APPLIED SCIENCE
FOR
METAL-WORKERS

By

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Man is weak of himself and of small stature. He stands on a basis, at most for the flattest soled of half a square foot insecurely enough, nevertheless he can use tools, can devise tools. With these the granite mountains melt into light dust before him; he kneads glowing iron as if it were soft paste; seas are his smooth highways; wind and fire his unwearying steeds. Nowhere do you find him without tools; without tools he is nothing; with tools he is all.—THOMAS CARLYLE.

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PREFACE

This book and its companion volume for the wood-working trades, first cover the general principles of science common to all industry, this material being identical in the two books. Additional material follows this, that relating specifically to the metal trades appearing in this volume, and that relating particularly to the wood-working trades appearing in "Applied Science for Wood-Workers." The books are constructed in this way to meet the needs of particular industrial, trade, continuation, or apprentice classes where the instruction is intensive.

Every craftsman should not only be trained in the handicraft of his trade, but, if he is to be a really skilled worker, should also master the scientific principles involved; that is, he should become familiar with the reasons underlying the various operations which he performs. Such knowledge is obtained through the study of industrial science. The teaching of related trade knowledge is not, so far as the author knows, adequately covered in any system of industrial education.

Experience proves that, though the average pupil who completes the regular high school course may know the principles of the sciences in an abstract way, he is unable to recognize these principles in operation in the every-day work of the world. This fact is not surprising. Observation shows that many minds are able to grasp a principle in the abstract but are not able readily to apply that principle in practice.

Therefore, the study of the application of the scientific principles underlying modern industry is worthy to be treated as a special subject.

The author believes that there is a place for the traditional courses in chemistry, physics, and biology in the regular high school, in addition to the first-year science course. He also believes that there is a type of mind in our intermediate and secondary schools that can profit by the study of the principles of science underlying the fundamental trades. A course of this kind should develop in a boy's mind that attitude of alertness toward theory on which all sound practice is based—a mental attitude which will be valuable to all manual workers, and particularly to those who are to enter the distributive or productive spheres of industry. Hence the title of this book, "Applied Science for Metal-Workers," the purpose of which is to provide an elementary course in applied science for the metal trades.

The author wishes to express his thanks to the following firms who have kindly furnished cuts and information: Dodge Sales and Engineering Company, The Lincoln Electric Company, The American Injector Company, Brown and Sharpe Manufacturing Company, Tolhurst Machine Works, Buffalo Forge Company, Bailey Meter Company, Novo Engine Company, Nicholson File Company, The Bigelow Company, Ingersoll-Rand Company, Babcock and Wilcox Company, American Steam Gauge and Valve Manufacturing Company, The L. S. Starrett Company, Norton Company, Millers Falls Company, James B. Clow and Sons, Watson Stillman Company, American Radiator Company, Whitall Tatum Company, Youngstown Sheet and Tube Company, Eberhard Faber, David Williams Company, American Screw Company, Enterprise Manufacturing Company, Edison

Storage Battery Company, Independent Pneumatic Tool Company, Riehle Brothers, National Carbon Company, Inc., Worthington Pump and Machinery Company, Western Electric Company, Greenfield Tap and Die Corporation.

Acknowledgment is also made of indebtedness to the teachers who have kindly read the manuscript and offered valuable suggestions.

The author will be pleased to receive any constructive criticism of the book.

WILLIAM H. DOOLEY.

NEW YORK CITY,
August 15, 1919.

SUGGESTIONS TO TEACHERS

The arrangement of this book is such that it may be used equally well by science teachers in the regular secondary and technical schools and by science teachers in vocational schools. When used in connection with a year's course in industrial science in the technical, industrial, or manual training courses of regular secondary schools, it will aid in correlating the principles of science with shop observation and experience.

The method of presenting the subject of industrial science in a vocational school should be different from the method used in the regular high school, since there is a wide difference both in the aims of the courses and in the types of pupils. In the vocational school it is well to consider first the practices of the trades and industries as based on practical shop experience and laboratory work, and from them to draw out the principles of science involved.

To illustrate: In considering the properties of matter in a metal like copper, present first the uses of copper; it is used, for instance, in the manufacture of sheet metal and wire. To be used as sheet metal, it must be capable of "being worked," that is, hammered into sheets—it must be *malleable*. The same reasoning applies to its use as wire; it must be capable of being "drawn out"—it must be *ductile*. As Walter Dill Scott says in "Influencing Men in Business". "Water is not adequately described by stating that it is composed of two parts of hydrogen to one of oxygen. The important thing about water is the uses which may be made of it."

This method will be found to be far more effective in teaching vocational school pupils than that of presenting the principle first and the illustrative practice afterwards.

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APPLIED SCIENCE FOR METAL-WORKERS

CHAPTER I

SCIENCE AND THE PROPERTIES OF MATTER

1. What Is Industrial Science?—The practice of different trades and crafts is based upon certain principles of science which may be appropriately called *applied science*, *industrial science*, or *shop science*. In the schools of college grade this subject is called *technology*. While the names industrial science and technology do not refer to any distinct science, they may be said to cover that body of information—consisting of some of the laws and principles of physics, chemistry, botany, bacteriology, geology, and hygiene—that explains the practices of the different trades and industries.

2. Classification of Scientific Knowledge.—*Physics* is the science which deals with those changes taking place in a substance which do not destroy its identity. Physics explains the properties of matter, physical force, liquids, gases, heat, magnetism, electricity, sound, and light. Thus, copper is used in the form of sheets and wires. Therefore it must possess properties that allow it to be hammered into sheets and pulled or drawn into wire. Air may be compressed, that is, "squeezed," into a small space and used to drive machines. Liquids, on the other hand, are practically incompressible. These are all physical properties.

Chemistry explains the changes that take place in a substance when its identity is destroyed. When iron, for example, is exposed to damp air, it becomes covered with a reddish brown substance called rust. This rust is due to a combination of the oxygen and moisture of the air with the iron. Copper or brass when exposed in this way becomes greenish in color from the same cause. The science of chemistry makes clear why such changes as these take place.

Other sciences explain the why and wherefore of other classes of phenomena or physical changes. Thus, *botany* treats of the growth and changes in plants. *Bacteriology* explains how changes in substances are caused by germs. An example of such a change is the rotting of wood. *Geology* treats of the structure of the earth, especially of rocks. *Hygiene* explains the principles underlying the care of our bodies. It is desirable to understand the principles of science as they relate to the different trades, so that we may have an intelligent knowledge of the processes and changes whereby raw substances or materials taken out of the ground are transformed into useful and beautiful things.

3. Properties of Matter.—Materials used in industry are generally defined and described according to their physical and chemical properties or characteristics. For most purposes the chemical properties are not so important as the physical, although in some cases the composition of the materials must be taken into account. The chief properties of materials are cohesion, adhesion, inertia, elasticity, ductility, brittleness, toughness, malleability, compressibility, porosity, durability, infusibility, hardness. Some of these characteristics, such as inertia, porosity, cohesion, and adhesion, are common to all forms of matter and may be considered as general characteristics. Others, such as brittleness and ductility, which are found only in certain kinds of matter, are called specific characteristics.

4. Cohesion, Adhesion, and Inertia.—The particles of matter in solids and liquids are held together by a force called *cohesion.* This cohesive force is stronger in some bodies than in others. Sometimes the word *tenacity* is used instead of cohesion. We may speak of a substance as possessing great tenacity or great cohesion; such a substance is said to be tenacious. Correctly speaking, tenacity is the measure of cohesion.

The property of a substance which enables it to stick or cling to another substance is called *adhesion.* Glue, for instance, is held to wood by adhesion.

Inertia is the tendency of a body to retain its condition of rest or of motion. The inertia of a hammer prevents it from moving itself. A lathe tends to run after the power is shut off.

5. Elasticity and Ductility.—When a carpenter bends the blade of his saw and releases it, the saw blade tends to return to its original position. This property is called *elasticity.*

A substance is said to be *ductile* when it can readily be extended or drawn out. Copper, because it possesses a high degree of ductility, can be drawn out into wire.

6. Brittleness and Toughness.—When a substance breaks easily under strain it is said to be *brittle.* Glass furnishes a good example of a particularly brittle substance.

Toughness, on the other hand, is that property which enables a substance to resist cutting and to bear strain without breaking.

7. Malleability and Compressibility.—A *malleable* substance is one which can be rolled or hammered into sheets without breaking or cracking. Gold and silver both possess a high degree of malleability.

When the particles of a substance can be forced to occupy a small space, that substance possesses the property of *compressibility.*

8. Porosity, Durability, and Infusibility.—Every body of matter is composed of very fine particles that fill the space occupied by the body. The particles of some bodies are held more closely together than are those of others, and we express this difference by stating that some bodies are more or less porous than others. A body whose particles are not very close together is said to possess *porosity.* Unglazed earthenware will absorb water.

The property of a substance which enables it to withstand long wear without decay or change is called *durability.* Painted oak, for instance, is a very durable wood, as it will stand a great deal of hard usage.

A substance which resists heat and will melt only at a high temperature is said to possess the property of *infusibility.* Platinum possesses a higher degree of infusibility than any other metal. The following table shows the order of malleability, ductility, tenacity, and infusibility of the most common metals. Those possessing these properties to the highest degree appear at the tops of the columns.

Table Showing the Order of

Malleability	*Ductility*	*Tenacity*	*Infusibility*
Gold	Platinum	Iron	Platinum
Silver	Silver	Copper	Iron
Aluminum	Iron	Aluminum	Copper
Copper	Copper	Platinum	Gold
Tin	Gold	Silver	Silver
Lead	Aluminum	Zinc	Aluminum
Zinc	Zinc	Gold	Zinc
Platinum	Tin	Tin	Lead
Iron	Lead	Lead	Tin

9. Indestructibility of Matter.—While all forms of matter may be changed or modified they can never be destroyed. As an illustration, when sugar dissolves in water the particles of sugar are so small or so minutely divided that they cannot be seen. Yet they are not destroyed because they can be recovered by boiling the water until it disappears in the form of steam and leaves the particles of sugar behind. Or, if wood or coal is burned and the ashes, vapors, and gases that have come from it are collected and separated from the gases of the air with which they have united during the process of combustion, it will be found that the united mass of the ash, gases, and vapors is the same as the mass of the original piece of wood or coal. It is a fundamental principle of science that matter is *indestructible.*

Questions

1. Is shop practice based upon any or many sciences?

2. Is it sufficient to know only the practice of the trade to be a successful mechanic?

3. How will it assist a mechanic to know why he performs each operation and uses each tool?

4. Does the average mechanic explain his work in terms of science? If he does not, explain the reasons.

5. Name the branch of science that explains the reasons for the following: iron rust; expansion of a metal by heat; freezing of water; boiling of water; protection of body by rubber gloves in working around electrical machines; finding lead in the form of sulphides in the earth.

6. Of what use to a practical man is a knowledge of the physical properties of water?

7. If the use of a material, such as copper (used in sheet metal tanks and electric wires), is known, is it possible to state its physical properties?

8. What are the physical properties of high-grade sheet metals? Wire? Copper? Lead? Zinc?

9. Give the names and uses of some materials that are: porous; compressible; elastic; soft; hard; heavy; light.

CHAPTER II

WEIGHTS AND MEASURES

10. Units of Measure.—Since not all objects have the same dimensions, it becomes necessary to have standards with which different bodies may be compared. The three fundamental units that are used in our daily experiences are the units of *time*, *length*, and *mass*. Without these units it would be impossible to do accurate work or to give and receive working instructions.

The unit of time is the *second* and is the same in all countries. The day is divided into 24 hours of 60 minutes each, and each minute contains 60 seconds. Twenty-four hours, or one day, is the time taken by the earth to make one complete revolution on its axis. In most trades the hour, minute, and second are used in place of the day as the practical working units of time.

The unit of length by means of which the English-speaking races measure distance is the *yard*. The standard of length in the British system is the imperial yard. It was defined by an act of Parliament in 1855 as the distance between two cross lines in two gold plugs in a certain bronze bar, kept at 62° Fahrenheit. This bar is preserved at the Board of Trade office in London. Though the unit of length was intended to be the same for England and America, in reality the United States yard exceeds the British by .00087 of an inch. The United States standard yard is the distance between the twenty-seventh and sixty-third inch marks of a scale prepared by the United States Geological Survey. It is kept at the Bureau of Standards, Washington, D. C. The foot is one-third of a yard, and the inch one thirty-sixth of a yard.

The units of area and volume are the square and the cube of the unit of length, i.e., the *square yard* and the *cubic yard.*

The American unit of volume for liquids is the Winchester wine *gallon,* which contains 231 cu. in.* The British unit is 277.274 cu. in. A quart is one-fourth, a pint (Fig. 1) one-eighth, and a gill one thirty-second of a gallon.

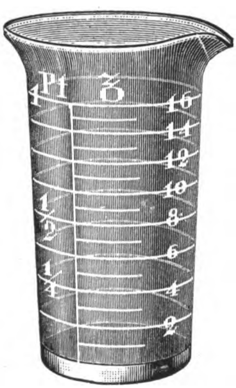

FIG. 1.—Pint Graduate. Graduated on right by ounces, on left by fractions of a pint. The symbol in the center is the symbol for pint.

The unit of weight, i.e., mass, is the *pound.* This weight is based on the force of attraction exerted by the earth upon a block of platinum called a pound weight. This block also is kept in the Board of Trade office in London. The United States standard weight is the avoirdupois pound which is copied from the English measure.

11. Measurement of Distance.—Distances of a few feet are usually measured with the ordinary foot rule graduated in inches, and in halves, quarters, eighths, and sixteenths of an inch. A carpenter's wooden rule is made of boxwood, because of all woods this is affected least by climatic conditions. Machinists' rules (Fig. 2) are usually made of hardened steel and are graduated to a fine degree.

* The unit by which gas is measured is the cubic foot. The unit by which building materials are measured is usually the cubic yard.

For convenience in carrying in the pocket, foot rules (Fig. 3) are often made with hinged joints so that they fold into a short length (4 in. or 6 in.) and longer rules are made in multiples of a foot. Formerly the most common rule used by mechanics was the folding 2-ft. boxwood rule. Present-day mechanics also use this rule largely, but where greater lengths are to be measured the zigzag folding rule is more commonly employed. This latter rule folds into 6-in. sections and may be obtained in any length up to 10 or 12 feet. The yardstick (3 ft. long), subdivided into feet, inches, and fractions of an inch, is also frequently used as a unit of measure, especially for the measurement of textiles.

FIG. 2.—A Machinist's Rule.

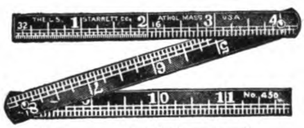

FIG. 3.—Folding Rule.

In building construction and timber measurements a 10-ft. pole is often employed. It is usually divided into 1-ft. sections, with the first foot subdivided into inches and fractions of an inch. Long objects, such as steam pipes, shaft lines, buildings, etc., are usually measured with a steel tape (Fig. 4). For ordinary purposes tape measures are made of various materials, such as linen braid or steel ribbon, in different lengths, and are graduated either in eighths or sixteenths of an inch. The graduations are printed on the braid, and the better grades are woven with wire selvages or edges to prevent stretching. Spring-tempered steel-

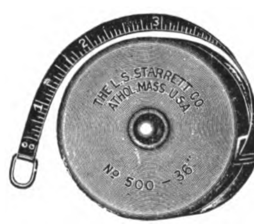

FIG. 4.—Steel Tape.

ribbon tapes on which the graduations are accurately etched are to be preferred for extremely careful measurements. They are very convenient in measuring curvilinear or irregular surfaces, as is done in measuring the circumference of a gas tank, the length of a belt to run over pulleys, or the length of band iron around a packing case. When using a tape measure for any considerable distance, care should be taken to see that the tape is supported at frequent intervals or rests on the floor. Otherwise an error will occur, due to the sagging and stretching of the unsupported tape.

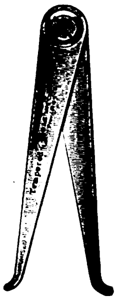

FIG. 5. Inside Calipers. For measuring inside bore diameters.

Compass-like devices with curved legs, called *calipers*, are used to measure the diameters of round bodies (Figs. 5 and 6).

12. Mass and Weight.—*Mass is the quantity of matter contained in a body.* When we speak of a pound of lead, the word pound expresses a definite quantity of matter. Commercially, weight always stands for mass. A merchant estimates his stock in pounds and usually understands by those weights nothing more than the quantity of matter possessed. The unit of mass is the quantity of matter in a standard pound.

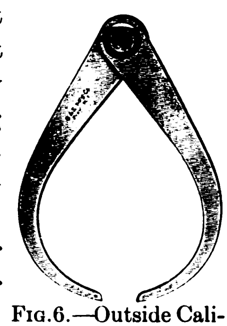

FIG. 6.—Outside Calipers. For measuring outside diameters.

The weight of a body is the measure of the force attracting it towards the center of the earth. Figure 7 illustrates the principle of ordinary weighing scales.

13. Density.—The simplest way to determine the weight of a large body is to measure its volume and then multiply that by the weight of a unit volume of the substance. *The weight of a unit volume of any substance is called its density.*

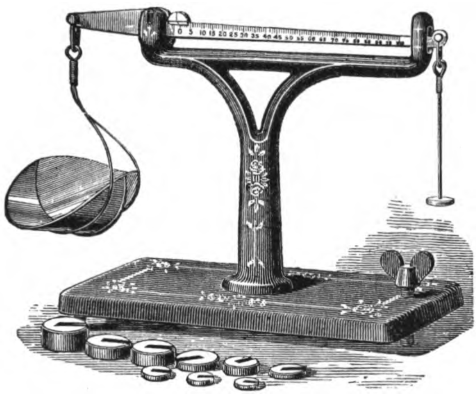

FIG. 7.—Weighing Scales.

These scales will weigh any body not more than 1 lb. in weight. Its scale is graduated in ten-thousandths of a pound. Such scales are used for weighing small articles, screws, samples of paper, etc. The weights are in front of the scales. The object to be weighed is placed in the pan.

The density of various substances has been compiled and reference tables have been prepared. The rule for determining the density of any substance may be written:

$$\text{Density} = \frac{\text{Mass or weight in pounds}}{\text{Volume in cubic feet}}$$

It follows therefore that:

$$\text{Weight} = \text{Density} \times \text{Volume}$$

$$\text{Volume} = \frac{\text{Weight}}{\text{Density}}$$

14. Speed.—The *distance* over which a body passes in a unit of *time* is called *speed.* Since the unit of space is usually the foot, etc., and that of time usually the minute, it follows that speed is measured in feet per minute, or in corresponding units.

15. Table of Weights and Measures.—The English system of weights and measures comprises the following tables which are in daily use in the shop, mill, and commercial work of America and England.

LONG MEASURE

12	inches	=	1 foot
3	feet	=	1 yard
2	yards	=	1 fathom
16½	feet	=	1 rod
4	rods	=	1 chain
10	chains	=	1 furlong
8	furlongs	=	1 mile
3	miles	=	1 league

SQUARE MEASURE

9	square feet	=	1 square yard
30¼	square yards	=	1 square rod
40	square rods	=	1 square rood
8	square roods	=	1 acre
640	acres	=	1 square mile

An acre is 208.71 feet square.

AVOIRDUPOIS WEIGHT

16 drams	=	1 ounce
16 ounces	=	1 pound
25 pounds	=	1 quarter
4 quarters	=	1 hundred
20 hundreds	=	1 ton

TROY WEIGHT

24 grains	=	1 pennyweight
20 pennyweights	=	1 ounce
12 ounces	=	1 pound

CUBIC MEASURE

1728 cubic inches	=	1 cubic foot
27 cubic feet	=	1 cubic yard
16 cubic feet	=	1 cord foot
8 cord feet or 128 cubic feet	=	1 cord

LAND MEASURE

7.92 inches	=	1 link
25 links	=	1 rod
4 rods	=	1 chain
80 chains	=	1 mile

CIRCULAR MEASURE

60 seconds	=	1 minute
60 minutes	=	1 degree
30 degrees	=	1 sign
60 degrees	=	1 sextant
90 degrees	=	1 quadrant
360 degrees	=	1 circle

Dry Measure

2 pints	=	1 quart
8 quarts	=	1 peck
4 pecks	=	1 bushel

Liquid Measure

4 gills	=	1 pint
2 pints	=	1 quart
4 quarts	=	1 gallon

Apothecaries Weight

20 grains	=	1 scruple
3 scruples	=	1 dram
8 drams	=	1 ounce
12 ounces	=	1 pound

Time Measure

60 seconds	=	1 minute
60 minutes	=	1 hour
24 hours	=	1 day
7 days	=	1 week
52 weeks 12 calendar months 365 days	=	1 year

Table of Quantities

12 units	=	1 dozen
12 dozen	=	1 gross
20 units	=	1 score
24 sheets	=	1 quire
20 quires	=	1 ream

General Measure

A mile	=	5280 feet
A cubit	=	2 feet
A pace	=	3 feet
A palm	=	3 inches
A hand	=	4 inches
A span	=	$10\frac{7}{8}$ inches

Wells and cisterns hold for each foot in depth:

Diam.		Gallons
2 feet	=	23
3 feet	=	53
4 feet	=	94
5 feet	=	147
6 feet	=	211
7 feet	=	288
8 feet	=	376

16. The Metric System.—The metric system of measurement is French in origin and is largely used in Continental Europe. It is the system used by nearly all scientific workers and is finding more and more favor in this country. In this system the unit of length is the *centimeter*, which is one-hundredth part of a meter. The meter is one ten-millionth part of the distance on the earth's surface from the equator to the pole. It is defined in the United States and France as the distance on certain bars in Washington and Paris which are kept at the temperature of melting ice. The unit of weight is the *gram*, which is equal to about onethirtieth of an ounce. The unit of volume is the *liter* which is a little larger than a quart. The gram is the weight of one cubic centimeter of pure distilled water at a temperature of 39.2° Fahrenheit; the kilogram is the weight of one liter of water; the metric ton is the weight of one cubic meter of water.

The principal advantage of the metric system consists in the use of decimal subdivisions and ease in calculations. The principle of the metric system is sound, but since there is no exact equivalent between the metric and English systems it is difficult to use the former for practical purposes where machines and formulas have been made according to the English system.

17. Table of Metric Measurements.—The metric system of weights and measures comprises the following tables. The symbols used to express the various units of measurement in abbreviated form are also given:

MEASURES OF LENGTH

10 millimeters (mm.)	=	1 centimeter (cm.)
10 centimeters	=	1 decimeter (dm.)
10 decimeters	=	1 meter (m.)
10 meters	=	1 dekameter (Dm.)
10 dekameters	=	1 hektometer (hm.)
10 hektometers	=	1 kilometer (km.)

MEASURES OF SURFACE (NOT LAND)

100 square millimeters (mm.)	=	1 square centimeter (sq. cm.)
100 square centimeters	=	1 square decimeter (sq. dm.)
100 square decimeters	=	1 square meter (sq. m.)

MEASURES OF VOLUME

1000 cubic millimeters (mm.)	=	1 cubic centimeter (cu. cm.)
1000 cubic centimeters	=	1 cubic decimeter (cu. dm.)
1000 cubic decimeters	=	1 cubic meter (cu. m.)

Measures of Capacity

10 milliliters (ml.)	=	1 centiliter (cl.)
10 centiliters	=	1 deciliter (dl.)
10 deciliters	=	1 liter (l.)
10 liters	=	1 dekaliter (Dl.)
10 dekaliters	=	1 hektoliter (hl.)
10 hektoliters	=	1 kiloliter (kl.)

Measures of Weight

10 milligrams (mg.)	=	1 centigram (cg.)
10 centigrams	=	1 decigram (dg.)
10 decigrams	=	1 gram (g.)
10 grams	=	1 dekagram (Dg.)
10 dekagrams	=	1 hektogram (hg.)
10 hektograms	=	1 kilogram (kg.)

18. Metric Equivalents.—The equivalent of the metric units in English measurements and vice versa, carried out when necessary to several decimal places, are given below. The *approximate* English equivalent for the metric units of measurement are found in the last table.

Linear Measure

1 cm. = .3937 inches (in.)	1 in.	=	2.54 cm.
1 dm. = 3.937 in. = .328 feet (ft.)	1 ft.	=	3.048 dm.
1 m. = 39.37 in. = 1.0936 yards (yds.)	1 yd.	=	.9144 m.
1 Dm. = 1.9884 rods (rds.)	1 rd.	=	.5029 Dm.
1 km. = .6214 miles (mi.)	1 mi.	=	1.6093 km.

Square Measure

1 sq. cm. = .1550 sq. in.	1 sq. in.	=	6.452 sq. cm.
1 sq. dm. = .1076 sq. ft.	1 sq. ft.	=	9.2903 sq. dm.
1 sq. m. = 1.196 sq. yd.	1 sq. yd.	=	.8361 sq. m.
1 are = 3.954 sq. rd.	1 sq. rd.	=	.2529 are
1 hektar = 2.47 acres	1 acre	=	.4047 hektar
1 sq. km. = .386 sq. mi.	1 sq. mi.	=	2.59 sq. km.

Weights

1 g.	= .0527 ounce (oz.)	1 oz.	= 28.35 g.
1 kg.	= 2.2046 pounds (lbs.)	1 lb.	= .4536 kg.
1 metric ton	= 1.1023 English tons	1 English ton	= .9072 metric ton

Approximate English Equivalents

1 dm.	= 4 in.	1 l.	= 1.06 quarts (qt.) liquid .9 qt dry
1 m.	= 1.1 yds.		
1 km.	= $\frac{5}{8}$ mi.	1 hl.	= $2\frac{5}{8}$ bushels (bu.)
1 hektar	= $2\frac{1}{2}$ acres	1 kg.	= $2\frac{1}{5}$ lbs.
1 stere, or cu. m.	= $\frac{1}{4}$ cord (cd.)	1 metric ton	= 2200 lbs.

19. Care in Using Right Units.—In performing all calculations care is required to see that the correct units are used. Oftentimes, through haste and confusion, inches instead of being first changed into feet are multiplied by feet to obtain area in square feet. This error is often overlooked because there are many formulas or rule-of-thumb methods that have been abbreviated to their lowest terms by cancellation so that in their final form it is possible to multiply inches by feet or pounds. Therefore in using a formula, care should be exercised to see that it is correct and that the proper units are employed.

To illustrate: the formula for determining the thickness of a lead pipe necessary for a given head of water is:

$$T = \frac{h \times s}{750}$$

where T is thickness of pipe *in inches*, s is size of pipe expressed s *decimal of an inch*, and h is the head of water *in feet*.

In this formula, feet are multiplied by a decimal of an inch. As an example, the thickness of a half-inch pipe carrying a 50-foot head of water would be:

$$T = \frac{50 \times .5}{750} = \frac{25}{750} = \frac{1}{30} = .033 \text{ in.}$$

20. Precision of Measurements.—Mechanical problems or operations usually consist of two parts: the collecting of data, and the solving of the problem. Both of these operations require a basic knowledge of materials, considerable judgment, and care for the accuracy of the work. One of the most effective methods of checking measurements is to take them twice, and then to arrange them in a systematic and tabular form. To avoid errors, it is well to refrain from using too many decimal places. It is generally a good plan to carry all calculations to one place further than that in which accuracy in the final result is desired. For instance, if it is desired to have a final result accurate to a hundredth of the whole, the calculations should be exact to the thousandth of the whole.

When one of a series of measurements has been taken and the results recorded to three decimal places, the second place of the decimals may be the same in all the measurements but the third place may differ. In other words, the result will be correct to two places, but the third place will be in doubt.

The following plan may be used to determine the place that is in error in the final product: Place a circle around the last digit that is nearest to the decimal place which is the least accurate. In the case of 6.845 × 4.5 this is .5.

```
 6.845
   4.5
------
 34225
27380
------
30.8025
```

Since **5** may be in error, any part of the partial product involving **5** may also be in error. Therefore it is doubtful whether any figure to the right of the first 0 of the result (which is in doubt) should be retained.*

21. Rules for Finding Area and Volume.—The forms of most tanks, compartments, and mechanical parts are those of simple geometrical figures such as squares, rectangles, hexagons, ellipses, and circles. Every pupil should be able to find the area and volume of such figures quickly and accurately. The following rules will be of assistance:

Rules Relative to the Circle

To Find Circumference:

Multiply diameter by 3.1416
Or divide diameter by .3183

To Find Diameter:

Multiply circumference by .3183
Or divide circumference by 3.1416

To Find Radius:

Multiply circumference by .15915
Or divide circumference by 6.28318

To Find Area:

Multiply circumference by one-quarter of the diameter

* For a more extended discussion of practical mathematics see "Vocational Mathematics," by William H. Dooley.

Or multiply the square of diameter by .7854
Or multiply the square of circumference by .07958
Or multiply the square of one-half diameter by 3.1416

To Find Side of an Inscribed Square:

Multiply diameter by .7071
Or multiply circumference by .2251
Or divide circumference by 4.4428

To Find Side of a Square of Equal Area:

Multiply diameter by .8862
Or divide diameter by 1.1284
Or multiply circumference by .2821
Or divide circumference by 3.545

Square:

A side multiplied by 1.4142 equals diameter of its circumscribing circle
A side multiplied by 4.443 equals circumference of its circumscribing circle
A side multiplied by 1.1284 equals diameter of a circle of equal area
A side multiplied by 3.545 equals circumference of an equal circle

To Find the Area of an Ellipse:

Multiply the product of its axes by .7854
Or multiply the product of its semi-axes by 3.14159

Rules Relative to Other Geometrical Figures

Contents of cylinder = area of end × length
Contents of wedge = area triangular base × altitude
Surface of cylinder = length × circumference + area of both ends
Surface of sphere = diameter squared × 3.1416, or = diameter × circumference
Contents of sphere = diameter cubed × .5236
Contents of pyramid or cone, right or oblique, regular or irregular = area of base × one-third altitude

Area of triangle = base × one-half altitude
Area of parallelogram = base × altitude
Area of trapezoid = altitude × one-half the sum of parallel sides

Questions

1. What measuring instrument is used to measure the length of a 9-ft. plate? 36-ft. boat? 20-ft. wind-shield?

2. What measuring instrument is used to measure the width of lumber? Length of bolts? Screws?

3. What measuring instrument is used to measure the diameter of a cylindrical metal bar? Balls?

4. What measuring instrument is used to measure the inside diameter of pipes? Elbows?

5. What measuring device is used in measuring the length and width of a table?

6. A foreman desires to measure the length of the shop floor. What measuring tool should he use?

7. What objection may be raised to measuring the length of a school room with a 2-ft. rule?

8. An apprentice was told to obtain the diameter of a pulley by measuring the longest distance across the pulley. Was this instruction correct?

9. How may the diameter of a small iron ball be obtained accurately?

10. Is there an exact number that shows the exact relation between the meter and the foot?

11. Give the advantages and disadvantages of the metric system of weights and measures. English system.

12. Explain some of the reasons why the metric system has not been extensively adopted in this country.

Problems

1. What is the area of a square surface 14 in. on a side? Give the area in square feet.

2. What is the area of a rectangular surface 1 ft. 5 in. by 8 in.? Give the area in square feet.

3. What is the area of circular piece of metal with a diameter of 8 in.?

4. What is the area of an elliptical shape with diameters 4 ft. 5 in. and 7 ft. 8 in.?

5. What is the volume of a cube 1 ft. 8 in. on a side? Give the answer in cubic feet.

6. What is the volume of a rectangular tank 8 ft. 5 in. by 7 ft. 7 in. by 5 ft. 4 in.?

7. What is the volume of a sphere 8 in. in diameter?

8. What is the volume of a cylinder 14 in. high with a diameter of 7 in.?

9. What is the area of a triangular surface, base 11 in. and height 9 in.?

10. What is the circumference of a pulley that measures 24 in. in diameter?

11. What is the side or thickness of a square bar, machine made from $1\frac{1}{8}$ in. circular stock?

12. A square bar is $1\frac{3}{16}$ in. thick, what size of circular stock must be used to make it?

13. What are the contents of a wedge with a triangular base of 14 sq. in. and 4 ft. high?

14. Give the area of the surface of a cylinder with diameter 7 in. and length $1\frac{1}{2}$ ft.?

15. What is the surface of a sphere in square feet with a diameter of 11 in.?

16. What are the contents of a sphere with a diameter $4\frac{1}{2}$ in.?

17. Give the contents in gallons of a conical-shaped vessel with a diameter of $2\frac{1}{2}$ in. and a height of $1\frac{1}{4}$ ft.?

18. What is the volume in cubic centimeters of a tank 2 m. $\times$ 4 dm. $\times$ 5 cm.?

19. Give the English equivalents of the following dimensions from a French blue-print: 1.7 m.; 26 dm.; 3 cm.; 5 mm.; 19 mm.; 24 dm.; 89 m.; 4 km.; 46 dm.; 7.9 m.

20. Give the metric equivalents of the following dimensions: 18 in.; 3 ft. 7 in.; 1 gal.; 7 qt.; 19 pt.; 5 ft. 9 in.; $2\frac{1}{2}$ lbs.; 1 lb. 9 oz.; 1 ton; 34 oz.

21. A milkman charges 60¢ a gallon for milk. What is the price per liter?

22. A powder sells for 70¢ a pound. What is the price per kilogram?

CHAPTER III

MECHANICAL PRINCIPLES OF MACHINES

22. Why Machines Are Used.—The invention of machines is the result of man's desire to save labor and to economize in the use of his own strength by utilizing, where possible, the natural forces of steam, wind, water, and electricity. Man possesses only a certain amount of energy. If one man works so fast as to exhaust himself by the end of the day, he will not accomplish so much in the long run as the workman who utilizes a little less than half his natural strength, and works at about one-third his greatest working speed.

Strength must be carefully distributed over the day's work, to obtain the best results. A machine never tires and can work almost constantly at its maximum practicable speed. It is for this reason that machines and labor-saving devices are continually being invented. These mechanical contrivances are the result of the experiences of the human race. The only tools that man possessed in the beginning were his hands and his teeth. As time went on he found that his hands and teeth were not sufficient, and he invented a club—a form of hammer. At later periods axes of stone, copper, bronze, and steel, and later the saw, plane, square, chisel, and file were invented. All these tools resulted from necessity, experience, observation, and the intelligent desire of the human race to save itself labor and toil.

23. Tools and Machines.—Tools are simple machines. When they become complicated they are called machines, and machines acting with great power take the name of engines.

Workshop tools are divided into two classes, hand-tools and machine tools. The former class includes hammers, chisels, files, ratchet braces, spanners, etc. The latter class includes lathes, planing, shaping, drilling, and slotting machines, used in the fitting shop; and punching and shearing machines, bending rolls, and steam hammers, used in the smith's shop. The compressed air attachment (Fig. 8) is a good example of a power tool.

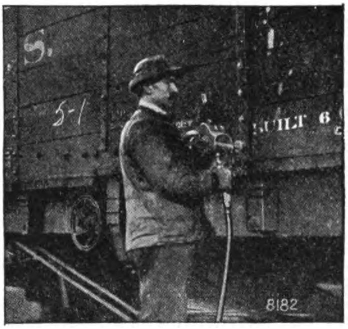

FIG. 8.—A power tool (compressed air attachment) tightening nuts on a freight car. Compressed air may be utilized in this way to screw on nuts and thus save the mechanic's strength.

24. Force and Work.—To understand the principles underlying the use of tools and machines, it is necessary chiefly to understand the differences between force, work, and energy. *Force is that which tends to produce, to change, or to destroy the motion of a body.* The force may be the strength of man or animal, or of steam, or electricity, etc. Tools and machines when stationary are in what is called a state of inertia. *The overcoming of resistance through any distance, such as putting tools or parts of machines in motion, is called work.* Work is done when a force produces or destroys motion.

25. Estimating the Work Done.—In estimating the work done two factors are employed—distance and force (weight)—the units of which are the foot and the pound respectively.

The unit of work is the product of the unit of weight and the unit of distance. When one pound is raised one foot (against the force of gravity) it is called a foot-pound.

Therefore the weight in pounds multiplied by the distance in feet gives the number of foot-pounds. By this means the *energy* expended in lifting a weight is measured.

$$\text{Pounds} \times \text{Feet} = \text{Foot-Pounds}$$
$$1 \text{ lb.} \times 1 \text{ ft.} = 1 \text{ ft.-lb. (one unit of work)}$$

When 847 lbs. is raised 12 ft., the work done is $847 \times 12 =$ 10,164 ft.-lbs.

Power is the rate of doing work, or work done in unit time. In other words, power is the number of foot-pounds of work that can be done per minute or per second.

To illustrate: If a man exerts a force of 80 lbs. in pushing a wagon 60 ft. in one minute, the rate of doing work during that minute is $80 \times 60 = 4800$ ft.-lbs. If the same amount of work is performed in two minutes, then the rate of doing work is $\frac{4800}{2} = 2400$ ft.-lbs. per minute. The unit of power is the horse-power (H. P.) 33,000 ft.-lbs. per minute, or 550 ft.-lbs. per second. Watt, years ago, found this to be the rate at which an average horse can work, hence the name.

Energy is the ability to do work, and is classified according to its source—animal energy, mechanical energy, electrical energy, etc.

26. Mechanical Principles.—A tool or machine is composed of one or more of the following mechanical elements: a lever, wheel and axle, pulley, inclined plane, wedge and screw. The force exerted on the mechanical principle is called acting force or power, and that given out is called weight or resisting force. We must bear in mind that none of these simple machines or mechanical elements can generate energy, but that they enable energy to be distributed and utilized to the best advantage. As an illustration, the ability to work hard and without rest varies according to the manner in which a workman applies his force, and the number of muscles he brings into action. In the operation of turning a crank, a man's strength changes in every part of the circle which the handle describes. It is greatest when he pulls the handle upward from the height of his knees, and weakest at the top and bottom of the circle, where the handle is pushed or drawn horizontally.

Questions

1. Is it possible to determine the degree of skill of a trade by the number of tools used? Explain.

2. What impression would you gather from a person who was driving carpet tacks with a machinist's hammer? Explain.

3. Is it economical to use a sledge hammer to drive ordinary wire nails into a board floor? Explain.

4. State the kind of energy used in the following cases: (a) a man lifts a casting from the floor; (b) a house is moved with horses; (c) a grist mill grinds corn by means of running water back of the mill; (d) a steam boiler drives the engine.

5. Has a mechanic more energy in the morning before going to work than after a day's work? Explain.

CHAPTER IV

LEVERAGE

27. The Principle of the Lever.—Many tools are based upon the principle of the lever. A lever is a rigid bar, straight or bent, free to turn about a point called a *fulcrum*. Levers are generally divided into three kinds or classes, the class being determined by the position of the fulcrum in relation to the applied force or effort and the resisting force, i.e., the weight. The mechanical principle of the lever was discovered by a Greek named Archimedes, who lived in the third century. He stated that if he had a lever long enough and a place to stand, he could move the earth.

28. Mechanical Advantage.—Since a lever is a tool, its object is to assist in distributing strength or speed to the best advantage. Suppose a lever is used in moving a heavy stone. By what means can the amount of assistance rendered by it be determined? This assistance, called the mechanical advantage, is obtained by *dividing the force arm or effort arm* (the perpendicular distance from the fulcrum to the direction of the force), *by the weight arm* (the perpendicular distance between the fulcrum and the weight), or *by dividing the resistance or weight by the effort or applied force.* In other words, there are two ways by which a lever can be made to be of more service: first, by lengthening or increasing the force arm; second, by shortening or decreasing the weight arm.

If a mechanic, for example, desires to have more advantage, or, as he usually says, more "leverage," he may increase the length of the force arm by taking a tool with a longer handle.

29. Moment of Forces.—All problems in leverage may be solved by arithmetic and without using a model.

Suppose that two weights are balanced as in Fig. 9 at the distances shown therein. As 11 times 18 equals 12 times 16½ (198) it follows that *the weight of one side times its distance from the fulcrum is equal to the weight on the other side times its distance from the fulcrum.*

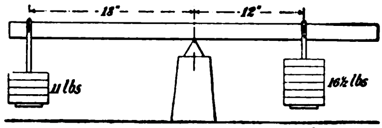

FIG. 9.—The Moment of Forces.

$$W \times D = W' \times D'$$

This rule always holds true for all classes of levers. If, therefore, the amount of both weights and one distance are known, the other distance can always be found; or if any three of the four quantities are known, the fourth can always be found. As an example, if we know all but the 16½ lbs. in Fig. 9 we can find this figure in the following way:

$$\frac{18 \times 11}{12} = 16\tfrac{1}{2} \text{ lbs.}$$

In all classes of levers *the weight or force times its perpendicular distance from the fulcrum is called the moment.*

Thus in the above problem, $12 \times 16\frac{1}{2}$ is one moment and 18×11 the other. As another example: What force will balance a weight of 100 lbs., 12 in. from a fulcrum located at the short end of a lever? The long end of the lever is 24 in. in length.

$$100 \times 12 = \text{moment of acting force}$$
$$W \times 24 = \text{moment of resisting force}$$

But, when a lever is balanced, the moments of forces are equal, according to the rule explained above.

$$W \times 24 = 100 \times 12$$
$$24W = 1200$$
$$W = 50 \text{ lbs.}$$

That is to say, it will take 50 lbs. at the long end of the lever to balance the 100 lbs. at the short end.*

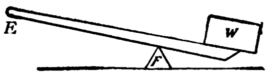

Fig. 10.—A Lever of the First Class.

30. Levers of the First Class.—In levers of the first class, the fulcrum is placed between the acting and resisting forces as shown in Fig. 10.

This figure illustrates the lifting of a heavy block by means of a crowbar and a support.

E = Effort
F = Fulcrum
W = Weight

By pressing down the end of the bar E the other end of the lever raises the weight W and the center of motion is at the fulcrum F. In other words, the applied force E acting on the lever supported by the fulcrum F overcomes the resistance, called weight W.

The force of the lifting power of the lever increases in proportion as the distance of the effort E from the fulcrum increases, and diminishes in proportion as the distance of the weight W from the fulcrum increases.

* It should be noted that when leverage problems are figured by arithmetic no account is taken of the weight of the lever itself. The results obtained by using simply weights and distances are exact enough for all practical purposes. If the designer had to allow for the weight of the lever itself, he would have to make a long and difficult calculation. Such allowance, however, is not necessary because, for safety, all parts of machinery are made at least five times as strong as they need to be.

31. Examples of Levers of the First Class.—Another example of a lever of the first class is the use of the fire poker with the bar of the grate serving as a fulcrum. When a lever consists of two parts fastened by a rivet, it is called a double lever. Scissors, pincers, and forceps are all examples of such a lever; the rivet serves as a fulcrum.

The scale beam used in weighing is also a simple lever. The arms on each side are of equal length and are suspended over the center of support. The axis at the point of suspension is sharpened to a very fine, sharp edge, so that when weights are placed in the scales, the beam may turn with as little friction as possible. When the arms are not of equal length, the scales cannot weigh accurately, although the beam may seem fairly balanced and the weights true. If one arm is 8 in. long and the other only 7½ in. the scale will balance with a 1-lb. weight on the short arm and 15-oz. on the long arm. Thus the customer of a merchant who uses such a scale loses an ounce in every pound. The deceit can, of course, be discovered by changing the weight and material to the opposite scales. In some cases where the beams of scales are not accurate, the articles to be weighed are put in one pan and balanced by weights; the article is then put in the other pan and balanced again. The correct weight is found by taking the square root of the product of the two weights.

32. Levers of the Second Class.—In the second class lever the weight and force are on the same side of the fulcrum, the weight being placed between the force and the fulcrum.

For example, if a mason desires to move a large piece of stone forward, instead of bearing down upon the lever to raise the stone up a little, he sticks his crowbar into the ground under the stone and at the same time pushes forward (Fig. 11). In this way he moves the stone onward little by little, the ground being the fulcrum. The same principle of leverage applies to the opening of doors or box covers. The oars of boats and the masts of a ship in which the cargo acts as resistance, the bottom of the vessel as the fulcrum, and the sails as the moving power, are also levers of the second class. Nutcrackers (Fig. 12), lemon-squeezers, and devices consisting of two legs joined by a hinge are further illustrations of this class of levers.

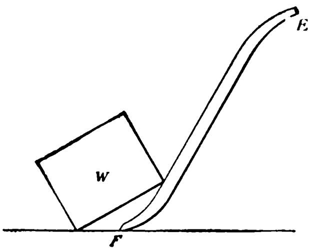

FIG. 11.—A Lever of the Second Class.

33. Levers of the Third Class.—In the third type of lever the fulcrum is at one end, the weight at the other, and the force is placed between them (Fig. 13). The advantage of this arrangement is that a small force causes the extreme point of a long arm to move over a great space.

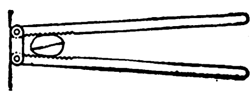
FIG. 12.—A Nutcracker. An example of a lever of the second class.

The mechanism of the muscles acting on the bones illustrates this form of lever. The elbow or joint is the fulcrum, the muscle the moving power, and the weight raised the resistance. The muscles of large migrating birds, for example, must be very powerful in order to sustain the weight of their bodies while they travel for days.

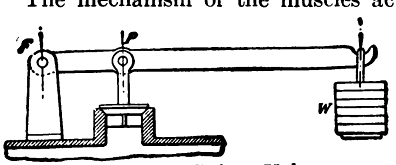

FIG. 13.—A Safety Valve. A lever of the third class.

34. Compound Levers.—Levers are said to be compounded or compound when their free ends are joined to the free ends of other levers. Large scales used in weighing luggage, bricks, wagon loads, and so on, consist of an arrangement of compound levers, whereby the arm on one side of the fulcrum is lengthened and the arm on the other side is shortened. The brake rigging on locomotives and cars is a familiar example of a compound lever.

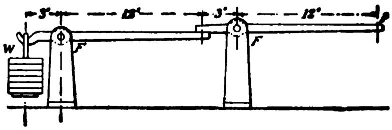

FIG. 14.—Compound Levers.

Two or more levers joined and working together (Fig. 14) illustrate this principle of leverage. Here a weight suspended on a hook at *W* causes the end of the second lever *P* to swing downward.

35. Problems in Compound Leverage.—Problems in compound leverage are easily reduced to repeated cases of simple leverage, the force at the end of the first lever being the weight or force applied to the second lever, and so on through any number of levers.

As an example: If the force at *W* in Fig. 14 is 12 lbs., what is the force at *P?*

For the first lever the force pushing up at the end of the long arm is: $\frac{12 \times 3}{12} = 3$ lbs. For the second lever it is: $\frac{3 \times 3}{12} = \frac{3}{4}$ lb.

While the safest way is always to figure each lever as a simple lever, as just explained, a shorter method of obtaining the answer is as follows:

Multiply the weight by the continued product of the short arms of all the levers, and divide this by the continued product of the long arms of the same levers.

Applying this rule to the above problem we have

$$\frac{12 \times 3 \times 3}{12 \times 12} = \tfrac{3}{4} \text{ lb.}$$

The answer is the same as before, and after a little thought it is evident that the two steps in the first case have merely been put together in one expression in the second case. If the weight, ¾ lb., on the long end of the second lever at P is known (see Fig. 14), and the pressure or weight which would be needed at W is to be found, the same rule will apply but will be expressed in this manner: *Multiply the weight by the continued product of the long arms and divide this by the continued product of the short arms:*

$$\frac{3}{4} \times \frac{12 \times 12}{3 \times 3} = 12 \text{ lbs.}$$

Regardless of how many levers there are working together, the rule is applicable. In all leverage problems the first, and the most important, thing is to find and locate the fulcrum, as the fulcrum is the point which determines the moment arms from which the required answer is obtained. The moment arm is always the perpendicular distance from the force or weight to the fulcrum.

36. Shapes of Levers.—The fulcrum of levers used in machinery is usually cylindrical in shape, made of soft metal, and supported in the interior of a cylindrical opening in which the lever works, so as to reduce the friction. The lever is not only oscillating or vibrating, but where the motion is circular the fulcrum becomes the axis of rotation.

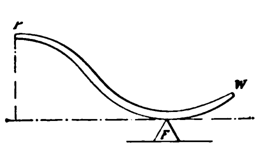

FIG. 15.—A Bent Lever.

A bent lever (Fig. 15) is often used for peculiar circumstances, but it acts obliquely and, consequently, with less effect.

The rules of leverage apply with equal accuracy whether a lever is straight or bent at an angle. Take, for example, the lever shown in Fig. 16. This lever, it will be noted, has one arm bent up at a right angle to the other and a weight hung on the horizontal arm. Imagine a force applied at the end of the vertical arm as shown. It is plain that the weight W times its distance A from the fulcrum is equal to the force F times its distance B from the fulcrum, just as if the lever were in the same straight line.

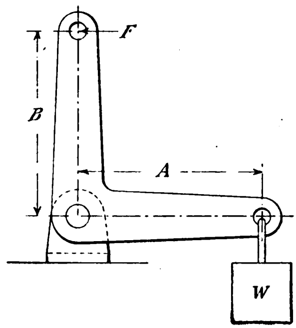

FIG. 16.—Bell-Crank Lever. Another type of bent lever.

It is, of course, understood that in all leverage problems the force must always be at right angles to the arm. Therefore, while the weight acts vertically, the force acts in a horizontal direction. The lever is bent up as the direction of the force on the end that is bent is thus changed.

Questions

1. Draw a sketch of a hammer removing a nail from a board. Where is the fulcrum? What class lever is it? Why?

2. Draw diagrams of the three classes of levers and give an example of each kind.

3. Name some examples of bent levers.

4. Give three examples of compound levers.

5. Define fulcrum, force arm, and weight arm.

6. Will a mechanic who knows why he performs each operation of his trade enjoy his work better than one who does not? Explain.

7. Explain why some hammers are large, some small, and of different shapes.

8. Is it necessary to know the principles of science in designing a tool?

9. What would happen to a mechanic if he used a hammer four times as heavy as necessary? Would he accomplish as much work with the large hammer as the small hammer (assuming the small hammer will do the work effectively)?

10. Why not use a claw hammer in driving tacks into the floor?

11. Name a number of "hitting tools." Notice the manner in which they are used. Is it practically the same? What is the mechanical principle involved?

Problems

1. Take a yardstick and balance it in the middle. Where is the fulcrum?

2. If a 2-lb. weight is attached 7 in. from the fulcrum, where should a 3-lb. weight be placed to balance it? Draw a sketch.

3. Examine common tools and devices, such as scissors, pliers, tack-lifters, lemon-squeezers, nutcrackers, can openers, pokers, etc., and measure the force arm and weight arms.

4. What is the weight or lift produced on a pump handle that has a weight arm of 5 in. and a force arm 21 in. long when 25 lbs. is applied at the handle? Draw a sketch.

5. A safety valve on a stationary boiler is loaded with a 50-lb. weight at *W* (Fig. 13). Distance *F P* is 4 in., *P W*, 12 in. Find the total steam pressure necessary to open the valve.

CHAPTER V

PULLEYS, INCLINED PLANES, AND WEDGES

37. Simple Form of Pulley.—The *pulley* is a machine which in its simplest form consists of a grooved wheel, made of wood, brass, or iron, with a rope or chain passing over it, fixed in a framework, and free to revolve. As the type of pulley shown in Fig. 17 turns on an axle fixed in one place it is called a fixed pulley.

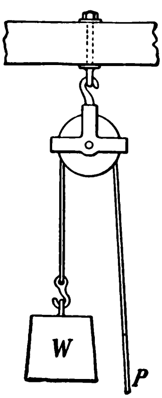

FIG. 17.—A Fixed Pulley.

Such a device makes it easier for a man standing on the floor to raise a weight by pulling on the end of the cord at P than if he pulled the weight straight up by the cord without any pulley, or carried the weight up a flight of stairs.

A pulley may be considered as a rotating lever which is used simply to change the direction of a force. The belt or rope does the work, not the wheel. There is no leverage in a single fixed pulley, and if the weight is 50 lbs., it takes a pull of 50 lbs. at P (ignoring the slight friction of the wheel axle) to raise it. In Fig. 17 the lever arms in the pulley are equal to the radius and the fulcrum is at the center; that is, in a pulley 16 in. in diameter one arm would be 8 in. on one side and the other 8 in. on the other side of the fulcrum.

38. Block and Tackle.—The advantage of the single pulley may be increased by combining several pulleys, as is done in the case of the appliance called the block and tackle.

Figure 18 shows the arrangement of a single pulley block or shop tackle, consisting of one fixed pulley in the upper block and a movable one in the lower block. One end of the rope is fastened to the upper block. This arrangement is merely a single movable pulley with its rope extended up and around another pulley, thus enabling the operator to pull down when raising the weight. The upper pulley therefore does not affect the amount of the force, but merely changes its direction from a pull-up to a pull-down on the rope. The advantage of this type of block and tackle is that the force is decreased one-half, while the space the worker pulls through is twice that of the movement of the weight. W is 100 lbs.; the worker has only to lift 50 lbs.; to raise the weight 1 ft. he must draw up 2 ft. of rope, that is, one on each side of the pulley. Without the pulley he would have 100 lbs. to raise 1 ft.

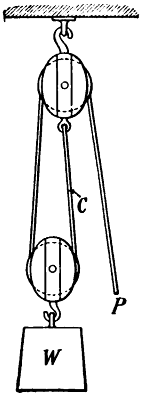

FIG. 18.—Block and Tackle.

Increasing the number of pulleys decreases the weight per strand, and allows a smaller force to overcome a larger at the expense of space and loss of time. (Fig. 19.) The pulley ropes used are called tackle, and the pulley, a block. A number of pulleys placed together occupy much space and are inconvenient to handle. To avoid this, and at the same time obtain the required mechanical advantage, it is common to have several pulleys, called

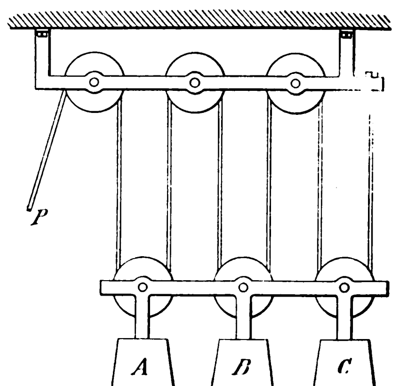

FIG. 19.—Series of Pulleys.

sheaves, assembled in one block on the same pin. Sometimes three, four, or more sheaves are placed thus side by side, a strong pin serving as an axis. In this way a force can move two, three, or four times its own resistance. Thus in a three-sheaved movable block, 100 lbs. would balance 300 lbs. Since the entire movement of the pulley is made up of a series of stops and starts, the movable pulley acts during its motion on the principle of a lever of the second class. As a result, *the force applied times the diameter of the pulley will always equal the weight lifted times the radius of the pulley.*

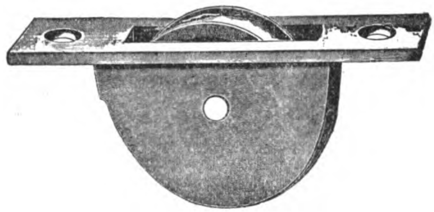

FIG. 20.—A Dumb-Waiter Pulley.

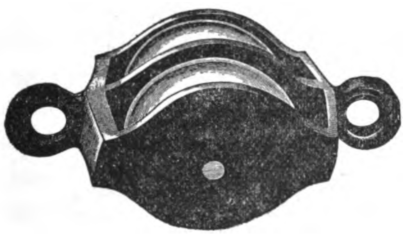

FIG. 21.—Tackle or Awning Pulley.

Figures 20, 21, and 22 show common forms of pulleys.

Problems on Pulleys

1. How much pull at P would be required to lift 150 lbs. at W? (Fig. 18.)

2. What force at W would just balance 200 lbs. at P?

3. With what force or how many lbs. is the rope C pulling on its fixed end when 300 lbs. is being lifted at W? (This force or pull is called the tension at C.)

4. If a rope is carried around six pulleys as shown in Fig. 19 and a pull of 100 lbs. is exerted at P, what weights would be lifted at A, B, and C?

5. How far would the three lower pulleys and frame be raised if the rope at P is pulled down 6 ft.?

6. How does the force of the arrangement shown in Fig. 19 differ from the force obtained from a block and tackle having three pulleys in each block (neglecting friction)?

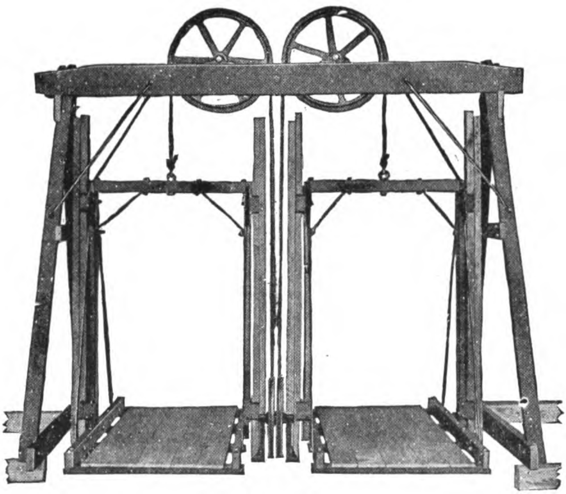

FIG. 22.—Use of a Single Pulley. Double-platform material elevator for lifting materials to a building. One elevator goes up while the other comes down, so that only force enough to lift the actual load is required.

39. Wheel and Axle.—The study of pulleys and tackles leads naturally to that of the wheel and axle, which consists of a wheel or crank attached to an axle. The weight is lifted or moved by means of a rope, belt, or chain running over the axle. The force is applied to the rim of the wheel. In previous problems the pulleys have all been of equal diameters, and operated by cords or ropes, but the wheel and axle may be considered as fixed pulleys of different diameters fastened on a shaft, the larger pulley being the wheel, and the smaller pulley the axle.

The principle of the wheel and axle is very important, since a great many machines, such as derricks, cranes, elevators, steam shovels, etc., are constructed on this plan.

Figure 23 shows the simplest form of wheel and axle, in which A is the wheel and B the axle or drum. If a weight P is hung from a cord wound on A it will wind up a certain weight W on drum B.

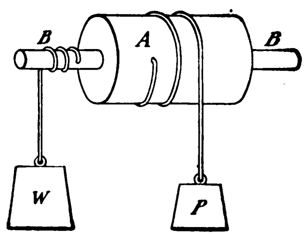

FIG. 23.—Wheel and Axle.

40. Comparison with the Pulley.—In theory the wheel and axle is nothing more than a single movable pulley, which instead of being a lever of the second class, and always lifting the weight exactly at its center, is a lever of the first class and lifts the weight some distance off the center. A single movable pulley moves the weight in the same direction in which the rope is pulled, but the wheel and axle moves the weight in the opposite direction from which the rope is pulled. The lengths of rope wound or unwound from the wheel and axle are always inversely proportional to the weights raised or lowered.

Problems on Wheel and Axle

Note carefully in all problems on the wheel and axle that more force is required the faster the weight is lifted. Moreover, if the axle is made smaller, the weight will be lifted more slowly and less force will be required.

These same principles are true in the case of pulleys and tackles. In fact, it will be found that in all machinery it takes more force to do work quickly than to do it slowly.

1. Figure 24 shows a common winch or hoist which is a good illustration of the wheel and axle; the crank is the wheel and the

6-in. drum is the axle. If a boy turns the handle P uniformly with a force of 50 lbs., what weight can he lift at W?

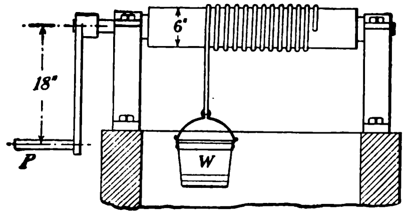

FIG. 24.—Hoist.

2. Suppose in problem 1, 15% were lost in friction, what would be the answer to the problem?

3. If 26 ft. 8 in. of rope were wound up on the drum in Fig. 24, how many turns and parts of turns did the crank P make? (Take $\pi \doteq \frac{22}{7}$.)

4. In Fig. 24, what is the ratio between the weight lifted and the force applied?

5. A wheel and axle has the wheel 24 in. in diameter and the axle 12 in. in diameter. If 10 ft. of rope are wound up on the wheel how many feet will be unwound on the axle?

NOTE.—To do this problem it is necessary only to consider the circumferences of the wheel and the axle. One turn of the wheel will wind up 3.1416×24 in. of rope and at the same time unwind 3.1416×12 in. of rope from the axle. This is the same as saying that the lengths of cord wound and unwound are proportional to the circumferences of the wheel and axle. But we already know that the circumferences of circles are proportional to their diameters and so we can say that the lengths of rope wound and unwound are proportional to the diameters of the wheel and axle and in the above problem we will have,

$$24 : 12 = 10 : \text{rope unwound from axle.}$$

or

$$\frac{12 \times 10}{24} = 5 \text{ ft. rope unwound from axle.}$$

A simple rule for this would read: *To find the length of rope unwound from the axle multiply the length of rope wound on the wheel by the diameter of the axle and divide this by the diameter of the wheel.*

If we wanted to find the length of rope wound up on the wheel the rule would read: *To find the length of rope wound on the wheel* *multiply the length of rope unwound from the axle by the diameter of the wheel and divide by the diameter of the axle.*

Or in the above problem,

$$24 : 12 = x : 5$$
$$\frac{24 \times 5}{12} = 10 \text{ ft.}$$

In the *derrick* (Fig. 25), the hoisting mechanism is a form of double wheel and axle in which the axle of the first works upon the wheel of the second by means of gears. It is used for raising heavy weights.

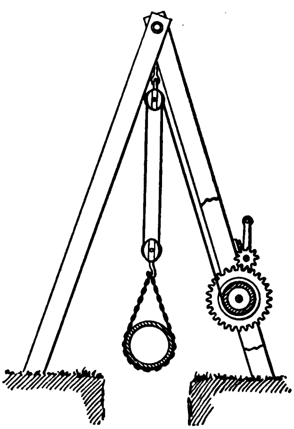

FIG. 25.—Derrick.

41. Inclined Planes.—Another simple machine, called an *inclined plane,* is a slope used to enable a small force, such as the strength of a man, to overcome the weight of a large body. When, for example, it is necessary to move heavy boxes, barrels, etc., from a sidewalk to a wagon or from a wagon to the sidewalk the teamster usually places a plank between the two distances, thus making an inclined plane and pushes the barrel or box onto the wagon. If a wagon bed is 4 ft. above the ground and a board 8 ft. long is placed against it, a man can then roll the barrel up the inclined plane with one-half the force he would have to exert when lifting, but in twice the time, as the distance covered is twice that of the vertical or upright height.

The mechanical power gained on an inclined plane is equal to the quotient obtained by dividing the length of the plane by the height. To illustrate: If a barrel weighing 300 lbs. is to be rolled onto a wagon 4 ft. from the ground and a plank 12 ft. long is used, a strength or force of 100 lbs. would balance the barrel, because the inclined plane is three times the perpendicular height. A slight force over the 100 lbs. would move the barrel.

Roads constructed to the tops of hills are either wound round and round, or made so broad that a person or driver of a vehicle can wind from side to side in climbing the hill. In building houses, an inclined plane in the form of a plank walk is used to facilitate the transit of wheelbarrows in and out of the building. The stairs of a house form a steep inclined plane on which the steps enable one to secure a firm footing.

42. An Example of the Inclined Plane.—Figure 26 represents an inclined plane supporting a ball A which is free to roll on an axle through its center. A cord attached to the yoke of the axle passes over a guide pulley B to a counterweight W. The weight W is then pulling against the ball in a direction parallel to the face of the plane and is preventing the ball from rolling down.

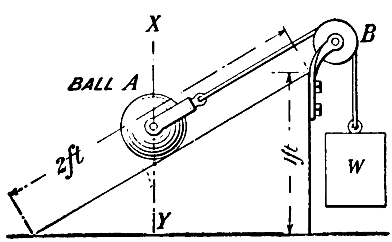

FIG. 26.—Inclined Plane.

Now it is easy to see that the weight W does not need to be so heavy as the ball to keep the ball from rolling, since part of the weight of the ball is supported by the plane. In other words, the ball naturally tends to fall straight down in the direction of the dotted line XY, just as though it were dropped from the hand and fell to the floor.

By a diagram of similar triangles, it can be proved that the length and height of the inclined plane are proportional to the weights A and W. For example, if in Fig. 26 we make the height of the plane 1 ft, and its length 2 ft., we know that the weight W need only be one-half as heavy as the weight of the ball to keep it from rolling down the plane. Stated as a proportion this would be,

$$\text{Weight } A : \text{Weight } W = 2 \text{ ft.} : 1 \text{ ft.}$$

We will now study the relative movements of the weights if the height of the inclined plane is one-half its length. In Fig. 26 when the ball rolls from the top of the plane to the bottom it has traveled 2 ft. on the plane but has dropped only 1 ft. in a vertical direction. By this we know that the distance the ball travels on the plane is to the vertical distance it moves through as 2 is to 1, when the height of the plane is one-half its length.

It has now been proved that there is a definite ratio or relation between the height and length of the plane and the weight of the ball and counterweight, and also between the distances the ball moves along the plane and perpendicular to it. Whatever the height or length of the plane, these relations always hold true.

From what has been explained, short, simple rules can be made for problems relating to inclined planes as follows:

I. To find the counterweight or force, *multiply the weight on the plane by the height of the plane and divide by the length of the plane.*

II. To find the weight on the plane, *multiply the force by the length of the plane and divide by the height of the plane.*

Problems on Inclined Planes

1. Neglecting friction, what force is necessary to keep a weight of 100 lbs. stationary on an inclined plane, the perpendicular height of the plane being 4 ft. and the length of its incline 14 ft.?

2. The length of an inclined plane is 15 ft. and its height 7 ft. What weight will a power of 78 lbs. sustain on the plane, neglecting friction?

43. The Wedge.—A combination of two inclined planes joined at their bases is called a *wedge*. This simple machine is used to split wood, rocks, etc., and to raise heavy weights short distances. The power of the wedge cannot be accurately estimated, as the force, number of blows, and incline all have to be taken into account. In splitting wood (Fig. 27), the sides of the opening in the log act as levers, and thus force the mass apart in advance of the point of the wedge. More power is gained by striking the head of the wedge with either a small or a large hammer, than by pressure, as the momentum of the blow tends to shake the particles of matter and cause them to separate.

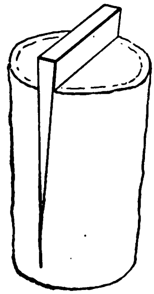

FIG. 27.—Wedge.

The lifting power of the wedge is utilized in dockyards, where large vessels are raised by its agency. The heads of hammers are fastened on by wedges driven in at the part of the handles near the heads. Nails, knives, needles, razors, hatchets, chisels—all act on the principle of wedges. A saw in motion represents a series of wedges which are drawn along and pressed on the object to be cut. When the edge of a razor is examined by a microscope, it is seen to be sawlike in formation; by being drawn along the beard, it cuts off the hairs.

44. Application of the Principle of the Wedge.—Just as the power of the inclined plane is proportional to the height and length of the plane, so is the power or force applied to the wedge proportional to its height and length. In this latter case, however, the length is the horizontal length or base *ac* (Fig. 28) and not the sloping face *bg*. By the principles of similar triangles, we can easily prove that when a force acts in a direction parallel to the base of a wedge, the wedge will lift a weight as many times greater than the force, as the base or length of the wedge is times as long as the vertical face or thickness This may be stated as a rule as follows:

To find the force required to lift a certain weight multiply the weight by the greatest thickness of the wedge and divide by the horizontal length.

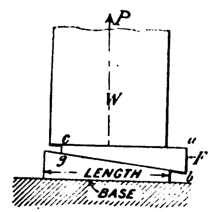

FIG. 28.—Lifting Power of Wedge.

On the inclined plane previously described the force acts in a direction parallel to the plane; that is, the cord attached to the ball pulls up the plane. In Fig. 28 a weight *W* is being lifted by driving two single wedges. To raise the weight we must strike or push on the face of either one of the wedges, as at *F* on the face *ab*. This force acting parallel to the base *ac* of the wedge causes a pressure *P* in a direction at right angles to the base.

Problem on the Wedge

A single wedge is 2 ft. long and 4 in. thick. What force must be applied to it to lift a weight of 600 lbs., neglecting friction?

45. The Principle of the Screw.—The screw possesses great industrial utility in pressing bodies together or in raising weights, and may be classed among the simple machines. The screw is an inclined plane, and the effect of a screw is produced when such a plane moves spirally around a cylinder. This movement may be illustrated by cutting out a wedge-shaped piece of paper and wrapping it about a round stick or bolt. The sloping side draws a thread on the stick as in Fig. 29. This thread is called a helix (Fig. 30).

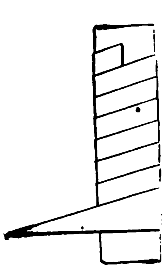

FIG. 29.—Principle of the Screw.

It really makes no difference in the result whether the inclined plane is wound in a spiral or circular path, or left straight; the wedging action will be there just the same. This means that all screw threads, nuts, bolts, etc., are circular or spiral wedges. The ease with which a screw turns and ascends depends on the slowness of the ascent, that is, on the number of turns, or threads, in a given distance.

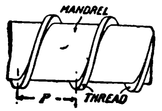

FIG. 30.—Helix.

46. Jack Screw.—The ordinary jack screw is a good example of the wedge principle. It is a screw in combination with a lever.

Figure 31 shows a common jack screw. The thread is the inclined plane or wedge and the circumference of the screw or thread corresponds to the base of the plane. The force P on the handle is the force acting parallel to the base and the weight W is the weight lifted. The same rule which is used for the wedge will now apply. If the length of the handle, the pitch of the thread (the distance between two successive threads), and the force applied to the handle are known, the weight which can be lifted, neglecting friction, can easily be calculated.

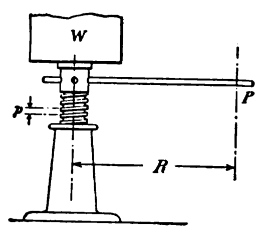

FIG. 31.—Jack Screw.

Referring to Fig. 31, for every turn of the handle the weight is raised an amount equal to the pitch:

$$P \times C = W \times p$$

where P, W, and p are as shown in the sketch and C is the circular distance the end of the handle moves through in making one turn, or

$$C = 2 \pi R$$

Problem on the Jack Screw

A jack screw has a single thread, seven turns to the inch, and a handle 18 in. long. If a force of 50 lbs. is applied to the end of the handle what weight can be lifted, neglecting friction? (Take $\pi = \frac{22}{7}$.)

47. Measurement of Machine Power.—It is often very desirable to determine the power necessary to operate a machine. This may be done by means of instruments called *dynamometers*. The prony brake is one of the most simple and familiar examples of the dynamometer.

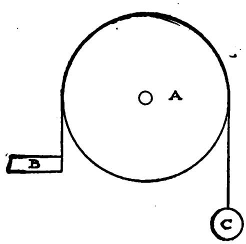

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FIG. 32.—Principle of Prony Brake.

Figure 32 represents one type of prony brake in which a fixed band of leather, or rope, is in contact with a portion of the circumference of a pulley or drum A. The band has one end attached as shown at B, while the weight C is hung at the other end.

The formula to find the foot-pounds per minute is:

$$\frac{3.1416 \times \text{diam. of pulley} \times \text{rev. per min.} \times \text{weight}}{12}$$

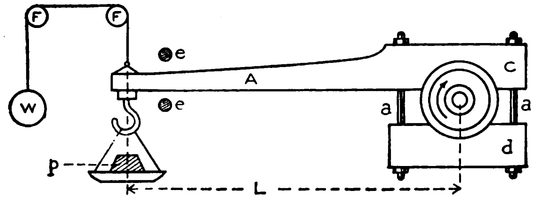
As an example, if the pulley of a band brake is 126.04 in. in diameter and makes 200 revolutions per minute, while a weight of 5 lbs. hung at end of the band just affects the speed, what is the H. P.?

$$\frac{3.1416 \times 126.04 \times 200 \times 5}{12} = 32{,}997.272 \text{ or approximately } 33{,}000$$

ft.-lbs. per minute = 1 H. P.

48. Another Form of Prony Brake.—Figure 33 shows the prony brake as generally constructed. The clamp shoes c and d

are clamped to the pulley with bolts *a, a*. As the pulley revolves in the direction indicated by the arrow, the tendency is for the entire brake to rotate in the same direction; this is prevented by



(Copyrighted by Millers Falls Co.)
FIG. 33.—Prony Brake as Usually Constructed.

the weights *P* in the scale pan suspended from the end of lever *A*. When the pulley runs at its normal speed, sufficient weight is placed in the pan at *P* to balance the lever between the pins *e, e*, which are provided to prevent the lever from revolving. The power absorbed by the clamp shoes *c* and *d* is equal to the amount of work which is accomplished in foot-pounds per minute by the revolving shaft.

$$\text{This work in foot-pounds} = N \times P \times L \times 2\pi$$

where *N* is number of revolutions per minute, and *L* the length of lever.

$$\text{The H. P.} = \frac{2\pi NPL}{33000}$$

The small pulleys *f, f*, and the weight *W* are provided as a counterbalance for the lever arm when the machine is at rest. The clamp shoes *c* and *d* should be well lubricated. To illustrate the calculation, assume that an engine shaft makes 240 revolutions per minute, what is the H. P. developed when a weight of 50 lbs. is just balanced at the end of a 10-ft. lever, as shown in Fig. 33?

$$\text{H. P.} = \frac{2\pi NPL}{33000} = \frac{6.2832 \times 240 \times 50 \times 10}{33000} = 22.8 \text{ H. P.}$$

49. The Cost of Mechanical Advantage.—It has been shown that by the use of tools and machines which are all based on one of the six principles just described, it is possible to apply a small force to overcome a large resistance. This advantage is obtained by sacrificing either speed to gain force or force to gain speed. The ratio of the resisting force to the applied force is called the mechanical advantage of the tool or machine. The advantage gained in all the simple machines is lost in time. No machine will enable a given amount of force to raise 2 lbs. with the same velocity as it can raise 1 lb. As a matter of fact, power is wasted by the use of machinery because the increase of friction adds to the amount of force which has to be used.

50. The Effect of Friction.—Thus far we have considered the relations of speed, force, and resistance from a somewhat theoretical standpoint; in actual practice a deduction has to be made from the advantage apparently gained because of the resistance of the machine to free motion. This resistance is due to the rough surfaces of the bearings of the machine, although to the naked eye these bearings may appear perfectly smooth. When polished surfaces are inspected or examined under the microscope (Fig. 34) they are seen to have many inequalities and to be comparatively rough. These inequalities fit into the hollows of the opposite surface, out of which it requires some force to lift or

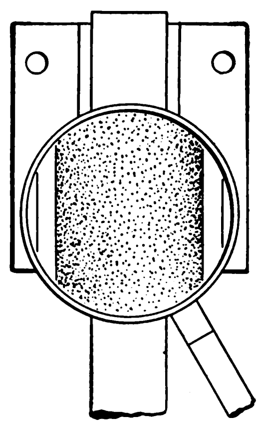


Fig. 34.—Metal Under a Magnifying Glass. Imaginative view of a shaft showing microscopic roughness that causes friction.

slide them. This is done first by polishing the surfaces until they are as smooth as possible and then by inserting some lubricant, such as oil, grease, or black lead which fills up the little holes and thus reduces friction. Friction is also reduced by having two different substances or metals in contact, as, for example, the brass or sometimes jeweled boxes in which the steel axles of wheels in clocks and watches revolve. The greatest amount of friction arises just before motion takes place, because the inequalities of the upper surface sink into those in the lower more completely at rest than in motion.

In going down a hill, drivers of heavy vehicles pass a chain through a spoke of the wheel to increase the friction, and thus prevent the wheel from turning. Friction between the ground and the shoe enables us to walk. Shoes with hob nails are dangerous on a smooth iron plate because the two iron surfaces give little friction.

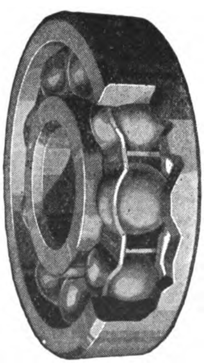


FIG. 35.—Ball Bearings.

51. Use of Ball Bearings.—Rolling friction is friction due to a solid rolling over a smooth surface, as in the case of a car wheel moving over a rail, while a sliding friction is due to the sliding of the same particles of a wheel over a rail. Sliding friction is greater than rolling friction, and in the case of iron it is 100 times greater. Hence the use of ball bearings (Fig. 35).

52. Measurement of Friction.—In all machines there is more or less friction. The work done by the acting force always exceeds the useful work by the amount that is transformed into heat. The ratio of the useful work to the total work done by the acting force is called the efficiency of the machine.

$$\text{Efficiency} = \frac{\text{Useful work accomplished}}{\text{Total work expended}}$$

The efficiency of simple levers is very nearly 100% because the friction is so small as to be disregarded. In the inclined plane the friction is greater than in the lever because the two bodies come in contact with a larger surface. The efficiency of a lever is somewhere between 90 and 100%. The efficiency of the commercial block and tackle with several movable pulleys varies from 40 to 60%. In the case of the jack screw there is necessarily a large amount of friction so that its efficiency is often as low as 25%. Gear wheels or chain gears, such as are used in bicycles, are machines of high efficiency, often running as high as 90% or more.

Questions

1. A crane consists of what simple machines?

2. Name a number of "twisting tools and appliances" such as are used in placing a nut in position. Notice the manner in which they are used. Are two distinct circumferences made in their operation? Name the mechanical principles involved.

3. Name a number of "screw tools and appliances," that is, tools and appliances that are based on a spiral groove. Divide them into two parts: those that communicate motion and those that are used as fastening agents.

4. Explain the manner in which a screw communicates motion.

5. Name a number of "hoisting tools and devices." How do they work? What is the mechanical principle involved?

6. Name a number of "cutting tools." What is the shape of the cutting edge? Does the part that "cuts" come to a point or sharp edge? Does the part away from the cutting edge become thinner or thicker?

7. Name a number of "run appliances," that is, appliances or tools connecting two floors or stagings at different levels.

8. Is the "run" appliance always longer than the perpendicular distance between the two levels?

9. Divide all the ordinary tools and appliances that you remember into the following groups: hitting tools; twisting tools; screw tools; hoisting tools; cutting tools; "run" appliances.

10. Name a list of simple tools and appliances and state whether "speed" or "power" is gained by the use.

11. Name some machines that involve more than one of the simple machines or mechanical principles.

12. What is the meaning of the expression "mechanical efficiency"? "Mechanical advantage"?

13. What is friction?

14. Where is friction found?

15. Is friction a form of energy?

16. Is friction a "necessary evil" or has it some advantage?

17. Do we use friction in walking?

18. Is friction used in the case of automobiles?

19. How is friction reduced?

20. What are roller bearings? Are they useful in reducing friction?

21. Why is sand placed on the railway track?

22. Why are roller bearings placed on skates?

23. Explain why it is difficult to walk on ice.

24. What is the object of waxing a floor before dancing?

25. Give the approximate percentage of efficiency of the different simple machines.

26. What is a lubricant?

27. What are some of the dangers of excessive friction among woody materials, paper, or cotton stock?

Problems

1. A plank 11 ft. long is used to raise a barrel of flour (196 lbs.) into a car $3\frac{1}{2}$ ft. high. What force is necessary to raise it?

2. A carpenter uses a force of 10 lbs. in pulling a saw across a piece of wood and 100 strokes of 2 ft. each to saw the wood in two. What amount of work was done?

3. A differential pulley has a large wheel 10 in. in diameter and a small one 8 in. What is the mechanical advantage?

4. A person desires to roll a barrel weighing 200 lbs. into a wagon that is 4 ft. above the ground. What is the most effective way to do it if he can push with a force of 80 lbs.? How long a plank will be necessary?

CHAPTER VI

LAWS OF MOTION

53. Three Laws of Motion.—Some interesting facts about the motion of bodies, which we ordinarily find out only as the result of long experience, can readily be understood by a knowledge of the laws of motion and momentum. A body set in motion by a force, such as steam or electricity, starts slowly and its speed increases in proportion to the strength of the force and the resistance of the body. To illustrate: When an electric car moves we experience a heavy jarring; this is due to the seat starting before our body and pulling us along.

The natural state of inorganic or lifeless bodies is one of rest, called inertia. *Every body continues in a state of rest, or when set in motion continues to move in a straight line, unless acted upon by some external force.* This is the first law of motion.

