5	48	72
6	54	78

Reliable Steel Square Tumbling Mills

Particularly Suited for Light Castings

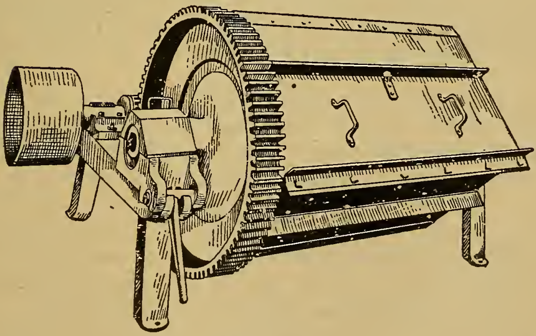


FIG. 219.

This is a strong mill with double heads. Each side is strengthened by a T bar run and riveted the full length and doubly bolted to each head. Edges are enclosed by an angle securely riveted and countersunk from end to end. Door opening is strongly reinforced.

Friction-driven Exhaust Tumbling Mills

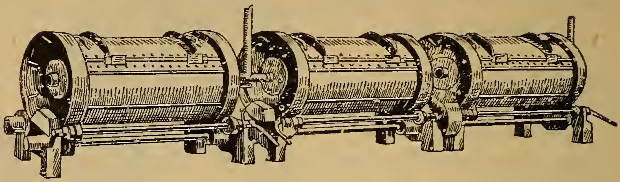


Fig. 220.

These mills are especially adapted to be run in gangs from one shaft and one driving pulley. They can be stopped or started independently or may be removed with contents from the driving frame by crane and conveyed to any part of the foundry. Mills may be equipped at small extra cost with reversing device, permitting rotation in either direction, mills still remaining portable and interchangeable.

They combine strength with simplicity.

Mr. Outerbridge discovered that the strength of castings was increased by tumbling. Following up this discovery Mr. Keep determined that the increase of strength by tumbling ceased after two hours treatment, that the increase in strength was due to smoothing and pressing the surface, closing any incipient cracks and openings.

Chipping

Much of the chipping must be done by hand. The pneumatic hammer has, however, superseded the hand chisel to a great extent. There are few foundries not equipped with this device.

Grinding

To finish castings properly, the fins and gate spots should be ground. In addition to the ordinary emery wheel, the portable wheel driven by a flexible shaft is employed advantageously.

The Sand Blast

This appliance is of the greatest importance. More surface can be cleaned with it in a given time than by any other means except the rattler. The use of the other appliances above mentioned is not displaced by it, however, as there are many recesses about castings which are protected from the blast, and which must be cleaned by hand.

The importance of properly cleaning castings should not be overlooked. No matter how well made or how good in respect of material, if they are sent from the cleaner in a slovenly condition, their commercial value is greatly impaired.

Pickling

Formerly pickling castings was largely employed, but of recent years, by reason of the improved facings used, the practice is not so much followed. Nevertheless there are places about castings from which the sand is not properly removed by the ordinary processes, and again some machine shops prefer pickled castings, as the cutting edges of their tools are not injured so quickly, by reason of the entire removal of the sand. This process is also followed where the castings are to be galvanized or tinned, as it leaves clean metallic surfaces.

For pickling, either sulphuric or hydrofluoric acid is used, the former more commonly. The acid solution must be weak; one part of ordinary vitriol to four or six parts of water attacks the iron rapidly, whereas the undiluted acid has no effect.

In diluting the acid, care must be taken to pour the acid into the water, and not the water into the acid. Dilute sulphuric acid dissolves the iron in contact, thereby loosening the sand. The action is more rapid with warm than with hot solution.

This solution, when applied to castings, will loosen the sand scale in from one to twelve hours, depending upon the thickness of the scale. The acid solution is kept in a lead-lined wood vat. The vat should be about two feet deep, the other dimensions varying with the amount of castings to be treated. At the bottom of the vat is a wooden grating fastened together by wood dowels. The grating is held down by lead weights. It must be high enough above the bottom of the vat for the sand to drop through. Upon this grating the castings rest as they are immersed.

After remaining in the bath the requisite length of time, they are removed and thoroughly washed with hot water. The acid must be completely removed or they will rust. It is a good plan to dip them in a strong solution of lye or soda before washing.

Another practice is to place a lead-lined platform so that one edge may overhang one end of the vat; the platform inclining a couple of inches toward the vat, and having the remaining edges raised two inches, so that all the drainage may be into the vat. Upon this platform is placed a wood grating, and the castings on the grating. The pickle is then dipped from vat with an iron bucket and poured over the castings.

They are washed thoroughly with the pickle, so that there may be no sand surface which has not been saturated. It may be necessary to repeat the operation more than once. When the sand scale begins to loosen, the castings are removed and washed as before. The washing may be done with a hose while the castings are on the bed, but in such case provision must be made to carry off the water in a trough so that it may not enter the vat.

The strength of the solution must be kept up by addition of fresh acid from time to time.

Hydrofluoric Acid

Where this acid is used for pickling, the solution should be one part of 48 per cent acid to 30 parts of water. Hydrofluoric acid dissolves the sand instead of acting on the iron. The treatment of the castings is the same as with the vitriol, but the sand must be removed from below the grating, otherwise the acid will be rapidly neutralized.

The workmen should be cautioned in handling either of these acids as they cause severe burns, if they come in contact with the flesh. Where acid is spilled on the flesh or clothing, wash the parts freely with water and then with dilute ammonia. Raw linseed oil applied to burns produces a soothing effect.

Hydrofluoric acid leaves the surface of the castings bright and clean, and is, therefore, best for electroplating.

CHAPTER XXV

Method of Ascertaining the Weight of Castings from the Weight of Patterns

Pattern weighing one pound	Weight when cast in					
	Cast iron, pounds	Yellow brass, pounds	Gun metal, pounds	Zinc, pounds	Aluminum, pounds	Copper, pounds
Bay wood	8.8	9.9	10.3	8.5	3.2	10.5
Beech	8.5	9.5	10.0	8.2	3.1	10.1
Cedar	16.1	18.0	18.9	15.6	5.8	19.2
Cherry	10.7	12.0	12.6	10.4	3.9	12.8
Linden	12.0	13.5	14.1	11.6	4.3	14.3
Mahogany	8.5	9.5	10.0	8.2	3.1	10.1
Maple	9.2	10.3	10.8	8.9	3.2	11.0
Oak	9.4	10.5	11.0	9.1	3.4	11.2
Pear	10.9	12.2	12.8	10.6	3.9	13.0
Pine, white	14.7	16.5	17.3	14.3	5.3	17.5
Pine, yellow	13.1	14.7	15.4	12.7	4.7	15.6
Whitewood	16.4	18.4	19.3	15.9	5.9	19.5

Allowance should be made for any metal in the pattern.

Specific Gravity and Average Weight per Cubic Foot of Pattern Lumber

Wood	Specific gravity	Average weight per cubic foot, pounds
Beech	.73	46
Cedar	.62	39
Cherry	.66	41
Linden	.60	37
Mahogany	.81	51
Maple	.68	42
Oak, white	.77	48
Oak, red	.74	46
Pine, white	.45	28
Pine, yellow	.61	38
Walnut	.75	38

Weight of Castings Determined from Weight of Patterns

(By F. G. Walker.)

A pattern weighing one pound made of	Will weigh when cast in						
	Cast iron, pounds	Zinc, pounds	Copper, pounds	Yellow brass, pounds	Gun metal, pounds	Aluminum, pounds	Lead, pounds
Mahogany, Nassau....	10.7	10.4	12.8	12.2	12.5	......	......
Mahogany, Honduras.	12.9	12.7	15.3	14.6	15.0	......	......
Mahogany, Spanish....	8.5	8.2	10.1	9.7	9.9	......	......
Pine, red............	12.5	12.1	14.9	14.2	14.6	......	......
Pine, white............	16.7	16.1	19.8	19.0	19.5	5.0	22.0
Pine, yellow...........	14.1	13.6	16.7	16.0	16.5	......	......
Oak...................	9.0	8.6	10.4	10.4	10.9	......	......

Weight of a Superficial Foot of Cast Iron

Thickness, inches	Weight, pounds	Thickness, inches	Weight, pounds	Thickness, inches	Weight, pounds	Thickness, inches	Weight, pounds
¼	9.37	¾	28.12	1¼	46.87	1¾	65.62
⅜	14.06	⅞	32.81	1⅜	51.56	1⅞	70.31
½	18.75	1	37.50	1½	56.25	2	75.00
⅝	23.43	1⅛	42.18	1⅝	60.93	....	....

Formulas for Finding the Weight of Iron Castings

Fig. 221.

To find the weight of square or rectangular castings, multiply the length by the breadth, by the thickness, by 0.26:

$$W = LBT \times 0.26.$$

To find the weight of solid cylinders, the weight equals the outside diameter squared, multiplied by the length, multiplied by 0.204:

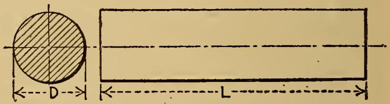


Fig. 222.

$$W = D^2L \times 0.204.$$

W = weight of casting in pounds;
L = length of casting in inches;
T = thickness of casting in inches;
B = breadth of casting in inches;
D = outside or large diameter in inches.

To find the weight of hollow cylinders, multiply the small or inside diameter plus the thickness, by the length, by the thickness, by 0.817:

$$W = (d + T)\,TL \times 0.817.$$

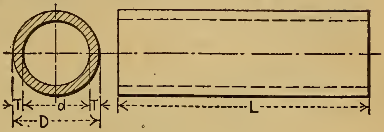


FIG. 223.

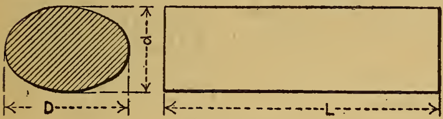


FIG. 224.

To find the weight of a solid ellipse, multiply the large diameter by the small diameter, by the length, by 0.204:

$$W = DdL \times 0.2c4.$$

W = weight of casting in pounds;
L = length of casting in inches;
T = thickness of casting in inches;
D = large diameter in inches;
d = small diameter in inches.

To find the weight of a hollow hemisphere, multiply the thickness by the small radius plus the thickness divided by 2, squared, by 1.652:

$$W = \left(r + \frac{T}{2}\right)^2 T \times 1.652.$$

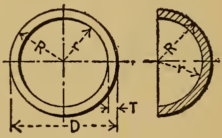


FIG. 225.

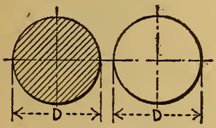


FIG. 226.

To find the weight of a solid sphere, multiply the diameter cubed by 0.1365:

$$W = D^3 \times 0.1365.$$

W = weight of casting in pounds;
R = outside or large radius in inches;
r = inside or small radius in inches;
T = thickness in inches;
D = outside or large diameter in inches.

Formulas for Finding the Weight of a Hollow Iron Sphere and a Body of Rammed Sand

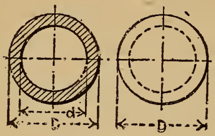


FIG. 227.

To find the weight of a hollow sphere multiply the outside diameter cubed, minus the inside diameter cubed, by 10.365:

$$W = (D^3 - d^3)\ 0.1365.$$

W = weight of casting in pounds;
D = outside or large diameter in inches;
d = inside or small diameter in inches.

To find the weight of a body of rammed sand, multiply the length by the breadth, by the height in feet, by 87:

$$W = LBH \times 87.$$

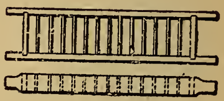


FIG. 228.

W = weight of body of sand in pounds;
L = length of body of sand in feet;
B = breadth of body of sand in feet;
H = height of body of sand in feet.

Formulas for Finding the Weight of Iron Castings

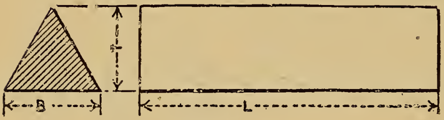


FIG. 229.

To find the weight of a triangular casting, multiply the length by the breadth, by the thickness, by 0.13:

$$W = LBT \times 0.13.$$

To find the weight of a flywheel, 11 feet in diameter, having elliptical arms. The first operation is to find the weight of the hub; second, the rim; and third, the arms. The sum of these gives the weight of the wheel.

To find the weight of the hub:

$$W = (d + T)\ TL \times 0.817.$$

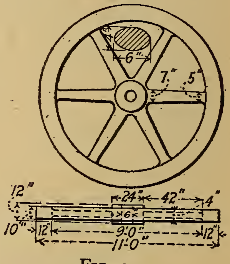


FIG. 230.

To find the weight of the rim, the same formula as above is used.

To find the weight of one arm:

$$W = DdL \times 0.24.$$

Multiply by six to find the weight of the six arms.

W = weight of casting in pounds;
D = outside or large diameter in inches;
d = inside or small diameter in inches;
L = length in inches;
T = thickness in inches;
B = breadth in inches.

To find the weight of a spherical segment of one base, multiply the square of the height by the difference between the radius of the sphere and one-third of the height, by 0.818; or, to the radius of the base squared, multiplied by the height by 0.409, add the height cubed multiplied by 0.136:

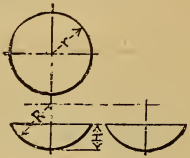


FIG. 231.

$$W = H^2\left(R - \frac{H}{3}\right) \times 0.818,$$

or

$$W = r^2H \times 0.409 + H^3 \times 0.136.$$

W = weight of casting in pounds;
R = radius of sphere in inches;
H = height of segment in inches;
r = radius of base in inches.

To find the weight of a spherical segment of two bases, from the radius of the sphere multiplied by the difference between the squares of the distances from the bases to the poles by 0.818, subtract the difference between the cubes of the distances from the bases to the pole, multiplied by 0.273, or:

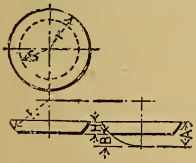


FIG. 232.

To the sum of the squares of the radii of the bases, multiplied by the height by 0.409, add the height cubed, multiplied by 0.136:

$$W = R(A^2 - B^2) \times 0.818 - (A^3 - B^3) \times 0.273,$$

or

$$W = H(r^2 + s^2) \times 0.409 + H^3 \times 0.136.$$

W = weight of casting in pounds;
R = radius of sphere in inches;
r = radius of large base of segment in inches;
s = radius of small base of segment in inches;
A = distance from large base to pole in inches;
B = distance from small base to pole in inches;
H = height of segment in inches.

To find the weight of a ring made by cutting a cylindrical hole through the center of a sphere, multiply the chord cubed by 0.136:

$$W = C^3 \times 0.136.$$

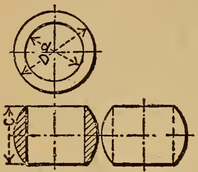


FIG. 233.

The chord is equal to the square root of the result obtained by subtracting the square of the diameter of the hole from the square of the diameter of the sphere:

$$C = \sqrt{D^2 - d^2}.$$

W = weight of casting in pounds;
D = diameter of sphere in inches;
d = diameter of hole in inches.

To find the weight of a ring of circular cross section, multiply the radius of the cross section squared by the radius of the circle passing through the center of the cross section, by 5.140:

$$W = r^2R \times 5.140.$$

W = weight of casting in pounds;
r = radius of cross section in inches;
R = radius of circle passing through center of cross section in inches.

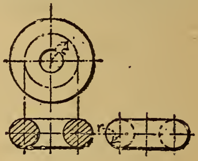


FIG. 234.

To find the weight of a frustrum of a hexagonal pyramid, multiply the sum of the side of the large base squared, the side of the small base squared and the product of the two sides, by the length, by 0.226, or multiply the sum of the distance across the flats of the large base squared, the distance across the flats of the small base squared and the product of these two distances, by the length, by 0.075.

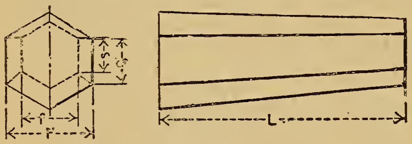


FIG. 235.

$$W = (S^2 + s^2 + Ss)\,L \times 0.226, \quad \text{or} \quad W = (F^2 + f^2 + Ff)\,L \times 0.075.$$

To find the weight of a straight fillet, multiply the radius squared by the length, by 0.0559.

$$W = R^2L \times 0.0559.$$

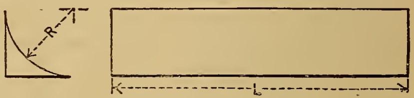


FIG. 236.

W = weight of casting in pounds;
L = length of casting in inches;
S = side of large base in inches;
s = side of small base in inches;
F = distance across the flats of large base in inches;
f = distance across the flats of small base in inches;
R = radius of fillet in inches.

Formulas for Finding the Weight Required on a Cope to Resist the Pressure of Molten Metal; and the Pressure Exerted on the Mould

To find the weight required on a cope to resist the pressure of molten iron, multiply the cope area of the casting in square inches by the height of the riser top above the casting in inches, by 0.21:

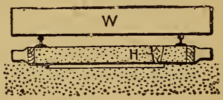


FIG. 237.

$$W = AH \times 0.21.$$

W = weight to be placed on a flask in pounds;
A = cope area of casting in square inches;
H = height of riser top above casting in inches.

To find the pressure exerted on a mold by molten iron multiply the height in inches from the point of pressure to the top of the riser by 0.26:

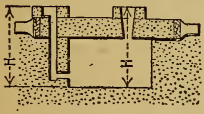


FIG. 238.

$$P = H \times 0.26.$$

P = pressure in pounds per square inch;
H = height from point of pressure to the top of the riser in inches.

To find the weight of an inside circular fillet, multiply the difference between the diameter of the cylinder made by the side of the fillet and the product of the radius and 0.446, by the radius squared, by 0.176, or, from the diameter of the cylinder made by the side of the fillet, multiplied by the radius squared, by 0.176, subtract the radius cubed multiplied by 0.0784.

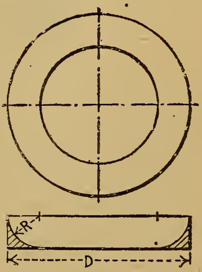


FIG. 239.

$$W = (D - 0.446\,R)\,R^2 \times 0.176,$$

or $$W = DR^2 \times 0.176 - R^3 \times 0.0784.$$

To find the weight of an outside circular fillet, multiply the sum of the diameter of the cylinder made by the side of the fillet and the product of the radius and 0.446, by the radius squared, by 0.176, or to the diameter of the cylinder made by the side of the fillet multiplied by the radius squared, by 0.176, add the radius cubed multiplied by 0.0784:

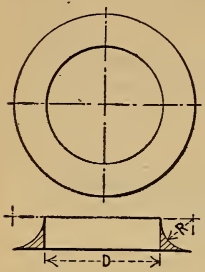


FIG. 240.

$$W = (D + 0.446\,R)\,R^2 \times 0.176,$$

or

$$W = DR^2 \times 0.176 + R^3 \times 0.0784.$$

W = weight of casting in pounds;
R = radius of fillet in inches;
D = diameter of cylinder made or generated by the side of fillet in inches.

CHAPTER XXVI

WATER SUPPLY, LIGHTING, HEATING AND VENTILATION

Water Supply

PROVISION for water supply to the foundry is a matter of the first importance. If water cannot be obtained from the public mains, facilities for pumping and distributing must be provided. The system must be so arranged, either by elevated tanks or otherwise, as to furnish water under a pressure of from 25 to 30 pounds. While the supply must be abundant, the natural tendency to its wasteful use must be suppressed.

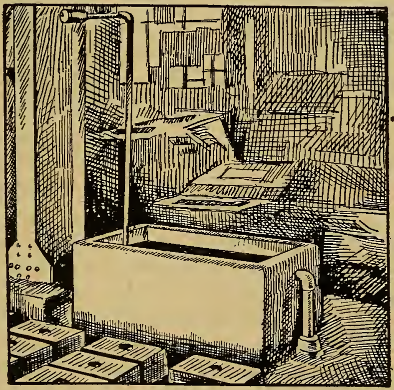


FIG. 241.—Water Box and Hose Connection.

Conveniently located near the cupola for quenching the dump, should be a hydrant with hose attached, ready for immediate use. Pipes should be so run about the foundry that taps may be conveniently distributed for wetting down the floors and sprinkling the sand heaps; each floor must have easy access to the sprinkling hose. Ample provision should be made for drinking; basins near the drinking fountains, in which to bathe their arms and faces, add greatly to the comfort of the workmen.

The illustrations herewith, taken from the Iron Age, show provisions made for this purpose and for lavatories, etc., in a large Cleveland foundry.

Running water should be supplied at the closets. In many foundries of recent construction, wash basins, shower baths and lockers are provided, enabling the men to wash and change their clothes before leaving the works. The free use of water implies, of course, a system of sewerage. Care must be taken to avoid puddles or wet spots about the floors. The matter of water supply for fire protection is entirely independent of that for foundry purposes, and should be provided for separately.

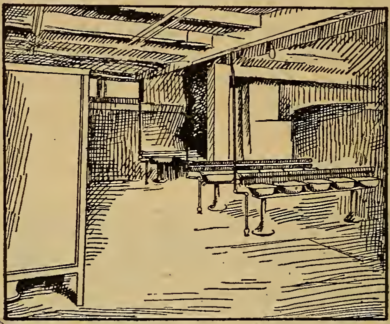


FIG. 242.—Porcelain Washbowls and Steel Lockers in Lavatory.

Lighting

Next to water supply in importance is the matter of lighting. Many foundries are deficient in this respect and suffer either in the character or quantity of product from improper lighting. Daylight is invaluable, and should be utilized to the fullest extent. In the construction of foundry buildings, the windows should be tall and as close together as the character of the structure will permit; they should not extend lower than four feet from the floor. A modern construction showing the sides of the building made almost entirely of glass is shown in the engraving below.

Windows in the moniter should be swiveled and arranged to open easily for ventilation. Skylights are to be avoided if possible, as they cause no end of annoyance. The weaving-shed roof gives excellent results, and is frequently used in foundry construction. The glazing should be of a character to prevent the direct admission of sunlight. Ground glass, wire glass or glass with horizontal ribs afford a mellow light, relieving the eyes from the glare of direct sunlight.

Artificial light for the early morning and late evening hours, during the season of short days, is best afforded by some adaptation of the electric lamp. Tungsten lamps in groups of four, distributed at intervals of about 40 feet are largely used. Such lamps are provided with reflectors to direct the rays downwards and diffuse them. The lamps must be placed so as to clear the crane ways, and should be elevated about 20 feet from the floor. The Cooper-Hewett mercury lamps, placed about 50 feet apart and covered with reflectors, are very satisfactory. The flaming arc lamps, similarly placed, furnish the greatest illumination for a given expenditure of current.

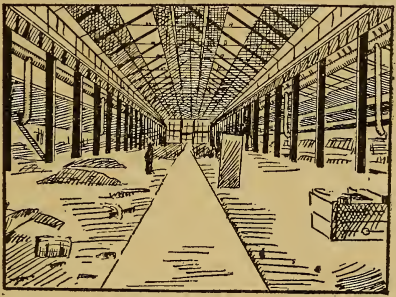


FIG. 243.

A recent type of kerosene burner, the Kauffman, having a mantel somewhat similar to the Wellsbach, is said to furnish a given candle power at less cost than any lamp known.

With any system of lighting, care must be taken to keep the lamps clean and in good order, otherwise their efficiency is soon greatly impaired. Where electric lights are used, the generators should be independent of those which furnish current to the motors. Power for fans, elevators, cranes, sand mixers, etc., is most conveniently supplied by electricity. Each machine should have an independent motor. Electric trucks, operated by storage batteries, and magnetic hoists, for service in the foundry and yard are almost indispensable. In fact the introduction of electricity has so simplified foundry operations that its use is imperative.

Heating and Ventilating

Heating and ventilating the foundry are subjects which formerly received little attention. A few stoves or open fires in iron rings, placed where they would be least in the way, constituted the usual equipment; foundries fitted with steam heating or hot-air systems were exceptional, Gradually foundrymen have learned to appreciate the advantages of a comfortable working temperature and good ventilation, as shown by increased output. A cold shop and chilled or partly frozen sand heaps may easily reduce the value of a morning's work from 20 to 25 per cent. As foundry operations require active physical exertion, the temperature of the shop should not exceed 50° to 55° F. At 7 o'clock in the morning the building should be warm throughout. For this purpose direct and vacuum steam heating systems are used with good results. Both are open to objections. The warm air is not evenly distributed; much of it is sent to the upper part of the building, where it does no good. With either system several hours are required in extremely cold weather to produce a comfortable temperature in the morning. Cold air enters through the windows and doors, causing drafts and an uneven distribution of heat.

More satisfactory results are furnished by the fan and hot-blast system. This consists of a sheet-iron chamber, in which are placed the requisite number of coils heated either by direct or exhaust steam, if the latter is available, an exhaust fan and the distributing pipes. The fan draws the air over the coils and from the chamber and forces it about the building through large ducts, from which branch pipes are taken at proper intervals; through these branches the warm air is discharged at the desired spots within the shop. This system is largely used and possesses advantages over those having direct radiation.

The amount of heat absorbed by air flowing over pipes increases rapidly with the velocity of the air. When the velocity of the air current flowing over the pipes in the heating chamber is about 1500 feet per minute (the usual velocity) the area of the heating surface required to accomplish a given heating effect is only about one-fifth that for direct radiation. With the fan and hot-blast system the building is filled with air under slight pressure, termed a plenum, which prevents cold air from entering; warm air flows out through all leaks. The warm air is discharged from the pipes near the floor, and uniformly distributed through the lower part of the building. By reason of such distribution and the great volume of air discharged, the shop may be quickly warmed in the morning. If the fan is driven by an independent engine, the exhaust steam is sent directly to the coils, thereby making the expenditure for power nominal. Where live steam is not available for an engine the fan may be driven by a motor. With the motor-driven fan, the watchman can start the apparatus during exceedingly cold nights, and thereby prevent the sand heaps from freezing. The ducts are usually circular in section, made of galvanized iron and supported by the chords of the building so as to clear the crane way.

The sketch below shows the usual arrangement for fans and ducts. In shops of moderate size, where but one fan is required, the ducts, of course, must run all around the building.

