Notes on Practical Mechanical *Drawing*

NOTES ON PRACTICAL MECHANICAL DRAWING

WRITTEN FOR THE USE OF THE STUDENTS IN GENERAL ENGINEERING DRAWING IN THE UNIVERSITY OF ILLINOIS

BY

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PREFACE.

The following book is a collection of notes upon practical mechanical drawing, originally the subject matter of a course of lectures, and was prepared to meet the needs of the students in the course in General Engineering Drawing in the University of Illinois.

It contains material not hitherto discussed but casually in existing books on drawing, notably, the treatment of sections, the arrangement and development of a set of working drawings, and machine sketching.

Attention is called to the fact that the book makes a long stride in advance of previous methods of teaching the subject. Formerly, and even to-day, in many colleges the elementary training is accomplished through line exercises and geometrical drawing. These are here reduced to a minimum, and practical problems take their place.

It is the author's belief, substantiated by experience, that the students' faithful adherence to minute directions as to methods of work, insures a ready grasp of the subject. And this is why methods are given such expanded treatment. It is also counting a great deal upon the student to expect him to grasp and apply all the practical points given, but in the past, this confidence has not proven vain, and by using practical problems from the beginning it has been possible to help him to do this and to keep him interested, as he never is in uninteresting geometrical figures. The departure is not altogether new, however, for the same progress is being paralleled in all manual training work.

The book is not yet complete. It still lacks a set of graded exercises upon working drawings and sketching, and a few illustrative examples. The elementary principles of orthographic projection are also left out, as they form the subject of a series of lectures with home exercises, intended to parallel the working drawings.

The author will be glad of any suggestions leading to a perfection of his idea. Quotations have been here and there been made from standard works upon drawing, and acknowledgement has been made where such has been done. The author wishes, in closing, to express his appreciation of the pains-taking work of Mr. C. L. McMaster, as shown in the illustrations, most of which were made by him. And not a little help was obtained from him, also, in the subject matter and in its arrangement.

Urbana, Ill., Sept. 1, 1907.

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CHAPTER I.

STRAIGHT LINE DRAWING.

1. Definition of drawing.

Drawing is the art or science of recording a person's impressions about things by more or less accurate suggestion of form. All drawings may be divided into two general classes. (1). The drawings of objects as viewed at a finite distance. (2). The drawings of objects as viewed at an infinite distance.

The first of these is called perspective. The point of view at a finite distance is called the center of projection. It is as if the eye were at the point and the drawing of the object was made upon a transparent plane placed between the latter and the center of projection, that is, projected upon it from this center by lines from the center passing through all points of the object. It is a kind of drawing that is found in pictures.

In the second class the center of projection or the eye is theoretically moved to an infinite distance, that is, the projecting lines from the object to the plane become parallel. This, in a certain form of drawing, is what is called orthographic projection.

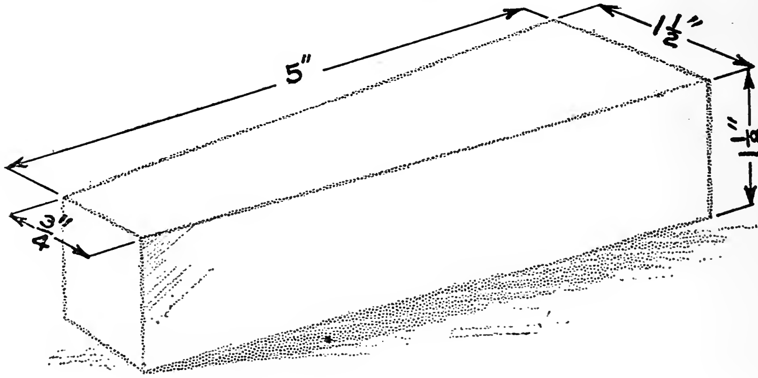
Now things are constructed and manufactured through the aid of drawings that are made according to the principles of the second kind mentioned, or orthographic projection. They may be made free-hand, that is by sketches, or they may be made by careful mechanical drawings; in the more careful and exacting work, they are always made in this way.