When an object is moving, its speed may be increased by applying more force. If the force is applied in a different direction from that in which the body is moving, the body will either stop or change its direction of motion. This principle may be expressed by stating that *every change of motion is in the direction of the new force applied to the body, and is proportionate to it.* This is the second law of motion.

A force never appears singly. That is, there are always two or more contending forces in every mechanical operation and in all mechanical work. To illustrate: When a mechanic attempts to unscrew a nut, the pull or force he applies to the nut is called *action*, and the resistance is called *reaction*. The reaction consists of friction and of the tendency of the nut to remain stationary. The relation between action and reaction is such that *every action is resisted by an opposite and equal reaction*. This is the third law of motion.

54. Momentum of Bodies.—*The momentum of a body is the quantity of motion in the body, and is the product of the mass and the speed.*

As an example: To find the momentum of a body 9 lbs. in weight, moving with a velocity of 75 ft. per second, the rule is:

$$\text{Mass} \times \text{Velocity} = \text{Unit of momentum}$$
$$9 \times 75 = 675 \text{ units of momentum}$$

We may abbreviate this rule by substituting letters for quantities. Let the mass be represented by M and velocity by V. Then

$$\text{Momentum} = M \times V$$

The multiplication sign is usually left out between letters; therefore the quantity is written MV. Momentum may be expressed as a product of pounds by feet per second and tons by feet per second. In the metric standard it may be expressed as a product of grams by centimeters per second, or kilograms by centimeters per second.

55. Gravitation and Center of Gravity.—If we take a thin bar of iron and place it on a table, it will remain there. Remove the support, and the bar will fall to the ground. All bodies act in the same way. The earth attracts them, and this force is called *gravitation*. If a bar of iron is laid across a support, one particular point will be found at which it will balance, and remain at rest; that point is called the *center of gravity* of the iron bar, because it is the point at which the entire weight of the body may be considered as centered;

if the bar is of the same thickness throughout its length, it will be exactly in the center. If the support is changed to any other point, the bar will fall to the ground; or if a weight of 1 lb. be fixed on one end, and a weight of 4 lbs. on the other end, then the center of gravity will be 1 ft. from the 4-lb. weight. The center of gravity is also called the *center of inertia* or *the center of mass. It is the point in a body about which the mass is evenly disposed and if pivoted at that point, the body ought to be balanced.*

56. The Line of Direction.—*A perpendicular line drawn from the center of gravity to the earth is called the line of direction.* This imaginary line is of great importance in the construction of buildings, chimneys, and other tall structures. By the use of the law of gravity and the "plumb line," the mason, bricklayer, or machinist can test a wall or other kind of structure as it is being built to see that it is perpendicular and perfectly straight.

FIG. 36. Mercury Plumb Bob.

57. Mercury Plumb Bobs.—Mercury plumb bobs (Fig. 36) are usually made of hollow steel rods filled with mercury or quicksilver. Consequently they are unusually heavy in proportion to their size, and their centers of gravity are low. Their comparatively small diameters also allow them to be used close to corners and walls; they are not easily affected by draughts of air; and they can be packed in a small space. As a result, they may be used to advantage almost anywhere.

58. Acceleration Due to Gravity.—If a body falls freely in vacuum, that is, without resistance from the air, its velocity will not be constant throughout the entire fall, but will increase at a uniform rate. This uniform increase in speed is called the *acceleration of gravity.* It is expressed in feet per second per second.

When a body falls freely in this manner it will have attained at the end of one second a velocity of 32.2 ft. per second. Thus the average velocity during the first second will be 16.1 ft. per second. Since the velocity increases at a uniform rate, it will be 64.4 ft. per second at the end of 2 seconds, and the space fallen through during this second second will be 48.3 ft.

The average velocity of the object for any second is the average of the velocity at the beginning and the velocity at the end of that second.

Thus:

Velocity at beginning of 1st sec.	=	00.0	ft.	per	sec.
Velocity at end of 1st sec.	=	32.2	"	"	"
		2)32.2			
Average velocity for 1st sec.	=	16.1	"	"	"
Velocity at beginning of 2nd sec.	=	32.2	"	"	"
Velocity at end of 2nd sec.	=	64.4	"	"	"
		2)96.6			
Average velocity for 2nd sec.	=	48.3	"	"	"
Velocity at beginning of 3rd sec.	=	64.4	"	"	"
Velocity at end of 3rd sec.	=	96.6	"	"	"
		2)161.0			
Average velocity for 3rd sec.	=	80.5	"	"	"

As the space fallen through in any given second is equal to the average velocity for that second, it follows that *the* *total distance fallen through at the end of any given second is equal to the average velocity up to the given point multiplied by the number of seconds during which the object has fallen.*

For example:

Initial velocity	=	00.0 ft. per sec.
Velocity at end of 3rd. sec.	=	96.6 " " "
	2)	96.6
Average velocity for first 3 sec.	=	48.3 " " "

$3 \times 48.3 = 144.9$ ft., space fallen through in first 3 sec.

The above theory supposes a body to be falling freely in a vacuum, but while the air will offer a resistance and somewhat reduce the actual motion the principle is the same. Acceleration due to gravity varies but little at different latitudes of the earth. Acceleration due to gravity decreases at higher altitudes, and increases as we go below the surface of the earth. All these variations on the earth's surface are so small that they hardly need to be considered in any calculation concerning practical problems in mechanics. Acceleration due to gravity may be considered as 32.2 ft. per second each second.

Since the velocity of falling bodies increases at the uniform rate of 32.2 ft. per second, the final velocity in feet per second must equal the product of the time in seconds multiplied by 32.2.

To illustrate the calculation: What final velocity will a body acquire in a free fall during 7 seconds?

$$V = 7 \times 32.2 = 225.4 \text{ ft. per second}$$

59. Kinds of Motion.—Motion may be *uniform* or *variable.* When equal distances are traversed or covered in the same length of time the speed is constant. On the other hand, when the speed changes and equal distances are not traversed or covered in the same length of time, the motion is said to be variable. The rate of change of velocity is called the acceleration. It is said to be positive when it increases, and negative when it decreases.

A body moving from one place to another in a straight line is said to undergo *translation* or *rectilinear motion*. When a body moves around a fixed point or axis it is said to *rotate*. The particles of the body make concentric circles, as a pulley rotates on a shaft; such motion is said to be *curvilinear*.

60. Cams.—In a great many machines, such as looms, sewing machines, printing presses, punch presses, automobile engines, etc., it is often necessary to give to each machine a motion peculiar to itself. In one machine it may be necessary to change circular or rotary motion into back-and-forth or reciprocating motion at definite times during the working of the machine. In another machine the opposite effect may be desired. A curved plate or groove, called a *cam*, is used for producing such irregular motion. Cams are constructed in various shapes and dimensions. They may consist of simply a wheel, a projecting part of a wheel, or a revolving piece. The nature of the motion given by the cam to a machine is determined by the shape of the cam.

61. Centrifugal Force.—Rotating bodies like grindstones, fly-wheels, etc., are built to run at a certain maximum speed. If this speed is exceeded the body may fly to pieces, as there is a tendency for particles of a rotating body to fly off in straight lines. The force that causes this movement away from the center of gravity is, as we have noted, called centrifugal force. This force is overcome by the cohesive force of the material that composes the fly-wheel, or the adhesive material that holds the particles of the grindstone together. This cohesive or resisting force is called *centripetal force* and is directed toward the center.

The principle of centrifugal force is utilized to great advantage in the construction of hydroextractors, i.e., machines designed to throw off the water contained in dyed or scoured fabrics, in sugar in a liquid state, and in bolts and nuts or other small metal parts. All centrifugal machines operate on essentially the same principle. Figures 37 and 38 show a machine designed to extract the liquid from solid or semi-solid matter by centrifugal force; this type of machine is known as a chip wringer. Figure 37 shows the basket about to be lowered into its casing; the machine is then ready for use. Figure 38 shows the machine open with the basket inverted, the material having been dumped out.

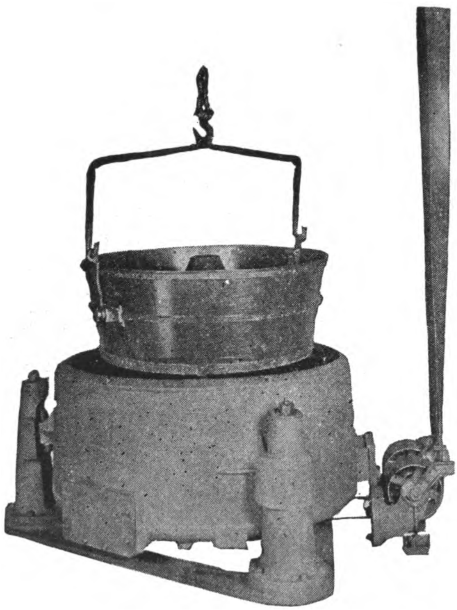


FIG. 37.—Centrifugal Machine. Showing basket about to be lowered into casing.

The operation of the chip wringer is comparatively simple. Suppose the liquid is to be extracted from a pile of bolts and nuts. The bolts and nuts are placed in the basket, suspended above its casing by means of a device. The basket is then lowered into its casing. When in this position, ready to be set in motion, there is a very narrow slit between the rim of the basket and the casing. This slit is so narrow that, although liquid can readily flow through it, the passage of any solid particles is prevented.

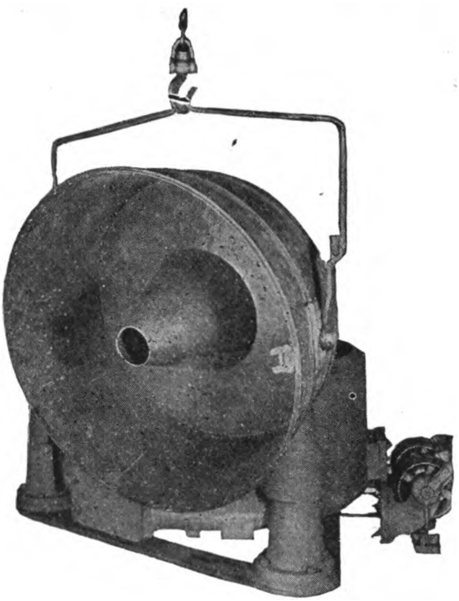


FIG. 38.—Inverted Basket of Centrifugal Machine.

The basket is then set in motion and made to revolve at a high speed. The centrifugal force thus generated forces the bolts and nuts to the sides of the basket and throws off the liquid. (The amount of centrifugal force generated increases with the revolutions per minute [R. P. M.] of the basket.) All the water thrown off is ejected from the basket through the narrow slit just described. When all the water has been removed in this way, the machine is stopped. The basket is then raised, carried along to a convenient place, and dumped.

62. Force Expressed Graphically.—Sometimes it is necessary to express or measure a force or forces graphically, that is, by means of lines. This is particularly true in the building of machinery and structures, where the results of the application of force and skill may be obtained with less labor than by calculation. Graphic expression also gives accuracy sufficiently near for good practice. Force is measured in this way by considering the beginning of a line to be the point at which the force is applied, the length of the line to be its magnitude, and the direction of the line to be the direction of the force.

To illustrate: If a force of 10 lbs. is applied at a certain point *A* in an easterly direction, it would be represented by the line *AB* drawn 10 units in length. If there are two forces acting on a body at *A* and at right angles, one with an easterly direction of 10 lbs. and another with a northerly direction of 5 lbs., the actual direction of the motion of the body may be represented by the following parallelogram, the lines of which are parallel to each other (Fig. 39). If *AC* represents a force of 5 lbs. (called a component force) and *AB* represents a component force of 10 lbs., *AD* will represent the resultant of the two forces. To maintain the forces *AB* and *AC* in equilibrium a force must be applied at *A* equal to *AD* and acting in the opposite direction *AF*.

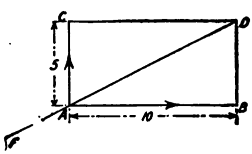


FIG. 39.—Parallelogram of Forces.

$$AF = AD$$

AF is called the equilibrant.

The above principle may be worked backwards. For example: If one force is given, it is always possible to find two others in given directions which will balance it.

63. Different Kinds of Energy.—There are, as noted in Chapter III, many forms of energy, such as chemical, electrical, muscular, mechanical, etc. Any one form may be transformed into any other form. For instance, electrical energy may be transformed into chemical energy by charging a storage battery; muscular energy into mechanical energy by sawing a board with a hand-saw; mechanical energy into electrical energy by means of a dynamo. It is impossible to create or destroy energy, but it is easy to transform it. A pile-driver head weighing 75 lbs. suspended 25 ft. above the ground possesses energy, to the extent of 1875 ft.-lbs. due to its position. *This energy is known as static or potential because it is stationary.* When the weight is released and falls, the energy is called *kinetic energy, that is, energy released or due to motion.* Potential energy is sometimes called energy of stress; for example, the spring in a spring balance is under tension when a weight is suspended from the hook. Of course in all cases the weight times height equals the energy of the body,

$$E \text{ (potential)} = W \times H,$$

although sometimes the velocity is given instead of the height. .Then the:

$$\text{E (kinetic)} = \frac{\text{W} \times \text{V}^2}{\text{2 Force of gravity}}$$

or

$$K = \frac{WV^2}{2g}$$

This is obtained by substituting in the formula for energy, for the height its value

$$\frac{(\text{Velocity})^2}{\text{2 Force of gravity}}$$

or

$$\frac{V^2}{2g}$$

Impulse equals force times time. Impulse may be defined as the force multiplied by the length of time it acts.

$$\text{Momentum} = \frac{\text{Weight} \times \text{Velocity}}{32}$$

The energy stored in a revolving fly-wheel is kinetic, and is, therefore, represented by the formula

$$K = \frac{WV^2}{2g}.$$

W stands for, or is equal to, the weight of the wheel in pounds, g for 32, attraction force of gravity, V for velocity of a definite point in the iron in feet per second. At this definite point the whole weight is assumed to be collected.

FIG. 40. Coiled Spring.

64. Springs as a Source of Energy.—Springs are useful as machine parts, because of their capacity for yielding to force without permanently losing their shape—technically called their "permanent set." Wound springs possess potential energy, because at some previous time work has been performed upon them in the winding. Coiled springs in watches and clocks which set the mechanism in motion, are an illustration. Steel is superior to all other materials for the manufacture of springs, but must be protected when exposed to dampness; otherwise it will rust.

The force of a spring is not exactly uniform in its action, for it has its greatest energy when most bent or most tightly wound. Since the elastic force of a spring is not affected by the force of gravitation, it is used to ascertain the amount of the earth's attraction (pull or weight) in various places. This is done by the use of a cylindrical spring balance to which a hook or ring is fastened (Fig. 41). The object to be weighed is hung from the hook which pulls the spring in proportion to the weight. From graduations on the scale it is possible to read directly the weight of the commodity.

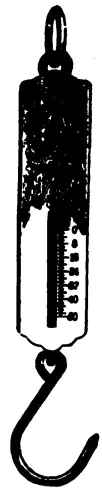


FIG. 41. Spring Balance.

65. Weights as a Source of Power.—Weights are used as a source of energy when uniform pressure or action is desired. The proper tension is maintained on a rope by means of a weight suspended on a movable pulley. There are many applications of weights as a motive force, but when they are used, the action is comparatively slow.

They are sometimes employed as the motive force for large clocks, such as those installed in towers.

A clock or watch contains three important pieces of mechanism or elements: (1) the source of energy to move the parts, which is a suspended weight in large clocks or a spring in small clocks and in watches; (2) the series of wheels, called a train of wheels, or gears, operated by the driving force; and (3) a device for controlling the movement of the train of gears.

66. Accumulated Energy.—We know that energy tends to accumulate in our muscles while at rest and that it can then be expended either gradually or by one effort, but to no greater extent than the reserve force that has been accumulated. The same accumulation of energy takes place in running before taking a jump. This accumulated energy or method of gathering momentum is utilized in machines by placing a fly-wheel on the driving shaft. When such a wheel revolves, the momentum will cause it to run a long time after the power has been shut off, due to the energy stored in the fly-wheel.

Questions

1. Explain why the wind is able to do the work of turning a windmill.

2. When the wood-chopper chops wood he usually swings the axe high when he comes to a knotty piece. Why?

3. Why is it more comfortable to ride in a carriage with pneumatic tires and springs than in a farm wagon with neither?

4. Explain why fortifications are usually made of earthwork and not masonry.

5. When an automobile runs too fast around a corner it "skids." Why?

6. Explain why a person riding in a rapidly moving railway car is thrown forward when the car stops suddenly.

7. Explain why a person standing in a street car is thrown back when the car starts suddenly.

8. (a) In attempting to kick the panel out of a door why does one experience a pain from the kick? (b) This pain is not severe when you kick a canvas curtain. Why?

9. Why does a man lean forward when he climbs a hill?

10. (a) What is the ballast of a ship? (b) What is the object of the ballast?

11. Why is it unsafe to stand in a canoe?

12. Which is more steady (stable) a load of wood or a load of metal equal in volume?

13. Explain the principle of a revolving clothes-dryer used in laundries.

14. The outer rail of a railroad curve is higher than the inner one. Why?

15. Give the kind of energy present in the following examples: pile-driver hammer 40 in. in the air; gunpowder; moving ship; water running over a dam; water in a lake on a mountain; water in a reservoir; charged storage battery; coal; wood; recoil of a gun; escaping steam.

16. Why is oil thrown off from gears and pulleys? Why is mud thrown off automobile wheels?

17. Why does a lathe continue to move after the switch is turned off?

Problems

1. How much energy does a mass weighing 3 tons acquire in falling through 100 ft.?

2. A machinist exerts upon a file a force of 11 lbs. downward and 15 lbs. forward. How much work does he do in 41 horizontal strokes each 6 in. long? In what units is the result expressed?

3. A pile-driver weighing 510 lbs. drops from a height of 15 ft. pushing the pile down 6 in. What was the potential energy of the weight before it started to fall? What is the resisting force of the pile?

4. If a drop hammer weighs 600 lbs. and falls from a height of 24 in., what kind of energy will it possess before falling, and how much energy will be expended?

5. A large weight of 700 lbs. is allowed to fall a distance of 18 ft. in order to break old car-wheels. What is the kind and the amount of energy?

6. An elevator in a public building weighs $3\frac{1}{2}$ tons. How much energy will be necessary to lift it from the first floor to the second, a distance of 20 ft.?

7. A pile-driver weighs 265 lbs. and falls from a height of 16 ft. What is the energy at the time it strikes the pile?

CHAPTER VII

MECHANICS OF LIQUIDS

67. The Utilization of Liquids in Industry.—Liquids, particularly water, possess certain properties which render them invaluable for many industrial purposes. These properties form the bases upon which hydraulic machines and many other devices are constructed. To know how to use all these contrivances efficiently and intelligently, it is necessary to know the principles underlying them.

68. General Properties of Liquids.—Water and all other liquids resemble solids in that they possess a definite size; that is, they occupy a definite space. Liquids differ in that they have no definite shape. The shape of a liquid is the shape of the vessel which holds it. A solid has a definite shape and retains it until acted upon by a force greater than the cohesive strength of its particles. The force of gravity is continually forcing liquids to seek the lowest level. This fact is illustrated when two vessels containing the same liquid are connected. The level in each becomes the same, regardless of the form or distance of the connecting pipe. This peculiarity of liquids is commonly expressed by the saying "water seeks its own level."

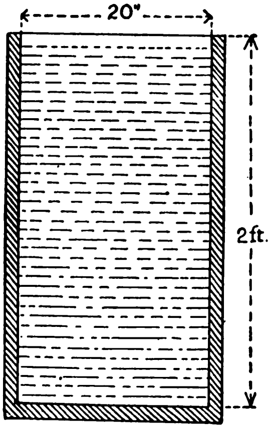
A force of any kind, however small, will change the shape of a liquid. To illustrate: If a pebble is dropped into a pond it moves the whole of the water and the motion can be seen by the ripples which form on the surface of the pond. The rate of this change in shape varies with different liquids. Those in which the change proceeds slowly are called viscous liquids, while liquids in which the change takes place quickly are called mobile.

Another important property of liquids is that they cannot be compressed. If force acts on any part of a liquid, it will transmit the pressure of the force equally in all directions. This principle, which is called Pascal's law from its discoverer, renders liquids very valuable as a medium for pressure transmission in all forms of hydraulic machines.

69. Water Pressure.—Water exerts a pressure on the bottom and sides of the vessel which holds it. Fill a vessel 1 cu. ft. in volume with water. If the water is weighed it is found to weigh about 62.5 lbs. Therefore 62.5 lbs. is pressing on the bottom of the box, the area of which is 144 sq. in. Therefore the pressure per square inch is $\frac{62.5}{144}$ or .434 lb. The unit of pressure is the amount of pressure to the square inch. Pressure equals force per unit area.

A liquid also exerts pressure on the outside of any object immersed or pushed into it and the pressure increases with the depth. This phenomenon may be explained by considering a liquid as made up of a large number of thin horizontal layers, each layer supporting the weight of those above. The lower the layer, the greater the weight of liquid it has to support; hence the greater the pressure exerted upon it. This pressure has nothing to do with the size and shape of the vessel and is evenly exerted upon each square inch of surface.

The total pressure of a liquid upon any portion of the vertical sides of a vessel is equal to the weight of a column of the liquid, whose base and length are respectively the area of that portion of the side and its average depth. This may be explained in another way. The pressure against the vertical side of a tank at the surface of the water is zero, for the liquid has no depth. But the pressure on the side increases with the depth until we reach the bottom of the tank, when it is equal to the pressure against the bottom. The average pressure on the side then is the pressure exerted on the middle of the side, and is equal to one-half the pressure per unit of surface against the bottom.



(Copyrighted by Millers Falls Co.)

FIG. 42.—Tank of Water.

The following laws apply to liquids:

I. *The pressure does not depend upon the size or shape of the vessel. The pressure increases with the vertical depth below the free surface.*

II. *At any point in a liquid, the upward, downward, and lateral or sideways pressures are equal.*

III. *To find the lateral pressure of water, upon the sides of a tank, multiply the area of the submerged portion of the side in inches, by the pressure of one-half the depth.*

As an example: What is the lateral pressure on one side of a tank 20 in. wide and 2 ft. deep (Fig. 42)? The solution is as follows:

20 in. × 24 in.	= 480 sq. in., area of side.
2 ft. × .434	= .868 lb., pressure at bottom of tank.
.868 ÷ 2	= .434 lb., average pressure due to one-half the depth of tank.
.434 × 480	= 208.32 lbs., pressure on one side of the tank.

70. Hydraulic Press Machinery.—It has already been shown that when pressure is applied to any part of a confined liquid, the pressure is transmitted equally in all directions. This law of Pascal is utilized to increase or multiply pressures. For example: If two pistons of unequal area are pressing upon the same liquid, held in connected tubes or cylinders, and weights are placed upon the pistons to keep them from moving up or down, it will be found that the weights must be proportional to the surfaces of the water if one piston is not to force out the other. This principle is applied in the construction of the hydraulic press. The hydraulic press is a machine used in mills and in boiler- and machine-shops for punching holes through plates, for exerting enormous pressure on paper, cotton, and cloth, for testing iron and wooden beams, and so on. It operates by creating a pressure over a small distance, by means of a lever and water.

The hydraulic press consists of two pistons of unequal area working in connected cylinders which are filled with water. When the small piston is raised, water rushes into the cylinders through a valve opening upwards. As soon as this piston is lowered, the valve closes. The small piston thus acts as a pump when water is forced from the small to the large cylinder, causing the large piston to rise slowly.

Usually the small piston is 1 in. in diameter, giving an area of .7854 sq. in. The large piston, called the ram, may be any size, depending upon the pressure required. The size of the cylinder is usually from 10 to 14 in. in diameter. The pressure per square inch is the same in both cylinders. As the flow of water is slow, and the distance is short, little or no pressure is lost in transmission. As the areas of the pistons are unequal, the total pressure must differ accordingly. To illustrate: If the diameter of the large piston is 10 in. and the diameter of the small piston 1 in., then the area of the large piston is 100 times that of the smaller, or 78.4 sq. in. (The areas of two circles are to each other as the squares of the diameters.)

Therefore, a pound pressure on the piston of the small cylinder gives a total pressure of 100 lbs. on the large cylinder. While the machine develops a certain amount of friction at the stuffing box, pins, etc., of the pump or smaller cylinder, the loss is probably only 5%. Therefore, as a general rule, 95% of the pressure applied to the smaller cylinder is given to or transmitted to the water in the pump. Figure 43 illustrates a hydraulic press designed to show a pressure up to 300 lbs. to the square inch. The handle of the pump which compresses the water in the small cylinder is seen on the left.

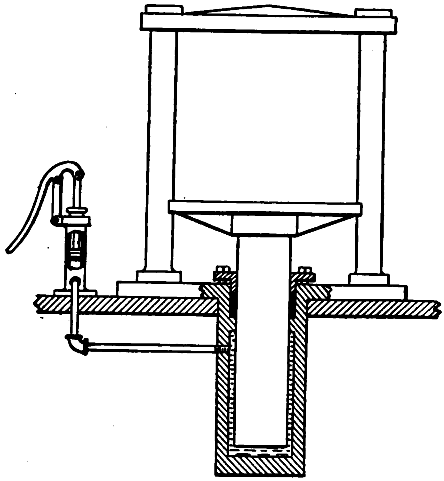


Fig. 43.—Hydraulic Press.

71. Uses of Hydraulic Machinery.—For the majority of operations requiring very great force applied through a comparatively short stroke, as in riveting, punching, shearing, lifting, forging, flanging, and many other similar operations, there is no other machinery so efficient as hydraulic; first, because there is absolutely no motion or power consumed except in the act, and at the moment of performing the desired operation—at all other times everything is at rest; secondly, because the water is carried or transmitted in a small pipe from its reservoir or tank to the machine. Under proper conditions, this transmission can be accomplished with an efficiency far surpassing that of the line-shaft, electric wire, or air tube. All the energy which a steam pump can deliver in the course of 10 to 15 minutes is utilized in the hydraulic machine within a few seconds. This is not possible in the use of any other form of machine tool.

72. Capacity of Pipes.—In computing the capacity of pipes used to convey liquids one should remember that the capacity varies with the area, and that the areas of similar figures vary as the squares of their corresponding dimensions. Pipes being cylindrical in shape are, therefore, similar figures. The areas of any two pipes are to each other as the squares of their diameters.

Thus, if one pipe is 6 in. in diameter, and another is 3 in. in diameter, their ratio is $\frac{36}{9}$, or 4 to 1, and the area of the larger one is, therefore, 4 times that of the smaller one.

73. Water.—A manufacturer usually stores quantities of water for manufacturing purposes in a tank at the top of each of the different buildings of the plant, but in case the factory or mill is near a stream, the water is stored in a dam, at a convenient height. The pressure of the water against the sides of the tank or dam is exerted perpendicularly to the surface on which it bears. Every pound of water in a tank or dam at some height above the point where the water is to be used possesses a certain amount of potential energy due to its position. To illustrate: W lbs. of water raised a definite height H possess the capacity of doing work which is equal to the weight of water in pounds multiplied by the height in feet. The result is $W \times H$ ft.-lbs.

To estimate the energy in the reservoir of a city or town so as to know the exact water pressure, it is necessary to know the perpendicular height from the water level in the reservoir to the point of discharge. The perpendicular height is called the "head." Mechanics, engineers, etc., often speak of a "head of water," meaning the pressure that water exerts. "A head of 50 ft.," for instance, is the pressure (due to its weight) of a column of water 50 ft. high.

The pressure per square inch at any point in a body of water equals the depth in feet below the surface, or the head times .434. If P is pressure per square inch and H is head,

Then $$P = H \times .434$$

and $$H = \frac{P}{.434}$$

To find the head when pressure is given the rule is: Divide the pressure by .434.

74. Dams and Water Wheels.—Look at a mill or factory erected on the side of a stream. The water will usually be found confined by a wall of earth or stone. The water runs from the stream through an opening called a canal and then to the water wheel. The difference in height between the canal and the river represents the fall or pressure of water which moves the machinery in the mill. In case of floods the water can run freely over the dam, without affecting the mill.

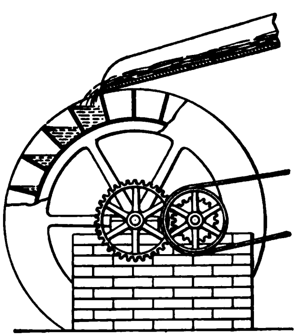


Fig. 44.—Overshot Water Wheel.

Falling water is a source of energy that supplies power to operate mills, factories, electric power plants, etc. Many factories and mills are located on the borders of rivers in the valleys of hilly communities. The water draining the hills rushes with considerable force down the rivers. The energy of this water is utilized by allowing it to run over an overshot water wheel (Fig. 44). The weight and force of the moving water are such as to cause the wheel to move, which in turn moves the machinery by means of belts or gears.

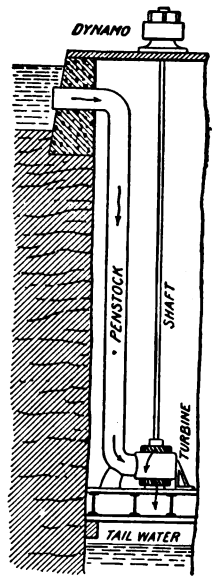


FIG. 45.—Use of Turbine.

The most effective method of utilizing water power is by means of a wheel called a turbine. The river is dammed, and the water is conducted through a canal which runs alongside the mills. The water is allowed to pass through a cylindrical tube to a penstock which surrounds an iron case containing the turbine or rotating wheel (Figs. 45 and 46). By means of a connecting shaft the wheel may be made to operate a dynamo.


FIG. 46.—Turbine Wheel.

Where there is current and little elevation, the energy of the water may be utilized by means of an undershot wheel (Fig. 47). The force of the current strikes against the lower part of the wheel.

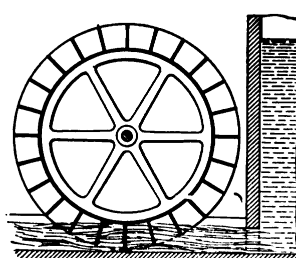


FIG. 47.—Undershot Wheel.

Where the water is delivered under considerable pressure its power may be utilized to run lathes, sewing machines, and other light machinery. A common rotary water motor is employed, and is attached to the faucet. The water striking against the cup-shaped fans attached to the axle of the motor causes it to rotate. The axle is attached to a shaft which is connected directly or by belts to the machines.

The motor is enclosed in a metal case with an opening in the bottom to allow the water to escape into the sink or outlet.

75. The Pelton Wheel.—The Pelton wheel (Fig. 48), a modified form of undershot wheel, has cup-shaped buckets sticking outward at regular intervals around its circumference. There is a partition in the center of each bucket. A nozzle is so arranged that it directs water on the buckets as they reach the lowest point of a revolution. The water strikes the partition of the cup and turns right and left inside of the cup. The change of direction transfers the energy to the wheel.

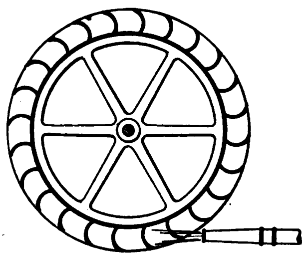


FIG. 48.—Pelton Wheel.

76. Wasted Water Power.—Very few people realize the vast amount of water energy that goes to waste every year. Every particle of falling or running water represents energy, the amount of which depends upon the quantity and the depth of the fall. This energy can be harnessed in the same way as the energy obtained from the coal we burn. Water that possesses energy, that is, water that falls, is often spoken of as "white coal." Power plants that transform the energy of falling water into electrical energy, oftentimes are the centers of distributing systems that cover hundreds of miles of territory, and give electrical service to many towns.

77. Measurement of Flowing Water.—Oftentimes, as when water is sold to a corporation or city, it is necessary to know the quantity of water coming down a stream. To measure this a device called a weir (Fig. 49) is constructed at the sides of the stream so as to form either a rectangular or angular opening through which the water flows. Where a large quantity of water is measured the opening is usually shaped in this way |______|; where the quantity is small the opening is V-shaped, as the flow of water may then be measured with greater accuracy.

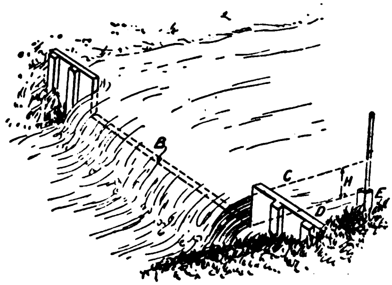


FIG. 49.—Measuring Water with a Weir.

The volume of the flow is measured by ascertaining the height of the water above the bottom of the notch. To do this a peg is driven into the bed of the stream as at E in Fig. 49. The top of this peg is exactly the same height as the bottom of the notch. A measuring scale inserted in the water as shown in the illustration then enables the exact height of the flow over the weir to be measured. The formula for determining the volume of flow is:

$$Q = \frac{4K}{15} \times B \times H\sqrt{2\,gH}$$

Where Q = cubic feet passing over the notch per second, K = .59, which is a constant, B is the breadth of the water in the notch, H is the height of the water in the notch, g = 32.2 (force of gravity).

The energy stored in the moving water is equal to the number of cubic feet passing down the stream per minute multiplied by the weight of a cubic foot of water, multiplied by the perpendicular distance this water falls. This equals the number of foot-pounds per minute. Weight of a cubic foot of water 62.5 lbs.

The *E. H. P.*, or estimated horse-power, stored in the moving water is expressed by the following formula:

$$E.\,H.\,P. = \frac{W \times H}{33000}$$

Where *E. H. P.* = estimated horse-power, W = weight of water passing per minute in pounds, H = height it falls in feet.

78. The Law of Buoyancy.—Explanation of why certain substances float on water depends upon what is called the law of buoyancy. When a ship is constructed, it is necessary to lay out the plans in accordance with the principle or law involved. Consequently a knowledge of the law of buoyancy is important.

When a body is immersed in a liquid, it is buoyed up by a force equal to the weight of the liquid displaced. The weight of a floating body is equal to the weight of the liquid displaced. The upward pressure, or buoyancy, of the liquid may be regarded as exerted at *the center of gravity* of the displaced water, *B*, which is called the *center of pressure* or *of buoyancy.* A vertical line drawn through it is called the axis of buoyancy or of flotation (Fig. 50). In a floating body at rest, a line joining the center of gravity of the

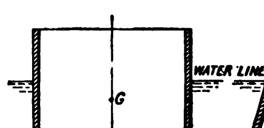


FIG. 50.—Principle of Buoyancy.

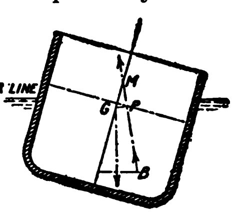


FIG. 51.—Principle of Stability.

body, G, and the center of buoyancy of the water, B, is vertical, and is called the axis of equilibrium. When an external force causes the axis of equilibrium to lean, if a vertical line is drawn upward from the center of buoyancy to this axis, the point where it cuts the axis is called the metacenter. If the metacenter is above the center of gravity the distance between them is called the metacenter height, and the body is then said to be in stable equilibrium, that is, tending to return to its original position, when the external force is removed.

79. Stability of a Ship.—A ship at sea is subject to rolling and pitching and must be designed to be stable and not capsize. Rolling is the motion of a ship from side to side. Pitching is the alternate rising and falling of bow and stern. In general a ship's motion is a combination of rolling and pitching. The principle of hydrostatics (water pressure) governing the stability is as follows: When a ship is floating at rest its center of gravity and its center of buoyancy are in the same vertical line. If the force of winds or waves causes the vessel to keel over as in Fig. 51, the weight of the ship W acting downward through G, and her buoyancy acting upward through B constitute a couple* which tends to pull the ship back again upon an even keel with a turning moment equal to $W \times GP$. If the couple be strong enough the ship will swing back towards an even keel. But since the vessel acquires kinetic energy as it swings, it will not

* A couple is composed of two equal parallel forces acting on the ends of a bar, for example, in opposite directions; so far as producing forward or backward motion is concerned their resultant is zero. They do, however, tend to cause the bar to rotate.

stop on the even keel, but will roll some distance the other way, and will continue to oscillate about its mean position for some time.

80. Specific Gravity.—*The specific gravity of a substance is the number of times it is heavier than the weight of an equal bulk of water.* It may be expressed thus:

$$\text{Specific gravity (sp. gr.)} = \frac{\text{Weight of body or substance}}{\text{Weight of an equal bulk of water}}$$

The specific gravity of a solid is obtained by first weighing or computing the weight of the object. The weight of an equal bulk of water is then computed. Finally, the weight of the object is divided by the weight of the equal bulk of water.

The following tables show the weights and specific gravities of the most important metals and liquids.

WEIGHT AND SPECIFIC GRAVITY OF METALS

Metals	W. per Cu. Ft., Lbs.	W. per Cu. In., Lbs.	Specific Gravity
Aluminum	166	.096	2.67
Antimony, cast	419	.242	6.72
Bismuth	613	.353	9.822
Brass, cast	524	.3	8.4
Bronze	534	.308	8.561
Copper, cast	537	.31	8.607
Copper, wire	555	.32	8.9
Gold, 24 carat	1208	.697	19.361
Gold, standard	1106	.638	17.724
Gun-metal	528	.304	8.459

Weight and Specific Gravity of Metals—(*Continued*)

Metals	W. per Cu. Ft., Lbs.	W. per Cu. In., Lbs.	Specific Gravity
Iron, cast	450	.26	7.21
Iron, wrought	485	.28	7.78
Lead, cast	708	.408	11.36
Lead, rolled	711	.41	11.41
Mercury	849	.489	13.596
Platinum	1344	.775	21.531
Platinum, sheet	1436	.828	23.
Silver, pure	654	.377	10.474
Silver, standard	644	.371	10.312
Steel	490	.284	7.85
Tin, cast	455	.262	7.291
Zinc	437	.252	7.

Weight and Specific Gravity of Liquids

Liquids	Specific Gravity	W. per Cu. In., Lbs.	W. per Gal., Lbs.
Water, distilled, 60° F	1.	.036	8.33
Water, sea	1.03	.037	8.55
Water, Dead Sea	1.24	.045	10.4
Acid, Acetic	1.062	.038	8.78
Acid, Nitric	1.217	.044	10.16
Acid, Sulphuric	1.841	.067	15.48
Acid, Muriatic	1.2	.043	9.93
Alcohol, pure	.792	.029	6.7
Alcohol, proof	.916	.033	7.62
Alcohol, of commerce	.833	.030	6.93
Cider	1.018	.036	8.4
Honey	1.45	.052	12.

WEIGHT AND SPECIFIC GRAVITY OF LIQUIDS—(*Continued*)

Liquids	Specific Gravity	W. per Cu. In., Lbs.	W. per. Gal.,Lbs.
Milk	1.032	.037	8.55
Molasses	1.426	.05	11.66
Oil, Linseed	.940	.034	7.85
Oil, Olive	.915	.033	7.62
Oil, Turpentine	.870	.031	7.16
Oil, Whale	.923	.033	7.65
Naphtha	.848	.031	7.
Petroleum	.878	.032	7.39
Tar	1.015	.036	8.4

Water.—The weight of fresh water is in practice usually assumed as 62½ lbs. per cubic foot. But 62¼ would be nearer the truth at ordinary temperatures, about 70°; or 1 lb. = 27.759 cu. in.

81. Hydrometer.—The common method of determining the specific gravity of liquids is by means of the hydrometer (Fig. 52). This instrument consists of a glass tube with mercury or lead shot in the bottom to keep it in the water. A scale is graduated on the narrow stem reading either directly or indirectly into specific gravity reading. The scale is graduated by placing it in liquids of known strength and marking the level of the liquid on the stem. It is usual to have two separate instruments, one for light liquids, on which the mark is near the bottom of the stem, and one for heavy liquids, on which it is near the top.

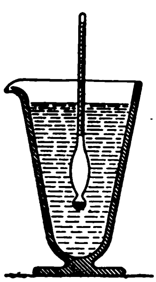


FIG. 52.—Hydrometer.

82. Beaumé Hydrometer.—The Beaumé hydrometer is used to determine the strengths of liquids in bleacheries, etc. The readings are expressed in degrees which may be changed into specific gravities by this formula:

$$\text{Sp. gr.} = \frac{146.3}{146.3 - N}$$

N is the reading on Beaumé scale.

EXAMPLE.—Change 30° Beaumé to specific gravity.

$$\text{Sp. gr.} = \frac{146.3}{146.3 - 30} = \frac{146.3}{116.3} = 1.258$$

83. Twaddell Hydrometer.—The Twaddell hydrometer is used by many manufacturers. The readings may be converted into specific gravity from this formula

$$\text{Sp. gr.} = \frac{100 + .5N}{100}$$

N is the Twaddell reading.

EXAMPLE.—Change 84° into specific gravity reading.

$$\text{Sp. gr.} = \frac{100 + 42}{100} = \frac{142}{100} = 1.42$$

Questions

1. Is water necessary for industry? Explain.

2. What great property do liquids possess that solids do not? What use is made of water in industry?

3. A liquid is often used as a part of machinery. What property is utilized?

4. How can the pressure of a liquid on the surface be ascertained?

5. Will the perpendicular sides of a trough filled with liquid sustain the same pressure, whether the trough be narrow or wide?

6. Explain the principle of science underlying hydraulic machines.

7. Name some of the applications of hydraulic machines.

8. Why does deep sea diving often cause pain and bleeding in the ears and nose?

9. Explain the importance of a knowledge of the principle of specific gravity in the trades.

10. Explain how a modern warship floats although made entirely of steel, its walls being of steel plate from 6 to 18 in. thick.

11. What is the water-line of a boat?

12. A boat passes from fresh into salt water. Will the water-line rise or fall?

Problems

1. What is the weight of a rectangular block of hardwood with the dimensions 8 ft. 4 in. × 7 ft. 6 in. × 3 ft. 3 in.? The specific gravity of wood is .7. The weight of a cubic foot of water is 62.5 lbs.

2. What is the weight of a cylindrical block of soft seasoned wood 8 in. in diameter and 4 ft. long? The specific gravity is .5. The weight of a cubic foot of water is 62.5 lbs.

3. What is the weight of salt water in a rectangular tank 5 ft. 2 in. × 4 ft. 7 in. × 3 ft. 5 in.? The specific gravity of salt water is 1.03 and the weight of a cubic foot of water is 62.5 lbs.

4. Express in pounds per square inch a "bend of 69 ft."

5. What is the pressure near the keel of a vessel drawing 18 ft. of water. (Salt water has specific gravity 1.03.)

6. A hole is cut in the bottom of a ship drawing 17 ft. of water. What force is necessary to hold a plank tightly against the hole?

7. It is desired to have a pressure of 60 lbs. at a hydrant. How high must the reservoir be above the main?

8. A rowboat weighs 230 lbs. How many cubic feet of water does it displace? A cubic foot of water weighs 62.5 lbs.

9. The cork of a life preserver weighs 19 lbs. What is the volume in cubic inches? The specific gravity of cork is 0.25.

10. Elevators are often run by water pressure obtained from the local water system. If the pressure on the main is 55 lbs. and the diameter of the plunger of an elevator is 11 in., how heavy a load can the elevator lift if the friction loss is 30%?

11. Soundings at sea are made by lowering a form of pressure gauge. If a pressure gauge reads 65 lbs., what is the depth? (Consider the density of sea water 1.026.)

12. What is the weight of a cylindrical piece of lead 4 ft. long with a diameter of 3 in. ? The specific gravity of lead is 11.4 and the weight of a cubic foot of water is 62.5 lbs.

13. What is the weight of concentrated sulphuric acid (specific gravity 1.84) contained in a cylindrical jar 8 in. in diameter and 2½ in. high? A cubic foot of water weighs 62.5 lbs.

14. Determine the weight of gasolene in a rectangular tank 3 ft. 7 in. × 2 ft. 2 in. × 1 ft. 8 in., if the specific gravity is .7 and a cubic foot of water is equal to 62.5 lbs.

15. The inside diameter of a lead pipe is 1 in. and the thickness of pipe is ¼ in. How many pounds in a foot of pipe? The specific gravity of lead is 11.4 and a cubic foot of water weighs 62.5 lbs.

16. What are some of the principles of science underlying the hydraulic machine?

17. What are some of the uses of hydraulic machines?

18. (a) What is the weight of a cubic inch of water if a cubic foot weighs 62.5 lbs.

(b) How may the weight of a cubic inch of a substance be determined, if the specific gravity of the substance is known?

19. In making solder (composed of lead and tin), the tin melts first and then floats on top. Why?

CHAPTER VIII

PROPERTIES OF GASES

84. Gas Pressure and Industry.—There are many tools driven by air pressure, and there are a number of devices that depend upon the properties of gases for their action. Therefore intelligent knowledge of trade work frequently depends upon an understanding of some of the fundamental properties of gases.

85. Three States of Matter.—Ice, water, and steam represent the three states of liquid matter. A block of ice has a definite form and volume. Water has a free, level surface, but assumes the shape of the containing vessel. Steam has neither shape nor volume. Notice the steam escaping from a kettle or from the exhaust pipe of a power plant, and see how it tends to spread out when released from the containing vessel. Almost all substances can be transformed into a solid, liquid, or gaseous state by suitable changes in temperature. We may summarize the characteristic differences of these three conditions by saying that solids have permanent form and volume; that liquids have no permanent form, but have a definite volume; while gases have neither permanent form nor permanent volume.

All gases tend to spread out or diffuse themselves and this tendency causes them to exert considerable pressure equally against the sides of the vessels holding them. If a piston were attached to the side of a vessel, the gas would tend to push the piston out, provided the pressure of the gas on the inside was greater than that of the atmosphere on the outside. This is the case when a gas is compressed in a tank. The gas may be transferred from place to place intact, and then allowed to pass through pipes, to the place where its energy is to be utilized.

86. Expansion of Gases.—Gases are said to be perfectly elastic because they have no elastic limit and expand and contract alike under the action of heat. That is to say, every substance when in the gaseous state and not near its point of liquefaction has the same coefficient of expansion, this coefficient being $\frac{1}{273}$ of its volume for each degree Centigrade or $\frac{1}{459.4}$ of its volume for each degree Fahrenheit.*

Since a gas contracts $\frac{1}{273}$ part of its volume when its temperature is lowered 1° C, such a rate of contraction would theoretically reduce its volume to zero at a temperature of −273° C (−459.4° F). Since all gases reach their liquefying point before this low temperature is attained, however, no such contraction exists. At the same time, it may be said that if heat is considered as a motion of the molecules of a substance, that motion is to be considered as having ceased when the temperature has reached −273° C.

This temperature of −273° C (−459.4° F), therefore, is called the absolute zero, and from it all temperatures should properly be reckoned. Whenever a temperature is mentioned as being in degree absolute, either in the Centigrade or the Fahrenheit scale, it is understood to be counted from

* The relation between the Centigrade and Fahrenheit thermometers is discussed in Chapter IX.

the absolute zero, and therefore is equal to the observed temperature plus 273 or 459.4 as the case may be.

The lowest temperature which has thus far been attained is $-252°$ C. Dewar produced it by the evaporation of liquid hydrogen.

87. Principle of the Barometer.—Gases, though generally lighter than air, all have a definite weight. This weight depends upon the volume of the gas and the pressure exerted, as may be proved by means of an instrument called a barometer (Fig. 53). The principle on which the barometer is based may be explained in the following manner.

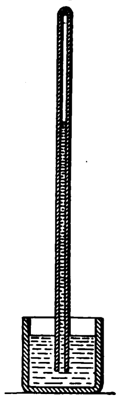


FIG. 53. Simple Barometer.

If you put one end of a tube into a bowl of water and the other end into your mouth, you can draw the water up through the tube into your mouth by sucking. You may think that you suck the water up, but you do not; you merely suck the air out of the tube by means of the muscles of your mouth. The weight of the outer air then presses down on the water in the bowl and forces it up into the tube. As soon as you let the air into the tube again the water runs back into the bowl. If you had a tube 40 ft. in length and could suck all the air out of it, the water would rise up in the tube nearly 34 ft. It would stop at that height, because the weight of the column would just balance the weight of the air which presses down on the surface of the bowl. As the tube is more than 34 ft. long, in the space above the water, there would be nothing, not even air. Such a space is called a *vacuum*, from the Latin word meaning space without air. If you put the tube into a fluid lighter than water, such as alcohol, the alcohol will rise higher in the tube than 34 ft., because it will take more fluid to balance the weight of the air. If the fluid were heavier than water, as is quicksilver or mercury, it would not rise so high, because it would require less of it to equal and balance the weight of air.

88. History of the Barometer.—In 1643, more than two hundred years ago, an Italian, named Torricelli, filled a glass tube, 33 in. long and open at one end, with mercury. Putting his finger over the open end so as to keep the mercury from falling out, he turned it bottom upward into a bowl of mercury, and then removed his finger. As mercury is one of the heaviest things in the world, it would seem as if it should have run out of the tube into the bowl; yet it only fell a little way, and then remained standing in the tube. As mercury is about fourteen times heavier than water, Torricelli saw that the height of the mercury in the tube was about $\frac{1}{14}$ part of the 34-ft. column of water. He at once concluded that the mercury was held up by the pressure of air on the surface bowl. He afterward noticed that the mercury did not always stand at the same height, but that it rose and fell with the changes in the weather, the air pressure decreasing in damp, wet weather and increasing in dry, fine weather. This led to the making of the barometer, which is the same in principle as the tube used by Torricelli.

89. Kinds of Barometers.—The barometer in its simplest form consists of a long inverted vacuum tube, sealed at the upper end. The lower end dips into a cup of mercury. A graduated scale on the side of the tube measures the rise and fall of the mercury. Such an instrument is often used to determine the height of mountains and other high places, The air becomes thinner or rarified, the higher one goes and the pressure becomes less and less on the mercury in the open cup, so that the mercury in the long tube is made to fall. If the distance the mercury will fall for every 100 ft. of altitude is known, the height of a mountain may easily be ascertained by noticing the height of the mercury column first at the bottom of the mountain and then at the top.

90. Aneroid Barometer.—The barometer most commonly made for commercial purposes is the aneroid barometer (Fig. 54). The word "aneroid" comes from the Greek and means "not wet," and was selected because this type of barometer operates without any fluids. It consists of a round, metallic, air-tight vacuum case, somewhat like a watch, the lid of which, held by metallic springs inside, rises and falls with the pressure of the atmosphere. By means of levers and a delicate chain inside, this rise and fall is made to turn the pointers on the index. The deflection may then be read on the circular scale.

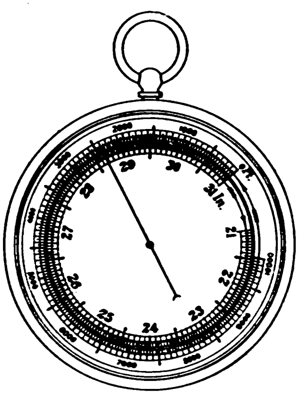


FIG. 54.—Aneroid Barometer.

91. Properties of Air.—The air or atmosphere which surrounds the earth is a mixture of two very different gases called oxygen and nitrogen. To every 21 parts of oxygen the air contains 79 parts of nitrogen. There are always present in the air some dust, moisture, and other impurities when atmosphere is put in motion by the unequal distribution of the heat. When such unequal distribution of heat occurs the air is called wind. By exposing a large canvas surface to the wind, boats may be propelled. The farmer utilizes the wind to turn a large wheel or windmill, and thus pump his water from a well.

92. Moisture in Air.—Absolutely dry air is a thing unknown in the natural world. The atmosphere is like a great sponge. It greedily takes up water and gives it back only when it has more than it can hold. Very few people realize that water in the form of vapor is much lighter than air, and that air containing a large proportion of water vapor weighs considerably less than the same bulk of perfectly dry air.

The amount of water vapor in the air varies of course with the temperature. In every cubic foot of air at 40° below the Fahrenheit zero, there is $\frac{1}{20}$ of a gram of water. When the atmosphere contains as much moisture as it will hold it is said to be saturated, and its humidity is 100%. If it contains only one-fourth of what it can absorb the humidity is 25%. The average humidity of the United States varies from 80% along the coasts to less than 40% in Arizona and New Mexico. A relative humidity of less than 50% indicates a comparatively dry climate, while a humidity of only 35% indicates the dryness of the desert.

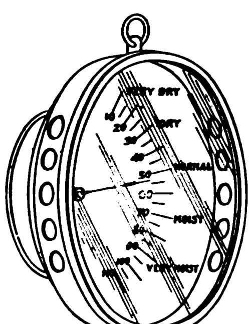


FIG. 55.—Hygrometer.

The percentage of water in the air is measured by an instrument called a hygrometer (Fig. 55).

93. Manufacturing of Ice.—Ice-making and cold storage depend upon the scientific principle that ammonia evaporates readily and absorbs a great deal of heat in passing from a liquid to a gaseous state. Apparatus for the manufacture of artificial ice con-

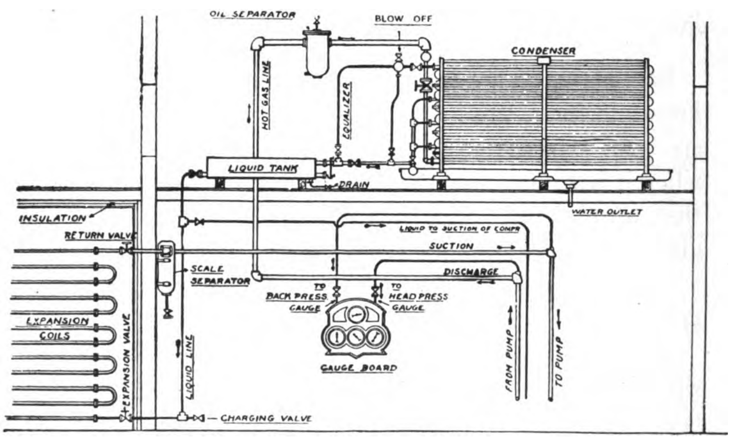


FIG. 56.—General Arrangement of Refrigerating Plant.

sists of a large cylinder containing liquid ammonia. Attached to the cylinder is a vat containing brine or salt water with coils of pipes passing through from the cylinder which holds the liquid ammonia. The ammonia flows from the cylinder to the coils. The vat is filled with galvanized iron boxes, the size of an ordinary cake of ice, and the boxes are filled with distilled water. A pump exhausts air from the coils, which in turn causes the ammonia to evaporate quickly. As the ammonia passes through the coils the latter attract the heat from the surrounding bodies to the extent of freezing the water.

94. How the Gas is Condensed.—The ammonia gas is taken from the refrigerating section and compressed by a pump. The ammonia starts from the compressor under a high pressure and temperature and passes to a cooling coil, which is the condenser. Here, by means of a cold water sprinkler, the gas is cooled to 45° or 50° F. and is condensed under high pressure to a liquid state. It then passes to the storage tank.

When ammonia is received ready for use, it is in a liquid state and enclosed in steel drums, which are only partly filled, leaving space enough for expansion so as to prevent an explosion. Ammonia drums have exploded, but always under conditions of overheating, for in general, with proper care, there is no danger.

95. Air Pumps.—It is often desirable to force air into or remove it from a vessel. Air is forced into a vessel by machines called air pumps, air compressors, condensing pumps, and blowing engines or blowers. The air pump consists of a tube or pipe with a rim, ground smooth and flat, extending from the cylinders.

Notice the tire of an automobile as air is pumped into it. As the air enters, the tube expands, due to the pressure of the gas, until finally the pressure becomes great enough to support the weight of the automobile. To remove air from a vessel, a screw connection is fitted tightly to it. As the piston is drawn up a partial vacuum is caused by the pressure of the air underneath, so that the air from the vessel immediately rushes to the cylinder, forcing the valve upward. This continues until the air pressure is reduced to such an extent that it is unable to force the valve of the cylinder open.

96. Boyle's Law.—When the outside temperature is the same as that of the air within a vessel, the product of the pressure and volume is constant. This is called Boyle's Law. To illustrate: If the volume of a gas is 2 cu. ft. at a pressure of 1 atmosphere (15 lbs.), then the volume would be decreased one-half as the pressure is increased twofold. Boyle's Law is sometimes expressed thus: *At constant temperature volume of gas varies inversely as the pressure.*

To calculate the volume of a gas at a given pressure, multiply the old volume by the old pressure and then divide by the new pressure.

$$P : P' = V' : V$$
$$P \times V = P' \times V'$$
$$V' = \frac{P \times V}{P'}$$

Where P and P' are the original and new pressures, and V and V' the original and new volumes.

The quotient will be the new volume. When a volume of gas is given it is understood to be at a pressure of 1 atmosphere unless some other pressure is expressed. One atmosphere is equal to 15 lbs. air pressure.

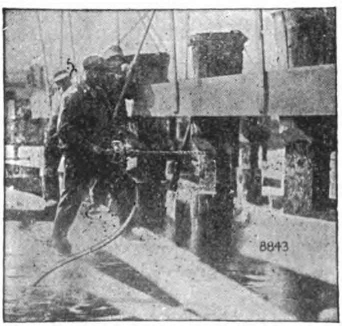


FIG. 57.—Wood-boring Machine Operated by Compressed Air.

NOTE.—In order to convey to the mind the relationship between quantities, such as between volume and pressure, the expressions "varies directly" and "varies inversely" are used. The expression "varies directly" is used to convey to the mind the idea that one quantity grows larger in the same proportion as the other. When the relation between two quantities is such that one quantity grows larger in the same proportion as the other grows smaller, the first quantity is said to vary "inversely" as the other.

97. Pneumatic Tools.—A pneumatic tool consists of a cylinder with a handle, which contains a working (percussion) piston with various air ports, a cap nut, and a spring. Air is usually supplied to pneumatic tools from air tanks. The air is pumped into the tank by means of a motor and a pump and the pressure in the tank is regulated to 7 atmospheres,

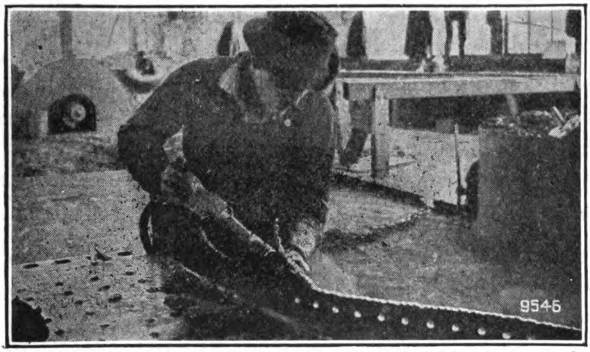


FIG. 58.—Pneumatic Hammer. Used in chipping rough metal off a fire box.

the motor starting and stopping automatically. The air is conducted through flexible tubes lined with materials capable of

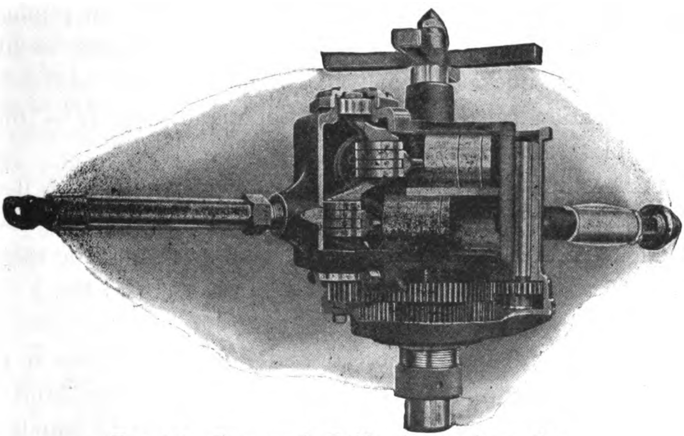


FIG. 59.—Pneumatic Drill. Partly in section.

withstanding this working pressure of 7 atmospheres. Figures 57, 58, and 59 show important types of pneumatic tools.

98. The Use of Compressed Air in a Sand Blast.—Sharp sand under air pressure is used in etching or frosting glass and cleaning castings. The pressure of the air and hardness of the sand is governed by the class of work.

A sand blast outfit includes a sand blast machine, hose and nozzles, and a standard air compressor of the size and pressure capacity required by the conditions of the work, together with a good-sized air receiver with the usual gauges, safety valves, and drain cocks. If air is already in use at the location, at higher pressures than required for the sand blast operation, a pressure reducing valve may be installed, leading preferably to a separate receiver which will be maintained at the proper pressure for the sand blast operation.

A clean, sharp sand, thoroughly dried, will give best results, and it is essential that the air used with the blast be kept as dry as possible by the installation of blow-off cocks, and occasionally "U" loops introduced in the line of air piping, with drip cocks installed at the bottom of the loops; or by the ordinary bucket steam trap. Sand especially suited to the operation can be obtained from manufacturers of the sand blast machines.

For etching on, or frosting glass, a pressure of 2 to 5 lbs. is ample; for cleaning brass castings and removing core sand, 15 to 20 lbs.; for cleaning the general run of iron castings, 15 to 20 lbs.; and for steel castings, 30 to 75 lbs.

99. Siphon.—In commercial and industrial plants it is often necessary to remove a liquid in a small stream from a large cask, without disturbing a sediment, to fill smaller receptacles. This is particularly true in the case of corrosive liquids, like acids, ammonia, etc., where there is great danger in pouring the liquid from the cask. In such cases the task is accomplished by means of a rubber tubing or bent glass tubing with unequal arms. This apparatus is called a siphon.

The principle of the siphon is explained as follows: In order to start the siphon it is necessary first to remove the air from it. This is done either by filling the siphon with water and placing a thumb at each end of the siphon, then placing the smaller end in the water that is to be removed from the vessel, or by drawing the water up through the long end of the tube. The water in the tube is driven toward the longer arm by a force equal to the difference in the weight of the water in the two arms. The difference in the lengths of the arms should be great enough to overcome the friction in the pipe and the weight of the water in the short arm. When this happens the water falls out of the long arm and tends to leave a vacuum at the top, but atmospheric pressure forces the water up the short leg to fill this space.

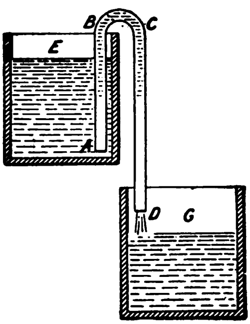


FIG. 60.—Siphon.

The tube *ABCD* (Fig. 60) is a siphon. The shorter leg *AB* is put into the liquid *E*, which is to be drawn off into *G*. If the air be taken out of the tube the pressure of the air on the surface of the liquid *E* will force the liquid up the tube *AB*, and it will then fill the whole tube and continue to run until all the liquid in *E* has run into the vessel *G*.

Questions

1. Why do clothes dry more quickly on a windy day than on a quiet day?
2. Does sprinkling the street on a hot day make the air cooler? If so, why?
3. In what part of the summer is the heat oppressive? Explain.
4. What becomes of the cloud of steam that escapes from the exhaust pipe of a power plant or a blowing locomotive whistle?
5. When does moisture gather on a water pipe? Why?
6. Why does the morning fog disappear usually before noon?

7. Why do we fan ourselves when we perspire?

8. Why must the bung of a barrel be removed in order to secure a proper flow of liquid from the faucet?

9. Why does high mountain climbing often cause pain and bleeding in the nose?

10. Small packages and folded papers are often transmitted in a carriage by air pressure through brass tubes called pneumatic dispatch tubes. An exhaust pump is attached to one end of the tube in which a tightly fitting carriage moves, and a compression pump to the other. If the air is half exhausted at one end and has twice its density at the other end, find the propelling force on the carriage if the tube is 4 in. in diameter.

11. Explain why it is impossible completely to exhaust a vessel of air by an air pump.

12. A pneumatic hammer, often called an "air gun," is used to drive rivets. Explain how it works.

13. Explain the care of a pneumatic hammer.

14. What is the practical value of a barometer? Explain the principle of a barometer.

15. Why is compressed air used in building a subway?

16. What advantage has compressed air over electricity in transmission of power?

17. Give some of the advantages of a pneumatic tire over a solid tire of the same size.

18. The general shape of boats and air-ships is usually made to conform to that of a fish. Why?

19. What is a fog?

20. What is a cloud?

21. Why is a bottle of hot water better than a hot stove cover for keeping your feet warm in bed?

22. Explain the principle of science underlying pneumatic machines.

23. Is it possible to measure gas pressure with the same gauges that are used to measure the pressure exerted by liquids?

24. How is air compressed? What is the commercial method of compressing air?

CHAPTER IX

HEAT AND EXPANSION

100. Generation and Movement of Heat.—If we file a soft iron nail for a moment and then feel the file surface, we find that it is warm or hot; that is, the surface of the file is warmer than the body. Another way of expressing the same idea is to say that the temperature of the surface of the file is higher than that of the body. There is then a transfer of heat from the warmer body to the colder body, until both are equally warm. Then both bodies are said to have the same temperature. A hot frying pan when plunged into a bucket of water gives off heat to the water, until the temperatures of the water and the frying pan become equal. *Temperature is a measure of the tendency of a body to give up its heat to other bodies.*

The surface of the file becomes warm or hot because of friction. The same effect is produced on the surface of a saw in sawing wood, in rubbing a metal surface on cloth, in the bearings of moving car-wheels, etc. Heat is generated also when a piece of lead or other metal is hammered and when a rifle bullet strikes a wall. This heat is caused by percussion.

Heat is also produced by compression, chemical means, and electricity. For example, the temperature of air is raised when it is compressed in a bicycle pump; when muriatic acid is added to zinc the chemical reaction which takes place produces heat; a current of electricity passing through a piece of platinum raises the temperature of the platinum.

Two very common effects of heat noticed in every-day life are the changes in length, surface, or volume of materials, and the changes of state—from solid to liquid and from liquid to gaseous. Since heat is due to the motion of the particles that compose a body, it will expand as the rate of motion is increased. This principle is utilized when the blacksmith first heats a tire before putting it on a wheel so that when the tire contracts as it cools it fits closely. For the same reason, rivets are made red-hot before they are put into boilers, bridges, or steel structures. When cool they contract and draw the parts tightly together.

Heat travels in three distinct ways: by conduction, by convection, and by radiation.

When a poker is placed in a fire, the heat passes along the poker from the hot to the cold part; this action illustrates conduction. Heat passes through some materials more readily than through others; materials of the first class are called good conductors and those of the second class, poor conductors. Iron, for instance, is a good conductor and wood a poor conductor of heat.

The heat from a stove passes through the air without any apparent motion; movement of heat in this manner is called convection.

Heat comes to us from the sun; this method of transmission of heat is called radiation.

101. The Manufacture of Thermometers.—For the measurement of modern temperatures there are two standard thermometers: the Fahrenheit used in this country and England for ordinary purposes, and the Centigrade used in Continental countries, and by scientists.

A thermometer consists of a cylindrical glass tube of a uniform bore and diameter, sealed at one end. A fluid is first placed in the tube, which then is heated until the fluid expands and fills the tube, thereby driving out the air. It is necessary to create a vacuum; otherwise the air would prevent the fluid from expanding in the closed tube. After the air has been driven out the tube is sealed. It is then placed in an atmosphere of free steam representing the boiling point of water, and next in an ice bath consisting of broken pieces of ice floating in water. The positions of the liquid at both of these points are marked on the tube, the boiling point representing 212° F. and the freezing point 32° F. The intervening distance between these two points is divided into 180 divisions and each division is called a degree. The Centigrade thermometer has 100 divisions between these two points. Mercury is especially adapted for use in thermometers on account of the uniformity with which it increases in volume, and also on account of its extremely high boiling point. Alcohol colored with some dyestuff is used in cheap household thermometers.

102. Measurement of Temperature in Industry.—Thermometers assist us in comparing or fixing the temperature of certain industrial operations. This is important, as in a great many manufacturing operations it is necessary to know when a certain temperature is reached. As a result a number of different kinds of thermometers have been invented. They are all based upon the same principle as are the Fahrenheit and Centigrade thermometers, namely, that substances expand with an increase and contract with a decrease of temperature. In the measurement of heat in stoves and furnaces where the temperature exceeds 900° F. an instrument called a pyrometer* is used.

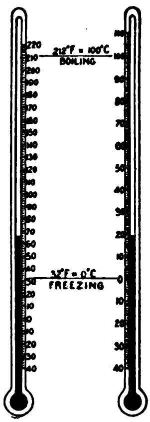


FIG. 61.—Centigrade and Fahrenheit Scales.

103. Relation between Fahrenheit and Centigrade Scales.—While all temperature measurements in American and English shops are expressed according to the Fahrenheit scale, it is often necessary to change the Fahrenheit into the Centigrade readings. Below is given a comparison of the two at the boiling and freezing points, together with conversion formulas for use in changing readings from one standard to the other. (Figure 61.) Fahrenheit is denoted by the letter F. and Centigrade by the letter C.

	Boiling Point	*Freezing Point*
Fahrenheit Scale	212°	32°
Centigrade Scale	100°	0°

To convert Fahrenheit to Centigrade:

$$\frac{5\,(F-32)}{9} = C$$

To convert Centigrade to Fahrenheit:

$$\frac{9}{5}C + 32 = F$$

* For a description and illustration of the pyrometer see Chapter XV.

This rule may be stated as follows:

To convert Fahrenheit to Centigrade subtract 32° from the Fahrenheit degree and divide by 1.8, or take $\frac{5}{9}$ of it.

To convert Centigrade to Fahrenheit multiply the Centigrade degree by 1.8, or $\frac{9}{5}$, and add 32.

EXAMPLE 1.—Convert 212° F. to Centigrade reading.

$$\frac{5\,(212-32)}{9} = 5\,\frac{(180)}{9} = \frac{900}{9} = 100°\text{ C.}$$

or

$$212 - 32 = 180$$
$$180 \div 1.8 = 100°\text{ C.}$$

EXAMPLE 2.—Convert 100° C. to Fahrenheit reading.

$$\frac{9\,(100)}{5} + 32 = \frac{900}{5} + 32 = 180 + 32 = 212°\text{ F.}$$

or

$$100 \times 1.8 = 180$$
$$180 + 32 = 212°\text{ F.}$$

104. Heat Units.—The unit of heat that is used in the industries and shops of England and America is *the British thermal unit* (B. T. U.) *It is the quantity of heat required to raise 1 lb. of water to a temperature of 1° F.* Therefore, the heat required to raise 5 lbs. of water through 15° F. is

$$5 \times 15 = 75\text{ B.T.U.}$$

Similarly 72 lbs. of water require, to raise its temperature ½° F.,

$$72 \times \tfrac{1}{2} = 36\text{ B.T.U.}$$

The unit that is used on the Continent and in scientific circles in America is the metric system unit called a *calorie.*

A calorie is the amount of heat necessary to raise 1 g. of water 1° C.

105. Latent Heat.—Examine a pan of water over the fire. Note that the heat passes first to the particles of the pan, then to the water nearest to the source of heat. As these particles expand, they become lighter and pass to the surface of the water. This process continues until the whole mass of water reaches a uniform and fixed temperature called the boiling point—212° F. under ordinary conditions. In the generation of steam under pressure higher than the ordinary air, the boiling point varies, increasing in proportion to the pressure. With a pressure of 16 lbs. to the square inch, water boils at 212.1° F.; with a pressure of 20 lbs. at 228.4°, etc.

After the boiling point has been reached the temperature of the water remains constant, however long the heat is applied to the vessel. The steam bubbles will rise rapidly, the whole mass will be in a state of agitation (ebullition), and the steam vapor will be given off in large quantities. *The heat that is absorbed and given off without raising the temperature* of the water *is called the latent heat* of the steam. This latent heat is either lost or dispelled in the air or is given off when the steam is condensed.

When a substance is heated as it passes from the solid to the liquid state, and from the liquid to the gaseous state, a certain amount of heat is expended in molecular work, separating the molecules of the substance without raising the temperature. The heat thus absorbed or lost is spoken of as latent. For example, when a pound of ice is heated its temperature remains the same until the melting point (32° F. or 0° C.) is reached; further application of heat, however intense, will cause no further rise in temperature until the ice has been entirely melted. Experiment shows that 144 B.T.U. are required to convert a pound of ice into water at 32° F. Further application of heat causes a rise in temperature, 180 B.T.U. raising it to the boiling point (212° F.). The rise in temperature ceases until all the pound of water at 212° F. has been converted into steam, which requires 970.4 B.T.U. This is called the latent heat of vaporization of water. When the steam is condensed to water, the same amount of heat is given off.

106. Steam Pressure.—When steam is generated under ordinary conditions it is termed "steam of one atmosphere" (15 lbs. per square inch). One cu. in. of water will produce approximately 1 cu. ft. of steam (1728 cu. in.). If the pressure is increased the volume is diminished; i.e., *the pressure varies inversely as the volume.* Thus with a pressure of 30 lbs. the volume is only one-half of what it would be under normal pressure. One cu. in. of water produces 864 cu. in. of steam under 30 lbs. pressure.

$$
\begin{aligned}
P : P' &= V' : V \\
15 : 30 &= V' : 1728 \\
30\,V' &= 15 \times 1728 \\
V' &= \frac{15 \times 1728}{30} \\
V' &= 864 \text{ cu. in.}
\end{aligned}
$$

107. Specific Heat.—If equal amounts of copper and water are heated, it becomes evident that it takes a great deal more heat to raise 1 lb. of water 1° F. than to raise 1 lb. of copper. The unit of heat has already been defined as the amount of heat necessary to raise the temperature of 1 lb. of water 1° F. *The quotient obtained by dividing the amount of heat required to raise the temperature of the substance one degree Fahrenheit and that required to raise the temperature of an equal mass of water one degree is called the specific* *heat of the body*. To illustrate: The specific heat of lead is .031 while the specific heat of water is 1. This means that it would require 31 times as much heat to raise 1 lb. of water one degree in temperature as it would to raise the temperature of 1 lb. of lead one degree.

The following table gives the specific heat of the different substances in which the mechanic and engineer are most interested.

TABLE OF SPECIFIC HEAT

Water at 39.1° F.	1.000	Copper	.095
Ice at 32° F.	.504	Lead	.031
Steam at 212° F.	.480	Coal	.240
Mercury	.033	Air	.238
Cast Iron	.130	Hydrogen	.404
Wrought Iron	.113	Oxygen	.218
Soft Steel	.116	Nitrogen	.244

108. Boiling Point and Vacuum Pan.—At the sea level, with an atmospheric pressure of 29.922 in. of mercury in the barometer—in other words at a pressure of 15 lbs. on the square inch—water boils at a temperature of 212° F. (100° C.). Above this level, the layers of atmosphere become less dense and consequently exert less pressure. The boiling point is, as a result, reduced several degrees below 212° F. With an increase of atmospheric pressure, as found in a deep mine, the reverse takes place, and water requires the application of several degrees of heat above 212° F. before it actually boils.

This variation of the boiling point of water under different pressures is taken advantage of in many manufacturing processes by the use of the vacuum pan. Under a reduced pressure, produced by mechanical means, liquors can be evaporated and concentrated in the vacuum pan without injury to the active ingredient they contain. By working under a low pressure, clarified sugar juices, food extracts, glycerin, dyewood, gelatin, and other liquors can be concentrated to any desired extent without injury. If such liquors were heated to a temperature of boiling water for any prolonged period, as would be necessary were they evaporated in an open pan, their nature or constitution would to a greater or lesser extent undergo a change and they would be spoiled.

For vacuum evaporation, a pump is necessary, first for exhausting the air and the steam from the vacuum pan and then for sending both to a vessel called a condenser where the vapors are condensed. One of the most practical devices is called the multiple effect system. This device consists of four simple vacuum pans so connected that the steam from the boiling liquid of the first is made to pass through the others. In this way the heat of the steam of the first pan is sufficient to heat the liquid of the second to the boiling point, the heat of the steam of the second raises the temperature of the third, and so on.

109. Expansion of Metals.—Heat causes metals to expand. The expansion of unit of length for one degree is called the linear coefficient of expansion. The increase per degree for unit of surface is called surface expansion; for unit of volume it is called cubic expansion. A steel joist 3 ft. long is, for example, about 1/8 in. longer in summer than in winter; hence long steel structures must not be rigidly fixed at both ends. Steel car-rails are laid about 1/2 in. apart to allow for expansion. The amount of expansion of various substances in length, area, and cubic contents or capacity is given in the following table. For each degree of heat the metal expands the fraction of an inch indicated.

COEFFICIENTS OF EXPANSION (1°F.)

Name of Substance	*Linear*	*Surface*	*Cubic*
Cast Iron	.00000556	.00001112	.00001668
Copper	.00000887	.00001774	.00002661
Brass (plate)	.00001052	.00002104	.00003156
Silver	.00001079	.00002158	.00003237
Iron (wrought)	.00000648	.00001296	.00001944
Steel (untempered)	.00000606	.00001272	.00001908
Steel (tempered)	.00000689	.00001378	.00002067
Zinc	.00001407	.00002814	.00004221

110. Expansion of Substance.—When a substance consisting of two or more bodies which have different coefficients of expansion undergoes any change of temperature, it is subjected to stresses, since its various parts do not expand in an equal degree. Thus, Portland cement, which has a coefficient of expansion of .000011, cannot make a reliable joint under varying temperatures with leading, the coefficient of which is .000028. On the other hand, the coefficient for steel fortunately approaches very closely to that of concrete, so that these materials may be combined to advantage in construction work. In the case of brittle substances fixed together, this unequal expansion is a frequent source of fracture. The cracking of glaze upon tiles and terra cotta may be attributed to this cause. The plastering on walls and the seams of cheap wall-paper sometimes open on account of unequal expansion.

Allowance for expansion in non-metallic bodies, such as stone, brick, or concrete, is not usually of importance because the coefficients of expansion of such bodies is as a rule smaller and the specific heat higher than those of metals. For this reason they require more heat to produce a given rise in temperature than do the metals.

The expansion of a number of common substances used in building construction is given below.

LINEAR EXPANSION OF SOLIDS AT ORDINARY TEMPERATURE

Substance	*For 1° F.*	*For 1° C.*
Aluminum, cast	.00001234	.00002221
Brick, best stock	.00000310	.00000550
Zinc	.00001407	.00001755
Cement, Roman, dry	.00000797	.00001435
Cement, Portland, mixed, pure	.00000594	.00001070
Cement, Portland: mortar mixed with sand	.00000656	.00001180
Concrete: cement, mortar, and pebbles	.00000795	.00001430
Copper	.00000887	.00001596
Ebonite	.00004278	.00007700
Glass, English flint	.00000451	.00000812
" French flint	.00000484	.00000872
" white, free from lead	.00000492	.00000886
" blown	.00000498	.00000896
" thermometer	.00000499	.00000897
" hard	.00000397	.00000714
Granite, gray, dry	.00000438	.00000789
" red	.00000498	.00000897

There are a few substances, of which water is perhaps the most common, that do not follow the rule of expansion and contraction. When a body contracts, its density, and therefore its weight per cubic inch or cubic foot, increases and we say that it becomes heavier. Water freezes at 32° F. and ice floats at 34° F. showing that it is lighter than water. Careful investigation reveals that water is heaviest at 39° F. (4° C.).

111. Drying and Evaporation.—The theory which underlies the process of drying is that dry air is capable of absorbing moisture; hence by circulating currents of dry air in and around wet substances, the absorbing power of the air draws off the moisture. For continuous drying, free circulation is a necessity, as air soon becomes saturated and incapable of taking up more moisture. Warming the air increases its capacity to absorb moisture; thus air at a high temperature is capable of drying material much more quickly than the same volume of air would at a low temperature. A free circulation of air at 85° to 100° F., evenly distributed, and with ample provision for the escape of the saturated air, is essential for good drying work.

Experience shows that when a liquid passes into a gaseous state it absorbs heat from the surrounding bodies. To illustrate: If a few drops of ether were placed on your hand you would notice the ether disappear in the form of a vapor by reason of the process termed evaporation, and your hand would feel cold. Evaporation produces coldness. Experience also shows that in condensing a gas by pressing the particles together, heat is given off. Thus the pressure on a gas, that is, its compression, generates heat, while the liberation of particles produces cold.

All gases may be liquefied by increasing the pressure sufficiently. If this pressure is suddenly removed the gas will evaporate quickly and expand, thereby absorbing heat and reducing the temperature of the surrounding bodies.

These scientific facts are taken advantage of in refrigerating plants, described in Chapter VIII, where ice is manufactured by means of the expansion of ammonia which is the most economical gas to liquefy.