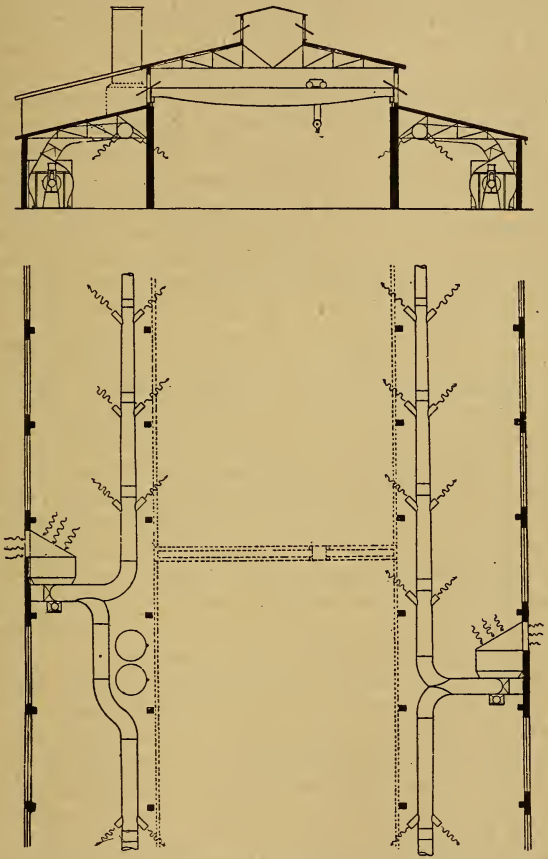


FIG. 244.—Typical Arrangement of Heating and Ventilating System for Foundry with Unobstructed Craneway.

From the ducts, discharge pipes are dropped at intervals of from 30 to 40 feet. These usually terminate about 8 feet above the floor line, and leave the ducts at an angle of about 45°, inclined in the direction of the air currents. Where the discharges are dropped as above stated, the open ends should incline about 20° from the vertical; they should alternately face the walls and the center bay. Six square inches of discharge opening are ordinarily allowed for every 1000 cubic feet of space, and the aggregate area of the openings should be 25 per cent greater than the area of the ducts. From these data the size of the ducts may be calculated for any building of known dimensions.

Underground ducts with vertical discharge pipes are desirable, as they offer no obstruction to foundry operations, but they are quite expensive; the overhead ducts seem best to meet all requirements.

Where steam or hot air is used for heating, the matter of ventilation requires no provision, except for that period of the day occupied in melting, as the leakages are sufficient to supply an abundance of fresh air. During the heat, vapor and gases rise in great volumes; to permit them to escape or to permit fresh air to enter, the swiveled windows in the monitor are opened.

Where steam heat is employed, discomfort is occasionally experienced during cold or stormy weather, as the gases fall as soon as they begin to cool, and the vapor is condensed by the incoming air. With the hot-blast system this difficulty does not occur, since the plenum is sufficient to drive out the gases and vapor through the open windows. Mr. W. H. Carrier of the Buffalo Forge Company, Buffalo, N. Y., has discussed the subject of Foundry Heating and Ventilating so fully in a paper presented at a meeting of the American Foundrymen's Association, that advantage is taken of the opportunity presented through the courtesy of the Buffalo Forge Company to make extensive extracts therefrom: "The proper distribution of heat in the foundry is comparatively difficult. In general the problem is that of a large open space, affording little opportunity for efficient placing of direct radiation. On account of the monitor type of building usually employed, there is relatively a great height. The hot air rises up into the lantern and passes out through the ventilators, if fans are not provided to deliver it near the floor. The heated column of air in the building serves to draw cold air from without at every opening. This inward leakage of cold air, not only demands a great amount of heat, but makes a thorough distribution of heat at the floor line most essential for comfort and economy of operation. A slight plenum, or outward leakage, of air at the doors and openings, caused by the delivery and proper distribution of sufficient heated air into the building is the only solution of the difficulty. Ample ventilation is at times most necessary. The lantern type of building is best adapted to quickly ventilate, since the ventilators simply have to be opened to permit the hotter and lighter gases and vapors to pass out. External air must enter the building to replace that escaping through the ventilators. Cold air entering the doors and openings tends to cool and condense the rising vapors. It is therefore essential that a system be installed which will deliver warmed fresh air during the pouring periods, when ventilation is of first importance.

Rapid heating of the building in the morning means that the best efficiency from the men will be obtained over the entire working period. A system which is elastic, and which may be rapidly varied to suit the requirements is to be favored. Coke or gas fired salamanders are apparently the most economical means of heating, as all the heat goes directly into the building. The atmosphere in a tightly closed building heated by this method becomes intolerable, and if sufficient ventilation is provided to make conditions healthful, the amount of heat required is greater than with other systems. The grade of fuel used is also considerably more expensive than that used in other systems of heating, to say nothing of the care of a large number of separate fires scattered about the building.

In heating with direct radiation, steam is usually employed, although hot-water systems with forced circulation have been successfully operated. Unless there is a large amount of hot water available, it is not an economical system to employ, on account of the greatly increased amount of radiating surface required at the lower temperature. In steam heating, the high pressure, the low pressure or the vacuum system of distribution may be used; the selection of the particular system depends on load conditions. Where high-pressure steam is available, and there is no exhaust steam, it should of course, be used. If, however, there is no high pressure or exhaust steam available from the power plant, then an independent low-pressure boiler should be installed, furnishing steam at from 5 pounds to 10 pounds pressure. For low-pressure work cast-iron boilers may be used; no boiler feed pumps are required. The boiler should be placed at a level low enough for the condensation to drain back by gravity. If this is impracticable, then a centrifugal pump may be employed to return the condensed water to the boiler. A vacuum system should always be used when exhaust steam from the power plant is available. In a vacuum system of distribution, the back pressure should not exceed 1 pound, as otherwise the losses will outweigh the gain. The fan system is undoubtedly the best for foundry heating and ventilating, and it is particularly adapted to the severe requirements of foundries, and other buildings of this construction, where there are large open spaces to be heated. The principal advantages of the fan system over direct radiation are:

1. The thorough distribution of heat secured by discharging the air under pressure through suitable outlets, with sufficient velocity to carry the heat to the points where it is most needed without causing perceptible draughts.

2. No heat is wasted as in direct radiation, where a large part is sent directly through the walls, with slight effect upon the temperature of the building. The fan system affords means of supplying heat directly to the interior of the building.

3. No heat is wasted by heating unoccupied spaces, as along the roof and in the monitor. Tests of the fan system installed in foundries have, in certain instances, shown lower temperatures in the monitors than at 5 feet above the floor line.

4. Fan systems heat up very much more rapidly in the morning, when it is desirable to bring up the temperature in as short time as possible.

5. It gives a rapid warm air change, which effectually removes smoke, steam and dust during pouring time; an effect possible only with a fan system. During such periods, when ventilation is required, the fresh and return air dampers should be adjusted to take all the air from out of doors. During the remainder of the day, however, the greater part of the air should be returned from the building to the apparatus, so that the heat required for ventilation may be the least possible. Precaution should always be taken to see that this feature is provided for.

6. Fan systems cost less to install properly, since the apparatus is centrally located, and it is not necessary to pipe the steam to all parts of the building as in direct radiation.

7. The cost of maintenance is less, since the radiating surface of a direct system along the walls is frequently damaged, while in the centrally-located fan apparatus, it is thoroughly protected.

As in direct radiation, steam or hot water can be used in the fan system heater coils; but as the cool air is drawn over these coils by the fan, a great deal more heat is obtained from the same amount of heating surface. This permits the square feet of radiation to be reduced about two-thirds. The fan is often driven by a direct-connected steam engine, the exhaust from which is used in the heater coils. This is an exceedingly economical method, as practically all of the heat of the steam is utilized.

A new type of fan heating system, which is giving the highest degree of satisfaction, has been developed by the Buffalo Forge Company; this is the direct air furnace system. Instead of burning fuel under boilers, generating steam, transferring steam from boilers to heater coils through a long run of pipe, and finally giving up heat to air from the heater coils, this system transfers the heat of the burning fuel directly to the air for distribution. An efficiency of 85 to 90 per cent has actually been attained, as against the usual efficiency of 50 to 60 per cent derived from steam service. The Buffalo Forge Company has made many installations using gas for fuel, and recently erected one in which powdered coal was used. Fuel oil can also be employed. The construction of the furnace is similar to that for a water tube boiler. The hot gasses pass through the tubes, a fan draws the circulating air around the tubes, by which it is heated, and then distributes it through the building. Fig. 244 shows one of these furnaces recently installed in an important factory in the West. The main hot air ducts from the fan are usually made of galvanized iron, and are carried in the roof trusses. When these ducts are placed at a height not exceeding 20 feet, the air may be delivered directly into the building through short outlets. The design of these outlets is of particular importance to the success of the system. The velocity must be properly proportioned to the height, to the size of the outlet and to the horizontal distance which the air is to be blown. The greater the distance and height above the floor, and the smaller the outlets, the higher the velocity must be to obtain the proper distribution. On the other hand, if the velocity is excessive for these conditions, objectionable draughts will be produced.

In some cases the main pipe has to be placed too far above the floor to permit good distribution of heat at the floor line with short outlets. In such cases it is usual to provide drop pipes from the main at the columns or along the side walls. Where the drop pipes are placed at the columns, each pipe is usually provided with two branches; one blowing toward the base of the windows at the side walls, the other blowing toward the center of the building. Where the drop pipes are extended downward at the side walls, it is usual to provide three outlets to each pipe, two blowing sidewise along the walls, and the third outward toward the center of the building.

In wide buildings it is customary to run two lines of pipes along the columns on each side; while in narrower buildings it is possible to obtain an entirely satisfactory distribution of heat with one line of main pipe, having outlets so proportioned as to blow across the building to the further side. A very neat, though more expensive system of distribution is with underground main ducts, with galvanized iron vertical risers, arranged along the columns or side walls; or in some instances, as in particularly wide buildings, at both places. The system of outlets in this case will be practically the same as where drop pipes are used. Fans may be either motor or engine driven. When an abundance of exhaust steam is available for use in the heater coils, the motor-driven fan will be found the more economical and satisfactory. It is preferred by many on account of the simplicity of operation and the slight care and attention required. With small fans it is good practice to direct-connect the motor to the fan; but with the larger apparatus the speed of operation is so low as to make it advisable to belt-drive the fan, by reason of the high cost of slow speed motors. Engine-driven fans are advisable when moderately high pressure steam is available. The steam can be used to drive the fan and the exhaust is available for the heater coils. This method is exceedingly economical, since practically all of the heat is utilized.

The power used to drive the fan is almost negligible, as the engine is really little more than a pressure reducing valve. The speed of operation with engine drive is also much more flexible, allowing a wider range of speed, as may be necessitated by varying weather conditions. Direct radiation and the fan system of heating cost practically the same to install, the fan system as a rule being somewhat cheaper. Of course, with the fan system, the power necessary to drive the fan is additional, and it might seem that the operating expense would be somewhat more than with direct radiation; but the more equable distribution of heat by the fan system cuts down the losses and reduces the radiating surface materially. The operating expenses of the two systems, however, vary little in the long run."

CHAPTER XXVII

FOUNDRY ACCOUNTS

Any system of foundry accounting must be subject to variation in details to meet the requirements of different classes of work.

A system suitable for a foundry producing pipe, car wheels or other standard work must be modified in some of its details to adapt it to the requirements of a jobbing foundry. The value of an accounting system, aside from determining the cost of production, lies in reducing the expenses and in pointing out by comparative analysis the direction in which reductions can be made.

Cost keeping is too often neglected. Many foundrymen establishing prices, etc., by those of competitors, have absolutely no knowledge of actual costs. There are few branches of business in which the indirect expenses, those apart from the cost of material and labor, exceed those of the foundry. Only by constant comparison, by tracing increase or decrease from one period to another, and continually following lines indicating improved results, can the expenses be made to approach the minimum.

An effective cost system must not only furnish accurate results, but must furnish them promptly, so as to permit ready and periodical comparison.

Prompt information as to any means of increasing production or of decreasing losses or costs greatly enhances its value. The system must not be so elaborate as to render it impractical, but simplicity must not be accompanied with neglect. One that is not accurately or systematically followed is worse than useless. Any effective system requires a large amount of clerical work, but the results are profitable in the highest degree.

The one given below has been in satisfactory use by a large manufacturing establishment, making castings for its own consumption.

An order emanates from the management, going to the drawing room. There it is given a shop order number. A form bearing this number is filled out, showing the patterns required, the drawing number, pattern number and number of castings wanted from each pattern, date of delivery from the foundry and any changes to be made. This form, No. 1, passes to the Requisition Clerk, who makes a requisition in quadruple, form No. 2, on the foundry. This form is about six by nine inches; and as many sets of blanks, all bearing the same shop order number, are used as are required. These forms are in shape for indexing with guide cards. Three of each set of these forms after completion are sent to the foundry, and the fourth is filed in the office.

Of the three sets sent to the foundry, one is marked "Foundry Requisition," one "Pattern Shop" and the third "Core Room."

The foundry clerk fills in date of receipt, date for delivery of patterns and cores and the casting date; then, having marked on them the deliveries required, he transmits to the Pattern Shop and Core Room their respective requisitions. The Pattern Shop and Core Room foremen each stamp them with date of receipt.

FOUNDRY REQUISITION

Williams & Jones

Form 2.

Shop Order, 5486. Date, 3/9/10. Castings wanted, 4/4/10.

For 25 9×12 C. Crank, S. Valve Throttling Engines.

Name of part	Drawing number	Pattern number	No. of pieces wanted	Alterations
Cylinder	7984	46,854	25	Increase thickness of flange at exhaust outlet ⅛ inch.
Front head	8092	46,855	25	
Back head	8093	46,856	25	
St'f'ng box gland	8140	46,857	25	
Steam chest cover	8098	46,859	25	Add 1/16 inch to each end of cover.
Steam chest glands	8099	46,860	25	
Cylinder lagging	7642	46,861	100	
Piston	7990	46,862	25	Reduce diameter ⅛ inch.
Piston ring	7991	46,863	8	

Requisition received in foundry, 3/10/10.
Requisition received in pattern shop.
Requisition received in core room.

Order to be completed, 3/31/10.
Floor date, 3/22/10.
Patterns wanted, 3/21/10.
Cores wanted, four sets, 3/22/10.
Four sets each day thereafter.

Record of Castings Made

Date	Good	Bad	Date	Good	Bad	Date	Good	Bad	Date	Good	Bad
3/22	3	1	3/29	2							
3/23	4										
3/24	4										
3/25	4										
3/26	4										
3/28	4										

In filling out the floor or casting date, the date of delivery, etc., the foundry clerk knows that only four cylinders can be made at each heat. He therefore fixes the date for completion at 3/31/10; this allows four days to provide for any contingencies. The Foundry Requisition is then filed under its floor date.

At the end of each week the index cards up to that date are withdrawn from the front and passed to rear of card box. There are enough cards in the box to cover six months or a year as desired.

Any unfilled orders at the end of the week are advanced to the first date of the coming week, so that the current orders are all at the front of the box. Each day the foreman and clerk spend time to select orders and make out a program for the next heat.

As the orders are completed, each requisition with its supplementary orders is filed away for reference.

The Foundry Pattern Loft is divided into two parts, one for uncompleted orders (Live End), and the other for completed orders (Dead End).

The patterns are delivered by Pattern shop at the Live End.

A man from Pattern Storage has a book in which he takes receipts for patterns delivered. He also receipts for patterns which he removes from Dead End.

Precisely the same system is pursued with core boxes. The Pattern Shop delivers and removes the boxes, taking and giving receipts.

Attached to each pattern is a tag, on which all the data above the heavy line is made out in Pattern Shop: all below is filled out in Foundry.

PATTERN CARD

Form 3	*Moulder's Tag.*	*Foundry Tag.*
	Date issued, 3/21/10. Shop order, 5486. Name of piece, 9×12 cylinder. Pattern No. 46,854. No. wanted 25. Date 3/31.	Date issued, 3/21/10 Shop order, 5486. Name of piece, 9×12 cylinder. Pattern No. 46,854. No. wanted 25, date, 3/31.
	Name of moulder, *John Hayes.* Date in sand, 3/22/10. Tally //// //// //// //// //// Moulder must return this tag with pattern.	Name of moulder, *John Hayes.* Date in sand, 3/22/10. Moulder's time. *John Hayes* — $\frac{22}{9}$ $\frac{23}{9}$ $\frac{24}{9}$ $\frac{25}{9}$ $\frac{26}{9}$ *John Hayes* — $\frac{27}{9}$ $\frac{28}{9}$ $\frac{29}{9}$ *Wm. Moran* — $\frac{22}{9}$ $\frac{23}{9}$ $\frac{24}{9}$ $\frac{25}{9}$ $\frac{26}{9}$ *Wm. Moran* — $\frac{27}{9}$ $\frac{28}{9}$ $\frac{29}{9}$

The tag is perforated across the middle. When the pattern is issued to the moulder, the clerk tears off and retains the foundry tag on which the time is entered and then filed away. The moulder's tag is destroyed when pattern is removed to storage.

The foreman of core room enters time of core makers on core room requisition. It will be noticed that the clerk has not only entered on the Foundry tag the time of John Hayes, but also that of Wm. Moran, helper.

There must be a case in which are kept cards showing records of pig iron, scrap, coke, sand, sea coal, fire clay and any other material received in car lots.

PIG IRON CARD

PIG IRON

From Jones, Smith & Company

Car, N. P. R.R., 438,827.
Wt., G. T., 24.23.

Brand No. 2, S.

Received, 2/10/10.
Price, $16.50 Dld.

Analysis

Silicon	Sulphur	Phosphorus	Manganese
2.38	.032	.43	.54

Net weight, 54,282.
Expended, 54,660.
Overrun, 378.

BACK OF CARD

Wt. charged, 54,282.
Wt. expended.

2/12..........	8,000
2/15..........	10,000
2/17..........	10,000
2/19..........	12,000
2/22..........	3,660
2/24..........	9,000
2/26..........	8,000
	54,660
Overrun..........	378

On back of this card the withdrawals and corresponding dates are entered and balance cast up on face.

The cards for sand, fire clay, etc., are the same as for coke, without the analysis. It is advisable, however, to have these supplies analyzed occasionally.

COKE CARD

Coke	
Form 5.	
Car No. 7482, N. Y. C.	Received, 2/7/10.
Ovens, Hamilton by-product.	Weight, 32,600.
$4.85 Deld.	
Analysis	
	Per cent
Fixed carbon	85
Sulphur	8
Ash	11
Moisture	1

As a matter of convenience to the foreman in making up the mixture, it is desirable to enter the pig iron in a special book, as per diagram below as well as to keep the cards.

PIG IRON

Form 6. Sample Page of Pig Iron Book.

Date received	Car No.	Brand	Net weight	Expended	Analysis
12/9/09	132,568	No. 2 S	78,594	12/20	1* Si 3.25 S .03 P .89 Mn .82 2* Si 3.09 S .032 P .85 Mn .76
12/9/09	35,689	No. 2 S	76,432	12/27	1 Si 2.84 S .038 P .76 Mn .68 2 Si 2.80 S .040 P .74 Mn .66
12/15/09	46,351	No. 2 N	69,496	1/14/10	1 Si 2.19 S .027 P .29 Mn .75 2 Si 2.10 S .026 P .27 Mn .74
1/7/10	25,135	No. 3 N	58,439	2/8/10	1 Si 1.67 S .024 P .26 Mn .69 2 Si 1.65 S .023 P .24 Mn .67
2/10/10	439,827	No. 2 S	54,282	3/2/10	1 Si 2.38 S .032 P .43 Mn .54 2 Si 2.25 S .036 P .48 Mn .52
					1 2
					1 2

* No. 1 is the furnace analysis; No. 2, that of the foundry chemist.

The Heat Book is given on page 592. In this book the foreman enters for the coming heat the irons which are to be used and the mixture. The remainder of the account may be filled out later by the clerk after returns are made. This book is of the greatest importance as it enables the foreman to repeat at once any mixture used at any time, or for any particular purpose.

The sheet shown is for the heat of 2/22/ from which 4 cylinders are to be poured and a special charge (the first) containing 10 per cent steel scrap is made. The cylinders weigh about 500 pounds each, and as there are crank disc and other castings requiring strong iron, the entire first charge will contain steel.

The charges are 4000 pounds each, and the mixture is uniform throughout the heat, except for first and last charges. Turning to the Pig Iron Book, the foreman selects such iron as will furnish the desired mixture for cylinders, also those for the remaining charges and enters them on the heat book. A memorandum is given the boss of the yard gang, showing the car numbers and the amount of iron from each car for each charge.

The number of charges for the ordinary mixture is left blank until later in the day, when the total amount to be melted is ascertained.

The weighman has a pad of forms upon which he prepares a slip for each charge giving the car number, weight of iron from each car, weight of coke and lime.

Each charge of iron is piled by itself on cupola platform in regular order. The coke with limestone is sent up in cars as the charging of cupola proceeds.

SAMPLE SHEET FROM HEAT BOOK

WILLIAMS & JONES FOUNDRY

Form 7. Heat of 3/22/10.

Pig iron	Car No.	Weight per charge, pounds	No. of charges	Analysis	Remarks
Silvery.....	8,296	200		Si 4.20 S .03 P .72 Mn .68	
No. 2 Sou .	439,827	400		Si 2.25 S .036 P .48 Mn .52	
No. 2 Sou. .	46,351	400		Si 2.10 S .026 P .27 Mn .74	First charge
No. 2 Nor..	328,503	800	1	Si 2.29 S .023 P .24 Mn .67	
No. 2 Nor..					
Scrap.......	......	1800		Si 2.10 S .084 P .63 Mn .63	
Steel scrap .	......	400			
No. 2 Sou. .	27,935	800		Si 3.75 S .017 P .86 Mn .36	
No. 2 Nor..	328,503	600		Si 2.29 S .023 P .24 Mn .67	20 charges
No. 2 Nor..	45,541	200	20	Si 1.92 S .024 P .28 Mn .63	
Scrap.......	......	2400		Si 2.10 S .084 P .68 Mn .63	
Clean-up...	......	1050	1		Last charge

Amount Charged

Pig iron.		33,800
Scrap.		49,800
Steel scrap.		400
Clean-up.		1,050
Total.		85,050
Coke.	10,950. Returned 320.	10,630
Flux.		1,600

Production

Good castings.		66,466
Bad castings.		2,708
Gates and sprues.		6,106
Over iron.		5,143
Shot.		650
Clean-up.		1,670
Total accounted for.		82,743
Lost in melt.		2,307
Per cent melt in good castings.		78.2
Per cent castings good.		96.1
Per cent castings bad.		3.9
Per cent melt in returns.		19.0
Per cent loss in melt.		2.7
Iron melted per pound coke.		8 lbs. to 1

Mixtures

1st charge special.	5% car 8296. 20% car 328,503.	10% car 439,827. 10% steel.	10% car 46,351. 45% scrap.
Regular charges.	20% car 27,935. 60% scrap.	15% car 328,503.	5% car 45,541.

Analysis

Computed.	1st charge.	Si 1.66	S .075	P .42	Mn .46	Have analyses made as required.
Computed.	Regular.	Si 2.21	S .088	P .63	Mn .47	
Actual.	1st charge.	Si 1.64	S .080	P .43	Mn .45	
Actual.	Regular.	Si 2.23	S .092	P .65	Mn .44	

Cost of Labor

	Productive		Non-productive		Totals		Gen. Av.	
	Hours	Cost	Hours	Cost	Hours	Cost	Cost per hour	Helpers are included in foundry as productive.
Foundry......	1133.6	$274.90	180	$28.80	1697.2	$383.38	22.60	
Core room.....	113.6	34.08	36	5.76				
Cleaning room	.....	.....	234	39.84				
Total......	1247.2	$308.98	450	$74.20				

Blast on, 1:50 P.M. Pressure, 9 ounces. First iron, 2 P.M.
First tap, 2:15 P.M. Bottom dropped, 4:45 P.M.
Test bar special. Transverse, 2800.
Test bar regular. Transverse, 2200.

The melter and boss of the yard gang are each furnished with a copy of charging schedule. After the charges are all up, the weighman turns in to foundry office, slips for the bottom coke, and one for each charge giving complete weights of everything entering the cupola.

Form 9. CHARGING SCHEDULE Date, 3/22/10.

Charges	Materials	Weights
1st charge............	Bottom coke..................................	2850
	Steel scrap..................................	400
	Car 8296..................................	200
	Car 439,827..................................	400
	Car 46,351..................................	400
	Car 328,503..................................	800
	Scrap (selected)..................................	1800
20 charges............	Coke..................................	400
	Car 27,935..................................	800
	Car 328,503..................................	600
	Car 45,541..................................	200
	Scrap..................................	2400
Last charge..........	Returned coke..................................	100
	Clean-up..................................	1050
	Use 80 pounds limestone from third to nineteenth charge inclusive.	

WEIGH TICKET

Form 10.
Charge No. 1. Date, 3/22/10.

Coke bottom	2850
Steel scrap	400
Car 8296	200
Car 439,827	400
Car 46,351	400
Car 328,503	800
Scrap	1800

Limestone.

WEIGH TICKET

Form 10.
Charge No. 2. Date, 3/23/10.

Coke	400
Car 27,935	800
Car 328,503	600
Car 45,541	200
Scrap	2400

Limestone.

On the day following the heat, after recovering the iron from the gangways, cinders, etc., the yard foreman turns the weight into the office.

RETURNS FROM FOUNDRY

Form 11.
3/23/10. Heat of 3/22/10.

Bad castings	650
Over iron	5143
Shot	650
Clean-up	1670
Returned coke	320

The bad castings on above slip are those thrown out in the foundry, to which are subsequently added those rejected in the cleaning room.

From the moulder's tags, turned in on the 22nd, and from information obtained from the floor concerning work on tags which have not been turned in, the clerk prepares in part, duplicate cleaning room reports. He enters the shop order numbers, pattern numbers, names of parts and number of parts made. This report then goes to foreman of cleaning room, who completes it, sending one copy to the foundry office and the other to the work's office.

The form is given on page 597. As many sheets as are necessary are used for each heat.

The Time Book, Weigh Tickets, Foundry Returns and Cleaning Room Report furnish all the data, except analysis and test, for completion of entry in heat book for 3 22 10. Information as to the last two items is obtained from time to time as required. The heat report is made out in duplicate; original sent to Works Office and duplicate filed in Foundry. This is followed by a weekly summary. At the end of each month an inventory is taken of all supplies; and their cost, per hundred pounds good castings, is determined for the month passed. This cost is used in making out foundry reports for the succeeding month.

All supplies except the bulky materials, such as sand, fire clay, etc. are kept in store room and are issued upon requisition from foremen or clerk, upon blanks as per sketch.

Requisition on Date, 3/21/10.

Store Keeper, Issue to
Jno. Sullivan,
5 Pounds Silver Lead.
Wm. Wilson, *Foreman.*

These requisitions, together with tallies of sand, fire clay, etc., are turned into office by store keeper at end of month.

Careful scrutiny and comparison of these monthly statements and expenditures result in marked savings. They promote among the departments a strife for the lowest record. The reduction in the amount of core supplies, nails, rods and sand is especially noticeable.