A mechanical drawing used for the purpose of construction then, consists of one or more views made according to the principles of orthographic projection; in addition to which the sizes of parts are clearly set forth by dimensions with accompanying dimension lines and arrow heads to show their limits.

No matter how simple is the subject to be constructed, an accurate and comprehensive and unmistakable drawing should be made of it. The test of a good working drawing lies in the fact that the workman can make nothing out of the facts contained thereon than what was intended by the draftsman. The entire meaning should be clear beyond the shadow of a doubt.

To choose the number of views that this may be attained, to put on the dimensions which the workman will need in making the subject is the problem of the draftsman. The needs of the workman should be constantly in his mind.

EXERCISE NO. 1



2. Exercise No. 1.

This a perspective sketch of a form to be made by a workman in wood or metal. From this sketch construct a plan, side view and two end views, and put on them the dimensions shown. The sketch shows just the dimensions required and their place, and also the relative distance from the views at which the dimensions should be placed in the working drawing.

3. General directions with regard to preliminary steps.

Tack the paper by the upper left hand corner, then with the T sq. head against the left hand edge of the board, swing the paper into line with its upper edge. Next, drawing it tight, put in the tack at the upper right hand corner, and then, stretching from the center out, put in the lower two tacks. Sometimes it is best just to clip the corners of the paper under the thumb tack head, in this case a very small amount of stretching can be effected by heading the point of the tack, as it is pushed in, slightly away from the corner to be tacked.

Drawings have frequently to be taken up from the board and reset again. When this is needed short horizontal lines drawn with the T sq. on each side of the sheet and extending onto the board are convenient for guiding the sheet into the same place it held on the board at first.

The border line for all plates, unless specially arranged for, is to be $\frac{1}{2}$ inch from the edge of sheet.

Hold the T sq. with the hand over the head or by the blade very close to the head. The advantage in the latter method is that by means of the fingers held at the upper and lower edges of the blade, it can be made to creep by short distances up and down the board.

Keep the T sq. always against the left hand edge of the board and always use, for working, only the upper edge of the blade. Sometimes large T sqs. are made tapering away from the head. When so made, the taper is always upon the under side.

Keep the triangles convenient to the T sq. always, that is, when not using, move to the right along the blade or away from the blade upward, but so that when needed again they can be drawn into place against the T sq. blade with the minimum of effort.

In using the triangle against the T sq. blade, observe the following proceeding. Adjust the T sq. first, with the right hand bring the triangle into place, and hold with the fingers of the left hand while the ball of the same hand holds the T sq. blade in place. The triangle can be thus moved, if desired, along the blade in easy stages as for section lining, etc.

Rule vertical lines upward against the left hand edge of the triangle placed as just described. Do not draw to the extreme point of a triangle or to the point it touches an adjacent ruling edge against which it may be resting, for the sharpness of the angle cannot be depended upon.

Rule all lines in pencil as shown in Fig. 1. This direction is given now in order that the habit may be formed preparatory to the use of the ruling pen, which requires this treatment.

Remember, as a final direction, that points for locating lines should be as far apart as possible, while lines used in

Fig. 1.

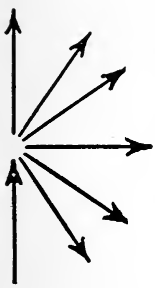
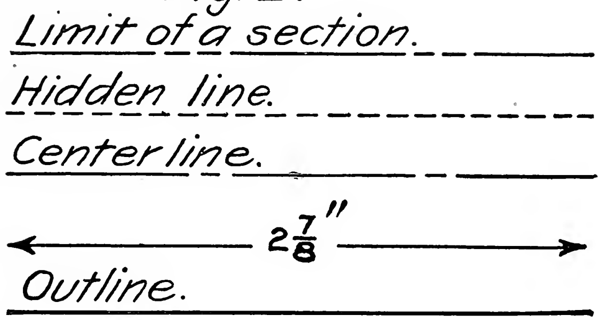


Fig. 2.



locating points should cut each other as nearly as possible at right angles.