Questions

1. When is a body hot?
2. When metals begin to melt, they liquefy at once. Why?
3. Why is ice packed in sawdust?
4. Why does a draft extinguish a flame?
5. Which will heat more quickly, rough or polished surfaces?
6. Why does sprinkling a shop floor cool the air?
7. Why are steam cylinders polished on the inside?
8. Why are glass tumblers broken by pouring hot water into them?
9. What is the basis of all cooling mixtures?
10. Explain why so much energy is lost in steam engines.
11. Is temperature a measure of the amount of heat in a body?
12. Explain why railroad engines have a polished sheet iron jacket around the cylinder and boiler.
13. What becomes of the cloud which forms about a blowing locomotive whistle?
14. Why are expansion joints added to long lines of steam pipes?
15. Place a ball through a ring, then heat the ball in an alcohol or Bunsen flame and try to pull it back through the ring.
16. Why do mechanics who work in a warm room wear flannel shirts to keep cool in the summer and warm in the winter?
17. Why is felt a better conductor of heat when firmly packed than when loosely packed?
18. Ducts and pipes are frequently covered with felt or asbestos. Why?

Problems

1. Change the following Fahrenheit readings to Centigrade readings: 56°; 75°; 5°; 0°; −23°; 45°; 54°.
2. Change the following Centigrade readings to Fahrenheit readings: 0°; 68;° 44°; −17°.

3. How many units (B.T.U.) will be required to raise 4863 lbs. of water 62° F.?

4. How many units (B.T.U.) will be required to raise 785 lbs. of water from 74° F. to 298° F.?

5. How many units of heat will be necessary to raise 40 g. from 50° C. to 70° C.?

6. A wrought iron bar 22 ft. long is heated from 70° F. to 300° F. How much will it lengthen?

7. A straight pipe 256 ft. long is heated from a temperature of 50° F., to a temperature of 370° F. How much will the pipe expand? How much would a brass pipe expand under the same conditions? (Coefficient of expansion of brass is .00001052. Coefficient expansion of iron is .0000065 ft. per foot of length per degree Fahrenheit.)

8. A bar of copper 12 ft. 6 in. long at 82° F. is heated to 289° F. What is its length while it is at 289° F.?

9. A brass rod measuring 36 ft. 3 in. at 78° is heated to 188° F. What is its greatest length?

10. A flat surface of zinc measuring 4 ft. 6 in. is heated from 81° F. to 312° F. How much does the surface expand?

CHAPTER X

LIGHT, COLOR, AND SOUND

112. Characteristics of Light.—We see objects by means of what we call light. Light comes from the sun by means of vibrations and produces an effect on the eye. These vibrations may also come from illuminated objects, but such objects give off only waves of light that fall on them from some other source. Bodies which give out light waves directly from themselves are called *luminous;* those that do not are called *non-luminous.* Light travels to our eyes very rapidly, and always in straight lines. A line of light is called a *ray.* A number of rays are called a *beam* of light.

Light passes through some objects, such as a piece of glass, very readily. Such objects are spoken of as being *transparent.* If light passes through a body with difficulty, the body is said to be *translucent.* When light fails to pass through a body at all, the body is said to be *opaque.* In this latter case, the light passes by the extremities or outline of the object, and a shadow is erected.

Objects may also be seen by means of *reflected* light. When rays of light fall on a smooth, opaque body, which is polished, they are reflected at the same angle at which they strike the surface (Fig. 62). These reflected rays form an

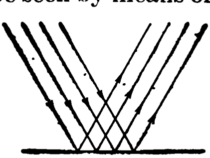


FIG. 62.—Regular Reflection of Light.

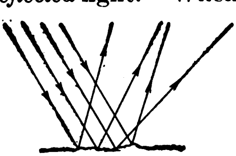


FIG. 63.—Irregular Reflection of Light.

image. When the image is quite distinct, the surface is called a *mirror*. When the surface is rough the rays are not reflected regularly, but at different angles (Fig. 63). This action is called *diffused reflection.* Diffused reflection throws the rays of light in all directions and assists, therefore, in illumination.

113. Refracted Light.—Light travels faster in a rare than in a dense substance. Therefore when a ray passes from a rarer to a denser substance, it is bent on entering and on leaving the denser substance, and in both cases the refraction or bending is toward its base (Fig. 64). When light passes from the air through water or a prism, the rays are bent.

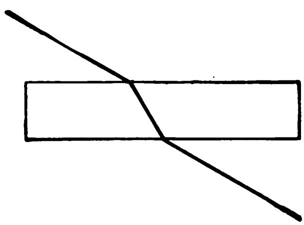


FIG. 64.—Refraction of Light.

This fact is taken advantage of by manufacturers and others who are located in thickly settled communities, where the streets are narrow and the buildings are high. The upper panes of the windows are then made of a peculiar combination of prisms and lenses. By means of this device, the rays of sunlight in the street or yard are deflected from their original direction and projected and diffused into the stores, rooms, and basements. All forms of prismatic glass reflect the rays of light downward.

114. Composition of Illuminants.—All practical illuminants are made of carbon brought to incandescence (glowing). The types of illuminants fall into two classes: first, particles heated by the combustion of their own carbon, such as candles, lamps, and gas flames; second, particles of carbon heated by outside means, such as mantle gas-burners, electric incandescent lamps, electric arc lamps, etc.

A flame is caused by the glowing of solid particles that have been volatized, converted into vapor, and rendered luminous by intense heat. The flame of a common lamp or candle is produced by the oil or melted tallow rising between the fibers of the wick through capillary attraction (attraction which causes liquids to go up into minute openings). When the wick is ignited, the oil is heated to a state of vapor, which inflames as the oil first raised is used in burning. Other portions are attracted up the fibers, become vapor, and are burned likewise. In this way a constant and steady combustion is maintained. The flame of a lamp is hollow, not solid, as the heated vapor must combine with oxygen before combustion can ensue. Hence, only the portions that come in contact with the air are transformed into flame. The vapor that rises from the wick in the center rises unburned. The hollow part of the flame is indicated by the darker and less luminous portion seen just above the wick.

115. Standard of Light.—The only standard of light used in this country is the English standard candle. The unit is one candle-power, which is the amount of light given off by a spermaceti candle, weighing 1200 g. and burning 120 grains per hour. Photometry is that part of the science of light that deals with the measurement of luminosity.

116. Importance of Proper Lighting.—The problem of an adequate amount of light presents itself to every manufacturer and city-dweller. With the increasing value of space and the constant crowding of buildings, the natural source of light, the sun, has been shut off in a great many buildings. The result is that artificial illumination in the daytime is a practical necessity. When such artificial sources of light are used in place of sunlight they must meet the needs of the eye and be installed with that aim in view.

Light should not shine directly into the eyes, but directly on the object we wish to see. The paper that gives the greatest amount of diffused reflection is white blotting paper. Dirty paper does not diffuse light as well as a clean, white board. White painted surfaces diffuse light well. Green, red, and brown surfaces have low diffusive values. Color on the walls of rooms and shops produces an effect upon the color of objects within the room. Any strong color on the wall will furnish a colored component of the total light.

Shades and reflectors are used either to modify the colors of the radiating object or the brilliancy of the source, so as to keep too bright a light out of the eyes, or to modify the distribution of light so as to put it where it will be of most service.

117. Incandescent Lamps.—The most common form of electric lighting at the present time is the incandescent lamp. It consists of a slender filament of some highly resisting material prepared from carbonized paper or bamboo and enclosed in a glass bulb. The ends of the filament are connected to platinum or lead wires fused in the glass. One of the wires is connected with the base of the socket, and the other with its rim. The intervening space is filled with white cement, which is a non-conductor. An attachment is placed on the socket by which the current enters and leaves the lamp. The air is exhausted from the bulb as completely as possible, and the exhaustion tube sealed off. When the electricity passes through the filament, it glows on account of the great resistance, but because of the lack of air does not burn. The glowing particles of the filament give off the illuminating rays. The way in which the light is distributed from the lamp depends upon the form in which the filament is bent.

When certain metals with a very high melting point, such as tungsten, osmium, etc., are made into fine wires or filaments, they possess remarkable endurance and a high degree of efficiency.

118. The Nernst Lamp.—The Nernst lamp has a filament of compressed oxides of certain rare metals. This filament conducts electricity only when heated to a high temperature, and as it is not combustible it need not be enclosed in an exhausted vessel. A small encircling coil of platinum wire (called a heater) through which a current of electricity passes brings the filament to incandescence.

119. Arc Lamps.—The ordinary arc light is formed between two carbons. When a current of electricity is passed through these carbons, the great resistance offered causes the ends of the carbon to become very hot and to glow. As the carbon gradually burns, the distance between the ends becomes greater. An automatic attachment by which the lower carbon is raised, keeps the distance between them constant.

120. The Drummond Light.—The Drummond light is produced by exposing small pieces of lime to ignition in a blow-pipe. Oxygen and hydrogen gases are directed upon the ball or disk of lime from separate vessels or gasometers through a flame arising from alcohol. This light, invented by Captain Drummond, is probably the most powerful known, and can be seen a distance of 30 miles. It is now much used for light-houses.

121. Gas Lighting.—Luminosity depends upon the reflection of glowing particles, and since a yellow flame heats many of these small particles of carbon, it gives off more light than does a blue flame. Consequently, the yellow flame is extensively used for gas lighting. The most effective gas light is produced by using a mantle. (A mantle is a screen which glows when the gas is lighted.)

122. Natural Gas.—A form of gas called natural gas is obtained from the earth by drilling a deep well. Such gas is formed as the result of decomposition of organic matter under pressure and heat. It comes to the surface often under great pressure and requires but little preparation for use. In different districts natural gas is of different composition, but its principal constituent is always "marsh gas," a compound of carbon and hydrogen that has a very low lighting but a very high heating value. It is used for both heating and lighting.

123. Manufactured Gas.—Manufactured or artificial gas is used in most places in this country and is made by heating coal gas, that is, gas obtained by distilling coal. Artificial gas is used for both heating and lighting, but its cost tends to be prohibitive for the former purpose.

124. Light and Color.—The color of a body depends on its nature, and the light in which it is viewed. A scheme of color that is harmonious by daylight may be just the opposite at night when viewed by artificial light. Different bodies or substances, like dyestuffs, etc., owe their property of color to the light that falls on them, and not to the body or substance itself. This fact may be illustrated by allowing different colored lights to fall on the same substance, and noticing the colors thus produced.

Sunlight, as any other light, comes to us in the form of waves vibrating at different rates. Each wave is one color, and when they are mixed in a beam they produce white light. Light may be separated into different colors or wave lengths, by means of a triangular prism of glass, whereby the rays are refracted and those with the greater vibra-

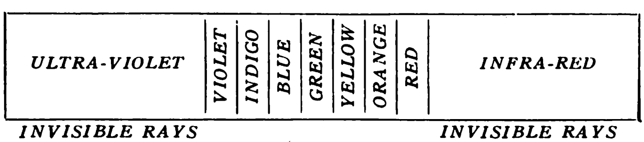


FIG. 65.—Spectrum.

tion are bent more. In this way sunlight is separated into its component parts. The colors thus obtained make up what is called the *spectrum* (Fig. 65). The spectrum contains *red, orange, yellow, green, blue, indigo, and violet rays.* These rays are not all of the numerous components of white light, but only the principal or primary ones.

Light in a dry goods store, where fabrics are displayed, should be diffused daylight, while in a ballroom a softer light, rich in yellow and orange tints, is preferable. Every opaque object assumes and reflects a color. A piece of red cloth looks red because it selects from white light mainly red for reflection.

125. Theory of Color.—Sunlight is called white light, and is, as just noted, composed of all the colors of the rainbow. When sunlight falls upon a body, a part of the light is absorbed by the body and converted into heat. The rest of the light is reflected to the eye and renders the body visible. If the body reflects all the colors of the rainbow equally, then the body is white. If the molecules of the body absorb certain compound colors of sunlight, then the reflected light is deprived of those particular colors. To illustrate: If blue is absorbed, the light reflected will be deprived of this primary color and the active remaining color which is red will predominate. Thus, the body will appear red.

This theory of light has been used to advantage in protecting the eyes of the workmen engaged in electric and oxy-acetylene welding. When metals are heated to a very high temperature, the eyes of the workman may be damaged by the repeated flashes of brilliant light from the glowing metals. Very careful experiments show that certain rays in large amounts, such as the ultra-violet rays and the infra-red rays, are harmful. Such rays are present in the working of molten iron or steel, or any incandescent material, where the temperature is 2000° F. or more. Special colored glasses or lenses will neutralize or cut out these dangerous rays.

126. Table of Colored Lenses.—The following table indicates the kind of colored lenses which should be used to nullify or prevent any injury to the eyes from the industrial processes tabulated below.

Group	*Process*	*Approx. Temperature* (F.)	*Correct Color**
Open-Hearth Steel	Charging machine	3400°	S + A Z
	Steel pourers	2800°	S + A A
	Platform men	3000°	S + A Z
	Melters	2800°	Special blue
Crucible Steel	Melting floor	3400°	S + A Z
	Hand-pouring	2800°	S + A Z
	All-steel pouring	2800°	S + A A
Bessemer Steel	Pulpit operators	3600°	Bessemer
	Blowing steel	3600°	"
	Pouring in molds	2800°	S + A A
Blast Furnace Steel	Tapping	2800°	S + A A
	Tuyeres	3500°	Special blue
Wrought Iron	Puddling Furnace	2800°	S + A A
Furnace	Gas heating	2500°	A K + D
	Electric heating	5000°	S + A A
	Large electric heating	6000°	S + A Z
Welding	Oxyacet. cutting	4000°	S + A A
	Oxyacet. welding	4350°	S + A Z
	Light spot welding		S + A A
	Heavy spot welding		S + A Z
	Iron arc welding	5500°	S + A Z
	Carbon arc welding	6450°	Arkweld
	Lapweld		A K + D or S + A A

* Symbols used by opticians.

127. Characteristics of Sound Intensity.—When a hammer strikes a piece of metal a noise is produced. The sound is caused by the particles of the two separate metals vibrating. The vibrations are transmitted through the air in a series of waves. The presence of the vibrations can be detected by pressing a stiff piece of cardboard against the surface or side of the metal when it is struck.

Sound possesses three properties—*intensity* or *loudness*, *pitch*, and *quality*—by which one sound may be distinguished from another. The intensity of a sound depends upon the density of the medium through which the sound is transmitted and upon the amplitude of the sound waves which reach the ear. The intensity varies inversely as the square of the distance. The waves become smaller and smaller as they leave the point at which the sound is produced, because the quantity of air through which the sound is conveyed becomes greater and greater. In other words, *the intensity of sound decreases as the distance from the source of sound increases.*

All forms of speaking tubes are based upon the principle that the sound waves set in motion in the tube are confined to the air space of the tube. Therefore the sound is transmitted without any decrease in intensity.

128. Pitch and Quality.—Pitch is the property of sound which determines whether the sound is high or low. *Pitch is determined by the number of vibrations per second made by the sounding body.* Comparatively slow vibrations produce a low sound, while rapidly vibrating substances produce a high-pitched sound. This difference may be quickly observed by entering a machine shop where the machines are running at a low speed and comparing the low drill sound to the high-pitched sound produced in a woodmill where the machinery is running at a high speed. Low speed gives a low vibration, while high speed gives a quick vibration It is possible to detect the difference in the sound produced by two bodies of different composition, but with the same intensity and pitch. *The property of sound by which we are able to distinguish this difference is called quality.* Quality depends upon the form of the vibrations.

Questions

Light and Color

1. Petroleum oil looks bluish green when it is on the water. Why?

2. Smoke and fine particles that float in the air deflect the short waves of light more than the long ones. Why? Why is the sky blue? Why is the sun red after a forest fire?

3. Should colors that are to be worn in an artificial light be selected by sunlight or by the artificial light?

4. Why does a piece of red cloth appear black when seen by blue light and red by red light?

5. Why is it desirable to have school windows reach to the ceiling?

6. Why is it desirable to have the light for writing come over your left shoulder?

7. Tell the advantages of rough gray plaster.

8. Why does a diamond sparkle?

9. Upon what principles may imitation stones be made?

10. When is a substance black?

11. Is black a color?

12. Is white a color?

13. Why are white clothes worn in the summer?

14. Why is a room with light walls better to work in than one with dark walls, even when the same amount of light comes in the room?

15. Why do rivers appear shallower than they really are?

16. Explain why a reddish lamp-shade makes a room more cheerful at night.

17. Colored lights are often seen in fireworks. What causes them?

Sound

1. An electric light bulb makes considerable noise when it breaks. Why?

2. How may a rotten spot in a wooden beam be detected?

3. Why is it that persons often hold the hand behind the ear that they may hear?

4. Watch a circular saw starting through a board and notice that the pitch of the buzzing tone is high. Why?

5. Why does the pitch fall soon after the saw enters the board?

6. Tap a steam pipe with a hammer. Can the sound be heard on the floor above?

7. If you burn gunpowder in the air it does not make a noise. If the gunpowder explodes in the cannon it makes a loud noise. Why?

8. Explain how a speaking tube acts so as to make sounds louder.

9. How do we know that sound does not travel through a vacuum?

CHAPTER XI

PRINCIPLES OF CHEMISTRY

129. Chemical Properties.—In previous chapters we have discussed the necessity of a thorough knowledge of the physical characteristics or properties of the various materials used in industry. It is equally important to understand the chemical "make up" of those materials; that is, their exact composition. Iron and steel, for example, are used more or less in every trade. The iron ore contains many other substances, such as carbon, silicon, phosphorus, sulphur, manganese, and so on. Experience has taught the steel-maker that it is desirable to have as little phosphorus and sulphur as possible in the raw pig iron from which he makes his steel. The foundry man requires pig iron without much manganese, because this property tends to make the iron hard and difficult to melt. Silicon in pig iron makes the carbon assume a form called graphite carbon. This tends to weaken the iron and steel bars, rails, sheets, etc., which are made from the pig iron, because it forms flakes between the particles of iron.

What has been said in regard to iron and steel, applies equally to other materials. A knowledge of the principles of chemistry is needed to understand the composition of these materials, and the chemical processes that take place when they are used in manufacture. In determining the chemical properties of a substance it is necessary to take a small amount of the mixture and analyze it (Fig. 66).

130. Mixtures and Compounds.—The great variety of solids, liquids, and gaseous substances that are used in one form or another in every-day industrial operations may be divided into *mixtures*, *compounds*, and *elements*.

FIG. 66.—Taking Test Borings of Pig Iron. Various parts of the bar are drilled and the borings thus obtained are mixed and analyzed.

When two or more substances are put together, the result is called a *mixture*. While the mixture may differ in some ways from each of the substances that compose it, no new compound is formed, and the original substances may be separated by mechanical means. We can mix substances *in any proportion*. Gunpowder, for example, is a mixture of sulphur, carbon, and saltpeter. Each one of these ingredients may be separated from the others. Water, for example, will separate the saltpeter.

A *compound*, the smallest part of which is called a molecule, is a substance composed of two or more special substances called *elements*, which are combined *in definite proportions*. The new substance formed as the result is generally unlike either of the elements which compose it. For example, by passing an electric current through a mixture of 2 parts of hydrogen and 16 parts of oxygen, both of which are gases, water, a liquid, is formed.

131. Elements.—Elements cannot be decomposed by any known method or divided into anything simpler. The smallest particles of elements are known as atoms. Elements are sometimes found alone in the earth, as are pure copper and gold, but are usually associated with other elements. Nearly eighty elements have been discovered and named, but many of them are not commonly found. In chemistry, every elementary substance is represented by what is called a symbol, which is usually a single capital letter or one capital letter and one small letter. Symbols are used to save time in writing and to describe briefly and clearly the composition of a complicated compound substance.

Frequently the symbol for a substance is derived from the first or the first and second letters of the Latin term for the substance. For instance, Cu is the symbol for copper, and the Latin term from which it is derived is *cuprum*. In like manner, zinc, carbon, manganese, and silver are designated by the symbols, Zn, C, Mn, and Ag. Latin has furnished a number of the symbols for others of the common elements; thus, the symbol for sodium is Na (*natrium*), for potassium, K (*kalium*), and for iron, Fe (*ferrum*). The symbol Hg (*hydrargyrum*) for mercury is from the Greek.

132. Metallic and Non-Metallic Elements.—The most satisfactory way to classify elements is to consider them as metals or non-metals. Non-metallic elements are those that combine readily with metals to form compounds; for example, chlorine, sulphur, silicon, phosphorus, etc. The non-metallic elements have not so much trade importance as the metals and consequently will not be considered in detail in this book.

Metals are good conductors of heat, that is, warmth or heat travels rapidly through them. About one-half of all the known metals are very scarce, and some of them have been seen by only a few persons. A few of the metals, like gold, platinum, silver, copper, and bismuth are found in a free state, that is, pure and unmixed with other materials. The majority of the metals are found in ores combined with oxygen or sulphur.

The art of extracting these metals from their ores and refining them is called *metallurgy*. This extraction may be accomplished in two ways: by the dry method, and by the wet method. In the dry process, the metal is separated from its ore by heat, and the use of high temperature in large furnaces of different kinds is involved. This is the process used in extracting pig iron (see page 370) from iron ore. The wet method involves crushing or pulverizing the ore, as in the case of copper ore, and treating it with chemical liquids and acids, through which an electric current is passed. This latter method is known as the *electrolytic process* and involves what is termed *electrolysis*.

133. Atomic Weight.—Atoms are assumed to have a definite weight. Hydrogen is the lightest element and has therefore been selected as the unit of weight; all other elements are measured in terms of hydrogen. For example: If equal volumes of hydrogen and oxygen are weighed, oxygen is found to weigh sixteen times as much as hydrogen. Hence the atomic weight of oxygen is 16.

The atomic weights of the commonest elements are given in the following table:

TABLE OF ATOMIC WEIGHTS

Element	Symbol	Approximate	Element	Symbol	Approximate
Aluminum	Al	27	Magnesium	Mg	24
Antimony	Sb	120	Manganese	Mn	55
Argon	A	40	Mercury	Hg	200.5
Arsenic	As	75	Nickel	Ni	58.5
Barium	Ba	137	Nitrogen	N	14
Bismuth	Bi	208	Oxygen	O	16
Boron	B	11	Phosphorus	P	31
Bromine	Br	80	Platinum	Pt	195
Cadmium	Cd	112	Potassium	K	39
Calcium	Ca	40	Radium	Ra	226.5
Carbon	C	12	Silicon	Si	28
Chlorine	Cl	35.5	Silver	Ag	108
Chromium	Cr	52	Sodium	Na	23
Cobalt	Co	59	Strontium	Sr	87.5
Copper	Cu	63.5	Sulphur	S	32
Fluorine	F	19	Tin	Sn	119
Gold	Au	197	Titanium	Ti	
Helium	He	4	Tungsten	W	
Hydrogen	H	1	Uranium	U	
Iodine	I	127	Vanadium	V	
Iron	Fe	56	Zinc	Zn	65
Lead	Pb	207			

134. Analysis.—If an electric current is passed through water, made slightly acid to increase conductivity (ease of passage), the water will be decomposed or separated into its elements, oxygen and hydrogen, which can be collected in separate tubes. *Separating compounds into their elements is called analysis.*

In the case of water, for every volume of oxygen there will be found to be just twice the volume of hydrogen. Every molecule of water contains two atoms of hydrogen and one atom of oxygen. The chemical formula expressing this is H_2O. In any formula the number of atoms is shown by writing the number below the symbol of the element and at the right.

135. Synthesis.—As already stated, when the proper proportions by weight of oxygen and hydrogen are mixed and a spark passed through, water is formed. This change, often called a reaction, may be written as follows:

$2H$	$+$	O	$=$	H_2O
2 atoms of hydrogen	combined with	1 atom of oxygen	forms	1 molecule of water

Abbreviating a reaction in this manner is called writing a chemical equation. In a very concise form it shows: on the left-hand side of the equation the substances (called factors) which enter the reaction, on the right-hand side the products, and also the exact amount of each that must be taken or formed. Once the products are determined (usually by experiments), the equation may be written and balanced by having the same number of atoms of the elements on each side of the equation. *Forming compounds by combining elements is called synthesis.*

136. Molecular Weight.—The molecular weight of a compound is the sum of all the atomic weights in the compound. To illustrate: H_2O is composed of two atoms of hydrogen and one atom of oxygen. According to the table of atomic weights (page 129), water has a molecular weight of 18, i.e., $(1 \times 2\ (H_2) + 16 \times 1(O) = 18)$. This means that 2 parts of hydrogen combined with 16 parts of oxygen form 18 parts by weight of water.

137. Law of Combined Weights.—When elements combine to form chemical compounds, they unite according to fixed proportions. To illustrate: When water is formed from the combination of hydrogen and oxygen there must be 2 parts of hydrogen to 1 part of oxygen. These gases must unite in this proportion or water will not be formed. Thus 2 atoms of hydrogen and 1 atom of oxygen unite to form 1 molecule of water.

138. Valence.—If we examine a number of symbols of binary compounds (compounds made of two elements) of hydrogen, such as HCl, H_2O, NH_3, CH_4, we find that the first compound contains one atom, the second two atoms, the third three atoms, and the fourth four atoms of hydrogen. This means that the different elements are combined with the same element (hydrogen), or other elements equivalent to it in combining power, in different amounts as expressed by the symbols. This power of an element to combine with different amounts of hydrogen or its equivalent is called a *valence.* The combining power of hydrogen, which is one, is selected as the unit.

139. Chemical Action.—Chemical change is due to the action of chemical force, which like other forces cannot be described, but is known by its effects. It is quite different, however, from the other forces of gravitation, heat, light, and electricity.

When two elements or compounds act chemically upon each other (disintegrate) or are treated in some special way, they are generally altered in appearance and state.

To illustrate: A mixture of oxygen and hydrogen is still a gas, but a chemical compound of oxygen and hydrogen is water, or a liquid. When zinc is added to muriatic acid ("raw acid") heat is given off, a gas is generated, and the zinc combines with the acid. The resulting compound, zinc chloride, is different from the original substances. The equation is:

Zn	+	$2\ HCl$	$ZnCl_2$	+	$2\ H$
Zinc		Hydrochloric Acid	Zinc Chloride		Hydrogen

These illustrations show that chemical action is distinguished from all other action: first, by producing a compound with properties entirely changed from those of the substances or compounds originally used; second, by the fact that it takes place between definite weights and volumes.

140. Hydrogen.—Hydrogen is a colorless, odorless gas, burning with a pale blue flame and very little light, but with great heat. It is chemically prepared by the action of zinc or iron, and hydrochloric or sulphuric acid. Zinc and sulphuric acid form zinc sulphate and hydrogen. The reactions may be represented by the equations:

Zn	+	H_2SO_4	=	$ZnSO_4$	+	$2\ H$
Zinc		Sulphuric Acid		Zinc Sulphate		Hydrogen
Fe	+	H_2SO_4	=	$FeSO_4$	+	$2\ H$
Iron		Sulphuric Acid		Iron Sulphate		Hydrogen

141. Oxygen.—Oxygen exists in a free state in the air, which is a mixture composed of 20% oxygen and 80% nitrogen. Oxygen is a colorless, odorless gas, and may be prepared by decomposing a compound rich in oxygen, like $KClO_3$ (potassium chlorate), with heat, or it can be extracted from the air. In this latter case the gas is collected over water.

142. Oxidation.—Oxygen unites readily with other elements, particularly metals, and forms compounds called *oxides*. For example: When iron is exposed to moisture and to the air which contains oxygen, it oxidizes and rusts. When the oxygen combines with a carbon, as coal, it gives off considerable heat and light. This process is called *combustion*. A substance or element which burns is called a combustible, and a substance or element that does not burn is called a non-combustible. Oxygen is called a supporter of combustion. Elements will not combine until a definite temperature, called a kindling point, is reached.

Ozone is a form of oxygen, and is a powerful oxidizing agent. When an electric spark passes through the air, it changes oxygen into ozone. Three atoms of oxygen form a molecule of ozone.

Questions

1. Why is a knowledge of the chemical "make up" of certain substances, such as iron, important?

2. What is the difference between a mixture and a compound?

3. Name a number of mixtures; compounds.

4. Give the names of five common elements with their chemical symbols.

5. Why is it desirable to abbreviate chemical names into symbols?

6. Why is hydrogen selected to fill balloons and some air-ships?

7. Give the characteristics of a metal.

8. What is the difference between a metallic and a non-metallic element?

9. What is analysis? Synthesis? Metallurgy?

10. What is the symbol for water?

11. How do we know what the definite symbol for water is?

12. What is the value of a chemical equation?

13. What is the valence of an element?

14. What is chemical action?

15. What is the difference between physical action and chemical action?

16. What is the molecular weight of hydrochloric acid?

17. Write the equation for "killing" (neutralizing) muriatic (hydrochloric acid) and zinc.

18. How much zinc chloride will be formed from 4 oz. of zinc?

19. Describe the properties of oxygen; hydrogen.

CHAPTER XII

ACIDS, ALKALIES, AND SALTS

143. Classes of Compounds.—Compounds may be divided roughly into four classes of substances: water, acids, bases or alkalies, and salts.

144. Properties of Water.—Pure water is the commonest compound that exists. The water we use comes to us either in the form of rain or of melted snow from the mountains. Part of it trickles or percolates through the ground and dissolves any soluble material or gases with which it comes in contact. When the water has passed into the ground and comes in contact with limestone and magnesium compounds, some of the substances are dissolved and the water becomes *hard*. This kind of water appears when an artesian well is drilled. Water that flows over the surface of the earth contains suspended matter or dirt and is generally called *soft* water.

Thus the distinction between hard and soft water depends upon the substances which they carry, and especially upon their chemical action. In soft water, soap readily lathers and the suds thus formed exert a rapid cleansing action. In hard water, soap lathers only with difficulty and often will not lather satisfactorily at all, because of the formation of lime soap, which is insoluble.

If hard water is boiled the hardness often disappears, and soap then acts as in soft water, but in some cases boiling has no effect. Such a condition is wholly due to the action of the dissolved solids upon the soap. Hard water contains either magnesium or calcium sulphates or carbonates. If carbonates only are present in the water, it is likely to become soft when it is boiled, for boiling drives out carbonic acid gas (CO_2) which holds the carbonates in solution.

Thus we see that water may differ in its properties according to the influence of substances to which it has been exposed. Rain and snow water are difficult to obtain; river water may be muddy, more especially in stormy weather; artesian well water will contain in solution the minerals with which it has come in contact. The source of the purest water is a location near a mountain, or in a mountainous country. There the upland surface water has not yet come in contact with impurities, and has had little opportunity to dissolve lime or magnesia compounds.

145. Importance of Acids and Alkalies.—In addition to water, the most important compounds or substances used in chemical changes are acids and alkalies. They may be called the fundamental chemical agents that produce chemical changes. It is important to know their properties.

146. Nature of Acids.—An acid is a compound of hydrogen with a non-metallic element or a group of elements that act as one, called a *radical.* The acid may be a gas soluble in water, as muriatic acid, or a liquid, such as sulphuric acid, or a solid, such as oxalic acid. All acids have a sharp, sour taste and most of them act on metals. The test used for determining whether or not a solution is an acid is to place a drop of the solution on a piece of blue litmus paper (paper dyed blue with the juice of a small plant). If the blue color changes to red, the solution is an acid. If the paper remains blue, the solution is not acid. Acids have different powers and uses. While some are healthful and are used for foods, others are poisonous. Acids are used very commonly in industry for dissolving metals (Fig. 67).

FIG. 67.—One Step in the Analysis of Iron. The iron is carefully weighed and then dissolved in acid over a lamp.

147. Mineral and Organic Acids.—There are two kinds of acids—organic and mineral. Organic acids are those, such as carbolic acid, oxalic acid, etc., which contain the element carbon in their composition. Mineral acids are those composed of any of the other elements, such as hydrochloric acid, nitric acid, and sulphuric acid, and are used principally in the trades and industries.

Nitric acid is largely used in the manufacture of explosives, and hydrochloric acid as a "pickling" liquor for cleaning metals. When nitric acid is added to some metals, it acts very quickly, and gives off reddish brown fumes that are suffocating in their effect.

The change that takes place is represented by the following equation:

$$\underset{\text{Copper}}{3\,Cu} + \underset{\text{Nitric Acid}}{8\,HNO_3} = \underset{\text{Copper Nitrate}}{3\,Cu(NO_3)_2} + \underset{\text{Water}}{4\,H_2O} + \underset{\text{Nitric Oxide}}{2\,NO}$$

The copper nitrate and water remain and the gas (nitric oxide) passes off. Ordinary commercial nitric acid has a specific gravity of 1.42 and contains about 68% of acid.

Sulphuric acid, often called oil of vitriol, is the most important chemical used in manufacturing operations. Its symbol is H_2SO_4 and in a diluted or weak form it acts on metals. When concentrated or strong it forms on the metal a coating of a salt which prevents further action.

The action of the acid on a metal may be represented by the following equation:

Fe	+	H_2SO_4	=	$FeSO_4$	+	H_2
Iron		Sulphuric Acid		Iron Sulphate		Hydrogen

Muriatic, or hydrochloric, acid is generally made by the action of sulphuric acid on salt.

The action may be represented by the following equation:

2 NaCl	+	H_2SO_4	=	Na_2SO_4	+	2 HCl
Common Salt Sodium Chloride		Sulphuric Acid		Sodium Sulphate		Hydrochloric Acid

148. Formation of Salts.—A salt is a compound of metallic and non-metallic elements or radicals. It is formed by the action of: (1) an acid on an alkali or base (a base is a compound of a positive, i.e., a metallic element, or a group of them called a radical, and OH, the hydroxyl group); (2) an acid and a metal; (3) an acid and a salt.

In forming a salt, the hydrogen of the acid is replaced by the metal or metallic radical. If there is an excess of acid—that is, if the base is only sufficient to combine with part of the hydrogen—only part of the hydrogen is replaced by the metal.

To illustrate: When sulphuric acid and sodium hydrate (NaOH) are mixed, the first action is as follows:

H_2SO_4	+	NaOH	=	$HNaSO_4$	+	H_2O
Sulphuric Acid		Sodium Hydrate		Acid Sodium Sulphate		Water

The second step in the change is:

$$HNaSO_4 + NaOH = Na_2SO_4 + H_2O$$

If excess sulphuric acid is used, NaOH may be formed immediately.

The salt formed at first is called an *acid* salt. If all the hydrogen were replaced it would be called a *normal* salt. Normal salts have no effect on blue or red litmus paper.

One of the principal sodium salts is sodium carbonate, often called soda ash, and is represented by the formula Na_2CO_3.

Soda crystals, or sal soda, are made by dissolving soda ash in hot water, and allowing the clear liquid to cool. Crystals then form, having the composition of $Na_2CO_3.10H_2O$. Soda crystals contain over 60% of water, do not dissolve as readily as does soda ash, and are, therefore, not economical to buy.

149. The Formation of Alkalies.—Alkali is the commercial and industrial name for a strong base, such as caustic soda (NaOH), caustic potash (KOH), and ammonium hydroxide (NH_4OH). An alkali is opposite to an acid in character and turns red litmus paper blue. When a limited amount of acid is added to an excess of alkali, only part of the OH (hydroxide radical) is replaced by a negative element or radical, and a basic salt is formed.

To illustrate: If excess iron (ferric) hydroxide and a limited amount of hydrochloric acid are mixed the result is:

$$Fe(OH)_3 + HCl = FeCl(OH)_2 + H_2O$$

or

$Fe\begin{cases}OH\\OH\\OH\end{cases}$	+	HCl	=	$Fe\begin{cases}Cl\\OH\\OH\end{cases}$	+	H_2O
Ferric Hydroxide		Hydrochloric Acid		Basic Ferric Chloride		Water

The most important of the alkalies is caustic soda which is made from soda ash by adding milk of lime (calcium hydroxide) to the solution.

Na_2CO_3	+	$Ca(OH)_2$	=	$CaCO_3$	+	$2\,NaOH$
Soda Ash		Milk of Lime		Calcium Carbonate		Caustic Soda

The calcium carbonate separates as a sediment.

150. Nomenclature of Acids, Salts, and Bases.—Acids usually have two names, the chemical and the common. The chemical names are given according to certain rules based upon the elements in the acid. The common name of the acid is the commercial name.

Binary acids which are compounds of hydrogen and a non-metallic element, are named *hydro-ic* acids. Thus, hydrochloric acid is HCl and hydrobromic acid is HBr.

When there are three or four acids formed of the same elements, oxygen is one of the elements and is the only element varying in amount, as in: HNO_3, HNO_2, HNO; and HClO, $HClO_2$, $HClO_3$, $HClO_4$.

The one with the most oxygen is called perchloric acid $HClO_4$, "per" meaning "above." The most common of the above acids is $HClO_3$, chloric acid. $HClO_2$ is called chlorous acid, and HClO hypochlorous acid, "hypo" meaning "under" or "lesser." When there are two salts composed of the same elements, the one with the smaller proportion of the non-metallic element usually ends in *ous*. The one with the larger proportion ends in *ic*. To illustrate: $CuCl_2$ is cupric chloride, and CuCl is cuprous chloride. $FeCl_2$ is ferrous chloride, and $FeCl_3$ is ferric chloride. The ending of a binary salt is always *ide*.

Salts with more than two elements or radicals are called tertiary compounds. When there are more than two salts, the ending *ic* acid is changed to *ate*, for example, *per-ic* acid is changed to *per-ate;* the ending *ous* acid is changed to *ite*, for example, *hypo-ous* acid to *hypo-ite*.

151. Compounds of Metals.—When combined with other elements, metals form compounds named generally after the element with which they are united. Thus, compounds with chlorine are called chlorides; with bromine, bromides; and iodine, iodides.

The most common compounds of metals are given in the following table.

Compounds With

Oxygen form oxides.
Oxygen and hydrogen form hydroxides.
Sulphur form sulphides.
Sulphur and hydrogen form hydrosulphides.
Nitric acid form nitrates.
Nitrous acid form nitrites.
Acids of chlorine and oxygen form chlorates.
Sulphuric acid form sulphates.
Sulphurous acid form sulphites.

Carbonic acid form carbonates.
Phosphoric acid form phosphates.
Arsenical acid form arsenates.
Silicic acid form silicates.
Boric acid form borates.

Many of the compounds are found in nature; thus sulphate of calcium ($CaSO_4$) is a very common salt called gypsum; oxide of iron, made up of iron and oxygen, is called iron ore; and carbonate of iron ($FeCO_3$) is another form of iron ore.

Questions

1. What are some of the common properties of an acid?
2. Name the mineral acids.
3. Name some organic acids.
4. What is the composition of the so-called "pickling" solution used in trades?
5. Write the action of copper and nitric acid.
6. Write the action of zinc and sulphuric acid.
7. Explain the difference in the products formed from nitric acid and a metal, and sulphuric or hydrochloric acid and a metal.
8. Give the symbol of oil of vitriol.
9. What is the composition of a salt?
10. How are salts formed?
11. Give the composition of any salt.
12. What is a base? An alkali?
13. Why are there two names to the common acids and alkalies?
14. Give the chemical names of the following symbols: $HBrO_3$; $HClO_4$; $NaCl$; HNO_3; $HClO$; K_2SO_4; $CuCl_2$; $FeCl_3$; Na_2SO_4.
15. The antidote or substance recommended to be taken in case of poison from ammonia is lemon juice in water. Explain the action.
16. Explain the difference between "hard" water and "soft" water.

CHAPTER XIII

PHYSICO-CHEMICAL PROCESSES

152. Nature of Physico-Chemical Processes.—Certain processes like:

1. Solution	6. Filtration
2. Ebullition	7. Crystallization
3. Evaporation	8. Sublimation
4. Precipitation	9. Distillation
5. Clarification	

are physical in character, though used extensively in combination with certain chemical processes. They must be considered, therefore, in discussing the principles of chemistry.

153. Solution.—When a solid substance is placed in a liquid and dissolves without a change in its chemical structure, the resulting liquid is said to be a *solution* of the dissolved substance. The liquid used is called the *solvent* of the substance. As an illustration: Sugar dissolved in water forms a solution of sugar. When the water will dissolve no more sugar, it is said to be a saturated solution at that temperature. A liquid saturated with one substance may still be a solvent for another substance.

154. Ebullition.—Ebullition or boiling is the violent agitation produced in a liquid when it is heated from a liquid to a gaseous condition. The heat acts first on that portion of the liquid resting against the heated surface, and converts a part of it into steam, which rises in the form of bubbles that break on the surface of the liquid. The temperature at which a liquid boils is called its *boiling point.* Each liquid has its specific boiling point as well as its specific weight at a specific atmospheric pressure. The boiling point remains constant during ebullition.

155. Evaporation.—Evaporation is the process by which a liquid is gradually changed into vapor which fumes into the air. Evaporation may take place at any temperature, but only on the surface of the liquid; thus it differs from boiling which goes on inside the liquid. Since liquids evaporate more or less at all temperatures, there is no specific evaporating point, as there is a specific boiling point.

156. Precipitation.—Precipitation is the process of separating solid particles from a solution by the action of either heat, light, or chemical substances. The solid particles separated are called the *precipitate,* and the liquid remaining the *supernatant liquid.* A precipitate may either fall to the bottom or rise to the top of the supernatant liquid. Precipitation caused by the action of heat is illustrated by the coagulation and precipitation of albumin, when albuminous fluids, such as the white of egg, are heated; precipitation of silver salts by light as in photography illustrates precipitation by light; and precipitation by chemical reaction occurs in many instances when salts are mixed in solution.

The objects of precipitation are: (1) to convert solid substances into the form of powder; (2) to purify liquids; (3) to test chemicals; and (4) to separate chemical substances.

There is a distinct difference between a sediment and a precipitate; a sediment is a solid matter separated merely by the action of gravity from a liquid in which it has been suspended. A precipitate, on the other hand, is a solid matter separated from a solution by chemical means.

157. Clarification.—Clarification is the process of separating from liquids, without making use of strainers or filters, solid substances which interfere with transparency. The principal methods of clarification are: (1) by the application of heat; and (2) through the use of gelatin and other substances. Boiling facilitates the separation, since the minute bubbles of steam adhere to the particles and rise with them to form scum, which may be skimmed off. This process takes place when milk is heated and the albumin rises to the top. If albumin be added and heat applied to a turbid ("milky") liquid, the albumin will, on coagulating, envelop the particles and rise to the top with them. Acids may be used to precipitate the casein (white curd) of milk, and the precipitated casein will carry with it the insoluble particles. If a cloudy liquid be agitated with paper pulp and then allowed to stand, it will gradually become clear.

158. Filtration.—The commonest method of separating solids suspended in a liquid is by filtration, i.e., by passing the liquid through the pores of some substance called a filter. The liquor that passes through is called a *filtrate*, and the material that remains, the *residue*. Various kinds of material, such as, paper, cloth, cotton, wool, asbestos, slag, sand, and other porous substances, are used as filters. Cotton cloth is often used by fastening it onto a wooden frame in such a way that a shallow bag is formed into which the liquid to be filtered is poured. The first portion of the filtrate that comes through is cloudy, but the rest soon becomes clear, and then the first portion may be returned to the filter. Filtration cannot be hastened by scraping or stirring the precipitate on the cloth, as this action will merely cause the filtrate to run turbid.

159. Processes of Purification.—When new compounds are manufactured by means of chemical reaction, they are seldom pure. In order to purify the product one or more of the three processes of crystallization, sublimation, and distillation are used.

160. Crystallization.—The crude product obtained directly from a chemical reaction is usually amorphous (not crystalline). To obtain the substance in uniform, well-defined crystals and to separate it from impurities it must be dissolved again with the aid of heat, filtered, and allowed to cool slowly. Then the dissolved substances will separate into large crystals or into very fine crystals termed "crystal meal," according to conditions. Since the large crystals are compact and offer a relatively small surface to the action of water, they dissolve slowly. Crystal meal, on the other hand, dissolves quite readily and is therefore more commonly used.

The theory of crystallization is based on the fact that every liquid has the power of dissolving substances. This power can usually be increased by raising the temperature of the liquid. There are a few substances, however, whose maximum strength of dissolving is reached at a temperature much lower than the boiling point. When a solution has dissolved all the solid that it can take up, it is said to be saturated; any decrease in the temperature will then result in the separation of a part from the main body of the substance—usually as crystals. While crystals are being formed, there is a tendency to exclude from the solution all matter not homogeneous with it, that is, all matter not of the same kind. If a concentrated solution which is impure is allowed to crystallize, the impurities may become enclosed or entangled among the forming crystals. This is undesirable and can be prevented by stirring the solution while crystallization is taking place. Thus the formation of the very fine crystals, called "crystal meal," is caused. These fine crystals may be washed free from the "mother liquor" (the liquor from which the impurities are obtained), and may be cleansed of all impurities.

161. Water of Crystallization.—A great many compounds crystallize very easily, and are sold in a crystallized form. In crystallizing they take up more or less water from the solutions and this water forms a definite part of the compound. For example, blue vitriol is crystalline copper sulphate. Its symbol, $CuSO_4.5H_2O$, means that crystalline copper sulphate contains 5 molecules of water. Merchants, in purchasing chemicals, desire them in the crystalline form as this form is considered the purest. Oftentimes compounds are sold on the basis of their dry weight, i.e., the weight of the substance minus the weight of the water.

The method of figuring the dry weight is as follows:

Assume that 34 lbs. of copper sulphate lose 7 lbs. on heating. What is the per cent of water of crystallization?

7 lbs. = amount lost
34 lbs. = whole amount
$\frac{7}{34}$ or .205 of the whole was lost

As it is customary to express the loss in per cent, the loss is:

$$.205 \times 100 = 20.5\%$$

162. Sublimation.—Most solid substances melt when a certain amount of heat is applied to them. Upon being heated further they vaporize. There are a few substances, like ammonium chloride, which vaporize without melting. To purify such substances, they must first be heated and their vapors collected. This process of purification is called sublimation.

163. Distillation.—Distillation is the process by which a liquid is boiled and its vapor condensed. It is used, like the processes of crystallization and sublimation, for purposes of purification. If impure water, for instance, is placed in a boiler to which a condensing apparatus (an apparatus for cooling the steam) is attached, the vapor or steam given off when the water is boiled, is condensed. It then becomes pure or distilled water, all the non-volatile impurities having been left in the boiler. The water has a lower boiling point than the impurities, hence it boils first, and is thus enabled to leave the impurities behind.

164. Chemical Properties of Coal.—The principal materials used for fuel are petroleum and coal. Ordinary hard coal is called anthracite coal, and the soft, lumpy kind that crumbles very easily is called bituminous coal. All fuels are composed of carbon, or compounds of carbon and hydrogen, called hydrocarbons, combined with such impurities as ash, sulphur, nitrogen, etc.

When fuel burns the chemical change which takes place is that the oxygen of the air combines with the hydrogen and carbon. The manner in which coal burns depends upon its composition, the nature of the fire, and the air supply.

If the draught of air is insufficient, the gases are only partly consumed. The oxygen then unites with the hydrogen and leaves the carbon in fine particles of soot or smoke, which float away with the draught or are deposited upon the surface of the boiler. Moreover, when the air is not sufficiently hot, partial combustion again results, changes the hydrogen to water vapor, and sets the carbon free as soot or smoke. If the gases become chilled, and pass off as a whole unburned, they thus carry away, not only their own heat of combustion, but also the heat which has been absorbed for their liberation. Smoke is therefore the sign of the imperfect combustion of hydrocarbons.

165. Chemical Bacteria.—Animal grease is not suitable as a lubricant because it soon becomes "rancid," that is, it gives off a disagreeable odor and forms acids. Careful experiments show also that the changes which take place in grease and other organic substances when exposed to warm, moist air are caused by small living plants or organisms. When these minute organisms alight upon certain vegetable and animal substances, they grow vigorously, and live on the material. As the result of their action, a chemical change takes place. In the case of starch or sugar this change is called *fermentation;* in the case of fat, *rancidity;* and in the case of proteids (compounds of nitrogen, carbon, oxygen, and hydrogen), *putrefaction.* These living organisms are called microbes, germs, and bacteria.

All the changes that take place in milk, such as souring, becoming tainted, etc., are due to bacteria. Cream, as it is obtained from milk, contains bacteria in large quantities, and as these organisms grow they produce the ripening effect which gives flavor to the butter. Certain species of bacteria carry disease and produce undesirable effects upon the flavor of the cream and butter. To counteract such harmful changes, growths of special protective bacteria called *cultures* are introduced into the butter for the purpose of preserving its flavor. Some bacteria are very harmful as they produce disease in both the human body and in other substances, but others are extremely useful in industry, as they produce desirable chemical changes and assist in converting raw materials into finished products. Such a beneficial change is produced by bacteria in the case of tanning.

166. Composition of the Earth.—Most of the raw materials used in trade and industry have their source in the earth. A few of these substances, such as gold, are found in a free state, but as noted before, the more common substances, such as iron, lead, tin, zinc, etc., are found combined with oxygen, sulphur, and dirt. To understand why these are found in this state, it is necessary to study the condition of the earth.

The interior of the earth is a hot, molten mass, from which constantly issues, on various parts of the earth, a stream of hot, molten stone or hot steam, gases, and so on. The gases are steam, carbonic acid, burning carbon, hydrogen, and hydrogen sulphide. The surface of the earth is in a comparatively cold condition. As we dig below the surface we find masses of stone and rock within which valuable metallic particles are embedded. These particles are called minerals. These combinations of mineral and rock are due to the mixing of hot masses. As a result, the metals that are acted upon by oxygen, acids (carbonic acid), hydrogen sulphide, etc., are found in the earth as oxides, sulphides, carbonates, etc. As gold is not acted upon by any of the ordinary gases it is found in a free state.

The earth appears to be composed of twelve main elements: oxygen, silicon, aluminum, calcium, magnesium, potassium, sodium, carbon, hydrogen, sulphur, chlorine, and iron. Of course many other elements, such as the precious metals, are present but are found in small quantities only. Most of the rocks found in the earth are mixtures of two or more minerals. Granite formed from volcanic eruption, for example, is a mixture of three minerals—feldspar, quartz, and mica; sandstone consists of particles of silica or sand; limestone consists of a carbonate of lime; slates consist of silicates of aluminum; and clay consists principally of aluminum compounds. The minerals are held together in the stone by some binding substance, like carbonate of lime, iron oxide, or silica. The color of the clay, rocks, and different parts of the earth is due to the presence of small quantities of iron and other metals. Changes in temperature cause the rocks to expand and contract and consequently they gradually split and crack. The rain then washes into the valley the loose parts of the rocks. Thus the soft, loose soil found on the surface of the earth is the result of the breaking up of the rocks in this way, and the process by which such soil is made is termed weathering or *erosion.*

Stones or rocks are designated as sedimentary, igneous, or metamorphic, the classification depending upon their origin.

Sedimentary rocks are remains of older rocks which have been deposited under water, layer by layer. Limestone and sandstone are examples of this class. Igneous rocks are formed by the solidifying in a crystalline state of lava from a volcano. Granite and allied stones are examples of this kind of rock. Metamorphic rocks are rocks that have, after formation, changed their original forms because of the movement or pressure of the earth. Slates and marbles are examples of this class.

167. Object of Lubrication.—Lubrication is the application or introduction of some substance that will cling to or flow between two surfaces and thus prevent friction. Bearings and joints of engines and machinery are lubricated to keep the various metal surfaces from coming in direct contact, and thus to prevent excessive friction and consequent heating. (See Fig. 34, page 49.) Perfect lubrication is secured when the surfaces are separated by means of the thinnest possible film that is sufficient to prevent heating. A thick film is harmful because it tends to produce fluid friction.

168. Kinds of Lubricants—Oils.—Lubricants may be divided into three general kinds or classes—fluid, plastic, and solid. To the first-named class belong the various oils; to the second, the greases; and to the third, such substances as graphite, talc, soapstone, or mica.

Where the speed of a machine is high and the pressure great, oils are, in nearly all cases, the most satisfactory lubricants to use. They cling to the contact surfaces and thus form an elastic coating to the metals and keep them apart. Oils also absorb the frictional heat and carry it away. Other advantages of oils are: (1) they can be obtained in almost any desired grade or density, from the thin oils to the heavy, dense oils; (2) they do not become rancid or gummy; and (3) they contain no free acids.

169. Greases.—Greases are suitable for use on slow-moving machinery where the pressure is not great. Even where the speed is comparatively high, but the pressure is light, a grease will often give excellent results, if the proper grade or consistency be selected. As a usual thing, however, if grease is used indiscriminately on a large scale, especially on textile machinery, a noticeable increase in the friction load results.

Greases may be divided into two classes, the lime and potash soaps, or high melting-point greases; and the tallow base, or low melting-point greases. The first are made by changing a small amount of fatty oil into a soap by means of lime water, caustic potash, or other alkali, and mixing it with a large amount of petroleum oil, such as engine oil. Such greases have a melting point of 140° to 180° F. The tallow base greases are composed of a large percentage of tallow combined with an alkali, and are brought to the desired density by means of vaseline, petroleum, or petroleum oils. Such greases, owing to their large content of tallow, have a low melting point, usually about 116° to 120° F.

The high melting-point greases usually require forcing down between the journal surfaces by means of compression grease cups. The low melting-point greases can often be packed in the journal box or directly on the bearings, as a low frictional heat causes them to melt, change to an oil, and lubricate the bearings.

170. Solid Lubricants.—The solid lubricants, such as graphite, soapstone, etc., usually have but a limited field of use. A certain form of graphite lately introduced, however, has been shown in experimental laboratory tests, to have great lubricating value with a low coefficient of friction. The great value of this new form of graphite is due to the fact that crystals of graphite appear as minute scales or plates, which present a very good sliding surface and thus serve as a lubricant.

171. Requirements of a Good Lubricant.—The selection of the proper lubricant in any particular case depends, of course, upon the class of machinery in which it is to be used. If on light-running and high-speed machinery, such as is used in the spinning, twisting, and other departments of textile mills, the light-bodied or more fluid oils give the best results. For slow-speed machinery, the heavier bodied oils are best. For use on slow-speed engines, where the oil is fed from cups, a heavy-bodied oil should be used. For high-speed work and engines where continuous oiling systems are used, a light-bodied oil is preferable. Cylinder oils have for their base what is known in the oil trade as cylinder stock, of which there are two classes—the light-colored or filtered stock, and the dark or steam-refined stock, the latter being almost universally used.

For steam turbine lubrication, a high-grade, pure mineral oil is best, as the oil is subjected to high pressure and constant churning, and consequently must be of good quality.

For gas cylinder lubrication, a pure mineral oil ranging in body from light to heavy is found most satisfactory. This type of oil burns freely without leaving a carbon ash.

Questions

1. What is a solution?
2. Will a cold solution dissolve more of a substance than a hot solution?
3. What is a solvent? Name two or three common solvents.
4. What is a saturated solution? How are you able to tell if a solution is saturated or not?
5. What is ebullition?
6. What is precipitation? Has it any industrial importance?
7. Explain the difference between a sediment and a precipitate?
8. What is clarification?

9. What is filtration? Has it any industrial importance?

10. Name the three methods by which substances are purified.

11. Explain crystallization.

12. Explain how large crystals may be obtained; "mealy" crystals.

13. What is the meaning of the term "water of crystallization"?

14. Give the percentage of water of crystallization in "washing soda," $Na_2CO_3.10H_2O$. (Refer to table of atomic weights in Chapter XI.)

15. What is the meaning of sublimation?

16. What are the two kinds of coal?

17. Explain the meaning of rancidity; putrefaction; fermentation.

18. What are germs?

19. Explain why metals are sometimes found as oxides; sulphides.

20. What is the difference between granite, sandstone, and marble?

21. Name the different classes of lubricants. State the advantages and disadvantages of each class.

22. Explain the difference between crystalline and amorphous.

CHAPTER XIV

THE CHEMISTRY OF COMMON INDUSTRIAL SUBSTANCES

172. Chemistry in Industry.—There are certain chemical changes, such as the burning of forms of carbon, explosions, etc., that are very common in industrial life. Moreover, the chemical composition of certain building materials, such as concrete, is so important to industry that everyone should understand the fundamental principles underlying their manufacture.

173. Forms of Carbon.—When an element is found in several forms which have essentially different properties, it is said to be allotropic in character. Carbon is such an element, the different forms or modifications of which are the diamond, graphite, and pure amorphous carbon.

The *diamond* is pure, crystalline carbon. It has a specific gravity of 3.5 and is one of the hardest substances known. On account of its hardness it is used to cut glass. The black, impure variety, called carbonado, is set into the end of a drill, called a diamond drill, which is used for boring holes in hard substances.

Graphite is a soft, lead-colored, shiny solid often called "black lead" or plumbago because it was originally supposed to contain lead. It is smooth and greasy to the touch and is used in the form of flakes as a lubricant because it does not become decomposed, as do oils, by high temperatures and the heat of friction. Since graphite is soft, it readily wears away and when drawn across a piece of paper the friction causes it to pulverize and leave a mark on the paper. Hence its use in pencils. In addition, graphite serves as the basic substance in the making of stove polish and as an ingredient in the manufacture of certain crucibles in which metals are to be heated and melted.

Amorphous or non-crystalline carbon includes a number of varieties of coal, charcoal, lampblack, coke, and gas carbon.

Charcoal is a black, brittle solid and is obtained by heating wood in a closed pile without much access to air. The heat drives out the liquids and gases. These are collected as a by-product and distilled into wood alcohol, acetic acid, etc. Charcoal resists the action of moisture, heat, and air, and consequently telegraph and other poles are often charred before being put into the ground. It is also used as a disinfectant, because it absorbs gases. Gunpowder has a basis of charcoal. The charring of bones and animal refuse gives a form of charcoal called animal charcoal or bone-black, which is used in making pigments.

174. Oxides of Carbon.—When any form of carbon or carbonaceous matter burns, it forms a gas called carbon dioxide. If there is insufficient air or oxygen and considerable heat, a lower form of the oxide, called carbon monoxide, is the result of the chemical change. Carbon dioxide has a slight taste, but no odor and will not burn. Hence it is used as a fire extinguisher. Carbon monoxide is a very poisonous gas. It is a constituent of illuminating gas and burns with a blue flame.

175. Hydrocarbons.—The many compounds of carbon and hydrogen are called hydrocarbons. Carbon unites with elements, particularly metals, to form carbides, such as calcium carbide and silicon carbide. Calcium carbide is made by heating lime and coke or coal in an electric furnace. It is a brittle, dark gray, crystalline solid which forms acetylene gas on the addition of water.

CaC_2	+	$2\,H_2O$	=	C_2H_2	+	$Ca(OH)_2$
Calcium Carbide		Water		Acetylene		Calcium Hydroxide

176. Flame.—When gases are burned a light is given off. This light is called a flame. Flame is due to the combination of a gas with the oxygen of the air. A flame may be luminous, as in the case of an ordinary gas light, or it may be non-luminous, as in the case of the blue flame of a gas-burner. The luminosity of a flame is due to the glowing of small particles of carbon. A yellow flame is caused by incomplete combustion.

177. Compounds of Carbons.—The following are the names, symbols, and uses of some of the most important classes of carbon compounds:

Class of Compounds	*Composition*	*Use*
Carbohydrates	Compound of carbon, hydrogen, and oxygen, the last two in the proportion to form water.	Sugars Starches Cellulose
Alcohols	Compound of carbon and hydrogen with an OH group. $C_2H_5.OH$, ordinary spirits of alcohol.	Wood alcohol Grain alcohol

Class of Compounds	*Composition*	*Use*
Fats	Salts of certain organic acids called fatty acids.	To make soaps, lubricants.
Oils	Liquid fats	"
Soaps	When fats are boiled with sodium hydroxide or alkali, a soap and glycerin are formed.	Washing purposes. Glycerin used to make smokeless powder.

178. Gunpowder.—Ordinary gunpowder is a mixture of charcoal, sulphur, and potassium nitrate. The efficiency of gunpowder depends upon the formation of a large volume of hot gases in a closed space. The pressure exerted by these gases propels the bullets, breaks the stones, etc. If gunpowder is wet, the potassium nitrate dissolves and the powder loses its effectiveness.

179. Sand.—Sand is composed of silicon dioxide (symbol SiO_2). On account of their hardness, some varieties of sand and mixtures are used for grindstones.

180. Glass.—When sand and several other substances are mixed and heated, the fused mixture forms glass. The coloring of glass is caused by the introduction of oxides of metals into the heated mass.

181. Clay.—Clay is an impure form of aluminum silicate. Clay is formed by the slow "breaking up" or decomposition of certain parts of rocks called the feldspars (silicates of aluminum, sodium, or potassium). The decomposition causes the feldspar to form an insoluble silicate and a soluble silicate (sodium or potassium silicate). The soluble part is washed away and the insoluble portion which remains—particles of mica, quartz, carbonate of lime and magnesium, and iron—is called clay. The greater part of the clay is pure aluminum silicate ($H_4Al_2Si_2O_9$).

182. Properties of Clay.—The principal property of kaolin, or clay, is that it becomes slightly soft (plastic) when wet and may be molded into various shapes. When clay is heated it shrinks and in cooling becomes very hard. The color of clay, which is due to the presence of iron and other impurities, varies from gray to red.

183. Porcelain.—Porcelain is a glazed material used for insulators, etc. It is made by mixing kaolin, fine sand, and powdered feldspar, shaping the mass, and then heating it to a high temperature. The surface is glazed by being coated with a mixture of salt and heated. The heat causes the glaze to melt and penetrate the surface.

184. Earthenware.—Impure plaster clay, when wet, shaped, and heated to a moderate temperature may be used for tiles, etc.

185. Bricks.—Many materials used in building construction, such as bricks, drain pipes, etc., are made from impure clay by wetting, molding, and then heating the mixture sufficiently to harden it. The red color in bricks is due to the iron oxide in the compounds of the clay.

186. Mortar.—To make mortar a thick paste is formed by mixing lime, sand, and water. This paste is placed between bricks or stones and slowly hardens or "sets" by losing water and absorbing carbon dioxide. The object of the process is to make the mortar porous and to facilitate the change of the hydroxide into the carbonate.

187. Cement.—Cement is either a natural or artificial mixture of limestone, clay, sand, and iron oxide. Limestone is an impure form of calcium carbonate mixed with silica (sand) and clay. When the limestone contains about 10% silica and clay it has the desired proportion to form a good mixture that hardens under water, as well as when exposed to the air. It is then good material for making cement and is called hydraulic lime. Portland cement is made by heating the powdered combination into a clinkered mass and then grinding it. A mixture of cement, sand, water, and crushed stone is called concrete.

188. Bleaching.—A better appearance may be given to cotton and many other fabrics by passing them through bleaching solutions. The most effective bleaching agent is bleaching powder, a white powder made by passing chlorine gas (made by heating common salt and sulphuric acid) into oxide of lime (CaO). Other bleaching agents, such as sodium sulphite (Na_2SO_3) and sodium peroxide (Na_2O_2), are sometimes used. The lime in the bleaching powder holds the chlorine gas. The cloth to be bleached is placed in a mixture of bleaching powder and water. The chlorine gas from the bleaching powder acts on the water forming hydrochloric acid and oxygen. The oxygen combines with the coloring matter and destroys it, thus leaving a white-surfaced fabric. Bleaching is a distinct chemical action and may weaken the fabric.

189. Dyeing and Dyestuffs.—The process by which coloring is added to fabrics by means of dyestuffs is called dyeing. Dyeing may be done in one of three ways: (1) by immersing loose raw material, such as unspun cotton threads, in the coloring solution; (2) by immersing yarn before it is woven; and (3) by immersing the woven cloth itself. The latter method is the cheapest and the one most commonly used.

Dyestuffs are obtained from animals, vegetable substances, minerals, and organic materials. Examples of the dyes obtained from these four classes of materials are furnished by cochineal coloring matter, indigo, Prussian blue, and aniline dyes respectively.

Fibers of animal origin, such as silk or wool, can be dyed by simply immersing them in the color solution, but materials such as linen and cotton, which have a vegetable origin, will not hold some dyestuffs. Therefore, in the case of these latter fabrics it is often necessary to apply to the cloth or to the coloring solution some chemical salt, such as alum, in order to make the dyestuff adhere to the material. The chemical salt applied for this purpose is called a *mordant.*

190. Printing on Fabrics.—It is often desirable to print a colored design on a fabric that has been already dyed. There are three modern methods of printing patterns: direct printing, discharge printing, and resist printing.

In direct printing the fabric is passed between polished copper rollers, on the surface of which a design has been engraved. When there is to be more than one color in the design a separate roller is necessary for every additional color. The coloring material, which consists of dyestuffs made into a paste, is placed beneath the rollers, a single color for each roller. As each roller rotates it comes into contact with the color and impresses the colored design on the fabric. A strip of steel, called a doctor, removes the color from every part of the roller except that covered by the design.

Discharge printing consists in removing color by means of a chemical from goods already dyed in the piece, thus leaving a white pattern.

Resist printing consists in stamping a chemical on a plain white cloth, and dyeing the cloth afterwards. The chemical makes the dye ineffective on the pattern.

191. Sizing.—Sizing is a process of applying a thickening agent or mixture to cloth, paper, etc. The change brought about is distinctly physical. The object of sizing is to add weight, strength, and smoothness (luster) to the material. A considerable variety of substances are used in size mixtures, the more important of which are included in the following list:

(*a*) Substances possessing adhesive properties to strengthen the material and fix other ingredients. This class includes flours and starches of wheat, sago, rice, maize, and potatoes.

(*b*) Substances to render the material soft, pliable, and smooth. This class includes tallow, grease, oils, wax, glycerin, and soap.

(*c*) Substances to make the material heavier. This class includes French chalk and salts of barium and sodium.

(*d*) Substances to destroy or prevent the growth of germs that cause mildew. Zinc chloride is almost exclusively employed for this purpose.

(*e*) Deliquescent substances to attract moisture to the material, whereby it may retain its pliability, and to prevent powdery substances from being rubbed off. This class includes magnesium chloride, calcium chloride, glycerin, and common salt.

192. Mercerizing.—Cotton may be made to resemble silk, so far as the luster is concerned, through the application of a solution of caustic soda under tension. This process is called mercerization. The effect of the caustic soda is to cause the cotton fibers to become smooth and cylindrical in form so that they reflect the light and appear "shiny" with a strong luster. It is a physical and not a chemical change.

193. Gassing.—The luster of mercerized cotton may be increased by passing the material rapidly over a platinum plate heated to a very high temperature. The effect is to take off the loose fibers. This operation is called gassing.

194. Spontaneous Combustion.—Spontaneous combustion is an expression used to explain the setting on fire of a substance without the employment of any external agent, such as a lighted match, a flame, or a spark. To illustrate: There are times when a pile of coal will burst into flame without the application of a flame or spark. The reason for this is quite different from the reason for the burning of coal in a stove or under a boiler. The first burning is caused by spontaneous combustion, and the second by the ordinary combustion of coal. In both cases, however, the fires follow definite laws.

All combustion is a chemical action attended with the liberation of heat and is the result of the combination of oxygen with the combustible material. Ordinary combustion or burning is merely the result of a substance being heated, in the presence of a supporter of combustion like air, to the point of ignition by some external agent, such as a match. When a substance oxidizes with great rapidity, a great deal of heat is evolved and a flame is formed. The temperature at which the flame forms is known as the *point of ignition* or the *kindling point.*

Certain kinds of damp organic matter, such as soft coal or cotton rags containing oil, confined tightly may absorb enough oxygen to raise their temperature to the kindling point. The result is spontaneous combustion. The quantity of heat is the same whether the combustion is slow or fast. A quantity of wood that decays gives off exactly the same quantity of heat as if the same amount of wood were burned in a furnace, provided in both cases the wood is completely destroyed. The products of combustion are exactly the same.

195. Chemical Solution for Extinguishing Fires.—The most effective method of extinguishing fire is by means of a solution used in chemical fire apparatus. This solution is much more efficient for fire-extinguishing purposes than plain water, because the chemical solution does everything that water can do exactly in the same way and for exactly the same reasons. In addition, it forms a considerable blanket of fire-extinguishing gases which are heavier than air and better supporters of combustion, and in this manner shuts off much more effectively the access of air (oxygen) to the fire.

Chemical fire-extinguishing solution extinguishes fire more by smothering than by cooling. The only drawback is that the supply of chemical solution must necessarily be comparatively limited. However, a reasonable supply of chemical solution, instantly available, makes a large supply of water unnecessary.

Questions

1. Why is a knowledge of the chemistry of common industrial substances desirable?

2. What is the meaning of the expression "carbon has four allotropic forms"?

3. Why do people prefer crystalline to powdered forms of substances?

4. Describe the importance of the different forms of carbon.

5. Explain the formation of the oxides of carbon.

6. Draw a sketch of an ordinary yellow gas flame and explain why it is luminous (bright) compared to the blue flame of the gas stove. Which is hotter?

7. What is an alcohol? Carbohydrate? Fat? Soap? Oil? Give an example of each kind.

8. What is sand?

9. Describe briefly the following: a dye; clay; gunpowder; bleaching; bick; mortar; cement; porcelain.

10. What is spontaneous combustion?

11. Explain the action of the chemical solutions used in fire extinguishers.

CHAPTER XV

MAGNETISM AND ELECTRICITY

196. Nature of Magnetism.—When we take a lump of lodestone, which is an iron ore, and place it near a piece of iron, the lodestone will attract the iron. The iron in its turn will then attract particles of iron. The iron is called an artificial magnet. Thus iron and steel when brought in contact with the lodestone have the property of becoming magnetized and attracting iron. Magnets made of soft iron lose their magnetism very easily and are called temporary magnets; while hard iron and steel retain their magnetism and are called permanent magnets.

197. Shapes of Magnets.—Magnets are of two shapes: straight or bar (Fig. 68) and horseshoe (Fig. 69). In every magnet there is a limited space surrounding each end or pole in which its magnetic properties are exhibited. This is called the magnetic field. If, for example, magnetized iron filings are sprinkled over a sheet of paper, they will assume curved lines, bringing into view a few of what are called the *lines of force of a magnetic field.* The portion of this magnetic field that is the strongest is assumed to contain the greatest number of lines of force

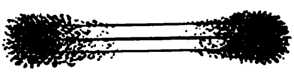


FIG. 68.—Bar Magnet with Iron Filings.

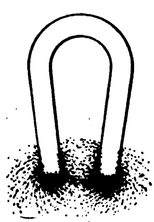


FIG. 69.—Horseshoe Magnet with Iron Filings.

The total number of lines of force which pass through a field is called the *magnetic flux*. The magnetic flux always flows in a complete circle or circuit. The material through which it flows affects variously the resistance offered to the free passage of the flux.

198. The Mariner's Compass.—Experience shows that, in all cases, *like poles of magnets repel and unlike poles attract.* This principle, called the law of magnets, is utilized in the device known as the mariner's compass (Fig. 70), which consists of a magnetized steel needle balanced on a point so that it will turn freely; the points of the horizon are marked on a compass card. The needle is acted upon by the earth, which is a magnet. The needle behaves the same way in all parts of the earth. The north magnetic pole is near Hudson Bay, the south magnetic pole in the Antarctic Ocean. As the true North Pole and the magnetic north pole are not the same, allowance must be made for this variation. Ships travel from point to point by the assistance of the mariner's compass.

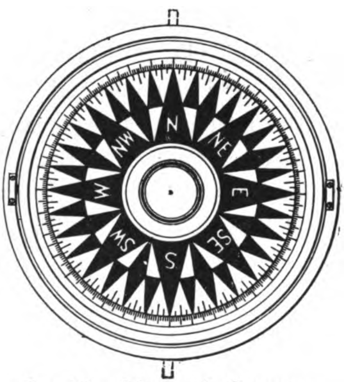


FIG. 70.—Mariner's Compass.

199. Nature of Electricity.—As we look about us we find electricity moving the cars on which we ride and producing the light by which we see at night, and we naturally ask, "What is electricity?" That question cannot, as yet, be answered definitely. Electricity is no doubt a form of energy having properties of its own, but obeying laws corresponding quite closely to those governing the motion of water. A great many explanations can be offered by comparing the action of electricity with water. For example, electricity flows through a wire in much the same way as water flows through a pipe. From their likeness it has become popular to speak of electricity as "juice."

Since electricity is, in a sense, considered a fluid, its flow is called a current, and any substance, such as copper wire, through which it flows is called a conductor. All metals, salts, and solutions, living vegetable substances, and water, are conductors of electricity. There are some bodies, however, such as glass and rubber, that offer a resistance so great as to prevent the passage of electricity. Most vegetable substances in a dry state, such as shellac, resin, rubber, paper, and cotton are in this group. Other non-conductors are wood, sulphur, glass, mica, silk, porcelain, and oil. The path through which a current passes is called a *circuit*. When a path is continuous it is called a closed circuit, but when there is a break it is called an open circuit.

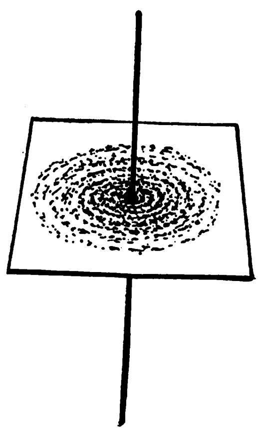


FIG. 71.—Lines of Magnetic Force Around an Electric Wire.

200. Relation of Magnetism to Electricity.—If a piece of copper wire through which a current of electricity is flowing is passed through a cardboard or glass plate and the card or plate is sprinkled with iron filings, the filings arrange themselves in circular lines (Fig. 71). If the card or plate is jarred and the iron filings displaced, they will rearrange themselves in the same circular lines.

If, on the other hand, the current is not flowing, the filings will not assume circular lines. This shows that there is a definite relation between magnetism and electricity. When a conductor passes through a magnetic field in the proper direction, it produces a current of electricity, or when a current passes through a conductor it produces a magnetic field.

201. Electromagnetic Force.—Soft iron retains very little magnetism and yet it can be magnetized to such an extent that it can be utilized in lifting large bodies. When a bar of soft iron, in the form of a horseshoe, is wrapped round with copper wire and a current of electricity is passed through the wire, the iron becomes a powerful magnet called an electromagnet (Fig. 72) and may be constructed to support a weight of many tons. By making one magnet fixed and another movable, and by causing one magnet to revolve within the lines of force of another, an attraction and repulsion of great intensity can be created, which will act as a great moving power.

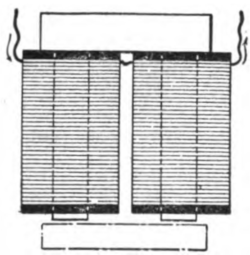


FIG. 72.—Electromagnet.

The strength or lifting power of a magnet is measured with a lever and scales by noticing the number of pounds registered. The lifting weight is the pull exerted minus the weight of the magnet. The magnetic flow is proportional to the number of turns of wire of the conductor and the current flowing around the turns. The magnetic flux is inversely proportional to the resistance of the circuit. The total resistance is the sum of the resistance of the iron path and the air path.

An electric bell (Fig. 73) depends upon the properties of electricity and magnetism for its action. When the button of the bell is pressed by the finger, an electric circuit is completed. The current flows around the coils of an electromagnet, which attracts a bar of soft iron metal fastened to a lever, at the other end of which there is a hammer that strikes the bell. When the soft iron metal is attracted the current is broken; this causes the bar to go back. This backward movement of the bar starts the current again and the operation is repeated. These operations are repeated in rapid succession so long as the button is pressed.

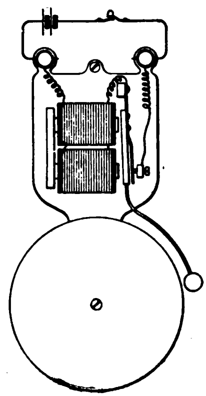


FIG. 73.—Electric Bell.

202. Chemical Means of Generating Electricity.—Electricity may be generated by chemical agencies. When any two different metals, such as zinc and copper, are placed in an acid or solution and wires are attached to them and connected, a current of electricity flows through the wire. This arrangement of metals in a liquid is called a cell. When the wires are not connected, bubbles of hydrogen collect around the zinc plate, but the moment the wires are connected, the hydrogen gas begins to appear on the copper plate.

Commercial zinc contains a great many impurities, such as iron and carbon. Little circuits are set up between the zinc and carbon impurities; hence the bubbles which appear on the zinc when it is immersed in the acid. This bubbling may be avoided by amalgamating the zinc, i.e., by covering it with mercury so that the zinc is used up only when the current is flowing.

203. Electrolysis.—The breaking up of a substance by passing electricity through a solution of the substance is called *electrolysis* and the solution in which it takes place an *electrolyte*. This process is of great industrial importance.

All chemical compounds—acids, salts, and bases—are made up of two parts; the positive or metallic part, and the negative or non-metallic part. When any compound is dissolved, it breaks up partially into these two parts. The positive or metallic portion is charged with positive electricity and is attracted to the negative electrode or plate.

204. Units of Measurements.—A quantity of electricity, like a quantity of water, may be measured. Since the flow or quantity of water depends on the pressure or "head" and on the resistance of the pipes, so the quantity of electricity depends upon the pressure and the resistance of the wires.

The acting force which gives rise to, or maintains, a current or flow of electricity is called the electromotive force (abbreviated E.M.F.). The E.M.F. corresponds to pressure in relation to water and *is measured by a unit called a volt.* That force against which the E.M.F. acts, that is to say, that force which retards the flow or current, is called the resistance, and corresponds to the friction of pipes in relation to water. *Resistance is measured by a unit called an ohm.* The quantity of electricity corresponds to the quart or gallon of water. *The current of electricity*, or rate of flow, *is measured by a unit called a coulomb*, which is the quantity passing per second of time, and corresponds to a flow of water of so many quarts or gallons per second. *A rate of flow of one coulomb per second is called an ampere.* The unit of rate of electrical work is the product of the E.M.F. and the rate of flow or current—just as the pressure with which the force acts is the work performed. The rate of flow of electricity or current is proportional to the impelling pressure or head.

205. Ohm's Law.—There is a definite relation between the volts, ohms, and amperes of a circuit of electricity. This relation was first stated by a man named Ohm, and is known as Ohm's Law.

The quantity of electricity in amperes delivered by a circuit is obtained by dividing the electromotive force in volts by the resistance in ohms. This rule may be abbreviated into a formula:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Resistance}}$$

$$I = \frac{E}{R}$$

where I is the quantity of electricity in amperes, E the electromotive force in volts, and R the resistance in ohms. By transformation of the formula

$$E = RI$$

$$R = \frac{E}{I}$$

Thus, if we know any two of the three units of a circuit, it is possible to find the third.

206. Measurement of Electric Power.—Electric power is measured in the same way as is water power. Water power is equal to the quantity of water in pounds that falls per minute multiplied by the "head" or "drop" in feet.

Electric power is equal to the intensity of current in amperes multiplied by the pressure in volts. The unit of electric power is a watt. *A watt is the power given by a current of one ampere flowing with a pressure of one volt.*

The watt is a very small unit, so that the kilowatt (1000 watts) is generally used. Electricity is measured by the number of kilowatts used per hour. To illustrate: If an electric generator gives 14 kw. for 9 hrs., it produces 126 kilowatt-hours of work.

207. Simple Voltaic Cell.—The voltaic cell (Fig. 74) consists of a strip of zinc and a strip of copper in a glass jar nearly full of sulphuric acid, supported side by side without touching each other. These two metal strips are connected by a copper wire. Electric current will flow from the copper to the zinc. The copper is called the positive pole and the zinc the negative pole of the cell. The current may be detected by placing the free ends of the copper wire on the tip of the tongue. A slight stinging sensation will be felt, thus proving the presence of an electric current.

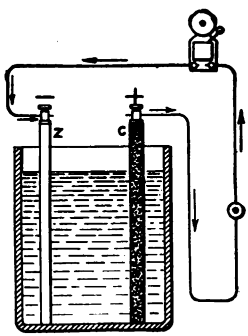


Fig. 74.—Simple Voltaic Cell.

208. Battery Cells.—When electricity is desired for bells, burglar alarms, etc., it is obtained from battery cells. The electricity is generated by chemical means. There are many forms, each of which has its advantages and disadvantages. The four types most commonly used are described below.

The Leclanché cell consists of a glass jar containing a solution of sal ammoniac (ammonium chloride) with a zinc rod for one pole and a carbon plate in a block of compressed manganese dioxide for the other. The purpose of the manganese dioxide is to prevent polarization of the cell, that is, the collecting of bubbles of hydrogen on the plate. Polarization diminishes the voltage by increasing the resistance. As the manganese dioxide is in a powdered form it hardens slowly, and if too large a current is taken from the cell, polarization takes place. The advantage of this type of cell lies in its freedom from local action and in the fact that it can be used for a long time without deterioration.