As regards iron flasks and other castings made for the foundry, if they are for permanent equipment, they are so charged. If on the other hand they are for temporary service, they are charged to foundry at cost of labor, plus the difference between the cost of good castings and scrap.

Monthly comparisons, or more frequent if desired, are made with statements from the works office. Comparisons are likewise made at the end of the fiscal year.

WILLIAMS & JONES FOUNDRY

CLEANING ROOM REPORT

Form 12. Date of heat, 3/22/10.

Shop order	Pattern No.	Name of piece	No. pieces wanted	Made by moulder	Castings made, 3/22/10		No. pieces made, 3/22/10	Weight		Total made
					Good	Bad		Good	Bad	
5486	46,854	Cylinder..........	25	No. 221 Jno. Hayes........	3	1	3	1580	506	3
5486	46,855	Front head........	25	No. 194 Alex. Forbes.......	2		2	96		2
5486	46,856	Back head........	25	No. 217 Wm. Jones.........	4		4	198		4
5486	46,857	S. B. glands.......	25	No. 214 P. Hale...........	3		3	30		3
5486	46,859	S. C. cover........	25	No. 210 F. Walsh..........	2	1	2	210	105	2
5486	46,860	S. C. gland........	25	No. 207 Chas. Lane........	4		4	36		4
5486	46,861	Cyl. lagging.......	100	No. 205 P. Cassady........	12	2	12	84	14	12
5486	46,862	Piston.............	25	No. 201 Jno. Maloney......	6		6	648		6
5486	46,863	Piston ring........	8	No. 198 R. Hall...........	1		1	54		1
5398	78,542	12×14 gov. wheel..	6	No. 186 Wm. Smith........	1		1	1800		3
				Total..................				66,466	2058	
				Gates and sprues.........					6106	

FOUNDRY

Williams &

Form 14.

Heat of

Grade	No. 1		No. 2		No. 3		No. 4	
	Car No.	Weight	Car No.	Weight	Car No.	Weight	Car No.	Weight
	Silvery		Sou.	No. 2 N.				
	8296	200	439,827	400	328,503	12,800		
			46,351	400	45,541	4,000		
			27,935	16,000				
Weight...		200		16,800		16,800		
Cost.....		$1.49		$123.73		$127.51		

	Total melt	Cost of Iron in good castings	Bad castings	Returns not including bad castings	Loss in melt	Accounted for	Per cent melt in good castings	Per cent castings good
Weight...	85,050	66,466	2708	13,569	2307	82,743	78.2	96.1
Cost.....	$634.66	$520.73						

Costs

	Moulding	Making cores	Non-productive	Total	Per 100 pounds good casting	Supplies per 100 pounds good castings	Iron per 100 pounds good castings	Total foundry cost per 100 pounds good castings
Hours....	1133.6	113.6	450	1697.2	2.55			
Cost	$274.98	$34.08	$74.40	$383.38	$0.5765	$0.0396	$0.783	$1.399

REPORTS

Jones Co.

3/22/10.

Steel scrap	Cast scrap	Returns (shot)	Total melt	Coke	Flux	Iron per 100 pounds coke	Cost per 100 pounds melted iron	Remarks
400 $3.00	49,800 $348.60	1050 $4.20	85,050 $608.53	10,630 $25.53	1600 $0.60	8–1	$0.746	

Per cent castings bad	Per cent loss in melt	Per cent melt in total returns	Total cost of melt.. Cr. Returns 16,275 pounds @ .70.	$634.66 113.93	Cost of iron in 100 pounds good castings	
			Cost of iron in good casting	520.73		
3.9	2.7	19			$0.783	

WEEKLY FOUNDRY REPORT

Williams & Jones Foundry

Form 15. Heats of 3/23-25 and 28/10.

Date of heat	Consumption							Product				
February	No. 2 pig iron	No. 4 pig iron	Scrap	Shot	Total	Coke	Flux	Good castings	Bad castings	Returns not including bad castings	Loss in melt	Total
23	36,500	5,800	32,980	5,000	80,360	11,250	1250	57,859	2703	16,172	3626	80,360
25	27,720	3,600	23,880	5,000	60,200	9,540	900	43,344	1340	13,244	2272	60,200
28	27,520	7,800	26,800	....	62,200	9,930	950	45,406	1900	12,406	2488	62,200
Totals..	91,740	17,280	83,740	10,000	202,760	30,720	3100	146,609	5943	41,822	8386	202,760

Summary

	Pounds		
Total iron melted	20,7260	$1476.09	
Total coke used	30,720	74.50	
Total flux used	3,100	1.17	
Total cost melt		1551.76	
Credit			
Returns (including bad castings) 70¢ per 100 pounds	47,765	334.60	
Total loss	8,386		
Total good castings	146,609		1217.16
Total bad castings	5,943		
	Hours		
Total productive labor	2,482	615.72	
Total non-productive labor	1,490	246.29	
Total labor	3,972		826.01
Total cost of supplies			58.05
Total foundry cost of good castings			2137.22
		Per cent	
Per cent of melt in good castings		72.3	
Per cent of melt in bad castings		2.93	
Per cent of melt in bad return (including bad castings)		23.5	
Per cent of melt in loss		4.1	
Per cent of castings good		96.1	
Per cent of castings bad		3.9	
		Cents	
Average cost of labor per hour		21.7	
Cost of iron per 100 pounds		0.728	
Cost of iron melted per 100 pounds		0.765	
Cost of iron in good castings per 100 pounds			0.830
Cost of labor, good castings per 100 pounds			0.588
Cost of supplies, good castings per 100 pounds			0.0396
Total foundry cost, good castings per 100 pounds			1.4576
Iron melted per pound of coke	6.6 lbs.		

MONTHLY EXPENDITURE OF SUPPLIES

WILLIAMS & JONES FOUNDRY

Form 16. February, 1910.

Materials	Quantity				Total	Price	Cost
	Cupola	Core room	Cleaning room	Moulding room			
Anchors							
Belting							
Belt lacing							
Bellows							
Beeswax							
Bolts							
Brick, red							
Brick, fire							
Brick, block							
Brooms							
Barrows, wheel							
Barrows, pig iron							
Brushes, soft							
Brushes, hard							
Brushes, core							
Brushes, casting							
Brushes, camel's hair							
Brushes, paint							
Brushes, white wash							
Brushes, wheel							
Blocks. chain							
Candles							
Cable wire							
Carbons							
Castings							
Cans, blow							
Chisels, cold							
Chaplets							
Charcoal							
Chain							
Chain links							
Chalk							
Chalk, line							
Clay							
Clay, fire							
Clamps							
Clamps, spike							
Clamps, screw							
Core, compound dry							
Core, compound liquid							
Core vent. metallic							
Coke forks							
Coke baskets							

Monthly Expenditure of Supplies (Continued)

Materials	Quantity				Total	Price	Cost
	Cupola	Core room	Cleaning room	Moulding room			
Coke scoops							
Crow bars							
Crucibles							
Cloth wire							
Cups, tin							
Cutter's emery							
Facing mineral							
Flour							
Fuel							
Gauges, wind							
Gauges, air							
Globes, electric							
Globes, lantern							
Glue							
Glutrin							
Grease							
Hammers							
Handles, hammer							
Handles, sledge							
Hose, air							
Hose, water							
Hose, couplings							
Hose, nozzles							
Iron bar							
Iron, sheet							
Irons, draw							
Irons, flasks							
Jackscrew							
Jack-bolts							
Levels, spirit							
Lead, bar							
Lead, sheet							
Lead, pipe							
Lead, red							
Lead, white							
Lead, silver							
Lime							
Lumber							
Litharge							
Lycopodium							
Mallets							
Mauls							

Monthly Expenditure of Supplies (Continued)

Materials	Quantity				Total	Price	Cost
	Cupola	Core room	Cleaning room	Moulding room			
Manganese, ferro							
Mercury							
Molasses							
Nails							
Nuts							
Oil, core							
Oil, coal							
Oil, belt							
Oil, lard							
Oil, linseed							
Oil, hard							
Oil, black							
Oil, machine							
Oil, rosin							
Oil, cans							
Pails, iron							
Pails, wood							
Pencils, lead							
Pipe, iron							
Pipe, fittings							
Picks, cupola							
Pliers							
Pliers, cutting							
Pots, sprinkling							
Paper, sand							
Paper, toilet							
Paper, emery							
Paper, wrapping							
Rammers							
Rammers, bench							
Riddles							
Riddles, brass							
Rivets, copper							
Rivets, iron							
Rosin							
Rope							
Saws, hand							
Saws, hack							
Screws							
Screws, drivers							
Stationary							
Scrapers							
Silicon, ferro							
Straps, lifting							
Stars, tumbler							
Sand, moulding							

Monthly Expenditure of Supplies (Continued)

Materials	Quantity				Total	Price	Cost
	Cupola	Core room	Cleaning room	Moulding room			
Sand, lake							
Sand, bank							
Sand, fire							
Shovels, moulders'							
Shovels, laborers'							
Sprayers, blacking							
Sponges							
Smooth-on							
Swabs							
Sledges							
Stone, emery							
Salt							
Sulphur							
Sea coal							
Talc							
Tacks							
Torches, blow							
Twine							
Straw							
Vitriol							
Wire, iron							
Wire, copper							
Wire, wax vent							
Wire, cable							
Washers							
Wheels, emery							
Wheels, sheave							
Wheels, barrow							
Wrenches, open							
Wrenches, monkey							
Wrenches, pipe							

Total	$284.56
Good castings for month	718.572
Cost of supplies for 100 good castings for February, 1910	$0.0396

Use this price for the month of March, 1910.

MONTHLY COMPARISON OF FOUNDRY ACCOUNTS

Works Office Statement for February, 1910, Williams & Jones Foundry

Form 17.

Foundry Dr.

Materials	Amount	Price	Cost	
No. 2 pig iron, gross tons	155.61	$17.50	$2723.18	
No. 4 pig iron, gross tons	28.56	15.00	248.40	
Scrap, net tons	162.28	14.00	2271.92	
Shot, net tons	16.23	8.00	129.84	$5,373.34
Coke, net tons	61.12	4.85	296.43	
Flux, net tons	5.08	.75	4.03	
Supplies, per 100 pounds		.0396	221.96	522.42
Labor, total fdy. per 100 pounds		.588	3295.74	
Labor, M. shop; Labor, B. S. shop; Labor, P. shop } 328½ hours		.40	131.40	3,427.14
Switching charges			9.00	
Piling pig iron; Unloading pig iron and coke			19.00	
Cartage			12.48	
Castings rejected, net tons	2.24	35.93	80.50	
Salaries in foundry			250.00	
Power per kilowatt-hour		.05	59.80	
Lights per kilowatt-hour		.06	28.85	
Water per 1000 cubic feet		1.00	7.50	467.13
Overhead charges			Monthly allotment	1,384.77
			Total Cost	$11,174.80

Foundry Cr.

Bad castings, net tons	11.39	$14.00	$159.46	
Returns, net tons	78.20	14.00	1094.80	
Rejected castings, net tons	2.24	14.00	31.36	1,285.62
Total cost of good casting, net tons (@ $1.7642 per cwt.)	280.25			$9,889.18

MONTHLY COMPARISON OF FOUNDRY ACCOUNTS

Foundry Statement for February, 1910, Williams & Jones Foundry

Form 18.

Date of heat	Consumption							Product				
February	No. 2 pig iron	No. 4 Pig iron	Scrap	Shot	Total	Coke	Flux	Good castings	Bad castings	Returns not including bad castings	Loss in melt	Total
1	31,570	8,450	28,670	4,480	73,170	11,175	1,110	53,414	1,652	15,177	2,927	73,170
3	23,070	3,850	29,360	....	56,280	11,880	840	41,084	1,271	12,007	1,918	56,280
5	28,120	4,600	26,400	2,500	61,620	9,360	930	43,750	1,823	13,582	2,465	61,620
8	28,680	6,400	30,100	2,500	67,680	10,070	1,020	50,083	2,087	13,430	2,030	67,680
10	23,680	3,300	21,220	2,500	50,700	8,800	750	37,011	1,642	10,024	2,023	50,700
12	40,605	5,750	32,845	1,500	80,700	10,740	1,250	59,718	2,488	15,144	3,350	80,700
15	25,020	6,200	18,980	....	50,200	7,965	750	37,148	1,548	9,496	2,008	50,200
17	29,120	4,200	25,880	3,100	62,300	9,222	930	45,479	1,895	12,746	2,180	62,300
19	26,970	3,950	27,370	5,880	64,170	12,315	960	46,202	2,432	12,969	2,567	64,170
23	36,500	5,880	32,890	5,000	80,360	1,250	1,250	57,859	2,703	16,172	3,626	80,360
25	27,720	3,600	23,880	5,000	60,200	9,540	900	43,344	1,340	13,244	2,272	60,200
28	27,520	7,800	26,880	....	62,200	9,930	950	45,406	1,900	12,406	2,488	62,200
Totals.....	348,575	63,980	324,475	32,460	769,580	122,247	11,640	560,498	22,781	156,399	29,904	769,580

Summary

Total iron melted	769,580	$5552.83	
Total coke used	122,247	296.43	
Total flux used	11,640	4.35	
Total cost melt		5853.61	
Cr.			
Total returns, 70 cents 100 pounds	179,180	1254.26	
Total loss	29,902		
Cost of iron in good castings	560,498		$4599.35
Cost of iron in bad castings	22,781		
	Hours		
Total productive labor	9,565	2369.28	
Total non-productive labor	5,592	926.46	
Total labor	15,157		$3295.74
Total cost supplies			$ 211.96
Total foundry cost good castings			$8107.05
Per cent of melt in good castings		72.8	
Per cent of melt in bad castings		2.96	
Per cent of melt in returns (including bad castings)		23.3	
Per cent of melt in loss		3.9	
Per cent of castings good		96.1	
Per cent of castings bad		3.9	
Average cost of labor per hour		21.7	
Cost of iron per 100 pounds		0.721	
Cost of iron melted per 100 pounds		0.761	
Cost of iron in good castings per 100 pounds			$ .821
Cost of labor, good castings per 100 pounds			$ .588
Cost of supplies per 100 pounds			$ .0376
Total foundry cost per 100 pounds good castings			$1.4466
Iron melted per pound of coke, 6.3 pounds			

ANNUAL COMPARISON OF FOUNDRY ACCOUNTS

Works Office Statement from Jan. 1, 1910 to Jan. 1, 1911, Williams & Jones Foundry

Form 19. Jan. 1, 1911

Foundry Dr.

Materials	Amount	Price	Cost		
No. 2 pig iron, gross tons	1336.32	$17.50	$23,385.60		
No. 4 pig iron, gross tons	210.33	15.00	3,153.95		
Scrap, net tons	1968.39	14.00	27,557.46		
Shot, net tons	159.75	8.00	1,278.45	$55,375.46	
Coke, net tons	511.64	4.85	2,481.00		
Flux, net tons	46.50	.75	34.90	2,515.90	
Supplies, per 100 pounds good castings		.82		2,266.52	
Total fdy labor, 100 pounds good castings		.567		31,344.33	$91,502.21
Labor, machine shop }					
Labor, Bk. S. shop }				785.34	
Labor, Pat. shop }					
Switching charges			92.75		
Yard labor, pig iron and coke			191.25		
Cartage			122.00		
Rejected castings, net tons	10.11	36.50	369.02		
Salaries in foundry			3,000.00		
Power per kilowatt-hour		.05	596.62		
Lights per kilowatt-hour		.06	274.84		
Water per 1000 feet		1.00	115.32	4,761.80	5,547.14
Overhead charges allotted to foundry					16,617.24
Total					$113,666.59

Foundry Cr.

Materials	Amount	Price	Cost		
Bad castings, net tons	112.26	14.00	1,571.64		
Returns, net tons	838.00	14.00	11,732.70		
Rejected castings, net tons	10.11	14.00	141.50		
Over run on pig iron, gross tons	15.46	17.16	265.30		
Total credits, net tons					$13,711.14
Total cost of good casting, net tons @ 1.808 per cwt.	2764.05	36.16			99,955.45
Cost of good castings per 100 pounds		1.808			
Iron melted per pound of coke	7.58				

ANNUAL COMPARISON OF FOUNDRY ACCOUNTS

Foundry Statement from Jan. 1, 1910 to Jan. 1, 1911

Williams & Jones Foundry

Form 20. Jan. 1, 1911.

Month	Consumption							Product				
	No. 2 pig iron	No. 4 pig iron	Scrap	Shot	Total iron	Coke	Flux	Good castings	Bad castings	Returns not including bad castings	Loss in melt	Total
	Net tons	Net tons	Net tons	Net tons	Net tons	Net tons	Net tons	Net tons	Net tons	Net tons	Net tons	Net tons
Jan.	126.76	31.69	131.33	9.60	299.38	41.18	3.36	212.35	8.49	66.56	11.97	299.38
Feb.	174.28	31.99	162.28	16.23	384.79	61.12	5.82	280.25	11.39	78.20	15.37	384.28
Mar.	157.58	39.39	223.32	6.65	426.94	52.40	4.80	307.40	12.29	88.95	18.30	426.94
April	125.92	31.48	135.30	33.60	326.30	44.40	3.67	234.94	9.40	67.98	13.98	326.30
May	109.81	19.99	176.04	25.47	331.31	41.78	3.72	241.13	8.44	67.88	13.86	331.31
June	92.26	15.61	113.11	19.29	240.27	27.05	2.50	171.13	5.59	54.05	9.50	240.27
July	106.48	19.19	143.70	14.90	284.27	30.44	3.18	199.15	7.25	66.50	11.37	284.27
Aug.	95.75	....	126.26	5.80	227.81	26.41	2.60	157.56	5.10	54.52	10.63	227.81
Sept.	85.11	....	122.54	7.52	215.17	24.59	2.40	165.86	4.63	35.40	9.28	215.17
Oct.	100.81	....	185.89	6.08	292.78	44.04	3.30	204.22	10.21	66.13	12.22	292.78
Nov.	133.98	....	217.19	5.26	356.43	48.74	5.88	245.43	12.27	82.81	15.92	356.43
Dec.	187.94	46.73	249.43	9.35	493.45	69.49	8.82	344.63	17.20	110.00	21.62	493.45
Totals	1496.68	236.07	1968.39	159.75	3878.90	511.64	48.05	2764.05	112.26	838.98	163.60	3878.90

Annual Comparison of Foundry Accounts (Continued)

Summary

Total iron melted	Net tons		$3878.90	$55,386.85	
Coke used	" "		511.64	2,481.45	
Flux	" "		47.68	35.76	
Cost of melted iron	" "			57,904.03	
Credit					
By returns	" "		951.24	13,317.36	
Cost of iron in good castings	" "		2764.05		$44,586.71
Total loss in melt	" "		163.60		
		Hours			
Productive labor		90,459		22,388.80	
Non-productive labor	Hours	54,274		8,955.52	
Total labor	"	144,733			31,344.32
Cost of supplies	"		.82		2,266.52
Total foundry cost of good castings	Per ton		$28.29		78,197.55
Per cent of melt in good castings	Net ton	71.30			
Per cent of melt in bad castings		2.89			
Per cent of melt in returns not including bad castings		24.52			
Per cent of melt in loss		4.22			
Per cent of castings, good		96.10			
Per cent of castings, bad		3.90			
Average cost of labor per hour		.2165			
Cost of iron per 100 pounds		0.713			
Cost of iron melted per 100 pounds		0.7463			
Cost of iron in good castings per 100 pounds		0.8065			
Average cost of labor per 100 pounds		0.567			
Average cost of supplies per 100 pounds		0.041			
Average cost of good castings per 100 pounds		1.4145			
Iron melted per pound coke		7.58			

Chart Showing Direction of Transmission of Shop and Foundry Orders, Together With That of Return Reports

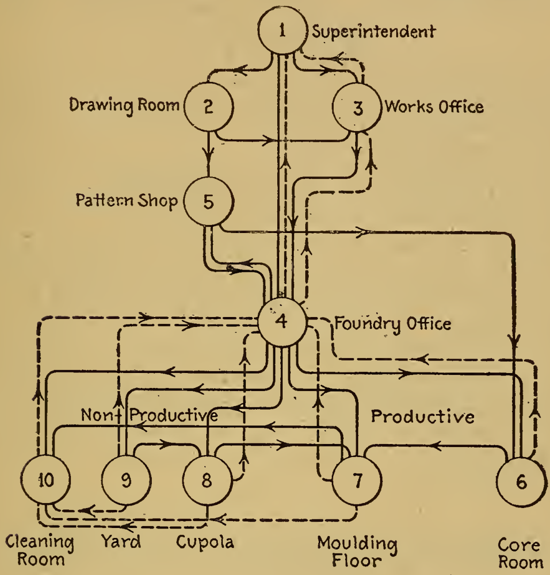


Fig. 245.

The chart above shows the direction of transmission of orders from the superintendent to the foundry office, and thence, with supplementary orders, to the delivery of the completed product at the cleaning room; as also that of return reports to foundry office, works office, and superintendent. Full lines indicate the course of orders outward; dotted lines that of the return reports.

From Superintendent..... (1) to	Works Office.......	(3)
	Drawing Room.....	(2)
	Foundry..........	(4)
From Drawing Room.... (2) to	Works Office.......	(3)
	Pattern Shop......	(5)
From Foundry.......... (4) to	Pattern Shop......	(5)
	Core Room........	(6)
	Floor.............	(7)
From Foundry Office..... (4) to	Cupola............	(8)
	Yard..............	(9)
	Cleaning Room....	(10)

From Pattern Shop......	(5)	to	{ Foundry Office.....	(4)
			{ Core Room.........	(6)
From Core Room.........	(6)	to	Moulding Floor....	(7)
From Cupola............	(8)	to	Moulding Floor....	(7)
From Moulding Floor....	(7)	to	Cleaning Room....	(10)

RETURN REPORTS

From Moulding Floor....	(7)	to	Foundry Office.....	(4)
From Core Room.........	(6)	to	Foundry Office.....	(4)
From Cupola	(8)	to	Foundry Office.....	(4)
From Cleaning Room....	(10)	to	Foundry Office.....	(4)
From Foundry Office.....	(4)	to	{ Superintendent.....	(1)
			{ Works Office.......	(3)
From Works Office.......	(3)	to	Superintendent.....	(1)

The system of accounting as above described has been followed for some years by one of the western foundries, with excellent results. It involves considerable clerical work, but one clerk can handle it.

Some modifications are required to adapt it to a jobbing foundry. These are indicated at once and are readily made.

As showing different methods of foundry accounting, each having its advantages and disadvantages, papers presented on the subject to the American Foundrymen's Association by Mr. B. A. Franklin and Mr. J. P. Golden are given. . . One can be developed from the lot which will meet any requirement.

AMERICAN FOUNDRYMEN'S ASSOCIATION

FOUNDRY COSTS

BY B. A. FRANKLIN, BOSTON, MASS.

" . . . Form 1 illustrates the first method of foundry cost showing: The operations are divided into the elements of

Section A

Melting.

1. Metal. 2. Fuel.
3. Melting Expense.

Section B

Moulding

4. Moulding Labor.
5. Moulding Expense — Floor and Bench separately

Section C

6. Cleaning Labor.
7. Cleaning Expense.
8. Tumbling Labor.
9. Tumbling Expense.
10. Pickling.
11. Pickling Expense.
12. Sand Blasting Labor.
13. Sand Blasting Expense.

Section D

14. Core Labor. 15. Core Expense.

Section E

16. General Expense.

"In discussing this system no attempt is made to discuss the method of getting the information because such methods are simple and easily worked out."

"The Basic Costs are illustrated in Form 1, which shows the weekly operation of the foundry as a whole, and Form 2 represents the cost of an actual casting. Form 3 represents the monthly foundry showing of profit and loss, offering means of proof of the foundry cost and showing the net result."

". . . As nearly as possible foundry shop economy demands, and foundry work permits a daily clean-up, though, of course, some operations happen one day after the beginning."

"A foundry cost might then be a daily record sheet. Weekly records, however, are sufficient generally, and the one presented is on this basis."

FORM 1

"*Section A*. Deals with metal."

"Here is shown, separately for each different mixture, of which one foundry might generally employ two or three, the weights and value of iron charged. These weights may readily be proved by checking as each car or lot of scrap is used up. In the case of scrap made in the foundry or 'own scrap' no value is put on this since it is put into the heat in an iron foundry, on the basis that scrap made on each heat will be approximately the same per cent, and what is made one day is gathered up and used the next day. The exception to this is in the case of 'bad castings,' charged at scrap value, and, as seen later, accounted for in casting cost."

"In a Steel Foundry it would be necessary to change all scrap at scrap value and credit same to particular castings."

"The 'metal-used' value is shown and the pounds melted, but the 'metal cost' is obtained by dividing, not by pounds melted, but by pounds of 'castings made'—*i.e.*, good and bad castings. The bad castings are to be charged to the particular order as will be seen later. We thus arrive at a weekly metal cost for each mixture."

"Likewise for purposes of general guidance, there is shown weekly the 'per cent, of good castings to melt,' the 'per cent of bad castings to castings made,' and the per cent of metal disappearance or 'per cent of loss.' "

"Now for management guidance toward general shop economy, these figures present standards and bases for striving for lower costs — viz., to make the percentage of good castings to the melt as high as possible, to make the percentage of bad castings to castings made as low as possible, and the record will quickly show that the cost fluctuates with these conditions."

"And it will be found that melting and handling of metal and fuel can be done on piece work to bring best economy in metal-cost."

"A definite and valuable point to note is that in addition to the weekly figure of cost per pound, there is carried along the average or 'period cost per pound.' This is the figure to be used in cost work. . . ."

". . . The weekly figures are constantly compared with the period figures showing whether the weekly result is better or worse than the average, and an observation of the detail shows why. . . . "

"In each section it will be noted that the costs are brought down to a few vital units or percentages, and when these vary, they are significant of a gain or loss in economy of production, the reason for which can be readily observed by casting the eye up the details and observing the comparison of them."

". . . *Section B. Moulding.* — Here are two elements to be considered — productive labor and expense. The expense is shown in relation to productive labor. It may be shown in relation to hours if desired, but in each class of moulding labor there is generally no great fluctuation of rate per hour. . . . "

"The productive labor and expense should be kept separately as to class of moulding, as floor, bench, machine, etc., since the expense varies considerably with the class."

". . . A little thought and experiment would seem to show that on the whole the expenses approximately vary according to time spent in productive labor rather than by the pound."

"In the matter of productive labor it is to be understood that money paid for moulding each job, whether day work or piece work, is to be known and used in figuring definite casting, as shown in Form 2."

"It is in this productive labor cost that the first element of variation in casting costs is to be found, the expense percentage being the same or taken as the same, except in the matter of certain direct charges or expenses to be discussed later."