The lead pencil may be sharpened in one of two ways, by a long, tapering, round point or by a double-edged chisel. Cut the wood back for at least $\frac{3}{4}$ of an inch from the end and leave from $\frac{1}{4}$ to $\frac{3}{8}$ of an inch of lead exposed. Taper both down continuously to, if possible, a slightly concave form. The advantage of a tapering point is that it holds its sharpness for a longer time, and again, the point is not thick enough to cover up the work in hand or to mislead as to where the lead is marking.

The double-edged chisel should not be quite as wide across as the lead is thick, but reduced somewhat, say to $\frac{3}{4}$ the diameter. A penknife for the wood and emery paper or a file for the lead will give the desired results most rapidly.

If the double-edged chisel is used it should only be for straight away lines, not for laying off measurements from the rule or scale. The round pointed form may be used either for picking off measurements from the rule or scale or to draw lines. If a chisel form is used for the lines, a pencil sharpened to a round point should be kept handy for picking off measurements.

In holding the pencil, keep it nearly perpendicular to the paper; if drawing lines with the round point, acquire the habit of slowly twirling the pencil during motion, so that the point will be worn down in a conical shape, and not irregularly.

Clean, firm lines, uniform in thickness and blackness both in penciling and in inking, are the kind which should be cultivated. The draftsman is known quite as well by the character of his penciling and construction as by his final inked drawing, carelessness and irregularity in the former is quite as surely to be repeated in the latter.

Avoid drawing superfluous lines, lines overrunning their proper limits or lines that are not to be inked. If accidental errors are made, correct them with the eraser at once. The neat draftsman is he who does his work with the least use of the pencil and eraser. Lines also which are to be dotted, in final drawing, should be dotted in pencil so that no mistake is made when inking. Wherever possible, locate the extremities of a line by the scale before drawing it, which is facilitated by placing the scale against the ruling edge.

After making an erasure, clean off the particles of dirt that are loose on the paper, for they interfere with the smooth and proper action of the other tools. This is a particularly important direction to observe preparatory to inking and when any alterations are made during inking. Too much care cannot be observed in freeing the paper and all tools from the dirt particles, for they are quite apt to get into the pen and give trouble.

4. Detailed directions for Exercise No. 1.

Draw the plan view first, laying out the center line, scaling the length over all, the width of each end, and then enclosing by lines. Draw the elevation next and then either end. After the views have been drawn put on the dimension lines, limiting lines, and arrow heads, lastly the dimension figures. The drawing is then ready to be inked.

5. General directions in regard to inking.

To put ink into a right line pen, hold the pen approximately horizontal with the kind of holding usually given to a writing pen. Hold the bottle down with two fingers and with two others lift the cork out and touch the quill end between the nibs of the pen, to let the ink run in, and do this over the bottle, for obvious reasons, corking it securely when through. If the nibs of the pen get ink on the outside, wipe off with a rag.

To hold the pen for ruling lines, raise the handle from the previously described position until it rests at or slightly in front of the second joint of the first finger. Have the end of the first finger just above the adjusting screw on the flat part of the nib, the thumb just opposite this, and the second finger touching the pen between the first finger and the thumb and just below them to steady it from any tendency to turn. Hold the pen always perpendicularly to the paper, steadying the hand against the ruling edge with the last finger or the last two.

The weight of the pen alone should be sufficient to make the desired line. If it does not, after trying a few times on a piece of trial paper, clean out and refill.