The Daniell cell consists of a zinc sulphate solution and a copper plate in a copper sulphate solution. They are separated by a porous cup to prevent undue mixing. As no hydrogen is developed in this cell, there can be no polarization. When the circuit is left open the copper coats the zinc and impairs its efficiency.

The gravity cell consists of a copper sheet placed in the bottom of a glass. Crystals of copper sulphate are placed over the plate and water is added until the jar is nearly full. A zinc plate is suspended at the top of the jar and sulphuric acid added to start the cell. The sulphuric acid acts on the zinc forming zinc sulphate. The zinc sulphate is so much lighter than copper sulphate that, so long as the cell is kept on a closed circuit, the solution mixes but slightly.

The bichromate cell is used for operating small cells or motors, and consists of a zinc and carbon plate in a solution of chromic acid (mixture of bichromate and sulphuric acid). When the cell is not used, the zinc must be removed from the liquid, so that the chromic acid will not attack it.

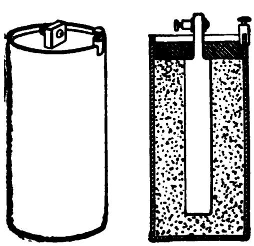


FIG. 75.—Dry Cell.

209. Dry Cells.—Dry cells (Fig. 75) are not actually dry. They contain the same ingredients as the Leclanché cell, but instead of containing a fluid electrolyte they have the solution absorbed in a plastic mass of manganese dioxide and plaster of Paris or other inactive substances.

The great advantage of the dry cell lies in the fact that the liquid will not spill out under any conditions and there are no vapors arising from the cell, as it is almost invariably sealed. Dry cells have the disadvantage, however, of having a very high internal resistance, because the electrolyte cannot so readily carry the current when in this form as it can when fluid. Furthermore, the small amount of liquid present and the method of construction do not allow the free escape of the gases which form when the cell is in operation. For this reason, the cell becomes polarized very soon and is satisfactory only where intermittent service is needed. It should not be used where the current must flow continuously for any length of time.

In order that the internal resistance of the cells may be reduced to its lowest point, the zinc and carbon are arranged to present as great a surface as possible and to be as near together as circumstances will allow. This arrangement affords a large conductor of short length for the current to flow through inside the cell. The carbon should be as porous as possible, as it can then absorb a great amount of oxygen and thus neutralize the hydrogen gas produced by the cell when in operation and prevent the cell from polarizing as soon as it would if there were no oxygen present to combine with the hydrogen.

210. Storage Batteries.—The storage batteries of commerce (Fig. 76) are built up with electrodes composed principally of lead peroxide (PbO_2) as the positive electrode, and sponge lead as the negative electrode. The positive plate is hard, like soapstone, while the spongy lead is so soft that it may be cut by the finger nail. Both plates are immersed in a dilute solution of sulphuric acid. On discharging the battery, the metallic lead, peroxide, and sulphuric acid react forming lead sulphate and water. On charging, the reverse takes place; the lead sulphate forms metallic lead, lead peroxide, and sulphuric acid.

When the battery is fully charged and in good condition, the positive plate is a dark reddish brown or chocolate color, while the negative plate is slate-colored. On discharging the battery, the SO_3 isobtained from sulphuric acid, which combines with water and forms lead sulphate with lead. When the battery is recharged the current releases the SO_3, restoring the plates to their previous condition. Storage batteries are measured in ampere-hours. Thus a 100 ampere-hour battery will give a continuous discharge of 12½ amperes for 8 hrs. Theoretically, it should give a discharge of 25 amperes for 4 hrs., or of 50 amperes for 2 hrs.

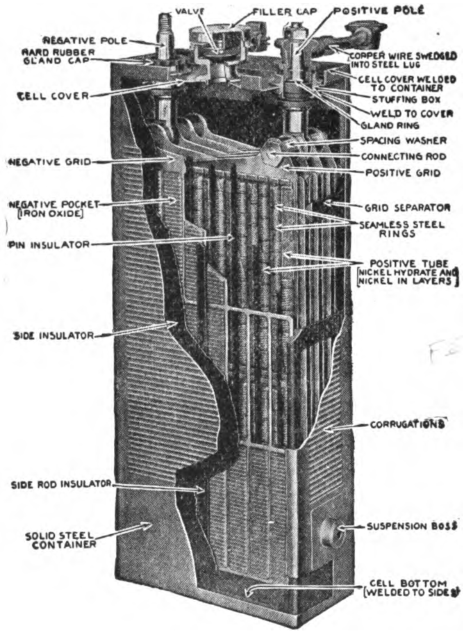


FIG. 76.—One Form of Storage Battery.

The capacity of a cell is proportional to the exposed area of the plates, the number of plates, and the active material present.

211. Arrangement of Electrical Apparatus.—A group of cells or electrical apparatus may be arranged in different ways. The wire from the zinc of the first cell may be connected to the carbon of the second, etc. (Fig. 77), or the wire from the zinc of the first may be connected to the zinc of the second, and the wire from the carbon of the first to the carbon of the second, and so on. (Fig. 78.)

A battery is rated commercially by the resistance, and by the electromotive force of a single cell. There are two resistances to be considered in the calculations of the capacity of batteries: the resistance of the battery, due to polarization, etc., which is represented by R, and the resistance of the external circuit, such as the wire, which is designated by r. The current given by a battery—according to Ohm's Law—is equal to the electromotive force divided by the resistance, which in this case is divided into two parts.

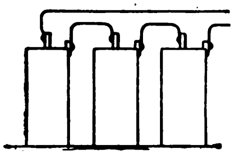


Fig. 77.—Cells Arranged in Series.

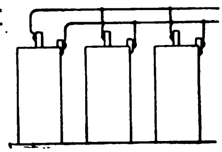


Fig. 78.—Cells Arranged in Parallel.

$$\text{Current} = \frac{\text{Electromotive force}}{\text{Resistance (internal)} + \text{resistance (external)}}$$

$$C = \frac{E}{R + r}$$

212. Galvanometer.—One of the instruments used to measure electricity is called a galvanometer. It depends for its usefulness on the principle of magnetism. There are many varieties of this device. The D'Arsonval galvanometer (Fig. 79) consists of a horseshoe magnet placed vertically. Between the poles of the magnet there is an iron cylinder; above the cylinder is suspended a fine wire wound on a thin copper frame so that it will swing freely between the cylinder and the magnet poles. When the current is sent through the coil it becomes a magnet which is acted upon by the horseshoe magnet which causes it to be deflected. The deflection is measured on a scale which gives the measurement of electricity.

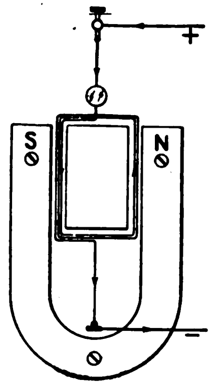


FIG. 79.—D'Arsonval Galvanometer.

213. Ammeter.—An ammeter (Fig. 80) is simply a commercial form of galvanometer. It is constructed in the same way, but only a small fraction of the current to be measured passes through the coil. The greater portion passes through the shunt, which is located in one of the leads coming from the machine. The terminals on the shunt are connected to the terminals on the ammeter by a pair of flexible leads about 10 ft. long. After the ammeter is made, it is tested by operating one machine on a certain number of lamps at exactly 110 volts and then throwing off that machine and operating the same number of lamps with another machine. If readings on the ammeter are the same, it is correct.

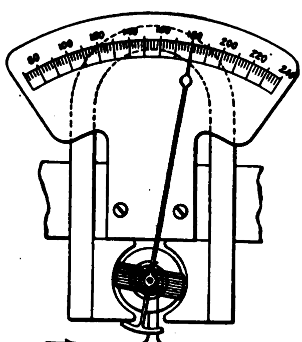


FIG. 80.—Ammeter.

214. Voltmeter.—The voltmeter is an instrument used to determine the voltage of a circuit. It consists of a light, rectangular coil of copper wire wound upon an aluminum frame, pivoted in jeweled bearings, and capable of rotating in a space between a soft iron core and the pole of a permanent magnet. A light tubular pointer, attached to the coil, moves over a graduated scale. The current is introduced into the coil by means of two spiral springs which serve to control the movement of the pointer. When a current passes through the wire, the coil tends to turn in a certain direction against the action of the springs which tend to hold it in place. The amount of deflection is proportional to the voltage. The scale is graduated to read in volts. It is accurate and substantial. This instrument should not be placed in a strong field, as such a field will permanently affect the permanent magnet. In this case the scale must be graduated again.

215. Electric Pyrometers.—In certain manufacturing processes it is necessary to determine the temperature of furnaces. Hence the need of some instrument that is simple, accurate, and capable of being handled by a workman without special mechanical or electrical knowledge. Such an instrument is found in the electric pyrometer (Fig. 81) which consists of a thermo-element, or insertion tube, for exposure to the heat, and a sensitive galvanometer to indicate the temperature at a convenient distance from the source of heat.

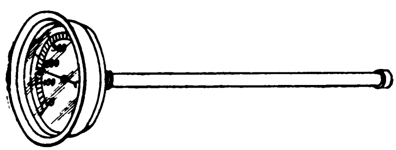


FIG. 81.—Pyrometer.

The principle underlying this pyrometer is that when any metal is heated an electric current is set up. The intensity of the current depends upon the temperature to which the metal is heated. Thus, measuring the current measures also the temperature at the extremities of the metal.

The lower portion of the thermo-element, which is inserted into the metal, is protected by crucible material (a clay substance that will resist great heat) or by a tube of pure graphite with an insertion of quartz glass. In the latter case, the graphite protection can only be 8 in. long, whereas in the former case (for temperatures up to 2370° F.), the protection tube for the thermo-element can be any desired length. The latter is particularly valuable in cases where the increase of temperature has to be watched while the crucible is in the oven, so that it can be lifted out at the correct moment.

The thermo-element consists essentially of two wires or rods of different materials, which are joined or fused together at their extreme ends and exposed to the heat. These ends are called the hot junction. The other extremes of the rods are called the cold junction. The cold junction projects into the open air and is connected to the leading wires of the galvanometer by means of screws.

The two rods of the thermo-element are of different electrical conductivity. If, therefore, the ends of the rods at the hot junction are heated, a difference of potential is produced, causing an electric current to flow, varying in strength with the degree of the thermal difference between the cold and the hot junctions, or with the intensity of the heat to which the thermo-element is exposed. The relation of this current to the temperature has been determined accurately by experiment, and the scale of the galvanometer can therefore be divided to read directly in Fahrenheit or Centigrade degrees. Thus, as soon as the thermo-element is exposed to heat or cold, the electric pressure or current produced in the two rods actuates the mechanism of the galvanometer, and the needle of the latter indicates directly the exact temperature of the hot junction at the place where the thermo-element is inserted.

Inasmuch as the electric current produced in the thermo-element through the heating of the hot junction depends on the difference between the temperature at the two extremes of the rods, it is, of course, essential that the outer ends of the rods or the cold junction be kept cool.

The insertion tubes are made in various lengths and fitted with protection tubes and flanges (screwed couplings) to adapt them exactly to the different processes or apparatus for which they are required. The constituents of the thermo-element vary according to the intensity of the heat for which they are intended. For temperatures up to 1100° F. or 600° C., the element consists of nickel and a special metal alloy; for temperatures up to 2300° F. or 1250° C., nickel and a special carbon are used; while for temperatures up to 2900° F. or 1600° C., platinum and platinum rhodium give the best results.

216. Galvanometers and the Measurement of Heat.—Galvanometers can also be used to measure temperature because, as noted above, an electric current is formed when metals are heated. The current thus produced is proportional to the temperature to which the metal is heated. Consequently, a galvanometer reading in current indirectly measures the temperature.

Galvanometers are used for the measurement of lower temperatures up to 1100° F. They are hung vertically, and the scale and finger are made very bold, so as to enable the operator or workman to recognize the temperature at a glance, without having to go close to the instrument.

When used for scientific and other work requiring exactness and precision, galvanometers constructed to register up to 1100° F. can be used only in a horizontal position on a table or in a bracket. This limited use is also common to galvanometers constructed to register higher temperatures up to 2900° C., and to those designed to register very low temperatures.

Questions

1. What is magnetism?
2. Explain the difference between a natural and an artificial magnet.
3. Describe the shapes of magnets.
4. Explain the expressions: "magnetic flux," "lines of force," "magnetic field."
5. What is a mariner's compass?
6. What is the relation between electricity and magnetism?
7. What is electromagnetic force? Name some of the industrial uses of this principle.
8. Describe an electric bell.
9. What is a simple voltaic cell?
10. Describe the chemical means of generating electricity.
11. What is electrolysis? Is it an important industrial process?
12. Describe some of the most common battery cells.
13. What is a dry cell?
14. Explain the use of a storage battery.
15. What is an electric pyrometer? Describe it.
16. What is a galvanometer?
17. What is an ammeter? Voltmeter?
18. In what units is electricity measured?
19. Explain Ohm's Law.
20. Describe the arrangement of electrical apparatus.

CHAPTER XVI

FRICTIONAL OR STATIC ELECTRICITY

217. Nature of Current.—When certain bodies, such as leather belting and pulleys, paper and steel plates, or cotton and steel rolls, are rubbed together, sparks are frequently produced. This kind of electricity is called *frictional* or *static*, and is quite dangerous because of its liability to cause a fire. Frictional electricity acts in many ways like magnetism. To illustrate: A magnetized body has at least two poles which are unlike and the magnetism appears more or less concentrated. In like manner, when a body which is rubbed becomes electrified, it shows two different kinds of electricity. For instance, if a sheet of glazed paper is rubbed vigorously with a smooth pencil and then placed over a small piece of paper, the sheet attracts the small piece, showing that the bit of paper has a different electrification from that of the sheet. When two different substances are rubbed or passed over one another quickly, one becomes charged positively with electricity, while the other is negatively or oppositely charged.

218. Leyden Jar.—Static electricity may easily be drawn off and bottled up in what is called a Leyden jar. This is a glass jar (Fig. 82) three-quarters of the surface of which is coated inside and outside with tin-foil. A brass rod with a knob at the end goes through the cork and into the jar until it touches the inside coating of tin-foil. If the knob of this jar be held about half an inch from the conductor of an electrical machine, sparks will pass for some time from the conductor to the knob of the jar and will then cease. The jar is then said to be charged, that is, the coating on its inside is as full of electricity as it will hold. The jar can be charged only when the outside is connected with the earth; if the outside be insulated, no electricity can be collected in it. It is enough to hold the outside of the jar in the hand, as in this way it is connected with the earth through the body. The positive charge from the conductor then passes into the inside coating of the jar.

FIG. 82. Leyden Jar.

219. Loss Due to Frictional Electricity.—Frictional electricity causes considerable loss in the manufacture of paper, cotton, wool, etc. When the paper or material passes over machines, two forms of electricity are generated, each with different properties of attraction. The result is that the fibers of the paper, cotton, wool, etc., are scattered and made uneven because of the attraction of the electricity on the fibers to the opposite electricity on the machine.

220. Electric Neutralizer.—Frictional electricity may be removed by attaching to the machine a device called a neutralizer, which is really a transformer.

This device may be bolted to the wall or ceiling in any convenient place and serves to deliver the electric current in the proper form to the various machines where the static electricity is to be neutralized. A single line of heavily insulated wire leads from the transformer to the various points of treatment. This line may be run along the ceiling over the machines or under the floor on which the machines are set. On each machine is placed one or more inductors connected to the line wire. The inductor is a steel tube of 1½ in. outside diameter and of suitable length to reach across the machines. This tube is also slotted on one side from end to end and has a series of porcelain blocks in the slot. These blocks contain the active points from which the influence is radiated to the charged material. The tube itself is grounded, but the line wire is connected directly with the cable inside of the tube. The connection is made through a convenient form of removable socket at the end of each inductor. The inductor is placed at some point in the machine where the charged material may pass by it at a distance of from 1 to 3 in., and the material becomes instantly neutralized thereby, even when running at a speed of 1000 ft. per minute. On a printing press, the inductor is placed across the press so as to treat the paper just after it leaves the cylinder or at least before it goes into the pile.

Electricity may be detected in some substances, such as cotton, glass, and wool, better than in a metal like silver, because the first-named substances are non-conductors and do not allow the electricity to escape easily while the reverse is true in the case of conductors. Moist air is a far better conductor than dry air; hence, electricity shows itself on cotton when the air is dried. In order to keep the air moist, humidifiers (apparatus for discharging moisture in the air) are distributed throughout cotton mills.

221. Lightning.—Much of the electricity of the air is caused by the rubbing of moist air against dry air. A great deal of moisture is made by the sun or wind turning into vapor or mist the salt water of the ocean. More water is turned into vapor during the heat of summer and autumn than in winter and for this reason there is more lightning in warm weather than in cold. The electricity in the air in clear weather is generally positive, but during fogs, rains, or snows it tends to change to negative. Sometimes it happens that two clouds, one charged with positive electricity and the other with negative electricity, come near each other. The two kinds of electricity then rush together and we see a flash of lightning and hear thunder. Lightning is the same thing as a spark from an electrical machine, the only difference being that a flash of lightning is sometimes several miles long and the spark only a few inches.

222. Danger from Lightning.—If a cloud filled with one kind of electricity comes near the earth when the latter is filled with the opposite kind, the cloud may discharge its electricity to the earth. If any tall object, such as a tree, a steeple, or a house, happens to be near where the cloud discharges, the electricity will often pass down it to the earth. In this way houses are sometimes injured and set on fire and great trees are split up into small pieces. Sometimes, too, human beings and animals are struck and killed. It is not safe, therefore, to stand under a tree or close to a high house during a thunder storm.

223. Forms of Lightning.—We see lightning in several different forms; sometimes its flash is straight, sometimes it looks forked or zigzag, sometimes it is round like a ball, and sometimes it spreads over the clouds like a sheet of fire. When a thunder cloud is near the earth, the flash comes straight down, because there is but little air for it to pass through. When, on the other hand, the cloud is at a considerable distance from the earth, the air in the path of the lightning is made denser or thicker by being pushed together, and as lightning can pass more quickly through thin than through thick air, it flies from side to side so as to pass where the air is thinnest. This makes its path zigzag or forked. When there is a great charge of electricity in a cloud it sometimes forces its way through the air in the shape of a ball. What is called sheet lightning is either the reflection or shine on clouds of a stroke of zigzag lightning which is too far off to be seen, or light discharges of electricity from clouds which have not enough in them to make zigzag lightning.

224. Cause of Thunder.—When lightning passes through air it leaves a vacuum, and the air rushing in to fill it makes the noise which we call thunder. We do not usually hear this until some time after the flash of lightning because light travels more than a million times faster than sound. When the thunder cloud is at a distance, the sound comes to us little by little and we then call it rolling thunder; but when the cloud is near the earth the sound comes in one great crash. You can generally tell how far off a thunder cloud is by noting how long the time is between the flash of lightning and the sound of the thunder. If you can count five as slowly as the tick of a clock between the two, you may be sure that the cloud is more than a mile away.

225. Use of Lightning Rod.—Lightning on its way to the earth always follows the best conductor and consequently will leap from side to side to find a building or a tree. It is attracted to pointed things rather than to round or blunt things, and for this reason lightning rods are made with sharp points. Buildings properly fitted with lightning rods are safe from being struck by lightning, because the rods lead the electricity into the earth. When a cloud filled with electricity comes over the rods, the electricity will flow down them until the cloud is discharged. We see no flash and hear no thunder; and we may feel sure that the building will not be struck. The tops of lightning rods are usually silvered or gilded, so that they will not rust and become worthless. The lower end of the rod must be carried down into damp earth; if the earth is dry it is better to carry the end into a well, because dry earth is not so good a conductor as moist earth and the lightning might leap from the rod at the lower end and go into the cellar of the building. High chimneys should have rods on them because soot is a good conductor, as is also the vapor which arises when fires are burning.

Questions

1. What is frictional electricity?
2. Has frictional electricity industrial importance?
3. What is a Leyden jar?
4. Does frictional electricity cause any danger? Explain.
5. How may this danger be removed?
6. Describe an electric neutralizer.
7. For what are humidifiers used in mills?
8. Describe lightning.
9. What dangers are attached to it?
10. Name the different forms of lightning.
11. Explain the relation of thunder to lightning.
12. What is a lightning rod?

CHAPTER XVII

GENERATION OF ELECTRICITY ON A COMMERCIAL BASIS

226. Generating Large Amounts of Current.—We have studied how electricity is generated by chemical means in batteries and by friction. These two forms of electrical energy are very valuable for commercial purposes where a small current is sufficient, such as is necessary for ringing electric bells, etc. The current generated by these two methods is not, however, strong enough to drive large machines or to light lamps. The commercial method of generating electricity on a large scale is by means of a machine called a *dynamo* or generator. The principal parts of a dynamo are: (1) the *magnetic field*, produced by permanent magnets or electromagnets; and (2) the *armature*, which consists of a moving coil or coils of wire wound on a revolving iron ring or drum.

227. The Principle of a Dynamo.—The generation of electricity by a dynamo is based on a principle of magnetism called induction. When the lines of force that pass from the north to the south pole of a magnet are cut by a wire there is produced or induced in the wire a current of electricity. That is, if we take a loop or coil of wire which has no current in it and a magnet which also has no current, and move the loop or coil between the poles, as shown in Fig. 83, a momentary current is produced. If a series of loops or coils are used instead of one loop, a current may be generated continuously. This method of generating electric current is called *induction.*

The strength of a current in electromotive force set up by induction depends upon: (1) the strength of the magnet, (2) the number of turns of wire in the coil or loop, and (3) the speed with which the magnetic lines of force are cut, that is, the speed at which the coil rotates.

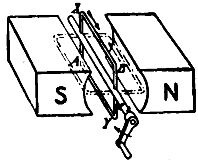


FIG. 83.—Magnetic Field. Showing loop of wire rotating between the north (N) and south (S) poles of a magnet.

228. Direction of an Induced Current. —The direction of an induced current depends upon two factors: (1) the direction of the motion of the wire, and (2) the direction of the magnetic lines of force.

A very valuable method of determining the direction of current used in practical life is called Fleming's Rule.

Place the thumb, forefinger, and center finger of the right hand so as to form right angles to each other. If the thumb points in the direction of the motion of the wire, and the forefinger in the direction of the magnetic lines of force, the center finger will point in the direction of the induced current.

It is very important to know the direction of the current in revolving a loop of wire between the poles of a magnet in order to understand the working of a dynamo.

Examine Fig. 83 and notice the loop of wire between the poles of the magnet. If the loop is rotated to the right, as indicated by the arrow head, the wire XB moves down during the first half of the revolution. According to Fleming's Rule, the current would be directed from B to X. The wire YA would move up during the first half of the revolution and the current flow from A to Y. As the result of the first half of the revolution, the current would flow in the direction $AYBX$.

Repeat the reasoning for the second half of the revolution. Notice that for every complete revolution, the current reverses its direction twice. It is accordingly called alternating current. As the strength of the current depends upon the number of lines of force cut, so the induced electromotive force starts at zero, goes to a maximum, and then back to zero in the first half-turn. That is, the induced electromotive force reaches its maximum when the loop is in a horizontal position because it cuts the most lines of force at this position. It cuts the least number of lines of force at the beginning and at the end of each half-vertical revolution.

229. Commutator.—We have seen that the current generated in the coil is alternating. Alternating current is very valuable for lighting and power, but there are cases in electroplating and charging storage batteries where it is absolutely necessary to have the current flow in the same direction. To do this, it is necessary to add to the dynamo a device called a *commutator*, the object of which is to make the current flow in one direction in the external circuit, regardless of the fact that the current reverses twice in every revolution.

A commutator consists of copper bars which are arranged in circular form and separated or insulated from each other by thin plates of mica. The bars connect with the armature wires, so that the current, as fast as it is generated, flows from the armature to the segments of the commutator.

230. Armature Brushes.—The electricity is taken off the commutator by strips of carbon which touch or lean upon it. There are usually two brushes on the opposite sides of the commutator. The brushes, when adjusted, can shift sections on the commutator just when the loop is in a vertical position, so that the current will flow out of the positive brush and in at the negative brush.

231. Armature and Core.—The armature of a dynamo (Fig. 84) consists of a steel or iron shaft on which are mounted a large number of thin circular iron disks held together by bolts. This arrangement makes a cylinder with a groove

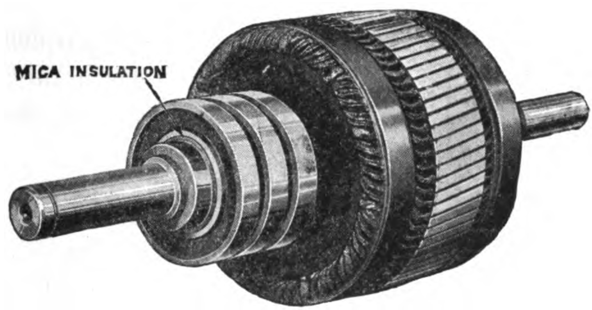


FIG. 84.—Armature.

cut in it, running parallel to the armature shaft. Insulated wire is wound around the core and laid in the grooves, which are lined with mica or some other insulating material. The wires are painted over with shellac. Binding wires are wound on the outside to hold the armature coils in place.

The iron core or shaft is used in the armature to concentrate the lines of force and to keep them from escaping. The electric current is generated by the rotary motion of the armature between the poles of the magnets.

232. Action of a Dynamo.—*A dynamo*, then, *is a machine for transforming mechanical energy* (which is the energy that rotates the armature) *into electrical energy*, and *for forcing the current of electricity through the wires.*

A dynamo, when in action, may be considered as a pump, which raises electricity from a low level or pressure to a high level. When the dynamo is in action the electricity flows through the circuit; when it stops the electricity ceases to flow.

233. Classes or Types of Dynamos.—There are three classes of dynamo machines on the market—*series, shunt,* and *compound*—each one adapted for special work. They differ in the manner in which their field magnets are wound.

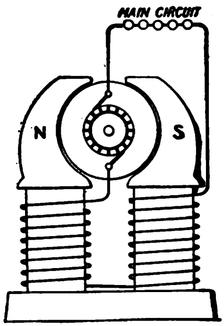


FIG. 85.—Series-Wound Dynamo.

234. Series Machine.—A series machine (Fig. 85) is a dynamo which allows all the current produced to pass through the field magnet coils by taking the wire from one brush and carrying it the required number of times around the field magnet, and then connecting it with the external circuit. The other end of the external circuit is connected with the other brush. Such a machine is not usually found on the general market, but is a common form of motor made especially for traction purposes.

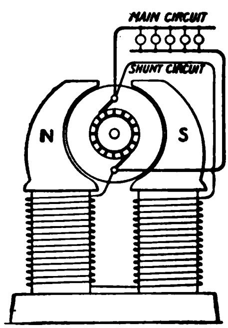


FIG. 86.—Shunt-Wound Dynamo.

235. Shunt Machine.—A shunt dynamo (Fig. 86) is a machine which has only a portion of its total current passing through the field magnet coil. It is used in all cases where it is desirable to have a constant pressure voltage at all loads, as in the case of the ordinary parallel or multiple system used for lighting buildings. The shunt machine is used in large plants, where the diversity factor is so large that the varying demands of customers tend to average up and keep the load either constant or very nearly so.

236. Compound Machines.—A compound dynamo (Fig. 87) is one having two series of windings; one series winding, around the part through which the main current flows, and a shunt winding through which a fraction of the main current flows. Compound machines are used in railway power plants, because of the violent fluctuations of load, and in small lighting plants of low diversity factor, where the consumers' demands fluctuate widely.

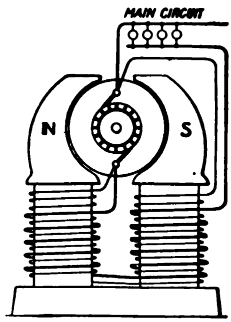


FIG. 87.—Compound-Wound Dynamo.

237. Direct Connected Machine.—A direct connected dynamo is one which is driven by an engine without the use of a belt; that is, the armature shaft is connected to the engine shaft by means of a flexible device; or the engine shaft is made extra long with a bearing, and the armature is mounted on the shaft. This device saves space, is quiet in operation, and increases efficiency, since there is no loss due to transmission of power by belts.

238. Direct and Alternating Dynamos.—While dynamos vary in the manner of winding the fields and armatures as described above, the most important difference between the different types is in the kind of current generated. This classification divides dynamos into the two types of direct and alternating. An alternating current dynamo is similar in its action to a direct current dynamo, except that in the former the two ends of the various armature coils are connected in a ring. As the armature travels past the poles of the field magnet, the armature coils cut through the magnetic field in opposite directions. This produces a flow of current in the coils which reverses as the particular wire passes each pole. The current is collected by means of the rings, and is transmitted through the circuit as a series of rapidly oscillating pulsations. It is necessary to have or maintain the magnetic field of an alternating current dynamo in a constant condition; that is, the lines of force must always travel between the poles in a constant direction. To attain this result, the field must be excited (receive its power) from a dynamo generating a continuous current.

239. Care of Dynamo.—A dynamo to run properly must be kept clean and dry. The parts that require the greatest care are the commutators and brushes. The commutator should be kept clean by wiping it with a hard cotton cloth. The occasional application of a little vaseline tends to diminish friction between the commutator and brushes. Oil should never be used for this purpose. As the commutator becomes roughened with age, it should be smoothed by holding fine sandpaper against it while the machine is revolving. If the commutator gets out of true (out of adjustment), it must be turned down in a lathe. If it becomes wet, the insulation of the armature and field coils will be injured or destroyed, because in such a case resistance between the frame and the electrical part becomes low. A commutator in which this trouble occurs is said to be "badly grounded." There should be an insulation resistance of 10,000,000 ohms. The bearings of a dynamo require no more attention than the bearings of any other machinery.

240. Electric Motor.—*An electric motor* (Figs. 88, 89, 90, 91) *is a machine for transforming electrical into mechanical energy.* An electric current causes the armature to rotate, and the mechanical energy due to the rotation may be utilized to drive machinery. The motor is quite similar to a

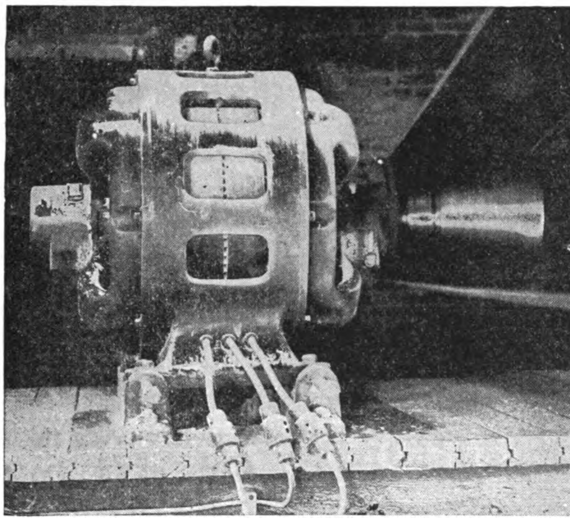


FIG. 88.—An Electric Motor.

dynamo; in fact, the direct current motor is almost identical with the dynamo in structure and circuit, although in detail of design its external appearance is sometimes quite different. The principle of magnetism on which the direct current motor works is as follows:

When a current of electricity is passed through a coil of wire on the armature, the coil will always revolve so as to include as many lines of force as possible. When it reaches this position, the commutator changes the current in the coil so that the armature must again rotate a half-revolution in order to include the greatest number of lines of force. Each turn of wire acts in the same way, so that the continual force acting on the armature causes it to rotate. By means

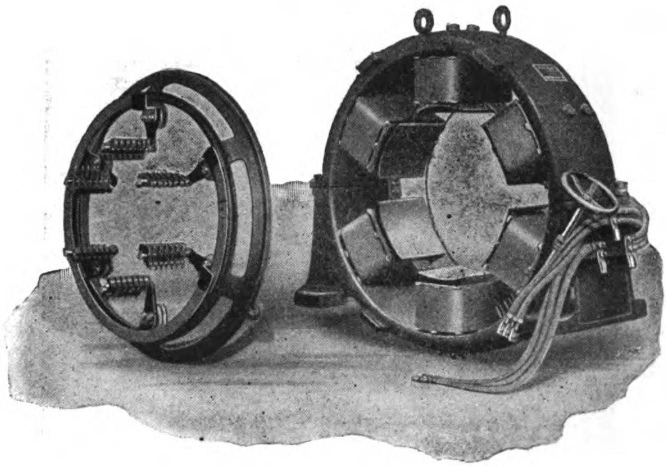


FIG. 89.—Brush-Holders.

FIG. 90.—Poles of a Multi-Pole Dynamo.

of shaft and pulley, the energy may be transmitted to other machines and made to do work. The direction in which a motor runs may be reversed by changing the connection so that the direction of current is reversed through either field or armature.

241. Kinds of Motors.—There are different kinds of motors as there are dynamos. *Series motors* are used in hoists, cranes, railways, etc., where it is necessary to start with a full load and where the automatic regulation of speed is not necessary. *Shunt motors* are used when automatic regulation is desired. In starting any direct current motor, it is necessary to put a considerable resistance in series with the armature. Otherwise, the very low resistance of the armature would permit the flow of an enormous current,

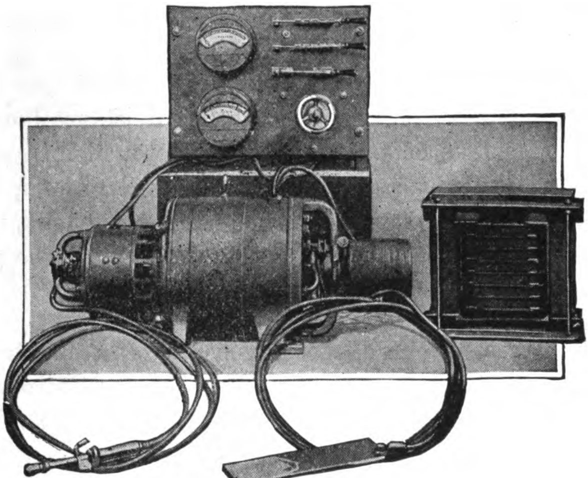


FIG. 91.

which would blow fuses or overheat armature coils and cause excessive sparking. As the machine increases in speed this resistance is cut out by using a starting box with each motor.

242. Electric Railway Motors.—The work of the electric railway requires a special type of motor of great flexibility. For example, the current demanded by a motor in starting a car is always in excess of the current afterwards required to run the car at full speed on a level track. The rating of a railway motor is the horse-power output it will deliver during a one-hour run at a rated voltage at the brushes with a temperature rise of any part of the motor not exceeding 70° C. A car motor usually has its four poles covered so as to be waterproof. It transmits power by means of a single reduction gear. The motor is suspended at one end upon the car axle, and the spring is suspended at the other end.

243. Resistance Box.—A device to resist or check the flow of current is commercially called a resistance box. It generally consists of an insulated wire, wound in a spool, the ends or terminals of which are fastened to large brass blocks. If the spools contain a large amount of silk, moisture tends to accumulate and cause inaccuracy. The plugs should be cleaned with coarse paper.

244. Rheostat.—A rheostat consists of a number of coils of wire connected in series for the purpose of introducing resistance into the circuit. An adjustable device allows the resistance to be varied by cutting out as many of the coils as is desired.

245. Starting Box and Controller.—A starting box is a rheostat used to cut down the voltage in the line, when starting a motor. The current should flow through it only while the motor is attaining its normal speed, the resistance being decreased as the speed of the motor increases.

A controller is a rheostat used in connection with a motor to cut down the voltage, and thereby to control the speed of the motor. It differs from the starting box in that it is intended for continuous service.

246. Efficiency of Dynamo.—The efficiency of a dynamo is the quotient obtained by dividing the amount of electric power furnished by the dynamo by the amount of mechanical power delivered to the dynamo. It is measured by indicating the engine while running the dynamo at full load and noting the reading of the ammeter and voltmeter, and then indicating the engine when the dynamo is idle. The difference between the two readings is approximately the mechanical power supplied to the dynamo.

$$\frac{\text{Watts}}{746} = \frac{\text{Volts} \times \text{Amperes}}{746} = \text{Horse-Power}$$

Motors are rated in horse-power (H.P.) Dynamos are rated in kilowatts (kw.).

$$1 \text{ H. P.} = \tfrac{3}{4} \text{ kw.}$$

247. Electric Transformers.—The commercial requirements of users of electricity are best served by distributing electricity at high voltage and low amperage and by changing the same current into low voltage and high amperage by means of transformer placed on a pole, or better in a vault, before the electricity enters the building.

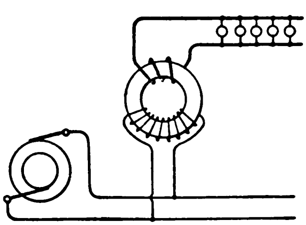


FIG. 92.—A Transformer.

A transformer (Fig. 92) consists of three parts: (1) the primary coil, which is the wire which connects with the alternating current from the supply lines; (2) a core of iron; (3) and a secondary coil or wire in which is generated an electromotive force by the change of magnetism in the core which it surrounds.

248. Fuse.—A fuse is a safety device intended to melt when a current exceeding a certain strength passes through a conductor. Thus the fuse protects the conductor from being overheated by excess current. The fuse, which consists of a piece of soft metal, such as an alloy of lead, is soldered to copper terminals, so shaped that they may be clamped.

249. Circuit-Breaker.—When a large volume of current is used it is necessary to have a device known as a circuit-breaker, as fuses are sometimes too slow in action. A circuit-breaker is practically a switch, which, when the current exceeds a certain amount, automatically opens by means of the pressure of a spring regulated by a coil through which the current passes. When the current becomes greater than a certain amount, the coils attract an iron rod attached to a trigger and release it. This trigger comprises a spring which acts upon the switch. One current-breaker is used for each generator.

Questions

1. What is the commercial method of generating electricity?
2. What are the principal parts of a dynamo?
3. Explain the principle of a dynamo.
4. The strength of a current depends upon what factors?
5. What is an induced current?
6. How may the direction of an induced current be determined?
7. What is a commutator?
8. What are armature brushes?
9. Describe the action of a dynamo.
10. Name and describe the different kinds of dynamos. .
11. What is the difference between alternating and direct currents?
12. What is an electric motor?
13. Describe the different kinds of electric motors.
14. Explain the expression "efficiency of a dynamo,"

15. Explain the care which should be given to a dynamo.
16. What is a transformer? Describe it.
17. What is a fuse? Describe it.
18. What is a circuit-breaker? Describe it.
19. What is a resistance box? Rheostat? Starting box?

CHAPTER XVIII

TRANSMISSION OF ELECTRICAL ENERGY

250. Practical Uses of Electricity.—Mechanical energy is transformed into electricity because in this form it can be conducted very readily from a convenient place of generation or source of power, such as a waterfall, to any spot within a reasonable distance and there be utilized as heat, light, or power.

Electric heating is only practicable when it is desirable to use heat for a short time at a certain point. In small quantities electric heat is used in cookers, welding processes, foot-warmers, cigar-lighters, etc. The advantage of this form of heat is that it is free from fumes, odor, and noises; its disadvantage is that it is too expensive for general heating. Electricity, when consumed in large quantities in a special electrical furnace, produces a very high temperature—ordinarily as high as 3500° C.—without difficulty, while in the case of a furnace used for smelting metals by the burning of coke under a forced draught, the temperature hardly ever exceeds 2000° C.

The practical use of electricity gives employment to a great many people. The various types of electrical work include over two hundred occupations. Four types of electrical work will be described in this chapter: (1) electrical apparatus work; (2) inside wiring; (3) outside wiring; and (4) power station work.

251. Electrical Apparatus.—Electrical apparatus work includes the manufacture of all electrical machines, instruments, and devices. This work is so varied and widely differentiated that no brief description can cover it. In general, however, it may be said to consist of the skilled electrical work required in the manufacture or repair of all forms of electrical apparatus, such as generators, motors, electric meters, rheostats, telephones, switchboards, and testing and signal apparatus.

252. Outside and Inside Wiring.—Outside wiring consists of the installation of all outdoor lines, such as general electrical power transmission lines, street lighting, telephone, telegraph, and signal lines. There are two general types of outside wiring: aerial, in which the wires or cables are supported high in the air on poles or other suitable devices; and underground, in which the wires or cables are laid in conduits.

Inside wiring consists of the installation of electric wires, appliances, and fixtures for all purposes within the confines of some structure. It includes such work as lighting, heating, power, bell, telephone, and signal installation.

There are four general types of inside wiring: (1) open work, in which the wires are exposed to view, and are mounted on cleats or knobs; (2) molding work, in which the wires are run in a special molding, made either of wood or metal; (3) concealed work, in which the wires are run in partitions and other places not exposed to view, and are insulated by means of knobs and tubes; and (4) conduit and armored cable work, in which the wires are run in metal pipes called conduits or are protected by an integral metal coating or armor. The above classification does not include all forms of electrical work, as there are some specialized occupations, such as power house work, which have been omitted.

253. Requirements of the Trade.—A very considerable amount of trade and technical knowledge is required by an electrician. The following are some of the details upon which an inside wireman must have ready and definite knowledge: (1) the methods of installation of electric wires and conduits; (2) the making of electrical connections (fixture wiring); (3) the installation of electrical appliances; (4) the testing of circuits; (5) the methods of computing the sizes of wires; (6) connections and fuses required for specific electrical currents; and (7) the methods of estimating the amount of current required for the specified work. This work presupposes a thorough knowledge of the electrical requirements of the trade as set up by experts, and called the code, together with some knowledge of the theory of electricity, with emphasis on the definition of terms and electrical measurements. Some knowledge of building construction is also necessary.

Electric wiring demands careful insulation from all surrounding material which might under any circumstances become a conductor of electricity. This need for special care in insulating has caused the establishment of definite and fixed rules. It is important that these rules (the electrical code) be understood and observed by the worker, since not only his business integrity and reputation are affected by poor or slipshod work, but the safety of property and even the lives of many people are dependent upon the proper installation of electric wires and appliances.

254. Switchboards.—The output from generators and dynamos is regulated by means of switches on a switchboard

(Fig. 9) which is divided into two sections: the machine panels, and the feeder panels. The machine panels are equipped with ammeters, with the switches necessary for regulating, and with voltmeters for measuring the electrical

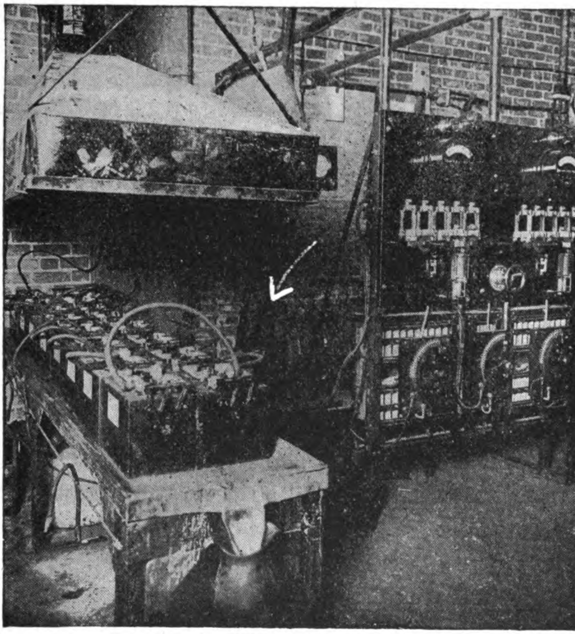


FIG. 93.—A Switchboard.

energy generated. The feeder panels have similar instruments for controlling the output of energy to the various circuits. The operator in charge of the switchboard is able to tell by a glance at these instruments the amount of work each machine is doing, and thereby to know when it is advisable to throw out of or put into operation additional machines. A rheostat is furnished for each generator so that the pressure may be varied. Circuit-breakers or fuses to interrupt any particular circuit through which an excessive current may flow, are also included in the switchboard equipment.

A switchboard is always placed away from the wall or ceiling to reduce the danger of communicating fire to adjacent combustible material. Conductors should be of soft annealed copper, about 97% pure, and should be insulated for their entire length by a vulcanized rubber compound that adheres to the wire. Wires should be arranged to secure distribution centers in easily accessible places so that cut-outs and switches may be conveniently located. The load should be divided as evenly as possible among all the branches, and complicated and unnecessary wiring should be avoided.

255. Transmission of Electrical Current.—The electrical current must be transmitted from the power plant to different points of distribution in an economical manner; that is, with very little loss of electricity, and at the same time in a way that will reduce the danger to life to a minimum. The problem is not serious when the generating plant is in the same or an adjacent building, as in the case of a private plant; but it is a serious problem in a central power plant that supplies electricity over a large area.

The current is usually transmitted, as noted above, through copper wire supported on steel poles or towers, or in underground conduits. The wire used underneath the ground must be insulated, while the wire used overhead may or may not be insulated. Overhead wires should be separated as far as possible so they will not swing together. Over long distances, such as 15 to 20 miles or more, the energy is transmitted as alternating current at from 11,000 to 22,000 volts. If the central station is near the center of distribution, the voltage is about 2200 volts, and is reduced by transformers before it reaches the consumer.

Alternating current is usually generated at a medium voltage and then raised by step-up transformers for transmission purposes. When the current of high voltage reaches the substation, it is reduced by means of step-down transformers. If necessary, the alternating current may be changed over to direct current by means of a rotary converter.

Electrical energy must be furnished to meet the maximum demand during any part of the day, even if this maximum demand continues only for a short time. To avoid the expense and large investment of an equipment big enough to supply such a maximum, storage batteries are utilized to store up current during the slack hours and distribute it during the rush hours of the evening when many lights are burning. In this way the equipment is kept evenly at work throughout the day.

256. Measurement of Strength of Current.—Electricity is distributed from the power station where the energy is generated to the different points where it is to be utilized for power or lighting. The amount of work done or "power" consumed in transmitting electricity from the power station to the point of consumption is found in the following manner: Multiply the electromotive force, determined by the voltmeter, and the strength of the current, determined by the ammeter, and the time in seconds; the result is the power consumed and is expressed in joules, the electrical unit of energy. This formula may be written:

$$\text{Energy} = \text{Pressure} \times \text{quantity} \times \text{time}$$
$$\text{Joules} = \text{Volts} \times \text{amperes} \times \text{seconds}$$

Power is the rate of doing work and the electrical unit is the number of joules per second. It is expressed as watts.

257. Size of Wire.—In distributing electricity there is, as previously stated, more or less resistance to its passage through wires. In overcoming this resistance heat is developed and energy is lost by the friction caused by the electricity moving through the conductor. The resistance offered to an electrical current depends upon the material through which it passes, the length and sectional area of the circuit wires, and the surrounding conditions.

To illustrate: If 900 ft. of a certain wire offers a resistance of 2 ohms, the resistance of 450 ft. of the same wire is 1 ohm. If the diameter of the wire were one-half, the area would be one-quarter and the resistance four times as great, or 4 ohms. This is often expressed in mathematical language by stating: Resistance varies directly as the length and inversely as the square of the diameter of wire.

Since watts are the product of electromotive force and current, the question of furnishing 15,000 watts to a certain point from a power station might be settled by having either an electromotive force of 1500 volts and a current of 10 amperes, or 150 volts and 100 amperes. The loss due to heat increases with the strength of the current.

The size of wire necessary to transmit a given current is determined by the drop in voltage allowed between the generator and the point of application of the current, and the increase in temperature due to the current.

High voltages are used in long-distance transmissions to increase the carrying power of a given size of wire, in other words, to decrease the cost of line necessary to transmit a given amount of energy.

258. Kilowatt and Kilowatt-Hour.—Many people confuse kilowatt (kw.) and kilowatt-hour (kw.-hr.). Kilowatts (watts divided by 1000) represent the number of units of energy used at any one time. Kilowatt-hours mean the amount of energy used over any given period of time.

To illustrate: Assume a motor of a different size makes an immediate demand on the power plant of 1 kw. If the motor continues running for two hours, the amount of electrical energy consumed is:

$$1 \times 2 = 2 \text{ kw.-hrs.}$$

That is, the motor demands 1 kw. and the consumption is 2 kw.-hrs.

259. Injuries in Electrical Work.—Injury in electrical work is usually caused by direct contact with a live conductor and may consist of either a shock, burns, or both.

When the electric current enters the body, it causes more or less complete paralysis of the nervous system; this in turn causes the heart and lungs to cease functioning. The degree of the shock depends upon certain conditions. For example, if an electric circuit is completed by making a contact with the body at the shoulder and hand of the same arm, the current will pass through the arm and not reach the heart and lungs. On the other hand, if the circuit is completed from hand to hand the current will pass through the body near the heart and lungs and may be sufficient to cause death. Sometimes the shock may not kill but stun the person to such a point as to stop his breathing. This is due to the fact that the skin of the body, unless wet, offers high resistance to the current and the conductor makes only a short and incomplete contact with the body. A person can be released from a contact with a live conductor only by means of a piece of dry, non-conducting material, such as a piece of wood, a coat, rope, or hose. If possible, the switch should be turned off or the wire should be cut by means of rubber protected shears.

Burns are produced either from an arc or by the heating of the tissues of the body by the current. In case burns are produced it is very necessary not to touch or irritate them. They should be protected from the air by a soft dressing, such as carron oil (a mixture of limewater and linseed oil), baking soda (teaspoonful to a pint of water), or a paste of flour and water. A dry or charred wound should never be covered by a liquid dressing, but simply with a clean cloth.

Questions

1. Name some of the practical uses of electricity.
2. What are the possibilities and limitations of electrical heating?
3. Describe some of the principle lines of electrical work.
4. What is the difference between outside and inside wiring?
5. Describe the method of transmitting electricity over a long distance.
6. How is the size of wire for transmitting electricity regulated?
7. What is the difference between the kilowatt and kilowatt-hour?
8. What are some of the common injuries in electrical work?

CHAPTER XIX

THE TELEPHONE AND TELEGRAPH

260. History of Telephony.—Less than forty years ago there were no telephones. Today there are more than 10,000,000 in use and they are found in every civilized country on the globe. The United States has more than 7,000,000 telephones. In New England alone there are over 1,000,000 miles of telephone wire, hundreds of central offices, and over half a million telephones.

The telephone was invented by Alexander Graham Bell in Boston in 1876. At first it was looked upon as a toy and considered as of little value. So strong was this general opinion that it was hard to get money to develop it. Today the money invested in telephony runs into billions and the telephone has proved one of the greatest inventions of all time. It has made possible instant talk over a wire between millions of people. One can talk from Boston to Chicago, and even hundreds of miles farther, almost as easily as across the street.

No business ever grew so rapidly. Although it was possible to talk over a crude telephone wire in 1876, it was not until years later that the invention was really established on a sound footing.

261. Telephone Principles.—Many people use the telephone daily without having the slightest conception of the principles upon which it operates. The fundamental principle is a comparatively simple one, involving merely the carrying of sound waves by means of an electric current, but in a large city with thousands of telephones and many exchanges, the problem of proper connection and transmission becomes a complicated one.

The transmitting and receiving instruments are identical in nature, each consisting of a coil of insulated wire connected with the line.

In transmitting, the message is spoken into the mouthpiece at one end. The to-and-fro motion thus imparted to the metallic diaphragm attached to the mouthpiece produces induction currents in the coil. These impulses passing over the main line produce similar movements in the diaphragm of the receiving instrument and thus cause the latter to reproduce the message in articulate sound to the one listening.

262. Making a Connection.—In order to understand how a call is made through a large city exchange, it is necessary to have in mind a distinct picture of a switchboard and to understand the functions of the various operators. (See Fig. 94.) For the sake of clearness it will be well to take a single typical case.

Between fifty and ninety subscribers' lines run to each operator's switchboard. Operator A, for instance, receives all the calls *from* the subscribers on the Audubon exchange whose numbers are from 1 to 50. At the bottom of her switchboard there is a hole, called an answering jack, for each of these lines. Should one of these subscribers, Mr. Smith, take his receiver from the hook in order to call, a small supervisory lamp lights below the answering jack in which Mr. Smith's line ends. Operator A is thus notified that Mr. Smith is calling, and connects herself with his line by inserting one of a pair of plugs in the answering jack.

The top of operator A's switchboard contains a hole for every number on the Audubon exchange, and an additional

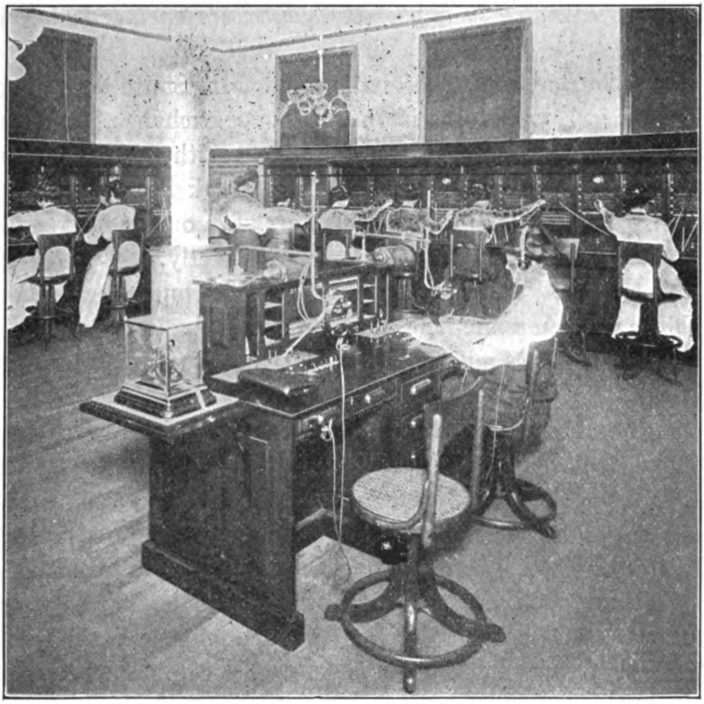


FIG. 94.—Operating Room in a Small City Exchange.

one for a trunk line. (The operation of the trunk line will be explained later.)

Should Mr. Smith be calling Mr. Jones, whose line is also on the Audubon exchange, the operator can make the connection directly by inserting the other plug of the pair at the top of the switchboard into the hole which marks the termination of Mr. Jones' line and which may be distinguished by the number it bears.

Operator A can be called only by those subscribers on the Audubon exchange whose numbers are from 1 to 50. She can, however, call directly any of the subscribers on the Audubon exchange.

Suppose, on the other hand, that Mr. Smith is calling Mr. Harper, whose line is on the Rector exchange. In this case, it is necessary for operator A to use the trunk line in order to make the connection. The trunk line is the line which connects the various exchanges with one another, and has nothing to do with the subscriber directly.

Operator A, in this case, inserts the second plug of the pair in the trunk line hole, the first plug being in the answering jack of Mr. Smith's line. Thus the trunk line operator is called. Operator A gives her Mr. Harper's Rector exchange number, and she then connects operator A with one of the Rector exchange operators. It does not matter which Rector operator is given the call, for just as operator A can call any subscriber on the Audubon exchange, so can any Rector operator call any subscriber on the Rector exchange.

In this case it may be assumed that the trunk line operator knows that operator B on the Rector exchange is the least busy and, consequently, gives her the call. Operator B then "plugs in" Mr. Harper's number at the top of her board and thus through operator A, the trunk line operator, and operator B, Mr. Smith on the Audubon exchange is connected with Mr. Harper on the Rector exchange. In very large cities there may be an operator for each exchange who merely receives calls from the trunk line operator and apportions them to the operators on her exchange. In such case, the trunk line operator would call this apportioning operator instead of calling operator B directly.

263. The Supervising Lamps.—There is, on the operator's switchboard, a supervising lamp associated with the calling plug as well as with the receiving plug. When a subscriber calls the operator, the supervising lamp under the receiving plug lights, as before noted. When the operator "plugs in" and connects herself with the calling subscriber, that lamp is extinguished. When she "plugs in" at the calling hole, the second supervising lamp lights, and remains lighted until the party called answers. So long as these two lights are extinguished, the operator knows that the subscribers are using the line. When the subscribers replace their receivers on the hooks, the lamps relight.

264. The Listening Cam.—The listening cam is a small key on the switchboard by means of which the operator puts herself in connection with a subscriber after having "plugged in" at his answering jack. After connecting two subscribers the operator closes her listening key and thus shuts herself off from their conversation. Were it not for this device, every conversation would, perforce, pass through the operator's ears.

265. Cables and Distributing Frames.—Wires enter and leave the telephone exchange building in the form of cables (Fig. 95). A cable is composed of pairs of twisted copper wires, insulated with spiral wrapping and enclosed in a lead casing.

Within the exchange these cables are supported by two frames; the main distributing frame and the intermediate distributing frame (Fig. 96). The main distributing frame allows the entering wires of the subscribers' lines to be changed

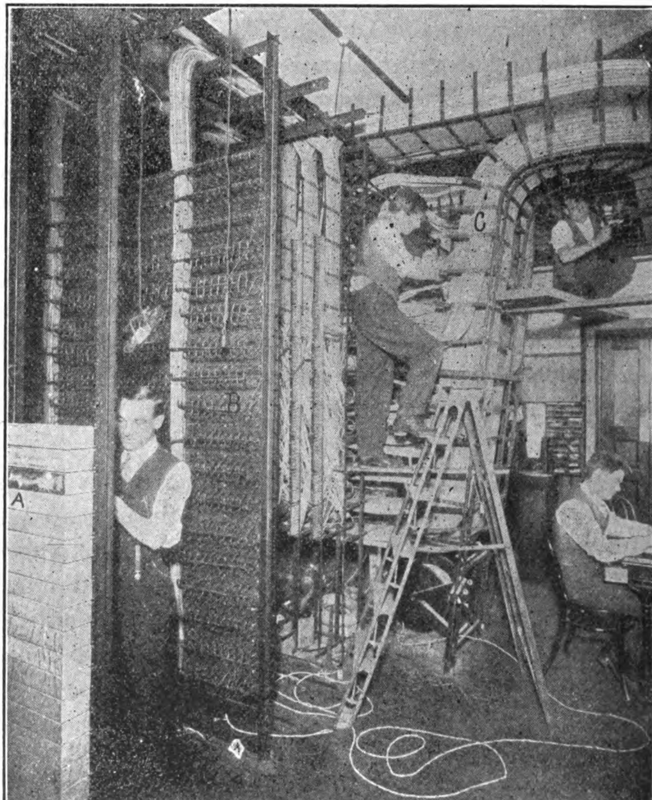


FIG. 95.—Terminal Room in an Exchange.
(*a*) Relay rack. (*b*) Intermediate frame. (*c*) Cables to switchboard

without changing the telephone number. The intermediate distributing frame is so constructed as to permit any call to be answered at any portion of the switchboard. Thus no individual operator need be overloaded with calls.

266. Construction Work.—The work of telephone company construction crews is almost entirely outdoors. The linemen work in gangs under a foreman, and generally not far from their homes. During the summer, however, they travel about putting up through lines of poles and trunk

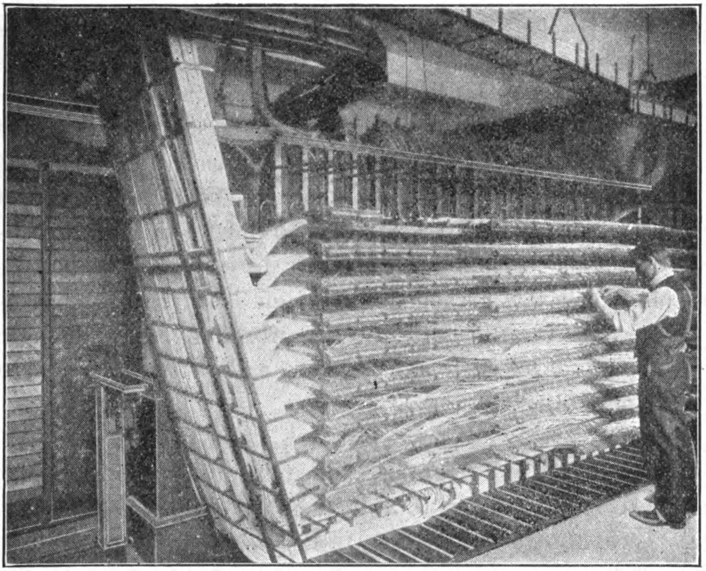


FIG. 96.—Intermediate Distributing Frame. Showing subscribers' lines spread on racks. From the racks the lines run to the switchboard.

wires. If the men cannot find accommodations in some house during such times, they camp out. After a great storm, linemen are called from every section with all possible speed to repair any damage which may have been done.

A large number of men are employed in central office repair work, testing the wires, installing telephones in houses and offices, and making inspections.

267. The Story of the Telegraph.—Samuel F. B. Morse, an American inventor, holds the most important place in the development of the telegraph. Although Wheatstone and Cooke in England occupied a distinct place in this field, the telegraph system invented by Morse in 1837 is the one that is almost universally used, except for railroad work, to which the needle instruments of the Englishmen are peculiarly adapted.

Morse was assisted in the practical and mechanical development of the telegraph by Alfred Vail, an uncle of Theodore N. Vail of more recent telephone and telegraph fame. It was, moreover, through the financial assistance of Alfred Vail's father that Morse was able to put up the first experimental line. The telegraph today, in connection with the cable which was perfected some time later, reaches practically every civilized portion of the world, gives employment to thousands of men and women, and renders service to millions of others.

268. Parts of Telegraph.—The telegraph is an instrument used to send messages to a distance by means of electricity. It is usually worked by electrical current or by an electromagnet. The instrument is made up of four separate parts: (1) the generator, or battery to generate the electricity; (2) the conductor, or insulated wires by which the electric current is carried to any distance; (3) the transmitter, or instrument which regulates the flow of electricity; and (4) the register, which records the signals. The generator is made up of one or more voltaic batteries, each of which is composed of a number of cells connected in a series. The Grove cell was formerly much used and then the Daniell cell; but a cell called the gravity cell, which is as good as either of these two and a great deal cheaper, is now commonly employed. To send a message a long distance a stronger battery is needed than to send one a short distance. A battery can be made stronger by adding more cups or cells to it.

269. Steps in Telegraphing.—To telegraph from one place to another it is necessary to stretch between the two places a wire, over which the electric current may flow. Iron wire is generally used, because it is stronger and cheaper

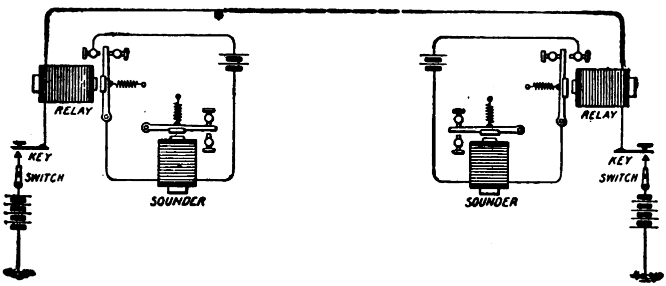


FIG. 97.—A Telegraph System.

than copper wire. In the United States, wires are usually stretched upon high poles. As the electricity would run down the poles to the earth if the wire touched them, the wire is fastened to a glass knob. Glass being a non-conductor, the electricity is thus insulated and flows freely between the places connected by the wire.

Figure 97 shows the actual arrangements of a telegraphic system. If the operator at one end of the line desires to send a message he opens the switch connected to his key, which is always kept closed except when sending a message. He then begins to operate his key. Every time he touches his key he closes the circuit and the electricity flows through the line causing his own sounder and the one at the other end to click. Because of the great resistance to the current, the electricity by the time it reaches the end of the line is so feeble that it is necessary to place in the local circuit a battery and a second electromagnet, called a sounder. On the main line there is another electromagnet, called a relay. This has a greater resistance, due to its fine wire, than the sounder, which has a small resistance.

When the telegraph operator at one end of the line presses on the key so as to close the circuit, the magnets at the other end of the line become magnetic, the end of the lever is attracted and drawn down by the magnets, the other end is pushed up and the steel point presses against the paper and dents a line in it. This line is made so long as the key is kept pressed down in the sending office.

As soon, however, as the sending operator takes his fingers from the key, the circuit is broken. The magnets in the register at the receiving station then lose their power on the lever, the end drops down, and a blank space is left on the paper. When the operator in the sending station taps on the key so as to close the circuit only for an instant, a dot or very short line is made on the paper in the receiving station as shown on the table below. By pressing on the key a little longer time, or not at all, the operator can make dots, lines, or blank spaces on the paper in the receiving station. By putting together these lines and dots in different ways all the letters of the alphabet may be made, so that any kind of a message may be sent.

The alphabetical application of the dot-and-dash code invented by Morse was made in 1837 by Alfred Vail, though it is universally known as the Morse alphabet. This alphabet, which is used in the United States and Canada, and in a modified form all over the Continent of Europe, is made up wholly of dots and lines, the letters most used having the simplest symbols.

Morse Alphabet

American				*International*			
a	- —	n	— -	a	- —	n	— -
b	— - - -	o	- -	b	— - - -	o	— — —
c	- - -	p	- - - - -	c	— - — -	p	- — — -
d	— - -	q	- - — -	ch	— — — —	q	— — - —
e	-	r	- - -	d	— - -	r	- — -
f	- — -	s	- - -	e	-	s	- - -
g	— — -	t	—	f	- - — -	t	—
h	- - - -	u	- - —	g	— — -	u	- - —
i	- -	v	- - - —	h	- - - -	v	- - - —
j	— - — -	w	- — —	i	- -	w	- — —
k	— - —	x	- — - -	j	- — — —	x	— - - —
l	——	y	- - - -	k	— - —	y	— - — —
m	— —	z	- - - -	l	- — - -	z	— — - -
				m	— —		

Morse Numerals

1	- — —	6	- - - - - -	1	- — — — —	6	— - - - -
2	- - — - -	7	— — - -	2	- - — — —	7	— — - - -
3	- - - — -	8	— - - - -	3	- - - — —	8	— — — - -
4	- - - - —	9	— - - —	4	- - - - —	9	— — — — -
5	— — —	0	——	5	- - - - -	0	— — — — —

Morse Punctuation, etc.

Period,	- - — — - -	- - - - - -
Comma,	- — - —	- — - — - —
Interrogation,	— - - — -	- - — — - -
Exclamation,	— — — -	— — - - — —
Colon,	— - — - -	— — — - - -
Semicolon,	- - - - -	— - — - — -
&,	- - - -	

Questions

1. How long has the telephone been used?
2. Who invented the telephone?
3. Explain the principle on which the telephone is based.
4. Describe the steps in telephoning.
5. Describe the construction of a switchboard.
6. Who invented the telegraph?
7. Describe a telegraph instrument.
8. Describe a telegraph system.
9. Explain the steps in telegraphing.
10. State some of the advantages of the telephone and telegraph.

CHAPTER XX

SCIENCE UNDERLYING MECHANICAL DRAWING SUPPLIES

270. Mechanical Drawing—Supplies Required.—Mechanical drawing plays a large part in directing the performance of all industrial operations. It is the guiding hand, so to speak, which directs the erector in the shipyard, the machinist in the shop, and the builder of bridges at the river. Therefore, a knowledge of the principles of science underlying its application is as important as a knowledge of the science of the trade.

In making a mechanical drawing, certain supplies are necessary. The first requisite is a pencil, properly made; the second, a paper of suitable quality for the work in hand; and the third, an eraser of just the right degree of hardness. With these simple yet important tools, together with a compass and ruler, the draftsman makes his working drawing. The tracing of the pencil-made drawing is the next step in the process. For the purpose of tracing, tracing cloth and paper are necessary, as well as a special kind of ink, called India ink. After a tracing has been completed, the making of the blue-print comprises the final step. A blue-print is used because if it is lost, another one can easily be made, whereas an original drawing can be made only at the cost of much time and money.

271. The Lead Pencil.—A lead pencil consists of a stick of graphite in the center of a cylindrical piece of red cedar wood. This particular type of wood is selected because it can be cut easily and smoothly with a penknife. The ease with which it can be cut is due to the closeness of its grain and the softness and tenderness of its fiber. The graphite used in lead pencils is of the highest grade. It is mined in Ceylon and Mexico and comes from the earth in the form of large, crude stones.

This crude graphite is crushed to a powder in a large rolling machine. A smooth clay, called a binding agent, is added to the graphite to hold the particles together. The ratio of the clay to the graphite determines the hardness of the "lead" in the pencil; increasing the proportion of clay makes the pencil harder. The mixture is washed to remove all particles of grit and other impurities.

To make the pencil rods, or "leads," the mixture of graphite and clay is placed in the bottom of a steel cylinder which contains dies of the proper gauge for the thickness of the "lead." Under enormous pressure the mixture is forced through the dies and emerges like a cylindrical shoe-string at the rate of 170 ft. per minute. This cylindrical string is straightened and dried, cut to pencil lengths, and placed in a crucible to harden. The heat toughens and gives the proper temper to the rods.

Six pencils are made at one time. The red cedar wood, already mentioned, is cut into slats. Each slat is slightly longer than a pencil, slightly thicker than half a pencil, and as wide as six pencils. The slat is well seasoned—kiln-dried—and passed through a planing and cutting machine. This machine planes the surface of the slat smooth and cuts in it six lengthwise grooves. Into each of these grooves a piece of lead is inserted by hand. Then another slat, similarly grooved and planed, is fitted over the slat into which the lead has been placed. This second slat is coated with glue before being fitted over the lead, so that the two slats hold fast after being brought together. After the glue has set thoroughly, the slats are fed lengthwise into another machine which separates their six parts into six pencils.

Since there is a demand for pencils of every grade, from the soft pencil of the news editor to the hard pencil of the draftsman, pencils are made in sixteen grades of hardness. These grades vary widely enough to meet every demand.

272. Drawing Paper.—Paper is a fabric or kind of cloth composed of numerous fibers or threadlike filaments, the rough edges of which cause them to stick together. Drawing paper and other fine grades of paper are made from linen rags. The first step in the process of manufacture is to place the rags in a vat filled with water and to beat and tear them until they are transformed into paper pulp, a substance which looks very much like cottage cheese. The pulp is then taken to another vat where it is mixed and churned with more water until in its more diluted form it becomes of the thickness or consistency of cream. This creamlike substance is then allowed to flow over the screen of the paper machine on which it is transformed into long rolls or sheets of paper.

The paper machine consists of a fine screen of wire about 6 ft. wide and 200 or more feet long. The screen runs over rollers on the principle of an endless belt. The creamlike pulp is allowed to flow on one end of the traveling screen which vibrates as it moves along. The water in the pulp gradually drains through the screen on which the fibers settle evenly in the form of a porous sheet, like very spongy blotting paper. As the screen travels along it passes between rollers which compress and squeeze out more of the water from the creamy substance, making the sheet of paper less spongy. After the pulp has been pressed into a sheet, the screen passes over hot rollers for the purpose of drying the wet sheet of paper. The distance which the paper pulp travels on the screen before it is transformed into paper is 100 ft. or more. The thickness of the paper depends upon the rate at which the pulp is allowed to flow on the traveling screen. "Hot pressed" paper is paper to which the extreme pressure is applied while the pulp is still hot, while "cold pressed" paper is not subjected to pressure until the pulp is cold. The former type of paper is of the highest grade.

273. Rubber Erasers.—Rubber erasers are used extensively in drawing to remove pencil and ink marks. They are made of rubber combined with sufficient sulphur to give the proper hardness. Other materials are added in varying proportions to give different degrees of softness and suppleness. It is by these qualities that the different grades of erasers are distinguished.

FIG. 98.—Tapping Rubber Trees.

The process of obtaining the rubber used for erasers, and for many other purposes as well, is a most interesting one. Rubber is obtained from the sap of certain tropical trees. A series of slanting cuts made in the bark allows the sap to run out (Fig. 98). A cup is hung at the bottom of the tree and gradually the milky sap runs into it. The contents of a number of these cups are then poured into a large vessel. A wooden paddle is dipped into the sap and when withdrawn is held over a fire made from palm nuts. The heat from the thick smoke hardens the sap. This process is repeated many times until a ball, called a biscuit (Fig. 99), is formed. The paddle is then withdrawn from the biscuit and the biscuit is ready for market. After coming to the market as balls or biscuits, the rubber is purified and made into sheets. Because of its softness and sticky nature, this crude rubber is useless for erasing and consequently must be subjected to a hardening process called vulcanization. This process consists in subjecting the rubber to supreme heat. After being vulcanized the rubber is suitable for erasers and other commercial products.

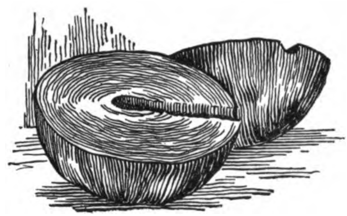


FIG. 99.—Rubber Biscuit.

274. The Working Drawing.—The drawing from which the blue-print is made is called a working drawing. The method of preparing it is simple. The draftsman merely looks squarely at the object and draws the outline of it. By changing the point of view, different views of the object may be obtained. The views usually drawn are of the front, top, and side. To show the interior, additional views may be drawn of the object in section.

The front view of an object is the view obtained by looking squarely at it from the front. This view is often called the elevation. The top view is the view obtained by looking squarely at the object from the top. This view is often called the plan. The side view is the view obtained by looking squarely at the object from the end. This view is often called the profile view or the end elevation.

275. Distinction between Working and Perspective Drawings.—A perspective drawing is one that portrays an object as it appears to the eye from one point of view. The rails of a car-track, for instance, appear to converge. The parallel lines of any object appear to the eye to converge in like manner, and a perspective drawing will show this feature. Any picture or photograph furnishes an example of the perspective drawing.

The working drawing, on the other hand, is designed not to present a picture, as is the perspective drawing, but to indicate all the various parts of the object together with their dimensions. In other words, a working drawing is really three distinct drawings of the same object, each of which is drawn from a different point of view. A working drawing of a cube, for instance, would comprise three drawings exactly alike, because a cube presents the same appearance whether viewed from the front, top, or side. A working drawing of a book, on the other hand, would present drawings of three rectangles, each of which would have different dimensions.

This distinction between a perspective and a working drawing is an important one, but once made clear, is very simple. A perspective drawing is the result of what the eye sees, while a working drawing is the result of what the ruler and compass tell.

276. Tracing Cloth.—Tracing cloth consists of muslin cloth heavily sized and pressed to make it translucent and smooth. There is some oil in the sizing preparation, and consequently before the cloth is used, whiting or chalk is rubbed into it to absorb the oil.

277. Tracing Paper.—Tracing paper is made from tissue paper of an even texture, and possesses long and strong fibers. This tissue paper is treated with oil and solutions of resins and varnishes.

278. India Ink.—India or Chinese ink is always used in making the tracing of a mechanical drawing, because of its permanence, its distinct blackness, and because it is waterproof. Moreover, India ink, because of its heavy composition, is less liable to "spread" and cause a blot. It is a mechanical mixture of pure, dense lampblack and a solution of gelatin, gum, or agar-agar. (Agar-agar is a gelatinous substance obtained from seaweed.) This mixture forms a black paste which is dried and pressed into cakes. It was formerly the custom to use it in this form, but at the present time it is easily obtainable in the liquid form ready for use.

Should the draftsman, however, buy India ink in the cake form, he can easily prepare it for use by shaving off a portion of the cake into water and stirring the mixture thoroughly.

279. The Blue-Print.—When a mechanic in the shop receives a working drawing, it is in the form of a blue-print, a blue paper on which the lines of the drawing appear in white.

A specially prepared paper, known as blue-print paper, is used for making blue-prints. This paper is prepared by the application of a chemical solution of red prussiate of potash, water, citrate of iron, and ammonia. The solution is applied with a camel's-hair brush and is then allowed to dry. After drying, the paper assumes a greenish yellow color.

The blue-print itself is made in the following manner. The tracing of the drawing is placed over a piece of blue-print paper. The two are then put into a frame constructed similarly to an ordinary picture frame. The frame is then exposed to the direct sunlight. The rays of the sun pass through every portion of the tracing paper except the black lines of the drawing, and act upon the chemical solution of the blue-print paper in such a way as to turn to a yellow color the entire paper, with the exception of that portion beneath the black lines. The blue-print paper is then dipped into water, which changes it, with the exception of the lines, to a blue color. The lines become white and are, of course, an exact reproduction of the tracing.

Questions

1. Describe the composition and manufacture of a lead pencil.
2. What constitutes a good grade of drawing paper?
3. Explain the composition of an eraser. What qualities must an eraser possess?
4. How is rubber obtained and refined?
5. What is a working drawing?
6. What is the difference between a working drawing and a perspective drawing?
7. What is tracing cloth?
8. What is tracing paper?
9. Describe the composition of India ink. Why is it used for drafting purposes?
10. What is a blue-print? How is it made?

CHAPTER XXI

STRENGTH OF MATERIALS

280. Need of Knowledge of Strength of Materials.—Mechanics are often called upòn to determine the size of rod or beam required to support a certain weight or force. Not all pieces of material have the same strength. The strength of any piece of material depends upon the nature of the material (cohesion of the particles composing it) and upon the position, shape, and bulk of the piece. Therefore, it is absolutely necessary to know something about the properties and laws governing the strength of materials used in industry. When a force acts on beams, structures, or bodies of any kind, it may be considered as weight, and may be measured in pounds.

281. The Effects of a Load of Force on a Body.—When a body is supporting a load, a force is acting on it. This force will produce a change, perhaps not very noticeable, in the form of the body. Unless this load is so great as to cause a break or fracture, the elasticity, which has previously been defined as the tendency of the particles of a body to unite, or return to their original positions, will support the load. *The forces of the body resisting the pull or pressure of the load are called stresses. The change of shape of the body producing these stresses is called a strain.* To illustrate: The molecules of a piece of iron are held together by the force of cohesion, which is stronger in iron than in some other bodies. This force must be overcome in order to change the condition, form, or size of the iron bar, or to break it into parts. When the iron bar is supporting a load, the resistance which the bar offers to the pressure or pull of the load that tends to overcome the force of cohesion is called a stress. If the load is not very great, the particles of iron may be separated while the iron is supporting the load, but they will return to their original position as soon as the load is removed.

The elasticity of different substances varies. The degree of elasticity of the various materials is found by measuring the forces required to produce equal changes in four pieces of the same material of like dimensions. In case the load is very great and the particles of iron are separated to such an extent as not to return to their original positions when the load is removed, the structure of the iron is more or less broken down. This is very clearly shown by the change in appearance of polished surfaces of a metal in a stressed condition. The bright surface suddenly becomes dull when the stress exceeds the amount which affects the permanent structure. Another example of stress is seen when a large casting is lifted by a crane or derrick. The chains supporting the casting are then said to be "in stress" or "stressed."

282. Different Kinds of Stresses.—Stresses may be divided into the following five classes according to the action of the force producing them:

(*a*) Tension (pulling stress) usually called tensile stress.

(*b*) Compression (crushing stress) usually called compressive stress.

(*c*) Shearing (cutting stress).

(*d*) Torsion (twisting stress).

(*e*) Flexure (bending stress).

Tension, or pulling stress, *is the force that overcomes external forces that tend to stretch a body.* A rope or wire supporting a load is an example of tensile stress. The rope or wire is subjected to a tensile stress of the weight of the load.

Compression, or crushing stress, *is produced when external forms act so as to compress a volume or any supporting body.* When an engine rests upon rails, the rails are subjected to the compressive stress of the weight of the engine.

Shearing, or cutting stress, *is produced when forces tend to cause the particles of one section to slide over the section of an adjacent body.* When a bolt is in tension the head of the bolt is subjected to a shearing stress tending to strip the head from the shank of the bolt.

Torsion, or twisting stress, *is produced when forces tend to twist.* A rotating shaft is obliged to resist a twisting force.

Flexure, or bending stress, *is produced when forces tend to bend.* A floor timber in a house has to resist the bending force that tends to break it.

283. The Effect of Strains.—Since a strain is the lengthening due to the action of a stress it is measured in fractions or decimals of an inch.

To illustrate: If a bar of steel, such as a piston rod, has been stretched or lengthened $\frac{1}{64}$ in. by the stress caused by the weight of the driving box, the strain in the steel rod is $\frac{1}{64}$ in.

If a weight is hung from a beam resting on two supports A and B as in Fig. 100, the beam is a lever of the second class. If we consider the pressure on the support A as the power and the pressure on the support B as the fulcrum, we can easily find the power if we know the weight. Then knowing the power, we can find the pressure on support B, provided we know the distance of the weight from one end and the distance between the supports. It makes a difference which support we consider to be the fulcrum.