. . . .

"*Section C. Cleaning Castings.* — In the matter of cleaning castings there must be some division. Tumbling, pickling, and sand blasting are taken separately as shown below. This leaves for consideration here the cleaning of castings by other than these three methods and applies mainly to large castings. . . . "

". . . In Tumbling the labor can best be put on piece work and will generally be done by the pound, and expenses will be shown by the pound. . . . "

"In Sand Blasting and Pickling the expenses are shown in relation to productive labor, and the work can be put on piece work. . . . "

"*Section D. Core Room.* — Here the labor can in the main be put on piece work and the expenses shown in detail. . . . "

"*Section E. . . . General Expenses.* — This is shown in relation to productive labor, the items of productive labor being those of Moulding, Core Making and Cleaning operations.

". . . Thus we arrive at certain weekly and period basic figures of cost in the main elements in the foundry of

Metal.
Moulding.
Cleaning.
Core Making.
General Expenses.

"The items of metal and expense are easily provable with the books monthly, and the labor with the pay roll weekly, so that we get a proved weekly picture of the foundry situation as compared with average or period, and we get it in such detail as will show the reasons of all variations of operation. . . . "

"*Consideration of Casting Cost.* The first element to consider is that of direct charges. In many jobs, but by no means all of them, are certain charges which it seems desirable should be charged directly to the particular order. They need in most foundry work be very small in number. These charges must essentially be gathered and held until the job is shipped and cost ready to work out."

FORM 2

"Form 2 illustrates this final casting cost."

"In all castings finished in a given period, the varying elements of unit cost would be purely the productive labor items of moulding and cleaning and direct charges, the metal, fuel, melting, moulding, cleaning and general expense charges being taken from the period figures on the weekly cost sheet."

"Therefore, in working out the cost of a finished casting, it is essential to know of it as a particular job; the weight — and the shipping slip gives that; the moulding and core making labor and the cleaning labor, where average rates per pound are not used."

". . . Direct charges are added and also loss on bad castings. A record of bad castings is necessary and simple."

"On bad castings the loss would depend on how far the work had progressed when discovered as bad, and what work on them had been paid for. The metal, of course, would be credited at scrap value."

"By this method then it will be observed that with very small clerical labor, the practical foundryman or manager gets a weekly, or daily, if he so designs, view of his foundry costs and their fluctuations which form a definite and correct basis for accurate estimate, and he can very quickly get a particular job or casting cost by having the money spent on moulding and cleaning, etc., gathered."

"The Cost System settled, the bookkeeping should be made to parallel the cost system, in which case the monthly showing would be made to show as per Form 3."

"Thus is obtained a complete monthly analysis. In most foundries one clerk and almost invariably two, can operate the system as far as costs are concerned."

. . . .

METAL — SECTION A. NO. I. FORM I

	Oct. 9		Oct. 16		Oct. 23	
	Pounds	Amount	Pounds	Amount	Pounds	Amount
MIXTURE NO. I						
Pig Grade 1	34,240	252.22	33,950	253.87	25,620	191.58
Pig Grade 2	32,270	234.10	33,290	249.68	25,440	187.39
Pig Grade 3	5,680	38.67	14,270	97.15	6,010	40.92
Pig Grade 4	36,310	259.35	32,070	232.65	30,150	218,72
Pig Grade 5	31,500	249.61	32,720	259.28	25,080	198.74
Bought scrap	15,900	106.47	17,000	113.84	11,900	79.68
Own scrap chillers	1,275	0	1,420	0	1,135	0
Own scrap floor scrap	7,300	0	9,000	0	7,700	0
Own scrap bad castings	10,000	70.00	9,000	63.00	10,000	70.00
Own scrap gates	36,100	0	34,800	0	26,500	0
Weekly totals metal used	210,575	1210.42	217,520	1269.47	169,535	987.03
Period totals metal used			428,095	2479.89	597,630	3466.92
Weekly total pounds castings made	149,280		150,441		116,451	
Period total pounds castings made			299,721		416,172	
Good castings made	140,125		139,867		109,069	
Period castings made			279,992		389,061	
Per cent good castings to melt	66.5		64.3		64.3	
Period per cent castings made					65.1	
Bad castings	9,155		10,574		7,382	
Per cent bad castings to castings made	6.1		7		6.3	
Shop scrap	51,800		54,400		43,700	
Per cent shop scrap.						
Total pounds (weekly)	210,080		204,841		160,151	
Total pounds (period).						
Pounds lost	9,495		12,679		9,384	
Period pounds lost			22,174		31,558	
Per cent lost	4.5		5.8		5.5	
Period per cent lost					5.3	
Weekly metal cost per 100 pounds		.81	.84		.85	
Period metal cost per 100 pounds			.83		.83	

METAL — SECTION A — NO. 2. FORM 1

	Oct. 9		Oct. 16		Oct. 23	
	Pounds	Amount	Pounds	Amount	Pounds	Amount
FUEL AND MELTING EXPENSE						
Labor (cupola men).........		45.65		44.70		33.70
Labor (handling coke and coal)......................		1.80				
Labor (miscellaneous).......						
Labor (handling iron).......		5.73		18.51		9.22
Coke.......................		53.50		55.97		44.08
Coal.......................		1.82				
Wood.						
Fire brick.						
Fire clay..................		3.20		.90		8.25
Oyster shells..............		1.64		2.00		1.53
Mica sand..................		2.63		2.63		2.63
Chg. from other depts.						
Analysis of iron.............		30.00		30.00		30.00
Relining cupola and repairs..		2.00				
Tumbling cupola bottom....		2.90				
Crane labor.................		10.95		10.75		9.30
Elevator labor..............		8.66		8.52		6.93
Blower labor................		.53		.80		.44
Handling oyster shells.						
Bituminous facing.						
Interest on investment......		10.20		10.20		10.20
Heat, light and power.......		6.15		6.15		6.15
Taxes, insurance and depreciation....................		12.42		12.42		12.42
Weekly expense.............		199.78		203.55		174.85
Period expense..............				403.33		578.18
Weekly pounds castings made	149,280		150,441		116,451	
Period pounds castings made.			299,721		416,172	
Weekly cost per 100 pounds..		.134		.135		.15
Period cost per 100 pounds...				.135		.139
Weekly pounds melted to pounds fuel...............		8.7		8.4		8.3
Period pounds melted to pounds fuel...............				8.5		8.5

MOULDING — SECTION B. FORM 1

	Oct. 9		Oct. 16		Oct. 23	
	Pounds	Amount	Pounds	Amount	Pounds	Amount
BENCH MOULDING						
Productive labor		884.80		858.80		715.40
Period productive labor				1743.60		2459.00
MOULDING EXPENSE ON PRODUCTIVE LABOR						
Non-productive labor		10.00		10.00		5.00
Flasks, snap boards and matches		6.58		6.88		1.15
Miscellaneous supplies		2.42		2.80		1.09
Ladles		7.50				
Shovels and screens		2.60				1.60
Rammers.						
Charges from other depts.		23.16		10.48		
Making bottom boards for moulding machines				23.54		
Repairing flasks						8.19
Sand		46.37		50.83		37.77
Handling sand		6.30		6.88		6.10
Handling weights and bands.		.47		.40		.62
Reclaiming sand		2.30				
Parting sand.				1.65		
Interest on investment		30.58		30.58		30.58
Heat, light and power.						
Taxes, insurance and depreciation		41.94		41.94		41.94
Weekly expense		192.22		185.98		134.04
Period expense				387.20		512.24
Per cent moulding expense to prod. labor		21.8		21.7		18.7
Period per cent moulding expense to prod. labor				21.1		20.8

Cleaning and Tumbling — Section C. Form 1

	Oct. 9		Oct. 16		Oct. 23	
	Pounds	Amount	Pounds	Amount	Pounds	Amount
Productive labor		74.62		70.92		57.14
Number of pounds cleaned and tumbled	134,462		139,089		105,203	
Period pounds cleaned and tumbled			273,551		378,754	
Cost per 100 pounds (if day work)		.056		.053		.054
Period cost per 100 pounds (if day work)				.054		.053
Cleaning and Tumbling Expense						
Supplies.						
Overseeing		2.45		.40		1.93
Non-productive labor				.40		.75
Charges from other depts.				.65		2.02
Tumblers				4.00		
Stars for tumbling						10.00
Interest on investment		5.44		5.44		5.44
Heat, light and power		55.44		55.44		55.44
Taxes, insurance and depreciation		8.40		8.40		8.40
Weekly gross expense		71.73		74.73		73.98
Stars used in No. 3.						
Weekly expense		71.73		74.73		73.98
Period expense				146.46		220.44
Weekly expense cost per 100 lbs		.053		.053		.07
Period expense cost per 100 pounds				.053		.058
Weekly total cleaning and tumbling cost		.109		.106		.124
Period total cleaning and tumbling cost				.107		.111

PICKLING — SECTION C — NO. 2. FORM I

	Oct. 9		Oct. 16		Oct. 23	
	Pounds	Amount	Pounds	Amount	Pounds	Amount
Weekly prod. labor		20.70		19.82		13.10
Period prod. labor				40.52		53.62
Weekly pounds pickled	62,818		65,600		36,220	
Period pounds pickled			128,418		164,638	
Weekly cost per 100 pounds (if day work)		.033		.030		.036
Period cost per 100 pounds (if day work)				.032		.034
PICKLING EXPENSE						
Non-productive labor		1.75		.75		1.10
Oil of vitriol		2.06				
Hydrofluoric acid		23.92		15.28		10.51
Acid spigots.						
Charges from other depts.				1.88		1.48
Interest on investment		3.40		3.40		3.40
Heat, light and power		3.08		3.08		3.08
Taxes, insurance and depreciation		2.53		2.53		2.53
Total weekly expense		36.74		26.92		22.10
Total period expense				63.66		85.76
Per cent dept. expense to prod. labor		177.5		135.8		168.7
Period per cent dept. expense to prod. labor				155.8		160

SAND BLASTING — SECTION C — NO. 3. FORM 1

	Oct. 9		Oct. 16		Oct. 23	
	Pounds	Amount	Pounds	Amount	Pounds	Amount
Weekly prod. labor..........		4.37		6.06		4.61
Period prod. labor...........				10.43		15.04
Weekly pounds sand blasted.	10,200		11,800		8,100	
Period pounds sand blasted .			22,000		30,100	
Weekly cost per 100 pounds (if day work)..............		.043		.051		.057
Period cost per 100 pounds (if day work)..............				.048		.05
SAND BLASTING EXPENSE						
Non-productive labor........				.61		.41
Supplies......................		.75				
Sand..........................		1.10		1.10		1.10
Charges from other depts....						
Interest on investment......		6.80		6.80		6.80
Heat, light and power.......		15.40		15.40		15.40
Taxes, insurance and depreciation....................		1.38		1.38		1.38
Total weekly expense........		25.43		25.29		25.09
Total period expense........				50.72		75.81
Per cent dept. expense to prod. labor................		581.9		417.4		544.2
Period per cent dept. expense to prod. labor.............				486.3		504.2
Prod. labor..................				486.3		504.2

CORE DEPARTMENT — SECTION D. FORM I

	Oct. 9		Oct. 16		Oct. 23	
	Pounds	Amount	Pounds	Amount	Pounds	Amount
Productive labor		233.55		220.65		165.65
Period productive labor				454.20		619.85
CORE MAKING EXPENSE						
Foreman		24.00		24.00		24.00
Tending ovens		12.65		12.63		7.87
Inspecting cores		19.14		18.08		13.89
Storing cores		12.10		11.78		9.62
General labor		17.11		15.16		13.37
Sand		21.80		18.32		25.89
Coke		2.92		2.45		1.56
Coal		6.44		5.58		1.73
Rosin.						
Miscellaneous supplies		5.54		3.00		1.55
Flour.						
Interest on investment		13.67		13.67		13.67
Heat, light and power		1.43		1.43		1.43
Taxes, insurance and depreciation		21.61		21.61		21.61
Weekly core making expense		158.41		147.71		136.19
Period core making expense				306.12		442.31
Weekly per cent expense to prod. labor		67.8		66.9		82.2
Period per cent expense to prod. labor				67.4		71.3
Labor				67.4		71.3

GENERAL EXPENSE — SECTION E. FORM 1

	Oct. 9		Oct. 16		Oct. 23	
	Pounds	Amount	Pounds	Amount	Pounds	Amount
Executive		27.00		27.00		27.00
Foreman		48.00		48.00		48.00
9396—2—B.						
Non-productive labor		12.74		25.08		16.67
Clerical		49.00		49.00		49.00
Supplies		.87		1.43		1.85
Charged from other Depts.		15.55		26.00		27.75
Scrap		45.38		3.57		13.98
Gas		1.00		1.00		1.00
Inspecting		63.20		64.59		42.65
Injured employee						5.00
Tending pattern safe		11.47		9.60		7.20
Brooms						.75
Interest on investment		11.56		11.56		11.56
Heat, light and power		22.59		22.59		22.59
Taxes, insurance and depreciation		310.45		310.45		310.45
Weekly general expense		618.81		599.87		585.45
Period general expense				1218.68		1804.13
Weekly prod. labor		984.49		955.60		790.25
Period prod. labor				1940.09		2730.34
Per cent expense to prod. labor		62.9		62.8		73.9
Period per cent expense to prod. labor				62.8		65.8

INDIVIDUAL JOB OF CASTING COST. FORM 2

Date, Oct. 12

150 Blocks — J. & S. Co. — 850 pounds

	Amount	Unit cost	Value
Metal		.83 per 100	7.05
Melting expense	850	.139 per 100	1.18
Moulding			3.00
Moulding expense		20.8%	.62
Cores			.50
Cores, expense		71.3%	.36
Cleaning and tumbling		.053 per 100 pounds	.45
Cleaning and tumbling expense		.058 per 100 pounds	.49
Sand blasting.			
Sand blasting expense.			
Pickling		.034	.29
Pickling expense		160%	.46
General expense		65.8%	2.13
Spoiled work			.42 3 spoiled
Total			16.95
Cost per pound			.0199

NOTE. — In this case no selling expense is added, as it might be in many cases.

MONTHLY SHOWING. FORM 3

Quick Assets.
Cash.
Accounts Receivable.

Permanent Assets.
Real Estate.
Building.
Machinery.

Raw Material on Hand.
Pig Iron. (Credit amount used each week as per costs and charge to Mfg. Acct.)
Scrap.

Manufacturing Acct. (See analysis below.)
Expenses undivided (meaning expense supplies not used).

Quick Liabilities.
Accounts Payable.

Permanent Liabilities.
Capital.
Depreciation.
Surplus.

Details of Mfg. Acct.

Dr.

Inventory at start of castings in process.
Metal.............. } each month.
Labor.............. }
Expense............ }

Cr.

Sales.
Inventory of castings in process 1st of each month.

Balance Profit or Loss monthly.

A SUCCESSFUL FOUNDRY COST SYSTEM

BY J. P. GOLDEN, COLUMBUS, GA.

". . . The system consists of, *first:* a Daily Cupola Report, the printed form having column for charge, number of pounds coke and brand, pounds pig iron and brand, and per cent silicon and sulphur, scrap, foreign and returns, and total charge also lines for weekly totals for use in weekly report. Ratio of coke to iron. Time blast started. Time bottom dropped. Average blast pressure. Per cent sulphur in heat. Per cent silicon in heat. Remarks. With each sheet signed by foreman.

"*Second:* The Daily Foundry Report, which is made up by the Rumbling Room foreman. This report consists of a sheet, with columns for name of moulder, hour or piece rate, number of moulds, number of castings, time of helper, pattern description with columns for weights of the various classes of work, as pulleys, sheaves, hangers, hanger boxes, pillow blocks, couplings, cane mills, factories, miscellaneous, etc. Also column for number of pieces lost, total weight of each kind of piece lost, and a cause column for same, showing if it did not run, if it was crushed, blowed, or whatever cause of defect. There is a line at bottom of sheet for weekly totals to be used in weekly report. The daily foundry report furnishes a ready means of comparison of each moulder's record, with his own, or with other moulders as to quantity of good castings, castings lost, weight and cost of same. This report also shows the amount of good and bad castings for each day, in each class, with the weekly total for each.

"*Third:* There is a book for defective and other castings returned from shop and customers, in which is the following rule:

> 'All castings returned by machine shop and customers, before being made over, must be entered in this book, giving cause for making over. Castings returned to foundry from shop or customers, through no fault of foundry, must not be deducted from net foundry castings, and should be considered as foreign scrap. If fault of foundry, they are charged back to foundry and are considered as foundry return scrap.'

This book has columns for showing date returned, by whom, description, cause and weight. Without this book, there could be returned defective castings, which were the foundry's fault and made over without the superintendent's knowledge. With the "to be made over" casting book, all castings returned are specified therein. If the fault of the machine shop, it is so stated. If returned from customers, this is noted with date, description, cause and weight. No casting is made over without being recorded in this book. This book, being always open to superintendent and foreman, saves inquiries and explanations. . . .

"*Fourth:* The Weekly Foundry Report Sheet. This sheet is made up from the daily foundry report, and cupola sheets and the book (to be made over castings). On this sheet, provision is made for record of bad castings returned from foundry, shop or customer, by classes, as well as the good castings made. The total of good castings minus defective castings gives net good castings for week. The average per cent of all castings lost is given, with the per cent loss in each class, with the total pounds pig and foreign scrap charged in cupola, and the net good castings deducted therefrom, we find the per cent lost in remelt, cupola droppings, gangways, etc. The weekly foundry report also has a record of total melt taken from daily cupola sheet, which with net good castings deducted gives per cent, bad castings, gates, etc., of total melt, including foreign scrap, returns and pig. In a division headed cupola charge is given the number of pounds pig iron, foreign scrap and coke, with current price of each and total cost per week. To these amounts are added the total wages, giving a total of material and wages for week, which divided by the net good castings gives the cost per 100 pounds, net castings, including pig iron, scrap, coke, wages.

"The weekly report also has separate divisions for non-producers, rumbling department, moulding department, core shop, day and night cleaning gangs, in which the wages of each class of men in each division are given separately, by total, and the wage cost per hundred pounds. . . . The weekly report also embodies the grand total wages cost per 100 pounds, and this is the most important item, for both foreman and superintendent, for this item is one which the foreman can control to the greatest extent, and which speaks the loudest in favor of the system."

". . . In connection with the weekly report is a detailed report of the pounds of good castings, to whom sold or charged, and price for each lot, and from this sheet is prepared, on the back of the weekly report, a statement giving the estimated profit or loss for week."

"And lastly, there is a ready reference sheet (headed Comparison of Per cents, Wages Cost per 100 Pounds in Different Departments of Foundry from Weekly Foundry Report) giving the comparison by weeks and the average comparison at the end of each year of the following items after date. Net good castings for week, castings killed, in machine shop with columns for the per cent loss of each of the several classes of castings, each class in a separate column, gives a ready means of comparison in that class for all of its weeks.

"There are also columns for the cost per week per 100 pounds, net castings including pig iron, scrap, coke and wages, the wage cost per 100 pounds, in the non-producers, rumbling and moulding departments, also the core shop, day and night cleaning gangs with a column for grand total wage cost per 100 pounds.

"Both the superintendent and foreman have access to the several reports giving each the means of knowing the actual conditions in all departments of the foundry at all times.

"This system gives the foreman the means of remedying a small or defective output by the knowledge of the cause producing it, and to place each moulder upon the class of work to which he is best fitted to increase the general output."

DAILY FOUNDRY REPORT

GOLDENS' FOUNDRY AND MACHINE CO., COLUMBUS, GA.

Date,____________

Name	Hour or piece rate	Number of moulds	Number of castings	Help	Pattern description	Pulleys	Sheaves	Hangers	Hanger boxes	Pillow blocks	Couplings	Cane mills	Lummus	Factory	Agricultural	Miscellaneous	Number pieces lost	Weight	Cause

". . . The system furnishes a basis for closer estimates than formerly upon work a little out of the usual run, by knowing exactly what prices can be accepted for the regular work. The foundry foreman in this case is allowed nominal control of the foundry, hiring and discharging his men, fixing their wages, and increases in pay for his men are by his recommendations subject to approval of superintendent. . . ."

SAMPLE SHEET FROM "CASTINGS RETURNED FROM SHOP AND CUSTOMERS, TO BE MADE OVER."

NOTE: All castings returned by machine shop and customers, before being made over, must be entered in this book, stating cause for being made over.

Castings returned to foundry from shop or customers, through no fault of foundry, must not be deducted from net foundry castings, but should be considered as foreign scrap; but if fault of foundry, they should be charged back to foundry, and considered as foundry return scrap.

All castings returned by shop or customers, in excess of number ordered, will be charged to foundry the same as defective castings, and placed in foundry return scrap, unless otherwise ordered by superintendent.

SAMPLE OF ENTRY

Date returned	By whom returned	Description	Cause	Whose fault	Weight, pounds
April 26, 1909	Our Mach. shop	1 S. B. pulley 36×8—2 7/16 in. bore	Bored too large	Mach. shop	240
April 29, 1909	Our Mach. shop	1 split pulley 24×6—2 3/16 in. bore	Broke lug in splitting	Mach. shop	120
May 3, 1909	Customer	12 gear castings P. 2	Cored too large	Foundry	14
May 5, 1909	Foundry	1 D. B. pulley 36×8—2 15/16 in. bore	Blow hole in face	Foundry	260

WEEKLY FOUNDRY

GOLDENS' FOUNDRY AND MACHINE CO., COLUMBUS, GA.

For Week Ending Friday, 19

Bad castings returned from foundry. Total pounds good castings made. Defective castings returned from shop and customers Net good castings for week. Total amount ( )	Average per cent of castings lost.
Total pounds pig and foreign scrap charged in cupola. Net good castings for week.	Remainder.
Per cent lost in remelt, cupola droppings, gangways, etc.	Total melt. Net good castings.
Per cent bad castings, gates, etc., of total melt. Including foreign scrap, returns and pig.	

Proportionate Wage Cost Per Hundred

No.	NON-PRODUCERS	WAGES	
	Foundry foreman. Foundry assistant. Pulley man. Crane man. Clerk. Cupola tender. Cupola helpers. Carpenters. Watchman.	$ Total $	Wages cost per hundred pounds net castings. $

No.	RUMBLING DEPARTMENT	WAGES	
	Foreman. Assistant. Men.	$ Total $	Wages cost per hundred pounds net castings, chipped, cleaned, and ready to ship. $

Grand Total Wage Cost

NOTE. — Castings returned to foundry from our shop and customers, through no fault of foundry, must not be deducted from net foundry castings, and should be

REPORT

Pulleys	Sheaves	Hangers	Hanger boxes	Pillow blocks	Couplings	Cane mills	Lummus	Factory	Agricultural	Miscellaneous	Total weight

CUPOLA CHARGE

Pounds pig iron @ per hundred $
Pounds foreign scrap @ per hundred
Pounds coke @ per hundred
Total wages $
Total $

Cost per hundred pounds net castings including pig iron, scrap, coke, wages. $

Material cost per hundred pounds net castings made as per sheet. $
Total cost per hundred pounds net castings made as per sheet. $

Pounds in Different Departments

No.	MOULDING DEPARTMENT	WAGES	
	Moulders (white).	$	Wages cost per hundred pounds net castings. $
	Helpers (white).		
	Helpers (black).		
	Total	$	

No.	CORE SHOP	WAGES	
	Foreman.	$	Wages cost per hundred pounds net castings. $
	Core makers.		
	Help.		
	Total	$	

No.	NIGHT CLEANING GANG	WAGES	
	Headman.	$	Wages cost per hundred pounds net castings. $
	Men.		
	Total	$	

No.	DAY CLEANING GANG	WAGES	
	Headman.	$	Wages cost per hundred pounds net castings. $
	Men.		
	Total	$	

per Hundred Pounds $

put in foreign scrap pile. Weekly foundry report, made up from daily foundry report and cupola sheet.

Pounds castings "killed" in machine shop.

Comparison of Per Cents, Wages Cost Per Hundred Pounds, etc., in Different Departments of Foundry, From Weekly Foundry Reports

19 . Goldens' Foundry & Machine Co. Week ending	Net good castings for week	Castings killed in machine shop	Total average per cent castings lost	Per cent pulley castings lost	Per cent sheave castings lost	Per cent hanger castings lost	Per cent hanger box castings lost	Per cent P. block castings lost	Per cent coupling castings lost	Per cent cane mill castings lost	Per cent Lummus castings lost	Per cent factory castings lost	Per cent agricultural castings lost	Per cent miscellaneous castings lost	Per cent lost in remelt cupola droppings, gang-ways, etc.	Per cent bad castings, gates, etc., of total melt, including F. S. return, etc.	Cost per 100 pounds net casting, including pig iron, scrap, coke and wages	Non-producers wages cost per 100 pounds net castings	Rumbling department wage cost per 100 pounds net castings, chipped, cleaned and ready to ship	Moulding department wages cost per 100 pounds net castings	Core shop wages cost per 100 pounds net castings	Night cleaning gang, wages cost per 100 pounds net castings	Day cleaning gang, wages cost per 100 pounds net castings	Grand total wages cost per 100 pounds

CHAPTER XXVIII

PIG IRON DIRECTORY

The Classification and Directory of Pig Iron Brands given herewith are taken from Professor Porter's Report.

"Pig Iron is classified as:

First. — Cold, Warm or Hot Blast.

Second. — Coke, Anthracite or Charcoal.

Third. — Sand or Machine.

Fourth. — Basic, Bessemer, Malleable, Foundry or Forge.

"It is only necessary to define the fourth classification as the others are self-explanatory."

"Basic iron means primarily one with low silicon. The standard for this grade having silicon under 1 per cent and sulphur under 0.05 per cent."

"Bessemer iron means primarily phosphorus under 1 per cent. Standard Bessemer contains from 1 to 1.25 per cent silicon with sulphur under 0.05, but the grade is essentially based on low phosphorus. Irons with extra low phosphorus and variable silicon are sometimes designated as low phosphorus irons."

"Foundry and Forge Irons embrace practically everything in the way of ordinary iron, these grades being subdivided on the basis of silicon and sulphur content."