Do not exert any pressure of the pen against the ruling edge, as it will tend to close the nibs. Make all lines by a continuous motion of the pen. Do not stop on a line to see where the rest of the line is to go. If it is absolutely necessary to stop in any case, even for a moment, lift the pen from the paper. Also, when stopping in this way, take the further precaution to move the ruling edge away from the wet line.

When requiring refilling, clean the pen out thoroughly so that no ink remains either upon the inside or outside of it. It is well to cultivate the habit of doing this early, making it invariable, for a pen clogged with ink is likely to give trouble. Devices for readily opening a pen to facilitate cleaning have been much advertised, and some are quite meritorious. However, they have not yet become indispensible to the experienced draftsman, for the cleaning can, with a little practice, be done very effectively without their aid. Use the nails of the thumb and first fingers successively, covered by one thickness of rag, and it will be found easy to clean one half of a blade with one finger and the other half with the other, and the remaining blade by turning the pen over and repeating the operation. Four wipes generally clean sufficiently and with perhaps no more expenditure of time than by the aid of the opening devices mentioned.

If the pen gives any trouble in marking at any time it is safest to empty, clean and refill.

The weight of an ink line on a drawing should be such that it will show clearly the form within the maze of dimension lines, etc., that it will blue print readily, giving an equally clear impression throughout, and that all annoyance is removed, due to the likelihood that the line will break through any obstructed flow of the pen. In Figure 2 are shown suitable conventions to use on a drawing, as well as the proper weight of line.*

It is highly important in the very beginning to cultivate a uniform line throughout. It takes experience and a trained eye to do this accurately and at the same time unconsciously.

6. Detailed directions for inking Exercise No. 1.

Rule the horizontal outlines of all the views first, beginning at the top and going down. Rule the vertical outlines next, including dotted lines or invisible edges, then the oblique lines. Rule the limiting and dimension lines next, and lastly put in arrow heads and dimension figures in the order named.

A drawing should be cleaned after all inking is finished. A very soft rubber will clean dirt very well, but it is hardly sufficient for superfluous pencil construction lines. Care should be exercised in erasing the latter with a harder eraser on account of injuring the ink lines, for much erasing will spoil the quality of any ink line.

In erasing, hold the paper firmly with one hand while the stroking of the eraser is in the direction away from it, or else hold with the thumb and forefingers of one hand opposed to each other and move the eraser between them, the whole object being to take the strain off the thumb tacks.

*NOTE.—Sometimes in fine careful drawings dotted lines can be made to appear equal in thickness to the solid lines, but to do this they have to be made actually thinner.

7. Detailed directions for penciling and inking Exercise No. 2.

Draw the plan view first, laying out the center line, scaling the length over all, and the width of the view. Next, lay off the shorter horizontal distances, preferably upon the center line, marking continuously from the scale, then the vertical measurements, either side of the center line at the points marking the horizontal distances. Line in the view, horizontal lines first and then verticle lines.