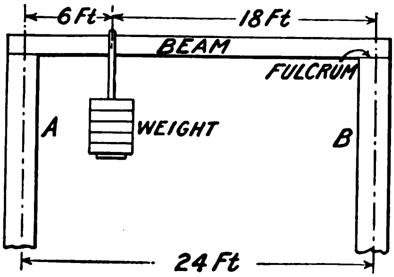


FIG. 100.

If the weight were hung from the center of the beam, it is plain that each support would carry one-half of the load. But if, as shown in the figure, the weight is hung a distance equal to one-fourth the length of the beam from A, the support A will bear three-fourths of the weight and the support B will bear one-fourth.

EXAMPLE.—Suppose instead of one weight, we had two weights hanging on a 1000-lb. steel beam as shown in Fig. 101. What will be the pressure or weight on supports A and B? Consider one end of the beam, A, as the fulcrum. Then the moment of the 6-ton weight will be: 6×6 or 36, and the moment of the 9-ton weight will be: 9×12 or 108. The moment of W, the weight supported at B, will be $18 \times W$. Then since the sum of the moments of the weights will be equal to the moment of the weight supported at B, we will have: $36 + 108 = 18 \times W$, or $W = 8$ tons, for the weight supported at B. But the beam itself weighs 1000 lbs., one-half of which is supported at A and the other half at B. Adding this to W makes 8 tons plus ¼ ton, or 8¼ tons for the total weight supported at B. The weight supported at A will, of course, be the amount left after subtracting the weight at B from the total weight:

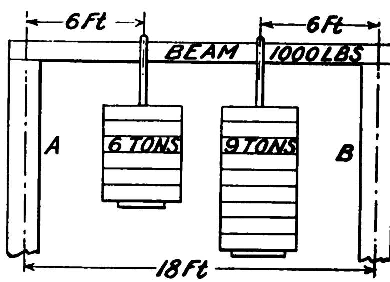


FIG. 101.

6 tons + 9 tons + ½ ton = 15½ tons, total weight
and 15½ tons − 8¼ tons = 7¼ tons, the weight supported at A

284. Bending Force.—When a beam is bent, the forces at any point tend to pull the fibers apart in the upper part and push them together in the lower part, while the portion between the two is subject to less stress. The nearer the center the force acts, the less becomes the stress, until finally the beam or neutral axis is reached. At this point the bending stress is zero. Accordingly structural steel beams are made with flanges (reinforcements) at the top and bottom to take care of the bending stresses. These flanges are connected by a plate called a web. The material of the web is subject to a shearing stress—the maximum of which occurs at the support and the minimum where the bending is greatest.

Wood offers the greatest resistance when placed in an upright position. A short post is stronger than a long one of the same section, since the stress in the short post is due merely to compression, while in the long post there is apt to be bending. By applying a stay or projection to the part about to bend, firmness may be given to the support.

A fluted column offers a greater resistance to a bending force than a smooth one; therefore it is stronger. When a beam is supported at both ends, it is twice as strong as one-half its length supported only at one end. Of two beams with the same cross-section area, the longer beam is the weaker.

285. Measurement of Stresses.—Stresses are measured in pounds per square inch.

For example, if we have a bar in tension there is a stress distributed equally all over its cross-section. In other words, if the bar is 1 in. square, each particle of that square inch will bear the same stress or load. If a bar is 2 in. square then its area is 4 sq. in. and each inch of this area has an equal load or stress acting upon it. The pounds of stress per square inch on a piece in tension or compression is called the *unit stress*.

If a bar of 4 sq. in. cross-section is under a total pull of 36,000 lbs., the unit stress is then one-fourth of 36,000 lbs., or 9000 lbs. per square inch.

When a piece is stressed beyond the elastic limit and consequently breaks, we say that it has been stressed to its *ultimate strength.* The ultimate strength or breaking stress is a unit stress and is always given in pounds per square inch. *The ultimate strength is that unit stress which is found just before rupture and is the greatest unit stress the piece will bear.*

Suppose we find, by testing, that a bar of wrought iron 2 in. square breaks under a tension of 240,000 lbs. What is its ultimate strength? Since the sectional area is 4 sq. in. and the total stress which it took to break the bar was 240,000 lbs., the stress per unit of area will be 240,000 ÷ 4, or 6000 lbs., the ultimate strength.

286. The Stress of Elongation.—Ultimate strength and the unit of ultimate elongation are closely related. *The ultimate elongation is a strain produced in a unit of length by a stress equal to the ultimate strength of the material.* In other words, the elongation of a test piece 1 in. long just at the point of rupture is its ultimate elongation. A rule for finding the ultimate elongation is: *Divide the total elongation of the piece at rupture by the original length.*

In making tests of materials, it is often well to record the percentage of elongation. This is nothing more than the ultimate elongation expressed in per cent.

Suppose we find that a 50-in. rod elongates $\frac{1}{2}$ in. under a certain load. The unit of ultimate elongation will then be $\frac{1}{2} \div 50$ or $\frac{1}{100}$ in. The per cent of elongation will be $\frac{1}{100}$ in. expressed in per cent. If the ultimate elongation is expressed as a decimal the same rule will hold; that is, simply multiply the decimal by 100 and call the answer per cent. For example, if an ultimate elongation figures .025 in., multiplying this by 100 will give us 2.5%.

In figuring the ultimate elongation of a test piece broken in the machine, it does not matter what the sectional area of the piece is. All we need to know is the increase in length over the original length. This increase should be divided by the original length. The quotient will be the ultimate elongation of the tested piece.

287. The Stress of Compression.—Compression is one of the most common of all stresses and everywhere things are seen undergoing compression. The foundation walls of the shop, the legs of the table, the foundation of the lathe, the shaper, the drill press, or the planer, the posts or columns that support the shop roof—are all in compression.

If the length of a piece is not more than five times its least transverse dimension, the laws of compression are similar to those of tension, and the strain is proportional to the stress until the elastic limit has been reached. Upon reaching the elastic limit, the strain increases more rapidly than the stress, as in the case of tension.

288. Testing Laws Applicable to Materials.—Repeated experiments with materials in testing machines and in practice have proved that there are certain laws which always hold true. These laws may be enumerated as follows:

I. When a body is subjected to a small stress a small strain is produced. When the stress is removed the body springs back to its original shape.

II. Within certain limits the change of shape, or strain, is directly proportional to the stress producing it. This is the same as saying that when a tensile force is gradually applied to a bar it elongates the bar and that up to a certain limit this elongation is proportional to the force.

For example, if we take a bar of wrought iron 1 sq. in. in section and subject it to a tension of 5000 lbs., it will be found to elongate .02 in.; if a tension of 10,000 lbs. be applied the elongation will be .04 in.; if a tension 15,000 lbs. be applied it will be .06 in.; for a tension of 20,000 lbs., .08 in., and for a tension 25,000 lbs., 10 in. When, however, the next 5000 lbs. is added, making a total stress of 30,000 lbs., it will be found that the total elongation is .14 in., which shows that the elongation is increasing more rapidly than the stress.

The point at which the elongation begins to increase more rapidly than the stress is called the *elastic limit.*

III. When the stress is sufficiently great a strain is produced which is partly permanent; that is, the body does not spring back entirely to its original shape when the stress is removed. This lasting part of the strain is called a set, and when a body is strained sufficiently to give it a permanent set it is said to be strained beyond its elastic limit.

IV. When a still greater stress is applied to a body after the elastic limit is reached, the strain rapidly increases and the body is finally ruptured or broken. Many materials, such as iron and steel, after the elastic limit is reached, act very much like molasses candy. When pulled they stretch and draw down thinner and thinner until finally they break apart. The machine designer must remember that the stress should never exceed the elastic limit of the material, because when a bar is thus stressed it is very unsafe and is likely to break.

V. A force acting suddenly, such as a sledge hammer blow, is called a shock and causes greater injury than the same force gradually applied, because of the velocity or speed of the blow and the effect of its sudden application. Familiar examples of steel subjected to repeated stresses and shock are found in the piston and connecting rods of a locomotive. These parts are always made heavier than would be necessary if they were to remain stationary.

289. Tables of Strength of Materials.—The first thing to know in determining the size of beam or timber is the weight or force load the timber is to support and the location of the load.

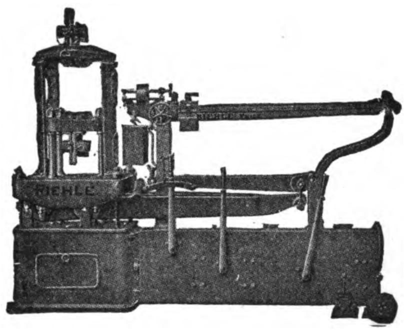


Fig. 102.—Testing Machine.

Very careful experiments have been made in testing laboratories (Fig. 102) to determine the tensile or pulling strength of materials under different conditions. The results of these experiments have been compiled and published in tabular form, as shown below. Mechanics and contractors can find the strength of any material of any size by looking in the table.

Average Tensile Strength of Materials in Pounds per Square Inch

Metals

Antimony	1053
Aluminum: Castings	15000
Sheet	24000
Bars	28000
Brass: Yellow	26880
Bronze: Cast: Lunkenheimer	34000
Delta metal: Cast	44800
Rolled	67200
Gun-metal	32000
Phosphor	40000
Manganese	62720
Tobin	78500
Copper: Cast	22400
Sheet	30240
Wire	40000
Cast Steel: Lunkenheimer	80000
Gold	20384

Average Tensile Strength of Materials in Pounds per Square Inch—*Continued*

Iron: Cast:	18000	Silver: Cast	40000
Lunkenheimer	25000	Steel: Cast	60000 to 80000
Wrought	45000	Forgings	60000 to 95000
Lead: Cast	1800	Tin: Cast	3360
Rolled Sheet	3320	Zinc: Cast	3360
Platinum Wire	53000	Sheet	15680
"Puddled" Semisteel: Lunkenheimer	35000 to 42000		

Woods

Ash	11000 to 17000	Locust	20500 to 24800
Beech	11500 to 18000	Maple	10500 to 10584
Cedar	10300 to 11400	Oak: White	10253 to 19500
Chestnut	10500	Pine: White	10000 to 12000
Elm	13000 to 13489	Pine: Yellow	12600 to 19200
Hemlock	8700	Spruce	10000 to 19500
Hickory	12800 to 18000	Walnut: Black	9286 to 16000

In designing a piece of machinery, the first thing to find out is the strength of the metal or material of which it is to be made. The technical meaning of "strength" is the power of a body to resist force and in mechanics the word "body" means any solid object. The word "force" means a push, a pull, a twist, or a cut.

290. Weight of Metals per Cubic Inch.—It is often necessary in designing a machine to know the weight of its parts, and any good engineer's handbook will give the weights per cubic inch of all the metals. Not all kinds of iron weigh exactly the same, since different processes of manufacture use different amounts of the materials of which it is made. The same thing is true of all metals, so only the approximate weight is given in the following table which shows some of the metals used in construction and their approximate weights per cubic inch.

Metal	*Wt. per Cu. In.*
Cast Iron	.260
Wrought Iron	.281
Steel	.282
Copper	.317
Brass and Bronze	.307
Lead	.409
Tin	.263
Aluminum	.096

291. Factors of Safety.—In building a machine or a structure of any kind, care must be taken not to subject any part to a stress that would strain it beyond its elastic limit. The usual practice is to divide the ultimate strength of the material by some number depending upon the kind and quality of material and upon the nature of the stress. This quotient is called the factor of safety. *The factor of safety of any material is the ratio of its ultimate strength to the actual stress to which it is to be subjected.*

Suppose the actual tensile stress on a rod 1 in. square is to be 10,000 lbs., and we have found by testing that the ultimate tensile strength of a material of this kind is 70,000 lbs. Then the factor of safety for this material would be

$$\frac{70{,}000}{10{,}000} = 7$$

The rod when stressed 10,000 lbs. will then have a factor of safety of 7.

As has been stated, a force acting suddenly is called a shock and does more damage than the same force gradually applied. This rapidly applied force has been found by tests to be about twice as much as the slowly applied one. Therefore, in designing machinery it is necessary to consider whether the part will be subjected to a steady stress, a varying stress, or a shock, before deciding the proper factor of safety to use.

The table below gives the factors of safety generally used in American practice:

Material	*Steady Stress*	*Varying Stress*	*Shock*
Timber	8	10	15
Brick or Stone	15	25	30
Cast Iron	6	10	15
Wrought Iron	4	6	10
Steel	5	7	10

292. Strength of Chains.—Chains for hoisting weights are made from a good grade of wrought iron, which has a tensile strength of from 40,000 to 48,000 lbs. per square inch. Chains used for raising weights should never be made from steel, as it is not so strong under shock as wrought iron, and does not weld so readily. Because of the possibility of the weld not being as strong as the balance of the link, the strength of the chain is not reckoned as twice the strength of the bar from which it is made. When buying chains in the open market it is advisable to base the computation of strength on the lowest tensile strength of iron used for the purpose, i.e., 40,000 lbs. to the square inch.

The strength of a chain link is 1.63 times the strength of the bar from which it is made. The strength referred to is the breaking, or tensile, strength. It is never safe to strain to anywhere near the breaking point, because every time a piece of metal is strained to a point beyond its elastic limit it is permanently stretched and weakened. For this reason, it is never considered advisable to strain a chain to more than one-half the amount shown by the method given for computing the tensile strength. In other words, the proof test of a chain should be about 50% of the ultimate resistance of the weakest link.

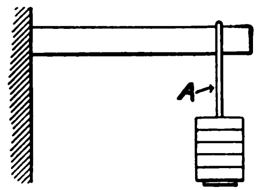


FIG. 103.

If, for example, the tensile strength of a chain made from ½ in. wrought iron is 40,000 lbs. per square inch, the safe working strength may be calculated as follows:

Area = Diameter squared × .7854 = .5 × .5 × .7854 = .19635
.19635 × 40,000 = 7854
7854 × 1.63 = 12,802 lbs. = ultimate breaking strength
12,802 × .50 = 6401 lbs. = proof test, or safe working strength.

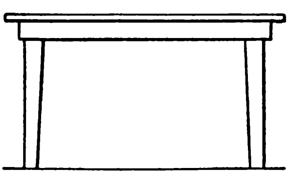


FIG. 104.

Questions

STRESSES

1. What name should be applied to the stress produced at point *A* in Fig. 103?

2. To what stress are the legs of the table subjected in Fig. 104?

3. To what stress is a boiler seam rivet subjected? (See Fig. 105.)

4. What stresses are produced in the main rod of a locomotive when the engine is working?

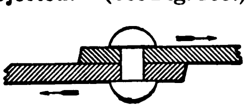


FIG. 105.

5. What stresses are produced in the piston rod of a locomotive when working?

6. To what stress are the stay bolts of a boiler subjected?

7. To what stress are the sheets of a boiler subjected?

8. To what stress does the blacksmith subject a piece of iron when he strikes it a blow with his hammer?

9. To what stress is the boom of a crane subjected when lifting a load?

Material-Testing

1. What makes one substance stronger than another?

2. What is elasticity of a body?

3. Is it possible to twist, bend, or stretch a body? How may each of these actions take place?

4. What is meant by a cross-section?

Problems

Stresses

1. What is the weight supported at *A* and *B* in Fig. 101?

2. Two men carry a weight of 20 lbs. on a pole, one end of the pole being held by each. The weight is 2 ft. from one end and 3 ft. from the other. How many pounds does each man carry?

Material-Testing

In the following examples, 271,000 is the breaking load.

1. A test piece 8 in. long between marks and $1\frac{1}{2}$ in. square shows an ultimate strength of 40,000 lbs. per square inch. What is the total load required to break it?

2. What is the ultimate elongation in the above test if the elongation of the whole piece is $\frac{1}{32}$ in.?

3. The breaking load in a tension test is 300,900 lbs. If the specimen is $1\frac{1}{2}$ in. in diameter, what is the ultimate strength?

4. A bar 8 in. between marks is pulled in a testing machine until it measures 8.125 in. just at the breaking point. What is the per cent of elongation?

5. A piece of boiler plate 16 in. long stretches .0125 in. during a test. What is the per cent of elongation?

6. The unit elongation of a piece in tension is $\frac{1}{128}$ in. What is its ultimate elongation?

7. If a cast iron bar $1\frac{1}{2}$ in. $\times$ 2 in. breaks under a tension of 60,000 lbs., what tension will break a bar of the same material $1\frac{1}{4}$ in. in diameter?

8. A bar of wrought iron $2\frac{1}{2}$ in. in diameter ruptures under a tension of 271,000 lbs. What is its ultimate strength?

Factor of Safety

For convenience in working the following problems we will use values given in the table below, unless otherwise specified. These are average values which have been established by actual test.

Material	*E. L.*	*U.T.S.*	*U.E.*	*U.S.S.*	*U.C.S.*
Brick.........					2,000
Stone..........					6,000
Timber.........	3,000	10,000	.015	3,000	8,000
Cast Iron.......	6,000	20,000	.005	20,000	90,000
Wrought Iron...	25,000	55,000	.20	50,000	55,000
Steel...........	50,000	100,000	.10	70,000	150,000

E.L. = Elastic limit
U.T.S. = Ultimate tensile strength
U.E. = Ultimate elongation
U.S.S. = Ultimate shearing strength
U.C.S. = Ultimate compressive strength

The above is given in pounds per square inch, except "ultimate elongation" which is given in inches per linear inch, "linear" meaning "inch of length."

1. A piece of steel shows a tensile strength of 85,000 lbs. per square inch, and is used in a bridge where it is subjected to a steady stress of 17,000 lbs. per square inch. What is the factor of safety?

2. If a piece of wrought iron has a tensile strength of 42,000 lbs. per square inch, find the load that would be needed to break, in the testing machine, a piece of the same material $\frac{3}{4}$ in. in diameter.

3. A wrought iron bar $\frac{3}{8}$ in. in diameter is pulled apart at a load of 4970 lbs. What would be the tensile strength of this iron?

4. What would be a safe load for the bar in problem 3 if it were to be subjected to a varying stress?

5. A piece of steel plate with a cross-section ½ in. × 1 in. pulled apart in the testing machine requires a load of 29,600 lbs. What load would a piece with 1 in. cross-section require?

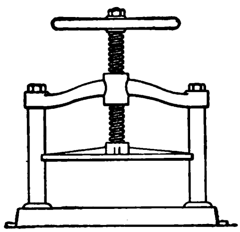


FIG. 106.—Letter Press.

6. A piece of steel ¼ in. square pulled apart in the testing machine requires a load of 6000 lbs. What is the ultimate tensile strength of this material?

7. There are four wrought iron bolts in the press shown in Fig. 106. If the capacity of the press is 10,000 lbs., what size should the bolts be?

8. What must be the diameter of a steel piston rod if the piston is 18 in. in diameter and the steam pressure is 110 lbs. per square inch?

$$\text{Area of piston} = 18^2 \times .7854 = 254.47$$
$$254.47 \times 110 = 27{,}991.7 \text{ lbs.}$$

or, about 28,000 lbs., which is the stress in the rod.

9. What size piston rod must we use if the piston is 22 in. in diameter and the steam pressure is 150 lbs.?

CHAPTER XXII

COMMON FASTENING AGENTS

293. Nails.—The most popular of all fastening agents is the nail. There are two common forms: wire nails (Fig. 107) and cut nails (Fig. 108). The wire nail is made of a cylindrical piece of wire, with one end sharpened to a point, and the other end flattened into a head. The wire nail is valuable because of its holding power and because it will not split the wood. A disadvantage is that it will bend unless hit squarely on the head.

FIG. 107. Wire Nails.

A cut nail, as its name implies, is made from cut iron or steel. It has two flat, parallel sides and edges which taper from the head to the point, thus forming a wedge. When a cut nail is driven into wood, it should enter the wood across and never parallel to the grain. In this way the wedge-shaped nail enters the wood in its strongest direction, the length of the fibers. The holding power of the nail is thus increased and the wood is not split. Because of their clinching power, cut nails are generally used to secure the short hinges of a barndoor. Nails are packed and shipped in kegs (Fig. 110).

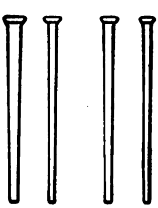


FIG. 108.—Cut Nails.

294. Screws.—There are a great many varieties of screws, but the principal one is the wood screw (Fig. 111), which is made by machine. Wood screws were originally made with blunt points. It was then necessary to make a hole in the wood before the screw could be driven. In the nineteenth century, the invention of the gimlet-pointed screw obviated

FIG. 109.—A Nail Factory. The wire is fed into machines which cut and shape the wire into nails.

the necessity for this preparatory process. When first manufacturing these screws by machinery, the metal was cut out between the threads. This method tended to weaken them, and they frequently broke when driven into wood. Later the method of manufacture which is in use today was introduced. The modern process consists of raising the thread by a system of rolling and compression. An operator feeds into a screw-making machine wire of various sizes, and the machine cuts off the wire at the desired length and turns the screw. The hammer part of the machine then strikes the exposed end of the wire, shaping the head of the screw. This method makes a screw that is strong and that possesses good holding power. Screws are usually made of steel, and are finished in many ways, so that we have on the market blued, brassed, and bronzed screws. Wood screws are

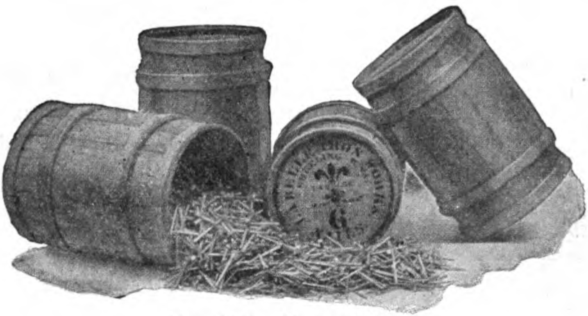


FIG. 110.—Kegs of Nails.

specified by their length, and by a number which is the gauge number of wire from which they are made. They are sold by the gross. The screw is capable of resisting a much greater force than the nail, and is therefore a much better fastening agent. It is, however, more expensive than the nail, and cannot be driven into wood so rapidly.

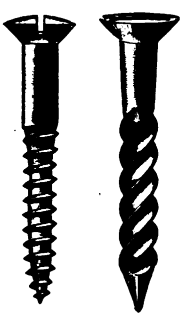
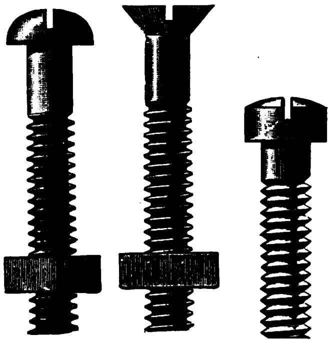


FIG. 111.—Wood Screws.

In addition to being used as fastening agents, screws are also used for communicating motion, as is the case of the lead screw of a lathe or the screw of a jack screw. These screws are produced by a cutting process in which the thread is formed from solid pieces of stock; that is, a single-pointed cutting tool, harder than the stock, cuts it, or it is cut by means of taps and dies. The tap and die are tools of hard steel used to produce internal and external threads respectively.

295. Bolts.—A bolt (Fig. 112) is a special form of screw with a nut attached or screwed on the end to hold it in place. A bolt can be more easily removed than a screw. Many machine shops, especially railroad shops, require a large number of more or less accurately threaded bolts. Bolt machines thread these bolts by means of a revolving die which may be opened at the desired place, permitting the quick withdrawal of the bolt.



(*a*) Round Head (*b*) Flat Head (*c*) Fillister Head
FIG. 112.—Bolts.

296. Parts of Screw Thread.—Certain definitions in regard to the screw should be carefully noted. A screw may be either right-handed or left-handed. Right-handed means that, when turning it into a nut or threaded hole the screw must be turned in the same direction as the hands of a clock. When the thread inclines or slopes so that the under side is nearer the right hand, it is right-handed.

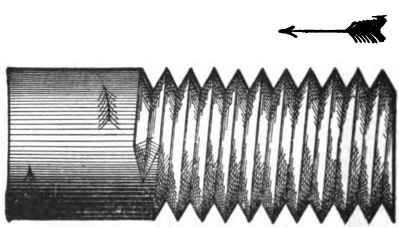


FIG. 113.—Single-Thread Screw.

The thread shown in Fig. 113 is a single thread. Figure 114 shows a double thread. If three threads are wound around the cylinder it would have a triple thread. Four or five threads are sometimes wound around the cylinder, but this type is not often found in shop practice.

The distance from the bottom of one groove to the bottom of the next is called the *pitch*, as *P* in Fig. 114. The pitch is always the distance from one thread to the next, no matter whether it is single, double, or triple thread. The distance that a screw enters a nut or hole for one complete turn is called the *lead*. For a single thread the lead is equal to the pitch, for a double thread the lead is twice the pitch, and for a triple thread the lead is three times the pitch.

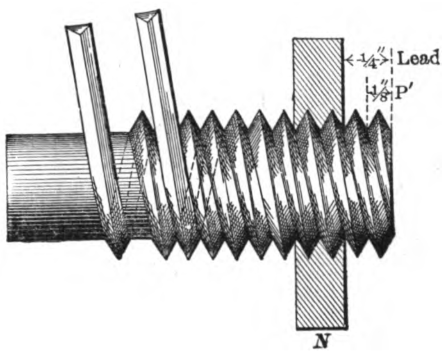


FIG. 114.—Double-Thread Screw.

The point of a thread is the projecting end. The diameter of a thread is the distance measured over it, and is the same as the diameter of the bolt before the thread is cut. The perpendicular distance from the top of the thread to the bottom of the groove is called the depth or height; twice this distance is called double-depth. The root is the bottom of the groove. The diameter at the root is the outside diameter minus the double depth. This is called the root diameter.

297. Measurement of Thread.—Figure 115 shows how to measure the number of threads to one inch of a bolt. In this case the threads are an even 8 to the inch and we see that there are just 8 grooves from the end of the scale to the 1-in. mark. If a thread is an even number per inch it can be easily measured with the scale as described, but when we have fractional threads such as 11½ per inch it is best to measure the threads for 2 in., which would give us 23 whole grooves. Dividing 23 by 2 gives 11½ threads per inch.

When a bolt is less than an inch long, it is necessary to count the grooves in ½ in. and multiply this by 2 to get the threads per inch. The best way to measure threads is with the thread or pitch gauge.

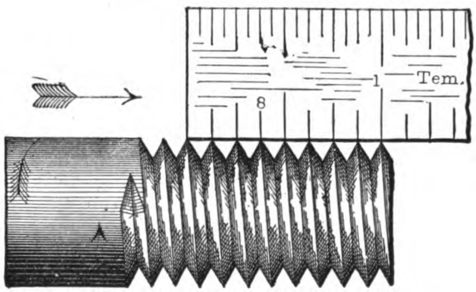


FIG. 115.—Measurement of Screw Threads.

The number of threads per inch is the same on the same sized bolt whether the thread is cut single, double, or triple. If a double thread, 8 threads per inch is wanted, we ask for "8 threads per inch double"; if a triple thread, we say "8 threads per inch triple." Although to avoid any misunderstanding it would be clearer to say for the double thread, "¼ in. lead, ⅛ in. pitch, double thread." There would then be no chance for mistake since we sometimes find an old print which calls for "8 threads per inch double," and means that a double thread, 16 threads per inch is wanted. With single threads the word "single" is not used, as it is understood. All single threads of coarse pitch weaken considerably the bolt or piece which is threaded. For this reason, multiple threads are used. With a double thread the groove is only one-half as deep as a corresponding single thread, and the bolt will advance just as far for one turn as it would if cut single. Figure 116 shows a triple thread with its corresponding single thread dotted.

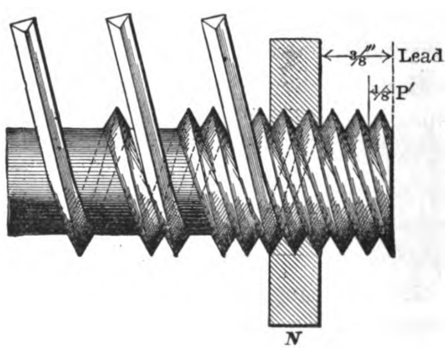


FIG. 116.—Triple-Thread Screw.

298. Depth of Thread.—It is important to be able to find the depth of a thread, for upon this depends the cutting of all threads and the size of all tap drills. By referring to Fig. 117, we see that the depth of the thread is the altitude of a right-angle triangle, since the angles are all 60° and the sides of the V or groove are equal to the pitch. Knowing two sides of a right-angle triangle we can easily find the other, since we know that the square of the altitude of any right-angle triangle is equal to the square of the hypotenuse minus the square of the third side. A simple problem in square root will give the correct figure for the altitude of depth.

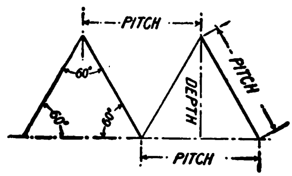


FIG. 117.—Measurement of Pitch of Screw.

An easier way to find the depth of a United States or V thread is to remember that the depth of a United States thread of 1 in. pitch is .65 in. and the depth of a V thread of 1 in. pitch is .86 in. Now if we wish to find the depth of any other thread we simply divide these figures by the number of threads to the inch. For example, we determine the depth of a United States standard thread 13 threads to the inch in this manner—.65 ÷ 13 = .05 in., and the depth of a V thread 4 threads per inch, in this manner—.86 ÷ 4 = .215. When figuring the size to bore or drill a nut or a hole to be threaded, subtract the double depth of the thread from the outside diameter of the thread on the bolt or rod.

299. Kinds of Screw Threads.—There are many kinds of bolts and screws to meet different needs and in order to specify a particular grade of bolt or screw it is necessary to mention:

(*a*) Shape or form of thread.
(*b*) Pitch, or number of threads to the inch.
(*c*) Shape of head.
(*d*) Outline of body, barrel, or stem.
(*e*) Diameter.
(*f*) Direction of thread.
(*g*) Length.
(*h*) Material.

Before 1861 every manufacturer had a peculiar thread that he made for his own work. The result was that the large number of threads caused confusion among engineers and machinists. To avoid this it was proposed to have a standard form; today each country has a standard of its own.

300. Standard Threads.—The two forms of screw threads in use in the United States are the common V thread and the United States standard thread, while the Whitworth screw is the most common in England.

The V-shaped thread (Fig. 118a) is a thread having its sides at an angle of 60° to each other and perfectly sharp at the top and bottom. This thread is used mostly on screws designed for wood-working and for small brass work. The objections to its use are that the top, being very sharp, is injured by the slightest accident; and that in the use of taps and dies, the fine, sharp edge is quickly lost, causing constant variation in fitting.

(*a*) V Thread (*b*) Whitworth Thread (*c*) United States Standard

FIG. 118.—Standard Screw Threads.

The V-shaped thread is the strongest form of screw thread used in the making of bolts. But because the thrust between the screw and nut is not parallel to the axis of the screw, there is a tendency to burst the nut. Therefore this form of thread is unsuitable for transmitting power.

The Whitworth's screw (Fig. 118b) is slightly rounded at the top and bottom. Compared with the American threads, the difference is in the angle between the sides, which is 55°. The French have a standard screw with the thread at an angle of 60°, with a flat top and bottom. Its pitch and diameter are given in millimeters. An international standard for metric screw threads was adopted at Zurich in October, 1898. This thread is based on the United States standard, which is an equilateral triangle truncated (cut) one-eighth of its height at top and bottom.

The United States standard thread (Fig. 118c), often called Seller's thread (from the man who first manufactured it), is also made with its sides at an angle of 60° to each other, but its top is cut off to the extent of one-eighth its pitch, and the same quantity is filled in at its bottom. The advantages claimed for this thread are that it is not easily injured, that the taps and dies retain their size longer, and that bolts and screws made with this thread are stronger and have a better appearance. As this thread has been recommended by the Franklin Institute of Philadelphia, it is sometimes called the "Franklin Institute Standard."

Since this thread is flattened or cut off at the point and root an amount equal to one-eighth of the pitch, it is only three-fourths as deep as a V thread of the same pitch. For example, a 1-in. bolt threaded with a United States standard thread will have a root circle .837 in. in diameter, while a V thread of the same pitch cut on a 1-in. bolt will have a root circle .784 in. in diameter. This shows that the V thread cuts into or "nicks" the bolt deeper, and therefore the bolt is not so strong as when threaded United States standard.

301. Taps and Tap Drills.—A tap is a tool for cutting inside or internal threads in holes so that the holes will hold tightly the bolts, screws, or studs which may be screwed into them. Taps are generally made from hammered round bar steel. After being drawn nearly to size, they are heated to a low, red heat, and covered with lime or ashes, that they may cool slowly. This process softens the metal and takes out the strains, which occur in iron or steel after it is hammered. The outside surface or skin, where the hammer blows affect the iron most, is subjected to the greatest strain, or as it is called "initial tension." There are many styles of taps, the most common being standard hand-taps, boiler taps, stay bolt taps, pipe taps, and machine screw taps.

Tap drills are drills used to make the proper sized hole for a standard tap, leaving the hole small enough in diameter to permit of threads being made by the teeth of the tap. For example, the size of tap drill for a $\frac{5}{16}$ in. screw is .24 in. in diameter; for a $\frac{1}{2}$ in. screw tap it is .4 in., leaving .1 in. for the diameter of threads on both sides of the hole. The size of a drill's or reamer's outside diameter and the size of a tap is the diameter outside of the threads, and not the size at the bottom of the threads.

Standard hand-taps are found in sets of three. Figure 119a is called a taper tap and is used to start the thread in the drilled hole; Fig. 119b is called a plug tap, and Fig. 119c, a bottoming tap. The plug tap will finish the thread if the hole goes through the piece, but if the hole "bottoms" or only goes part of the way through, the bottoming tap must be used to cut a full thread the entire depth of the hole.

The word "standard" means that the number of threads to the inch is United States standard, and all taps made to this standard are exactly alike.

302. Teeth of Taps.—The teeth or cutting edges of taps are radial. The cutting edge of a tap penetrates the metal very much like a wedge. For this reason taps for taking very heavy cuts are backed off much more than finishing taps which take light cuts. Too much backing off makes the tap wobble in the hole and weakens the cutting edges of the teeth.

(*a*) Taper Tap

(*b*) Plug Tap

(*c*) Bottoming Tap

FIG. 119.—Taps.

Taps made for cutting the threads in solid wood and split dies for screw cutting are called hobs. They differ from ordinary taps chiefly in having from six to eight more flutes. A large number of flutes makes the tap stiffer and less likely to wobble. As a result, the thread cut will be more perfect than if made with an ordinary tap. The term hob is also applied to the milling cutter used for cutting the teeth of worm wheels.

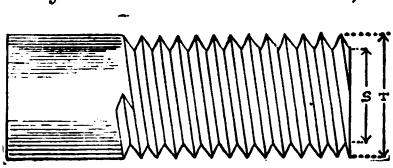


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FIG. 120.

303. How to Determine the Size of a Tap Drill.—A simple method of finding a tap drill for a V thread, or a United States standard thread tap, is provided by the following formulas (see

Fig. 120), where S is the desired size, T the diameter of the tap or screw, and N the number of threads per inch.

For V thread:

$$S = T - \frac{1.733}{N}$$

For U. S. standard thread:

$$S = T - \frac{1.3}{N}$$

EXAMPLE.—What is the tap size drill for a ¾ in. diameter 10 thread per inch V-thread tap?

$$S = T - \frac{1.733}{N} = \frac{3}{4} - \frac{1.733}{10} = .75 - .1733 = .5767 \text{ in.}$$

304. Rivets.—A rivet before being driven is a simple cylinder finished at one end with a *head*. Various forms of heads are shown in Fig. 121. The *point* of a rivet is formed when it is driven, while the rivet is hot. Various forms of points are shown in the sketch. A *tap rivet* is not really a rivet, but a form of screw. After being tightly screwed in place and secured, the square projecting portion shown in the sketch is cut off leaving a flat or *flush* head. Tap rivets are used for connecting thin to relatively thick parts.

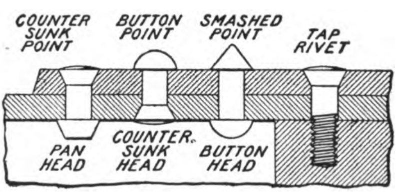


FIG. 121.—Rivet Heads and Points.

Questions

1. State the advantages and disadvantages of a cut nail. What causes a nail to split the wood?

2. State the advantages and disadvantages of a wire nail.

3. What advantage has a screw over a nail, as a fastening agent?

4. Explain the manufacture of screws.

5. What is a bolt?

6. Explain the construction of different screw threads.

7. What are the advantages and disadvantages of each? Draw sketches.

8. Define the following terms: thread, triple thread, pitch, lead, point, depth of a thread, root of thread, root diameter, pitch of screw, number of threads to the inch.

9. What are the uses of the different screw threads?

10. How is a thread placed in a hole?

11. What is a tap?

12. What are the standard hand-taps?

13. How would you determine the size of a tap drill for a thread?

CHAPTER XXIII

COMMON HAND-TOOLS

305. Kinds of Hammers.—Among the hand-tools there are a number of hammers that are common to most trades. Therefore it is necessary to know the principles underlying their construction and use.

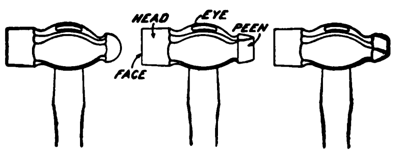
The small end of the hammer is called a peen, and "to peen" means to hammer lightly with the small end. Hammers are made of tool steel and tempered very hard on each end, the eye being left soft. The neck of the hammer handle is made small so that it will spring a little under the shock of the blow. The spring makes it less tiresome to use. The face of the hammer is made slightly crowning or rounding.

FIG. 122.—Claw Hammer.

The claw hammer (Fig. 122) used principally for driving nails, is probably the most commonly used tool. It is based upon the principle of the lever. The hammer should not be grasped near the head but at the end of the handle, so that the greatest leverage may be utilized. To deliver a free, accurate blow, the wrist should be kept up so that the handle is horizontal when the blow falls. Claw hammers are graded by the weight of the head; the ordinary claw hammer weighs from ½ to 1¾ lbs.

Machinists' hammers for metal work are made in three forms as shown by Fig. 123. Fig. 123a represents a ball-peen hammer, the small end of which is shaped like a ball; Fig. 123b a straight-peen; and Fig. 123c a cross-peen hammer.

The sledge hammer, used many times every day by the blacksmith, is a tool so large and heavy that two hands are usually needed to wield it. Sledge hammers are also used for breaking coal, those designed for this purpose having a particularly long head. The heavy smooth-faced hammer, frequently used for driving wedges in splitting stone, is also referred to as a sledge hammer. The peen of a sledge hammer is usually made of steel.

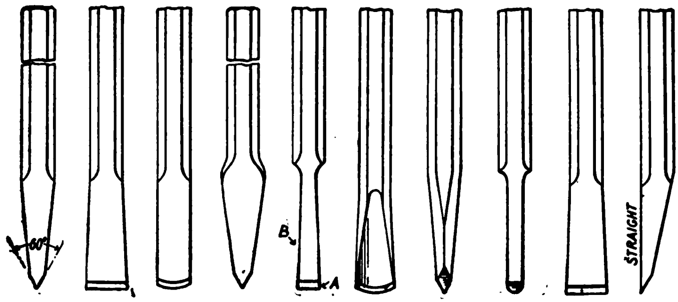


(*a*) Ball-Peen Hammer (*b*) Straight-Peen Hammer (*c*) Cross-Peen Hammer

FIG. 123.—Machinists' Hammers.

There is still another hammer called a lead or copper hammer which is used for striking on finished parts that would be dented by a steel hammer. The machinist never uses a steel hammer on finished work. Other hammers used for special purposes are the chipping and riveting hammers.

306. Kinds of Chisels.—The simplest form of metal cutting tool is the chisel, called a cold chisel. The mechanical principle of the cutting edge of the chisel is that of the wedge. Chisels for machine work differ from wood chisels in several ways, the principle difference being that cold chisels have no handles. There are many kinds of chisels in common use in the metal trades, some small and some large, but all are generally made of ¾ in. octagonal (8-sided) tool steel 8 in. long. After the chisel is forged (hammered in a hot condition) to the required shape, the end is hardened by drawing the temper (heating) to a purple color. There are three elements to be considered in making a good chisel, namely, shape, temper, and cutting edge. Chisels must be forged and tempered at a low heat, as a high heat will burn the steel (burn the carbon out of the steel).



(a) (b) (c) (d) (e) (f) (g) (h) (i) (j)

(a) Flat Chisel (Side View).
(b) Flat Chisel (Front View).
(c) Flat Chisel with Curved Edge.
(d) Cape Chisel (Side View).
(e) Cape Chisel (Front View).
(f) Gouge Chisel.
(g) Diamond-Point Chisel.
(h) Round-Nose Chisel.
(i) Side Chisel (Front View).
(j) Side Chisel (Side View).

FIG. 124.—Chisels.

Chisels made for use in the pneumatic hammer are longer than hand-driven chisels. The shanks are fitted to the holder or socket in the hammer and the chisel head should be tempered to keep it from upsetting. Ordinary chisels should never be used in the pneumatic hammer. The flat chisel (Fig. 124, a and b) is the form most commonly used. The cutting edge is generally drawn out about ⅛ in. wider than the stock from which it is made and then ground to an angle of 60°. For cutting soft metal the angles should be less; 30° for lead or Babbitt metal (a soft mixture of metals), and 45° for brass and soft cast iron, may be used. For very fine chipping, the cutting edge may be curved slightly, as shown by Fig. 124c. A small cutting angle used for cutting steel would soon break, while a blunt or large angle would not cut Babbitt metal but would simply tear it off. The flat chisel is used for all-around chipping, snagging castings, etc.

Figure 124, d and e, shows another common form of chisel called a cape chisel. It is made of the same steel and tempered in the same way as the flat chisel, but the point is drawn down to a width of about 3/8 in. The cape chisel is made wider on the cutting edge at *A* than it is at *B* to provide a clearance, and keep the sides of the chisel from breaking out the edges of the groove or channel which is being cut. The cutting edge is ground to the same angle as on the flat chisel.

There are four other forms of chisels used, but they are not so common as the flat and cape chisels. These are the gouge (Fig. 124f), the diamond-point (Fig. 124g), the round-nose (Fig. 124h), and the side chisel (Fig. 124, i and j). They are made of the same stock as the other chisels and tempered in the same way. The diamond-point and round-nose, like the cape chisel, should be made wider at the cutting edge than farther back, for clearance. The round-nose is very much like the cape chisel except that the cutting end is rounded and the bevel is on one side only. The side chisel is ground with only one bevel, like a wood chisel, but with angles just the same as if it had two bevels. This chisel should also be ground thinner or "backed off" near the point for clearance.

The gouge is used for work on round corners and on all concave surfaces. The diamond-point is used for cutting V-shape grooves and finishing out square corners; it is also used for drawing drilled holes and for cutting round corners and oil grooves.

There are several other forms of chisels used especially by boiler-makers. Figure 125 shows four handle chisels, so called because they are held by the wooden handle when used. A hot chisel (Fig. 125a) is used for trimming or cutting hot plates, etc. The cold handle chisel, used for general chipping on boiler work as well as erecting work, is very similar, except that the cutting edge is not drawn so thin as that of the hot chisel. Figure 125c shows a round punch used for knocking off rivet heads and driving out stay-bolts, rivets, etc. Figure 125b shows a square punch used for driving keys and knocking off rivet heads. Figure 125d shows a side set which is also used for cutting off rivet heads. All these tools are made of tool steel. The hot chisel is tempered to a dark straw color and the cold chisel to a blue color; the set is also tempered slightly. It is customary not to temper or harden punches since they would be apt to break off. The handles in all these tools should fit loosely and should be made of soft yielding wood so that the shock or jar of a glancing blow will not hurt the hands.

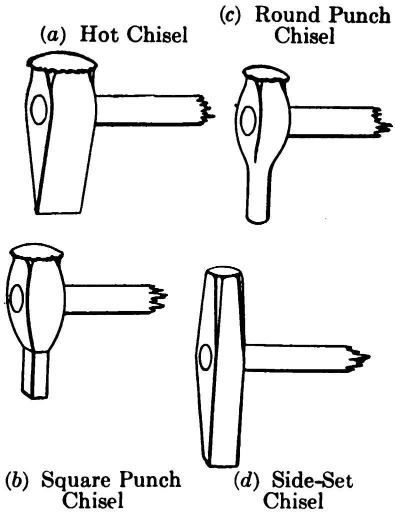


FIG. 125.—Handle Chisels.

307. Kinds of Files.—A file is a bar of high-grade crucible steel, pointed at one end for a handle and having cutting edges or teeth extending from a point near the handle to the opposite end. The mechanical principle of the teeth of a file is that of the wedge. The handle acts as a lever. In the course of manufacture, files pass through the successive processes of forging, annealing (gradually heating and cooling), grinding, cutting, hardening, and tempering. They are annealed before being ground and cut, and thus the hardness is reduced. File teeth are like a series of small chisels cut at an angle to the sides of the file, as shown in Fig. 126. Cutting on the return stroke dulls the teeth and injures the file. It is possible to destroy some of the teeth of a brand new file in one minute's careless work.

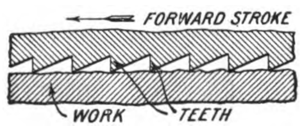


FIG. 126.—Action of File Teeth.

Many new kinds of files of all shapes and sizes, have recently appeared, so that there are now at least 104 different varieties on the market. All may be divided into three general classes, namely single-cut, double-cut, and rasps (Fig. 127). The files in each of these classes vary in length, in shape, and in coarseness of teeth.

A single-cut file has the teeth all running diagonally across the face in one direction only. A double-cut file has the teeth criss-crossing or running across the face in two directions, making a surface covered with small, sharp points. Each style or shape of single-cut and double-cut file has several grades of coarseness. These grades are called coarse, bastard, second-cut, and smooth, the coarseness varying with the length of the file. The longer the file, the coarser the teeth and the cut. Single-cut files are generally used for cutting soft metals and for lathe work. Their coarser grades are sometimes called float files, or "floats."

The double-cut files are used for all kinds of hand-work. The teeth of a rasp are entirely separate. They are round on the top and are formed by raising with a punch, small portions of stock from the flat surface of the file flank. The rasp is used

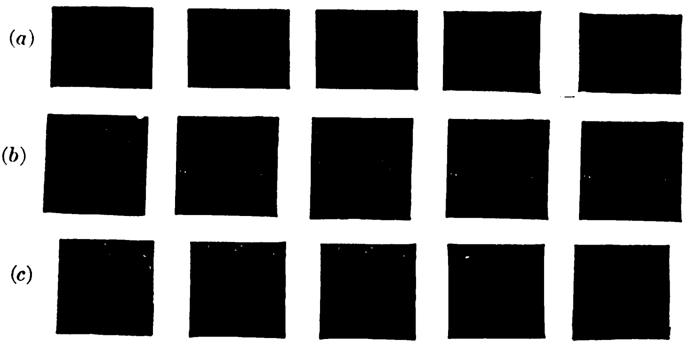


Fig. 127.—File Cuts.

(a) Single cut. (b) Double cut. (c) Rasps.

for removing large quantities of stock quickly and will work well on soft metals and even on wood. When a good job is wanted a rasp must be followed up with a file of finer grade.

Files are made convex, i.e., rounding, as shown in Fig. 128, for three reasons: (1) to overcome the effect of the spring down or bending of the file due to the pressure of the hands in making a cut; (2) to overcome the spring or warp caused by heating and hardening the file when made; (3) to make the file bite or cut with only a few teeth in the middle of its length.

Fig. 128.—Shape of File.

Figure 129 shows the end view of sections of files. *A* is the flat file, *B* the hand, *C* the square—the most commonly used—*D* the triangular or 3-square, *E* the half-round, and *F* the round.

The length of a file is the distance from the heel H to the point P (Fig. 130). The tang T is not included in the length. In ordering a file from the toolroom it is necessary to state the length, the degree of coarseness, and the shape. For example, you may want a 14 in. flat bastard, or a 16 in. half-round float.

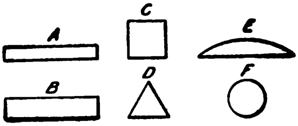


FIG. 129.—Cross-Sections of Files.

308. **Methods of Filing.**—It requires a great deal of practice to file a surface flat, as there is a great tendency for the file "to rock or fulcrum" on the corners of the work and make the surface rounding or crowning. The worker should always take long strokes, not short jerky ones. Figure 131 shows the correct method of holding a file. If the file is always driven or pushed one way a series of small grooves will be cut across the work. It is always best to drive the file diagonally across the first direction to make a smoother surface. If this is done the file will always bite (cut) better, and as the marks can be seen the eye will tell when you have filed over the whole surface.

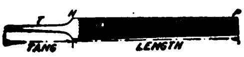


FIG. 130.—Measuring a File.

Sighting (looking) along the length of a new file will show which side is the most "bellied" (curved). This side is the best one to use.


FIG. 131.—Proper Method of Using a File.

Cast iron is harder to cut with a file than wrought iron or soft steel. A new file should never be used on rough cast iron, as the scale will dull the teeth and soon spoil the file. If the scale is not very deep it can be removed with the cutting edge of a flat file. When a file is too dull for cast iron, it may still be useful for cutting wrought iron or soft steel. Some flat files have a safe edge, i.e., a smooth edge with no teeth. Such files are used when it is necessary to file out a corner, as the safe edge prevents cutting a groove in one side of the corner when the other side is being filed. Such a file is shown in Fig. 132.

Files get clogged with chips and should be frequently cleaned with a wire brush, called a file-card. This will remove the chips, and keep the work from being scratched and grooved. File-cards are generally carried in the toolroom. When cutting cast iron with a new file, a little white chalk should be rubbed on the file; this chalk will absorb the oil and the chips will not be so likely to stick. Oil should never be used on a file for cast iron, but will sometimes make a file work better on wrought iron. It is, however, best not to use oil if only one file is available for both metals. When filing cast iron, the hand or finger should not be rubbed over the work, as the work will become greasy as a result and keep the file from cutting.

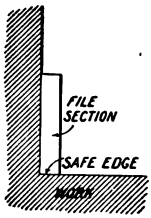


FIG. 132.—File with Safe Edge.

When filing finished work in the vise, the lead or copper jaws should always be used. Otherwise the vise jaw will bite into the work. The work may be given a very smooth finish by draw filing, which is simply drawing the file in a direction at right angles to its length. A single-cut, second-cut, or smooth file is best for draw filing.

309. Use of Scrapers.—When a job cannot be finished accurately enough with a file, a tool called a scraper (Fig. 133) is used. Scrapers are generally made from octagonal steel flattened on both ends and tempered very hard to a light straw color. After grinding, the edge should be rubbed down on an oil stone. On one end of the scraper the edge may be slightly curved as shown.

Another type of scraper with a wood handle, sometimes called a graver, is used for work in lathes and for hand-work on round corners. A good scraper can be made from an old file.

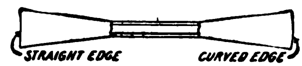
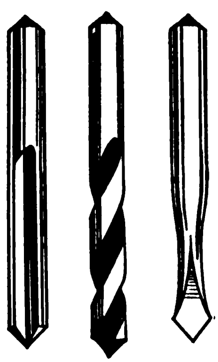


FIG. 133.—A Scraper.

When work is to be scraped it must be first rubbed or tested on a standard and perfectly flat plate called a surface plate. The method used is to put a very thin coating of red lead mixed with oil on the surface plate. The high points which must be removed first, are shown by small red spots on the surface of the block. When the work is heavy and awkward to handle the surface plate may be rubbed on it. Care is required to rub over the whole plate evenly to prevent wearing and dishing the center.



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(a) Straight-Fluted (b) Twist (c) Flat

FIG. 134.—Drill Points.

310. Kinds of Drills.—Drill points are used for boring small holes in wood, iron, brass, or other materials. There are three kinds of drills; flat, straight-fluted, and twist drills (Fig. 134). The *flat drill* can be used for almost any material, but does not cut so rapidly as either of the others. It is best suited for use on thin metals and on tile. The *straight-fluted drill* can be used advantageously on wood and the softer metals. It is especially satisfactory for drilling holes all the way through a piece of material, as it does not have a tendency to "draw in" when breaking the hole through. The *twist drill* is the most rapid cutter of the three, and is especially desirable for work on very hard woods or heavy metals, and for work where a deep hole is to be drilled. The twist drill, besides presenting a cutting edge at the point, carries the chips up to the surface, and thus prevents clogging. It is, therefore, unnecessary to remove a twist drill from the hole to clear it of chips.

311. Drills and Drilling.—Most drills are made from round bars of tool steel hardened and tempered to suit the work to be performed, generally to a dark straw color. The flat drill is made in the shop and is used because it is cheap. It is impossible to drill a hole accurately with a flat drill, although such a drill does very well for rough work in the boiler or smithshop. The flat drill was the first form of drill made, but later it was found to wear out quickly and require frequent grinding. Thus the cutting edge or lip wore away so rapidly that the drill soon had to be redressed (made over) by the tool-maker. To overcome this fault the lips were twisted into a curve or spiral. This improvement was found to give a cutting edge which did not change its shape when the drill was reground. Thus it is evident that the twisted flat drill led to the fluted twist drill and later to the flat twist drill. The former drill is a round bar of tool steel having two straight grooves or flutes cut on opposite sides. This form of drill is used for drilling in brass, copper, or Babbitt metal.

312. Mechanism of Drill Points.—To understand the principle of drilling efficiently, it is necessary to study the mechanism of a drill point. Drills are used to separate small particles of metal by scraping or cutting and to do this there must be a central or leading point about which the cutting edges turn. Figure 135 shows the cutting edges of a flat drill. The mechanical principle of the cutting edge of the drill is that of the wedge. It is seen that the left lip *AB* is ground at an angle sloping in the opposite direction from the right-hand lip *CD*. The angle of these slopes, called the clearance angle, is shown in the side view. The line *bd* in the plan view represents the intersection of these sloping lip faces and is called the drill point.

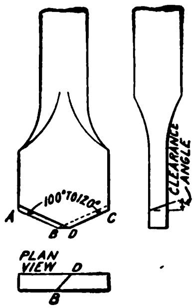


FIG. 135.—Cutting Edge of Flat Drill.

Clearance with a drill is practically the same as with a cold chisel. It is very important that the clearance angle for the metal to be cut should be ground correctly. Giving the lip of a drill clearance is nothing more than cutting back or "backing off" the face of the lip, so that its cutting edge will cut clean and will not scrape or rub on the bottom of the hole which is being drilled.

FIG. 136. Two-Fluted Twist Drill.

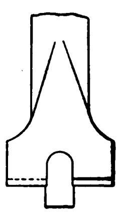


FIG. 137. Counter-bore.

The two-fluted twist drill (Fig. 136) and the counterbore (Fig. 137) are among the most extensively used types. Twist drills work more accurately than flat drills. The cylindrical shape fills the hole, keeps the drill properly ground, and also serves as a channel through which the chips may pass out of the hole, their spiral form wedging or forcing them out as the drill rotates. Twist drills are sometimes made with three flutes. These are used for enlarging cored or punched holes, but they will not drill the initial hole. Some twist drills are made with a small groove cut around the outside, which contains a tube for carrying oil to the drill point.

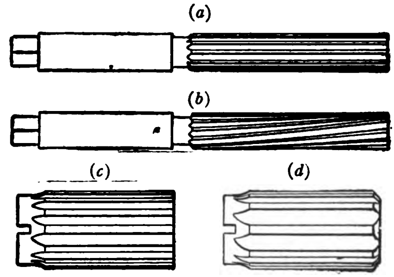
313. Operation of Reaming.—It is difficult, if not quite impossible, to drill a hole to an exact diameter. For most work, however, a variation of a few hundredths of an inch is of no account, but when greater accuracy is required the hole must be reamed. Holes to be reamed are first drilled a little smaller than the desired size ($\frac{1}{64}$ in. or even $\frac{1}{100}$ in.), and then reamed out to exact size. They should never be drilled over $\frac{1}{32}$ in. smaller than the size of the reamer. Reaming is especially necessary where two or more parts are to be bolted together, since the drill in passing through them will often cut more out of one part than another because of the variation in the structure of the metal.

Reaming may be done by hand or with a drilling machine; or the reamer may be held in the drilling machine, or in the drill spindle socket and turned by hand with a wrench. Reaming should be done very carefully, and it may be necessary to tap the reamer gently with a hammer or wrench to feed it. There should be no "wobbling" or irregular motion, but a very steady and slow motion under light pressure. In some cases the weight of the reamer and the wrench is sufficient to feed the tool through the hole.

In reaming with a drill press a power feed may be used in some cases, but great care must then be exercised to see that the reamer does not stick and break. Some reamers have a shallow screw thread cut on the small end which makes them self-feeding. Oil, drilling compound, or some other lubricant should always be used when reaming wrought iron or steel, but not when reaming cast iron or brass.

314. Kinds of Reamers.—When not carefully sharpened, all forms of reamers have a tendency to produce a rough hole. Too much clearance reduces the support of the reamer in the hole and tends to make it work unsteadily.

Reamers are made from tool steel and then hardened and tempered to a straw color; they may be straight or tapered, and may have a square end or tapered shanks. The square-end reamer is generally operated by hand. Reamers may be solid or may be made with inserted, adjustable blades. The solid reamer has the disadvantage of becoming undersized as soon as worn, but the adjustable reamers are considerably more expensive.



(a) Straight-Fluted Reamer
(b) Spiral Straight Reamer
(c) Straight-Fluted Shell Reamer
(d) Rose Reamer
FIG. 138.—Reamers.

Figure 138a shows a straight-fluted reamer with a square end, the type most commonly used. Figure 138b shows a spiral straight reamer, which is used when a slow feed is required. The spiral is made left-handed, while the reamer, in cutting, turns right-handed; this construction tends to prevent the reamer from drawing into the hole and sticking. Figure 138c is a straight-fluted shell reamer, so called because it is made hollow in the center in order that it may be used with a mandrel. Figure 138d shows a rose reamer. There are a great many other kinds of special reamers made for different classes of work, but space will not permit their being described here.

Reamers are rarely given less than 6 flutes, and usually have from 6 to 20, the number depending upon the size of the reamer. The number of flutes is generally made odd in order that there will always be two teeth opposite one tooth. These two teeth stay or hold the tool better so that it does not tend to wobble or chatter as much as it would with but one tooth opposite one tooth. It is easier, however, to caliper (measure) a reamer with an even number of flutes, having one tooth exactly opposite another on the diameter. With reamers having a large number of teeth, the odd or even feature is not of so much consequence. Shell and rose reamers may be given the same number of flutes and have their cutting edge formed in the same manner as solid reamers.

315. Emery Cloth.—The art of finishing or polishing wood and metal is very old. Originally it was done by taking the dried skins of sharks and rubbing the material. Later sandpaper and emery cloth were invented. As nearly as can be ascertained, emery cloth and sandpaper came into use about two hundred and fifty years ago. The process of manufacturing was then very primitive, consisting of coating the backing with glue, covering it liberally with the desired abrasive, shaking off the superfluous material, and hanging the sheet up to dry. The steady march of progress, however, has brought about wonderful improvements in the manufacture of abrasive papers and cloths. At the present time emery cloth is made from Turkish emery of different grades. Turkish emery is a hard black and brown stone found in Turkey and brought to this country for use in machine shops. Its quality, for hardness and durability in mechanical work, has never been excelled in any stone yet found. The cloth made is of various grades of coarseness. The numbers representing the grades of emery run from 8 to 120, and the degree of smoothness of surface they leave may be compared to that left by files as follows:

8 and 10	represent	the	cut	of	a wood rasp
16 " 20	"	"	"	"	a coarse rough file
24 " 40	"	"	"	"	an ordinary rough file
36 " 40	"	"	"	"	a bastard file
46 " 60	"	"	"	"	a second-cut file
70 " 80	"	"	"	"	a smooth file
90 " 100	"	"	"	"	a superfine file
120 F and FF	"	"	"	"	a dead-smooth file

316. Polishing and Burnishing.—Metal is polished to give it a fine finish and to produce a smooth surface which will reflect light to its highest degree—in other words to give it a "shine." The principal substances or abrasives used to produce such a surface are emery, carborundum, rouge, putty powder, silica, and burnishing materials. While emery is not so hard as some other abrasives, it is the strongest abrading powder. The powder principally used for giving a fine polish to small articles is called rouge, and is composed of ferric oxide. Most polishing compounds contain rouge. Its color and properties depend to a large degree on the temperature at which it is manufactured. Rouge made at a low temperature is soft proportionally. For this reason, jewelers' rouge is made at a low temperature, while rouge for polishing iron is made at a high temperature. Putty powder is an oxide of tin. Silica is the oxide of silicon, and is found in different forms: in the crystalline form it is called quartz; in the form of sandstone, which consists of particles of crystalline or rounded silica cemented with silica powdered sand, it is used for grindstones. Artificial polishing stones are made by cementing very fine white sand with shellac or other materials.

Burnishing is the process of producing a smooth surface by pressing down the inequalities or rough spots. It is, therefore, best adapted to soft materials.

317. Development of Grinding Stones.—Tools were originally shaped by chipping one stone against another until the stone which was to be the tool was made the desired shape. When man learned the use of metal, he continued to sharpen his tools on certain grinding stones or rocks. Experience taught him that the most effective way to grind his tools, was to make the stone circular, with a flat edge, and mounted on a shaft, and that to reduce the heat of friction the stone should be rotated through a water bath.

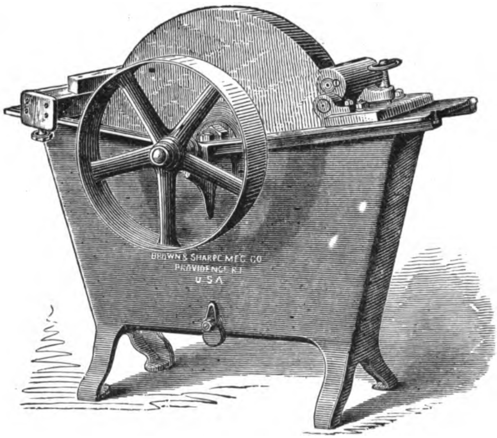


Fig. 139.—Grindstone.

Originally grindstones were made of sandstone, composed of hard, sharp particles of sand or quartz. Since then better and harder forms of stones have been discovered and placed on the market. These modern grindstones (Fig. 139) are made of emery, alundum, corundum, and carbide of silicon. Emery has a rounded, opaque grain, while alundum grain is particularly sharp. Corundum grain is sharp and transparent, with distinct evidences of crystallization. Carbide of silicon grain presents a distinct crystalline structure with a sharp cutting edge. From these materials are made a wide variety of grinding wheels and sharpening stones.

318. Corundum and Emery Wheels.—Corundum is an extremely hard oxide of aluminum. Emery is a very hard, granular variety of corundum, containing a small amount of magnetite or hematite. Ground to a powder, these substances are used for polishing, grinding, or abrading stone, metal, glass, etc. In the crushing and grinding process, which is conducted in machines more or less enclosed, considerable fine dust is given off. After sifting and grading according to fineness, the product is stored in appropriate compartments, from which it is taken as needed. Wheels are made of emery or other abrasive material.

The proper selection of a grinding wheel may be the means of saving much money and time, as each metal requires some special difference in the wheel. Wheels are of different coarseness and grades, and when ordering, the diameter, thickness, size of hole, and grade number must be given. It is not reasonable to expect a wheel which was made for cast iron to grind properly brass or steel. Some wheels are made so that they will stand a constant stream of water running over them, while others will not. When moisture is to be used with the wheel, this fact should be stated in ordering.

The grade letter of a wheel denotes the hardness to which the wheel has been baked in the retorts. The number of the emery denotes the particular grade of that substance which is used in making the wheel. The number of emery and the grade letter of wheels to be used for some of the most important materials are as follows:

Materials	*Emery No.*	*Grade Letter*
Large Iron or Steel Castings	16–20	P–Q
Small Castings	20–36	P–A
Hard or Chilled Castings	16–20	R–J
Wrought Iron Forging	16–30	O–P
Lathe and Planer Tool	34–46	N–O
Brass Castings	20–30	P–R

The makers of emery wheels usually paste tags on each wheel stating the grade, speed, and order letter, but in some cases the machinist may have to find the speed for special wheels. If the wheel is run at a higher speed than that stated on the tag, the centrifugal force may, as before stated, break the wheel.

Some emery wheel houses advise a speed of 5500 ft. per minute. From this we can calculate the speed for any diameter by multiplying the diameter in inches by 3.1416, reducing to feet, and dividing this figure into 5500. A 10-in. wheel would give us $10 \times 3.1416 = 31.416$ in., or 2.6 ft. 5500 divided by $2.6 = 2108$ revolutions per minute.

319. The Discovery and Use of Carborundum.—The discovery of carborundum nearly thirty years ago, brought into use a new and exceptionally efficient abrasive. In 1891, experiments with electric furnaces showed that when clay and crushed coke were heated through a piece of carbon in an electric furnace, the heat fused the two ingredients, and that when the carbon was withdrawn, minute crystals adhered to it. These tiny crystals were found to be amazingly sharp and hard. Subsequent tests proved that the material had great value as an abrasive, and it is now in general use.

The principal materials entering into the manufacture of carborundum are coke, which supplies the element of carbon, and sand, which supplies the silicon. The coke is crushed in a mill, and is then mixed with the sand. The mass of raw material is then placed in an electric furnace for 36 hrs. and a current of 2000 electrical horse-power is passed through it.

The resistance thus interposed results in the generation of enormous quantities of heat, so great is the temperature of the resistance path; the surrounding mass of coke and sand is heated to a point which is between 4000° and 4500° F. In this terrific heat all known metals not only melt, but volatilize (disappear in the form of a gas). Iron and steel are turned to vapor and granite rocks melt away. All the impurities and substances in the coke and sand other than carbon and silicon are destroyed or driven off in gaseous form, and the atoms of these two elements fly together and unite as carborundum.

The total energy used in a single run of a carborundum furnace is 72,000 horse-power hours. Incidentally, enough electric power is consumed to operate an arc light continuously night and day for twelve years, or to operate one 16 candle-power carbon incandescent lamp for two hundred and twenty years.

Questions

1. Draw a sketch of a hammer removing a nail from a board. Where is the fulcrum?
2. Would you gain more advantage in holding the handle of the hammer in the middle or the end? Explain.
3. Why are hammers graded by weight?
4. Why is the neck of the hammer made small?
5. Name the common hammers and their uses.
6. How does a chisel for cutting steel differ from one used in cutting wood? Why?
7. Explain the different forms of cold chisels.

8. Explain the manufacture of a file.

9. What is the mechanical principle of a file?

10. What is the difference between a file and a rasp?

11. Draw a sketch of a file. Name the principal parts.

12. Name the different kinds of drills and the shape and properties of each.

13. Explain the mechanism of a drill point?

14. Is it possible to drill a hole to exact diameter? Why?

15. What is reaming?

16. What effect will irregular motion have in reaming?

17. Why is it necessary to use oil or some lubricant when reaming wrought iron or steel?

18. What is corundum? Describe some of its physical properties.

19. Why is it necessary to have a special difference in grinding wheels for different metals?

20. What holds the particles of a grinding stone together? Is there any danger of the stone's breaking?

21. What is emery cloth?

22. Why are metals polished? Explain the operation.

23. What is rouge?

24. Explain the development of artificial grinding stones.

CHAPTER XXIV

TRANSMISSION OF POWER

320. Methods of Transmitting Power.—The power that drives a machine is usually transmitted in one of three ways: (1) from a fly-wheel in the power house to a pulley on a main line of shafting in the shop and then to another pulley on a small shaft over each machine, called a countershaft; (2) directly from the pulley of an electric motor, located in the shop where it drives the main line of shafting; or (3) by means of gears from a separate electric motor attached to each machine. The first two methods are called power transmission by *shafting*, and the third is called power transmission by *separate motor* or "*individual drive.*"

321. Arrangement of Shafting.—The transmission of power by shafting is accomplished by means of pulleys and belts, or ropes attached to the shafts, which in turn are supported by hangers. Shafting consists of cylindrical bars of steel or wrought iron from $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in. in diameter. The different lengths of shafting are connected by a device called a *coupling*. The shafting is supported by hangers attached to the ceiling (Fig. 140) and revolves through an opening in the hanger called a *bearing*. The part of the shaft which rotates in the bearing is called the journal. The bearing is encased in a soft metal called Babbitt metal, to reduce the friction to a minimum. Babbitt metal is white alloy of copper, tin, and antimony. The hardness of the alloy increases according to the amount of tin which it contains, the usual proportion being 8% tin and 9% copper. The resistance to wear is sometimes increased by the addition of 2% phosphorus. The speed of shafting, that is, the number of revolutions per minute (abbreviated R. P. M.), is governed by the type of machine run by the shafts. This speed varies from 125 to 150 R. P. M. in metal-working shops to more than 250 R. P. M. in wood-working shops.

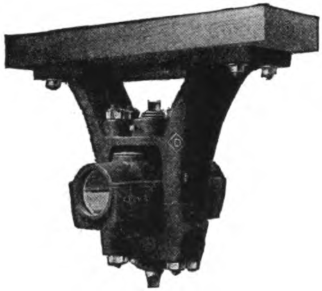


Fig. 140.—Heavy Head Shaft Hanger.

322. Formula for Horse-Power a Shaft Will Transmit.—To find the horse-power which a shaft of a given diameter will transmit, multiply the cube of the diameter in inches by its revolutions per minute and divide by 92 for steel shafts and by 190 for wrought iron shafts. The quotient is the horse-power. To find the revolutions per minute necessary for a shaft to transmit a given horse-power, multiply the given horse-power by 92 for steel and 190 for wrought iron and divide the product by the cube of the diameter of the shaft expressed in inches. The quotient is the required revolutions of the shaft per minute.

Considerable power is lost by the use of shafting and the average loss would be about as follows. For each 100 H. P. generated, 10 H. P. is consumed by the friction of engine, 15 H. P. by the line-shafting, 15 H. P. by the belts and pulleys, 15 H. P. by non-productive machinery, and only 45 H. P. goes for productive work. Therefore every effort is made to reduce friction and waste to a minimum, and shafts are usually adjusted every ten or twelve hours.

323. Setting Line-Shafting.—There are two points to be considered in setting line-shafting in line. One is that it should be either horizontally or vertically in line with its journal; the other that the line-shaft and counter-shafting should be in line with each other. Unless these precautions are taken much difficulty will be experienced in the trailing of the belts. One of the best methods of making sure that two shafts are in line with each other is to place two slender reach poles or rods of exactly the same length from one shaft to the other at their opposite ends. The shaft may then be adjusted until the distance is the same at each end.

324. Flange Couplings.—Line-shafting which is to encounter much shock and sudden variations of load must be coupled with what are known as *flange couplings.* The distance between the hangers must be regulated by the number of pulleys on the shaft. If the number is large the hangers must be closer together.

325. Bending and Twisting of Shafting.—Shafts are subject to bending and twisting. The bending is due to the load strain of the pulley, while the twisting is caused by the rotation of the shaft. Because it is liable to be rendered useless in this way, it is important that the shaft selected be of a size suitable for withstanding the expected load.

326. Leather Belting.—Most belts used in machine shops are made of oak-tanned leather (Fig. 141), but canvas is sometimes substituted for leather belting. Single belts are made from one thickness of leather or canvas, and are $\frac{3}{16}$ of an inch thick. Double belts are made from two thicknesses cemented together, triple belts from three thicknesses, and quadruple belts from four thicknesses. As a rule it is not advisable to use anything but single belts on pulleys smaller than 12 in. in diameter. Double belts, however, transmit about 70% more power than single ones of the same width. There are various formulas given for finding the horse-power that can be transmitted safely, but a common rule used by mechanics is: *A single belt one inch in width, running at the rate of 1000 ft. per minute, will transmit one horse-power without making the belt so tight that undue strain from journal friction will result.*

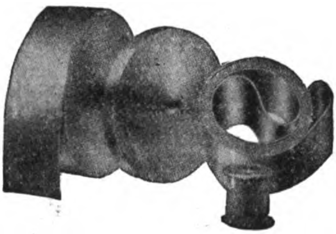


FIG. 141.—Oak-Tanned Leather Belting.

327. Fastening Belts.—There are several methods of fastening the ends of belts together. It is customary in the case of wide belts (8 in. and over) to fasten the ends by cementing. Narrow belts are fastened by lacing, wiring, hooks, or any one of the numerous forms of belt-fasteners on the market. The smooth or hair side of a belt should run next to the pulley with the flesh side out, as this latter side is softer than the other. While belts must be made tight enough to run the machine, they should never be tight enough to strain the journal bearings, or excessive heat and wear will result.

328. Sag of Belts.—When placing in position shafts that are to be connected by belts, care should be taken to separate them by a proper distance, so that the belt may be allowed to sag a little when running. No arbitrary rule can be given, as the location is the determining condition, but a general rule may be stated as follows: Where narrow belts are to run over small pulleys, a separation of 15 ft. is a good average, as the belt may then have a sag of about 2 in. For larger belts, the shafts should be placed farther apart, say 20 to 25 ft., and a sag of 3 to 4 in. will be permitted. If possible, shafts should be arranged so that the sag of the belt will increase the arc of contact with the pulley. If they are not so arranged, the sag will lower the efficiency of the belt.

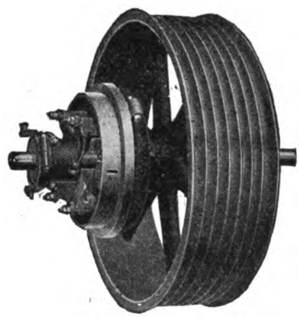


FIG. 142.—Pulley used for Rope Drawing.

329. Rope Drives.—Sometimes instead of a pulley, a wheel with grooves on its circumference (Fig. 142) is used for rope transmission. The use of rope for the transmission of power is more common in Europe than in the United States. The advantages claimed for this method of power transmission are:

(*a*) A larger amount of power is transmitted.
(*b*) A rope can be run in any direction or to any distance.
(*c*) Smooth and quiet running is obtained.
(*d*) Electrical disturbances are absent.
(*e*) Economy is obtained in first cost and in maintenance.
(*f*) There is an absence of slip.

For successful work the pulleys must be large in diameter and must have a smooth surface where the rope bears upon them. The speed and the load on the rope must be only such as experience has shown to be economical. When these conditions are fulfilled a rope drive is one of the most satisfactory methods of transmitting power.

330. Measurement of Coiled Belting.—When belting is purchased it is not necessary to uncoil it to determine its length. It may be measured in the coil in the following manner: *To the diameter of the coil in inches, add the diameter of the hole in inches; multiply by the number of coils in the belt and multiply the resulting figure by .1309. The product will be the length of the belt in feet.*

EXAMPLE.—How many feet of belt are there in a coil that is 22 in. in diameter? The hole is 4 in. in diameter and there are 48 coils.

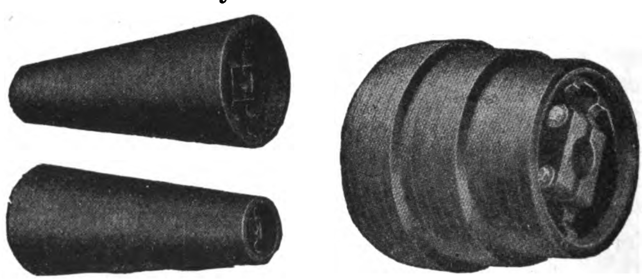
$22 + 4 = 26$

$26 \times 48 = 1248$

$1248 \times .1309 = 163.36$, the number of feet of belting in the coil.

If *exact* measurements are desired, it is necessary to get the *average* diameter of the coil and the hole, and also any fractional parts of a turn the belt makes in the coil.

331. Pulleys and Their Management.—Pulleys are made of wood or steel (Figs. 143 and 144). They are measured by their diameter and by the distance across the face or rim.



(*a*) Taper Cone Pulleys (*b*) Step Cone Pulleys
FIG. 143.—Wood Split Pulleys.

As the tendency of the belt on a pulley is to run to its highest portion, the highest part of the face should be in the center of the pulley, towards which the face should taper or crown. It is the practice to crown pulleys with a taper of ¾ in. per foot or 1 in. per foot.

As shop machines are usually arranged so that they may be disconnected from the power while the shafts are moving, it is very important in starting or stopping them to avoid sudden jars or changes, as such sudden movements are dangerous to the machine. To avoid this danger a device, called the fast and loose pulley (Fig. 145), is used. This consists of two pulleys placed on the shaft, the one being firmly fixed, and the other loose so that it may easily turn while the shaft remains at rest, or vice versa. The belt is made to pass over either pulley by means of a forked guide; if on the fast pulley, the machine moves; if on the loose pulley, the machine remains at rest.

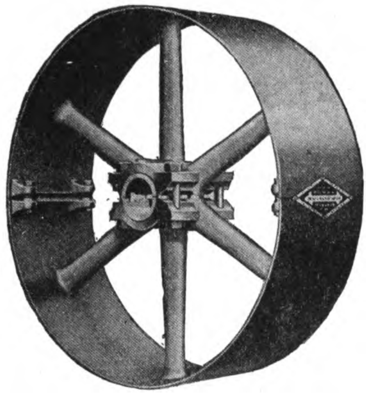


FIG. 144.—Split Iron Pulley. Pulleys are split to permit their being applied quickly to any shaft already in place.

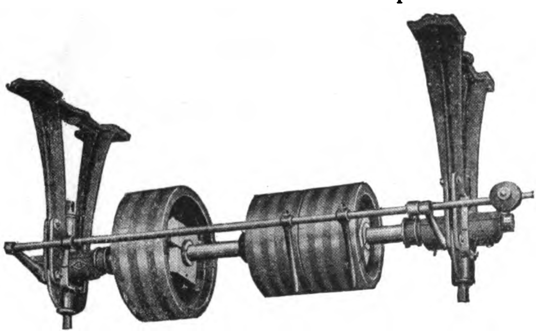


FIG. 145.—Countershaft with Fast and Loose Pulley on Right. A shifting rod throws the belting from one pulley to the other.

332. Speed of Pulley.—The size of the pulley governs the speed of the machinery and this speed is determined by the relative movements of the pulleys and the ratios between their diameters and speeds. Pulleys are usually arranged in pairs, each with a different diameter and on a separate shaft. The mechanical principle involved in a pair of pulleys is that of the wheel and axle, the larger pulley being the wheel and the smaller one the axle. (See Chapter V.) Since the belt running over the two pulleys always runs at the same speed as their rims, it is plain that the rims of both pulleys run at the same speed. The pulley running the smaller number of revolutions must be the larger of the two.

Take, for example, a 16 in. driving pulley making 180 R. P. M. running with a pulley making 320 R. P. M. The rim of the 16 in. pulley will travel in one minute a distance equal to 180 times its circumference, or $180 \times 16 \times 3.1416$, and the rim of the other pulley will travel, if we call D its diameter, $320 \times D \times 3.1416$. Since the rims of the two pulleys will always travel at the same speed we can put these two expressions equal to each other, or

$$180 \times 16 \times 3.1416 = 320 \times D \times 3.1416$$

and solving this equation to find D, we will have

$$D = \frac{180 \times 16 \times 3.1416}{320 \times 3.1416}, \text{ or } D = 9 \text{ in.}$$

Now, according to the rule, we will have

$$16 \times 180 = 9 \times 320$$

or

$$2880 = 2880$$

which proves that the rule is correct.

333. Size of Pulley.—To illustrate the method of finding the size of a pulley, suppose a shaft is to make 360 R. P. M. and that it is driven from a line-shaft making 180 R. P. M. The larger pulley on the line-shaft is already in place and is 16 in. in diameter. What diameter should we make the pulley on the shaft making 360 R. P. M?

Since we know the ratio of the speeds and diameters, we have the proportion: Speed of small pulley is to speed of large pulley as diameter of large pulley is to diameter of small pulley, or using the same figures as above, we have

$$360 : 180 = 16 : \text{diameter of small pulley}$$

The rule thus deduced is as follows:

The diameter of the driving pulley multiplied by its speed equals the diameter of the driven pulley multiplied by its speed.

In practice it is found that a belt creeps or slips so that it does not usually drive a pulley quite so fast as the calculations indicate. For this reason, the relative speeds of pulleys are only approximately exact and are always subject to slight variation.