"The following subclassification of Foundry and Forge iron has been agreed upon by the blast furnace interests of the districts indicated:

CLASSIFICATION AND GRADES OF FOUNDRY IRON

	Silicon, per cent	Sulphur, per cent
SOUTHERN POINTS		
No. 1 foundry	2.75–3.25	.05 and under
No. 2 foundry	2.25–2.75	.05 " "
No. 3 foundry	1.75–2.25	.06 " "
No. 4 foundry	1.25–2.00	.07 " "
Gray forge	1.25–1.75	.08 " "
No. 1 soft	3.00 and over	.05 " "
No. 2 soft	2.50–3.25	.05 " "

Classification and Grades of Foundry Iron (Continued)

	Silicon, per cent	Sulphur, per cent
Eastern Points		
No. 1 X	2.75 and up	.030 and under
No. 2 X	2.25–2.75	.045 " "
No. 2 plain	1.75–2.25	.050 " "
No. 3 foundry	1.25–1.75	.065 " "
No. 2 mill	1.25 and under	.065 " "
Gray forge	1.50 " "	.065 and up
Mottled and White by Fracture, Central West and Lake Points		
No. 1 foundry	2.25–2.75	.05 and under
No. 2 foundry	1.75–2.25	.05 " "
No. 3 foundry	1.75 and under	.05 " "
Gray forge		.05 and over
Buffalo Grading		
Scotch	3.00 and over	.05 and under
No. 1 foundry	2.50–3.00	.05 " "
No. 2 foundry	2.00–2.50	.05 " "
No. 2 plain	1.50–2.00	.05 " "
No. 3 foundry	1.50 (under)	.05 " "
Gray forge		.05 and (over)

Note.—If sulphur is in excess of maximum, it is graded as lower grade, regardless of silicon.

"Charcoal is not as a rule graded according to the above table but is sold by fracture, by analysis, by chill tests, or by some special system of grading according to the custom of the maker and demand of the purchaser."

"It will be noted that so far as Foundry iron is concerned the grading system is based exclusively on silicon and sulphur. One reason for this is that the phosphorus and manganese are fixed by the composition of the ores used, whereas the silicon and sulphur can be varied at will by slight changes in the method of operating the furnace. Since in many, perhaps, the majority of, cases a blast furnace will be limited to a very few ores as a source of supply, it follows that it will be limited also in the range of phosphorus and manganese in the iron it produces. For this reason, a given brand of iron will usually run fairly constant as regards phosphorus and manganese, although its silicon and sulphur can be varied at the wish of the management. However, this condition, while common, is not universal, for some concerns possess a variety of ores and can by mixing them produce iron of any composition desired.

. . . .

"In using this directory please bear in mind that it is not infallible. Much of the data has been difficult to get, a few concerns refusing absolutely to furnish information. Again, in some cases time brings changes in ownership and character of ore supply, etc., and of course, these things will affect the character of the product. In spite of these deficiencies, however, it is believed that the following tables represent the most accurate information along these lines available at the present time and that they will be found of considerable value."

"Finally, it must be emphasized that the use of the data is not to tell the foundryman the exact analysis of any carload of any brand, but rather to help him locate those brands which have, or can be made to have a composition suitable for his work."

"In these tables the percentage of sulphur is not usually given. It should be understood that all furnaces strive for, and usually obtain, low sulphur in their iron. Practically all foundry grades are sold on the understanding that the sulphur is under 0.05 per cent and hence no useful purpose is served in giving the sulphur range except in a very few cases where it normally runs unusually low."

Coke and Anthracite Irons

Adrian. — Adrian fce., Du Bois, Pa. (Adrian fce. Co.)
Hot blast coke, sand cast, foundry iron, from Lake Superior ores.
Sil. 1.0–4.0% Mang. 0.4–1.2% Phos. 0.4–0.9%

Alice. — Alice fce., Birmingham, Ala. (Tenn. Coal, Iron & Ry. Co.)
Hot blast, coke, sand or chill cast iron, from Ala. red and brown ores.

Fdry.	Sil. 1.0–4.0%	Mang. 0.1–0.4% *	Phos. 0.71–0%
Basic	Under 1%	0.1–0.4	Under 1%

Alice. — Alice fce., Sharpsville, Pa. (The Youngstown Sheet & Tube Co.)
Hot blast, coke iron, from Lake Superior ores.
Usually make Bessemer only for use in their own steel works.

Alleghany. — Alleghany fce., Iron Gate, Va. (Oriskany Ore & Iron Co.)
Hot blast, coke, sand cast, foundry iron, from local brown ores.
Sil. 1.0–4.0% Mang. 0.7–1.5% Phos. 0.2–0.6%

Allegheny. — McKeefrey fce., Leetonia, O. (McKeefrey & Co.)
Hot blast, coke, sand cast, foundry iron, from Lake Superior ores.
Sil. 0.7–2.0% Mang. 0.4–0.8% Phos. 0.4–0.7%

* Sometimes higher.

Andover. — Andover fce., Phillipsburg, N. J. (Andover Iron Co.)
Hot blast, coke, sand cast, foundry iron, from local magnetic ore, Lake Superior ore, iron nodules and roll scale.
Sil. 1.5–4.0% Mang. 0.6–1.5% Phos. 0.6–0.9%

A. R. Mills. — (2 stacks), Allentown, Pa. (Allentown Rolling Mills Co.)
Hot blast, anthracite and coke iron, from local hematites and N. J. and N. Y. magnetites.

Ashland. — Ashland fces. (2 stacks), Ashland, Ky. (Ashland Iron & Min. Co.)
Hot blast, raw coal and coke, sand cast iron, from local brown and Lake Superior ores.

High Sil. Fdry.	Sil. 5.0–12.0%	Mang. 0.5–0.8%	Phos. 0.5–0.9%
Bess. Ferro Sii.	9.0–14.0%	0.5–0.8%	under 1.0%

Aurora. — Aurora fce., Columbia, Pa. (Susquehanna Iron Co.)
Hot blast, anthracite and coke, forge and foundry iron, from native and Lake Superior ores.
Not in operation, March, 1910.

Battelle. — Battelle fce., Battelle, Ala. (Lookout Mt. Iron Co.)
Hot blast, coke, sand cast, foundry iron, from local red hematite.
Not in operation March, 1910.

Bay View. — Bayview fces. (2 stacks), Milwaukee, Wisc. (Illinois Steel Co.)
Hot blast, coke, sand cast iron, from Lake Superior ores.

Mall. Bes.	Sil. 1.0–3.0%	Phos. under 0.20%	Mang. 0.50–1.0%
Fdry.	1.0–3.0%	over 0.50%	0.50–1.0

Belfont. — Belfont fce., Ironton, O. (Belfont Iron Works Co.)
Hot blast, coke, fdry iron, sand cast, from Lake Superior and native ores.
Sil. 1.50–2.50% Phos. 0.40–0.70% Mang. 0.50–0.90%

Bellefonte. — Bellefonte fce., Bellefonte, Pa. (Bellefonte Furnace Co.)
Hot blast, coke, sand cast, foundry iron, from native and Lake Superior ores.
Sil. 1.75–4.0% Phos. 0.5–0.7% Mang. 0.5–0.7%

Belmont. — Belmont fce., Wheeling, W. Va. (Wheeling Iron & Steel Co.)
Hot blast, coke, sand cast, from Lake Superior ores.
Make only iron for their own steel plant.

Bessemer. — Bessemer fces. (5 stacks), Bessemer, Ala. (Tenn. C. I. & Ry. Co.)
Same as De Bardeleben, which see.

Bessie. — Bessie fce., New Straitsville, O. (Bessie Ferro Silicon Co.)
Hot blast, coke and raw coal, sand cast, ferro silicon, from Lake Superior low phos. ore.
Sil. 8.0–14.0% Phos. under 0.10% Mang. under 1.0%

Big Stone Gap. — Union fce. No. 1, Big Stone Gap, Va. (Union Iron and Steel Co.)
Hot blast, coke, sand cast, fdry iron, from local fossil brown ores.
Sil. usually high Phos. 0.40–0.80% Mang. 0.40–1.0%

Bird. — Bird fce., Culbertson, O. (The Bird Iron Co.)
Hot blast, coke, sand cast, fdry iron, from Lake Superior and native ores.
Not in operation March, 1910.

Boyd. — Ashland fces. (2 stacks), Ashland, Ky. (Ashland I. & Min. Co., Inc.)
Hot blast, raw coal and coke, sand cast, fdry iron, from Bath Co. & Lake Superior ores.
Sil. 1.50–3.0% Phos. 0.40–0.90% Mang. 0.50–0.80%

Brier Hill. — Grace fce., No. 2, Youngstown, O. (The Brier Hill I. & C. Co.)
Hot blast, coke basic and Bessemer iron, from Lake Superior ores.

Bristol. — Bristol fce., Bristol, Tenn. (Va. Iron, Coal & Coke Co.)
Hot blast, coke, from local brown ores.

Fdry.	Sil. 2.0–2.75%	Phos. abt. 0.50%
Basic (chill cast)	low	abt. 0.60%
	Mang. abt. 0.75%	
	1.0–1.50%	

Brooke. — Brooke fces. (2 stacks), Birdsboro, Pa. (E. & G. Brooke Co.)
Hot blast, anthracite and coke, from Lake Superior, Newfoundland and magnetic ores.

Buckeye. — Columbus fces. (2 stacks), Columbus, O. (The Columbus I. & S. Co.)
Hot blast, coke, chill mold iron, from Lake Superior ores.

Fdry	Sil. 1.0–3.0%	Phos. 0.40–0.60%	Mang. 0.60–0.80%*
Mal. Bes.	0.50–2.50	under 0.20	0.60–1.0.†
Basic	under 1.0	under 0.20	0.80–1.0
Stand. Bes.	1.0–2.0	under 0.10	

* Sometimes higher. † Higher or lower if desired.

Buena Vista. — Buena Vista fce., Buena Vista, Va. (Oriskany Ore & Iron Co.)

Hot blast, coke, chill, and sand cast iron, from Oriskany brown hematite.

Fdry.	Sil. 1.0–4.0%	Phos. 0.2–1.0%	Mang. 0.6–1.5%
Basic	under 1.0	0.2–0.5	0.6–1.5%
Spec. car wheel	1.0–1.50	0.2–0.5	0.6–1.5

Buffalo. — Buffalo Union fce. (3 stacks), Buffalo, N. Y. (The Buffalo U. F. Co.)

Hot blast, coke, sand cast iron, from Lake Superior ores.

Fdry.	Sil. 1.50–3.25%	Phos. 0.40–0.70%	Mang. 0.50–1.0%
Mal.	0.75–2.0	0.10–0.20	0.40–1.0

Burden. — Burden fce., Troy, N. Y. (The Burden Iron Co.)

Hot blast, mixed anthracite coal and coke, occasionally coke alone. Magnetic concentrates from northern New York.

Out of operation March, 1910.

Carbon. — Carbon fce., Perryville, Pa. (Carbon Iron & Steel Co.)

Hot blast, anthracite coal and coke foundry iron, magnetic from N. J. & Lake Champlain, Lake Superior, and foreign ores.

Sil. 1.50–3.00% Phos. 0.40–0.90% Mang. 0.40–0.90%

Carondelet. — Missouri fce., So. St. Louis, Mo. (St. Louis Blast Fce. Co.)

Hot blast, coke, Missouri red and brown hematite.

Analysis refused.

Chateaugay. — Standish fce., Standish, N. Y. (Northern Iron Co.)

Hot blast, coke, sand cast, foundry iron, from local magnetic ores.

Sil. 1.0–3.0% Phos. 0.02–0.035% Mang. 0.15–0.50%

Chattanooga. — Chattanooga fce., Chattanooga, Tenn. (The Southern I. & S. Co.)

Hot blast, coke, sand cast, foundry iron, from Alabama red and Georgia brown hematite.

Sil. 1.50–3.50% Phos. 1.0–1.5% Mang. 0.6–1.0%*

Cherry Valley. — Cherry Valley fce., Leetonia, O. (United I. & S. Co.)

Hot blast, coke, sand cast, foundry iron, from Lake Superior ores.

Sil. as desired Phos. 0.20–0.60% Mang. 0.60–0.80%

Chickies. — Chickies fces. (2 stacks), Chickies, Pa. (Standard Iron Min. & Furnace Co.)

Hot blast, anthracite and coke, sand cast, foundry iron, from magnetites.

* Sometimes higher.

Citico. — Citico fce., Chattanooga, Tenn. (Citico Furnace Co.)
Hot blast, coke, sand cast, soft foundry, from red and brown hematites from Tennessee and Georgia.
Sil. 2.0–3.0% Phos. abt. 1.25% Mang. abt. 0.60%

Claire. — Claire fce., Sharpsville, Pa. (Claire Furnace Co.)
Hot blast, coke, Bessemer iron only, from Lake Superior ores.

Cleveland. — Cleveland fces. (2 stacks), Cleveland, O. (Cleveland Furnace Co.)
Hot blast, coke, from Lake Superior ores.
Analysis refused.

Clifton. — Clifton fces. (2 stacks), Ironton, Alabama. (Alabama Consol. C. & I. Co.)
Hot blast, coke, sand cast, foundry iron, from local brown hematite.
Sil. 1.0–6.0% Phos. 0.35–0.70% Mang. 1.0–2.0%

Climax. — Hubbard fces. (2 stacks), Hubbard, O. (The Andrews & Hitchcock I. Co.)
Hot blast, coke, sand cast, strong foundry iron, from Lake Superior ores.
Sil. 1.35–1.75% Phos. 0.30–0.40% Mang. 0.50–0.80%

Clinton. — Clinton fces., Pittsburgh, Pa. (Clinton I. & S. Co.)
Hot blast, coke, sand cast, foundry iron, from Lake Superior ores.
Sil. up to 3.0% Phos. 0.20–0.75% Mang. 0.50–1.0%

Colonial. — Colonial fces. (2 alt. stacks), Riddlesburg, Pa. (Colonial Iron Co.)
Hot blast, coke, sand cast, foundry iron, from Lake Superior and native ores.
Sil. up to 4.0% Phos. 0.40–0.60% Mang. 0.50–0.80%

Covington. — Covington fce., Covington, Va. (Low Moor Iron Co. of Va.)
Hot blast, coke, sand cast iron, from native brown hematite.

	Sil.	Phos.	Mang.
Fdry.	1.5–3.0%	0.90–1.2%	0.70–1.0%
High Sil. silvery	4.0–8.0	0.90–1.2	0.70–1.0

Cranberry. — Cranberry fce., Johnson City, Tenn. (The Cranberry Fce. Co.)
Hot blast, coke, sand cast, low phos. iron, from local magnetic ore.
Sil. 1.0–3.5% Phos. under 0.035% Mang. 0.4–0.6%

Crane. — Crane fces. (3 stacks), Catasauqua, Pa. (Empire S. & I. Co.)
Hot blast, anthracite and coke, sand cast iron, from N. J. magnetic, Pa. hematite, Lake Superior and foreign ores.

Fdry.	Sil. 0.75–3.50%	Phos. 0.60–0.90%	Mang. 0.50–2.0%
Basic	under 1.0	under 1.0	0.50–0.80
Low phos.	1.0–3.0	under 0.03	0.50–3.0

Crozer. — Crozer fces. (2 stacks), Roanoke, Va. (Va. Iron, Coal & Coke Co.)
Hot blast, coke, sand cast iron, from Va. limonite, mountain and specular ores.

Fdry.	Sil. 2.10–2.75%	Phos. 0.60–0.80%	Mang. 0.60–0.90%
Basic	abt 0.70	abt. 0.70	abt. 1.25

Cumberland. — Cumberland fce., Cumberland Fce. P. O., Tenn. (Warner Iron Co.)
Hot blast, coke, sand cast foundry, from local brown and red hematites.
Sil. 2.0–4.5% Phos. abt. 2.0% Mang. abt. 0.30%

Dayton. — Dayton fces. (2 stacks), Dayton, Tenn. (The Dayton C. & I. Co. Ltd.)
Hot blast, coke, sand cast, foundry iron, from Tenn. fossil and Georgia hematite.

De Bardeleben. — Bessemer fces. (5 stacks), Bessemer, Tenn. (Tenn. C. I. & Ry. Co.)
Hot blast, coke, sand and chill cast iron, from local red and brown hem.

Fdry. & Mill	Sil. up to 3.25%	Phos. 0.70–1.0%	Mang. 0.10–0.40
Basic	up to 1.0	up to 1.0	0.10–0.40

Detroit. — Detroit fce., Detroit, Mich. (Detroit Furnace Co.)
Hot blast, coke, sand cast, foundry iron, from Lake Superior ores.

Dora. — Dora fce., Pulaski City, Va. (Va. Iron, Coal & Coke Co.)
Hot blast, coke, sand cast foundry iron, from native limonite and mountain ores.
Sil. 1.50–3.00% Phos. 0.40–0.80% Mang. 0.50–0.90%

Dover. — Dover fce., Canal Dover, O. (The Pa. Iron & Steel Co.)
Hot blast, coke, sand cast, foundry iron, from Lake Superior ores.

Dunbar. — Dunbar fces. (2 stacks), Dunbar, Pa. (Dunbar Furnace Co.)
Hot blast, coke, sand or machine cast iron, from Lake Superior specular and soft ores.

Fdry.	Sil. 1.5–3.0%	Phos. 0.30–0.60%	Mang. 0.30–0.60%
Malleable	1.0–2.0	under 0.20	0.30–0.80

Durham. — Durham fce., Riegelsville, Pa. (Durham Iron Co.)
Hot blast, anthracite and coke, sand cast iron, from Lake Superior, local hematite and New Jersey magnetite.

Eliza. — Pittsburgh fces. (5 stacks), Pittsburgh, Pa. (Jones & Laughlin St. Co.)
Hot blast, coke, Bessemer and basic, machine cast iron, from Lake Superior ores.

Ella. — Ella fce., West Middlesex, Pa. (Pickands, Mather & Co.)
Hot blast, coke, foundry and malleable iron, from Lake Superior ores.
On account of the large assortment of ores available, this furnace can make practically any desired composition.

Embreeville. — Embreeville fce., Embreeville, Tenn. (Embree Iron Co.)
Hot blast, coke, foundry iron, from local brown hematite.

Empire. — Reading, Pa. (Empire Steel & Iron Co.)
Hot blast, anthracite and coke, foundry iron, from Lake Superior, Porman and magnetic ores.
Sil. 2.0–3.0% Phos. 1.25–2.50% Mang. 0.50–1.0%

Emporium. — Emporium fce., Emporium, Pa. (Emporium Iron Co.)
Hot blast, coke, foundry iron, from brown hematite.
Sil. as desired Phos. abt. 0.80% Mang. abt. 0.60%

Ensley. — Ensley fces. (6 stacks), Ensley, Alabama. (Tenn. C. I. & Ry. Co.)
Hot blast, coke, machine cast iron, from red and brown hematite.

Basic	Sil. up to 1.0%	Phos. 0.70–1.0%	Mang. 0.10–0.40%*
Fdry. & Mill	up to 2.50	0.70–1.0	0.10–0.40*

Essex. — Northern fce., Port Henry, N. Y. (Northern Iron Co.)
Hot blast, coke, foundry iron, from local magnetic ores.
Sil. 1.0–2.50% Phos. 0.40–0.90% Mang. 0.10–0.40%

Etowah. — Etowah fces. (2 stacks), Gadsden, Ala. (Ala. Consol.)
Hot blast, coke, foundry iron, from local red and brown hematite.
Sil. 1.0–.06% Phos. 0.70–1.20% Mang. 0.40–0.80%

Eureka. — Same as *Oxmoor*, which see.

Everett. — Earlston fce., Earleston, Pa. (Jos. E. Thropp.)
Hot blast, coke, foundry iron, from Lake Superior and local brown ores.
Sil. 1.50–3.50% Phos. 0.40–0.70% Mang. 0.50–0.90%

* Sometimes higher.

Fannie. — Fannie fce., West Middlesex, Pa. (United Iron & Steel Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.
Sil. as desired Phos. 0.20–0.60% Mang. 0.60–0.80%

Federal. — Federal fces. (2 stacks), S. Chicago, Ill. (Federal Furnace Co.)
Hot blast, coke, mal. and foundry iron, from Lake Superior ore.
Sil. as desired. Phos. as desired. Mang. as desired.

Florence. — Philadelphia fce., Florence, Ala. (Sloss-Sheffield S. & I. Co.)
Hot blast, coke, sand cast, foundry iron, from Ala. brown hematite.
Sil. as desired. Phos. 0.80–1.25% Mang. 0.40–0.80%

Fort Pitt. — Cherry Valley fce., Leetonia, O. (United I. & S. Co.)
Hot blast, coke, spec. car wheel iron, from Lake Superior ore.
Sil. as desired. Phos. 0.20–0.80% Mang. 0.60–0.80%

Franklin. — Franklin fce., Franklin Springs, N. Y. (Franklin Iron Mfg. Co.)
Hot blast, coke, foundry iron, from fossil, red hematite from Clinton, N. Y.
Not in operation March, 1910.
Sil. 2.25–3.0% Phos. 1.25–1.50% Mang. 0.25–0.40%

Gem. — Same as *Shenandoah*, which see.

Genesee. — Genesee fce., Charlotte, N. Y. (Genesee Furnace Co.)
Hot blast, coke, from Lake Superior ore.
Not in operation March, 1910.

Girard. — Mattie fce., Girard, O. (Girard Iron Co.)
Hot blast, coke, foundry iron, from Lake Superior ore.
Sil. 1.50–3.0% Phos. 0.40–0.70% Mang. 0.50–0.80%

Globe. — Globe fce., Jackson, O. (Globe Iron Co.)
Hot blast, raw coal and coke, sand cast, high silicon silvery iron, from native ores.
Sil. 4.0%–12.0% Phos. 0.40–0.80% Mang. 0.40–0.80%

Grafton. — McKeefrey fce., Leetonia, O. (McKeefrey & Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.
Sil. 2.0–2.50% Phos. 0.40–0.70% Mang. 0.40–0.80%

Graham. — Graham fce., Graham, Va. (Va. Iron, Coal & Coke Co.)
Hot blast, coke, foundry and basic iron, from Lake Superior and native brown hematite.

Hamilton. — Hamilton fce., Hanging Rock, O. (The Hanging Rock Iron Co.)
Hot blast, coke, sand cast iron, from native block and limestone and Lake Superior ores.

Fdry.	Sil. as desired.	Phos. 0.3–0.4%	Mang. 0.5–0.7%
Mall.	as desired.	under 0.20	

Hector. — Clinton fce., Pittsburgh, Pa. (Clinton Iron & St. Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.
Sil. up to 3.50% Phos. 0.50–0.75% Mang. up to 1.0%

Helen. — Helen fce., Clarksville, Tenn. (Red River Furnace Co.)
Hot blast, coke, sand cast soft, fluid foundry iron, from local brown hematite.
Sil. 2.0–3.0% Phos. abt. 1.25% Mang. 0.40–0.60%

Henry Clay. — Henry Clay fces. (2 stacks), Reading, Pa. (Empire Steel & Iron Co.)
Hot blast, anthracite coal and coke, foundry and forge iron, from local hematite and magnetite.
Fdry. Sil. 1.50–4.50% Phos. 2.50–3.50%

Hillman. — Grand River fces. (2 stacks), Grand Rivers, Ky. (Hillman Land & Iron Co.)
Hot blast, coke, foundry and forge sand cast iron, from local brown hematite.
Not in operation March, 1910.

Hubbard. — Hubbard fces. (2 stacks), Hubbard, O. (The Andrews & Hitchcock Iron Co.)
Hot blast, coke, malleable iron, from Lake Superior ore.
Sil. 1.0–2.0% Phos. under 0.20% Mang. under 0.80%

Hubbard Scotch. — Hubbard fces. (2 stacks), Hubbard, O. (The Andrews & Hitchcock Iron Co.)
Hot blast, coke, soft foundry iron, from Lake Superior ores.
Sil. up to 3.00% Phos. 0.50–0.65% Mang. about 0.60%

Hudson. — Secausus fce., Secausus, N. J. (Hudson Iron Co.)
Hot blast, anthracite coal and coke, foundry iron, from N. Y. magnetite, N. J. limonite and Lake Superior ores.
Sil. up to 3–4% Phos. 0.60–0.95% Mang. up to 0.50%

Imperial. — Shelby fce., No. 1, Shelby, Ala. (Shelby Iron Co.)
Hot blast, coke, iron from local brown hematite.
Not in operation March, 1910.

Inland. — Inland fce., Indiana Harbor, Ind. (Inland Steel Co.)
Hot blast, coke, basic iron, from Lake Superior ores.

Ironaton. — Clifton fces. (2 stacks), Ironaton, Ala. (Alabama Consol. C. &. I. Co.)
Hot blast, coke, foundry iron, sand cast, from local brown ore.
Sil. 1.0–6.0% Phos. 0.70–0.90% Mang. 0.70–1.0%

Iroquois. — Iroquois fces. (2 stacks), S. Chicago, Ill. (Iroquois Iron Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.
Sil. 1.35–2.50% Phos. 0.3–0.4%* Mang. 0.40.–0.70%

Ivanhoe. — Ivanhoe fce., Ivanhoe, Va. (Carter Iron Co.)
Hot blast, coke, sand cast, foundry iron, from local and Lake Superior ores.
Sil. % as desired. Phos. abt. 0.40% Mang. abt. 0.70%

Jenifer. — Jenifer fce., Jenifer, Ala. (Jenifer Iron & Coal Co.)
Hot blast, coke, sand cast, foundry iron from local brown hematite.
Not in operation March, 1910.

Jisco. — Jisco fce., Jackson, O. (Jackson Iron & Steel Co.)
Hot blast, coke and raw coal, high silicon iron, from native and Lake Superior ores.
Sil. 4.0–14.0% Phos. up to 0.9% Mang. up to 0.9%

Josephine. — Josephine fce., Josephine, Pa. (Josephine Furnace & Coke Co.)
Hot blast, coke, sand cast iron, from Lake Superior ores.

Fdry.	Sil. up to 4.0%	Phos. 0.50–0.80%	Mang. under 0.90%
Bessemer	1.25–2.0	0.085–0.10	under 0.90

Juniata. — Marshall fce., Newport, Pa. (Juniata Fce. & Fdry. Co.)
Hot blast, anthracite coal and coke, sand cast, foundry iron, from local hematite and Lake Superior ores.
Sil. up to 2.0% Phos. under 1.0% Mang. under 1.0%

Lackawanna. — (12 stacks). (Lackawanna Steel Co.)
Lackawanna fces. (7 stacks), Lackawanna, N. Y.
Bird Coleman fces. (2 stacks), Cornwall, Pa.
Colebrook fces. (2 stacks), Lebanon, Pa.
N. Cornwall fce., Cornwall, Pa.
Hot blast, coke, Bes. and basic iron, from Lake Superior and Cornwall ores.

Lady Ensley. — Lady Ensley fce., Sheffield, Ala. (Sloss-Sheffield S. & I. Co.)
Hot blast, coke, sand cast, foundry iron, from local brown hematite.
Sil. as desired. Phos. 1.0–1.50% Mang. 0.50–0.80%

* Sometimes higher.