334. Object of Gears.—The liability of belts and ropes to slip when transmitting heavy loads renders their use practically impossible when a constant ratio of velocity between the driving and driven shafts must be maintained. In these cases toothed wheels, called gearing, are usually employed.

335. The Principle of Gearing.—The principles underlying the design of gears may be best understood by considering the historical development of the gear. Originally transmission of power in machines was carried out by two smooth cylinders placed close together, as in Fig. 146, the revolution and friction of one causing the revolution of the other. Smooth cylinders, however, tend to slip when under a load, so projections or notches were placed on their surfaces, as in Fig. 147. Here the diameters D and d are the same size as on the rollers in Fig. 146. Teeth were simply added to gear *A* and corresponding notches cut in gear *B*. These two gears did roll together without slipping, but as the teeth were short their points soon wore off. To overcome such troubles, the teeth on gear *B* were made twice as long

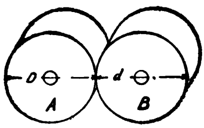


FIG. 146.

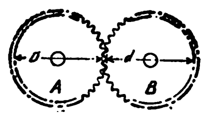


FIG. 147.

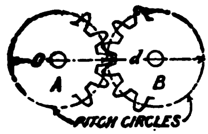


FIG. 148.

and the corresponding grooves or recesses in gear *A* were cut twice as deep, as in Fig. 147. Today this is the design of the teeth. Gears are made by casting a blank wheel and then cutting the teeth in the gear according to the above design.

Note that the inside dotted circles in Fig. 148 are exactly the same size as the rollers in Fig. 146 and are called pitch circles. When the gears turn together they simply roll together on the dotted circles just as they would do if they had no teeth.

Two gears represent the mechanical principle of the wheel and axle. The large gear represents the wheel and the small gear the axle. The most important part of gearing is the relative movements of the gears and the ratios between their diameters, their teeth, and their speeds.

When a small gear drives a larger one, the latter will make fewer revolutions in a minute. Just the reverse is true if a large gear drives a smaller one; i.e., the smaller one will make fewer revolutions in a minute. The rate at which a gear revolves is always proportional to the number of its teeth.

As there are driver and driven pulleys, so there are driver and driven gears. The driver gear and the driven gear may be distinguished by the following characteristics: The teeth of the former are bright or worn on the front side—that is, the side which faces in the direction of the motion of the gear; the teeth of the latter are worn on the side opposite from the direction of motion.

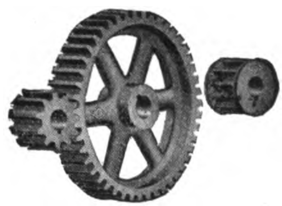


FIG. 149.—Spur Gear.

Since gears are simply pulleys with teeth on them, the principles underlying pulleys apply to gears. When the teeth of two gears interlock they are said to *mesh*.

336. Types of Gears.—Of the different types of gears in use the principal ones are the *spur* (Fig. 149), the *bevel* (Fig. 150), and the *worm* (Fig. 151) gears. Spur gears are wheels with the teeth or cogs arranged round the outer or inner surfaces of the rim, in the direction of radii from the center, and their action may be regarded as that of two cylinders, rolling one upon the other. Bevel gears are wheels the teeth of which are placed upon the outer periphery (circumference) in a direction converging to the apex of a circle and their action is similar to that of two cones rolling upon each other. When two bevel wheels of the same diameter work together

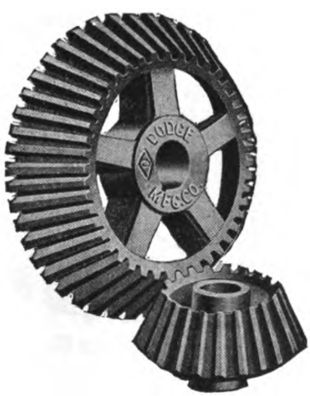


FIG. 150.—Bevel Gear.

at an angle of 45°, they are called *miter* wheels (Fig. 152). The teeth are called *teeth* when they are of the same piece as the body of the wheel, and *cogs* when they are of separate material. Wheels in whose rims cogs are inserted are called *mortise* wheels.

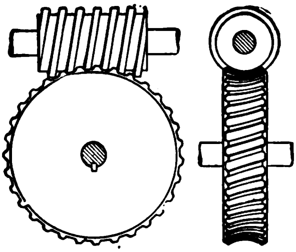


FIG. 151.—Worm Gear.

337. Teeth of Gearing.—Toothed gearing is employed for transmitting motion from one shaft to another. Under favorable conditions it is the most economical of all means of transmitting power from one shaft to another, but when the twisting effort is very irregular and the space between the teeth great, much noise arises from them, due to the teeth striking against each other. This striking is called *backlash*. When backlash is excessive it reduces the life of the wheel, but is seldom so great, except in much worn teeth, as to be a source of danger. It should be remembered that impulsive (sudden) loads produce twice the strain on the teeth that dead (steady) loads of the same magnitude produce, and that an impulsive load may strain the teeth up to, or beyond, the elastic limit of the material. If stress of this kind is repeated many, many times, the life of the teeth is greatly shortened.

FIG. 152.—Miter Gear.

When the position of gears requires that they be installed so as to operate noiselessly, the teeth of one made of wood, or rawhide, are let into and fixed in the iron rim of the gear. The gear so formed is termed a mortise gear, and is always the quicker running gear of the pair. It is in such a case as this that the teeth are termed cogs and they are usually made of hornblende or beech, both of which are compact in grain and take a smooth surface. Machine gears which are subject to much vibration and shock are frequently made of phosphor-bronze (an alloy of copper, tin, and phosphorus), gun-metal, steel, or malleable cast iron, because these materials have a high tensile strength and greater elasticity than ordinary cast iron.

338. Relation between Speeds and Diameter.—In the mechanical world or in speaking of machines, the expression "geared to 75" is often heard. This means that one turn of the driving wheel will cause the circumference of the drive to pass over 75 in.

To illustrate: A bicycle sprocket with a circumference of 30 in. and a rear wheel of 80 in. would give this ratio of speed: $\frac{80}{30} = \frac{8}{3} = 2\frac{2}{3}$; i.e., one turn of the pedal would turn the rear wheel $2\frac{2}{3}$ times. The gear of the wheel is found by multiplying this number by the diameter of the wheel, say 27 in.; $27 \times \frac{8}{3} = 72$ in.

The proportion between the speeds and the diameters of gears is just the same as the proportion between the speeds and the number of teeth. This means that we can find the ratio of the speeds of two gears just as well if we know their diameters as if we know the number of their teeth. Suppose the diameters of two gears are 12 in. and 24 in. respectively. Then the ratio of their speeds would be as 2 is to 1, if the 12 in. gear is the driver. If the 24 in. gear is the driver the ratio would be as 1 is to 2; i.e., if the 24 in. gear is driving and turns once, the 12 in. gear would turn twice.

Sometimes it is easier to figure the ratio of the speeds of gears from their diameters, but as the diameter used is the diameter of the pitch circle and not the diameter outside of the teeth, it is often hard to measure it exactly. For this reason gears are usually classified according to the number of teeth. As we can count the teeth we can get a more exact answer when figuring their speeds than if we figured from pitch circles.

339. Ratio of Gears.—Suppose we have two shafts, *D* and *F*, as shown in Fig. 153 and that we want to connect these shafts by gears so that shaft *D* will make one revolution while shaft *F* makes two. In order to do this we must place a gear on shaft *D* having twice the number of teeth of the gear on shaft *F*. If we put a gear on *D* with 24 teeth, the gear on *F* will then have 12 teeth, or half as many, and each time the gear on *D* turns around once the gear on *F* will turn twice; that is, the 24 teeth on gear *D* will have to turn gear *F* twice in order to mesh with 12 teeth on *F*.

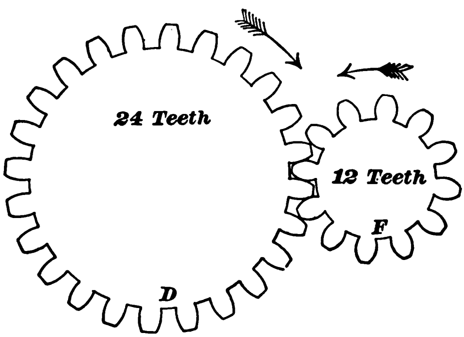


FIG. 153.—Ratio of Gears.

The relation of the speed of *F* to the speed of *D* is 2 to 1. This is called the ratio of the gearing. We can now write the ratios between the speeds and the number of teeth in the form of a proportion thus: $24 : 12 = 2 : 1$, that is, the number of teeth on gear *D* is to the number of teeth on gear *F* as the speed of *F* is to the speed of *D*.

340. Direction of Gears.—*The number of turns or revolutions which a gear makes is always proportional to the number of its teeth.* It makes no difference how many gears there are in a train, the gears between the first and last gear have nothing to do with the speed of either of these two. That is to say, the ratio between the speeds of the first and last gear is not changed by putting any number of gears between them. The continued product of the revolutions of the first driver and the teeth of all the driving gears is equal to the continued product of the revolutions of the last follower and the teeth of all the driven gears. The formula for this is $RDd = rFf$. This principle is true for any number of driving and driven gears. The position of a driver does not affect the speed of the last follower. Thus, either driver in Fig. 154 can be placed at D or at d. Either follower can go on at F or at f without affecting the speed of the last follower.

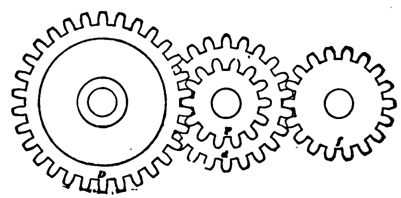


FIG. 154.—Train of Gears.

341. Gearing Terms.—There are certain terms relating to gears with which the mechanic should be familiar. Some of the most important of these are explained below. (See Fig. 155.)

Spur.—Spur originally meant a projection or tooth, but is now used to distinguish spur gears from other varieties of gears, such as bevel gears and worm gears.

Pitch Circle.—The pitch circle of a gear is the distance around the teeth and is the same size as the friction rollers or cylinders would be if no teeth were present: i.e., when two spur gears roll together their pitch circles are considered to be constantly in contact.

Pitch Diameter.—The pitch diameter of a gear is the diameter of the pitch circle.

Circular Pitch.—The circular pitch of a gear is the distance measured along the pitch circle from the center line of one tooth to the center line of the next.

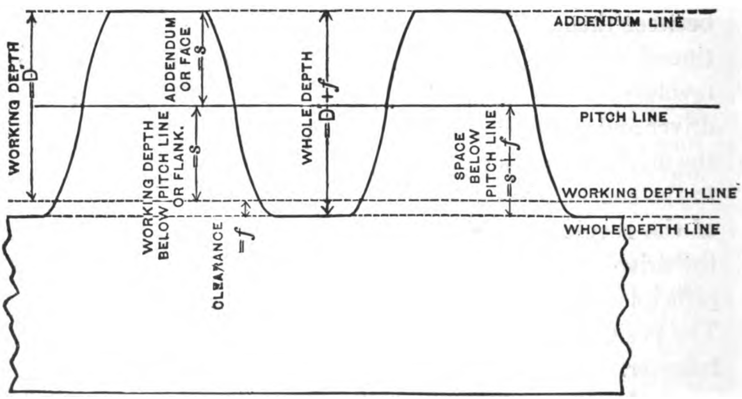


FIG. 155.

Diametral Pitch.—The diametral pitch of a gear is the number of teeth per inch of pitch diameter. (For example, if a gear has 30 teeth and its pitch diameter is 3 in., the diametral pitch is 30 ÷ 3 or 10.)

Addendum.—The addendum of a gear is the height of the top part of the tooth, i.e., the distance from the pitch line to the point of the tooth.

Dedendum.—The dedendum of a gear is the working depth of the tooth below the pitch line. It is always equal to the addendum.

Working Depth.—The working depth of the teeth of a following gear is the depth to which the teeth in the meshing gear center into the spaces between the teeth of the first or driving gear.

Clearance.—The clearance of a gear is the amount that the tooth space is cut deeper than the working depth. (The working depth of a tooth equals the sum of the addendum and the dedendum, while its total depth equals the sum of the addendum, dedendum, and clearance.)

342. Ratio of Gear Measurements.—Repeated designs and tests of spur gears prove that the dedendum (or addendum) should always have a certain definite ratio or relation to the diametral pitch which is: dedendum times diametral pitch = 1, or, what is the same

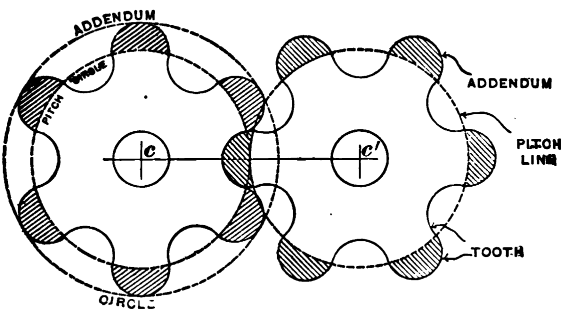


FIG. 156.

thing, dedendum = 1 ÷ diametral pitch. This relation, of course, holds true for the addendum, since the addendum and the dedendum are equal. It is well to remember this relation, since the diametral pitch is the most important thing to know about a spur gear and all gears are ordered and made according to their diametral pitch. The clearance is also referred to as the diametral pitch. Most gear-makers use the Brown and Sharpe rule which is to make the clearance times the diametral pitch equal .157; expressed as a formula this would read:

$$F = .157 \div P$$

Where F equals the clearance and P equals the diametral pitch.

Since we know that the outside diameter is equal to the pitch diameter plus the two addendums, and since the addendum equals

1 ÷ diametral pitch, we can make a formula for the outside diameter which will read:

$$O = D + \frac{1}{P} + \frac{1}{P}$$

or, adding up, we will have $O = D + \frac{2}{P}$

where O = outside diameter, P = diametral pitch, and D = pitch diameter.

Questions

1. State some advantages and disadvantages of the transmission of power by individual drive.
2. What is the mechanical principle involved in pulleys transmitting power by belting?
3. What is the property of matter that allows the belt to turn the pulley?
4. What kind of motion is illustrated in a rotating pulley?
5. Explain how Babbitt metal reduces friction.
6. Is frictional electricity ever generated by the belt going over the pulley?
7. Why is it necessary to have shafting of different diameters?
8. Explain two forces at work on a rotating shaft.
9. Is leather belting stronger than canvas?
10. Why is a pulley "crowned"?
11. Explain the difference between a pulley and a gear.
12. When is transmission by gearing preferred to transmission by pulley and belt?
13. Name the common types of gears and explain their uses.
14. Explain the meaning of the following terms used in gearing: diametral pitch, circular pitch, diameter of pitch circle, whole diameter, bottom diameter, number of teeth, working depth of tooth, velocity of gear, distance between centers of teeth, whole depth of tooth.

Problems

1. One gear has 200 teeth and another 50 teeth. What is the ratio of the diameters of their pitch circles?

2. Two gears have pitch circles of 85 in. and 17 in. in diameter respectively. What is the ratio of their speeds? What is the ratio between the number of teeth in their gears?

3. A 48-tooth gear drives a 120-tooth gear. What is the ratio of their speeds?

4. Two shafts are connected by gears. One turns 55 times a minute, and the other turns 11 times a minute. If the smaller gear has 32 teeth, how many teeth has the larger gear?

5. Three gears of a train have 69, 30, and 74 teeth respectively. If the 69-toothed gear makes 100 R. P. M., how many R. P. M. will the 74-toothed gear make? Figure the result and make a sketch of the gears, showing by arrows the direction in which each turns.

6. A train of gears is made up of 6 gears having teeth as follows: 46, 60, 32, 72, 56, and 48. While the first gear in the train makes 10 turns, how many turns will the last gear make?

7. What two gears will give a ratio of speeds so that the driver will make $\frac{13}{14}$ as many turns as the follower; in other words, while the driver makes 13 turns the follower will make 14?

8. A horse used for moving a house walks around in a 12-ft. circle pulling 800 lbs. on a capstan bar. If the drum of the capstan is 24 in. in diameter, how much pull will the rope exert on the house?

CHAPTER XXV

BOILERS AND THE GENERATION OF STEAM

343. Source and Characteristics of Steam.—The source of energy used in driving many forms of machinery is the oil or coal consumed—usually in the boiler-room of the power plant. When this oil or coal is burned it gives off heat. The heat converts water into steam, and the expansion of the steam drives the engine. The steam that issues from a steam locomotive or from an open pipe of a power plant, like the steam that is given off from a kettle on the stove, is a watery (aqueous) vapor and is always found when water is heated. Steam resembles common air and other gases in many of its properties. It differs from gases in that it does not retain permanently its gaseous condition. For this reason it is not called a gas but an aqueous vapor. The white cloud of vapor noticed when steam is liberated is due to water particles in suspension in the air.

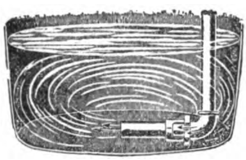


FIG. 157.—Heating Water by Steam. The arrow represents the passage of heat (by steam) into the water. The attachment is screwed onto the steam pipe.

The chief property or characteristic of steam is its elasticity which makes it capable of enormous expansion.

344. The Boiler of the Steam Engine.—The principal parts of a steam engine are the boiler and the engine. The boiler is a cylindrical steel vessel located over a fireplace.

Both the boiler and fireplace are enclosed in fire-brick. Boilers may be divided roughly into two general classes: water-tube, and fire-tube boilers. The distinction between the two is that in water-tube boilers water flows through the tubes and

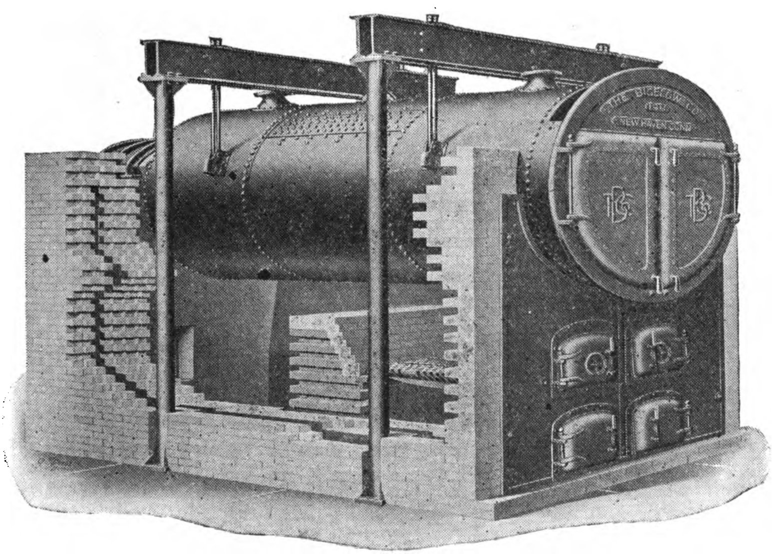


Fig. 158.—Return Tubular Boiler.

the fire is on the outside of the tubes, while the conditions are reversed in the case of fire-tube boilers.

The most widely used of all boilers in America and England is the return tubular boiler (Fig. 158). This is a closed vessel made of steel or iron, simple in construction, and easy to clean and repair. The first horizontal tubular boilers were ordinary iron storage tanks, 30 or 40 ft. long and 48 to 56 in. in diameter. This type of boiler frequently exploded at the girth seam over the fires, and 50 or 60 lbs. was considered high pressure.

Steel instead of iron is used in the construction of modern boilers. Although the average diameter of boilers has increased only slightly and the average length has even decreased, the modern type is capable of carrying three times as high a pressure as the old type. The diameters of modern boilers range from 48 to 69 in., and the lengths from 16 to 20 ft., but a boiler carrying a pressure as high as 150 lbs. per square inch is not at all uncommon; some carry even a much higher pressure.

345. Water-Tube Boiler.—The water-tube boiler is the result of a demand for high pressures of steam. In this type of boiler the water is contained in tubes which, on account of their comparatively small size, reduce the thickness of metal, the quantity of water contained, and consequently the total weight of the boilers. At the same time the small tubes increase the rapidity with which steam can be generated without injury from unequal expansion. Water-tube boilers are in extensive use for both stationary and marine work (Fig. 159). They are more com-

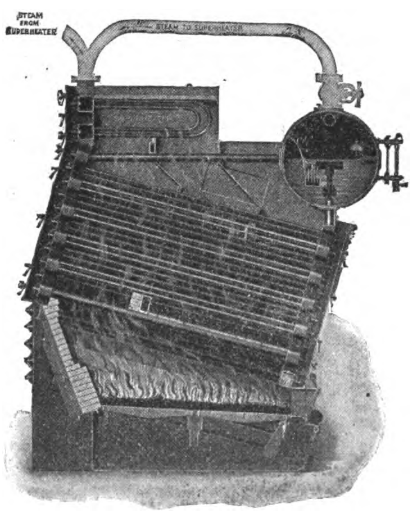


Fig. 159.—Marine Boiler. The tubes are of small diameter and shorter than in land type. Oil may be burned in this boiler. In this boiler the entire surface is composed of fire-brick.

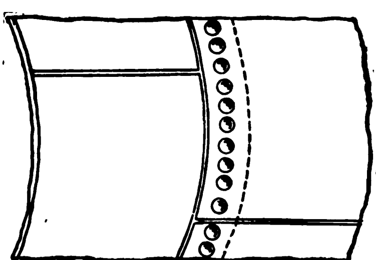
plicated, as a general thing, than some of the forms of fire-tubular boilers and under the best conditions for each type have not shown any particular increase in economy. This type is claimed, however, to be the safer of the two because it contains a less amount of water. When an explosion occurs the tubes simply blow out. The cause is generally defective welds or the thinning of the tubes from corrosion.

The common type of water-tube boiler is made of lap-welded wrought iron tubes placed in an inclined position, connected with each other and with a steam-and-water drum on the top of the tubes by a vertical passage at each end. A mud drum is connected to the rear and lowest point of the boiler. The steam-and-water drums are made of sheets of iron or steel of the desired thickness to withstand the pressure. The plates are double-riveted. The mud drum is made of cast iron, as this is the best material to withstand corrosion.

The tubes are fitted by an expander into drilled holes accurately sized and tapering at the end connections. These connections are in one piece for each vertical row of tubes. The tubes are arranged so that each row comes over the space in the previous row.

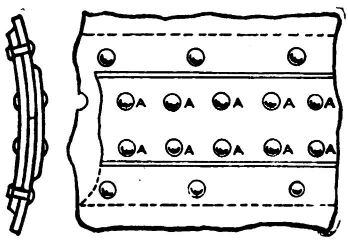
346. Boiler Building—Boilers 14 ft. or less in length are constructed of two plates, each forming the entire circumference. Above 14 ft. in length the shell is constructed in three parts, i.e., three plates are required to make the length of the boiler shell. These steel plates are $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, or $\frac{5}{16}$ of an inch thick and range from 45,000 to 85,000 lbs. per square inch tensile strength. They are ordered by the boiler-maker from the steelmill usually $\frac{1}{2}$ in. larger than the finished size required and they come to the shop perfectly flat. Here they are first weighed to find out if they are up to specifications in thickness. They are then placed on a bench and laid out, "squared up" on the edges, and the location of every rivet hole, nozzle, etc., is marked off with a soapstone pencil. The rivet holes are punched ¼ in. less than their finished size, then reamed full size, after which the plates are brought to a planing machine and planed to the exact size on the edges. Edges that are to be calked (pressed together by a compressed air hammer) are beveled (inclined to an angle other than 90°), while the others are planed at right angles to the surface of the plate.

The cylindrical shell of a boiler retains its shape without the need of a brace or support for the very simple reason that the internal pessure tends to keep it cylindrical. On the other hand, this internal pressure has a constant tendency to force or "bulge" out the flat surface of the heads of the boiler which in consequence are reinforced by means of the diagonal brace and stay-rods. The brace is used for low pressure, and the stay-rods for high pressure. Stay bolts extend from head to head. These bolts are often broken by the unequal expansion of the fire-box and outer shell.


(Copyrighted by Millers Fall Cos.)
FIG. 160.—Lap Joint.

347. Joints of a Boiler.—It is very important that a boiler should safely withstand the pressure of steam for which it has been constructed. Though the tensile strength of the boiler plate is marked on it, it is necessary to test it when the boiler is completed. When a rivet hole is punched, the plate is weakened proportionally because a quantity of metal has been removed. Therefore an additional piece of metal, known as a strap, must sometimes be placed around such rivet holes to make up this deficiency to some extent.

At the present time, most fire-tube boilers made to generate steam for engines have the different portions of the shell overlapping one another, as shown in Fig. 160, and these are held with a single row of rivets. This arrangement forms what is called a lap joint. Lap joints are not used to any great extent in joining the two ends of the same sheet. In this case the ends are brought together and one strap is placed on the inside and another on the outside, as shown in Fig. 161. This method forms what is called a butt joint. These straps and the plate are joined by riveting, as shown. If a single row of rivets is used on each side of the joint through the outer plate, as shown at *AA*, it is called a single-riveted butt joint. If a double row is placed on each side of the joint through the outer strap, as shown in Fig. 162, it is called a double-riveted butt joint; if three rows are used, it is called a triple-riveted butt joint.



(Copyrighted by Millers Falls Co.)
FIG. 161.—Butt Joint.

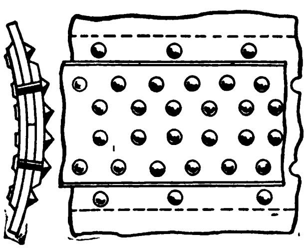

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FIG. 162.—Double-Riveted Butt Joint.

348. Thickness of Boiler Plate.—The Boiler Inspection Department of Massachusetts recommends the following formula for determining the thickness of boiler plate:

$$T = \frac{P \times R \times FS}{TS \times \%}$$

Where T = thickness of the boiler plate in inches.
P = boiler pressure in pounds per square inch.
R = radius (½ diam. of boiler) in inches.
FS = factor of safety.
TS = tensile strength of the metal in pounds per square inch.
$\%$ = strength of the joint.

The efficiency or strength of a joint is the percentage of the strength of the solid plate that is retained in the joint. It depends upon the kind of joint and method of construction. If the thickness of the plate is more than ½ inch, the joint should always be of the double-bolt type.

EXAMPLE.—What thickness of plate should be used when making a 40-in. diameter boiler to carry 125 lbs. pressure, if the strength of the plate is 60,000 lbs. per square inch, using a factor of safety of 6, and 50% as the strength of joint?

$$T = \frac{125 \times 20 \times 6}{60{,}000 \times .50} = \tfrac{1}{2} \text{ in. sheet}$$

To find the safe working pressure use the following formula, where the letters have the same significance as in the previous formula:

$$P = \frac{TS \times \% \times T}{R \times FS}$$

EXAMPLE.—Find the safe working pressure of the same boiler.

$$P = \frac{60{,}000 \times .50 \times .5}{20 \times 6} = 125 \text{ lbs.}$$

349. Testing Boilers for Defects.—Boilers are tested in two ways: (1) by hydraulic pressure, and (2) by the hammer test. The hydrostatic test consists in filling the boiler with water and then exerting by means of a boiler test-pump (Fig. 163) one-half more pressure than the boiler is expected to carry. For instance, if it is expected to carry 100 lbs. pressure, it is tested up to 150 lbs. The hammer test is made by going over the boiler and tapping it with a small hammer. An experienced ear can tell by the sound of a blow and by the feel of the iron whether a weakness has developed. Corrosion and strains from expansion and contraction are liable to cause a decrease in the strength of a steam boiler. Corrosion, which may be either internal or external, is the wasting away of the material of the boiler by pitting, grooving, etc. Internal corrosion is mainly caused by the action of oxygen, minerals, or acids in the water. External corrosion takes place generally through rusting and from the action of sulphur in the fuel. Under certain conditions this sulphur attacks the metal when the boiler is "starting up" or "cooling down," a time at which the gases are much reduced in temperature.

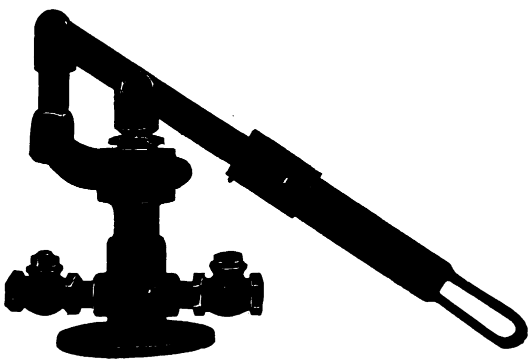


FIG. 163.—Boiler Test-Pump.

Boilers should be fed with hot water. Cold water tends to reduce the temperature of the water already in the boiler, particularly in the parts near the opening of the feed pipe, causing these parts to contract. This contraction strains the seams and the plates more or less severely, according to the temperature and volume of the water introduced. Draughts of cold air have the same effect, often resulting in leaky tubes and seams.

350. Boiler Repairs.—Boilers may be repaired by placing a hard or soft patch on the defective part. For a hard patch, the defective part is cut out, rivet holes are drilled or punched around the opening, and the patch is applied and calked. A soft patch is made by placing a piece of boiler plate over the place that threatens to give way. The plate is held in place with ⅝ or ¾ in. countersunk screw bolts. A piece of sheet packing covered with red lead is often put under the patch, or the red lead is used alone.

351. Principal Parts of a Boiler.—The principal parts of a boiler are the shell, tubes, fusible plug, hand-hole, safety valves, and water gauge. The shell and tubes have already been explained. A fusible plug is a brass plug with a tapering center of Banca tin (Fig. 164). The large end is put next to the pressure to prevent the soft metal from blowing out. This plug is screwed into the rear head of a boiler not less than 2 in. above the top row of tubes, and extends 1 in. into the water to prevent its becoming scaled. If the water "shrinks" below this plug the soft metal melts, allowing steam to escape, and thus giving timely warning.

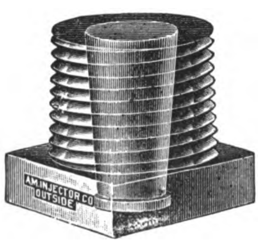


Fig. 164.—Fusible Plug.

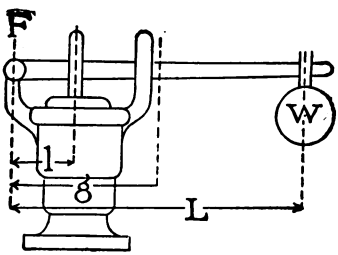
The manhole, through which it is necessary to enter to inspect the inside of the boiler, is cut in the top or in one of the heads, and is made steam-tight by a rubber gasket. Hand-hole plugs are located in the bottom of the front and rear heads for the purpose of permitting the boiler to be cleaned. The blow-off is connected, at the bottom of the shell at the rear end, with a valve on the pipe outside of the brick-work called the blow-off valve. This valve is designed to empty the boiler and should be used every morning, so that the sediment that has settled at the bottom of the boiler over-night may be blown out. The boiler should be emptied and washed out at least once a month.

352. Safety Valves.—As the cylinder of the boiler is made to stand a certain pressure, any excess may cause it to burst. Therefore it is essential that the fireman should know when that pressure is exceeded. Various devices have been designed to give the fireman warning. Among these are the safety valve, the pressure gauge, and the water gauge.

A boiler usually has two safety valves, a water gauge, and a pressure gauge. The function of a safety valve is to relieve the boiler of all pressure in excess of that allowed. The valve is placed at the top of the boiler and piped outside. As it oftentimes becomes corroded and sticks, it should be tried every day.

The size of the safety valve is a very important matter, and is determined by the area of the grate, the weight of fuel burned, and the steam pressure. The amount of steam generated in a given time will depend upon the weight of coal burned, while the velocity of escape through the valve will depend upon the pressure. Low pressure safety will not run higher than 30 lbs. The figure stamped on the lever shows the limit.

A lever safety valve (Fig. 165) consists of a disk, a stem, and a lever with a weight hung on the end. The weight keeps the valve in its place until the steam pressure under the valve overcomes that of the weight and some of the steam escapes. If it were not for the safety valve, boiler explosions would be much more frequent.



(Copyrighted by Millers Falls Co.)
FIG. 165.—Safety Valve.

353. Construction of Safety Valves.—Calculations for lengths of arms and weights required for any boiler pressure are obtained from the formulas for levers, taking into account the weight of the lever and valve.

The center of gravity is the point at which the lever and valve attached to it will just balance over a balancing bar (bar with knife edge). The fulcrum is at the center of the pivot on which the lever works.

Where F = the fulcrum on which the lever works.
W = weight of ball in pounds.
g = distance in inches from fulcrum to center of gravity.
Vl = weight of valve and lever in pounds.
L = distance between ball and center of fulcrum in inches.
l = distance between fulcrum and center of valve in inches.
P = boiler pressure per square inch.
A = area of safety valve in square inches.

Then $$W = \frac{A \times P \times l - (Vl \times g)}{L}$$

and $$L = \frac{A \times P \times l - (Vl \times g)}{W}$$

EXAMPLE.—At what distance from the center of fulcrum must a weight be placed, if the boiler pressure is 100 lbs., weight is 16 lbs., area of valve is 3 sq. in., and valve and lever weigh 16 lbs., center of valve is $2\frac{1}{2}$ in. from fulcrum, and center of gravity is 12 in. from fulcrum?

$$\frac{3 \times 100 \times 2\frac{1}{2} - (16 \times 12)}{16} = 34\frac{7}{8} \text{ in.}$$

354. Water Gauge.—The function of the water gauge (Fig. 166) is to register the height of the water in the boiler. It consists of a small cast iron drum placed in an upright position in front of the boiler, provided with a glass gauge, cocks, water and steam connections. Pipe connections are arranged so that steam enters the top and water enters the bottom. Water gauge and cocks are essential to the safety of the boiler and should be blown out frequently to prevent clogging. Water should stand halfway in a gauge glass cock while working, and at night should be raised to the top gauge cock. The first duty of a fireman in taking charge of his boiler is to see if the water is at a proper level. To tell if the glass is registering correctly, the gauge cocks must be tried. The water column should be blown

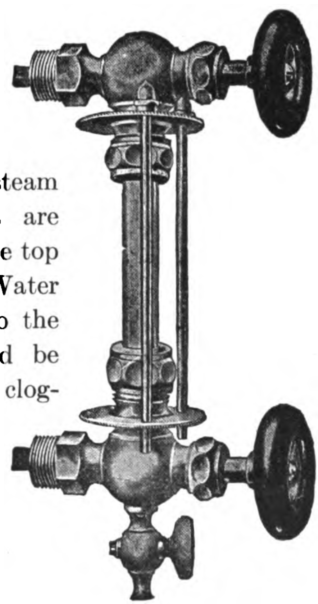


FIG. 166.—Water Gauge.

out at least once a day, and sometimes three or four times, depending upon the quality of the feed water. The gauge cocks should be opened after blowing out the water column to see that the level in the glass coincides with the level indicated by the gauge cocks. The water has to be kept at about the same height all the time, and the engineer can tell whether it is right or not by opening the gauge cocks. One of these is below the water line, and one is above it. If the

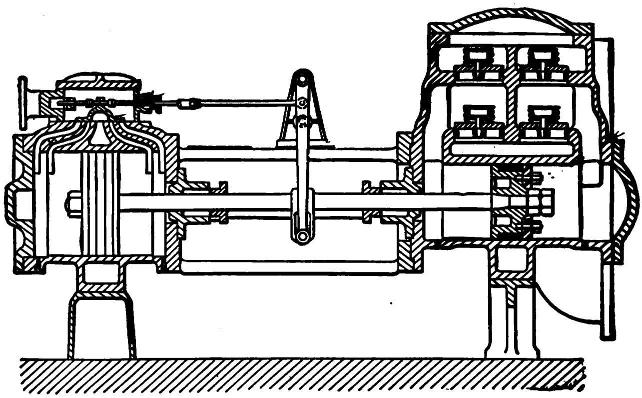


FIG. 167.—Cross-Section of a Boiler Pump.

water in the boiler is right, steam will come out of the upper one and water out of the lower one; if it is too low, steam will come out of both.

355. Boiler Pumps and Injectors.—A boiler should have at least two means of feeding water, because one might fail to work. The water inside a boiler is usually kept at a proper level by either pumps or injectors. Steam pumps (Fig. 167) are most commonly used on stationary and marine boilers, and may be classified as boiler-feeders, general surface pumps, tank pumps, or water-work pumps.

The steam pump is commonly used in power plants to supply feed water to the boiler. It is very important for the engineer in charge of the plant to see that the pumps supplying the steam boilers are in first-class order at all times, as any failure to maintain the water at a proper level in the boilers may result in serious injury to the boilers; an explosion may even occur.

One end of a boiler pump is called the engine or steam end and the other the pump or water end. A boiler-feeder is intended to feed water into steam boilers while they are under pressure. To illustrate: If the boiler is under a pressure of 100 lbs. to the square inch, and the steam piston in the pump receives 100 lbs. to the square inch, it is clear that there will be equilibrium between the steam pressure and water pressure of the pump. This is overcome by reducing the plunger diameter to perhaps one-half the size of the steam piston. In this way an unequal area in the steam piston and pump plunger is obtained. This difference enables the pump to force water against a pressure greater than that of the boiler. The necessary allowance for friction varies from 5 to 40%.

When a pump takes in water at only one end of the piston, it is called a single-action pump; when it takes water in at both ends, it is called a double-action pump.

All single, direct-acting pumps make use of an auxiliary plunger to carry a valve which gives steam to the main piston. By means of various devices, steam pressure is made to drive this auxiliary plunger backward and forward.

356. Measurement of Pump Pressure and Capacity.— The formula for lifting or forcing water either under pressure or head is as follows: $P = HAW$.

Where H = the distance from the level of the source of supply to the point of discharge.

A = area in square feet of surface in contact with the water.

W = weight of a cubic foot of water, or 62. 5 lbs.

EXAMPLE.—What is the pull on a pump rod, when the diameter of a bucket is 6 in. and water is raised 20 ft.?

$$P = HAW = 20 \times \frac{6^2 \times .7854}{144} \times 62.5 = 245.437 \text{ lbs.}$$

From the above solution we find that the pull on the pump rod is 245.437 lbs.; to this must be added the amount of power necessary to overcome friction.

357. Measurement of Water Cylinder Contents.—To find the cubical contents of a water cylinder per stroke, in cubic inches, multiply the area of the piston in square inches by the length of stroke in inches. To find the contents in gallons divide this product by 231, and to find it in cubic feet divide the product by 1728.

EXAMPLE.—What is the capacity per hour of a single-action pump with a water piston 6 in. in diameter and a 10-in. stroke, when the piston makes 60 strokes per minute?

If the water cylinder is filled at each stroke, the contents are $A \times L = (6 \times 6 \times .7854) \times 10 = 28.274 \times 10 = 282.74$ cu. in.

At 60 strokes per minute there will be $60 \times 60 = 3600$ strokes per hour. If the piston pumps 282.74 cu. in. per stroke, then for one hour it will pump

$$282.74 \times 3600 = 1{,}017{,}864 \text{ cu. in. per hour}$$
or
$$1{,}017{,}864 \div 1728 = 589 \text{ cu. ft. per hour}$$
or
$$1{,}017{,}864 \div 231 = 4406.33 \text{ gal. per hour}$$

To find the H. P. required to pump water to a given height, multiply the weight in pounds of water to be raised per minute by the height in feet and divide by 33,000; the quotient will be the H. P. required. The formula is:

$$\text{H. P.} = \frac{W \times H}{33{,}000}$$

EXAMPLE.—Find the H. P. required to pump 4406.33 gal. of water per hour to a height of 40 ft. above the source of supply.

If a pump will raise 4406.33 gals. of water per hour, it will raise 4406.33 ÷ 60, or 73.438 gals. per minute; and as 1 gal. of water weighs 8⅓ lbs., 73,438 gals. weigh 73.438 × 8⅓ or 611.983 lbs. This weight of water is to be raised 40 ft. high. Then by formula:

$$\text{H. P.} = \frac{W \times H}{33{,}000} = \frac{611.983 \times 40}{33{,}000} = \frac{24{,}479.32}{33{,}000} = .741 \text{ H.P.}$$

358. Injectors and Ejectors.—The injector (Fig. 168) is an apparatus for forcing water against pressure by the direct action of steam on the water. It is universally used on locomotive and sometimes on stationary boilers. Steam is led from the boiler through a pipe, which terminates in a nozzle surrounded by a cone. This cone-shaped pipe is connected with the water tank or well where the water is stored. When steam is turned on, so as to pass into the injector, it rushes from the nozzle and thereby creates a partial vacuum in the cone. Since this pressure in the cone is now less than the atmospheric pressure in the water well, the water is forced up to the cone. As the steam meets this water it condenses, but not before its force has imparted enough of its velocity to the water to give the latter sufficient momentum to force down the valve that prevents the steam and water of the boiler from escaping. An injector does not work well if the feed water is too hot, as in that case the steam does not condense quickly.

An ejector is similar in form and operation to an injector, but is used to lift water without forcing it against pressure. An inspirator is a double-jet injector; one jet lifts the water, and the other forces it into the boiler.

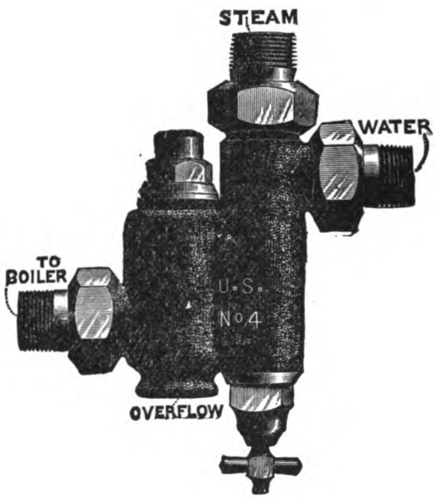


FIG. 168.—Injector.

359. Water-Heater.—Before entering the boiler, water is heated in a heater by exhaust steam. This heater consists of a vessel filled with brass tubes. Steam passing through or around the tubes causes the temperature of the water to be raised. This process prevents steam from condensing in the boiler as it would if cold water entered. Moreover, the salts are deposited in the boiler instead of in the heater. An economizer is a device consisting of iron or steel tubes through which feed water passes while the products of combustion circulate around the tubes. A steam separator is used to remove moisture from steam before entering the engine cylinder. A steam trap is a device to remove condensed steam from steam pipes without allowing any of the live steam to escape.

A damper regulator is an apparatus for regulating the damper and controlling the draughts by the pressure of steam on the boiler. This regulator has the power to move the damper or dampers in both directions by water pressure, and will close or open them on a variation of one pound of steam. It makes a partial stroke and stands at any point; that is, it will move from the open position to one-quarter, one-half, three-quarters, or fractions thereof, and come to and remain indefinitely at a state of rest, and then return to the open position, thereby making the only true and proper movement of the damper.

360. Cleaning the Boiler.—When the water is heated and converted into steam, the sediment or suspended dirt remains in the boiler and forms scales. These scales are composed principally of mineral matter and affect the economical generation of steam by preventing the water from coming in contact with the plates and tubes. The latter are then heated to a much higher temperature than would otherwise be necessary and to too high a temperature for the good of the metal. Thick scales on the surface of a boiler cause unequal expansion of the plates and tubes, resulting in leaky tubes and seams, and largely accounting for blisters and bagging.

Various methods have been invented for removing and preventing scale. Kerosene oil removes oil scale very effectually. About half a pint of kerosene oil per day fed continuously into the feed water will be found sufficient to remove scale as fast as it can be taken care of by cleaning the boiler, and without danger of accumulating and causing serious overheating. Scale may be to some extent prevented by the use of a good compound, provided the water has been analyzed and the compound which has been prepared particularly for that water is used. Mechanical boiler cleaners may also be used with good effect, but with any method a boiler should be thoroughly cleaned at regular and frequent intervals. Boiler tubes also should be cleaned often. The soot that collects in them is a non-conductor of heat, and, therefore, when the surface of the tubes is covered with soot only a portion of the heat of the gases passing through them can get to the water surrounding the tubes. The remainder is carried to the chimney. In a boiler tube, a layer of soot $\frac{1}{8}$ in. thick will cause as much waste of fuel as $\frac{3}{32}$ in. of scale. When burning bituminous coal, soot will collect to the above depth in about ten hours. Therefore, in order to have reasonably clean tubes at all times it is necessary to clean them once each day.

361. Care of Boiler.—The boiler should be inspected frequently during construction, and when completed should be thoroughly tested. After the boiler is in position and the brickwork completed, it should be allowed to stand, if possible, for a week in order to give the brickwork a chance to dry and set. After this it may be filled to the proper level and a small fire kept burning under it for a few days. Great care should be taken at this time not to heat up the boiler and brickwork too quickly.

In starting up a new boiler, it is a good plan to put a few pounds of sal soda in the water, and then, after the brickwork is well dried and set, to let down the fire and steam, run off the water, and give the boiler a good washing out. This treatment will be found to prevent the foaming which so often occurs when a new boiler is started. This foaming is caused by the grease left in the boiler by the boiler-makers.

The fireman who has charge should at all times, before starting his fire, see that the water in the boiler is at the proper level. He should not be satisfied by merely looking at the water glass, but should open the cock at the bottom of the glass, and also try the gauge cock. Many accidents have occurred through neglect of this duty. He should also see that the blow-off cock is in order and closed, that the ash pit is clear of ashes, that the tubes are clean, and that the safety valve is raised off its seat, or that some valve or cock is open to the atmosphere until steam issues from it. The grate bars should be covered with coal from the bridge wall toward the furnace door for about 3 ft. The fireman should then put some light wood on the grate in front of the coal and with a little oily waste set fire to it. When the fire has thoroughly kindled the wood a little coal may be put on it. During this time the ash pit should be closed and the furnace door left open a little so that the flames may be communicated to the coal at the back of the furnace.

As soon as a good fire is burning in the front of the furnace, the front coals may be pushed back a little and the ash pit damper opened. The fire should not be forced, but should be allowed to work up gradually. An unequal strain through forcing the fire when the boiler is cold may cause leakage and make expensive repairs necessary. The fires should be maintained level and of a uniform thickness, but the thickness must be determined by the demand for steam, the condition of the chimney draught, and by the quality and nature of the fuel.

362. Firing the Boiler.—Firing can best be done when combustion is good, as but little dense smoke then is given off. Dark spots in the fire, abundance of smoke, unsteady steam pressure, unsteady water line, dirty tubes, and coal in the ash heap are all evidences of careless firing, and should not be tolerated. Experience is the only guide to the best methods of handling the different kinds of fuel under the different conditions to be met with in practice.

The coal should be put in lightly at regular intervals in order to fire the green coal in the front of the furnace and to allow the smoke to pass over a bed of incandescent fuel at the back, and be consumed. Later the coal in front may be pushed back and new coal added to take its place.

Side-firing, i.e., keeping one side of the fire always brilliant while firing green coal on the opposite side, works very well. No established rule, however, can be set for every condition, and much must be left to the judgment of the fireman in each individual case. When firing or cleaning fires where the chimney draught is very strong, it is advisable to check the stack damper to prevent too great a quantity of cold air entering the furnace and causing undue contraction of the plates. In boilers having a large furnace, it is well when cleaning fires to clean one side at a time.

The feed water should be kept constantly on, and the water line maintained at the proper level all the time. Every day the steam pressure should be raised to the blowing-off point, so that the fireman may know that the safety valve is in working order. If at any time, from any cause, the gauge should show the pressure increasing rapidly up to or past the limit, the feed should at once be put on and the draught checked.

363. Chimneys and Flues.—A chimney is a vertical flue, usually of iron or brick, for conveying the heated air and combustion gases from the fire to the outer air. It usually extends some distance above the tops of buildings. The height of the chimney determines the intensity of the draught. The capacity of the chimney depends upon its height and area. A draught may be natural, induced, or forced.

A natural draught is produced by a chimney alone, and is due to the difference between the weight of a column of the hot gases inside the chimney and an equal column of air on the outside. To illustrate: The air entering the furnace may have an average temperature of 62° F., while that in chimneys often has a temperature of 500° F. A cubic foot of air at 62° weighs .0761 lbs., and at 500° it weighs .0413 lbs. The heated air is therefore .0348 lbs. lighter than the average air. Hence its rapid passage to the smoke-stack and the consequent draught. The length of stack or passageway has much to do with the rapidity with which the smoke travels. On every square foot of the cross-section of a 100-ft. stack, there is at the bottom an upward pressure of 100 times .0348 lbs., or 3.48 lbs.

Induced draught is obtained by placing a fan-blower at or above the boilers. The uptake from the boiler is connected to the inlet of the blower and the outlet is carried to the chimney, discharging the gases and heated air into the chimney.

Forced draught is obtained by conducting the discharge of a powerful blower to the ash pit, the air being forced through the fire.

364. Theory of Combustion and Smoke.—Smoke is a by-product of the combustion of fuel, and is invariably the result of incomplete combustion. It is composed chiefly of minute particles of carbon and steam, and is due largely to an excess of air admitted to the fire, although in a few cases the production of smoke is due to an insufficient supply of air. If the boiler is not crowded and the draught is good, the volume of smoke will be reduced by first allowing the coal to coke in front of the grates and by then pushing it back over the bright coals. The hollow bridge wall, with suitable means for regulating the supply of air, also gives good results where there is a strong draught. A small grate area and a very hot fire will reduce the volume of smoke, as will a very large grate area and a slow fire, although the former arrangement is the more economical.

An economical manner of banking fires is to push the live coals back against the bridge wall, leaving the forward part of the grates covered with ashes only, then covering the live coals with a moderately thick layer of fresh coal. Fine coal is preferable as the air does not readily pass through it, especially when the draught is diminished by closing the damper; this should be done just before covering the fire with fresh coal. The damper should be left open a very little to avoid the accumulation of gas in the furnace and the possibility of an explosion. This method of banking fires saves much time when preparing to start again. The grates may be quite thoroughly cleaned without disturbing the low fire at the bridge wall.

In case the water level becomes dangerously low, the fire should be drawn immediately. The engine should continue to run, and water should not enter the boiler in any quantity. When the furnace has cooled down to about the same temperature as the boiler, the water level may be raised very gradually until water appears in the glass. The boiler may then be filled more rapidly and the fire started.

365. Temperatures of Steam.—After steam has been once generated, the temperature remains constant, and the latent heat, not observable by the thermometer, is absorbed. The temperature of steam in contact with the water from which it is generated depends upon the pressure. If the vessel is closed, as in boilers, the pressure becomes greater and raises the boiling point of the water. Steam under pressure and confined has considerable energy due to heat, which is measured, as already noted, by the heat unit, B. T. U.

When the steam is taken directly from the boiler to the engine, it is termed saturated steam and is generated in contact with its water of generation.

When the boiler is overworked, the steam, due to the violent action of its generation, takes with it particles of water. Such steam is called wet steam. Dry steam contains no watery moisture; it may be saturated or supersaturated.

Steam from the boiler, heated to a higher temperature by passing it through a vessel or coils of pipe separated from the boiler, called a superheater, is termed superheated steam. Steam loses heat as quickly as it acquires it, and so every passage conveying superheated steam should be well covered with non-conducting material.

366. Terms Used in Calculations.—One should be familiar with a number of terms which are frequently used in calculations.

Heating surface means all surface having water on one side and fire or heated gases on the other.

Grate surface means the surface of the grate bars, or the area of the surface which supports the burning fuel.

Steam room is the space above the water line, or all the space in a boiler not occupied by water.

Horse-power. There is no such thing as the horse-power of a boiler. The term horse-power refers to the measurement of power or energy produced in a given time. A boiler does not produce energy; therefore, the work of a boiler cannot be measured by horse-power. Energy is the product of a given force in pounds multiplied by the distance in feet through which it moves; horse-power is obtained by dividing the energy thus obtained in one second by 550; in one minute, by 33,000; and in one hour by 1,980,000. A boiler contains a force only. Therefore the term horse-power is merely relative, and when applied to a boiler conveys to the mind the horse-power of an engine which a boiler of a given size is capable of supplying with steam.

Priming is that process by which the water is carried up into the steam pipes in considerable quantities and frequently over into the engine. The most common cause is a high water line, which may be the effect of a faulty boiler design. Too many tubes, the forcing of a boiler, irregular firing, or sudden opening of the stop valve may also cause it.

Questions

1. Trace the energy used in a steam boiler from its original source.

2. Why is steam considered an aqueous vapor and not a gas?

3. Describe the properties of steam.

4. What properties of steam are common to gases?

5. What is a boiler?

6. Describe the two classes of boilers.

7. Explain the manufacture of boilers.

8. Why is a boiler cylindrical and not square?

9. State the advantages of water-tube boilers.

10. State the advantages of return tubular boilers.

11. How are boilers tested? Explain the principle underlying each method.

12. What objection is there to adding cold water to boilers?

13. How are boilers repaired? What is the difference between a hard and a soft patch?

14. What are the principal parts of a boiler?

15. What is a fusible plug? Why is it used?

16. Why is a manhole elliptical and not circular?

17. What are the devices used on a boiler to tell when the maximum pressure is exceeded?

18. Describe a safety valve; pressure gauge; water gauge.

19. How is water fed into a boiler?

20. Describe an injector. State the principle on which it works.

21. Describe a water injector.

22. Describe a water heater.

23. What is a damper regulator?

24. Why is it necessary to clean a boiler? How is it cleaned?

25. Describe the steps in starting a fire in a new boiler.

26. Describe the steps in firing a boiler.

27. What is a chimney?

28. Explain the theory of combustion and smoke.

29. Define the following terms: saturated steam; wet steam; dry steam; supersaturated steam; heating surface of a boiler; horse-power of a boiler; priming.

CHAPTER XXVI

THE STEAM ENGINE

367. History of the Steam Engine.—The steam engine is one of the most important mechanical contrivances used in trade and industry. With its discovery came the great industrial development of the world. The first steam engine was invented by James Watt in 1781. For a long time he seems to have been practically the only engine-builder doing business and his patents probably prevented others from entering this field until about the beginning of the nineteenth century. The steam engine of today is the controlling feature of our industrial civilization. It furnishes the motive power for all our factories, and without it scarcely one of the articles we use in every-day life could be produced in sufficient quantity to satisfy human needs.

The steam pressure of the first engines was very low. Watt ran his engines with a pressure of only seven or eight pounds more than atmospheric pressure. The boiler pressures in current use have steadily risen during the past century as better materials and better workmanship made higher pressures safe and advisable. Today 125 lbs. per square inch is a very common pressure for ordinary stationary engines; 150 to 175 lbs. pressure is frequently met with in large power plants; and in special cases 200 lbs. pressure is employed. This increased pressure, of course, enables the steam engine to yield a much larger output of power per ton of total weight and the limit is not yet reached. As it has been possible to increase boiler pressures, so also the working parts and the structure of steam engines have been improved and strengthened, until now the weight of engine per horse-power of capacity and the cost of the plant are much less than in Watt's time.

368. Principal Parts of Steam Engines.—The principal parts of a simple engine (Fig. 169) are the frame, cylinder,

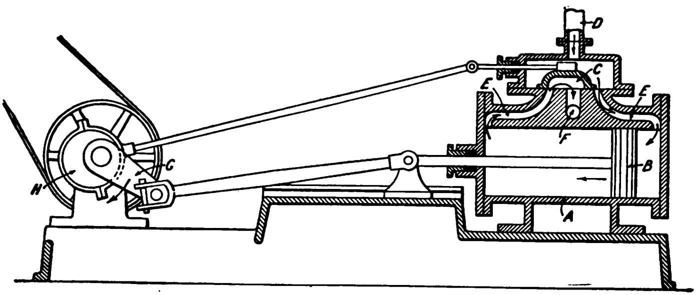


FIG. 169.—Steam Engine.

A—Cylinder	*D*—Steam Inlet	*G*—Crank
B—Piston	*E*—Steam Ports	*H*—Slide Valve Eccentric
C—Slide Valve	*F*—Exhaust Port	

piston, rods, eccentric, crank shaft, governor, and wheels. The *cylinder* is the long, round, iron barrel or tube in which the piston works. The *piston* is a disk, fitting into the cylinder and dividing it into two compartments. Packing rings are provided to make it steam-tight. The piston moves back and forth, forced by the steam which is alternately admitted on each side of it by means of openings called ports. That is, steam is allowed to enter the cylinder by one port, and forces the piston along, the other port being opened by the slide valve into the exhaust port during this stroke. As soon as the piston has reached the end of the cylinder, the first port closes for the admission of steam, while the second port admits steam which pushes the piston back again to its original position.

The back and forth movement, thus imparted to the piston by the steam, is transmitted to the crank and then to the heavy fly-wheel. The fly-wheel by means of belting or rope transmits motion to the smaller wheels or pulleys which drive the machines in factories.

After moving the piston, the steam either escapes into the air, as it does in the case of a steam locomotive, or passes into one or more other cylinders where it exerts its force until it condenses. An engine that allows steam to escape into one cylinder only, is called a simple engine. If the steam expands twice it is called a compound expansion, and if it expands three times it is called a triple expansion.

369. Purpose of a Governor.—The governor (Fig. 170) of a steam engine is a device which controls the supply of steam by letting into the cylinder just the right quantity. In the pipe which carries the steam from the boiler to the cylinder is a valve called the throttle valve, by which the communication between boiler and engine may be opened or closed. A rod connects this valve to the governor, which is made to turn round by a belt from the crank shaft. The faster the crank shaft turns the faster the governor goes round. At the lower end of the governor are two heavy balls, so hung that as the speed of the governor increases they swing out farther from the center rod and as it slows down

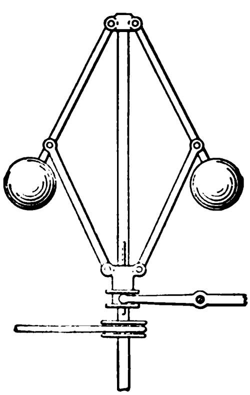


FIG. 170.—Governor.

they swing nearer to it. This action of the balls is due to centrifugal force. It opens and shuts the throttle valve by raising and lowering the rod which leads from the governor and in this manner the supply of steam is regulated. If the engine moves too fast, the balls of the governor swing out, and this pulls on the rod and partly closes the valve, shutting off some of the steam; if it goes too slowly the balls swing inward and thus open the valve and let in more steam. Thus the speed of the engine is regulated by the governor.

The speed of the governor should be carefully adjusted, and all its parts kept clean and in perfect working order. When this is done, the engine will always run at a uniform speed, no matter what load or work is on at any time. If any machine is suddenly thrown out of action, the governor should at once control the speed of the engine by cutting off the supply of steam. On the other hand, when a heavy load comes on more steam is admitted by the governor, and thus the speed of the engine is kept nearly constant or uniform.

370. Crank.—The "crank" is a mechanical device employed for converting the parallel or reciprocating motion of the piston into a rotary motion. It is connected by a key to the shaft, which carries the fly-wheel. The power transmitted to the crank exactly represents that exerted by the steam in the cylinder against the piston, minus the friction.

Between the piston and crank, connection is made by means of a cross-head and connecting rod; the cross-head runs to and fro between guides. This motion of the cross-head is necessary to prevent the piston rod from being broken or bent by the oblique positions of the connecting rod when the crank is at mid-travel. The distance from the center of the shaft to the center of the crank pin is called the crank's throw, and is half the piston stroke.

371. Dead Center.—When the piston rod is fully out or fully in, and the connecting rod and the crank in consequence lie in a straight line, the crank is said to be at a *dead point* or *dead center*. When the crank is in this position the admission of steam will not produce motion since the thrust would be absorbed by the bearings. A locomotive engine must be constructed so that it may be started in any position. In order that this may be done the engine must have at least two cylinders, and the cranks must be set at an angle to one another, so that when the crank of one is at a dead point the other has reached a position where it exerts its maximum turning power.

372. Steam Valves.—The steam is admitted into the cylinder of an engine by means of valves, as previously stated. There are three distinct types of valve—(1) slide, (2) Corliss, and (3) poppet valves.

The *slide valve* is a simple casting similar in its lengthwise section to the letter D. By being moved back and forth over the steam ports of the engine it admits and exhausts the steam alternately, thus causing the piston in the cylinder to work back and forth.

Corliss valves are semirotary valves, cylindrical in shape, which partly turn in cylindrical chambers.

Poppet valves are simply disks attached to a stem, which work over a circular opening. They are raised and lowered over the parts.

The mechanism controlling these valves is called the *valve gear*.

373. Condensing Engines.—Non-condensing or high-pressure engines are less economical than condensing or low-pressure engines, because they use much more steam. When the waste steam is let out of the cylinder, the air rushes in and takes its place. This air presses hard against the piston so that it takes power to drive it down.

After the steam is condensed in the condensing engine there is a vacuum, or an empty space, on one side of the piston, so that but little fresh steam is necessary to drive it. Thus the object of condensing is to do away with the back pressure on the piston and thereby increase the mean effective pressure. There is a gain of 20 to 33⅓ % in economy, depending on the size and type of engine. In small engines the saving is not enough to be considered.

Where fresh water is scarce, it is of great importance to the marine engineer to condense the steam by leading it into a condenser when it has finished moving the piston. In this process the steam as it leaves the cylinder enters a condenser and passes over a number of copper tubes, through which sea water is circulated by means of a pump. The steam is thus condensed into water and a vacuum is created. Since this water is warm, it is pumped into a hot-water well, whence a pipe leads it to a pump, which in turn carries it back to a boiler.

374. Installation of Pipes.—In installing pipes and metal fittings of all kinds it is absolutely necessary to make proper provision for expansion. (See Chapter IX, "Heat and Expansion.") When steam is turned on the temperature is raised and the pipes expand. Pieces of curved pipe called *bends* are usually used to take up the expansion and prevent the joints from leaking. When steam is suddenly admitted to a pipe partly filled with cold water, the water is set in violent motion and travels the length of the pipe in the form of waves often with sufficient velocity to break a valve or other obstruction in its path. The extent of the break will depend upon the manner in which the valve is opened. If opened suddenly, a violent explosion is almost certain to follow, but if opened very gradually, while there may be a certain amount of noise and vibration, no serious results will occur.

Engines are usually placed in a house separate from the boiler, although it is a good plan to have them near so as to avoid the necessity of laying great lengths of steam pipe. Steam pipes are made of wrought iron or steel with flanged joints. The pipes conducting the steam from the boiler to the engines are covered with non-conducting material, such as asbestos, to prevent the escape of heat. Draw-off cocks are placed in convenient positions along the pipe to draw off the water formed from condensed steam.

375. Alignment of Pipes.—When pipes are not in a straight line, they are said to be out of alignment. Want of alignment sometimes causes trouble by throwing excessive strains on the flanges at the joints of stop valves, separators, etc. This trouble is brought about, as a rule, by forcing the flanges together by means of their joining bolts instead of fitting them carefully into place. The flanges of modern steel pipes and valves are usually of ample thickness, and if they do not come together fairly, they should be taken down and replaced. A thin ring of metal may be put in to make up the length, if necessary.

When erecting heavy pipes, every length of piping should be placed in position and properly supported and leveled by its own slings and brackets. Then it will usually be found that several lengths have to be altered before the flange faces come into alignment. Not until this has been done and every pair of flanges inspected by some responsible person, should the various lengths be bolted together permanently.

When a number of small or moderate-sized engines are connected with the same pipe system and stand on the same foundation, or in the same building, it is sometimes difficult to prevent the pipes from vibrating and at the same time insure the necessary freedom for expansion and contraction. Installations of this kind should therefore be arranged in such a way that the pipes are quite free to move in one direction, parallel with their length, while movement in other directions should be restricted so far as possible.

High-speed engines are those whose fly-wheels rotate at a high speed; i.e., make a large number of revolutions per minute. Such engines are less expensive to operate than low-speed engines, because the power of an engine depends upon area of its piston, the mean pressure of steam, and the speed at which its fly-wheel rotates. Therefore by doubling the speed, an engine may be built very much smaller and cheaper per horse-power. Engines of this type are used for driving electrical machinery, which requires high speed of rotation and uniform angular velocity.

376. Horse-Power.—The power of a steam engine is commonly designated as horse-power. *One horse-power is a force strong enough to raise 33,000 lbs. one foot high in one minute;* this has been found to be about what a very strong horse could do working 8 hrs. a day. An engine of 100 H. P. would be, of course, able to do a hundred times as much as this. A steam-boat of 1000 tons generally has an engine of 360 H. P. A man-of-war usually has one horse-power for every ton.

There are several kinds of horse-power referred to in the discussion of a steam engine; *nominal, indicated,* and *actual* or *net.*

Nominal horse-power was a term used during the invention of the steam engine to express the amount of work an engine could perform during a given time.

Indicated horse-power is obtained by multiplying the mean effective pressure in the cylinder in pounds per square inch, by the speed in feet per minute, and dividing the product by 33,000.

Actual or *net horse-power* is the difference between the indicated horse-power and the amount of horse-power expended in overcoming friction.

EXAMPLE.—What is the horse-power of an engine that can pump 68 cu. ft. of water from a depth of 108 ft.?

$$\text{1 cu. ft. of water} = 62\tfrac{1}{2}\text{ lbs.}$$
$$68 \times 62\tfrac{1}{2} = 4250\text{ lbs.}$$
$$4250 \times 108 = 459{,}000\text{ ft.-lbs.}$$
$$\frac{459{,}000}{33{,}000} = \frac{153}{11} = 13\tfrac{10}{11}\text{ H.P.} = 13.9\text{ H.P.}$$

377. Corrosion of Pipes.—If the feed water contains lime salts, a deposit will be formed in the economizer and feed connection which will more or less effectually protect the pipes from internal corrosion ("rusting" or "eating away"). If, however, the water is very free from lime, and air is introduced by the feed pump, internal pitting (small hollows) will be formed. Considerable damage may then be done before the danger is discovered and steps taken to prevent further mischief.

External corrosion does not as a rule give much trouble, but under certain conditions the combined action of heat and moisture on asbestos pipe-covering will set up pitting. This, however, can be prevented by painting the pipes with any good graphite paint before the covering is applied.

378. Piping Material.—For all ordinary and high pressures used in connection with land boilers, steel pipe is almost invariably adopted, the longitudinal joints being lap-welded. Cast steel is largely employed for bends and elbows, although copper is used in high-class work. Many old plants with pressures up to 100 lb. per square inch are working with cast iron pipes. On board ship, pipes are usually made of copper.

Pipes of small diameter are generally solid drawn, but many steam pipes on board ship are made with brazed joints. In their construction, makers usually allow a factor of safety varying from 10 to 15 tons per square inch, assuming the copper to possess an ultimate tenacity of about 15 tons per square inch.

Steam pipes expand and contract about one inch in fifty feet, through variation of temperature. It is best to allow for this movement, when possible, by arranging springing lengths, so that the whole arrangement may be elastic. When there are long lengths between fixed supports, expansion sockets are sometimes adopted. These, however, should always be fitted with guard bolts, to prevent the pipe from being accidentally drawn apart.

Steam pipes should always be kept free from water, and drain taps should, consequently, be fitted wherever necessary. Should an accumulation of water accidentally occur in a long horizontal length of pipe, its drainage under steam pressure is very liable to cause fracture. Therefore drainage should not be attempted without first isolating the boilers so as to minimize the danger.

379. Turbines.—We have already seen the uses of water wheels or water turbines. Steam turbines (Fig. 171) consist of a wheel with blades. The steam, in the form of jets, strikes against the blades and moves the wheel. This machine was invented to overcome the backward and forward (reciprocating) movement of the piston, which jars and shakes the engine.

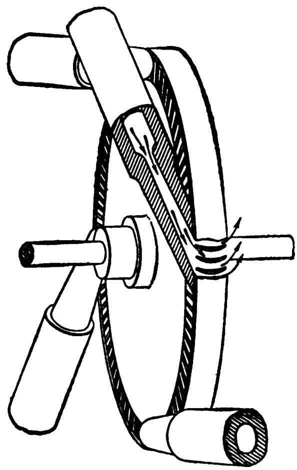


FIG. 171.—Steam Turbine.

Steam turbines utilize the kinetic energy of the steam. As steam at the usual pressures employed has a very low density, a cubic inch of steam must have a very high velocity if it is to expel any considerable amount of kinetic energy.

380. Action of Steam in a Turbine.—In entering the turbine, steam acts in two ways, and turbines are accordingly constructed on two plans. The more important type and the only one to be described here, is the impulse turbine, in which the steam from the boiler is completely or almost completely expanded into an expanding nozzle. As the steam forcibly strikes the vanes of the wheel, the turbine wheel rotates at a very high velocity. This is illustrated in the De Laval turbine which is used in place of the ordinary steam engine in the generation of electric power, or in the transmission of any other form of energy derived from steam.

The working of the De Laval turbine is as follows: The steam is blown through stationary divergent nozzles where it is allowed to expand to the pressure of the exhaust chamber. Each particle of steam, which moves very rapidly, strikes against a concave vane or plate which projects from the drum like a spoke. This causes the wheel to move rapidly. The outer end of the buckets are covered by a ring which prevents the centrifugal escape of the steam. The nozzles vary in number and can be closed independently of each other, so that the number in use may be made to suit conditions of running.

As the material composing the turbine machine limits the speed at which it can safely be run, it is necessary to have some form of reducing gear in the transmission. The smaller types of De Laval turbines run at about 30,000 R. P. M., and are geared down to about 3000. The larger sizes run at about 10,000 R. P. M. under gear. Even with all the disadvantages of gearing, the turbine is used extensively in units ranging from 1½ to 200 H. P.

Its principal parts are the shaft, drum, cylindrical case inside of which the drum revolves, vanes on the drum and cylindrical part, balance pistons.

381. Measurement of Work in Heat Units.—Experiments show that one unit of heat is equivalent to 772 ft.-lbs. of work, and when this quantity of work disappears in friction, one unit of heat is generated. Other experiments show that the unit should be 778 ft.-lbs. It is not of much importance which number is used; some use one, and some use the other, but all agree in naming this quantity of work after the discoverer of the relationship, James P. Joule of Manchester, England. The unit is therefore called Joule's equivalent, or the mechanical equivalent of heat.

EXAMPLE.—One pound of good coal gives out on complete combustion, 14,500 B. T. U. of heat. Find the amount of work stored in one pound of coal.

Units of heat × Mechanical equivalent = Work in foot-pounds.

$$14{,}500 \times 772 = 11{,}194{,}000 \text{ ft.-lbs.}$$

Questions

1. Who invented the steam engine?
2. What effect has the development of the steam engine had upon trades and industry?
3. What is a steam engine?
4. What property has steam that allows it to drive a piston?
5. What is the purpose of the fly-wheel?
6. Why is a fly-wheel large and heavy?
7. What kind of motion has the moving piston of an engine?
8. What kind of motion has the fly-wheel of an engine?
9. How is the motion of the piston communicated to the fly-wheel?
10. Why is it desirable to have the escaping steam enter a condenser?
11. What is a condensing engine?
12. What is a non-condensing engine?
13. What is the eccentric of an engine?
14. What is the governor of an engine?
15. What is the efficiency of an engine?
16. How is the power of an engine expressed?
17. What is a rotary engine?
18. What is a turbine?
19. What advantage has the turbine over the reciprocating (straight-line) engine?
20. Explain how a turbine works.
21. Explain the measuring of indicated horse-power.

Problems

1. What is the H. P. of an engine that is required to pump out in 8 minutes a basement 51 ft. × 22 ft. × 10 ft. deep, full of water?

2. What is the H. P. of an engine that is capable of raising 3 tons of coal (2240 lbs. to the ton) from a mine 289 ft. deep in 3 minutes?

3. How many tons of coal can an 8 H. P. hoisting engine raise in 34 sec. from the hold of a coal barge, a distance of 61 ft.?

4. How long will it take a 10 H. P. hoisting engine to raise an 812-lb. ram of a pile-driver to a height of 23 ft.?

5. How many pounds of water per half-minute can an 8 H. P. pump raise to a height of 86 ft.?

6. If 1 lb. of coal gives off 15,337 B. T. U. of heat, find the amount of work stored in 1 lb. of coal.

7. If 1 lb of coal gives off 14,897 B. T. U. of heat, find the amount of work stored in 1 lb. of coal.

8. If 1 lb. of coal gives off 15,111 B. T. U. of heat, find the amount of work stored in 1 lb. of coal.

CHAPTER XXVII

METHODS OF HEATING

382. Starting a Fire.—In countries where the winters are cold it is necessary to devote a great deal of time and labor to the heating of dwellings. Heat is usually obtained by the burning of wood, coal, etc. Such substances are called fuel. The harder the fuel, the more difficult it is to kindle. Coal is harder to light than wood because of its density, which increases the difficulty of raising it to the temperature which is necessary for burning. If the heat of another fuel, such as kindling wood, be applied to the coal in sufficient quantity and long enough to ignite it, it will then produce a fire much more powerful and much more durable than will the lighter fuel. Lighter fuel kindles easily, but the mixture of air in its pores causes it to burn out rapidly. Hence the heat it produces is but temporary, though often very strong. The usual method of getting rid of the smoke from a fireplace is through a chimney.

383. Methods of Heating.—Modern buildings and houses are heated by stoves, steam, hot water, or furnaces. The choice of any particular method will depend upon special conditions and requirements. Heat is given from a stove by radiation (Fig. 172); that is, the stove becomes hot, due to the burning of coal, and the metallic parts radiate the heat. A stove is not an economical means of heating, because much of the hot air goes up the chimney and is wasted. Moreover, to heat a home it is necessary to have a stove in each room. A large furnace in the cellar overcomes these drawbacks, and is consequently used in most houses. From the furnace, hot air is distributed through ducts to the different rooms. Such a furnace draws in fresh outside air and passes it into a dome over and around the hot coal. As the air becomes hot, it expands, and thus makes its way to the several rooms.

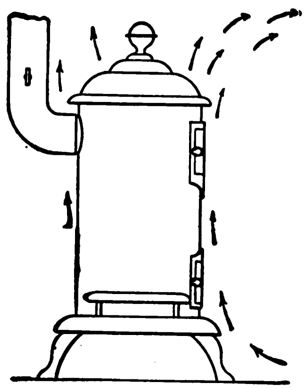


FIG. 172.—Heating by Stove.

Steam radiates its heat with ease, and also condenses very rapidly. Heat given off by a steam furnace is called steam heat and may be provided directly or indirectly. Direct heat is given off by radiators in the room to be warmed, while indirect heat is supplied by distributing throughout the building air that has been warmed by passing over radiators in the basement.

Wood and coal stoves, gas heaters, steam and hot-water radiators, coils of heated pipe, and electric resistance heaters are all examples of direct radiation. The air in a room is heated over and over again, and fresh air is admitted usually only by leakage around doors and windows or by the opening of one or the other.

384. Steam Heating.—Steam for heating (Fig. 173) is obtained from a boiler fitted with coils of pipe. As the steam passes through the radiator it gives off its heat and is condensed into water. This water flows back into the boiler, either through another return pipe or through the same pipe.

The double-pipe system requires greater length of piping, but the single-pipe system requires larger piping, so as to allow the condensed water to return to the boiler while the steam is ascending the pipe.

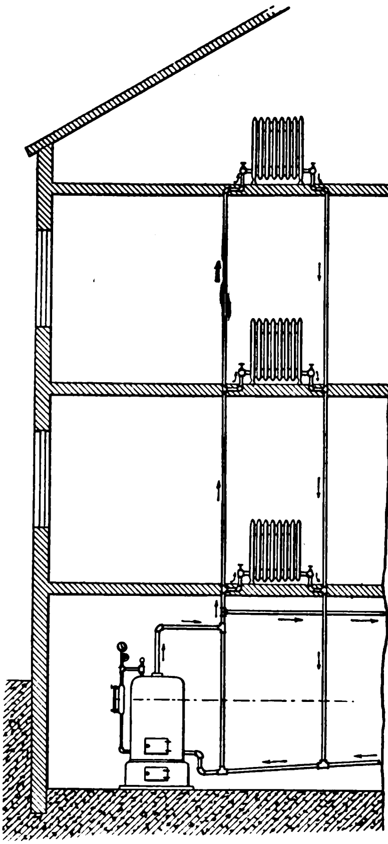


FIG. 173.—Steam Heating System.

385. Indirect Method.—The indirect method of heating (Fig. 174) is the more effective system for large buildings and schools. The heater is generally placed in a cellar or basement. The air is passed over its surface of pipes, and is then directed by a distributing system of sheet iron or tin pipes up into the rooms to be warmed. Heating has the effect of circulating the air in the conducting pipes. The air may, too, be forced into the circulating pipes by a blower or fan located in the cellar. The well-known hot-air furnace is an example of the indirect method of heating.

386. Advantages and Disadvantages of the Indirect Method.—One great advantage of the indirect system is that there is always some ventilation. New air is always entering the rooms, while at the same time the older air must make its escape around windows and doors, or pass out through flues built into the walls of the building for this purpose.

Ideal ventilation is not often secured, however, even by indirect heating, for the air that comes from a cellar is not always pure and fresh. It is more often dusty and odorous from the refuse or decaying matter which frequently lies about a cellar. To overcome this difficulty, the air should be brought in from outside the building by means of an air-tight flue or box. The inlet to the box should be carried up high enough outside of the building to avoid drawing in litter and dust and should be covered with a strong wire-mesh screen to keep out rats. In many public school heating systems the outside air, before entering the heater, is purified by being passed through a water-spray curtain.

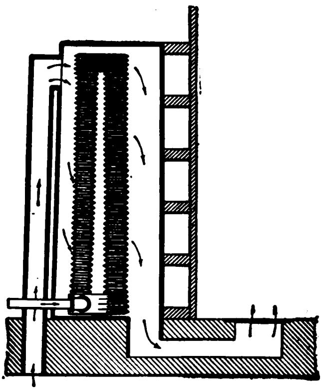


FIG. 174.—Indirect Heating System.

387. Exhaust Steam Heating.—Exhaust steam from an engine is often used for heating. The water of condensation from an exhaust steam heating plant is frequently allowed to run to waste, but as its temperature is near boiling, coal is saved if the water is collected in a receiver and pumped back into the boiler. Mill engines that are run with condensers cannot furnish exhaust steam for heating. In such a case, live steam must be taken from a branch opening in the main steam drum in the boiler-room. This requires the use of a reducing valve to let the pressure down between 5 and 15 lbs. for the heating coils. A receiving tank is necessary for the return water, and a pump must be installed to force it back to the boilers. Some mills have spare boilers that are used only for heating purposes. These may be run at a low pressure, 10 lbs., and the steam may be passed directly into the heating system without the use of a reducing valve. When the return water is piped directly to the feed pipe of the boilers we have what is known as a gravity return system. Since there is the same pressure in the heating system that there is in the boiler, the water of condensation runs back into the boiler simply by its own weight. This requires that all heating pipes be on a higher level than the water line in the boiler. If any radiators or coils were lower than the boiler, they would, of course, fill with water, and a pump would be required to return the water from the low coils to the boiler. The gravity return system is used in many dwellings, office buildings, churches, and stores

388. Low-Pressure Steam Heating.—When steam at atmospheric pressure is condensed into water at a temperature of 212° F., each pound of steam gives up 966 B. T. U. of heat; but if steam of 100 lbs. gauge pressure (115 lbs. absolute) is condensed into water at 212° F., each pound of steam must give up 1004 B. T. U., which is only 38 heat units more than are contained in steam of atmospheric pressure. It is evident from this that for heating purposes there is no advantage in using steam of a high pressure. One pound of exhaust steam, only a pound or two over atmospheric pressure, is almost as valuable an agent for heating purposes, as live steam at 100 lbs. pressure direct from the boiler.

389. Gas for Heating Purposes.—Gas, both natural and manufactured, is used extensively for heating. It burns with either a blue flame or yellow, luminous flame, depending upon the type of flame device or burner which is used. The yellow flame is suitable only for fireplaces or portable heaters and its burner must be kept cleaned and regulated so that no smoke or soot is given off. Since blue-flame gas heating appliances do give off smoke and soot they are usually connected with a flue or set in a fireplace that has an effective flue.

The blue flame is hotter than the yellow flame because it is the product of perfect combustion, while particles of unburned carbon are floating about in the yellow flame. The burners of blue-flame heating appliances are usually provided with an air shutter by which the quantity of air which mixes with the gas within the burner can be regulated. If a large amount of air is admitted the number of carbon particles is increased and the result is imperfect combustion. The shutter should be opened sufficiently so that the flame above each burner opening will have a sharply defined inner blue or bluish green cone. This indicates that an adequate amount of air is mixing with the gas in the burner.

If the air shutter is too wide open the gas may "fire back" and burn within the burner itself. When the gas burns inside the burner, combustion is incomplete and dangerous products of partial burning are given off. The improper burning of the gas within the burner is sometimes called "lighting back" and is accompanied by a roaring noise. When this unusual noise is heard the gas should be turned out at once and, after a moment, lighted again.

390. Hot-Water Heating.—A hot-water heating system (Fig. 175) operates by the movement of hot water from the boiler to radiators, where it gives off heat. The colder water, which has already given off its heat, returns to the boiler to become reheated. By the circulation of water, heat is conveyed from the boiler to the room. The movement of the water is due to the fact that hot water is lighter, or in other words its density is less, than cold water; hence it will rise and more cold water will come in to take its place. This movement will continue so long as there is a difference in temperature in the system. One sq. ft. of heating surface is required for 30 to 60 cu. ft. of space heated.

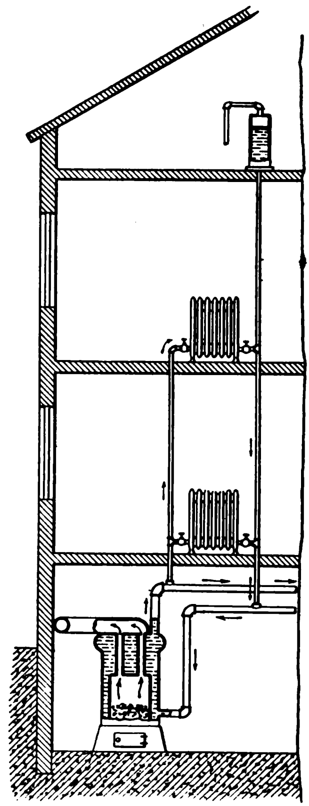


Fig. 175.—Hot-Water Heating System.

391. Air Circulation. — The circulation and ventilation of the air in a room is necessary in any method of heating. Warmed air rises to the top of a room and the cooler air settles nearer the floor. A steam radiator warms the air directly in contact with it and this air therefore rises. Cold air takes its place and is in turn warmed. The temperature of the air in the room gradually rises until the air, walls, ceiling, and furniture or machines have all been warmed. A certain amount of heat is lost through the walls, ceiling, and windows, and there is always a leakage of cold air into a room through cracks at windows and doors. This loss of heat outwards and cold air leakage inwards increases as the difference between the temperature of the inside and outside air increases. Double-windows, storm-doors, building-paper under shingles, clapboards, and plastering tend to check these losses.

392. Radiators and Radiation.—Radiators are made up of hollow sections of cast iron. The outer surfaces are so shaped as to give the greatest possible area or, as it is generally called, the greatest radiating surface. The castings for radiators are purposely made rough, and are often elaborately figured in pleasing designs, so as to present a larger radiating surface than would be the case if they were smoothly finished. The transfer of heat from hot metal surfaces to air is more efficient if the radiating surface is rough and the color is dark. Radiators are sometimes gilded for appearance, but practically they do not heat as well as if left ungilded. A cheap form of radiator for stores and shops is cast with innumerable projecting plugs or pins.

For large rooms a radiator may be made up of pieces of 1 in. or 1¼ in. pipe joined together by elbows and return bends. Such a radiator is called a box coil. A more common method of installing a direct radiation system is to run a group of 1¼ in. steam pipes along the side of a room and around the corner, by means of couplings to provide for expansion and contraction, and to connect the ends of the run into branch trees. The advantage of this arrangement is that it distributes the heat throughout the whole length of the room.

In a dwelling house the radiators are generally placed near the windows, since the cold air then reaches the radiators quickly. The direction of the flow of air along the floor is towards the windows. Pipe coils in mills may be run along the walls on brackets under the windows. The cold air dropping downwards from the windows meets the current of warm air rising from the coil and is tempered and warmed at once. When it is desirable to have the hot-steam coils near the working space they are generally hung from the ceiling near the outer walls. This plan works well in a shop or mill where there are shafts with whirling pulleys and belts in constant motion. The air is churned by such motion and the heated air is brought downward and mixed with the cool. In office buildings and stores, coils placed near the ceiling are not effective, for there is nothing to cause circulation and the warm air naturally tends to remain at the top of the room.

393. Measurement of Heat Radiation.—The quantity of heat given off by radiators or steam pipes, in the ordinary methods of heating buildings by direct radiation, will vary from 1¾ to 3 heat units per hour per square foot of radiating surface for each degree of difference in temperature. An average of from 2 to 2¼ heat units is a fair estimate.

One pound of steam at about atmospheric pressure contains 1146 heat units. If the temperature in the room is to be kept at 70°, while the temperature of the pipes is 212°, the difference in temperature will be 142°. Multiplying this by 2¼, the emission of heat will be 319½ heat units per hour per square foot of radiating surface. A boiler must always be capable of generating as much steam as the radiators are condensing. There should be 1 sq. ft. of heating surface in the boiler for every 8 to 10 sq. ft. of radiating surface.

394. Main Piping.—All piping must be carefully put up, and horizontal piping must have a pitch or slope of ¼ to ½ in. in 10 ft., so that the water will flow out of the system as quickly as possible. A low place or sag in the pipes or heating coils may trap the water. The result will be that a noisy snapping or hammering will take place when steam is turned on.

The pipe coils are hung on rollers to allow for expansion. After the first heating season in a new building, and occasionally in all buildings, the piping system should be examined. The shrinkage and settling of floors may throw pipes and radiators out of place sufficiently to cause serious trouble in the action of the system.

The rule for finding the size of the main steam pipe is: Divide the amount of the direct heating surface in square feet by 100; divide the quotient by .7854; then take the square root of this last quotient. The result will be the diameter of the pipe in inches. (Pipe area = $\frac{1}{100}$ of heating surface.)

395. Risers and Returns.—Risers are the pipes that pass from the lower floor to the upper floors and to which the radiators are connected by short pipes or nipples. These connections must allow for expansion, and it is advisable to put a valve into the lower end of every riser. By taking the steam from the top of the main, less water enters the riser.

Returns are the pipes that receive the water of condensation from the coils and conduct it back to the boiler room.

396. Steam and Air Valves.—A heating system, when cold, fills with air by leakage around valve stems. This air must be allowed to escape so that steam may enter. Automatic air valves may be placed on every radiator and coil. These valves are open when cold. As steam enters the system, the air escapes ahead of the steam and finally when steam reaches the air valve, the heat of the steam expands a plug in the valve, which thus closes automatically. As the air valves often get out of order, it is a great convenience to run small $\frac{1}{4}$ in. pipes from each radiator to the boiler-room. The engineer can then open each air pipe until steam appears. When this happens he can be certain that the coils are working properly.

397. Steam Productions from Water.—The weight of water required to make 1 cu. ft. of steam at any pressure is the same as the weight of 1 cu. ft. of steam.

Therefore, the weight of water is obtained by multiplying the number of cubic feet of steam required by the weight of one cubic foot.

Example.—How much water will it take to make 300 cu. ft. of steam at 100 lbs. absolute pressure?

One cubic foot of steam at 100 lbs. pressure is given as weighing .2307 lbs. Therefore, 300 cu. ft. will weigh $300 \times .2307$, or 69.21 lbs. of water.

One cubic foot of water may, for any practical purpose, be reckoned to weigh $62\frac{1}{2}$ lbs., and the weight of one gallon of water may be taken as $8\frac{3}{10}$ lbs. Therefore, 69.21 lbs. divided by 62.5 gives 1.1 cu. ft., or 69.21 divided by 8.3 gives 8.34 gals.

At atmospheric pressure one cubic foot of steam has nearly the weight of one cubic inch of water, and the weight increases very nearly as the pressure; therefore, the rule: Multiply the number of cubic feet of steam by the absolute pressure in atmosphere and the product is the number of cubic inches of water required to give the steam.

In all such calculations, for practical purposes, a liberal allowance must be made for loss and leakage.

Questions

1. What is fuel?
2. Is a hard (dense) fuel difficult to kindle?
3. Why is it harder to light coal than wood?
4. What is smoke?
5. How is smoke removed from a fire?
6. What principle of science causes a draught?
7. Explain the method of heating by a stove.
8. Explain the method of heating by steam.
9. Explain the method of heating by hot water.
10. Explain the method of heating by a furnace.
11. What is meant by the indirect method of heating?
12. Is it possible to use exhaust steam for heating? Explain.
13. What is low pressure heating?
14. Explain why heating and ventilation go hand in hand.
15. Why are radiators rough?
16. Where are radiators usually placed?
17. How is heat radiation measured?
18. Why should steam pipes be examined after the first season?
19. What are risers? Returns?
20. Describe the valves used in steam heating.

CHAPTER XXVIII

VENTILATION

398. Object of Ventilation.—Ventilation is the process of removing from an enclosed space foul air, laden with impurities, and replacing it with fresh air. An exact displacement, however, does not always take place. The incoming fresh air may merely dilute the foul air to a point suitable for healthful breathing. The standard of pure air is taken as that existing in the open country; it contains about four parts of carbon dioxide (CO_2) per ten thousand of air and is free from dust. An increase of two parts of carbon dioxide is accepted as the standard of pure air. Any excess above this is considered impure air. Badly ventilated rooms often contain as many as 80 parts of carbon dioxide per ten thousand of air.

399. Methods of Ventilation.—There are three ways of removing dust and impurities from air in a building: (1) the natural method; (2) forced ventilation by means of fans, and (3) the exhaust method.

Natural ventilation is produced through doors and windows. The air in a room is changed by this method about three times an hour. If there is a fireplace in addition, the total number of changes per hour will be about four. A furnace will produce five changes of air per hour. Every room should be large enough to allow proper ventilation without too much draught. Authorities agree that not less than 300 cu. ft. of air space should be allowed for each person.

Heating by a hot-air furnace and by the indirect method of steam heating necessarily involves the movement of air, and therefore insures that the room will be ventilated.

Forced ventilation is produced by forcing the air into a building with a fan or blower. Such a fan operates by means of the centrifugal force of a paddle wheel which sends the air off the edge of the blades.

Exhaust ventilation is that in which fans are placed at the top of the house, or ventilating flue, thus lessening the pressure within the building by producing a slight vacuum.

400. Waste Products.—The waste products of life and industrial processes that interfere with indoor occupations are:

(*a*) Carbon dioxide and moisture from the lungs and skins of animals.

(*b*) The products of combustion from lamps, gas burners, and other artificial lights.

(*c*) Gases that are the products of cooking and manufacturing processes.

(*d*) Irritating and poisonous dusts and gases.

The human body is constantly giving off heat, carbon dioxide, and perspiration. The heat is due to the chemical combination of the oxygen in the air we breathe with the carbon of the body. The products formed are heat and carbon dioxide. The heat given off keeps the temperature of the body at about $98^2/_5°$ F. As we are constantly breathing, there is a continual supply of heat which would increase the temperature of the body above normal, unless it were radiated in this manner to the air and surrounding objects. Some of the heat is given off to the air in immediate contact with the body, by conduction, and some is lost by evaporation and perspiration.

401. Perspiration.—Perspiration consists of water charged with waste products. This water is evaporated from the skin by the air. If the air is saturated with moisture, as it often is during the summer, water does not evaporate quickly and consequently perspiration does not evaporate at its usual rate. As a result we sweat or perspire very freely. When we fan ourselves we create a small breeze which quickly evaporates or absorbs the perspiration.

Moisture is, however, readily taken up by dry air, and a consequent cooling results. But if the atmosphere has a humidity of 100 per cent, as it has just before or after rain, the perspiration cannot be evaporated since the air already has all the moisture it can hold. Everyone has noticed that when the sun shines on a hot day just after a rainfall, the heat is almost unbearable.

402. Noxious Gases.—Operatives who are exposed to irritating or poisonous gases and fumes, such as lead and its compounds, are likely to become victims of chronic poisoning. Gases that are merely irritating are of less importance than those that are poisonous, because irritating gases cannot be borne in large amounts and the person suffering from their effect is forced to seek the relief afforded by fresh air.

Offensive vapors and fumes, such as those given off in soap-making, glass-making, tanning, and rendering, etc., may cause general disturbance of the digestive system and headache for a time to those who are not used to their effects, but as a rule, tolerance is soon established and the odors are not even noticed. These odors are popularly regarded as leading to infectious disease, but this is not true, as they do not, in reality, undermine the human system.

403. Dust.—In the emery, corundum, sandpaper, and allied industries, great attention is given to keeping the dust away from the mouth and nostrils of the workmen by means of hoods and exhaust fans. Oftentimes workmen remove their hoods recklessly and thereby expose their lives to danger. There are two or three times as many deaths among grinders, polishers, and cutters due to disease of the lungs brought on by breathing these particles, as among adults following other occupations. Proper working conditions and a due amount of precaution on the part of the workman, however, render a comparatively good protection against these dangers.

In the rag-dusting, sorting, and cutting rooms of some paper mills, objectionable amounts of dust are often present. Workmen exposed to dusty atmospheres are especially susceptible to diseases of the lungs, such as tuberculosis, because of the constant irritation of the respiratory tract. Constant coughing causes the mucous membrane of the throat to become inflamed and this condition allows germs to thrive. In a healthy individual the normal mucous membrane would not allow the germs to penetrate the membrane.

404. Cause of Tuberculosis.—It is a well-known fact that a large percentage of deaths among factory operatives is due to consumption. While perhaps some of this may be traced to the environment of the home, many cases are contracted in the factory from people who are in the early stages of the disease. The reason lies in the fact that in every act of spitting, coughing, sneezing, and speaking, minute droplets of saliva, which may contain tuberculosis germs (specific bacilli), are sent forth into the air, in which they remain suspended for some time. The spitting consumptive is usually a victim of the disease long before it is known. Sputum cast about upon the floor and elsewhere becomes dried on exposure to the air and then ground to powder, the bacilli spreading in all directions.

Enough has been said to show the need of a systematic method of removing the waste gases, dust, etc., from rooms and buildings. Natural agencies, like the air, that pass through the cracks of floors, doors, and windows may be sufficient to remove some of the carbon dioxide of a dwelling house by replacing it with new air, but in a factory where hundreds of people are employed in the same rooms this method is ineffective.

Questions

1. What is ventilation?
2. Why is ventilation necessary?
3. What are the different methods of ventilation?
4. Describe each method of ventilation.
5. What are the waste products of industrial processes?
6. Describe the changes that take place in the human body and some of the waste products.
7. Name some noxious gases and the evil effects produced by them.
8. Name some of the forms of dust found in industries.
9. What are some of the causes of tuberculosis?

CHAPTER XXIX

GAS ENGINES

405. Principles on Which Based.—The gas engine (Fig. 176), which is coming gradually into use, requires but a small amount of fuel. In a steam boiler, the energy is transmitted to water inside the vessel. In the gas engine, the gas or oil is brought in contact, mixed with the air, and exploded. Gas engines are constructed in somewhat the same way as an ordinary high-pressure steam engine, and are built both as single and coupled engines. The cylinder is specially constructed and is surrounded by a water jacket provided with an ample supply of water to keep it cool (Fig. 177). The piston and rod, guards, connecting rod, crank, and fly-wheel are the same as those of a steam engine. The propulsive force of the gas engine is furnished by an explosion produced by igniting within the cylinder a mixture of air with coal gas, kerosene, gasoline, or alcohol vapor. To have complete combustion, it is necessary to have sufficient air, as the oxygen must combine with the hydrogen and carbon of the fuel. The gas is admitted at every other revolution, since the products of combustion must first be expelled by the piston on its first return stroke. During the second stroke the mixed gases are admitted through a valve, which closes like a pump valve when the piston shoots back. When the piston is at the end of its stroke and has compressed the gases, it closes an electric circuit, which is broken when the piston shoots on its second outward stroke. This produces a spark which ignites the gases, and the operation is then repeated. This method of sparking is classified as a make-and-break system, and should be distinguished from the spark-plug system.

As the force is excited on but one side of the piston, and only once in two revolutions, the gas engine is less steady than the steam engine, which has two impulses for each revolution. This fault is overcome to some extent, however, by the use of heavy flywheels.

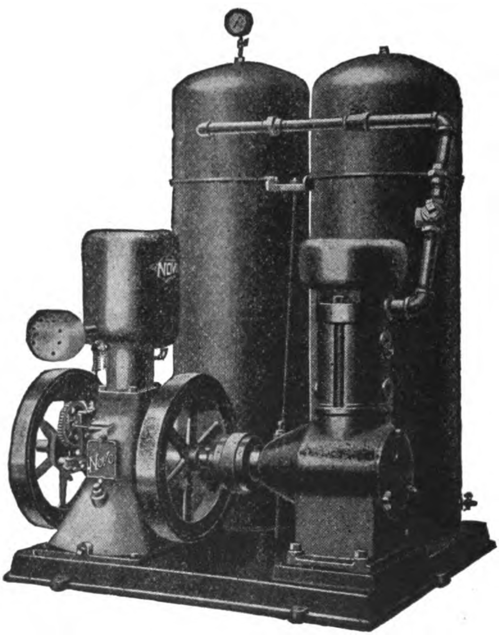


FIG. 176.—Gas Engine with an Air Compressing Outfit. Used for compressing air in a garage. The two large tanks or receivers in the rear are for storing the compressed air. A gauge is on top of the tank to indicate the pressure in the tank.

406. Types of Gas Engines.—Most gas engines are of the four-cycle type used in many motor car engines. It differs from the two-cycle type, in that the explosive mixture is admitted and ignited after every other revolution of the engine, instead of after every revolution as in the two-cycle type (Fig. 178). To get a more constant turning effect, certain machines, like motor cars, have engines composed of two, three, four, six, and sometimes eight cylinders. The six-cylinder engines are the most popular for touring cars.

407. Operation of Engine.—The operation of a four-cycle machine may be understood by studying the four different steps in the working of the engine. There are two openings or valves in the cylinder—an inlet valve for the mixture to enter, and an exhaust valve for the disposal of the gases. When the piston is at its highest position, the valves are closed. As soon as the engine is running, the motion of the fly-wheel carries the piston down, and the partial vacuum created behind causes the inlet valve to open because the outside atmospheric pressure is greater than the inside pressure. Many up-to-date engines have a mechanical inlet, and do not depend upon atmospheric pressure to open the inlet valve. The explosive mixture of air and gas enters and fills the cylinder. The momentum of the fly-wheel is sufficient to keep the piston moving. The greatest power is derived from an engine when the gas explodes just before the piston reaches the highest point, because the speed of the piston makes it necessary to ignite the gas at the top of the stroke in order to have complete combustion. The spark-plug, screwed into the opening, gives off a spark which explodes the mixture. As the piston rises again, the exhaust valve opens mechanically and the burnt gases, still very hot, escape through the

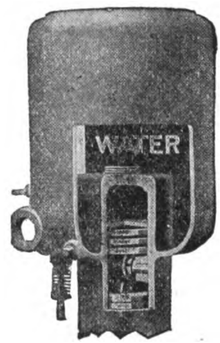


FIG. 177.—The Cylinder and Water Jacket (in section) of a Gas Engine. Designed to prevent premature ignition of the mixture and to assist in lubricating the piston. The water surrounds the cylinder in the section marked "Water."

exhaust pipe. The piston passes through the cylinder four times, twice in each direction. The first mixture of air and gas is drawn in during one stroke; then the mixture is exploded; the force of the explosion starts the next stroke, and on the return the burnt gases are driven out.

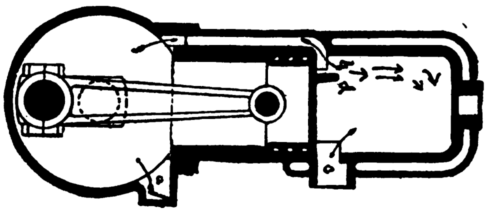


FIG. 178.—The Action of a Two-Cycle Engine. The explosive mixture is taken into the crank case through a non-return valve at *a* on the up stroke of the piston. It is compressed on the downstroke and allowed to flow into the cylinder when the piston passes over and uncovers the port *b*. The charge is compressed on the upstroke of the engine, is fired and expanded on the downstroke, and exhausted when the piston passes over and uncovers the part *c*. *D* is a deflecting plate to deflect the explosive mixture toward the top and preventing it from going out at *c*.

The heat generated by the burning of the oil is so great that the walls of the cylinders would become red hot if water were not circulated over them by a pump. The cranks of the engine revolve in an oil-tight case and are dipped in oil so that it will splash up into the cylinder and in this way keep the piston well lubricated.

408. Principal Parts of a Motor Car.—To show the "works" of an automobile it is necessary to remove the body or top of the car. What remains is called the chassis (Fig. 182).

Starting in front of the seat we see the handle, which is a lever for setting the engine in motion. Underneath the hood is the engine. The lever connects to the engine. Front of the engine is a heavy fly-wheel. The shaft of the engine is continued to the gear-box which contains the gears for altering the speed of the driving wheels to that of the engine. In the rear of the gear-box is the propelling shaft, which connects by means of bevel gears, a special device of gears called a differential, to the axle of the driving wheel to which the power of the engine is transmitted. The engines, gear-box, etc., are all mounted on the frame of the car. Between the frame and axle are the springs which absorb the shocks caused by bumping over rough roads.

FIG. 179.—Valves and Valve Cages. Showing how they may be removed.

Sometimes the power is transmitted from gear-box to axle by means of chains. In this case there is a sprocket wheel on a shaft behind the gear-box, and a larger sprocket wheel attached to the hubs of the driving wheels. The axles of the driving wheels are fixed to the springs and wheels revolve around them.

409. Other Parts of Motor Car.—The other parts of an automobile which need a brief description are the starting handle, the carbureter, silencer, governor, magneto, and gears.

Starting Handle.—In front of the car there is a handle attached to a tube which terminates in a clutch. A powerful spring keeps this clutch from a second one that is keyed to the engine shaft. When one desires to start the engine he presses the handle towards the right, so as to bring the clutches together and turns the handle in the direction of the hands of a clock. When the engine begins to fire the clutches slip over one another.

Carbureter.—The carbureter (Fig. 183) reduces the liquid fuel to a fine spray and mixes it with sufficient quantity of air

FIG. 180.—Ignition Apparatus for a Gas Engine. The illustration to the left shows the interior with four dry cells and a spark-coil. The illustration to the right shows the waterproof case, switch, and necessary wiring.

so that it will burn. It consists of two parts—a device for regulating the supply of fuel called the float chamber, and a device for controlling the amount of air to be mixed with the liquid spray.

Silencer.—As the products of combustion are given off at high pressure they expand violently and cause a vacuum in the exhaust pipe. The air rushes back with terrific force (15 lbs. per square inch) causing a loud noise. To overcome this noise, a device called a silencer is fitted to the machine which allows the gas to escape gradually, or reduces it to atmospheric pressure so that the noise becomes a gentle hiss.

Brakes.—There are usually two brakes on each car—a side hand-lever that acts on the axle of the driving wheel and another, operated by the foot, that acts on the transmission gear.

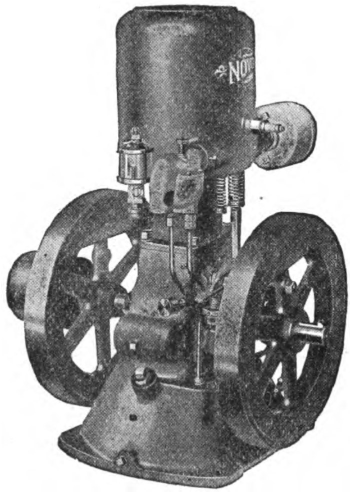


FIG. 181.—Electrical Gas Engine. Notice the two fly-wheels and the pulley attached on the left. Power is transmitted from the pulley by means of belting.

Governor.—The speed of the engine may be regulated in three ways by a centrifugal ball governor. When the speed exceeds a certain limit it either raises the exhaust valve so that no fresh charges are drawn in, prevents the opening of the inlet valve, or throttles the gas supply. The last arrangement is the one most commonly employed.

Gear-Box.—The gear-box of a motor car is very important. An explosion engine must be run at a high speed to develop its full power. There are times when a machine must do heavier work than usual, as for example, when it passes from a level road to a steep hill. It accomplishes this task by altering the speed ratio of the engine to the driving wheel. This change in the speed ratio is made possible by the mechanism of the gear-box.

Spark-Plug.—An accumulator and induction coil is an arrangement for producing a spark. It consists of a disk of insulating material mounted on a cam or half-speed shaft with a piece of brass, called a contact piece, attached. A

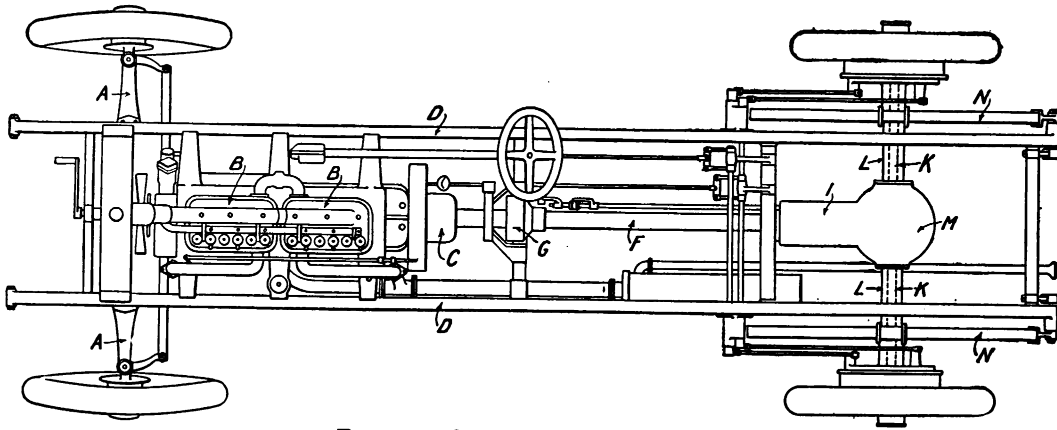


FIG. 182.—CHASSIS OF A MOTOR CAR.

A—Front Axle
B—Engine
C—Fly-Wheel Clutch
D—Frame
F—Driving Shaft

G—Universal Joint
H—Silencer
I—Change Speed Gearing
K—Rear Axle (live)
L—Housing

M—Differential Gear
N—Car Springs
O—Brake
P—Rear Axle

movable plate rotates and presses against the disk. When this contact takes place a current flows from the accumulator through the different parts, including the induction coil, and back to the accumulator. In this circuit is a spark plug so arranged that there is a small gap through which the current passes and produces a spark.

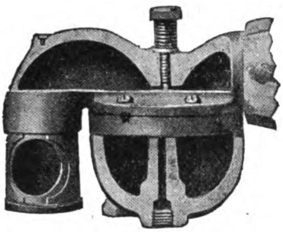


FIG. 183.—Carbureter in Section.

Questions

1. How does a gas engine work?
2. What is the combustible or inflammable material used?
3. What is the supporter of combustion?
4. What are the gases exploded?
5. How is gasoline made into a gas?
6. What is the source of energy of the gas engine?
7. What are the two types of gas engines commonly used?
8. Explain the operation of each type.
9. How does the two-cycle engine differ from the four-cycle engine?
10. What is the object of compressing the charge in a gas engine?
11. Does the nitrogen of the air take part in the explosion?
12. What are the products of combustion in the explosion if we assume the gas is composed of hydrocarbons?
13. At what point should ignition take place to get best results?
14. Upon what does a successful and reliable ignition depend?
15. How is ignition accomplished in a gas engine?
16. Name two systems of ignition.
17. Give advantages and disadvantages of each system.
18. What is the great source of loss of power in a gas engine?

Problems

1. The horse-power of a four-cycle engine is estimated approximately by multiplying the area of the piston by the length of stroke,

and this product by the number of revolutions per minute and dividing the final product by 15,000. What is the horse-power of a four-cycle gas engine with a 5 in. bore, 6 in. stroke, and 400 R. P. M.?

2. The proportion of gas and air in an explosive mixture is ordinarily a mixture of one volume of gas to seven to ten of air. How much air should be mixed with 6 cu. in. of gas?

3. The maximum pressure in a gas-engine cylinder may be calculated approximately by multiplying the gauge pressure of compressure by four. What is the maximum pressure in a gas-engine cylinder if the gauge pressure is 70 lbs.?

CHAPTER XXX

IRON AND IRON MOLDING

410. The Value of the Metal Trades.—Before designing and building a machine, it is necessary to know what the machine is expected to do, and the strain under which the whole machine and each part will be expected to operate. Given this information, the designer is able to draw, and the machinist to build, a machine that will not break. Machines are made of different kinds and grades of metal. The kind of metal selected depends upon its strength, ease of manufacture, its price, and its resistance to the rubbing of other metals. Cast iron is suitable for large, intricate shapes. Brass and bronze are used for small castings, because they are easier to mold.

As cast iron is exceedingly brittle, it cannot be used in some cases; therefore parts of wrought iron and steel are substituted. Shape is given to these two metals in the machine-shop by hammering and pressing them when hot, and the parts thus shaped are called *forgings*. It is necessary, then, to know the properties of the different metals* and how they are made and finished before a machine can be designed. Before the parts of the machine or contrivance are cast, a pattern is usually prepared of the same shape. The pattern-maker builds the model from a drawing made by a designer or draftsman.

* The student should review Chapters XI, XII, and XIII at this point.

411. Iron Ores.—Iron, in the forms of wrought iron, cast iron, and different kinds of steel, is used in the industries and trades more than any other metal. All forms of iron are obtained from the earth and are found combined in different amounts with other elements and substances which can be separated only by strong heat. In addition to being found as a compound, iron is mixed in all proportions with rock, dirt, etc.

The most common forms of iron ores are as follows:

Magnetite or lodestone (symbol Fe_3O_4), the richest of all iron ores, possesses the property of attracting to itself small pieces of iron.

FIG. 184.—Inspection of Pig Iron. The amount and kind of pig iron is carefully determined before it is placed in the cupola. This illustration shows the inspection of the pig iron before it is dumped into the furnace. Notice the shape of the bars.

Hematite (symbol Fe_2O_3), the next richest ore, is very abundant in this country.

Limonite ($2Fe_2O_3 . 3H_2O$), sometimes called bog-iron ore, is not a pure oxide and is known by the yellow streak it produces on porcelain.

Siderite ($FeCO_3$), called spathic iron ore, contains about 48% of iron.

412. The Refining of Iron.—Since iron is found in a combined state and mixed with either sand, lime, or clay and a small percentage of manganese, phosphorus, and sulphur, it is necessary to free it of the elements with which it is combined. This process is performed in a blast furnace (Fig. 185). A blast furnace in a modern plant consists of a tower of masonry from 50 to 100 ft. high, lined with firebrick and cooled by means of

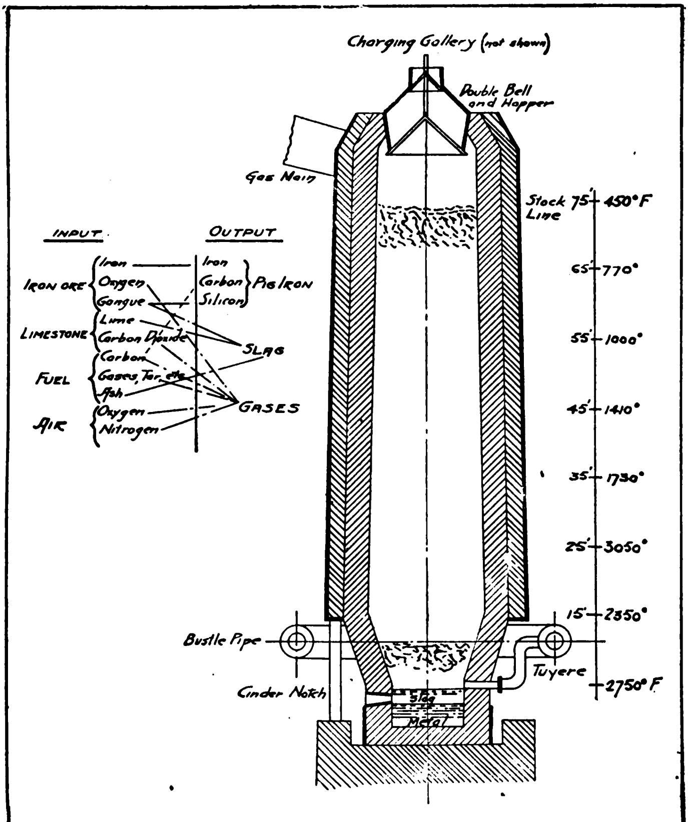


FIG. 185.—Blast Furnace.

water flowing through the pipes surrounding it. Boiler plates are used as a reinforcement. The furnace is charged from the top through a hopper, first with kindling wood, followed later by alternate layers of coke, iron ore, and limestone.

413. Action of the Fluxes.—When the fuel is burning, a strong blast of hot air of a temperature of 1200° F. is forced through the tuyeres (pronounced *tweers*) at the bottom of the furnace. The blast of air acts on the burning fuel causing an intense heat which gradually melts the iron. In order to make the iron ore melt easily, limestone—called a basic flux—or sand, an acid flux, etc., is added to the coke fuel. The flux combines with the earthy materials of the ore and causes them to melt at a lower temperature. When the iron ore contains a great deal of limestone it is said to be basic in character and sand is used as a flux; when the ore contains clay, the flux must be of a limestone nature. In each case, the sand, clay, and limestone unite at a red heat to form a salt called slag.

The space inside the blast furnace below the tuyeres is called the crucible. Here the metal separates from the slag. Immediately above the crucible, the diameter of the furnace is made wider to provide for the contraction in the volume of the charge before melting. The sides of the furnace slope gradually from the top to allow for the expansion of the charge as it heats up before fusing. When the flux unites with the earthy material (called gangue) of the ore it forms a glassy matter (called slag), setting free the iron. As the iron melts or fuses, its high specific gravity causes it to fall to the bottom of the furnace. When a suitable quantity has accumulated it is allowed to flow out of a tap-hole onto a sand bed along a large groove called a sow, from which at right angles it enters smaller grooves or hollows, forming the molds for the pigs. When the iron cools it is broken up into lengths suitable for shipping to foundries and is known as pig iron.

414. Chemistry of the Blast Furnace.—The glassy slag is formed by the combination of the alumina, silica, and lime contained in the ore and flux. Being lighter than the iron, the slag floats on the molten metal and is run off near the bottom of the furnace. The chemical action which takes place in the furnace is as follows: Part of the carbon of the fuel burns to carbon monoxide and combines with the iron oxide, setting free the iron; the remainder combines with the oxygen in the air and with the ore, thus forming carbon monoxide (CO) and carbon dioxide (CO_2) which pass out through a pipe at the top. The burned and unburned gases are allowed to enter other furnaces where they give off great heat on burning. This heat is used to raise the temperature of the air that enters the tuyeres.

415. Properties of Pig Iron.—During the process of smelting, the liquid iron absorbs and combines with a considerable quantity of carbon, sulphur, silicon, phosphorus, and manganese from the ore and coke. Some of the carbon is chemically combined with the iron in the form of iron carbide, while the remainder exists as a form of free carbon called graphite. While the fusibility (ease of melting) of iron depends upon the percentage of carbon that it contains, too high a per cent of carbon weakens the iron. The slower a casting cools, the larger the amount of graphite formed and thus the softer the iron. Pig iron is graded according to the appearance of its fracture.

416. Iron Foundry.—The pig iron is shipped to different foundries, where it is melted with scrap iron (old pieces of iron parts) in a furnace called a *cupola*. When the heating is of long duration, or when dirty or burned (oxidized) iron is used in charging the cupola, it becomes necessary to employ a flux, that is, some mineral substance that is lighter than iron. The flux when melted floats on the liquid iron and absorbs and liquefies its non-metallic residue and the ash of the fuel, so that they may be drawn off by means of the slag holes before the heat is run off. The liquid iron is then taken from the furnace in ladles, and carried by men to different molds where it is "poured" (Fig. 186). As the hot iron flows into the mold and cools, it takes the shape of the mold.

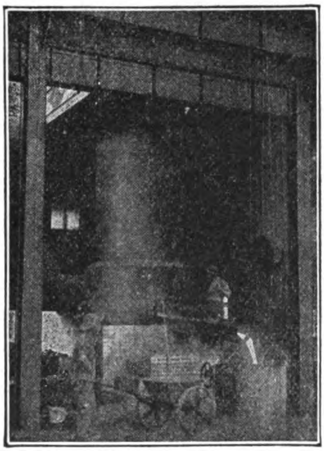


FIG. 186.—Drawing Iron from Cupola. When the iron has been melted down in the furnace it is drawn from the cupola into large ladles which are picked up by the overhead traveling cranes and taken to the flasks where later it is poured.

417. Mixing the Iron.—The best results for strength and elasticity are obtained by mixing a number of carefully selected kinds of iron, as such a mixture gives higher tensile strength than the average strength of the different samples cast separately. When all the carbon in iron is in a combined state, the fracture of a freshly broken piece has a silvery white color. When only a little carbon is combined, most of the carbon particles crystallizing separately, the fracture is gray in color, and the iron is weaker and more fusible. Hence the founder must exercise good judgment in selecting suitable mixtures of different sorts and qualities to obtain the desired strength, softness, hardness, toughness, and clearness of grain for different castings.

418. Clearing and Smoothing Castings.—When iron castings are taken from the mold they present a rough surface and must be cleaned and smoothed before they can be assembled into a machine. This is done in various ways, such as by means of emery wheels and revolving wire brushes, by rotating the casting in "tumblers" or "rattlers," by chipping with pneumatic chisels, or by removing the scales by means of a sand blast. In these processes a great amount of dust may arise, but light polishing on emery wheels equipped with good hoods and adequate exhaust ventilation gives rise to but comparatively little dust.

The scales which sometimes form on castings are removed also with dilute sulphuric acid. The fumes arising in this process, while the castings are draining, are very irritating to the nose and throat. Small castings may be dipped into a tank set into the floor. The acid is thrown over large ones resting on the floor, which is so constructed as to permit the excess of acid to drain back into the tank. This process is termed "pickling" and the chemical action which occurs is that the sulphuric or other acids partially dissolve and separate the scales or oxides on the surface of the metal, by acting on the metal underneath the scales. Since acids act on all iron, it is necessary to remove all traces of the pickling by washing the casting with water and alkali, which neutralizes the acid. Otherwise the acid will continue to eat or corrode the metal.

419. Molding.—Most of the iron used in industry is made into castings. Castings are made by pouring hot molten iron into a mold, which is a body of a certain kind of sand held in a boxlike frame called a flask. The top part of the flask is called the cope, the lower part the drag (Fig. 187).

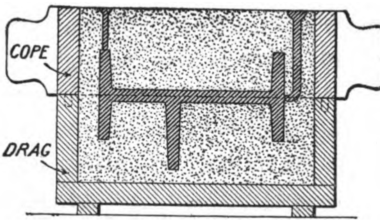


FIG. 187.—Cope and Drag of a Mold.

The sand forms a cavity of a desired form in which the hot metal flows. When the iron cools, it forms the casting.

420. Steps in Molding.—The pattern is placed on a board or plate called a bottom board, and a special kind of sand, called facing sand, is placed around and above the pattern to a thickness of about 1½ in. The rest of the flask is filled in with unriddled (unsifted) sand and rammed (hammered) properly. Sometimes gaggers or cast rods with projections are embedded in the sand to help hold it together. A board is then placed on the top of the flask and clamped. The flask is then rolled over.

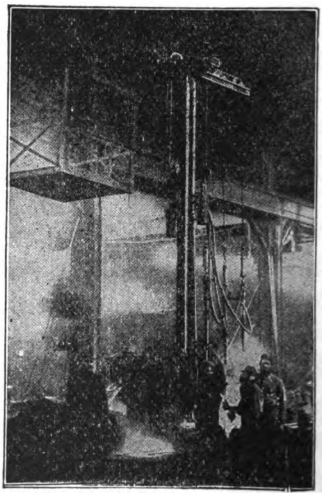


FIG. 188.—Ramming Molds—the First Step in Molding a Cast Iron Pipe. A large cast iron flask is placed in a pit and a pattern is placed in the flask. Sand is then filled in around the flask and rammed down hard. In this case, the rammers are driven by compressed air and are suspended by a stationary overhead crane. The pattern is then drawn and the mold is ready for the core.

Next the molding board is removed, and the face of the drag smoothed over firmly with a trowel to make it smooth and firm. After this a gate pin is embedded in the face of the mold about one inch deep, or at least deep enough to make it retain an upright position, and a groove is cut from this pin to the pattern. Parting sand, a mixture of burnt sand and charcoal, is then dusted over this face and the cope half of the pattern is placed on the drag and centered by dowel pins.

The drag part of the flask is then placed in position, and the pattern is covered to a thickness of $1\frac{1}{2}$ in. with facing sand, after which the flask is filled with unriddled sand and rammed until it is compact. A form of pin, called a riser pin, is embedded in this half of the mold until it touches the pattern. This riser helps to carry off the gases, and also causes any foreign matter that may have accumulated in the mold to flow out; it also warns the molder as to when the mold is filled with metal.

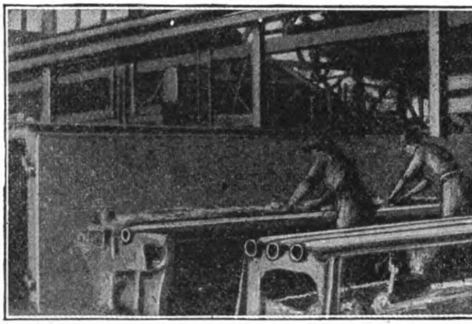


FIG. 189.—Making Cores for Cast Iron Pipe. Cores for pipes are made on a bar. Hay is wound on this bar and then loam is carefully worked into the hay. The core is then dried and given a second coat of mud, dried again, and blackened. It is then placed in the mold.

The mold is then vented by $\frac{1}{8}$ in. rods inserted into the sand about two inches apart, until they hit the pattern. When withdrawn, they leave small holes in the mold by which the gases escape. A cover board is placed over the flask and clamped on, the cope lifted and dressed, the gate pin and riser pin withdrawn, and both parts of the pattern are rapped and withdrawn from the sand. The mold is washed with a solution of lampblack and molasses to form a smooth face.

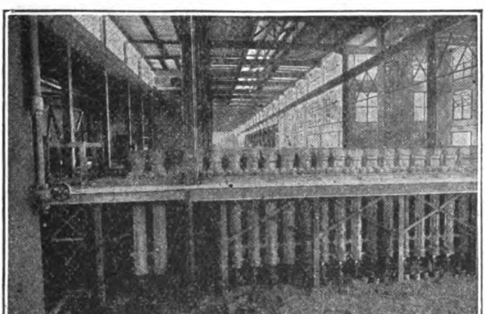


FIG. 190.—Drying Molds. Before the core can be placed, the mold must be thoroughly dried. This is done by either gas or coke fires.

If necessary, the drag part of the mold can be vented by forcing $\frac{1}{8}$ in. rods from the inside of the mold to the side of the flask, but this is not always necessary. The core, a body of sand baked hard, is then placed in its proper position and fastened by wire or nails to keep it stationary. This core, which is made in the coreroom, forms the inside of the finished casting, and in some cases is very frail and must be handled with care. Some cores are of necessity made in half a dozen parts and care must be taken to fit these parts properly. After the cope is replaced, and the two parts clamped together, the mold is ready for pouring. This is done either by hand- or crane-ladle, a bucket-shaped vessel of wrought iron lined with fine clay.

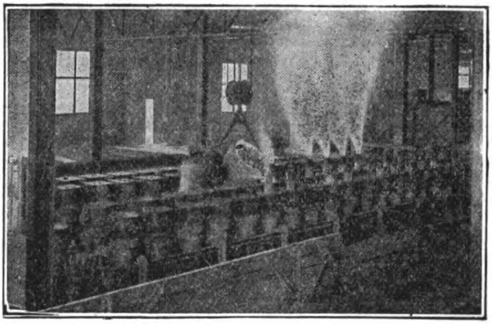


Fig. 191.—Pouring Pipe. After the mold has been rammed and dried and the core set, the next step is to pour the iron from the ladle into the mold.

Figures 188–192 show various steps in the molding of cast iron pipes.

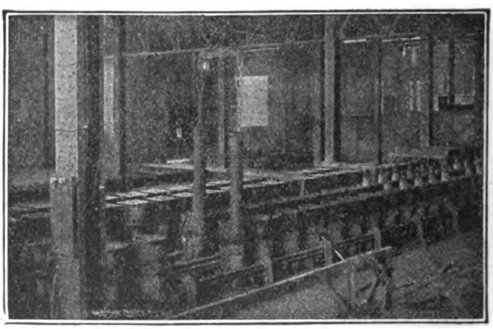


Fig. 192.—Pulling Pipe from the Flask. When the iron has cooled sufficiently, the completed pipe is pulled from the flask. The pipe is placed on the skids where the core is cut out and the outside is cleaned.

421. Essentials of Good Molding.—The first essential in the process of molding is to select the proper kind of sand for the mold (Fig. 193). In selecting sand, the weight of the casting should be taken into consideration. Mold sand is a mixture of sand, clay, and molasses, or other binding material that aids the sand in retaining its shape under pressure.

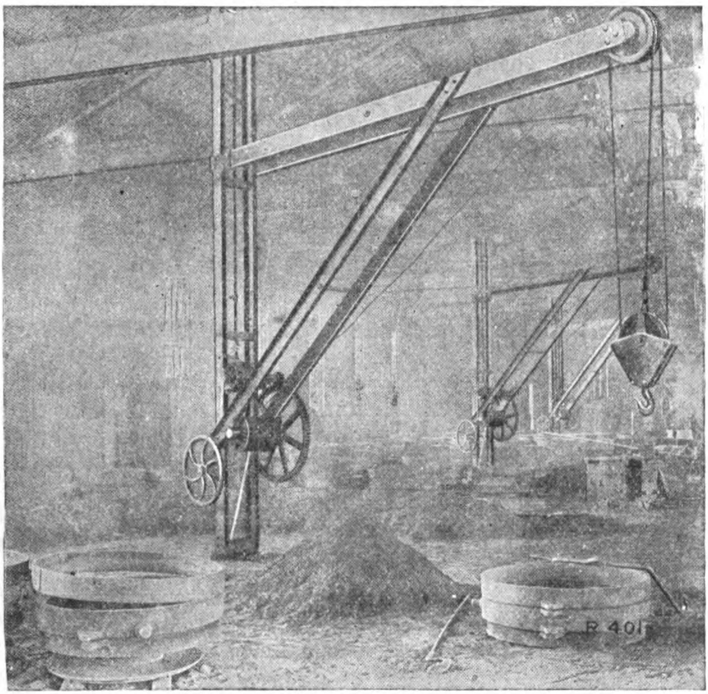


FIG. 193.—Refining of Sand. Showing foundry derrick for lifting heavy loads of sand, etc., and sieves to separate the fine from the coarse sand.

Sand is said to be sharp when its grains are angular, and dull when they are round. It is termed strong when a body of it manifests a disposition to retain any shape that may be given it, and weak when it tends to fall apart. For light castings the sand should be of fine grain, because less gas is created in light bodies of molten metal than in heavy bodies, and fine, close sand offers more resistance to venting than coarse, open sand. Molds for heavy castings are made from sands of coarse, open-grain texture.

422. Branches of Molding.—There are three branches of molding—(1) green-sand, (2) dry-sand, and (3) loam molding.

Green-sand molding involves the making of castings in molds that are composed entirely of damp sand, or that have their surfaces "skin dried," that is, dried by building a fire in the mold to harden its surface without baking its entire thickness.

In dry-sand molding, the sand is damp when the metal is poured, after which the mold is dried in an oven, or otherwise, so as to remove all moisture and leave the body of the mold dry and firm. In other words, the sand is drier than green sand.

In loam-sand molding, castings are made in molds constructed with skeletons of patterns. A mixture of loamy sand and other material is used to form the surface of the mold and to form its outer and inner supports. This class of work, like dry-sand molding, requires drying before it is ready to receive the melted metal.

423. Green-Sand Molding.—The practice of some shops embraces all three kinds of molding, but most foundries make only green-sand molds. These involve, however, more risk in making medium-sized and large castings. In many cases inexperienced men may be employed for making dry-sand molds, but it is seldom wise to trust other than skilled workmen with the construction of green-sand molds, especially in heavy work. Loam work varies greatly in the degree of skill required. Some classes of loam molds permit the employment of inexperienced workmen, while others demand extraordinary experience, skill, and good judgment in their production.

While the finished products of the three types of molding differ, as outlined, in shape, size, and use, the method is practically the same in all cases.

424. Brass Foundry.—Brass castings are made by heating copper and zinc in pots in a furnace, and pouring the alloy into a mold. The principal differences between molds for brass and molds for iron are that brasswork molds are made from finer and cleaner sands; that in brass molding a greater allowance must be made for contraction; and that different facings, parting sands, and finishings are used. Very nearly the same blackening mixtures are used in brass molding as in iron molding, and the methods of drying and venting are practically the same in both classes of work. The method of cleaning brass castings is the same as that of cleaning iron castings.

425. Properties of Cast Iron.—Cast iron has certain advantages and disadvantages as a material. It is easy to give it any desired form by molding. It resists oxidation (rust) better than either wrought iron or steel. Its compressive (crushing) strength is very high, but its tensile (stretching) strength is comparatively low. It cannot be riveted or welded by forging. It is brittle, breaking off without giving much warning, and stretching but little before giving way. It is liable to have hidden and small surface defects and air bubbles, which make its strength uncertain.

Another serious drawback in the use of cast iron is its liability to initial stresses from inequality in cooling after it is poured into the molds. That is, if one part of the casting is very thin and another very thick, the thin part cools first, and in cooling contracts; the thick part, cooling afterwards, causes stresses in the thin part, which may be sufficient to break it; or if not quite that strong the stress may be so great in the thin part that a small additional force will break it.

In the construction of machines and structures, no metal used by engineers varies so much in strength and soundness as cast iron; hence it is particularly important to know its physical properties. Cast iron may, if of inferior quality, have a tensile strength of only 5 tons per square inch, or even less. When this is the case, it has no value where strength is required; it may, however, be used for balance weights, foundation blocks, or for purposes where weight alone is of consequence. Some samples may have a strength as high as 19 tons, but the average strength is 7 tons. The strength of iron castings may be increased by the addition of vanadium. The high compressive strength of cast iron makes it desirable for use in columns and posts of buildings.

Questions

1. Why is it necessary to design a machine carefully before building it?

2. What are forgings? Why are they used?

3. What is a pattern?

4. Where is iron obtained?

5. Name some of the principal iron ores.

6. How is free iron obtained from the ore? What is smelting?

7. What is a blast furnace?

8. What is a flux?

9. Draw a sketch of a blast furnace.

10. Explain the chemistry of the blast furnace.
11. What is the difference between pig iron and cast iron?
12. How are varieties of cast iron known?
13. What is a foundry?
14. What is a cupola?
15. Explain why it is necessary to clean a casting.
16. Describe the molding of a casting.
17. What is molding sand?
18. Name the different kinds of molding.
19. State some of the disadvantages of the molding trade.
20. Explain brass molding.
21. State advantages and disadvantages of cast iron.

CHAPTER XXXI

PROBLEMS IN PATTERN-MAKING

426. Allowances for Shrinkage.—All molten metal shrinks when solidifying. The amount of shrinkage varies in different metals and also in different castings of the same metal. A cylinder, for example, will shrink more in length than in diameter, largely because of the resistance of the central core. Therefore, patterns must be made larger than the required castings. The usual allowances for different metals are as follows:

Cast iron	$\frac{3}{32}$ in. per foot	Aluminum	$\frac{7}{32}$ in. per foot
Steel	$\frac{3}{16}$ in. " "	Zinc	$\frac{7}{32}$ in. " "
Brass	$\frac{3}{16}$ in. " "	Lead	$\frac{7}{32}$ in. " "
Yellow brass	$\frac{7}{32}$ in. " "	Tin	$\frac{3}{16}$ in. " "
Bronze	$\frac{5}{32}$ in. " "		

When the molten metal cools to the point at which it is about to become solid, it suddenly flashes, expands, and then immediately contracts. The flash is called a "higher heat." This sudden expansion makes it possible to get impressions of small, fine lines on the casting.

427. Graduated Shrink Rule.—A graduated rule, the purpose of which is to allow for shrinkage, is known as a shrink rule. Such rules are on sale in almost all graduations, and in one, two, and three shrinkages.

428. Allowance for Finish.—The allowance for finish is the amount added to a pattern to allow for machining in the machine-shop. As all castings are more or less rough when they come from the mold sand, and as they warp or spring in cooling as well as contract or shrink unequally, it is necessary to allow for their being machined to the required size and shape. No set rule can be laid down to cover the allowance for these irregularities. On small iron or brass castings, an allowance of $\frac{1}{16}$ to $\frac{1}{8}$ in. is usually sufficient. Under the modern method of mounting small patterns on a plate and molding them by machine, this allowance may be reduced to a minimum.

The allowance for finish on steel castings must be greater in all cases than for iron castings because steel has a greater shrinkage, contracts unequally, and warps. The allowance should be from $\frac{1}{4}$ to $\frac{1}{2}$ in., but in many cases more is allowed. In every instance, however, much of the allowance for finish is made necessary by the distortion of the casting in cooling.

429. The Match or Odd Side.—A device to aid the molder to obtain quickly and easily a "parting line" in the mold is called a match. It supports the pattern and consists of a false part of the flask on which the drag is rammed. The match is about 3 in. deep and is made of some material confined within a wooden box or part of a flask to which a bottom board is securely fastened, the pattern or patterns being partly embedded.

Many different compositions are used to make up the hard support for the pattern. Sand, mixed with linseed oil and baked after shaping, is a very good mixture. Sand mixed with litharge also gives a very hard match, as does plaster of Paris. While this latter composition is more brittle than the other mixtures, an addition of litharge will tend to toughen it.

Since the invention of the molding machine, the match is not so much used as formerly. The great advantage of the molding machine is its facility in the production of small castings in which the patterns are of metal, mounted, or "gated," as it is termed, on a runner. Several castings may be obtained in each mold with no more labor than is needed to obtain one casting if only a single pattern is used.

The making and preparation of the patterns for match-molding are usually the work of the metal pattern-maker. The first pattern is usually of wood and is called the master-pattern. From it the metal patterns are obtained.

430. The Molding Board.—Many patterns are of such an irregular shape that a straight parting line cannot be obtained while molding. In cases of this kind, the pattern is usually mounted on a molding board (sometimes called a follow board). This board is so contrived as to support the pattern upside down in the desired position in the mold. The drag is reversed and rammed while the pattern is supported upon the molding board. Then the drag is turned over, the board removed, and the cope rammed as usual.

The molding board is used also to support small patterns which tend to spring from the force of the ramming. All stove-plate work that is not mounted on machines is molded in this way, the method, of course, making necessary a special equipment of flasks.

431. The Match Plate.—In the molding of small castings where a great number are required, it is customary to mount several patterns on a plate called a match plate. This plate is of metal (as are also the patterns), $\frac{3}{8}$ in. thick, projects beyond the flask, and has two holes, one on each end, through which the flask pin is inserted.

In the use of the match plate, a molding machine is generally used, but the plate can be used without the machine. The patterns are mounted on the plate, one-half on each side directly opposite to each other. One side of the flask is rammed at a time, the flask pins locating the plate so accurately that the two parts of the flask form a perfect match when placed together.

The making of these match plates by the metal pattern-maker is expensive because of the difficulty of working metal. Hence it is only profitable to use the match plates when a great number of castings are desired and when a firm is continuously engaged in the production of a line of small goods.

432. The Molding Machine.—The cost of production is reduced by the use of a match plate on a machine. The rapidity with which the molds can be produced and the possibility of producing castings which require the minimum of machining, lowers the cost. Machine-work in finishing is always a costly process.

In recent years the molding machine has been improved so that at the present time very large castings are produced by it. Of course, its use is only possible or profitable for large-scale production, as the machines for large work, with their patterns, are very expensive.

A large machine of this type is the stripping plate machine in the operation of which the sand is rammed by hand and the pattern drawn down through a metal plate which supports the sand and prevents breaking. By this method, castings can be produced close to uniform size.

When a pattern is rapped to loosen it in the sand before drawing, it is impossible to produce castings of uniform size, as the rapping is left to the molder's judgment. Rapping a long and narrow pattern results in making a casting longer than the pattern unless great care is taken. Such a pattern moves endwise easily because of its narrowness, but moves sidewise very little because its greater surface is not so easily moved. A casting of this kind is often found to be wider on one end because of carelessness in rapping.

433. Molding in Cores.—Many large castings, the patterns of which would require a great amount of material and labor, may be molded in cores. In this process no pattern is used, the practice being to make a core-box of some part of the casting and, after baking, to assemble the various parts in a flask. In many cases this is not the most economical method, but it is sometimes used of necessity because the peculiar shape of the required casting makes it impossible to draw the pattern if it be made in the same shape as the required casting.

As few castings are obtained without the use of cores, it is essential that the pattern-maker give this branch of molding close study. The proper location of core prints on the pattern may make the difference between success and failure.

Any pattern could be so designed that it might be molded in cores, but such designing is economical only where a duplication of parts formed from one core-box is possible.

434. Weights of Materials and Castings.—The weight of a casting may be approximately estimated from the weight of the pattern, as shown in the table below. In all cases where there are core prints or batteries to sustain the pattern, or other parts which are on the pattern but not on the casting, their weight must be estimated and deducted from the weight of the pattern.

WEIGHT OF CASTINGS CAST IN A 1-LB. PATTERN

1-lb. Pattern	*Cast Iron in lbs.*	*Zinc in lbs.*	*Copper in lbs.*	*Brass in lbs.*	*Gun-Metal in lbs.*
Mahogany, Nassau	10.7	10.4	12.8	12.2	12.5
" Honduras	12.9	12.7	15.3	14.6	15.
" Spanish	8.5	8.2	10.1	9.7	9.9
Pine, Red	12.5	12.1	14.9	14.2	14.6
" White	16.7	16.1	19.8	19.	19.5
" Yellow	14.1	13.6	16.7	16.	16.5

Questions

1. Is a pattern made larger than a casting? Why?

2. What is the allowance for cast iron? Is it the same for each metal?

3. Describe the steps in working a casting.

4. What is a pattern-maker's shrink rule?

5. Must a pattern-maker make allowance for machining a casting?

6. Is it necessary for a pattern-maker to know machine-shop work?

7. What is the match?

8. What is a molding board?

9. What is a match plate?

10. Describe a molding machine. State the advantages.

11. What is the meaning of molding cores?

12. Is it possible to calculate the weight of a casting from the weight of a pattern?

CHAPTER XXXII

THE MAKING AND WORKING OF WROUGHT IRON

435. Manufacture of Wrought Iron.—Wrought iron, oftentimes called bar iron, is made from the rough pig iron. In the process of manufacture, it is first refined in the "puddling furnace." Here it is exposed to a very great heat, and is stirred about while a strong current of air plays over it. The intense heat converts the carbon matter remaining in the iron into carbon dioxide. As this escapes, all earthy impurities rise to the surface in the form of slag, and are allowed to run off. Gradually as the iron is purified it becomes pasty or tough, and when this toughening process begins the iron is called a bloom. This takes place even though the heat of the furnace be undiminished. After a while, the iron is withdrawn and while red hot is either beaten (worked) with a forge trip hammer, which drives out the remaining slag, or is subjected to rolling. This latter process compresses its particles and makes it more tenacious. The metal is rolled while hot into bars of inferior quality. These bars are cut into short lengths and piled crossways. They are later reheated and rehammered or rolled, after which they are known as merchant bars and in this form are used for common girder work, ladders, fire bars, etc. Any desired shape may be given to the bars by means of dies. The operations of cutting, piling, etc., may be repeated several times to give the desired strength and tenacity.

436. The Effect of Drawing and Rolling.—When iron bars are rolled, their molecules become stretched into a fibrous condition. Rolling gives to the metal, especially when thin as in boiler plates, a greater tensile strength in the direction of its fibers. Wire drawings and cold rolling (passing over cold rolls of steel) increase the tenacity and hardness of wrought iron, but annealing returns it to its original strength and softness.

437. Case-Hardening.—The process of hardening the surface of iron or steel is called case-hardening. The piece to be treated is first heated to a bright red and the surface rubbed with prussiate of potash. When it has cooled to dull red, it is immersed in cold water. When the piece is to be highly finished, the finish may be obtained by heating it in a cast iron pot containing red-hot lead. A good case-hardening mixture may be made with three parts prussiate of potash and one of sal ammoniac. The temperature for cherry red is given at 1832° F. Machine nuts, set screws, wrenches, and collets are samples of such work.

438. Characteristics of Wrought Iron.—Wrought iron possesses one of the most valuable properties of metals; small masses of it will weld or unite into one. No other metals except platinum and aluminum possess this property. If two pieces of iron are heated to a white heat, they become sticky or viscous so that when hammered together they adhere and may be perfectly united by forging. This kind of iron is used by blacksmiths and, unlike cast iron, may be hammered into any desired shape. Because of its greater strength, wrought iron is used for making bars, plates, wires, structural material, and parts of machinery. It is tougher, stretches more, and gives more warning before fracture than does cast iron. Moreover, cast iron is not malleable or ductile like wrought iron. Neither cast nor wrought iron can be hardened and tempered.

439. Malleable Cast Iron.—Ordinary white cast iron can be rendered sufficiently malleable to admit of changes if heated with iron oxide. By this means the carbon in the cast iron is slowly oxidized by the oxygen in the surrounding oxide. The iron should be as free as possible from phosphorus and should contain some manganese. This process produces a layer of pure iron possessing the property of wrought iron. Malleable iron is practically wrought iron which can be hammered into any desired shape when cold, but which is very brittle when hot. Cast iron can be made harder by a chilling process.

440. Blacksmithing.—Blacksmithing is a distinct mechanical trade, and consists of working and shaping iron and steel for ornamental, structural, and general repair work. One branch of the trade is devoted to horseshoeing. The equipment of the blacksmith consists of a forge, an anvil, and the necessary tools.

The forge is generally a structure of iron, although it may be built of brick or stone, upon which a smith's fire is built. In the bottom of the hearth, upon which the coal is placed, is an opening known as the tuyere through which a forced draught is applied by bellows. The mouth of the tuyere is generally covered with a perforated sheet which allows the air to pass through freely, but prevents cinders or any other foreign matter from dropping into the blast pipe. A hood, the purpose of which is to catch and conduct the smoke to the chimney, covers the forge. This hood is constructed of sheet metal, and is fastened to the chimney. In a modern shop, the forge is operated by a suction draught. Fastened to the forge, for the convenience of the smith, is a water and coal trough and a rack for tongs.

The anvil is a heavy body of cast or wrought iron with a case-hardened steel face welded onto it. This steel face prevents indentations being made in the anvil by hammering. One end of the anvil is horn-shaped for the rounding and shaping of small work. The opposite end contains two holes, one square and one round, into which fit the ends of the various anvil blocks.

441. Blacksmith's Tools.—The tools of the blacksmith comprise hammers of various kinds, fullers, flatters, chisels, tongs, and the hardy. The simplest and one of the most useful tools is the sledge hammer which is employed for nearly all striking done on the anvil. The hand-hammer is used to bind the iron, while various other tools, such as the fuller, are used for shaping it. The fuller, of which there are two kinds—top and bottom fullers—is a half-round tool used to draw or force out the heated metal to form grooves, and so on. The top fuller has the appearance of a hammer, and is held on the work by a handle; the bottom fuller is shaped like the top one, but contains a stem which fits into the anvil. The flatter is a broad-faced hammer used to dress and smooth work after it has been drawn into shape by the use of hand-hammers and fullers. Two kinds of chisels are generally used—a blunt one for cutting cold iron and a finer edged one for cutting hot iron. They are usually made in the shape of hammers, one side being forged and flat with a cutting edge ground on it, and the other end shaped for striking purposes. Another cutting tool is the hardy, which fits on the anvil. It is a block of iron ground to a sharp or chisel edge. Various shaped anvil blocks and hand-hammers, which may be classed as special tools, are also used. Tongs for holding the iron are made in a wide variety of shapes and sizes.

442. Lighting the Blacksmith's Fire.—To fire a forge, all clinkers are first removed and some inflammable material, such as wood shavings or oil waste, is selected and placed on the hearth over the tuyere. The fuel should be the best quality soft coal thoroughly moistened, so that it will coke or stick together when heated. Coal containing hard spots will cause an uneven fire. The fuel is carefully placed around and over the ignitible material, leaving one opening on the top for the draught, and one in front for the placing of the metal to be heated. After the material is ignited the proper draught is applied until the coal catches. The fire is shaken occasionally in order to maintain a live and even heat. If this is not done, the interior burns out, leaving a hollow space which is worthless for heating. When necessary the fire is banked by covering it with fine, damp coal.

443. Scarfing and Welding.—The two principal operations performed by a blacksmith are scarfing and welding. The process of scarfing consists of flattening the edges of two pieces of iron preparatory to welding, so that when the edges overlap they are of the same thickness at the junction of the two pieces as the rest of the iron. Care should be exercised in performing this operation, as the class of weld depends almost entirely upon the nature of the scarf. Scarfing is not, however, necessarily preparatory to all welding. For instance, in the butt weld, the two pieces to be welded are simply abutted together, sometimes in the fire.

The process of welding, as already stated, consists in joining two pieces of wrought metal at a white heat. The metal pieces at this temperature are in a plastic or semifused condition and when placed together and properly hammered readily unite, causing a solid body or joint. It is necessary to take the metals from the fire at just the proper time. If removed too early, the pieces cannot be successfully welded, and if left in the fire too long, the metal will be burned and rendered useless for service. Great care should be exercised in heating both pieces evenly and to the same temperature.

Unless the iron or steel is properly heated a scale will form which prevents the uniting of the two pieces. This scale or oxide melts at a lower temperature than the iron, and as a result the weld will be good if the proper heat has been secured. When using soft steel or Norway iron, the scale melts at a higher temperature than the welding heat and to overcome this difficulty, it is necessary to use a flux to soften or melt the scale.

Fluxing is the application of some good welding preparation to the joint. A good, clean beach sand serves the purpose, as it melts and combines with the scale, causing it to liquefy, in which form it is easily forced from between the pieces to be welded. For welding tool steel to iron or soft steel, the flux consists of borax and sand.

444. Welding Processes.—There are two classes of welding—forge or pressure welding, and autogenous welding. Forge or pressure welding is applied to two pieces of metal heated to a plastic state, which are forced together by pressure or hammering. The familiar example of this is the weld which the blacksmith makes by heating two pieces of steel or iron in the forge fire and then hammering the ends together on the anvil. Another form of forge or pressure welding is seen when two pieces of metal are heated by an electric current, and then forced together. This latter process is known as butt or spot welding.

445. Autogenous Welding.—Autogenous welding is applied to welds which are made by heating metals to such a temperature that they will fuse together on contact, without the application of pressure. The difference between forge welding and autogenous welding lies mainly in the difference in the temperature of the metals. In the autogenous weld, the metal is heated to a state of fluidity, and the two pieces flow together. This name is also applied to the process of adding molten metal to other metal pieces, thus building up or filling defects in the latter. There are different methods of autogenous welding—by the electric arc, by the oxyacetylene flame, by the thermit method.

446. Electric Arc Welding.—Electric arc welding consists in joining two pieces of metal by filling in the cracks with molten metal. This is done by attaching or laying upon the steel or metal to be welded one wire of the current, and attaching the other wire to a piece of carbon or metal which the welder holds. The current passes from the piece which is to be welded to the electrode which the operator holds. Great heat is generated and consequently the electric arc is one of the most efficient methods of producing welding heat.

447. Oxyacetylene Welding.—Oxyacetylene welding is one of the most practical methods of welding. The heat is derived from burning acetylene in oxygen gas. Oxyacetylene flame is also used in cutting metal. The flame actually cuts the metal by melting it very rapidly.

448. Thermit Welding.—Thermit welding depends upon the chemical combination of certain substances which produce a great heat. It is particularly successful in combining broken parts of machines. The work is carried out by building around the two ends, a mold, into which the molten metal or steel generated by this process is poured. New metal is thus added to the ends and the parts are united.

449. Drop Forging.—The bending and shaping of large pieces of iron and steel is called drop forging. An oblong block of steel case in a steel foundry is called an ingot. As soon as the steel is set in the mold, the hot mass is taken by a crane from the ingot mold and placed in a soaking pit to be annealed. While the metal is setting the exterior of the ingot becomes chilled. The soaking pit is a brick mold with all air excluded. When the ingot is placed in the mold, the interior heat of the ingot reheats the exterior surface, and causes it to soften or anneal. When this process is finished, the ingot is carried by a crane to the steam hammer, where it is drawn out roughly to shape. The number of times it may be necessary to heat the ingot depends upon the amount of work to be done on it and the speed at which that work is to be accomplished.

450. Steam Hammer.—The steam hammer is a forge hammer consisting of a steam cylinder placed vertically over an anvil. The trip or hammer-head rises and falls by the power of steam. The trip is controlled by a lever, which is generally operated by a hammer boy. The work is carried to the hammer by means of hooks, and held in place by special tongs. A large portion of steam hammer work is drawn out to templates.

451. Template.—A template is a temporary pattern guide, or model by which work is marked out, or by which its accuracy is checked. Working to a template requires accuracy on the part of the operator, as the forging is generally finished by him, except where it is to be spotted or finished in the machine shop.

452. Shrunk Fits.—Blacksmiths and metal-workers usually fasten one piece of metal around another by shrinking the first onto the second. This process, known as a shrink, is applied in attaching various kinds of bands, collars to shafts, in putting tires on locomotive wheels, and in shrinking steel gear rings to steel centers. The piece of metal to be shrunk on must be slightly smaller than the outside diameter of the part to which it is to be applied. It is heated and expanded until it can be slipped into place, so that when it cools it will cling to the part with sufficient strength to hold it in place during service.

453. Allowance for Shrunk Fits.—It is the practice in shrunk fits to allow $\frac{1}{1000}$ of an inch for each inch in diameter.

To illustrate: A locomotive tire 68 in. in diameter should be turned $68 \times \frac{1}{1000}$ in., or $\frac{68}{1000}$ in., smaller than 68 in. Expressed in a formula this is:

$$A = .001 \times D = \frac{D}{1000} \text{ in.}$$

Where A is allowance in inches, and D is diameter in inches.

454. Forced Fits.—Sometimes parts are assembled in a cylindrical or slightly tapered form, and fitted under pressure. The method is called a forced fitting. An allowance of .001 or .002 is made for each inch in diameter.

To illustrate: What pressure would be required for forcing a 9 in. diameter crank pin into a cast steel center? The pressure required is expressed by the following formula, where P is pressure and D diameter of pin.

$$P = 15\,D + 15$$
$$\therefore P = 15 \times 9 + 15 = 150 \text{ tons}$$

Questions

1. What is wrought iron?
2. How is it made?
3. What are the physical properties of wrought iron?
4. What effect has drawing and rolling on the metal?
5. What is case-hardening? Why is it desirable?
6. What is malleable cast iron? How is it made?
7. Give the physical properties of each kind of iron.
8. What is blacksmithing?
9. Describe a forge. State how a high temperature is obtained.
10. What is an anvil? How is an anvil made so as to resist dents?
11. Name some of the blacksmith's tools. Draw sketches and show the mechanical principle of the sledge hammer and chisel.
12. What is scarfing?
13. What is welding?
14. Explain the drop forging.
15. What is a shrunk fit?
16. What is a forced fit? Give the principle of science underlying it.
17. What is autogeneous welding?
18. What is electric arc welding?
19. What is thermit welding?
20. What is oxyacetylene welding?

CHAPTER XXXIII

THE MAKING AND WORKING OF STEEL

455. Properties of Steel.—Steel is a chemical compound of iron and carbon, but contains no carbon in the free state as cast iron does. Its tensile strength is greater than that of wrought iron and its compressive strength greater than that of cast iron. It is by far the strongest metal used in the mechanical arts and its strength varies greatly with its purity and the amount of carbon it contains. Steel is divided into *high, medium,* and *low grade.* The high-grade steel contains the most carbon, and, unlike wrought iron, is fusible. Unlike cast iron, steel can be forged, and, with the exception of the higher grades, can be welded by heating and hammering, although care must be exercised in performing this operation.

456. Hardening and Tempering.—The special characteristics of steel, except the very lowest grades, are that when raised to a cherry red heat and suddenly cooled, it becomes brittle and exceedingly hard; and that by subsequent heating and slow cooling the hardness may be reduced to any desired degree down to the point of least hardness that steel possessing that amount of carbon can have. The first process is called *hardening* and the second *tempering.*

457. Tools and Tool Steel.—Practically all tools are made from a selected grade of steel called crucible steel. For example, one kind of steel makes excellent razor blades, where keenness is demanded, while another is able to resist blows as well to hold a lasting edge. While it is possible to use the same grade of steel for different tools, it is very necessary to vary the treatment of the steel for the different purposes to which the tool will be put.

In making tools, the steel is forged into the desired shape. Care must be taken not to overheat it while it is being worked. After forging, the steel is brought to a good red heat and then plunged into water, to render it hard and brittle. The cutting edge is then rubbed bright with a piece of emery cloth tacked on a piece of wood. After being thoroughly rubbed, the tool is held over a fire and heated slowly. Here it begins to show color—at first a faint yellow, then a tinge of blue. It finally assumes the color possessed by the bar previous to forging.

The operation of reheating, polishing, and allowing the color "to run" is called "drawing." The faint yellow color indicates that the steel has become toughened—that it has lost its hardness or brittleness and become springy.

458. Tempering.—When steel and iron are heated to a high temperature they first become red, then orange, and then white. The temperatures may be approximately told by the color as follows:

First sign of red	957° F.	Dull orange	2010° F.
Dull red	1290°	Bright orange	2190°
Cherry red	1655°	White heat	2370°
Bright red	1870°	Bright white	2550°
Dark cherry	1470°	Dazzling white	2730° to 2910°

The following table represents the colors which appear on a polished steel surface when heated in the air.

Color	*Approximate Temperature*	*Used in Tempering*
Very pale yellow	430° F.	Hammering tools, lathe and planer tools, scrapers.
Straw yellow	460°	Taps and dies
Dark straw color	480°	Reamers, knives, punches, and dies
Brownish yellow	500°	Drills, stone-cutting tools
Yellow tinged with purple	520°	Angles, draft pins
Light purple	530°	Cold chisels for steel, augers
Dark purple	550°	Springs, screw-drivers, cold chisels for iron, hatches
Dark blue	570°	Saws for wood
Pale blue	610°	
Blue tinged with green	630°	

459. Bessemer Process.—The principal grades of steel are made by the Bessemer, Siemens-Martin, and open-hearth processes. Bessemer steel is manufactured from gray pig iron, which is free from phosphorus, sulphur, and manganese. In this process there are two separations—the conversion of the molten cast iron into pure iron, and the changing of the pure iron into steel by the addition of a small and definite quantity of alloy of manganese and carbon.

Steel may be made directly from pig iron by allowing the latter to run from the cupola into a converter lined with fire-brick and by blowing air into the metal through an opening in the bottom for about twenty minutes. This treatment removes all the carbon, since the oxygen in the air combines with the carbon of the iron to form carbon dioxide. From 5 to 10% manganese is then added and the blowing is resumed long enough to incorporate the mixture. The molten mass is ladled into iron molds to form ingots. As these are more or less porous they are reheated and run through a clogging mill or steam hammer and are finally rolled or forged into shape. This kind of steel is named from Bessemer, the inventor of the process, and is largely used for structural purposes.

The disadvantage of this process is that no sulphur or phosphorus is removed from the metal, so that it is necessary to use a grade of iron very nearly free from these impurities, if the steel is to have the required properties for tools, etc.

460. Basic Bessemer Process.—A modification of the foregoing method, by which the phosphorus is removed from the iron, is known as the basic Bessemer process. Its special feature is that calcined or burnt lime is added to the charge just before pouring. The lime unites with the phosphorus forming phosphate of lime, removing the phosphorus from the steel and bringing it into the slag. The removal of the phosphorus makes it possible to use an inferior grade of iron.

461. Siemens-Martin Steel.—In the Siemens-Martin process, steel is produced either by melting a certain quantity of pig iron in the hearth of a reverberatory furnace and adding wrought iron till the bath attains the desired degree of carbonization, or by mixing cast iron and certain kinds of iron ores. The oxides of the ores are removed and carbon and manganese are added by the introduction of a small quantity of ferromanganese, similar to spiegeleisen. The amount of carbon left in the metal is ascertained by removing a small quantity of metal in a ladle, cooling it, and then breaking it up and testing it. If found satisfactory, the charge is tapped and the metal run into the ingot molds. The ingot is later reduced to a slab, called a bloom, by passing it back

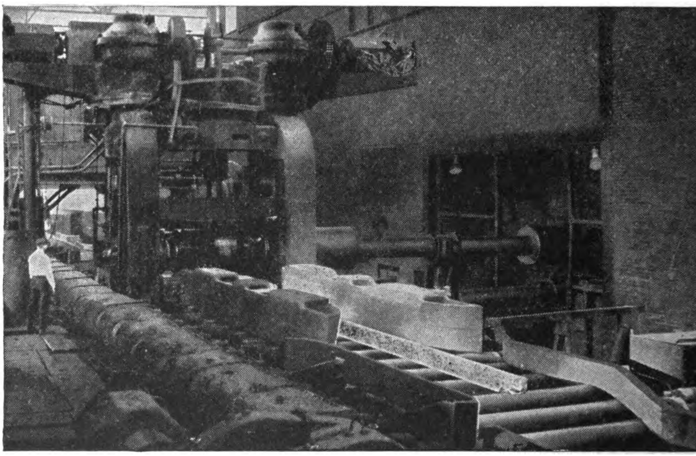


FIG. 194.—Blooming Mill Showing Steel Ingot Reduced to Bloom.

and forth between heavy rolls until it is reduced to the thickness desired (Fig. 194). The operation is slower than the Bessemer, but it enables the manufacturer to produce more readily the desired grade of steel. It is the usual method of producing steel of good and uniform quality at a low cost and on a large scale; the product competes with Bessemer steel in price.

462. The Open-Hearth Process.—In the open-hearth process, a charge of material, consisting of wrought iron, cast iron, steel scrap, and other ores, is melted on the hearth of a reverberatory furnace and heated by gas, as in the Siemens-Martin or regenerative system. Sometimes the molten metal from the blast furnace is poured directly into the open-hearth steel furnace, as shown in Fig. 195. The carbon is thus partially burned out, much as in the wrought

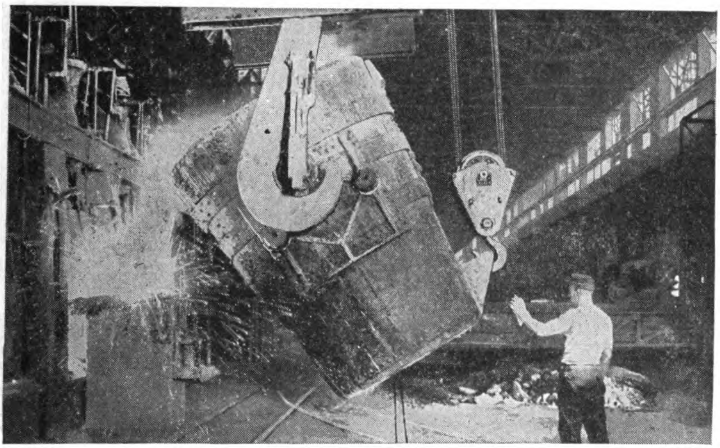


FIG. 195.—Pouring Molten Iron into Open-Hearth Steel Furnace.

iron process, and its proportion is brought down to the desired point or somewhat below. A charge of spiegeleisen is then added, in order that the manganese may act on any oxide of iron slag which remains in the bath, and which would make the steel red-short (brittle when hot) if allowed to form a part of the charge. The manganese separates the iron from the oxide, returns it to the bath, and the carbon joins with that already present.

In the open-hearth, as in the Bessemer process, there is no removal of sulphur or phosphorus, and only materials nearly free from these ingredients can be used. The product of this process is more reliable than that of the Bessemer process, because it is more homogeneous and is therefore less likely to show unexpected or inexplicable weaknesses. For these reasons it is used very much more than the Bessemer steel.