La Follette. — La Follette fce., La Follette, Tenn. (La Follette C., I. & Ry. Co.)
Hot blast, coke, sand cast, foundry iron, from local fossil, red and brown hematite.
Sil. up to 4.0% Phos. 1.0–1.25% Mang. 0.50–0.75%

L. C. R. — Lebanon, O. (Lebanon Reduction Co.)
Coke and charcoal, low phos. pig.
Operated for experimental purposes only.

Lebanon Valley. — Lebanon fce., Lebanon, Pa. (Lebanon Valley Fce. Co.)
Hot blast, anthracite coal and coke, sand cast, foundry iron, principally Cornwall ore.
Sil. as desired. Phos. 0.3–0.4% Mang. 0.3–0.4%

Leesport. — Leesport fce., Leesport, Pa. (Leesport Furnace Co.)
Hot blast, anthracite coal and coke, sand cast, foundry iron, from local hematite and magnetite.
Sil. as desired. Phos. 0.2–0.3% Mang. abt. 1.00%

Lehigh. — Lehigh fce., Allentown, Pa. (Lehigh Iron & Steel Co.)
Hot blast, anthracite and coke, sand cast, foundry and mill iron, from Lake Superior, local hematite and New Jersey magnetite.
Not in operation March, 1910.

Lone Star. — Sam Lanham fce., Rusk, Texas. (State of Texas.)
Hot blast, coke, from local brown hematite.
Not in operation March, 1910.

Longdale. — Longdale fce., Longdale, Va. (The Longdale Iron Co.)
Hot blast, coke, chill cast iron, from local brown hematite.

	Sil.	Phos.	Mang.
"Basic"	under 1.0%	0.90–1.0%	1.0–1.5%
"Off Basic Sil."	1.0–1.75	0.90–1.0	1.0–1.50
"Off Basic Sul." *	0.25–0.75	0.90–1.0	1.0–1.50

Lowmoor. — Lowmoor fces. (2 alt. stacks), Lowmoor, Va. (Lowmoor I. Co. of Va.)
Hot blast, coke, sand cast iron, from local brown hematite.

	Sil.	Phos.	Mang.
Fdry.	1.50–3.0%	0.80–1.0%	0.90–1.2%
High Sil. silvery	4.0–8.0	0.80–1.0	0.90–1.2

Macungie. — Macungie fce., Macungie, Pa. (Empire Steel & Iron Co.)
Hot blast, anthracite and coke, sand cast, foundry iron, from local hematites, Lake Superior and foreign ores.
Sil. 0.75–3.50% Phos. 0.60–0.90% Mang. 0.50–2.0%

* Sulphur over .05 per cent.

Malleable. — Iroquois fces. (2 stacks), S. Chicago, Ill. (Iroquois Iron Co.)
Hot blast, coke, sand cast, foundry iron, from Lake Superior ores.
Sil. 1.25–2.50% Phos. under 0.2% Mang. 0.40–0.70%

Mannie. — Allens Creek fces. (2 stacks), Mannie, Tenn. (Bon Air C. & I. Co.)
Hot blast, coke, sand cast, foundry iron, from local brown hematite.
Sil. up to 8.0% Phos. abt. 2.0% Mang. 0.40–0.65%

Marshall. — Marshall fce., Newport, Pa. (Juniata Fce. & Fdry Co.)
Hot blast, anthracite and coke, sand cast, foundry iron, from local hematite and Lake Superior ores.
Sil. up to 3.0% Phos. under 1.0% Mang. under 1.0%

Martin's Ferry. — Martin's Ferry fce., Martin's Ferry, W. Va. (Wheeling Iron & Steel Co.)
Hot blast, coke, Bessemer only, from Lake Superior ores.

Max Meadows. — Max Meadows fce., Max Meadows, Va. (Va. Iron, Coal & Coke Co.)
Hot blast, coke, sand cast iron, from Va. limonite and mountain ores.

Fdry.	Sil. 1.75–2.75%	Phos. 0.40–0.70%	Mang. 1.0–2.0%
Basic	under 1.0	under 1.0	Mang. abt. 1.50

Miami. — Hamilton, O. (Hamilton Iron & Steel Co.)
Hot blast, coke, iron, from Lake Superior ores.

Fdry.	Sil. 1.0–3.50%	Phos. 0.40–0.70%	Mang. 0.50–0.80%
Mall.	0.75–2.0	under 0.20	0.60–1.0
Basic	under 1.0	under 0.20	as desired

Missouri. — Missouri fce., S. St. Louis, Mo. (St. Louis Blast Furnace Co.)
Hot blast, coke, basic iron, from Mo. red and brown hematites.
Analysis refused.

Musconetcong. — Musconetcong fce., Stanhope, N. J. (Musconetcong Iron Works.)
Hot blast, anthracite and coke, foundry iron, from New Jersey magnetic, Lake Superior, Cuban and other foreign ores.
Sil. 2.50–3.50% Phos. 0.60–0.70% Mang. 0.60–0.70%

Napier. — Napier fce., Napier, Tenn. (Napier Iron Works.)
Hot blast, coke, foundry iron, from local brown hematite.
Sil. 2.0–2.75% Phos. 0.75–1.50% Mang. 0.40–0.80%

Nellie. — Ironton, O. (The Ironton Iron Co.)
Hot blast, coke, from Lake Superior ores.

Fdry.	Sil. 1.25–3.0%	Phos. 0.40–0.60%	Mang. 0.50–0.80%
Mall. Bes.	1.0–2.0	under 0.20	0.50–0.90

Nellie. — Alice & Blanche fces. (alt. stacks), Ironton, O. (The Marting I. & S. Co.)
Hot blast, coke, sand cast iron, from Lake Superior and Kentucky ores.

Fdry.	Sil. 1.0–3.0%	Phos. 0.40–0.60%	Mang. 0.50–1.0%
Mall.	0.50–3.0	under 0.20	0.50–1.0

Niagara. — Niagara fce., N. Tonawanda, N. Y. (Tonawanda Iron & Steel Co.)
Hot blast, coke, foundry iron, from Lake Superior hematite.
Analysis refused.

Nittany. — Same as *Bellefonte*, which see.

Norton. — Ashland, Ky. (Norton Iron Works.)
Hot blast, coke, mall. and Bess. iron, from Lake Superior ores.

Norway. — Colonial fces. (2 alt. stacks), Riddlesburg, Pa. (Colonial Iron Co.)
Hot blast, coke, foundry iron, from Lake Superior and native ores.
Sil. up to 4.0% Phos. 0.60–0.90% Mang. 0.70–1.0%

Oxford. — Oxford fce., Oxford, N. J. (Empire Steel & Iron Co.)
Hot blast, anthracite and coke, basic iron, from local magnetic and special ores.
Sil. under 1.0% Phos. under 1.0% Mang. 0.75–1.25%

Oxmoor. — Oxmoor fces. (2 stacks), Oxmoor, Ala. (Tenn. Coal, I. & Ry. Co.)
Hot blast, coke, foundry and forge, sand cast, from red and brown hematite.
Sil. up to 3.50% Phos. 0.70–1.0% Mang. 0.10–0.40%*

Perry. — Carbon fce., Perryville, Pa. (Carbon Iron & Steel Co.)
Hot blast, anthracite and coke, Bess. iron, from Lake Superior, foreign, Lake Champlain and New Jersey ores.

Paxton. — Paxton fces. (2 stacks), Harrisburg, Pa. (Central I. & S. Co.)
Hot blast, anthracite and coke, various ores.

Peerless. — Iroquois fces. (2 stacks), S. Chicago, Ill. (Iroquois Iron Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.
Sil. 3.0–3.5% Phos. 0.30–0.40% Mang. 0.40–0.70%

Pencost. — Bessie fce., New Straitsville, O. (Bessie Ferro-Silicon Co.)
Hot blast, coke, ferro-silicon, from Lake Superior ores.
Sil. 5.0–12.0% Phos. 0.30–0.70% Mang. under 1.0%

* Sometimes higher.

Pequest. — Pequest fce., Buttzville, N. J. (Pequest Co.)
Hot blast, anthracite and coke, foundry iron, from N. J. magnetic and manganiferous ores.
Out of blast March, 1910.

Perry. — Perry fce., Erie, Pa. (Perry Iron Co.)
Hot blast, coke, sand cast iron, from Lake Superior ores.

Fdry.	Sil. 1.75–3.0%	Phos. 0.40–0.70%	Mang. 0.40–0.80%
Fdry.	1.00–2.00	1.15–0.30	0.40–0.80
Special	2.00–3.50	1.00–1.50	0.40–0.80

Pioneer. — Pioneer fces. (3 stacks), Thomas, Ala. (Republic Iron & St. Co.)
Hot blast, coke, foundry iron, from red and brown hematite.
Sil. up to 3.50%* Phos. 0.75–0.95% Mang. 0.40–0.80%

Poughkeepsie. — Poughkeepsie fces. (2 stacks), Poughkeepsie, N. Y. (Poughkeepsie Iron Co.)
Hot blast, anthracite and coke, from Lake Superior, local brown hematite and Port Henry magnetite ores.
Not in operation March, 1910.

Poughkeepsie. — Poughkeepsie fces. (2 stacks), Poughkeepsie, N. Y. (Poughkeepsie Iron Co.)
Not in operation March, 1910. (See *Poughkeepsie.*)

Princess. — Princess fce., Glen Wilton, Va. (Princess Furnace Co.)
Hot blast, coke, foundry iron, from local limonite.
Sil. up to 3.0 or 4.0% Phos. 0.60–0.80% Mang. up to 1.0%

Pulaski. — Pulaski fce., Pulaski, City, Va. (Pulaski Iron Co.)
Hot blast, coke, foundry iron, from local brown ores.
Sil. 2.0–3.50% Phos. 0.50–0.80% Mang. 0.40–0.70%

Punxy. — Punxy fce., Punxsutawney, Pa. (Punxsutawney Iron Co.)
Hot blast, coke, foundry iron, from Lake Superior hematite.
Sil. 1.0–4.0% Phos. 0.40–0.60% Mang. 0.45–1.60%

Radford. — Radford Crane fce., Radford, Va. (Va. Iron, Coal & Coke Co.)
Hot blast, coke, foundry iron, from Va. limonite and mountain ores.
Sil. 1.5–2.75% Phos. abt. 1.00% Mang. abt. 1.25%

Rebecca. — Rebecca fces. (2 stacks), Kittanning, Pa. (Kittanning I. & S. Mfg. Co.)
Hot blast, coke, chill cast iron, from Lake Superior ores.

Fdry.	Sil. up to 3.0%	Phos. 0.40–0.80%	Mang. under 1.0%
Basic	under 1.0	under 0.50	under 1.0
Mall.	1.0–1.50	under 0.20	under 1.0

* Sometimes up to 8.00 per cent.

Red River. — Helen fce., Clarksville, Tenn. (Red River Furnace Co.)
Hot blast, coke, from local brown hematite.

Fdry.	Sil. 2.0– 3.0%	Phos. abt. 0.80%	Mang. abt. 0.65%
Scotch	3.5– 5.5	abt. 0.80	abt. 0.60
High Silicon	8.0–12.0	abt. 0.80	abt. 0.40

Rising Fawn. — Rising Fawn fce., Rising Fawn, Ga. (Southern I. & S. Co.)
Hot blast, coke, iron from red and brown hematites.
Not in operation March, 1910.

Roanoke. — West End fce., Roanoke, Va. (West End Furnace Co.)
Hot blast, coke, foundry iron, from Va. brown hematite.
Sil. as desired. Phos. 0.75–1.0% Mang. 0.50–1.0%

Robesonia. — Robesonia fce., Robesonia, Pa. (Robesonia Iron Co. Ltd.)
Hot blast, anthracite and coke, foundry iron, from Cornwall ore.
Sil. 2.0–3.50% Phos. under 0.04% Mang. abt. 0.10%

Rockdale. — Rockdale fce., Rockdale, Tenn. (Rockdale Iron Co.)
Hot blast, coke, iron from Tenn. brown hematite.

Fdry.	Sil. 2.0 –2.75%	Phos. abt. 1.40%	Mang. abt. 0.25%
Ferro Phos.	0.07–0.75	17.0–22.0	0.15–0.25

Rockhill. — Rockhill fces., (2 alt. stacks), Rockhill P. O., Pa. (Rockhill Fce. Co.)
Hot blast, coke, iron from fossil and Lake Superior ores.
Not in operation March, 1910.

Rockwood. — Rockwood fces. (2 stacks), Rockwood, Tenn. (Roane Iron Co.)
Hot blast, coke, foundry iron, from red fossil ore.
Sil. 1.75–2.75% Phos. abt. 1.40% Mang. abt. 0.50%

Sampson Strong. — Upson fce., Cleveland, O. (Upson Net Co.)
Hot blast, coke, foundry iron, from Lake Superior ore.
Sil. 1.5–1.8% Phos. 0.40–0.60% Mang. 0.60–1.0%

Sarah. — Sarah fce., Ironton, O. (The Kelley Nail & Iron Co.)
Hot blast, coke, Bessemer iron, from Lake Superior ore.

Saxton. — Saxton fces. (2 stacks), Saxton, Pa. (Jos. E. Thropp.)
Hot blast, coke, foundry iron, from Lake Superior and local brown ores.
Sil. 1.5–3.5% Phos. 0.40–0.90% Mang. 0.50–0.90%

Scottdale. — Scottdale fce., Scottdale, Pa. (Scottdale Furnace Co.)
Hot blast, coke, foundry iron, from Lake Superior ore.

Senega. — McKeefrey fce., Leetonia, O. (McKeefrey & Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.
Sil. 1.0–2.0% Phos. under 0.20% Mang. 0.40–0.80%

Sharpsville. — Sharpsville fce., Sharpsville, Pa. (Sharpsville, Fce. Co.)
Hot blast, coke, mostly Bess. iron, from Lake Superior and New York magn. ores.

Sheffield. — Sheffield fces. (3 stacks), Sheffield, Ala. (Sheffield C. & I. Co.)
Hot blast coke, foundry iron, from Alabama and Tennessee brown hematites.
Sil. as desired. Phos. abt. 1.0;% Mang. abt. 0.50%

Sheffield. — Hattie Ensley fce., Sheffield, Ala. (Sloss-Sheffield S. & I. Co.)
Hot blast, coke, foundry iron, from local brown hematite.
Sil. as desired. Phos. abt. 1.20% Mang. abt. 0.50%

Shenandoah. — Gem fce., Shenandoah, Va. (Oriskany Ore & Iron Co.)
Hot blast, coke, foundry iron, from local brown hem. and Lake Superior ores.
Sil. as desired. Phos. 0.40–0.80% Mang. 0.60–1.0%

Shenango. — Shenango fces. (5 stacks), Sharpsville, Pa. (Shenango Fce. Co.)
Hot blast, coke, basic, chill cast iron, from Lake Superior ores.
Sil. under 1.0% Phos. under 0.05% Mang. 0.70–1.30%

Sheridan. — Sheridan fce., Sheridan, Pa. (Berkshire Iron Works.)
Hot blast, anthracite and coke, foundry iron, sand cast, from Cornwall local hematite.
Sil. 1.0–4.0% Phos. 0.40–0.90% Mang. up to 0.75%

Silver Creek. — Rome fce., Rome, Ga. (Silver Creek Furnace Co.)
Hot blast, coke, sand cast, foundry iron, from red and brown hematite, local.
Sil. up to 5.0% Phos. under 1.0% Mang. up to 2.0%

Silver Spring. — Paxton fces. (2 stacks), Harrisburg, Pa. (Central I. & S. Co.)
Hot blast, anthracite and coke, foundry iron, from various ores.

Sloss. — Sloss fces. (4 stacks), Birmingham, Ala. (Sloss-Sheffield S. & I. Co.)
Hot blast, coke, foundry iron, from red fossil, hard and soft and brown hematites.
Sil. as desired. Phos. abt. 0.75% Mang. abt. 0.40%

Soho. — Soho fce., Pittsburg, Pa. (Jones & Laughlin Steel Co.)
Hot blast, coke, basic and Bes. iron, from Lake Superior ores.

South Pittsburgh. — So. Pittsburgh fces. (3 stacks), So. Pittsburgh, Tenn. (Tenn. Coal, Iron & R.R. Co.)
Hot blast, coke, mill and foundry, sand cast iron, from local hard red hematite, and brown hematite from Georgia.
Sil. up to 3.50%* Phos. 1.00–1.50% Mang. 0.50–1.50%

Spring Valley. — Spring Valley fce., Spring Valley, Wisc. (Spring Valley Iron & Ore Co.)
Hot blast, coke or sometimes charcoal, sand cast iron, from brown hematite ore.

Mall.	Sil. 0.80–1.50%	Phos. under 0.20%	Mang. 1.0–1.5%
Fdry.	1.5–3.00	under 0.20	1.0–1.50

Standard. — Standard fce., Goodrich, Tenn. (Standard Iron Co.)
Hot blast, coke, foundry iron, from local brown hematite.
Sil. 1.75–4.50% Phos. abt. 0.95% Mang. abt. 0.40%

Star. — Star fce., Jackson, O. (Star Furnace Co.)
Hot blast, raw coal and coke, sand cast, Jackson Co. softener, from native limonite and block ores.
Sil. 5.00–12.00% Phos. 0.43–0.80% Mang. abt. 0.70%

Star & Crescent. — Rusk fce., Cherokee Co., Pa. (Frank A. Daniels.)
Hot blast, coke, foundry iron, from local brown hematite and black ores.
Not in operation March, 1910.

Sterling Scotch. — Iroquois fces. (2 stacks), So. Chicago, Ill. (Iroquois I. Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.
Sil. 2.50–3.0% Phos. 0.30–0.40% Mang. 0.40–0.70%

Stewart. — Stewart fce., Sharon, Pa. (Stewart Iron Co., Ltd.)
Hot blast, coke, sand cast iron, from Lake Superior ores.

Bess.	Sil. 1.0–2.50%	Phos. 0.09–0.10%	Mang. 0.60–0.80%
Low Phos.	1.0–2.50	under 0.04	0.20–0.40

Struthers. — Aurora fce., Struthers, O. (The Struthers Fce. Co.)
Hot blast, coke, sand cast iron, from Lake Superior ores.

Basic	Sil. under 1.00%	Phos. under 0.25%	Mang. 0.60–1.2%
Mall.	1.00–1.50	under 0.20	abt. 1.0

Susquehanna. — (2 stacks), Buffalo, N.Y. (Buffalo & Susquehanna I. Co.)
Hot blast, coke, from Lake Superior ores.
Analysis refused.

* Sometimes higher.

Swede. — Swede fces. (2 stacks), Swedeland, Pa. (Richard Heckscher & Sons Co.)

Hot blast, coke, sand cast iron, from Lake Superior and high grade foreign ores.

Fdry.	Sil. up to 3.25%	Phos. up to 0.80%	Mang. up to 0.80%
Basic	up to 1.00	up to 1.0	up to 1.25
Bess.	1.0–2.0	up to 0.10	up to 2.0
Low Phos.	1.0–2.50	up to 0.035	up to 4.50
Spec. High Mang.	1.0–1.50	up to 0.80	over 1.50

Sydney. — Mayville fces. (2 stacks), Mayville, Wisc. (Northwestern Iron Co.)

Hot blast, coke, foundry iron, from Lake Superior and local ores.

Sil. 1.40–2.50% Phos. 0.60–0.80% Mang. 0.50–1.0%

Talladega. — Talladega fce., Talladega, Ala. (Northern Ala. C., I., & R.R. Co.)

Hot blast, coke, foundry iron, from native brown ore.

Not in operation March, 1910.

Temple. — Temple fce., Reading, Pa. (Temple Iron Co.)

Hot blast, anthracite and coke, foundry iron, from Lake Superior, local hematite, N. J. magnetic and foreign ores.

Sil. 1.75–3.50% Phos. 0.60–0.80% Mang. 0.40–0.80%

The Mary. — Mary fce., Lowellville, O. (The Ohio Iron & Steel Co.)

Hot blast, coke, Bessemer only, from Lake Superior ores.

Thomas. — Thomas fce., Milwaukee, Wisc. (Thomas Furnace Co.)

Hot blast, coke, sand cast iron, from Lake Superior ores.

Mal. Bess.	Sil. 1.00–2.00%	Phos. 0.10–0.20%	Mang. 0.40–1.25%
Fdry.	as desired.	0.15–0.60	0.50–1.25

Thomas. — (9 stacks.) (The Thomas Iron Co.)

Hokendauqua fces. (4 stacks), Hokendauqua, Pa.

Keystone fce. (1 stack), Island Park, Pa.

Lock Ridge fces. (2 stacks), Alburtis, Pa.

Saucon fces. (2 stacks), Hellertown, Pa.

Hot blast, anthracite and coke, sand and chill cast iron, from local brown hematite, N. J. magnetic and foreign ores.

Fdry.	Sil. as desired.	Phos. 0.60–0.90%	Mang. abt. 0.50%
Basic	under 1.0%	under 1.0	variable

Toledo. — Toledo fces. (2 stacks), Toledo, O. (Toledo Furnace Co.)
Hot blast, coke, sand cast iron, from Lake Superior ores.

Mal.	Sil. 1.00–2.00%	Phos. under 0.20%	Mang. 0.60–1.25%
Basic	under 1.0	under 0.20	0.60–1.25
Fdry.	1.25–2.25	0.50–0.60	0.60–1.25
Scotch	2.25–3.00	0.50–0.60	0.60–1.25

Tonawanda Scotch. — Niagara fces. (2 stacks), N. Tonawanda, N. Y. (Tonawanda Iron & Steel Co.)
Hot blast, coke, foundry iron, from Lake Superior hematite.
Analysis refused.

Top Mill. — Top fce., Wheeling, W. Va. (Wheeling Iron & Steel Co.)
Hot blast, coke, Bess. iron, from Lake Superior ores.

Topton. — Topton fce., Topton, Pa. (Empire Steel & Iron Co.)
Hot blast, anthracite and coke, foundry iron, from Lake Superior, native hematite and magnetite ores.
Sil. 0.75–3.50% Phos. 0.60–0.90% Mang. 0.50–2.00%

Trussville. — Trussville fce., Trussville, Ala. (Southern I. & S. Co.)
Hot blast, coke, sand cast, foundry iron from Alabama red and Georgia brown hematites.
Sil. up to 3.50% Phos. 0.90–1.20% Mang. 0.50–1.50%

Tuscaloosa. — Central fce., Holt, Ala. (Central Iron & Coal Co.)
Hot blast, coke, sand cast, foundry iron from red and brown hematites.
Sil. 1.25–2.75% Phos. 0.80–1.0% Mang. 0.50–0.90%

Tuscarawas. — Dover fce., Canal Dover, O. (The Penn. I & C. Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.

Union. — Buffalo Union fces. (3 stacks), Buffalo, N. Y. (Buffalo Union Furnace Co.)
Hot blast, coke, foundry scotch iron, from Lake Superior ores.
Sil. 1.75–2.50% Phos. 1.20–1.50% Mang. 0.50–1.0%

Upson Scotch. — Upson fce., Cleveland, O. (Upson Nut Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.
Sil. 2.0–3.0% Phos. 0.40–0.60% Mang. 0.60–0.90%

Vanderbilt. — Vanderbilt fces. (2 stacks), Birmingham, Ala. (Birmingham C. & I. Co.)
Hot blast, coke, foundry iron, from local hematites.
Sil. up to 4.00% Phos. under 1.00% Mang. 0.40–1.00%

Vesta. — Vesta fce., Watts, Pa. (Susquehanna Iron Co.)
Hot blast, anthracite and coke, foundry iron, from local hematites and magnetites.
Not in operation March, 1910.

Victoria. — Victoria fce., Goshen, Va. (The Goshen Iron Co.)
Hot blast, coke, foundry and forge iron, from brown hematite from Rich Patch mines.
Sil. as desired. Phos. 0.40–0.80% Mang. 1.0–1.50%

Viking. — Same as *Carbon*, which see.

Warner. — Cumberland fce., Dickson Co., Tenn. (Warner Iron Co.)
Hot blast, coke, foundry iron, from local red and brown hematite.
Sil. 2.0–2.75% Phos. abt. 1.60% Mang. abt. 0.40%

Warwick. — Warwick fces. (3 stacks), Pottstown, Pa. (Warwick I. & S. Co.)
Hot blast, coke, machine cast foundry iron, from Lake Superior, N. Y., New Jersey, and foreign ores.
Sil. 1.0–3.0% Phos. 0.40–0.80% Mang. 0.40–0.80%

Watts. — Watts fces. (2 stacks), Middlesborough, Ky. (Va. Coal & Coke Co.)
Hot blast, coke, foundry iron, from native ores.
Sil. 1.50–2.75% Phos. abt. 0.45% Mang. abt. 0.20%

Wellston. — Wellston fces. (2 stacks), Wellston, O. (Wellston S. & I. Co.)
Hot blast, coke, sand cast iron, from Lake Superior ores.

Str. fdry.	Sil. 1.50–1.75%	Phos. 0.18–0.20%	Mang. 0.60–0.90%
Mall.	0.60–2.00	under 0.20	0.40–1.00

Wharton. — Wharton fces. (3 stacks), Wharton, N. J. (Joseph Wharton.)
Hot blast, coke, occasionally some anthracite, from N. J. mag., N. Y. and Lake Superior hematites.

Wickwire. — Wickwire fce., Buffalo, N. Y. (Wickwire Steel Co.)
Hot blast, coke, basic iron, from Lake Superior ores.

Williamson. — Williamson fce., Birmingham, Ala. (Williamson Iron Co.)
Hot blast, coke, iron from red fossil, and brown hematite.

Woodstock. — Woodstock fces. (2 stacks), Anniston, Ala. (Woodstock I. Wks., Inc.)
Hot blast, coke, foundry iron, from local brown hematite.
Sil. 1.50–5.00% Phos. abt. 1.15% Mang. 0.80–1.25%

Woodward. — Woodward fce., Woodward, Ala. (Woodward Iron Co.)
Hot blast, coke, foundry iron, from local red fossil ores.
Sil. 1.0–3.0% Phos. abt. 0.80% Mang. abt. 0.30%

Zenith. — Zenith fce., W. Duluth, Minn. (Zenith Furnace Co.)
Hot blast, coke, iron, from Lake Superior ores.

Bess.	Sil. 1.00–2.00%	Phos. 0.08–0.10%	Mang. under 1.0%
Mall.	1.00–2.00	under 0.2	0.80–1.20
Fdry.	1.50–5.00	under 0.20	over 0.60

Zug. — Detroit, Mich. (Detroit Iron & Steel Co.)
Hot blast, coke, foundry iron, from Lake Superior ores.

Charcoal Irons

Aetna. — Aetna, Ala. (J. J. Gray.)
Hot or cold blast, charcoal, car wheel iron, from local brown hematite.
Not in operation March, 1910.

Alamo. — Quinn fce., Gadsden, Ala. (Quinn Furnace Co.)
Hot blast, charcoal, foundry iron, from local red and brown hematite.
Not in operation March, 1910.

Anchor. — Oak Hill, O. (Jefferson Iron Co.)
Warm blast, charcoal, strong foundry iron, from native limestone and block ores.
Sil. abt. 2.26% Phos. abt. 0.87% Mang. abt. 0.51%

Antrim. — Antrim fce., Mancelona, Mich. (Superior Charcoal Iron Co.)
Hot blast, charcoal, foundry iron, from Lake Superior ores.
Sil. up to 2.62% Phos. 0.15–0.22% Mang. 0.30–0.70%

Berkshire. — Cheshire fce., Cheshire, Mass. (Berkshire Iron Works.)
Warm blast, charcoal, foundry iron, from local red and brown hematite.

Berlin. — Glen Iron fce., Glen Iron, Pa. (John T. Church.)
Cold blast, charcoal, iron from local fossil, and hematite.
Sil. 1.0–1.5% Phos. 0.50–0.65% Mang. 0.40–0.60%

Bloom. — Bloom Switch, O. (The Clare Iron Co.)
Hot blast, charcoal, foundry iron, from local hematite.
Not in operation March, 1910.

Blue Ridge. — Tallapoosa fce., Tallapoosa, Tenn. (Southern Car Wheel Iron Co.)
Cold and warm blast, charcoal, iron from brown hematite.
Phos. 0.18–1.50% Mang. up to 2.0%

Buckhorn. — Olive fce., Lawrence Co., O. (McGugin Iron & Coal Co.)
Hot or cold blast, charcoal iron, from native limestone ore.
Not in operation March, 1910.

Cadillac. — Cadillac fce., Cadillac, Mich. (Mitchell-Diggins Iron Co.)
Hot blast, charcoal iron, from Lake Superior ores.
Sil. up to 2.50% Phos. 0.16–0.20% Mang. up to 1.0%

Center. — Superior P. O., O. (The Superior Portland Cement Co.)
Charcoal iron, from native limestone.
Not in operation March, 1910.

Champion. — Manistique, Mich. (Superior Charcoal Iron Co.)
Warm blast, charcoal, foundry iron from Lake Superior ores.
Sil. up to 2.62% Phos. 0.15–0.22% Mang. 0.30–0.70%

Cherokee. — Cherokee fce., Cedartown, Ga. (Alabama & Georgia Iron Co.)
Hot blast, charcoal, sand cast, strong foundry iron, from brown hematite.
Sil. up to 2.50% Phos. 0.35–0.70% Mang. 0.30–1.60%

Chocolay. — Chocolay fce., Chocolay, Mich. (Lake Superior Iron & Chemical Co.)
Warm blast, charcoal iron, from Lake Superior ores.

Fdry.	Sil. up to 2.0% and over	Phos. 0.17–0.22%	Mang. up to 0.65% and over
Car Wheel	0.05–2.0 and over	0.17–0.22	0.30–0.65 and over
Mall.		0.17–0.22	0.30–0.65 and over

Copacke. — Copacke Iron Works, N. Y. (Copacke Iron Works.)
Cold and warm blast, charcoal iron, from N. Y. ores.
Not in operation March, 1910.

Dover. — Bear Spring fce., Stewart Co., Tenn. (Dover Iron Co.)
Cold blast, charcoal, foundry iron, from local brown hematite.
Sil. 0.40–2.0% Phos. abt. 0.40% Mang. abt. 0.25%

Elk Rapids. — Elk Rapids, Mich. (Superior Charcoal Iron Co.)
Hot blast, charcoal, pig for car wheels and mall., from Lake Superior ores.
Sil. up to 2.62% Phos. 0.15–0.22% Mang. 0.36–0.70%

Excelsior. — Carp fce., Marquette, Mich. (Superior Charcoal Iron Co.)
Warm blast, charcoal iron, from Lake Superior ores.
Sil. up to 2.62% Phos. 0.15–0.22% Mang. 0.20–0.70%

Gertrude. — Maysville fces. (2 stacks), Maysville, Wisc. (Northwest Iron Co.)
Hot blast, charcoal, foundry iron, from Lake Superior and local ores.
Sil. 2.50% and over Phos. 0.60–0.80% Mang. 0.50–1.00%

Glen Iron. — Glen Iron fce., Glen Iron, Pa. (John T. Church.)
Cold blast, charcoal iron, from local fossil and hematite.
Sil. up to 1.00% Phos. 0.70–1.25% Mang. 0.60–1.50%

Hecla. — Hecla fce., Milesburg, Pa. (The McCoy-Linn Iron Co.)
Cold blast, charcoal, foundry iron, from Nittany Valley hematite.
Sil. 0.65–1.25% Phos. abt. 0.30% Mang. 0.15–0.25%

Hecla. — Hecla fce., Ironton, O. (Hecla Iron & Mining Co.)
Cold or warm blast, charcoal, foundry iron, from local ore.

Hematite. — Center fce., Center, Ky. (White, Dixon & Co.)
Cold blast, charcoal, foundry iron, from local hematite.
Sil. 0.50–1.40% Phos. 0.25–0.39% Mang. 0.20–0.25%

Hinkle. — Ashland fce., Ashland, Wisc. (Lake Superior Iron & Chemical Co.)
Warm blast, charcoal iron, from Lake Superior ores.
Sil. up to 3.00% Phos. 0.10–0.18% Mang. to 0.70% and over

Jefferson. — Jefferson fce., Jefferson, Tex. (Jefferson Iron Co.)
Hot blast, charcoal iron, from local brown hematite.
Not in operation March, 1910.

Liberty 1812. — Liberty fce., Shenandoah Va. (Shenandoah I. & C. Co., Va.)
Warm blast, charcoal iron, from brown hematite.

Marquette. — Pioneer fce., Marquette, Mich. (Superior Charcoal Iron Co.)
Hot blast, charcoal, foundry iron, from Lake Superior ore.
Sil. up to 2.62% Phos. 0.15–0.22% Mang. 0.30–0.70%

Michigan. — Newberry fce., Newberry, Mich. (Superior Charcoal Iron Co.)
Warm blast, charcoal iron, from Lake Superior ores.
Sil. up to 2.62% Phos. 0.15–0.22% Mang. 0.30–0.70

Muirkirk. — Muirkirk fce., Muirkirk, Md. (Charles E. Coffin.)
Warm blast, charcoal iron, from local carbonate ores.
Sil. 0.70–2.50% Phos. 0.25–0.30% Mang. 0.80–2.50%

Olive. — Olive fce., Lawrence Co., O. (The McGugin I. & C. Co.)
Hot or cold blast, charcoal iron from native limestone ores.

Pine Lake. — Boyne City fce., Boyne City, Mich. (Superior Charcoal Iron Co.)
Hot blast, charcoal iron, from Lake Superior ores.
Sil. up to 2.62% Phos. 0.15–0.22% Mang. 0.30–0.70%

Pioneer. — Pioneer fce., Gladstone, Mich. (Superior Charcoal Iron Co.)
Warm blast, charcoal iron, from Lake Superior ores.
Sil. up to 2.62% Phos. 0.15–0.22% Mang. 0.30–0.70%

Reed Island. — Reed Island fce., Reed Island, Va. (Va. Iron, C. & C. Co.)
Cold blast, charcoal iron, from local limonite.

Richmond. — Richmond fce., Berkshire Co., Mass. (Richmond Iron Works.)
Warm blast, charcoal iron, from local brown hematite.
Sil. up to 2.00% Phos. 0.28–0.35% Mang. up to 0.44%

Rock Run. — Rock Run fce., Rock Run, Ala. (The Bass Foundry & Machine Co.)
Warm blast, charcoal iron for chill rolls, car wheels, strong castings, from local brown hematite.
Sil. 0.30–2.25% Phos. 0.30–0.50% Mang. 0.40–1.00%

Rome. — Rome fce., Rome, Ga. (Silver Creek Furnace Co.)
Warm blast, charcoal iron, from local red and brown hematites.
Sil. 1.75–2.25% Phos. 0.35–0.60% Mang. 0.50–0.80%

Round Mountain. — Round Mt. fce., Round Mt., Ala. (Round Mountain Iron & Wood Alc. Co.)
Cold blast, charcoal iron, from local red hematite.
Not in operation March, 1910.

Salisbury. — Canaan fces., East Canaan, Conn. (2 stacks). (Barnum Richardson Co.)
Warm blast, charcoal iron, from Salisbury brown hematite, sand cast.
Sil. 1.32–1.92% Phos. abt. 0.30% Mang. 0.50–1.0%

Salisbury Chatham. — Chatham fce., Chatham, N. Y. (Union Iron & St. Co.)
Charcoal iron.

Shelby. — Shelby fce., Shelby, Ala. (Shelby Iron Co.)
Warm blast, charcoal iron, from local brown hematite.
Sil. 0.15–2.25% Phos. 0.30–0.50% Mang. 0.50–0.80%

Sligo. — Sligo fce., Sligo, Mo. (Sligo Furnace Co.)
Hot blast, charcoal iron, from local blue specular and red ore.

Spring Lake. — Fruitport fce., Fruitport, Mich. (Spring Lake Iron Co.)
Hot blast, sand cast, charcoal iron, from Lake Superior ores.
Sil. up to 2.50% Phos. 0.16–0.20% Mang. up to 1.0%

Spring Valley. — See under Coke Irons.

Tassie Bell. — Tassie Bell fce., Rusk, Tex. (New Birm. Devel. Co.)
Hot blast, charcoal iron, from local brown hematites.
Not in operation March, 1910.

White Rock. — Smyth Co., Va. (Lobdell Car Wheel Co.)
Warm and cold blast, charcoal iron, from local brown hematite.
All used by the Company.

Wyebrooke. — Isabella fce., Wyebrooke, Pa. (W. M. Potts.)
Cold blast, charcoal iron, from local magnetic and hematites and foreign and Lake Superior ores.
Not in operation March, 1910.

AUTHORITIES

Boland, S.
Buchanan, J. S.
Buchanan, Robert.
Byron, T. H.

"Castings."
Carpenter, H. A.
Carr, W. N.
Christopher, J. E.
Chrystie, J.
Cheney, F. R.
Colby, A. L.
Cook & Hailstone.
Cook, E. S.
Crobaugh, F. L.
Custer, E. A.
Cunningham, R. P.

De Clercy, Jules.
Dickinson, W. E.
Diller, H. E.

Fay, A. E.
Field, H. E.
Firmstone, F.
Franklin, B. A.
"The Foundry."

Gilmore, E. B.
Golden, E. B.

Hall, J. L.
Hatfield, W.
Hawkins, D. S.
Hiones, A. H.
Holmes, J. A.
Hooper, G. K.
Howe, Prof. H. M.
Hyndman, N. P.

"Iron Age."
"Iron Trade Review."

Jewett, L. C.
Johnson, F.
Johnson, J. E., Jr.

Kane, W. H.
Keep, W. J.
Kent, Wm.
Kirk, E.
Knoppell, C. E.

Lane, H. M.
Ledebur, Prof. A.
Long, A. T.
Longmuir, P.
Loudon, A. M.

Marshall, S. P.
May, W. J.
McWilliams & Longmuir.
McGahey, C. R.
"Mechanics."
Moldenke, Dr. R.
Mumford, E. H.
Murphy, Jos. A.

Nagle, A. F.

Outerbridge, A. E.

Palmer, R. H.
Pierce, E. H.
Porter, Prof. J. J.
Probert, R. H.
Putnam, E. H.

Rankine, Prof. W. J. M.
Ries, Prof. H.
Raup, P. R.
Recketts, Prof. P. C.
Robertson, J. S.
Rogers, S. M.
Rott, Prof. Carl
Rossi, A. G.

Sadlier, J. G.
Saunders, W. M.
Sameur, Prof. A.
Scott, W. G.
Shed, N. W.
Sissons, C. W.
Stahlund, Eissen.
Stickle, F. W.
Stupakoff, S. H.
Stead, J. E.
Sleeth, S. D.
Stoughton, Prof. B.

Trautwine, J. C.
Turner, Prof. T.
Taylor, E. M.

West, Thos. D.
Whitehouse, J. S.
Whitney, A. W.
Williams, A. D.
Wangler, J.
Wuest, Prof. F.
Wylie, C.

INDEX

Abbreviations and signs, v.
Acceleration of falling bodies, 191–93.
Accounts, *See* Foundry accounts.
Acid open hearth, 417, 419, 422.
Acid-resisting-castings, mixture for, 276.
Addition in algebra, 8.
Agricultural castings, average of five meltings, 459.
Agricultural machinery, mixtures for, 276.
Air, weight of, for combustion, 204; properties of, 215–18; required for combustion of one pound each of coke and coal, 444; loss in pressure and horse power from friction in pipes, 447.
Air, compressed, horse power required for, 217–18.
Air cylinders, mixture for, 276
Air furnace, American, 391.
Algebra, 7–15.
Alligation, 5.
Alloys, 222–27.
Aluminum, properties of, 266; influence of, in cast iron, 266–67.
Aluminum bronze, 226.
American Foundrymen's Association, *See* Foundrymen's Association.
American Steel & Wire Co., gauge of sizes, 146.
Ammonia cylinders, mixture for, 276.
Analysis, mixing iron by, 274–89.
Anchors, gaggers and soldiers, 523–24.
Angle, problems of the, 17–18.
Angles, approximate measurement of, 115–16.
Annealing boxes, mixtures for, 277.
Annealing-oven equipped for gas, 392.
Annealing steel castings with micrographs, 400–1.
Anthracite coal, 425.
Antimony, alloys containing, 227.
Apothecaries' or wine measure, 38.
Apothecaries' weight, table of, 36.
Appliances about cupola, 462–67.
Arithmetic, 1–7.
Arnold, Prof. J. O., on carbon in steels, 241, 347; mechanical properties of normal steels, 396.
Atmosphere, pressure of, at various readings of barometer, 216.
Authorities, 660–61.
Automobile castings, mixtures for, 277.
Avoirdupois weight, table of, 36.

B.t.u. = British thermal unit, 207.
Babbitt metal, 227.
Baby (Robert) converter, the, 397.
Balls for ball mills, mixture for, 277.
Band and hoop iron weights, 121–22.
Barometric readings, pressure of atmosphere at various, 216; corresponding with different altitudes, 217.
Bars of wrought iron, weight and areas of square and round, 136–39.
Basic open hearth, 418, 419, 423.
Bauxite, fire bricks of, 436.
Beams, transverse strength of, formulas for, 188–90.
Bearing-metal alloys, 226.
Bed-plates, mixture for, 277.
Belt velocity, tables of, 229–30.
Belting, formulas for, 227–28.
Benjamin, Charles H., strength of materials, 213–14.
Bessemer process, the, 396.
Binder bars, 505.
Binders, *See* Agricultural machinery.
Birmingham gauge for sheet metals except steel and iron, 120.
Black heart malleable cast iron, 382–85.

Blast, the, in the cupola, 446–47; loss of air pressure from friction in pipes, 447.
Blast pipes for pressure blowers, tables of, 450.
Blow-holes, trouble with, 316; in steel, 398.
Blowers, pressure, for cupolas, tables of, 448–49.
Board and timber measure, 44.
Board measure, table of, 91–92.
Bod stick, the, 463–64.
Boiler castings, mixture for, 277.
Boiling points at sea level, 204; at atmospheric pressure, 210.
Bolt ends and lag screws, 158.
Bolt heads and nuts, weights of, 159.
Bolts and nuts, U. S. standard, 150–51.
Bolts, machine, weight of, per 100, 155–56; list prices, 157.
Borings and turnings, melting, 293; per cent of, 322.
Box strapping, 236.
Brake shoes, mixture for, 287.
Brass, fillets of, areas and weights of, 145.
Brass foundries, alloys in use in, 223.
Brass, moulding sand for, 472.
Brass, sheet and bar, weight of, 144.
Brass tubes, seamless drawn, 167–69.
Brass wire and plates, weight of, 143.
Breaking loads, formula for, 301; ratio of tensile strength to, 10 to 1, 302.
Breast of cupola, 440–41.
Buffalo steel pressure Blowers, 449.

Cables, *See* Chains and cables.
Cables, transmission or standing, 179.
Calorie, French thermal unit, 207.
Cap screws, 161.
Car castings, mixtures for, 278.
Car wheel iron test bars, moduli of rupture of, 300.
Car wheels, qualities of iron for, 275; mixtures for, 278; specifications for, 350–55.
Carbon and iron, forms of combination of, 313.
Carbon, combined, *See* Cementite.
Carbon content in steel, 395.
Carbon, properties of, 252–53; influence of, as constituent of cast iron, 253–54; loss or gain of, in remelting, 254–56.
Carbon, total, per cent, 308, 310; in micrographs, 311; ways of reducing, 315–16; for elasticity, 323; reduced for hardness, 328; high to decrease shrinkage, 332; high aids fluidity, 335; for resistance to heat, 337–38; for high permeability, 340; for resistance to corrosion, 341; determination of, 379–80.
Carpenter shop and tool room, 562.
Carr, W. M., open-hearth methods for steel castings, 411–16.
Carrier, W. H., on foundry heating and ventilating, 582–86.
Cast iron, constituents of, standard methods for determining, 377–80: Silicon, 377–78; sulphur, 378; phosphorus, 378; manganese, 379; total carbon, 379–80; graphite, 381.
Cast iron, effect of structure of, upon its physical properties, 306–14; microscopic evidence, 308–12; Prof. Porter on, 312–14.
Cast iron, fillets of, areas and weights of, 145.
Cast iron, influence of chemical constituents of, 252–72: Carbon, 252–56; silicon, 256–60; sulphur, 260–63; phosphorus, 263–64; manganese, 265–66; aluminum, 266–67, nickel, 267; titanium, 267–68; vanadium, 268–70; thermit, 270; oxygen, 270–71; nitrogen, 271–72.
Cast iron, mechanical analysis of, *see* Mechanical analysis.
Cast iron, weight of a superficial foot of, 570.
Casting, direct, 562.
Casting properties of iron, 343–45.
Castings, mixtures for various classes of, 273–74; (alphabetical) 276–87; amounts of different irons to be used found by percentage, 287–89.
Castings, qualities of iron necessary for different grades of, 275.

Castings, shrinkage of, per foot, 234.
Castings under pressure, 562.
Castings, weight of, determined from weight of patterns, 569–70; formulas for finding, 570–76.
Cement mortar, tensile strength of, 215.
Cementite (combined carbon), 241; in micrographs, 308–11; physical characteristics of, 313; per cent combined carbon, 315, 319–20, 323; causes hardness, 324–29; for fusibility, 332–34; low for fluidity, 335; for resistance to heat low, 337–38; low for permeability, 340; in micrographs, 346–49.
Center of gravity, 195–97.
Centigrade to Fahrenheit, equivalent temperatures, 211–12.
Centismal years, 43.
Centrifugal castings, 561–62.
Centrifugal force, 215.
Chain end link and narrow shackle, 174.
Chain hooks, proportions for, 172.
Chains and cables, U. S. Navy standard, 173.
Chaplets, 528–36; peerless perforated, 530; double head, 531–32; wrought-iron, 533–35.
Charcoal iron, 250.
Charcoal pig irons, directory of, 655–59.
Charging cupolas, 452–54.
Charging floor, the, 453–54.
Charpy & Grenet's experiments on irons, 383.
Chemical analyses of cast iron, 315–49: Strength, 315–22; elastic properties, 322–29; shrinkage, 329–32; fusibility, 332–34; fluidity, 334–35; resistance to heat, 335–38; electrical properties, 338–40; resistance to corrosion, 340–42; resistance to wear, 342; coefficient of friction, 342–43; casting properties, 343–45; micro-structure, 345–49.
Chemical analyses of test bars, 308–12; micrographs, 308–11; forms of combination of iron and carbon, 313.
Chemical constituents of cast iron, influence of the (W. G. Scott), 252.
Chemical reactions in the cupola, 443–45.
Chilled castings, mixtures for, 274, 275, 278.
Chilled iron defined, 326–28.
Chilled roll (furnace) iron test bars, moduli of rupture of, 299.
Chills, mixture for, 278.
Chipping and grinding, 566.
Chords for spacing circle, 89–90.
Chords of arcs from one to ninety degrees, 88.
Circle, length of chord for spacing, 89–90.
Circle, problems of the, 15, 18–20; ratio of circumference to diameter, 28; area of, 28.
Circles, areas and circumferences of, for diameters from $\frac{1}{10}$ to 100, by tenths, 70–79; rules to compute larger, 79.
Circles, areas and circumferences of, for diameters in units and eighths, 64–69.
Circular arcs, table of, 80–82.
Circular arcs, table of lengths of, to radius 1, 82–84.
Circular measure, 43.
Circular segments, table of areas of, 84–87.
Cisterns and tanks, number of barrels in, 100–1.
Clamps, 506.
Clarke, D. K., formula for extreme fibre stress, 304; volume, density and pressure of air at various temperatures, 216.
Cleaning room, the, 563–68; tumblers, 563–66; chipping, grinding, the sand blast, 566; pickling, 567; hydrofluoric acid, 568.
Clout nails, tinned, 536.
Coach screws, gimlet points, 159.
Coke and anthracite pig irons, directory of, 635–55.
Coke, 425–29: Analyses of various kinds of, 425–26; by-product coke, 426–27; effect of atmospheric moisture upon, 427;

specifications for, by R. Moldenke, 428–29; number of pounds of iron melted by one pound of, 444–45.
Colby, A. L., influence of the mould upon pig iron, 249.
Coleman, J. J., heat-conducting power of covering materials, 210.
Collars and couplings, mixture for, 278.
Combining equivalents, 204.
Conductivity of metals, 206, 209.
Cone, the, 32–33.
Contraction or shrinkage, 329–32.
Converter linings, 404–5; practice, 405–9.
Converter steel, cost of, 420, 421.
Converters, the Baby (Robert) and Tropenas, 397.
Cook, E. S., on different results from two irons of same chemical composition, 330–32.
Cook, F. J., and G. Hailstone, microscopic evidence why similar irons have different relative strengths, 306–12, 317–19.
Cooling, influence of rate of, 318.
Cope, formula to find weight required on a, to resist pressure of molten metal, 575.
Copper and tin, alloys of, 222.
Copper and zinc, alloys of, 223.
Copper-nickel alloys, 224.
Copper, round bolt, weight of, per foot, 144.
Copper, tin and zinc, useful alloys of, 225.
Copper tubes, seamless drawn, 167–69.
Copper wire and plates, weight of, 143.
Core machines, 499.
Core mixtures, 480–86.
Core ovens, 492–95.
Core plates and driers, 498–99.
Core room and appurtenances, 492–500: The oven, 492–96; core oven carriages, 496; mixing machines, sand conveyors, rod straighteners, wire cutter, 497; sand driers, 498; core plates and driers, 498–99; core machines, mould-machines, cranes and hoists, 499–500.
Core sand with analysis, 479–80.
Corrosion, resistance to, 340–42.
Corrugated iron roofing, weight of, 141.
Cosine, 107.
Cotters, steel spring, 164.
Cotton machinery, mixture for, 278.
Covering materials, heat-conducting power of, 210.
Cranes and hoists for core room, 499–500.
Cranes for cupola service, 466.
Cranes for moulding room, 502.
Crucible castings, 423.
Crusher jaws, mixture for, 278.
Cube of a whole number ending with ciphers, to find, 56.
Cube root, 4–5.
Cube root of large number not in table, to find, 62–63.
Cube roots of numbers from 1000 to 10,000, 57–61.
Cubes and cube roots of numbers from .01 to 1000, tables of, 46–56.
Cupola, construction of the, 437–52: Five zones, 437, 442–43; the lining, 437–39; tuyères, 439–40; the breast, 440–41; sand bottom, 441; chemical reactions in ordinary, 443–45; wind box, 445; builders' rating, 446; blowers for the blast, 446–49; diameter of blast pipes, 450–51; dimensions, etc., of, 451–52.
Cupola appliances, 462–67: Ladles, 462–65; tapping bar, 463; bod stick, 464–65; cranes, 466; spill bed, 466; gagger mould, 467; rake, 467.
Cupola charging and melting, 452–61: The charging floor, 453–54; tables of meltings and losses, 455–61; melting ratio, 461.
Cupola makers, best known, 446.
Custer, Edgar A., on permanent moulds, 559–61.
Cutting tools, mixture for, 278.
Cylinder, the, 32.
Cylinder iron test bars, moduli of rupture of, 300.
Cylinders or pipes, contents of, 102–3.
Cylinders, locomotive, mixtures for, 273, 282; specifications for, 355.

Cylinders, marine and stationary, mixtures for, 273; *see also* Cylinders, 279.
Cylinders, solid and hollow iron, formulas for finding weight of, 570–71.

Decimal equivalents of parts of one inch, 6.
Deflections, table of, 183–85.
Delta metal, 225.
Diamond polishing wheels, mixture for, 279.
Dies for drop hammers, mixture for, 279.
Diller, H. E., tests of use of steel scrap in mixtures of cast iron, 290–91; on malleable cast iron, 390–91.
Division in algebra, 10.
Dry measure, British Imperial, *see* Liquid and dry measures, British Imperial, 39–40.
Dry measure, table of U. S., 39; weights of, 39.
Dynamo and motor frames, mixtures for, 279.
Dynamo frame iron test bars, moduli of rupture of, 299.

Earth, measurements of, and on the, 238–39.
Eccentric straps, 279.
Elastic properties, 322–23.
Elasticity, modulus of, 181; table of moduli, 182–83.
Electric furnace steel, cost of, 424.
Electrical and mechanical units, equivalent values of, 220–21.
Electrical castings, mixture for, 279.
Electrical properties, 338–40.
Elimination, 12–13.
Ellipse, construction of an, 21–22; circumference and area of an, 29.
Ellipse, solid iron, formula to find weight of a, 571.
Engine castings, mixtures for, 279.
Equations, quadratic, 14–15.
Equations, simple, 11–14; solution of, 12.
Expansion, lineal, for solids, 205.
Eye bolts, table for, 175.