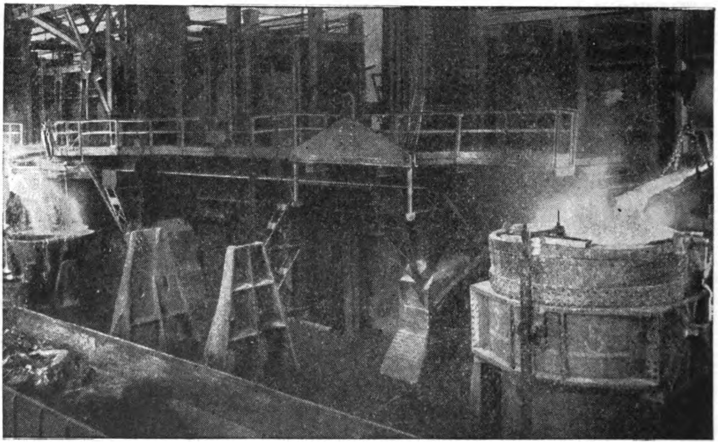


FIG. 196.—Drawing Steel from Open-Hearth Furnaces.

463. Crucible Steel.—Crucible steel is made by rolling a pure grade of wrought iron into flat bars. These bars are cut up and placed in piles in a crucible with layers of pounded charcoal between them. The piles are then subjected to a high temperature for several days. When withdrawn from the furnace the steel is found to have absorbed some of the carbon and to be hard and fusible. As its surface is covered with small bubbles, it is called blister steel. When the bars are heated with a flux, it is called shear steel, because this grade of steel is most suitable for making shears, scissors, etc.

When melted and run into ingots it is termed cast steel, which is the strongest form of steel. These ingots are broken up and melted in crucibles to be cast into any desired shape.

Crucible steel is used to a large extent for making machine-shop tools and is often spoken of as tool steel. The best grade usually contains fron .9 to 1.1% of carbon and has a wide range of uses. Other grades contain:

.1 to .5%	carbon, used for	lathe tools and small drills.
.5 to .75%	" " "	battering tools, hot work.
.75 to 1%	" " "	dies, axes, large-sized drills.

The properties of tool steel are due to the carbon they contain.

464. Tungsten Steel.—A number of grades of steel are called alloy steels and owe their properties to the alloy which is added to them. The principal one is tungsten steel, which is made by adding ferrotungsten (an alloy of tungsten and iron) to the metal while it is in the crucible. Tungsten steel is also called high-speed steel, because the tools made from it can be used at a higher speed than others.

465. Steel Castings.—Steel castings are made by pouring mild steel into molds. Crucible steel castings are made by melting bar blister steel in crucibles and pouring it into molds. Large steel castings, such as beams for stationary engines, steam chests, large shafts, pistons, cross-heads, stands for steam hammers, large stop valves, etc., are made by simply charging the furnace with pig iron, scrap steel, and broken ingot molds. The disadvantage of this process is that the castings are not perfectly sound because of pores or blow-holes below the surface of the metal which cannot be seen. When they are on the surface they can be eliminated in machining.

466. Mild Steel.—Mild steel, a grade of steel that does not harden when heated and chilled with cold water, is made from Siemens, open-hearth, or Bessemer ingots. The ingots are heated and hammered into slabs. These slabs are reheated and rolled into plates or bars. They resemble wrought iron because of their low percentage of carbon (.15 to .5%) and can be easily welded. In welding, care must be taken to see that the pieces to be united contain the same proportion of carbon. Otherwise, the welding temperatures will be different.

Mild steel has now taken the place of wrought iron for many purposes, especially for boiler plates and stays, bolts and shafting, engine parts, etc. The lower the strength of the mild steel the higher is its elasticity. Boiler plates must be ductile.

Engine parts such as pistons, connecting rods, shafts, and valve rods, are made of mild steel forged from Siemens or Bessemer ingots.

467. Influence of Impurities on Steel.—Impurities, similar to those found in iron, are present in steel. Sulphur in the steel tends to make it red-short and to interfere with its welding and forging properties. Steel should not contain more than .1% of sulphur, and when possible the amount should be reduced to .03 or .04%. Manganese tends to counteract the effects of the sulphur.

Phosphorus increases the tensile strength and raises the elastic limit of low carbon or structural steel, but detracts from its ductility and strength to resist shocks. Phosphorus is, therefore, considered a dangerous ingredient, and should never exceed .2%.

Silicon influences the form which carbon takes in cast iron and its rate of cooling; it increases the tensile strength and reduces the ductility of steel. The process of manufacture, however, usually removes all silicon, and therefore that element gives very little trouble.

Manganese increases the elastic limit, the tensile strength, and the ductility of steel. It also counteracts the sulphur and phosphorus. It is thus an important factor in preventing red-shortness. The proportion of manganese necessary to produce good results is between .2 and .5%.

468. Influence of Nickel on Steel.—Nickel gives great strength to steel, and is, consequently, widely used for shafting, rods, engines, etc. The addition of chromium to nickel steel gives an exceedingly hard steel that is used for gears and springs. Vanadium chrome steel is used for some automobile parts.

469. Case-Hardened Steel.—Case-hardened steel is produced by placing bone-dust, specially prepared for the purpose, or burnt leather scraps in a cast iron box together with the article to be hardened. The top of the box is covered with plenty of the hardening material to keep out the air. The whole mass is slowly and uniformly heated from two to five hours until it finally attains red heat. A few iron rods about $\frac{5}{16}$ in. in diameter are packed in the box, one end of the rods reaching to the middle and the other projecting through the hardening material on the top. When the heat appears to be about right, these rods are pulled out one at a time so as to ascertain the heat in the center of the mass. When the box has been exposed to the fire the desired length of time, its contents are quickly dumped into cool water.

Sieves of iron netting are laid on the bottom of the tub into which the case-hardening material is dumped, so that the hardened articles may be conveniently taken up from the water by one of the sieves. The case-hardening material itself is taken out by another sieve which is of very fine netting and which is placed under the first one. The material is dried and used over again with the addition of a little new material.

When articles are finished before hardening, this process gives a very fine color to both soft steel and wrought iron.

Case-hardening may also be effected by packing the articles in soot, but this process does not give a good color. Horn and hoof are also used for case-hardening. Malleable iron may be case-hardened, but requires careful handling to prevent its cracking and twisting out of shape.

470. Annealing.—Of the several methods of annealing steel, the most common, when but a few pieces are to be treated, is to heat the metal red hot and then bury it in ashes, powdered charcoal, or lime. If the pieces are small, it is advisable to heat a heavy piece of iron red hot and bury it in the ashes or other material, leaving it until the articles to be annealed are heated to the desired temperature. The heavy piece is then removed and the articles are placed in hot ashes. If the small pieces of steel are buried in cold ashes or lime, or if the material is damp, the metal may be chilled and thus rendered hard. Large pieces are not easily affected; but for the process of annealing to be satisfactory, the metal must be dry and warm.

As steel is sensitive to heat, it is necessary to exercise extreme care when annealing or hardening it. If it is heated above a certain temperature, the grain of the metal is opened and made coarse. If the piece is broken, the appearance of the fracture is granular. Such steel is weak and for this reason steel should not be overheated.

471. An Alternative Method.—Steel that is kept red hot for a long period also is materially weakened. On the other hand, its temperature must not be lowered so fast that the metal chills and hardens. The work should be left in the annealing box until nearly, or quite, cold.

Another method of annealing steel consists in packing the pieces in some material in an iron box, placing the box in a furnace, and heating it until the contents are red hot throughout. The pieces may then be removed from the furnace and allowed to cool while in the box. When removed from the furnace the box should be placed where no current of air or any moisture will strike it.

472. Annealing Tool Steel.—Often articles of tool steel which are to be threaded give trouble when machined, if annealed by either of the methods mentioned. When annealing steel for taps, extreme care must be exercised, for if the steel is hard, the threading tool will not work properly; if overannealed the steel is not strong enough to withstand the cutting action of the tool, and rough threads result. Either condition is fatal to the production of a good tap.

A satisfactory method of annealing for work of this nature consists in taking an iron box and placing a quantity of hot ashes in the bottom. A board is laid on them and the articles to be annealed are placed on the board after having been heated to a uniform low red heat. They are then covered with another piece of board and the whole is buried. The wood absorbs heat from the steel fast enough to insure good annealing, while the wood in turn is heated and holds the steel just below a red heat long enough to soften it properly. Steel intended for dies, the surface of which is to be engraved, should be annealed by this method.

473. Water Annealing.—When it is necessary to anneal a piece of steel quickly, the process may be accomplished by heating it to a uniform red heat and then allowing it to cool in the air. A current of air should not be allowed to strike it until the red disappears. The instant the red disappears, the steel should be plunged in water and left until cool. Soapsuds or oil give better results than water. While water annealing is not to be advocated for general use, in an emergency it is extremely useful.

While annealing is intended primarily to soften steel, it has another use, which is to do away in a great measure with the tendency which steel has to spring when hardened. This tendency arises from the internal stresses which are caused by the various operations through which the steel passes in the steelmill or forgeshop.

When steel is to be annealed to remove stresses, the skin, i.e., the outer surface, is first cut away. The remaining piece must be large enough to be machined to size without straightening after annealing, as the operation of straightening steel when cold tends to set up strains that show themselves when the steel is hardened.

474. Test of Steel Strength.—Nitric acid will produce a black spot on steel; the darker the spot the harder the steel. Iron, on the contrary, remains bright if touched with nitric acid. Good steel in its soft state has a clean fracture and a uniform gray luster; in its hard state, a dull, silvery, uniform white luster. Cracks, threads, or sparkling particles denote bad quality.

Good steel will not bear a white heat without falling to pieces. It will crumble under the hammer at a bright red heat, while at a moderate heat it may be drawn out under the hammer to a fine point.

Iron is more active than copper. If a piece of iron wire is placed in a copper salt solution, the iron wire becomes coated with metallic copper and part of the iron is dissolved in the solution. Thus, when a piece of iron wire is placed in a solution of copper sulphate the copper immediately coats the iron and part of the iron takes the place of the copper which is deposited according to this equation

$$Fe + CuSO_4 = Cu + FeSO_4$$

These facts are taken advantage of in marking iron tools.

Questions

1. What is steel? Give some of its general physical properties.
2. How is steel graded? What are the properties of each grade?
3. Explain the meaning of hardening; annealing; tempering.
4. What is the meaning of the phrase "drawing to a faint yellow color" in tempering?
5. What is Bessemer steel? How is it made?
6. What is the open-hearth method of making steel?
7. What is crucible steel? Describe its special properties.
8. How is high-speed steel made?

9. What is mild steel? Describe its physical properties.
10. What are the impurities in steel?
11. Explain the influence of impurities on steel.
12. What is case-hardened steel?
13. Name methods of annealing steel.
14. What is the test of steel strength?

CHAPTER XXXIV

STRUCTURAL STEEL

475. Uses of Structural Steel.—Within the last generation, steel has been increasingly used for structural and ornamental purposes. Under the head of ornamental work comes the manufacture of inside and outside stairs, fire escapes, grillwork, elevator enclosures, balcony railings, fences, collar caps, vault lights, and all forms of metal-work which are decorative in character. Cold-rolled steel is always chosen for work requiring sharp corners and clear lines, such as balcony railings, doors, and grillwork, while iron is generally selected for rougher work and for jobs that do not require sharp edges. Castings are sometimes used in such cases.

476. Ornamental Steelwork.—Before an order for a piece of ornamental steel is sent to the factory, detail drawings are made in the drafting room and checked; they are then sent to the foreman of the ornamental department, who allots the work. Some men can do one class of work better than another, and the foreman picks the specialists for their particular lines. A mechanic, called the layer-out, selects the iron of the proper size and kind, lays out from the drawing the proper lengths of stock, marks off the rivet holes, half-lap joints, drill holes and all other laying out necessary for the information of the helpers and other mechanics.

After the stock has been selected, cut, and laid off, it goes to the helpers or mechanics in the various parts of the shop. All punching is done on a punching machine, which punches the various-sized holes for riveting. Holes that cannot be punched are drilled either on the drill press or by portable hand-drills, and cuts are sawed and slotted by the backsaw and the slotter. Castings are ground and filed by helpers. Curved-work and bentwork are sent to the blacksmith, who shapes them up into forms according to templates. If any duplicates are to be made, a form is forged or cut to the exact size and shape of the finished product, and all pieces are forged into shape around this form. Pieces of pipe are often needed for railings. When put to such use, they are bent to shape and the ends are threaded by the blacksmith or his helpers.

After all work has been punched, sawed, filed, drilled, and forged, it goes to the finisher for assembling. From the detail drawing he is able to place the different parts in their proper places and to fasten them together with screws, bolts, or rivets. When the finisher has properly assembled the job, he passes it on to a helper who paints it. It is then ready for delivery to the customer, or for erection.

477. Structural Steelwork.—In structural steelwork, after the draftsman has completed the detail drawings they are sent to the foreman of the structural department, who assigns the work to the layers-out. The proper I-beam or channel beam is selected and cut into lengths and the places for the rivet holes are marked off. If cutting to a certain shape is required, this shape is marked on the steel. The work, after it is laid off, is sent to the punchers, cutting-off machines, or drill presses. Here the pieces are cut to size and shape, holes are punched or drilled, and everything is done to put the work in shape for the assemblers. When the parts are ready to be assembled, they are riveted by means of riveting machines operated by compressed air. After the ends have been faced off, the work is ready to be painted and erected. Men known as erectors put the beams in place and supervise the riveting of them by the riveters.

Questions

1. Explain the demand for structural steel.

2. Explain how structural steel is made.

3. What properties of steel and iron are utilized in structural work?

4. What fastening agents are used in structural steel?

CHAPTER XXXV

MACHINE-SHOP PRACTICE

478. Operations on Castings.—Castings and forgings are usually taken to a machine-shop, where the surplus metal and rough parts are removed to make the castings conform to the design of the machine for which they are intended. This process is known as machining. They go next to the fitting shop for the necessary handwork, and finally to the erecting shop where the parts are assembled into a finished machine. The machine is then tested, taken apart, crated, and shipped to the customer; it is again set up by men called erectors.

The parts of a machine are finished to the exact dimensions called for in the blue-print by removing, when necessary, a certain portion called a cut or turning. There is a limit to the speed of tools made from ordinary steel because of the friction and heat generated. If too great a speed is used, the heat may take the temper out of the steel, render it useless, and cause the casting to expand. A mixture of soap and water is used to lubricate the casting and tool, and reduce the heat as much as possible. High-speed steel, which has already been described, has a cutting capacity four or five times that of tool steel and for this reason is used extensively.

479. Work of Machinists.—The work of the machinist is to shape metal to a definite form, size, and finish by the use of grinding and cutting tools, and to assemble, repair, and erect machines. The metal in its original form may be a casting, a forging, or a piece of stock of indefinite form from which the required object is to be shaped. Designing the part often tests the ingenuity of the machinist, as he must devise ways and means to perform the various operations so that the dimensions when finished will be accurate and will correspond to those given on the blue-print. Before a machinist begins to grind or cut a casting he marks out the outlines, holes, and machine cuts required. This is called laying-off work; the measurements are carried out by means of a center punch and dividers. The casting is then attached to the plate or table of the machine tool by means of special bolts and plates. When a great many castings of the same kind are to be machined special devices, called jigs, are employed to hold them. A jig is a great aid to quick work.

The casting is shaped by cutting or grinding the excess metal by means of various power tools. Chips may be removed also by means of a hammer and chisel. The surface is smoothed by filing. Benchwork or visework consists in fitting and finishing the machine, and floorwork in assembling the parts. Considerable skill is often required to file and scrape the parts true, so that they fit perfectly when the machine is finally assembled.

480. Measurement of Work.—To do good work, a machine must have perfectly plane surfaces, must afford a rigid support to the tool, and must give an accurate motion to the part to be machined. There must be no slackness or backlash between the parts which move over one another. All edges must be truly rectangular, and there must be equal distances between all parts of a parallel surface. To insure this accuracy mathematical instruments are required.

481. Micrometer.—Accurate mechanical work can be done only when diameters are carefully measured. As a means to this end the micrometer caliper (Fig. 197) is employed to measure the one-thousandth or one five-thousandth part of an inch. Its principal parts are the screw, the hub, and the thimble.

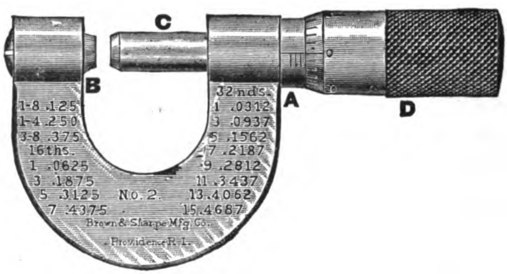


Fig. 197.—Micrometer Caliper. This caliper will measure the thickness of articles upwards by thousandths of an inch. The table of decimal equivalents is stamped on the frame.

The screw of the micrometer is covered by a thimble to protect it from dust and rapid wear. By turning the thimble the screw is moved backward or forward, increasing or decreasing the distance between the measuring points, and therefore opening or closing the instrument for larger or smaller diameters.

One complete revolution of the thimble changes the opening of the caliper .025 in. As the pitch of the screw in the caliper is 40 per inch, and the circumference of the thimble is graduated in twenty-fifths, one turn of the screw changes the caliper opening .001 in.

The heel is graduated in a straight line parallel with the screw length and conforms to the pitch of the latter, each division being .025 in. The fourth division, which is .1 in., is made on the frame with the figure 1; the eighth, with the figure 2, and so on. When the thimble is turned one complete revolution, the screw advances $\frac{1}{40}$ in., and $\frac{1}{25}$ of $\frac{1}{40}$ is .001.

In calipering with the micrometer, care must be taken to get the proper touch. If the points of the instrument are crowded or forced to overwork, the resulting error may be $\frac{1}{1000}$ or even $\frac{1}{500}$ in. less than the actual size; if too loose contact is made with the measuring points, the measurement will be larger than the real diameter and equally incorrect. The micrometer should never be laid where excessive heat or widely varying temperatures come in contact with it, as expansion and contraction of the frame injure its accuracy. In very fine and exact work, the heat of the hand may be sufficient to change a micrometer reading.

482. Machine-Shop Tools.—After the machine parts have been cleaned, the remaining operations consist of drilling holes, changing rough and uneven surfaces into smooth and plane surfaces, and so on. This work is done by chipping or turning the metal. For this purpose, tools of very hard steel, attached to one of the different metal-working machines, are used. The most common machines, and the ones generally found in all well-equipped machine-shops, are lathes, planers, milling machines, drills, power hammers, and grinding machines. In addition, many special devices or modifications of the above named machines are used for making standard parts.

483. Classification of Machines.—Machines may be divided into the two classes: (1) rotating machines, such as lathes, boring mills, drills, presses, milling and grinding machines; and (2) reciprocating machines, such as slotters, planers, and shapers.

The speed of machines of the first class is constant throughout each operation, and most of their energy is used to overcome the friction of boring, grinding, or cutting metal, the amount of power consumed by the friction of the machine itself being comparatively small. In machines of the second class, the power is subject to great fluctuations because, in addition to the friction of the work, friction and loss of energy are caused by the retardation, return, and acceleration of the machine. The work of shapers, slotters, and other machines, is done by the stroke of a reciprocating tool in one direction During the working stroke the tool must move at a suitable cutting speed, while on the return stroke, when no work is performed, it is desirable that it should travel as rapidly as possible.

484. The Cutting Capacity of a Machine.—To save expense and labor, a casting should be cut in the most economical way and in the shortest possible time. To do this, the cutting tool should attain the highest possible speed without injuring the metal or casting. The amount of metal removed in a given time represents the cutting capacity of the machine. This depends upon three factors: (1) the speed of the cut; (2) the distance covered by the tool in passing from one cutting part to the next; and (3) the depth of the cut, that is, the thickness of the strip removed from the casting.

The cutting feed of a tool is the thickness of the chip or the travel of the tool sideways during one revolution of the work. Thus, if the feed of a lathe is $\frac{1}{16}$ in. for each revolution of the work, the tool moves along the lathe bed $\frac{1}{16}$ in. and cuts a chip $\frac{1}{16}$ in. wide. Sometimes the feed is given as the number of turns which the work makes while the tool advances 1 in., as 50 or 60 turns to the inch. This is, of course, the same as saying $\frac{1}{50}$ or $\frac{1}{60}$ in. feed per revolution. The feed is occasionally stated as so many inches per minute, but this is not the common practice. The cut or depth of cut is not the feed; it is the distance the tool enters the work when feeding. Twice the depth of the cut subtracted from the original diameter of the work will give the new diameter after turning.

The rate of feed may vary from $\frac{1}{125}$ in. per revolution to 1 in. per revolution. A well-known authority on lathe practice gives the following figures and directions for roughing cuts. On soft cast iron the feed should be $\frac{1}{4}$ to $\frac{1}{5}$ in. per revolution; on soft steel it should be $\frac{1}{5}$ to $\frac{1}{8}$ in. per revolution; for finishing cuts on soft cast iron, from $\frac{1}{16}$ to $\frac{1}{25}$ in. per revolution; and on soft steel, $\frac{1}{20}$ to $\frac{1}{40}$ in. per revolution.

The volume of metal removed from a casting in the unit time of one minute is equal to the cutting speed multiplied by the feed multiplied by the depth of cut. To illustrate: If the speed of cut is 1 ft. per minute, the feed .07 in., and the depth of cut $\frac{5}{16}$ in. what is the weight of the volume of metal removed in one minute? 1 cu. in. of metal weighs .277 lbs.

$$12 \times \tfrac{7}{100} \times \tfrac{5}{16} = .2625 \text{ cu. in.}$$
$$.2625 \times .277 = .0727 \text{ lb.}$$

485. Theory of Cutting Metal.—A harder material will cut or scratch a softer material. Therefore the cutting tool must always be harder than the stock. Different metals, such as iron, wrought iron, steel, copper, brass, etc., possess different grades of hardness. The harder the metal, the greater the friction, the quicker the tool is worn away, and the greater is the strain on the machine. For these reasons it is necessary to have different cutting speeds for different metals. If this speed is exceeded or if too great a cut is removed, the heat will be correspondingly greater. This heat may be sufficient to take the temper out of the steel or warp the stock. Therefore it is very important to know the best cutting speed and feed in all cases, so that the maximum output of the machine can be obtained.

486. Kinds of Lathes.—Probably the most essential machine in the general machine-shop is the lathe. It is used for turning all cylindrical work, both straight and tapered; for boring and thread-cutting, both internal and external; and for turning spherical work or parts of spheres by means of special devices. Most of the other machines used in the machine-shop have been evolved from the lathe.

Machine-shop lathes have been perfected and specialized during recent years, until there are now many forms of this machine. They may be classified into: (1) turning, (2) engine, (3) speed, and (4) turret lathes.

487. Engine Lathe.—An engine lathe (Fig. 198) is the commonest form of this type of machine and is used mostly for turning straight pieces. It is constructed to support a spindle which is free to revolve through the medium of stepped-cone pulleys and belts. The spindle is supported by the head-stock, which is fastened to the bed which rests on legs of convenient height. The work is revolved or driven by centers, face plates, or chucks. The chucks are fastened to the spindle. If the casting or metal requires a support at both ends, the tail-stock with an adjustable center is used and is operated by a hand-wheel. When used for turning, a tee rest is employed to support and assist in guiding the tools. Cylindrical or round work is held between centers, and the tool is gripped in a tool post, which in turn is part of the carriage. The carriage is advanced by means of a screw feed, or through gears driven by means of a feed rod.

488. Engine, Turret, and Speed Lathes.—The engine lathe, described above, is also used for general work, such as turning, boring, facing, reaming, and other machine operations.

The turret lathe is a special machine device for the manufacture and rapid production of studs, bolts, screws, collars, etc. These products are cut and turned from round bar stock.

The speed lathe is specially designed for high-speed work —hence its name. It is employed mainly for such opera-

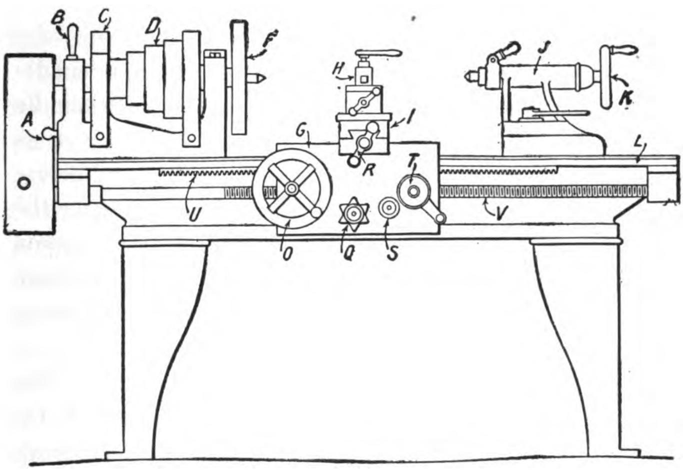


Fig. 198.—Engine Lathe.

A—Reverse	*I*—Compound Rest	*R*—Cross-Feed Ball Crank
B—Back Gear Lever	*J*—Tail-Stock	*S*—Cross-Feed Lever Knob
C—Back Gears	*K*—Tail-Stock Hand-Wheel	*T*—Apron Nut Cam
D—Spindle Cone	*L*—Lathe Bed	*U*—Rack
F—Face Plate	*O*—Apron Hand-Wheel	*V*—Lead Screw
G—Saddle	*Q*—Apron Clutch	
H—Tool Post		

tions as center drilling, polishing, reaming, and hand-turning small pieces of work.

489. Size of Lathe.—The size of the lathe is expressed by stating the length of the bed, and the largest diameter it will swing on centers. The "swing" is found by measuring from the point of the head-stock center to the "ways" on the bed, and multiplying by two. The length of a lathe's bed is the distance the tail-stock will move backward. If accuracy is desired, this measurement should be the distance between the two centers when the tail-stock is pushed backward as far as it will go. The length of the piece the lathe will turn is limited by the distance between its centers.

490. Simple and Compound Lathes.—A simple or single-geared lathe has a straight train of gearing from its spindle to its feed screw, with intermediate gears which serve as idlers to take up the distance between the driver and driver gears or spindle and screw gears. Index plates, giving the change of gear used for different threads, are usually found on lathes, but when threads are called for that are not indexed or when those ending in fractions are to be cut, the machinist must resort to his own figures.

The term *compound* in lathe practice means that in the train of gearing from the spindle to the lead screws of the lathe, there is a stud or spindle with two different sized gears. These gears are so connected as to change the link of revolution between the spindle and the lead screw to a different number of revolutions from that which would take place if the straight line of gears were used.

491. Lathe Tools.—The ordinary lathe tool is a short bar or rectangular cross-section of tool steel with a cutting edge at one end. It is produced by forging and grinding. It must be hardened and tempered to cut the metals upon which it is to operate. The lathe chuck is a device for holding the work firmly and adjusting it accurately.

492. Vise.—The machinist's vise is one of the simplest as well as one of the most important parts of the machine-shop outfit. Its mechanical principle is based on that of the screw. Much of the success of the work on lathe and planer often depends on the accuracy with which the work at the vise has been done. Such preparatory machine operations as center punching, the scribing of outlines, and the laying off of holes and machine cuts require experience in handling a vise.

Machinists' vises are made in various shapes and sizes to meet different requirements and in two styles of base: (1) stationary and (2) swivel. Some have patent self-adjusting jaws, while others have solid jaws. Different sizes are specified by their amount of "open" and the size of their jaws. A No. 18 vise has a 2⅝ in. jaw and opens 3½ in., while a No. 20 has a 4½ in. jaw and opens 6 in. Rough pieces to be filed or chipped may be clamped between the jaws, but smooth finished pieces are held between copper or lead strips, fitted over the vise jaw so as not to bear too hard on the stock. No undue strain should be put on a vise to make it grip firmly as already noted in Chapter XXIII, "Common Hand-Tools." A piece of pipe should never be used to obtain more leverage on the vise handle.

493. Screw Machine.—The screw machine is practically the same as the turret lathe, but is used for different purposes; in fact, the screw machine when first designed had a turret, the tools of which were advanced in the proper order by means of levers and guide straps fastened to a guide drum. The screw machine is now built along the general lines of a lathe, but without a carriage. The tail-stock is replaced by a turret arranged to hold six or more tools, so that each one may be brought into play in the order in which it is needed, and each operation may be thus performed in its progressive order.

The latest machine of this class instead of permitting only one bar of stock at a time to be fed into the machine, and the tools advanced in order, allows five bars to be fed at once, five operations being performed at the same time. The only skill required to operate the machine is in the setting up of the tools and in the adjustment of the machine. The man who does this is not necessarily a machinist, but he must understand the screw machine and give close attention to the details of its operation.

494. Drilling.—A different cutting speed is necessary for nearly every material, and drills are constructed so as to meet the various requirements. A large drill must run slower than a small one, the turns per minute becoming less as the size of the drill increases. For example, a drill ½ in. in diameter should make twice as many revolutions per minute as a 1 in. drill, and four times as many as one 2 in. in diameter. For this reason, there must be a number of different feeds, as well as speeds. Hand-feeding is to be preferred to machine-feeding for small or delicate work, since it is possible to "feel" the drill and keep it going through the work at a varying rate according as the metal is hard or soft or contains blow-holes and imperfections. A heavy power-driven feed will sometimes break quickly into a blow-hole and spoil the drill or the work.

The cone pulley shown in Fig. 143b (page 288) gives three different speeds to the drill spindle and the drill. There are two cone pulleys, an upper and a lower; when the belt is on the smallest step of the upper cone pulley, the fastest speed is obtained.

The drill table generally swings about the post or upright frame of the machine, thus allowing the work to be adjusted under the spindle. Some machines are provided with tables which pull in and out in a straight line as well as swing in a circle. This straight-line adjustment allows a number of holes to be drilled in a row without swinging the table.

495. Shaper.—Shapers and planers are used for finishing plane surfaces. The shaper is a small machine on which light work is fastened to the bed or held in a planer chuck. The tool is held in a tool post at the end of a ram which is made to move forward and back, the cut taking place on the forward stroke. There are both geared and crank shapers, the kind used depending on the method of running the ram. With a crank shaper one belt is required to drive the machine, while a geared shaper requires two belts running in opposite directions. This latter type may be operated either by friction between the two pulleys or by shifting the belts alternately onto a tight pulley and thus alternating the direction of the ram.

496. Planer.—A planer works on the same principle as the shaper, the shaft to which the tight pulley is fastened being geared to the platen or table so that the table runs back and forth. The work is fastened to the platen or held in a chuck. The tool is held in a head which may be raised or lowered to suit the work. This head is fed across on a cross-guide by means of a screw actuated by a ratchet-feed. Heads are also placed on the housings so that they may be adjusted to plane on the edges or sides of the work. Considerable skill is required to fasten the work, so that when completed it will not spring out of shape, but will remain true.

497. The Operations of Planing.—The planer is one of the heaviest of machine tools. Planing is rough and heavy work, and rigid construction and stiffness are needed to take the heavy cuts, as the surfaces of castings and heavy forgings are usually hard crusts difficult to remove. In most shops much of this rough cutting is saved by the use of a pickling solution of one part sulphuric acid to eight parts of water. This solution is painted over the casting, and after four or five hours washed off with clear water, thus removing the sand and hard grit from the surface. If the castings are small, they are put with the pickling solution into a wooden vat into which a small amount of steam is injected. The castings are thus easily prepared for machining.

For roughing cuts on a planer, a highly tempered diamond-nosed tool is used which must be kept sharp by grinding. The cut of the roughing tool should be deep enough to go below the scale or surface, and thus allow the tool point to reach soft metal. Care must be taken not to allow the tool to ride over the hard scale, without doing any work, as a heavy drag on the machine will thus be caused. In cases where the casting is out of level, it should be leveled as nearly as possible. In such cases several cuts will be necessary to get the planer properly started. Any hard burr or sand-hole lump on the surface of the casting is best removed by a chisel and hammer, as an unnecessary strain is thrown on the machine tools when an attempt is made to remove them by planing.

After the surface is smooth, the round-nosed tool may next be used to plane to size and to proper depth. Some work may require no further finish than this. In cases where a smoother finish is desired, a square or flat-nosed tool is fed with a rapid revolution of the feed screw, sometimes as much as one-fourth revolution per stroke of the planer platen. The cross-rail is supplied with two feeding devices on single-head planers, "cross" and "vertical." The tool-head is marked with graduations for any desired angle.

Care must be taken during the operation of a planer that chips and dirt from the platen are not swept or allowed to blow into the V-ways, as this will cause injury to the machine. Oil should also be freely supplied to the machinery under the planer platen; these parts are likely to be neglected because they are hidden.

The installation and erection of a planer is of much importance, as poor work will result from a machine built on a poor foundation. A planer 24 in. $\times$ 24 in. $\times$ 6 ft. will consume an average of .035 horse-power for every pound of cast iron removed per hour and .065 horse-power for every pound of machinery steel removed per hour. The ignorant operator may, by the way he grinds and sets his tools, waste much power in driving the machine.

498. Shaping Machine.—The shaping machine differs from the planer in that the tool post moves while the work is stationary. Both machines are used for planing flat, level, and oval surfaces but the shaper is nicely adapted for cutting grooves, slots, and dovetails, and for work on small pieces and short travels.

Shaping machines are designated by the length of their stroke in inches or by the extreme length they will plane. A vise is attached on the shaper to hold the work, and on 12-in. shapers four cone speeds are usually provided for changes in speeds. The round-nose, diamond-point, cutting-off or parting tools, and the side-shearing tools are the ones most commonly used. Shapers are of three types: (1) crank, (2) back or geared, and (3) friction, the crank and geared types being the more common.

The shear, clearance, and cutting edge of shaper tools should be in good condition. Shear is the angle given to the face of a tool, which throws its cutting edge forward into the metal. Tools without clearance drag and pull heavily through the metal. The important features of a shaper are its column, ram, head, stroke, index, table, cross-feed, cross-rail, vise (swiveled and graduated), and driving cone centers. When working on the shaper, the small try-square and the surface block are constantly in use to show when the finished pieces are square with the shaping machine vise, and when one cut is square with another. A graduated universal bevel or a bevel protractor is also employed to lay out angles for planing. A scriber and a 4-in. outside caliper enable the beginner to grasp the first operations of shaping and planing. Cast iron is planed dry, as are steel and wrought iron unless the work is a key-seat, or requires a thin or delicate tool. In this latter case, lard oil is fed to the tool.

Before starting the planer the ram should be adjusted to the proper length of the stroke. If a piece of work which measures 2¾ in. is to be placed on the machine, the ram should not be set to a 3½ in. stroke. A sufficient cut for the tool is ¼ in., and ⅛ in. is even more than enough to allow the head to overreach. These additions then give us a total stroke of 3⅛ in. and any over this means time lost and unnecessary wear on the machine.

499. Key-way Machine.—The key-way machine is used for the purpose of cutting a slot or a key-way in any thick piece of metal, such as a pulley. The machine is not complicated and its operation requires very little skill. A cutter resembling a very coarse file makes the proper width of cut and is held to the work by the machine.

The operation of a slotter is similar to that of a shaper with the difference that as the ram works vertically instead of horizontally, the tool cuts on the down stroke, and the ram is counterbalanced to return easily. The slotter is used on irregular shapes and especially on all kinds of heavy work. Such work requires only an ordinary machinist, although specialists are sometimes employed.

500. Drilling Machines.—Probably the first power machine that every machinist runs is the drilling machine or drill press. Sometimes it is simply called the drill, although this term usually refers to the small drill that actually does the work.

The different parts of all drilling machines have practically the same names, so that by becoming familiar with the parts of one type, the student will have learned the essential features of all. The drilling machine consists of a revolving spindle carrying a socket for holding the tool, a table for supporting or holding the work, and an arrangement for feeding the tool into the work either by hand or power. Different speeds for running the drill in different kinds of metal are provided for by cone pulleys and back gears, the back gears giving the slower speeds.

In all drilling machines the work is held stationary while the tool turns. This order is reversed in the action of a lathe, where the work turns and the tool remains stationary.

501. Milling Machines.—The milling machine (Fig. 199) is not so generally used as its worth merits, because comparatively few machinists know how to operate it. This machine is not limited to plane milling, but will mill irregular shapes by the use of formed cutters. The work is done by fastening to the bed the casting or metal, held in a chuck or on centers. The variety of operations which the milling machine can perform is almost limitless. The work is fed against a cutter whose teeth are so cut that it works on the principle of a coarse file. Spur gears, bevel gears, and spiral gears may be cut, taps and reamers fluted, and many other things performed which could be done on other machines only with difficulty, unless the machine were specially built. To run the milling machine to its best advantage a knowledge of trigonometry is required. Charts are furnished covering the most common requirements, but to cover everything the machine can do would require an unreasonable number of charts.

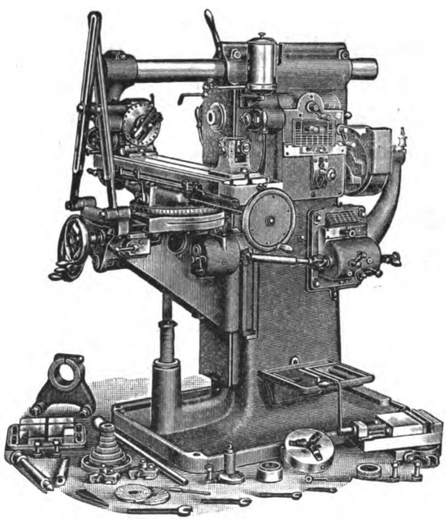


FIG. 199—Universal Milling Machine.

There are three classes of milling machines: (1) the plane milling, (2) the universal milling, and (3) the special milling machine. The operation of successful milling requires much study of milling cutters. These cutting tools turn on the arbor (principal support) of the machine, while the table feeds the work horizontally, vertically, or crosswise. The action of the machine is as follows: The power is transmitted from the pulley on the countershaft to that on the spindle, causing the spindle which carries the cutter to revolve while the table to which the work is fastened travels by. The depth of cut can be regulated by the operator through the medium of screws which raise or lower the knee upon which the table is carried. The position of the cut is also controlled by a screw which operates the lateral motion.

502. Power Press.—The power press is used for cutting and forming sheet-metal parts. It has a strong base sup-

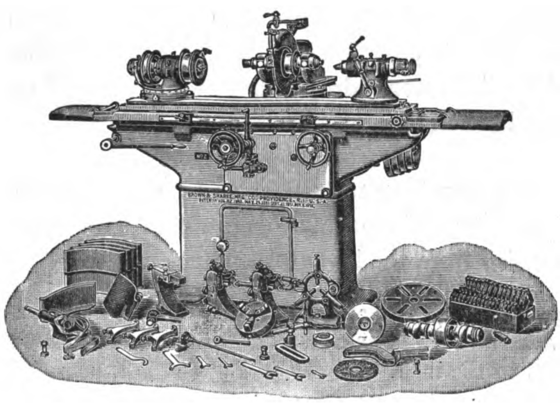


FIG. 200.—Grinding Machine.

porting a crank shaft, which converts the rotary motion imparted by the pulley or fly-wheel into the rectilinear motion of the gate or ram. A punch is fastened to the ram and carried by its motion through the die. The die is held stationary in a chair or bolster plate.

503. Grinding Machines.—Universal grinding machines (Fig. 200) are used for grinding pieces which have been distorted by hardening, although it is sometimes profitable to finish soft pieces also by this method. This machine is similar to a lathe, with the exception that instead of a tool for removing the stock, a revolving wheel made of abrasive material is employed.

A surface grinder is a modification of the planer, but uses a revolving, abrasive wheel instead of a tool for removing stock from flat surfaces.

504. Power Hammer.—Power hammers may be divided into three classes: (1) trip hammers, (2) friction board or drop hammers, and (3) steam hammers. In all classes, dies are used to shape or form the hot metal. Trip hammers are used for light work, drop hammers for work of medium weight, and steam hammers for heavy work.

505. The Vernier and its Use.—An important measuring instrument used in machine operation is the vernier (Fig. 201), so called from the inventor's name.

It consists of a bar of metal divided into inches, each inch being again divided into ten parts, and each tenth into four parts, making forty parts to the inch. On the sliding jaw is a line of division called the vernier which consists of 25 parts, numbered 0, 5, 10, 15, 25. The 25 parts on the vernier correspond, in extreme length, with 24 parts or $\frac{24}{40}$ of an inch on the bar. Consequently each division on the vernier is smaller than each division on the bar by one-thousandth of an inch.

If the sliding jaw of the caliper is pushed along the other, so that the line marked 0 on the vernier corresponds with that marked 0 on the bar, then the two next lines to the right will differ from each other by one-thousandth of an inch. The difference continues to increase one-thousandth of an inch for each division, till they again correspond at the line marked 25 on the vernier. To read the distance when the caliper is open, we begin by noticing how many inches, tenths, and parts of tenths the zero point on the vernier has been moved from the zero point on the bar. We now count upon the vernier the number of divisions, until one is found which coincides with one on the bar. This division will be the number of thousandths to be added to the distance read off the bar. The best way of expressing the value of the divisions on the bar is to call the tenths, one hundred times one thousandth (.100), and the fourths of tenths, or fortieths, twenty-five times one thousandth (.025).

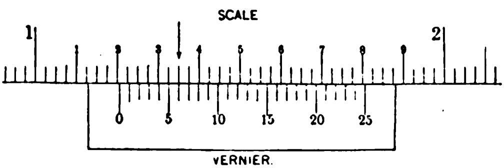


FIG. 201.—Vernier.

The vernier shown in Fig. 201 has been moved to the right, $1\frac{2}{10}$ in., or 1.2 in., as indicated by the bar; and the sixth line on the vernier coincides with a line on the bar, thus making six-thousandths (.006) of an inch to be added to the reading from the scale, which would make the total reading one and two hundred and six thousandths (1.206) inch.

In making inside measurements with a 6 in. vernier, two and one-half tenths, or two hundred and fifty thousandths (.250), of an inch and with the 12 in. and 24 in. vernier, three-tenths, or three hundred times one thousandth (.300), of an inch, should be added to the apparent reading on the vernier side for the space occupied by the caliper points. With a vernier caliper (Fig. 202) reading to metric measure, add 6 mm. When the other side of the instrument is used no deduction is necessary, as there are two lines, one indicating inside and the other outside measurements.

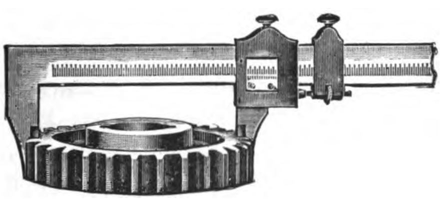


FIG. 202.—Vernier Caliper. For determining accurately the depth of gear teeth.

506. Thickness Gauge.—The thickness of metal may be determined by means of a thickness gauge, which consists of many levers, varying in thickness by thousandths of an inch, and each designated by a number. By applying these levers successively, it is possible to determine the thickness of a piece of metal. A similar arrangement of plugs, called thickness plugs, are used for determining the diameter of a hole.

507. Screw Pitch Gauge.—It is very desirable at times to be able to tell quickly the pitch of a screw thread. This may be done by means of a screw pitch gauge, which consists of many thin pieces or leaves of steel fastened to a holder (Fig. 203). On the edge of each piece of steel there are teeth corresponding to a standard thread section. By placing leaves successively over the thread until a leaf coincides, it is possible to determine the screw pitch.

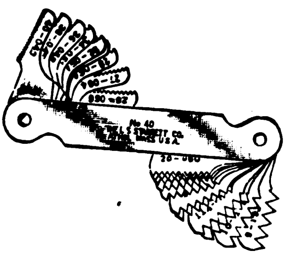


FIG. 203.—Screw Pitch Gauge.

508. Division of Machine-Shop Trades.—The machine trade is divided into machine construction, tool-making, and die-sinking. Under the first type of work are grouped all those operations, discussed in previous sections, which have to do with making and repairing machinery.

Tool-making requires a higher degree of skill than the average machinist usually possesses. The work ranges from making shop tools, such as jigs, boring bars, templates, etc., to the making of fine hand-tools and instruments of precision. The principles involved in tool-making are the same as in other machine-work. Greater care, however, must be exercised because of the greater accuracy demanded, as sometimes work is required to be exact to the ten-thousandth part of an inch. When such accuracy is expected the work is ground to size on a universal grinder, which grinds either cylindrical or plane surfaces.

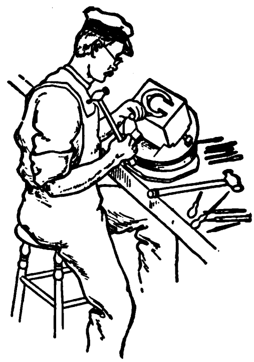


FIG. 204.—Die-sinking.

Drop forgings, in which a form is made to conform to the desired shape, are made by means of dies or blocks of steel.

The work of making the dies is called die-sinking (Fig. 204). As it is necessary to work on the metal by various means, making allowance for shrinkage and the flow of metal, a considerable amount of skill is required to work out these forms and finish them so that the product will be properly made.

Questions

1. Explain the different steps in finishing and machining castings.

2. How are the castings made to exact size?

3. What is high-speed steel? Why is it very useful in the machinists' trade?

4. What is chipping and filing?

5. What is the meaning of "benchwork" in the machine-shop?

6. Is it necessary to use mathematical instruments in doing machine-work? Why?

7. Describe a micrometer. How is it used? Does the heat of the hand affect it?

8. Name some machine tools built on the principle of rotary motion; reciprocating motion.

9. Which is the most economical tool, so far as the energy put into it and the useful work it will do is concerned?

10. Upon what does the cutting capacity of a machine depend?

11. Define the following expressions: "cutting feed of a tool," "depth of cut," "cutting speed."

12. Is it possible to cut all metals at the same rate of speed? Explain.

13. Why is it necessary to have different speeds on a machine tool? How are different speeds obtained?

14. What is a lathe? Explain the difference in action and uses of different lathes.

15. What is meant by the expression "size of a lathe"? Why is it important?

16. What is a simple lathe? Compound lathe?

17. What is a lathe tool?

18. Describe a machinist's vise.

19. What is a screw machine? Explain its action.

20. What is a drilling machine? Explain its action.

21. What is a shaper? What is a planer? How do they differ in use and action?

22. What is a key-way machine?

23. Explain the purpose of a milling machine. Describe its action.

24. What is a grinding tool?

25. Describe the different kinds of power hammers.

26. Explain the use and action of a vernier.

27. What is a screw pitch gauge? Thickness gauge?

28. What is the difference between a general machinist toolmaker and die-sinker? Name some of the principles of science that a general machinist should know in order to understand and do his work intelligently.

CHAPTER XXXVI

SHEET METALS

509. Nature of Work.—Formerly the workman who made household utensils out of tin was called a tinsmith. Nowadays the use of tin for this purpose has greatly decreased, and aluminum and enamel ware has taken its place to a large extent. Today the man who works on sheet tin, galvanized tin, sheet brass, and copper is called a sheet-metal worker.

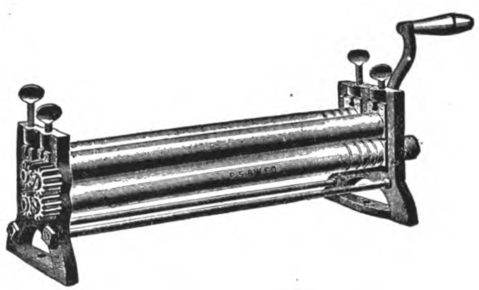


FIG. 205.—Bending Roll.

Sheet-metal work consists in the utilization of sheets of metal for industrial purposes and comprises the laying out of tin or other sheet-metal utensils, the forming and making of waterspouts, the bending of lock joints by the use of the folder or brake (a machine for bending metal—Fig. 205), the laying of tin on roofs, and the closing of joints by the use of mallet seamers, or roofing tongs. The tinsmith or sheet-metal worker erects metal ceilings and side-walls, makes crestings, awnings, hollow circular moldings, metal sash-frames and skylights, and covers fire-doors and windows.

Sometimes a distinction is made between coppersmiths and sheet-metal workers. The coppersmith makes copper forms by hammering and then brazing (a form of soldering) the plate into the desired shape, while the sheet-metal worker makes a form by developing it from the sheet.

510. Common Sheet Metals.—Certain metals and alloys, such as brass, copper, lead, tin, zinc, tinned iron (tin-plate), aluminum, and thin sheet iron, possess strength, durability, lightness, and a clean, smooth surface. Most of these metals, particularly copper and tin, possess the property of malleability in a marked degree and can, as a result, be hammered into various shapes without being fractured. Sheet metals are made by passing metal bars through heavy rollers until the desired thickness is obtained.

Copper, the most useful of metals next to iron, is found in all parts of the world, but principally in the states of Montana, Arizona, and Michigan. It occurs in both the free and the combined forms. The combined compounds are the oxide (Cu_2O) and the sulphide (Cu_2S). Copper is not affected by water or by oxygen at any temperature, which accounts for its being found frequently in the free state.

511. Smelting of Copper.—There are two methods of obtaining copper—by smelting and by electrolysis. It is desirable to mix different ores so that they will be in proper condition for smelting, as one often acts as a flux to the other. The whole mass is roasted (heated to a high temperature) for twelve hours in the furnace, from which it is raked out in a black and pulverized condition. The next process is smelting, during which the slag or earthy part of the ore rises to the surface, and is cleared off, after which the metal is run into pits filled with water. This causes it to become granulated. These two processes are repeated twice, and then the metal is again roasted so as to oxidize completely the iron and other metals still combined with the copper. Finally the copper is toughened by being covered in a furnace with charcoal. While in the furnace it is stirred with a pole of birch wood to cause ebullition. The grain gradually becomes finer, the color lighter, and the metal more malleable. Copper obtained in this way, however, is not 100% pure.

512. Copper Refining by Electrolysis.—Pure copper is obtained by means of electrolysis.* Bars of impure copper are melted in an ordinary furnace and are granulated by being placed on a copper tray at the bottom of a tank of cold water. This highly concentrated alloy of copper serves as the anode of a battery. The cathode is an exceedingly pure bar of copper (about 99.93% pure). The electrolyte is a copper sulphate solution containing free sulphuric acid. The principle of the process is that by electrolytic action the metal to be refined is dissolved from the anode by the free acid in the electrolyte. The current of electricity passing through the solution deposits the copper from the electrolyte on the cathode in a pure form. The foreign metals and impurities remain on the anode or in the anode slime. The cost of the electrolytic process is covered first by the high price of the refined metal and second by the value of the silver and gold that is recovered from the copper. To have high electric conductivity the copper must be free from arsenic and antimony.

513. Physical Properties of Copper.—Copper when pure is of a red color, exceedingly malleable and ductile. When

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* See page 171.

rolled, hammered, or worked into sheets, it is used to a great extent for roofing and sheathing vessels, and for making cylindrical pipes and copper wire. When hammered or worked in the cold, copper becomes brittle, but its toughness is restored by heating it to 500° F. When heated to redness it can be drawn apart and forged, but if overheated it becomes coated with black oxide of copper. In the ingot or cast condition it contains much oxide and therefore is not so strong as when it is rolled out into sheets.

514. Chemical Properties.—When a piece of copper is heated in the air it combines slowly with the oxygen and two oxides are formed: cuprous oxide (Cu_2O) and cupric oxide (CuO). The cuprous oxide is red and the cupric oxide is black. In a moist atmosphere, the carbon dioxide of the air combines with these oxides forming a green layer which contains the hydroxide, $Cu(OH)_2$, and the carbonate, $CuCO_3$—verdigris.

Copper is not affected by hydrochloric acid, but a weak, cold or hot concentrated acid will quickly dissolve it.

515. Properties of Aluminum.—Aluminum resembles silver in its whiteness but is much lighter. The ore of this metal is obtained from pure clay, a substance with which man was familiar for ages without suspecting the treasure it contained. The metal is not found in a pure state although its compounds are common. It is now made on a large scale by an electrolytic process which has greatly reduced its cost.

When an electric current is passed through cryolite (a fluoride of aluminum and sodium found abundantly in Greenland), the aluminum oxide which is added is decomposed and the aluminum goes to the negative pole and is collected in the molten state.

Pure aluminum is acted upon neither by the oxygen of the air, by water, nor by dilute acids, but the commercial grade is impure and is rapidly oxidized by steam at a high temperature. Dilute or concentrated sulphuric or nitric acid does not, when cold, act on aluminum, but when heated dissolves the metal rapidly. Dilute or concentrated hydrochloric acid also will dissolve the metal readily. Since it is not affected to any great extent by organic acid, and the salts of aluminum are quite harmless, this metal is widely used for cooking purposes in place of tin and copper. Caustic alkalies readily dissolve aluminum with a formation of aluminates and the liberation of hydrogen.

Aluminum in a pulverized condition is gray in color, is very malleable and ductile, and has a specific gravity about that of glass (2.7). It melts at a red heat and vaporizes at a very high temperature.

516. Aluminum Alloys.—Aluminum is used to make alloys of various kinds, the most important of which is aluminum bronze. This alloy is made up of from 5 to 8% aluminum and from 92 to 95% copper. It is used to imitate gold, is very rigid and strong, and is not affected by air or water. Hence it is valuable for many purposes. Just before it is poured from the cupola, steel from which castings are to be made has added to it small quantities of aluminum and bronze. This insures that the castings will be free from blow-holes. Lately, a new flash-light powder containing aluminum has been placed on the market.

517. Uses of Tin.—Tin is obtained from the ore oxide of tin by smelting. Because of its high price and its low tensile strength (about two tons per square inch), tin is comparatively little used. As one of the constituents of gun-metal or bronze, however, it is of great value. Since it is not acted upon by salts and weak acids in the cold nor by animal or vegetable juices and also since it resists oxidation, tin is often applied to other metals as a protective covering.

In making tin plate, sheet iron is thoroughly cleaned by acid baths, then greased with melted tallow or palm oil to prevent contact with the air, and dipped in a bath of molten tin. A layer of palm oil or other grease also covers the melted tin. After the bath a thin layer of tin sticks to the sheet iron. With this addition the sheet iron is passed through rollers to squeeze off superfluous metal and perfect the coating. This plate is made into tin cans to hold oil, paint, fruit, vegetables, fish, etc. It is also used for roofing and for the manufacture of kitchen utensils.

518. Uses and Chemical Properties of Lead.—Lead is seldom found in a pure state, but usually as the carbonate ($PbCO_3$), the sulphate ($PbSO_4$), or the sulphide galena (PbS). To obtain lead it is necessary to free the ore of its combining elements. The processes of stamping, washing, and smelting are used for this purpose.

The ore put into the furnace should consist of from five to eight different kinds, as a mixture of ores produces better lead. This charge is first roasted to oxidize the sulphur or arsenic contained in the ore to sulphur dioxide and arsenic oxide. After the remaining ore has been fused, a layer of slag or refuse forms to the depth of two or three inches. The slag is drawn off, and then the molten lead is allowed to run into a pan where it is skimmed and ladled into molds.

Lead sheets are used by the plumber for roofing, for making pipes, cisterns, tanks, leaden coffins, and for many other purposes. The ease with which lead can be worked causes it to be employed in all countries which have arrived at any degree of civilization. The Chinese use large quantities for making the thin sheets in which they pack their tea. Their process for making these sheets is simple and ingenious. One workman sits on the floor with one large flat stone before him and another at his side. A second workman stands by with a pot of melted lead, part of which he pours on the stone. The first workman places the movable stone on the melted metal and compresses it into a flat thin sheet which is afterwards trimmed. The process is expeditious and effectual.

Lead boils at white heat, absorbs oxygen from the air, and passes into lead oxide (PbO). Lead is little acted upon by muriatic acid, but is readily dissolved by nitric acid.

519. Alloys of Lead.—Oftentimes it is necessary to use an alloy which will expand on cooling. Such an alloy is obtained by melting together 9 lbs. of lead, 2 lbs. of antimony, and 1 lb. of bismuth. The alloy is used to fasten bolts firmly into foundation stones. The process is as follows: After the bolt hole is drilled in the stone a couple of short, small holes are drilled at an angle to the big hole. As the metal is poured in, it flows around the bolt and also into these small holes. On cooling, the metal expands and for this reason it is almost impossible for the bolt to pull out. When drilling holes in stone, water is always used and care must be taken to see that the holes are dried out by the use of red-hot iron rods before the melted metal is poured in. If this precaution is not taken, the metal will blow out, and may burn the hands and face of the man who is pouring it in.

520. Properties of Zinc.—Zinc is a bluish white metal which has only lately been discovered in its pure form, though its ores have long been known and used. It is obtained from the ores in the following manner:

Zinc carbonate is reduced to zinc oxide by heating, thus:

$ZnCO_3$	=	ZnO	+	CO_2
Zinc Carbonate		Zinc Oxide		Carbon Dioxide

The sulphide may be oxidized to an oxide by wasting, thus:

ZnS	+	$3O$	=	ZnO	+	SO_2
Zinc Sulphide		Oxygen		Zinc Oxide		Sulphur Dioxide

The oxide is finely powdered, mixed with charcoal, and heated in earthenware retorts. The heating process is continued until the temperature rises above the boiling point of zinc (918° C). The oxide then passes off as a gas and condenses in an iron receiver. Pure zinc may be obtained by repeated distillations in vacuum. The largest proportion of zinc comes into the market in ingots formed by pouring it into molds. In this form it is hard, crystalline in structure, and rather brittle, but at a moderately high temperature (212° to 300° F.) it possesses great malleability and ductility. It can then be readily drawn into wire, rolled into plates, or worked in other ways. Zinc is well suited for casting models, as it melts readily, liquefies completely, and therefore copies every line of the mold more accurately than do the harder metals. Zinc dust is obtained by distilling zinc and allowing it to condense in a cold chamber. Granulated zinc is made by pouring melted zinc into water.

521. Use of Zinc.—Zinc is used with copper to form brass and other alloys, and as a covering to protect iron from the action of the atmosphere or of sea water. By placing blocks of zinc in metallic contact with the iron of boilers, corrosion is prevented. Zinc plates are used for many purposes; in roofing they are valuable for their lightness, since they weigh but one-sixth as much as lead.

522. Chemical Characteristics of Zinc.—Air attacks zinc very slowly and even the pressure of moisture forms only a basic carbonate which acts as a protective coating. Consequently, only the outer layer is affected. When heated, zinc burns in the air forming zinc oxide. Dilute hydrochloric and sulphuric acid act on zinc and form hydrogen in addition to the salts.

523. Properties of Mercury.—Mercury, also called quicksilver because it looks like silver and flows quickly, is the only metal that is liquid at an ordinary temperature. Small drops of pure mercury are sometimes found, but it is usually made from an ore, called cinnabar (mercuric sulphide), made up of mercury and sulphur. The metal is easily obtained by roasting the ore and vaporizing the mercury which is condensed and purified. The reaction is:

$$\underset{\text{Mercuric Sulphide}}{HgS} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Mercury}}{Hg} + \underset{\text{Sulphur Dioxide}}{SO_2}$$

The sulphur burns to sulphur dioxide and the mercury passes off as a vapor. The vapor is conducted through tubes into a vessel containing water, where it is condensed into liquid mercury.

Pure mercury is very heavy, as bright as silver, and is not tarnished by air at an ordinary temperature. When heated it takes up oxygen from the air and is turned into a red powder (mercuric oxide). By continuing to heat the mercuric oxide, the oxygen can be driven off and the mercury turned back into a fluid state. Mercury becomes a solid only at a great degree of cold (39° to 40° F. below zero).

524. Uses of Mercury.—Mercury is much used for making thermometers and barometers. It is also used for extracting gold and silver from their ores, by allowing the crushed ore to flow in a thin mud over plates covered with mercury. The gold amalgamates with the mercury, and is separated later by distillation.

Mercury was once much used for silvering the backs of mirrors but a solution of silver has been found to be cheaper for this purpose. Mercury unites with most of the other metals to form alloys, called amalgams. Amalgams of silver and other metals are used in filling teeth.

Mercury is the basis of fulminating mercury, the explosive powder put into percussion caps, cartridges, and fuses. Dry fulminating mercury will explode violently when struck with a hammer or any other hard object. When wet it is non-explosive and is kept in this condition until wanted for use. It can be obtained as a fine, gray powder by shaking it violently with flour, grease, etc., so as to coat the minute drops and prevent them from uniting to form a fluid mass. Pure dilute acids do not attack mercury, but concentrated nitric acid dissolves it readily.

525. Properties of Platinum.—Platinum is a metal discovered only in the eighteenth century. The principal supply comes from South America and Russia. It is as durable as gold, as hard as iron, resembles silver in color, and is extremely ductile and tenacious. It melts at 2000° F. Owing to its high melting point and its resistance to the action of most chemicals, no single acid will act on it. A mixture of nitric and hydrochloric acid (aqua regia) will dissolve it. Finely divided platinum is called platinum black and has the power of absorbing gases.

526. Properties of Antimony.—Antimony is a hard metal used as an alloy with tin and lead for various purposes where great hardness and durability are needed. Printers' type metal, which must be firm enough to bear the pressure of a heavy printing press, is composed of lead and antimony. Antimony is also used as a medicine, while its oxide is valuable for the purpose of coloring glass. Sometimes found in the native state, its most important ore is the sulphide, stibnite (Sb_2S_3). The pure metal is obtained by strongly heating the ore with iron filings in a crucible, or by roasting the sulphide in a furnace until it is converted into the oxide (Sb_2O_4). It is then mixed with powdered coal and heated to a redness. As a result the carbon dioxide escapes and antimony remains.

527. Bismuth.—Bismuth has a reddish white metallic luster, and is found as a pure metal, or in compounds as a sulphide. The ore is first roasted to oxidize the arsenic and sulphur, and is then mixed with carbon and iron filings and melted in a crucible. The metal collects in the bottom of the crucible. Bismuth is chiefly used because of its extreme fusibility, as it melts at 270° F., while its alloys melt at even a lower temperature.

528. Brass.—Brass is an alloy of copper and zinc. The malleability and ductility of this alloy depend upon the amount of copper in the mixture. The ordinary yellow brass of commerce, known as high brass because it contains a large amount of zinc, varies from 60% copper and 40% zinc to 75% copper and 25% zinc. Brass is used in the joining of pipes because it does not rust or corrode as iron does.

529. Anneals and Tempers of Sheet Metals.—Sheet metals are used to meet definite conditions and are softened or hardened accordingly. The degree of softness is expressed as "anneal" and the degree of hardness as temper. Therefore in describing a sheet metal, the character of the "anneal" or the temper should be specified. To illustrate, the temper of sheet brass may be expressed as "half-hard," "hard," or "spring."

530. Extended Metal Shapes.—There are many brass and bronze alloys that may be made into irregular shaped bars by forcing the hot metal through dies of the required shape. These bars are spoken of as extended metal.

531. German Silver.—German silver is an alloy of nickel, copper, and zinc. Its quality is designated by figures which indicate the percentage of nickel in the mixture. It is called white metal when containing 18% or more of nickel. As the percentage of nickel is reduced, its color shades off towards the yellow color of brass. While German silver is not so soft and ductile as brass, it may be worked and spun to shapes on chucks of lathes. The metal has a very fine, dense grain, takes a high polish, is non-corrosive under atmospheric influences, and is extensively employed in the manufacture of knives, forks, spoons, etc., for table use.

532. Kinds of Bronzes.—In the early days of manufacture the term bronze was applied to a non-corrosive metal made of a mixture of copper and tin, dark in color, hard in temper, and of high tensile strength. Today bronze refers to any metal that possesses any of the above characteristics. In order to distinguish the different bronzes, a prefix should be used, such as "Tobin," "phosphor," "naval," "manganese," etc.

Tobin-bronze is a composition of copper, tin, and zinc, in such proportions as are necessary to secure the physical properties and the resistance to corrosion desirable in a metal intended for engineering purposes. It has a bright golden color and resists the corrosive action of sea water.

Phosphor-bronze, which is bronze containing phosphorus, resists shocks. Hence it is used for the bearings of rolling mills, railway axles, for valves of air pumps, etc. It is affected by the heat more than is gun-metal. Phosphor-bronze offers great resistance to corrosion, has great tensile strength, and has no tendency to disintegration. It may be made into springs without "setting" or crystallizing. It is better than any other copper alloy because of its antifriction properties.

Naval-bronze is made according to specifications of the United States Navy. It is particularly adapted to marine engineering, where strength must be accompanied by non-corrodibility.

Manganese-bronze is an alloy of copper, zinc, and tin, deoxidized by means of manganese. It may be readily rolled or forged at a red heat resulting in the production of an exceedingly tough, dense, and close-grained metal. It will resist vibratory and sudden stresses and shocks, and will not rust or corrode in the presence of air or sea water.

533. Gun-Metal.—Gun-metal is an alloy of copper and tin, with sometimes a small proportion of zinc. It is a harder metal than either of its constituents and has a greater density. It is more fusible and less likely to corrode than copper. When a casting of gun-metal rapidly cools or chills, the density, strength, and toughness of the metal are increased because the composition becomes more uniform. For heavy bearings hardness is considered of greater importance than strength. A hard gun-metal consists of 79% copper and 21% tin.

The general effect of tin in an alloy is to increase its hardness, and whiten its color. Zinc in small quantities with copper increases fusibility without reducing hardness; in large quantities it prevents forging when hot, but increases malleability when cold. Common bronze mixes better when a small quantity of zinc has been added.

534. Nickel.—Nickel is a hard, white metal, more nearly resembling silver than tin and is used because of its luster and permanence. Dilute sulphuric and hydrochloric acid affect it only slightly, but nitric acid will dissolve it readily. It will neither rust nor corrode in the presence of air, even though the air be moist. Nickel forms valuable alloys and is used extensively for nickel-plating.

535. Bronzing.—Bronzing is an attempt to produce the effect of bronze on other metals or substances. A solution of sal ammoniac and salt of sorrel in vinegar is used for metals, while a composition of yellow ocher, Prussian blue, and lampblack dissolved in glue water is used for wood, plaster figures, etc.

536. Bell-Metal.—Bell-metal is a compound of tin and copper, which becomes not only more sonorous, but heavier than either of the separate ingredients which compose it. While the proportions of tin and copper in the compound differ, ordinarily 23 lbs. of tin are mixed with 100 lbs. of copper, the latter being somewhat increased if the bells are large. Brass, spelter, and even lead are sometimes added. Silver, which much improves the tone of the metal, is infrequently used.

537. Britannia Metal.—Britannia is an alloy metal composed of block tin, a small portion of antimony, and less than one-third as much copper as brass. This compound which is bright and silvery looking, is now extensively used instead of pewter, and for many purposes to which pewter was never adapted. It is very easy to work by rolling, casting, turning, and planing, as well as by stamping in dies. Consequently, the articles made from it are almost unlimited in variety and very cheaply produced. Teapots, candlesticks, and spoons are some of the articles frequently made of this metal.

538. Arsenic.—Arsenic is used in many metallic alloys. Its various oxides are important ingredients in different dyes. It is employed as a flux for glass, and it produces many kinds of coloring in glass. It is a virulent poison in all its forms, though employed as a medicine in proper solutions. The arsenic of commerce is a white oxide of the metal.

539. Pewter.—Pewter is a dull looking alloy formerly used for making plates and dishes, beer measures, wine measures, and large vessels. Good hard pewter is made of tin, copper, and antimony, but a very inferior kind and that most frequently met with at the present day, is made chiefly of lead, a small proportion of tin, and copper.

540. Common Solder and Fluxes.—Solder is an alloy used to stick metals together. It is a mixture of lead and tin usually in the proportion of half and half. Many other solders are used in soldering gold, silver, German silver, and aluminum. Only pure metals can be soldered together.

When the two metals are heated a scale, called an oxide, forms on their surface. To prevent the formation of this while soldering, a substance or liquid called a flux is applied to the surfaces to be soldered. The flux acts by dissolving the oxide formed and at the same time forms a coating which prevents oxidation.

There are a number of fluxes, such as rosin, zinc chloride, muriatic acid, borax, and sal ammoniac, each of which has a particular use. Rosin is used on sheet tin and seems to act more effectively than zinc chloride, which is used on tin, brass, copper, iron, and steel. Sal ammoniac is used in tinning.

541. Process of Soldering.—Soldering or "sweating" is a difficult operation. Careful investigations show that as much as 90% of the soldering work done is defective. This trouble is due principally to improper and careless cleaning of the metal surfaces to be joined. Then again an improper flux may be used. The most effective method of soldering is first to fit the parts accurately, to make the joint strong;

then to clean the parts to be soldered thoroughly. A solder with as high a melting point as possible should be used and the heat applied so that the temperature of the work to be joined is brought as near as possible to the fusing point of the solder. Thus the solder will be allowed to flow freely and a better union will result.

542. Aluminum Solder.—Aluminum solder consists of aluminum, phosphor-tin, zinc, antimony, and an acid. In forming the solder, the zinc, tin, and antimony should be melted before the acid is added. The following flux should be used in soldering aluminum: 12 oz. zinc chloride, 1 oz. sal ammoniac, and 13 oz. water.

Zinc chloride as a flux is made by adding zinc shavings or pieces to muriatic acid until the bubbles have disappeared. The zinc chloride formed in this way is often called cut-acid or killed (neutralized) acid to distinguish it from the muriatic acid, which is also used as a flux.

An acid flux, like muriatic acid and zinc chloride, should never be used on an electrical connection or on any article that is to be painted. An alcoholic solution of rosin is a good flux for this work.

543. Brazing Metals.—The flanges and fittings for copper pipes are made of an alloy of 84% copper and 3% zinc, called brazing metal. Brazing solder must contain more zinc than tin in order to have the solder fuse before the copper.

544. Shears for Cutting Metals.—Since sheet metals come into the trades in flat sheets, shears for cutting these sheets have been devised. There are two kinds of shears, namely, a power shear for cutting out edge lines, and a machine shear for cutting out circles and perforating holes.

Sheet-metal tools usually are more difficult to make than other grades of tools, because those parts which stand out or project must be hardened. The part of the tool that does not require hardness is usually made of iron, while the working parts, which must be firm and hard, are made of composite steel.

Questions

1. What is sheet-metal work?
2. Explain the difference between the work of the coppersmith and the sheet-metal worker.
3. What are some of the metals used for sheet-metal work? Why are these particular metals used?
4. How are sheet metals obtained?
5. Explain the processes by which copper is obtained.
6. What are the physical properties of copper?
7. What are the chemical properties of copper?
8. Why has aluminum been used extensively in recent years?
9. How is it obtained? What are its physical and chemical properties?
10. What is an alloy? Why are alloys used? Name some alloys of aluminum.
11. Explain why tin is not used more extensively. How is tin plate made?
12. Give the uses and the physical and chemical properties of lead.
13. Name some alloys of lead and give properties of each.
14. Explain how zinc is obtained. Give the physical and chemical properties of zinc.
15. For what is mercury used in the trades and industries? Give physical and chemical properties.
16. Name some of the physical and chemical properties of platinum.
17. Explain some of the properties and uses of antimony and bismuth.

18. What is brass? What are its physical characteristics?

19. Explain the meaning of the following sheet-metal terms: anneal, temper, extended metal?

20. What is German silver? Name some of its uses and its physical properties.

21. What is a bronze? Name some of the common bronzes, their uses and their physical characteristics.

22. What is soldering? Why is it necessary to use a flux? Name some fluxes.

CHAPTER XXXVII

PLUMBING AND WATER SUPPLY

545. Relation of Plumbing to the Water Supply.—In large communities where people live close together, pipes for conducting water and sewerage must be installed. To make installations intelligently so as to have enough water for household use, fire protection, and other purposes, it is necessary to know something about the water supply.

Water is usually obtained from rivers, lakes, springs, or wells.

546. Rivers and Lakes.—A river usually begins with a small stream in the hills and represents the drainage of the rain, ice, or snow that falls there. If there is a growth of trees on the hills, the roots of the trees tend to hold the water in the ground and prevent it from trickling down the slope rapidly. A lake usually has no outlet but is fed either by springs or by the drainage of the hills.

547. Wells.—In small communities the householder usually receives his supply of water from a well near the house. To understand how a well obtains its water, it is necessary to recall what has been said concerning the structure of the earth.* The earth is made of layers of sand,

* Pages 150–151.

chalk, clay, etc. Water will soak through sand and chalk thoroughly, but clay, on the contrary, will not allow water to pass through it. As the result of various upheavals of the earth, the layers are not horizontal but are tipped at angles and are often exposed to the surface of the earth. When a layer (stratum) of sand is supported by a layer of clay, the water is held up as in a basin. Therefore, when a hole is dug into the ground through the sand and not below the clay, water is usually found to have percolated through the ground and settled in the sand. Figure 206 shows a

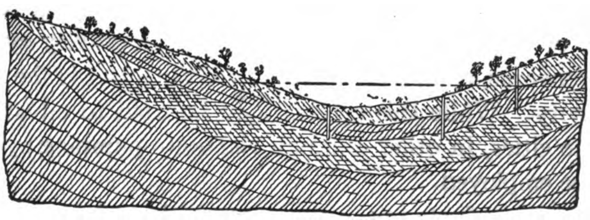

FIG. 206.—Section of Earth showing Conditions which Produce Artesian Wells.

section of the earth and illustrates how flowing wells are formed. The upper and third layers of earth are porous, the second and fourth non-porous. The force of gravity causes the water to sink into the lower porous layer and remain at this level.

This water comes from the rain, ice, or snow and takes up considerable impurities as it passes along the ground. The sand usually filters or removes these impurities, although sometimes it fails to do so completely. This is most frequently the case in a shallow well. A well should be at least 150 ft. from the nearest known source of pollution.

The water is raised from wells or from the source of supply to reservoirs by means of pumps.

548. City Waterworks.—A large community cannot use wells to advantage because of the danger of contamination. Therefore, it is necessary to secure water from a distance and allow it to flow to the community. It is therefore pumped to a basin, called a reservoir, which is situated at the highest elevation in the vicinity. At the reservoir there is usually erected a large steel stand-pipe to supply the water to the houses near or on the same level as the reservoir.

Water is pumped to a reservoir to secure a uniform pressure which will force the water to the tops of buildings. As water seeks its own level, it will rise in the buildings to the height of the reservoir. This is called the gravity system of waterworks, as the force that drives the water is the force of gravity. While this system may be used to advantage in some cities, in other cities an elaborate pumping system must be employed.

Water is conducted from the reservoir through broad pipes called mains. Smaller pipes are attached to the mains and run at an angle to the sidewalk. At the edge of the sidewalk there are valves, called hydrants, for shutting off or turning on the water. The pipes enter the houses through the cellars and pass through meters where the volume of water is measured in gallons. Pipes are conducted from the cellars to different rooms. Water is obtained from the pipes by means of valves called faucets.

549. Faucet.—The faucet consists of a bar handle which operates a screw. The screw raises or closes a disk to which a leather washer is attached. If it closes the disk, the water is prevented from running through to the opening. If the disk is opened by turning the handle in the opposite direction, the water flows through the opening. If the washer becomes loose or wears away the water escapes until a new washer is added.

550. Water Hammer.—Water under pressure in pipes is subject to the force of gravity in the same manner as a body falling through the air. To illustrate: When water flowing through a pipe is suddenly checked, a noise is heard, caused by the striking of the water against the end of the pipe or whatever stops the flow. The noise is heard at every part of the pipe and in case of a long length of pipe the noise appears to repeat itself very quickly. This "chattering" is called water hammer. Water faucets that shut off the water quickly always have water hammer. Its effect is often sufficient to break a pipe. Faucets that gradually check the flow of water overcome water hammer. An air cushion at the end of pipe will often overcome this noise.

551. Water Meter.—When the public realize that water is measured, the consumption is less per capita (per person) than when it is not measured. Therefore, within the last few years drinking water has been metered in many cities; that is, the water is run through a measuring device that records in gallons the amount of water which passes.

552. Sewerage.—The disposal of waste water and sewerage is a very important question. In the country, where houses are not thickly settled, the waste water is allowed to drain into the ground. The sewerage is disposed of by using it as manure or by covering it with dirt to prevent the odor from escaping.

553. Traps.—In large communities where houses are quite close together, the sewerage and waste water is disposed of by being allowed to flow into an outlet pipe, called a drain pipe. The drain pipe flows into a larger one and thence, by the force of gravity, to the sea, river, or to a specially prepared place called a filter bed. To prevent the escape of odors from the drain pipe, each pipe must be equipped with a trap — an S-shaped form — partially filled with water (Fig. 207). The water in the trap acts as a seal and prevents the gas from escaping into the house. The trap connects with a pipe, called a vent pipe, that runs to the roof. The object of a vent pipe is to prevent the water from being forced out.

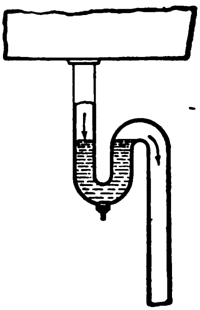
FIG. 207.—Trap.

554. Work of the Plumber.—A plumber's work consists of the installation of fixtures for gas, water, sewerage, and drainage purposes; the setting up in buildings and residences of plumbing fixtures and their appurtenances, such as water filters, water meters, hot-water tanks, suction tanks, cold-water tanks, bathtubs, showers, washbasins, sinks, water-closets, and urinals; the installation of water, gas, and waste piping for laundry machines; and of all compressed-air work. The plumber also puts in all toilet and bathroom auxiliaries, such as paper holders, glass shelves, medicine closets, towel racks, and soap and sponge holders. His work also includes the installation of waste-water leaders, soil and vent lines, and the sewerage drains within and beyond the house line to the street main. He plans pipes for hot and cold domestic water supplies, and puts in cooling jackets and priming pumps. He must be familiar with ice-machine work, thermostatic work connected with plumbing, pipework connected with pneumatic vacuum-cleaning systems, gas piping, with making connections for gas fire-logs, stoves, furnaces, driers, boilers, and heaters, and must be adept in assembling, hanging, and connecting gas illuminating fixtures and iron pipe for speaking tubes.

There is nothing in the work of the plumber which embodies physical or nervous strain, and as the work is extremely varied in character, it should stimulate the intelligence of the worker. The successful plumber must have strength, endurance, initiative, and special adaptability for his work. Plumbing cannot be termed an unhealthy occupation, although there is some danger of disease from germs, gases, waste matter, dampness, etc., especially on repair work. This danger, however, can be practically eliminated when the proper precautions are taken.

555. Plumbers' Tools.—The tools most commonly used by plumbers are as follows: the shave hook, for cleaning the tarnish from pipe in preparation for wiping the joint; the ladle, for handling molten lead; the cloths, for wiping joints; the tap borer, to tap pipe for branch lines; the calking tools, yarning iron, and right-, left-, and main-facing tools; the asbestos joint runner, for running molten lead into horizontal pipe joints; tools for setting fixtures; 8, 10, 14, and 18 in. pipe wrenches; the strap wrench, for handling nickel-plated fixtures; level; plumb-bob; screw-driver; brace and drills; $1\frac{1}{4}$, $1\frac{1}{2}$, and 2 in. springs for making bends in waste pipe; hammer and cold chisel, for cutting soil pipe; hack, compass, and tenon saws; gasoline furnace, for heating lead; and stock and dies, for threading pipe.

556. Joints.—The joints most commonly used by plumbers are the wiped and screw joints. The wiped joint is made by scraping and fitting the parts together and then pouring molten solder upon the place of joining. This solder, while still in a plastic condition, is wiped around the joint, with a moleskin or cloth pad. Thus a neat and reliable connection is made. The screw joint is made by cutting threads upon the pipes with stock and dies, painting the threads with white or red lead to make the joint tight, then turning each piece of pipe half through a coupling by means of pipe wrenches.

557. Cement.—Plumbers use a mixture of one part Portland cement and two parts clean sand over a ring of oakum* in making joints on earthenware house sewers.

Questions

1. Describe the importance of plumbing.
2. State the advantages of a good water supply.
3. Name the different sources of water supply.
4. How does water reach a well?
5. Describe a water system of a city.
6. How does water enter a house from the street?
7. Is the flow of water on the top floor as good as on the first floor? Explain.
8. What is a faucet?
9. What is water hammer?
10. How is the waste water disposed of?
11. What is a trap? State its advantages.
12. Describe the work performed by a plumber.

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* Oakum is prepared from old ropes, untwisted, loosened, and picked to pieces. The material is then treated with tar to make it flexible. It is used in calking the seams of vessels, etc.

13. Name some of the common plumbers' tools and their uses. State the mechanical principle upon which each of these tools operates.

14. What is a joint? Why is it used?

15. Name the common joints.

16. State the conditions under which a plumber works.

17. What per cent of clean sand is used in making joints of earthenware house sewers? What per cent of Portland cement?

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