Facings, 486–87; graphite facing and analyses, 488–91.
Factors, useful, 44–45.
Fahrenheit to Centigrade, equivalent temperatures, 211–12.
Falling bodies, acceleration of, formulas and table, 191–92.
Fans and blowers, 280.
Farm implements, mixture for, 280.
Fe-C-Si, influence of, on cast iron, 315, 320.
Ferrite, pure iron, 241, 347.
Field, H. E., on carbon and silicon in pig iron, 253.
Fillet, cast iron straight, formula to find weight of a, 574; of a circular, 575–76.
Fillets of steel, cast iron and brass, areas and weights of, by E. J. Lees, 145.
Fire brick, 236.
Fire brick and fire clay, 434–36; analyses, 434–35; ganister, 435; fine sand, 435; magnesite, 436; bauxite, 436.
Fire clays, analysis of, 237.
Fire pots, mixture for, 280.
Flanged fittings, cast iron, 232.
Flasks, 506–18: Wooden cope and drag, 506–9; iron, 510–14; sterling steel, 515–17; snap, 517–18; slip boxes, 519; in machine moulding, 547–50.
Flat rolled iron, *see* Iron, flat rolled.
Flat rolled steel, *see* Steel, flat rolled.
Floor plates, grate bars, etc., average of two meltings, 460.
Fluidity, factors governing, 334–35.
Fluxes, 429–34: Limestone and fluor spar, 430–31; analyses of slags, 432–33.
Flywheel, cast iron, formulas to find weight of a, 572–73.
Foot, inches to decimals of a, 6.
Foot pound, the unit of work, 45.
Forces, parallelogram and parallelopipedon of, 192.
Foundry accounts, 587–632: Foundry requisition, 588–89; pattern card, 589–90; pig iron card, and book, 590, 591; coke card, 591; heat book, 592–96; cleaning room re-

port, 597; foundry reports, 598–600; monthly expenditure of supplies, 601–4; monthly comparison of accounts, 605–7; annual comparison, 608–10; chart of transmission of orders, 611–12; foundry costs (B. A. Franklin), 612–25; successful foundry cost system (J. P. Golden), 625–32.
Foundry cost system, a successful (J. P. Golden), 625–32.
Foundry costs (B. A. Franklin), 612–25; outline of scheme, 612–13.
Foundry pig iron, *see* Pig iron.
Foundrymen's Association, American, standard specifications for foundry pig iron, 246–48; table of mixtures for various castings, 275–76; report of committee on test bars, 294–306.
Fractions, products of, expressed in decimals, 7.
Fracture, of pig iron, index of composition, 273.
Franklin, B. A., foundry costs, 612–25; outline of scheme, 612–13.
Frick, Louis H., dimensions of standard wrot pipe, 167.
Friction clutches, mixture for, 280.
Friction, coefficient of, 215, 342–43.
Frustrum of a cone, 33; center of gravity of a, 196.
Frustrum of a hexagonal pyramid of cast iron, formula to find weight of, 574.
Frustrum of a pyramid, 30–31.
Fuels, foundry, 425–29: Anthracite coal, 425; coke, 425–29.
Furnace castings, mixture for, 280.
Furnace temperatures, 206.
Fusibility, or melting point, 332–34.

Gagger mould, 467.
Gaggers, 524.
Galvanized sheet iron, weight of, 141.
Ganister, composition of, 435.
Gas engine cylinders, mixture for, 280.
Gases, specific gravity of, 197.
Gates, tables of areas of, 524–25; top pouring, 526; whirl, 527; "cross" skim, 527; horn, 527.
Gears, mixtures for, 280–81.
Geometry, plane, problems in, 15–24.
German silver, 224.
Golden, J. P., a successful foundry cost system, 625–32.
Grain structure of cast iron, 329.
Graphite, shown in micrographs, 308–11, 346–48; physical characteristics of, 313; per cent of, 315–17, 330–31; size of flakes in relation to strength, 317–19; per cent of, for fusibility, 333–34; for resistance to heat, 337–38; low, for friction, 342.
Graphite facing, with analyses, 488–91.
Grate bars, mixture for, 281.
Gray iron castings, specifications for, 296–97.
Grinding machinery, mixture for, 281.
Grinding wheel speeds, table of, 231.
Guldin's theorems, 34.
Gun carriages, mixture for, 281.
Gun iron, mixture for, 281.
Gun iron test bars, moduli of rupture of, 300.
Gyration, radius of, 197.

Hailstone, G., *see* Cook, F. J.
Hangers for shafting, mixture for, 281.
Hardness, control of, 324–28.
Hardware, light, mixture for, 281.
Hatfield, W. H., experiment on deflection with six bars, 384; in breaking bars, 387–88.
Heat, measurement of, 206–10; radiation of, 208; resistance to, 335–38.
Heat unit defined, 45.
Heat-resisting iron, mixture for, 281.
Heating and ventilating, 579–86.
Height corresponding to acquired velocity, 193.
Hemisphere, hollow iron, formula for finding weight of a, 571.
Hexagon, relations of inscribed, to circle, 20.
Hoisting rope, pliable wire, 179.
Hollow ware, qualities of iron for, 275; mixture for, 282.
Hooks, slings and chains, 502–3.
Hooper, G. K., on continuous melting, 554–55.

Horse power defined, 45; required to compress air, 217–18.
Housings for rolling mills, mixture for, 282.
Hydraulic cylinders, mixtures for, 282.
Hydraulic pressures, formulas for dimensions of cast iron pipe to withstand, 232–33.
Hydrofluoric acid used for pickling, 568.
Hyperbola, the, 23–24.

Inch, one, decimal equivalents of parts of, 6.
Inches to decimals of a foot, 6.
Inclined plane, 194.
Information, useful, 234–39.
Ingot mould iron test bars, moduli of rupture of, 299.
Ingot moulds and stools, mixture for, 282.
Iron and carbon, forms of combination of, 313.
Iron, band and hoop, weights per lineal foot, 121–22.
Iron, burnt, of no use except for sash weights, 293.
Iron castings, formulas for finding weight of, 570–75.
Iron, flat, weight of, per foot, 45.
Iron, flat plates, weight of, per square foot, 45.
Iron, flat rolled, weights of, per lineal foot, 123–28; areas of, 129.
Iron, mixing, by fracture, 273–74; by analysis, 274–89; mixtures for various classes of castings (alphabetical), 276–87.
Iron ores, varieties of, 240.
Iron, physical properties of, 241.
Iron, pig, *see* Pig iron.
Iron roofing, corrugated, weight of, 141.
Iron, round, weight of, per foot, 45.
Iron, sheet, gauges used by U. S. mills in rolling, 120; weight per foot, 141.
Iron, temperatures of, corresponding to various colors, 239.
Iron wire, gauges and weights of, 146; list prices of, 147.
Iron, wrought, weight and areas of square and round bars, 136–39.

Jigs, by S. H. Stupakoff, 540–46.
Jobbing castings, general, average of five meltings, 455.
Jobbing castings, light, average of four meltings, 455.
Joule's equivalent, 207.

Keep, W. J., on pig iron cast in iron moulds and in sand, 249–50; influence of silicon on cast iron, 259–60; injurious influence of sulphur, 263; effect of manganese, 266; on recovery of shot iron, 292; shrinkage of test bars, 371–72; shrinkage chart, 372–74; strength table, 375; process of making coke, 426.
Kent, William, altitudes corresponding to barometric readings, 217; head in feet of water corresponding to pressure, 219; pressure for different heads, 219.
Kettles to stand red heat, mixture for, 274.

Ladles and table of capacities, 462–65.
Lag screws, 158.
Land measure, table of, 37.
Le Chatelier, M., on furnace temperatures, 206.
Lead pipes, sizes and weights of, 171.
Ledebur, Prof. A., influence of silicon on annealing temperature, 391.
Lees, Ernest J., areas and weights of fillets of steel, cast iron and brass, 145.
Lever, the, 194.
Lifting beams, 503–5; table of safe loads for, 504.
Lighting, importance, 578–79.
Lime mortar, tensile strength of, 215.
Liquid and dry measures, British Imperial, weights of, 39–40.
Liquid measure, table of U. S., 38; weights of volumes of distilled water, 39–40.
Liquid pressure on moulds, 529–30.
Locks and hinges, *see* Hardware, light.
Locomotive castings, mixtures for, 282.

Locomotive cylinders, mixtures for, 273, 282; specifications for, 355.
Long measure, table of, 36; miscellaneous, 37.
Longmuir, Percy, on the sulphur content of cast iron, 261–62; microstructure of cast iron, 345–49; on silicon in malleable castings, 386; on steels, 394.
Loudon, A. M., comparative values of core binders, 481–86.
Lumber, weight of, per 1000 feet board measure, 93.

McGahey, C. B., tests of use of steel scrap in mixtures of cast iron, 291.
Machine-cast pig iron, *see* Pig iron, 248–50.
Machinery castings, heavy, average of four meltings, 457.
Machinery castings, light, average of six meltings, 456.
Machinery castings, qualities of iron for, 275; mixtures for, 283.
Machinery iron test bars, moduli of rupture of, 299, 300.
McWilliams & Longmuir on malleable castings, 382; on annealing, 400–1; on moulding machines, 548.
Magnesite, bricks of, 436.
Malleable cast iron, 382–93: Black heart, 382–85; experiments on varying compositions of, 383–84; ordinary or Réaumur, 385–88; mixtures in American practice, 389–91; specifications and tests, 391–93.
Manganese, per cent, 308, 310, 315; high, 322; for elasticity, 323; as hardening agent, 324–25; in chilled iron, 328, 337; effect on grain structure, 329; increases shrinkage, 332; little effect on melting point, 334; for heat resistance, 337; low for permeability, 340; for acid resistance, 341; for resistance to wear, 342; skin effects, 344; in micrographs, 346–48; determination of, 379.
Manganese, properties of, 265; influence of, as constituent of cast iron, 265–66, 272.
Mann, W. I., lengths of chords for spacing circle whose diameter is 1, 90.
Martensite "beta" form of iron, 313.
Mayer, Dr. A. M., on radiation of heat, 208.
Measures, miscellaneous, 39; and weights, 44.
Measures of work, power and duty, 45.
Measures, *see* Weights and measures; *also* name of measure, as Dry measure, Liquid measure, etc.
Mechanical analysis of cast iron, 371–77; Keep's shrinkage chart, 372–74; strength table, 375.
Mechanical equivalent of heat, 207.
Melting, continuous, 551–55.
Melting losses in cupolas, tables of, 454–61.
Melting ratio, 461.
Mensuration, 26–34.
Metalloids, influence of the more important, on combined carbon, 272; method of adding, to the iron, 465.
Metals, conductivity of, 206, 209; weights per cubic inch of, 239.
Metals, sheet, Birmingham gauge for, except steel and iron, 120; weights of, per square foot, 142.
Metric measures and weights in U. S. standard, 40–43.
Micrographs of graphite, 308–11.
Micro-structure of cast iron by P. Longmuir, 345–49.
Mixing machines in core room, 497.
Modulus of elasticity, 181–83.
Modulus of rupture, 185–86; formula for, 304; in pounds per square inch, 298–303.
Moldenke, Dr. R., effects of titanium and vanadium in cast iron, 268–70; on fusibility of cast iron, 332–33; contents of malleable cast iron, 389; specifications for foundry coke, 428–29.
Molten iron, formulas to find pressure of, 575.
Moment of inertia, 187; of rotating body, 197.
Moments, location of, 180.

Monomial, 10.
Mortar, lime and cement, tensile strength of, 215.
Motor frames, *see* Dynamo.
Mould, pressure on, by molten metal, formula to find, 575.
Moulding, dry sand, mixtures for (West), 477–78.
Moulding machines, 538–50: Jigs by S. H. Stupakoff, 540–46; flasks, 547–50; diagram of moulding operations, 549.
Moulding operations, diagram of (Stupakoff), 549.
Moulding room and fixtures, 501–37: Cranes, 502; hooks, slings and chains, 502–3; lifting beams, 503–5; binder bars, 505; clamps, 506; flasks, 506–19; pins, plates and hinges, 519–21; sweeps, 522–23; anchors, gaggers, and soldiers, 523–24; sprues, risers and gates, 524–27; tables of areas of gates, 525; strainers and spindles, 528; weights, 528; chaplets, 528–37; liquid pressure on moulds, 529–30; sprue cutters, 537.
Moulding sand, 468–91: Cohesion, 468; permeability and porosity, 468–69; refractoriness, 469; durability, 469; texture, 469, 471; grades of various, 470; analysis, 471; sand for brass, with analysis, 472; test bars of green sand, 473–76; for dry sand moulding, 477–79; skin drying, 479; core sand, and analyses, 479–80; core mixtures, 480–86; parting sand, 486; facings, 486–87; graphite facing, 488; analyses, 488–91.
Moulds, multiple, 555–58; permanent, 558–61; mixtures for permanent, 283.
Multiplication in algebra, 8–10.

Nagle, F. A., on erratic results of investigation of test bars, 298, 301–3.
Nails, common wire, 148.
Nails, force required to pull, from various woods, 238.
Nickel, properties of, 267; effect of, in cast iron, 267; imparts most valuable properties to steel, 267.
Niter pots, *see* Acid-resisting.
Nitrogen, properties of, 271; effect of, on cast iron and steel, 271.
Nonconductivity of materials, 209–10.
Novelty iron test bars, moduli of rupture of, 300.
Nuts and bolt heads, weights of, 159.
Nuts and washers, number of, to the pound, 152.

Open-hearth methods for steel castings by W. M. Carr, 411–16.
Ordway, Prof., on non-conductivity, 209.
Ornamental work, mixture for, 283.
Outerbridge, A. E., tests of moulding sands, 473–75.
Oxygen, effect of dissolved oxide on cast iron, 315, 318, 319, 320.
Oxygen, properties of, 270; causes foundryman much trouble, 270–71; effective deoxidizers, 271.

Parabola, the, 22–23.
Parallelogram, area of, 26.
Parenthesis, in algebra, 10.
Parting sand, 486.
Pattern lumber, specific gravity and weight per cubic foot of, 569.
Pattern plates, preparation of, 540–46.
Patterns for test bars of cast iron, 297.
Pearlite, a mixture of fernite and cementite, 241, 347.
Pentagon, to construct a, 20.
Percentage, 5–7.
Permeability and porosity of moulding sand, 468–69.
Permeability, importance of, 339–40.
Phosphorus, properties of, 263; influence of, as constituent of cast iron, 264, 272; per cent, 308, 320–21; in micrographs, 309–11; low, for strong castings, 321; and for elasticity, 323; slight hardening effect, 324; slight influence on chill, 328; decreases shrinkage, 332; increases fusibility, 332–33, 336; keep high for fluidity, 334–35; low for wear resistance, 342;

presence in micrographs, 346–49; determination of, 378.
Physical constants, tables of, 202–3.
Piano plates, mixture for, 283.
Pickling, 567–68.
Pig iron, physical properties of, 241–42; grading, 242–43; foundry, 244–48; machine-cast, 248–50; charcoal iron, 250; grading scrap iron, 250–51; fracture of, index of composition, 273.
Pig iron directory, 633–59: Coke and anthracite irons, 635–55; charcoal irons, 655–59.
Pillow blocks, mixture for, 284.
Pins, plates and hinges, 519–21.
Pipe and pipe fittings, mixtures for, 284.
Pipe, cast-iron, specifications for, 356–63; tables of dimensions, 358; of thicknesses and weights, 359; volume and weight, 364–65; pattern, size and weight, 366–70.
Pipes, contents of, 102–3.
Piston rings, mixture for, 284.
Plane figure, irregular, area of any, 27–28.
Plane figures, properties of, 24–26.
Plane surfaces, mensuration of, 26–29.
Plow points, chilled, mixture for, 284.
Polygon, area of a, 27.
Polyhedra, 31–32.
Polynomials, 10–11.
Porter, Prof. J. J., effects of sulphur on cast iron, 262–63; of phosphorus, 264; influence of the metalloids on combined carbon, 272; report on mixtures for various classes of castings (alphabetical), 276–87; on properties and mixtures of cast iron, 312–14; pig iron classification and directory, 633–59.
Pouring temperature, influence of, 318.
Powers of quantities, 9–10.
Prince, W. F., process for melting borings, 293.
Printing presses, *see* Machinery casting.
Prism, the, 30.
Prismoid, the, 31.
Probert, Richard H., analysis of iron for permanent moulds, 558–59.
Propeller wheels, mixture for, 284.
Proportion, 1–2.
Pulleys, circumferential speed of, 229–30; rules for speeds and diameters of, 231; mixtures for, 274, 284–85.
Pumps, hand, mixture for, 285.
Pyramid, the, 30–31.

Quadratic equations, solution of, 14–15.
Quadrilateral, area of any, 27.
Quantities, in algebra, 7–10: addition of like and unlike, 8; multiplication of simple and compound, 9.

Radiation of heat, 208.
Radiators, mixture for, 285.
Railroad castings, mixture for, 285; average of three meltings, 459.
Rake, cupola, 467.
Ratio, 1–2.
Réaumur malleable cast iron, 385–88: Remelting, 385–86; annealing, 386; analyses, 387–88.
Retorts, *See* Heat resisting castings.
Richards, horsepower required for air compression and delivery, 217–18.
Ries, Prof. H., analyses of moulding sands, 472–73.
Rings, cast iron, formulas to find weight of, 574.
Rivets, iron, round head, 166.
Rolling mill rolls, mixture for, 274.
Rolls, chilled, mixtures for, 274, 275, 285.
Roofing, corrugated iron, weight of, 141.
Roofing, tin and other, 169–70.
Root Positive Rotary Blowers, 449.
Roots of numbers, 3–5.
Rossi, G. A., on effect of titanium in cast iron, 268.
Rupture, modulus of, 185–86; formula for, 304.

Sand blast, the, 566.
Sand bottom of cupola, 441.
Sand conveyors and driers, 497, 498.

Sand, rammed, to find weight of, 572.
Sand roll iron test bars, moduli of rupture of, 299.
Sanitary ware, qualities of iron for, 275; average of eight meltings, 458.
Sash weight, mixture for, 274, 275.
Sash weight iron test bars, moduli of rupture of, 299.
Scales, mixture for, 285.
Scott, W. G., influence of the chemical constituents of cast iron, 252.
Scott, W. G., specifications for coke, 426; for moulding sand, 472; analyses of core sands, 479–89; analysis of Yougheogheney gas coal, 487; analyses of graphite, coke dust, coal and charcoal, 488–91.
Scott, W. G., specifications for graded pig irons, 243.
Scrap iron, grading, 250–51.
Secant, the, 108.
Set screws, steel, list price per 100, 160.
Shafting, *See* Steel shafting.
Sheath, Mr., on continuous melting, 551–54.
Sheet brass and all metals except steel and iron, Birmingham gauge for, 120.
Sheet iron, *See* Iron, sheet.
Sheet metals, weights of, per square foot, 142.
Shot iron, recovering and melting, 291–93.
Shrinkage chart, by W. J. Keep, 372–374.
Shrinkage of castings per foot, 234.
Shrinkage or contraction, 329–32.
Signs and abbreviations, v.
Silica brick, analysis of, 435.
Silicon, per cent, 308, 310; should be low, 315, 321; for elasticity, 323; for hardness, 325; for chill, 327; decreases shrinkage, 332; little effect on fusibility, 334; aids fluidity, 334; favors growth by repeated heating, 337; increases permeability, 340; increases acid resistance, 341; decreases resistance to wear, 342; unrecognizable in micrographs, 346; determination of, 377–78.
Silicon, properties of, 256; influence of as a constituent of cast iron, 256–60, 272.
Sines, natural, tangents and secants, 107–8; tables of, 110–14.
Skin drying moulds, 479.
Slag car castings, mixture for, 285.
Slags, comparison of analyses of, 432–33.
Smoke stacks, locomotive, *See* Locomotive castings.
Soil pipe and fittings, mixture for, 286.
Soldiers, 524.
Solids, and their mensuration, 30–34.
Solids, center of gravity of, 196–97; lineal expansion for, 205.
Specific gravity of various substances, 197–201.
Specifications for steel castings, standard, 409–11.
Speeds, grinding wheel, 231.
Speeds, surface, rules for obtaining, 232.
Sphere, the, 33–34.
Sphere, hollow iron, formula for finding weight of a, 572; of a solid iron, 571.
Spheres, table of surface and volumes of, 93–98.
Spherical segments, cast iron, formulas to find weight of, 573.
Spill bed, 466.
Sprocket wheels for ordinary link chains, 176–78.
Sprue cutters, steel, 537.
Square measure, tables of, 37–38.
Square of a whole number ending with ciphers, to find, 56.
Square root, 3–4.
Square root of large number not in table, to find, 62.
Square roots of numbers from 1000 to 10,000, 57–61.
Squares and square roots of numbers, of from .01 to 1000, tables of, 46–56.
Stead, J. E., on relations of iron and phosphorus, 348.
Steam chests, *See* Locomotive and Machinery castings.
Steam cylinders, mixtures for, 286.

Steel castings in the foundry, 394–416: Content of carbon in varieties, 394–95; mechanical properties "Normal steels," 396; Bessemer process, 396; Baby converter (Robert), 397; gases in, 398; chemical changes in Tropenas converter, 397–99; annealing, with micrographs, 400–1; Tropenas process, 401–3; chemistry of the process, 403–4; converter linings, 404–5; converter practice, 406–9; standard specifications, 409–11; open-hearth methods by W. M. Carr, 411–16.
Steel, comparative cost of, made by different processes (B.Stoughton), 417–24: Acid open hearth, 417, 419, 422; basic open hearth, 418, 419, 423; converter, 420, 421; crucible castings, 423; electric furnace, 424.
Steel, fillets of, areas and weights of, 145.
Steel, flat rolled, weights of, per lineal foot, 130–35.
Steel scrap, use of, in mixtures of cast iron, 290–91; points to be watched in melting, 316–17; closes the grain, 319; per cent of, 322.
Steel shafting, cold rolled, weights and areas of, 140.
Steels, mechanical properties of "normal," 396.
Steels, unsaturated and supersaturated, 241.
Stoughton, Bradley, tables of comparative cost of steel made by different processes, 417–21.
Stove plate, qualities of iron for, 275; mixture for, 286; average of three meltings, 457.
Stove-plate iron test bars, moduli of rupture of, 300.
Straight line, problems of the, 15–17.
Strainers and spindles, 528.
Straw rope for core bodies, 499.
Strength of beams, transverse, formulas for, 188–90.
Strength of cast iron, nine factors which influence, 315–22.
Strength of materials, 185–86, 213–14.
Strength table by W. J. Keep, 375.
Strengths, transverse, table of, 185–86.
Stupakoff, S. H. Chapter on jigs, 540–46.
Sturtevant Steel Pressure Blower, 448.
Subtraction in algebra, 8.
Sulphur, properties of, 260; deleterious influence of, in cast iron, 261–63, 272; per cent, 308, 315, 321; low for elasticity, 323; hardening effect of, 325; increases combined carbon, 327–28; effect on shrinkage, 332; on melting point, 334, 336; low for heat resistance, 337; and for corrosion resistance, 339–42; increases resistance to wear, 342; causes dirty castings, 343; in micro-structure, 346–48; determination of, 378.
Sulphuric acid, use of, in pickling, 567–68.
Sweeps, 522–23.

Tacks, length and number of, to pound, 148.
Tangent, 107.
Tanks, rectangular, capacity of, in U. S. gallons, 99–100; number of barrels in, 100–1.
Tapers per foot and corresponding angles, table of, 117–18.
Tapping bar, 463.
Taylor and White, temperatures corresponding to various colors of heated iron, 239.
Temperatures, equivalent, Centigrade to Fahrenheit, 211–12.
Temperatures, furnace, 206.
Tensile strength, ratio of, to breaking loads, 10 to 1, 302; D. K. Clarke's formula for, 304.
Tensile test, size of bar for, 295–97.
Test bars, report on by committee of American Foundrymen's Association, 294–306: Character of the heats, 294; making of coupons, 295; specifications for gray iron castings, 296–97; patterns for, 297; moduli of rupture, 298–300; erratic results, 298, 301–2; comparison of, 302–3; casting

defects, 304; circular, 304–6; microscopical evidence why similar irons have different relative strengths, 306–12; Prof. Porter on the physical properties of cast iron, 312–14.
Thermit, use of, in the foundry, 270.
Thermometer scales, comparison of, 213.
Threads, U. S. standard, 149.
Thumb screws, 165.
Tin and copper, alloys of, 222.
Tin, copper and zinc, alloys of, 224–25.
Tin, roofing, 169–70.
Tin, sheet, sizes and weight of, 142.
Titanium, properties of, 267; effect of, in cast iron, 267–68.
Tobin bronze, 225.
Tons, gross, in pounds, 235.
Transverse strength, *See* Strength.
Transverse test, size of bar for, 295-98; *See* Test bars.
Trapezium, area of a, 27.
Trapezoid, area of a, 27.
Triangle, area of a, 26.
Triangle, right-angled, solution of, 109.
Triangles, oblique-angled, solution of, 109.
Tropenas converter, chemical changes in a, 397.
Tropenas process of steel making, 401–3; chemistry of the process, 403–4.
Troy weight, table of, 36.
Tubes, brass and copper, seamless, 167–69.
Tumblers and tumbling mills, 563–66.
Turn-buckles, drop-forged, 162–63.
Turner, Prof. T., on varieties of pig iron, 253; percentages of combined carbon, 256; on the use of silicon, 257–59; phosphorus in cast iron, 264.
Tuyères, construction of, in cupola, 439–40.
Two-foot rule, measurement of angles with, 115–16.

Unit of heat, 207.
Units, electrical and mechanical, equivalent values of, 220–21.

Valves, mixtures for, 286.
Vanadium, properties of, 268; Moldenke's experiments on action of, on cast iron, 269–70.
Ventilating, *See* Heating and ventilating.

Walker, F. G., shrinkage of castings per foot, 234; weight of castings determined from weight of patterns, table, 570.
Washer, lock, 153; positive lock, 154.
Washers, wrought steel plate, 153.
Water, distilled, weights of volumes of, 39–40.
Water heaters, mixtures for, 286.
Water, pressure of, 219.
Water supply, 577–78.
Watts in terms of horse power, 45.
Wear, resistance to, 342.
Weaving machinery, *See* Machinery castings.
Wedge, the, 31, 195.
Weight of castings determined from weight of patterns, 569–70; formulas for finding, 570–76.
Weights, 528.
Weights and measures, 35–45; tables of various, 46–106.
Wells, contents of linings of, 104–6.
West, Thomas D., on power of cast iron to stretch, 332.
Wheel and axle, 194.
Wheels, mixtures for, 287.
Whitehouse, J. S., on side blow converters, 404–8.
Willson, E. M., table of tapers per foot and corresponding angles, 117–18.
Wind box of the cupola, 445–46.
Window glass, panes of, in a box, 236.
Wine measure, table of, 38.
Wire, brass, *See* Brass.
Wire, copper, *See* Copper.
Wire, coppered Bessemer spring, 147.
Wire, coppered market, 147.
Wire gauges, different standards for, 119–20.

Wire, iron, gauges and weights of, 146; list prices of, 147.
Wood working machinery, *See* Machinery castings.
Wrot pipe, dimensions of standard, 167–69.
Wrought Iron, *See* Iron, wrought.

Zinc and copper, alloys of, 223.
Zinc, copper and tin, alloys of, 224–25.
Zones in cupola, 437, 442–43.