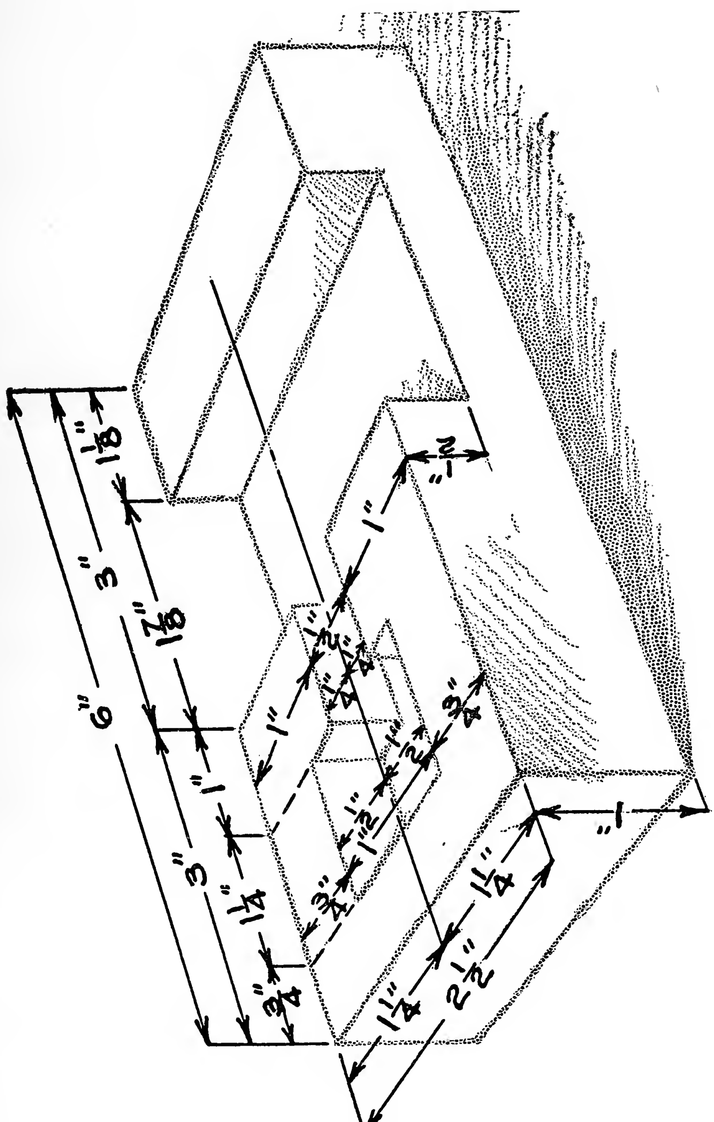
Lay out the elevation in the same manner as the plan. Put on the limiting lines, dimension lines, arrow heads and figures in the order named.

In inking, rule the horizontal outlines of all the views first, beginning at the top and going down. Rule the vertical outlines next, including dotted lines or invisible edges. Rule the limiting and dimension lines next and lastly put in arrow heads and dimension figures in the order named.

8. Detailed directions for penciling and inking Exercise No. 3.

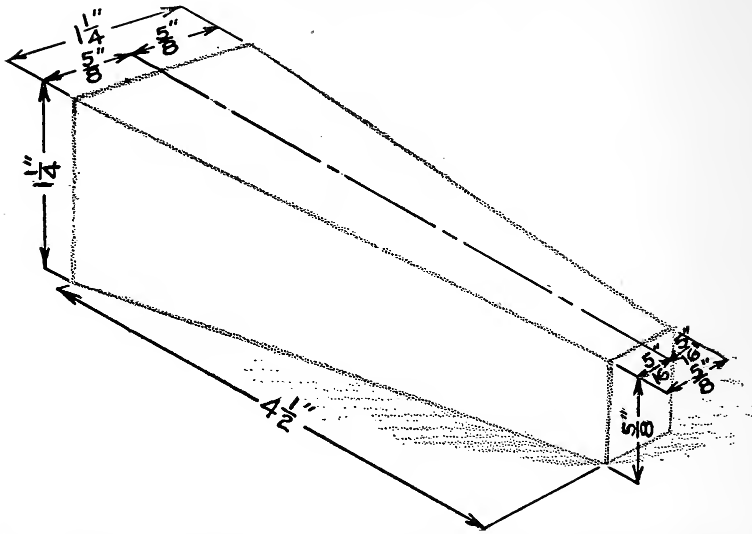
Draw the plan view first, laying out center line, scaling the length over all and the width of each end, then enclosing by lines. Draw the elevation next, and then either end. After this put on the dimension lines, limiting lines, and arrow heads, lastly the dimension figures.

In inking, rule the horizontal lines of all the views first, beginning at the top and going down. Rule the vertical outlines next, finally the oblique lines. Next, rule the limiting lines and dimension lines, then put in arrow heads and dimension figures.



EXERCISE NO. 2

EXERCISE NO. 3

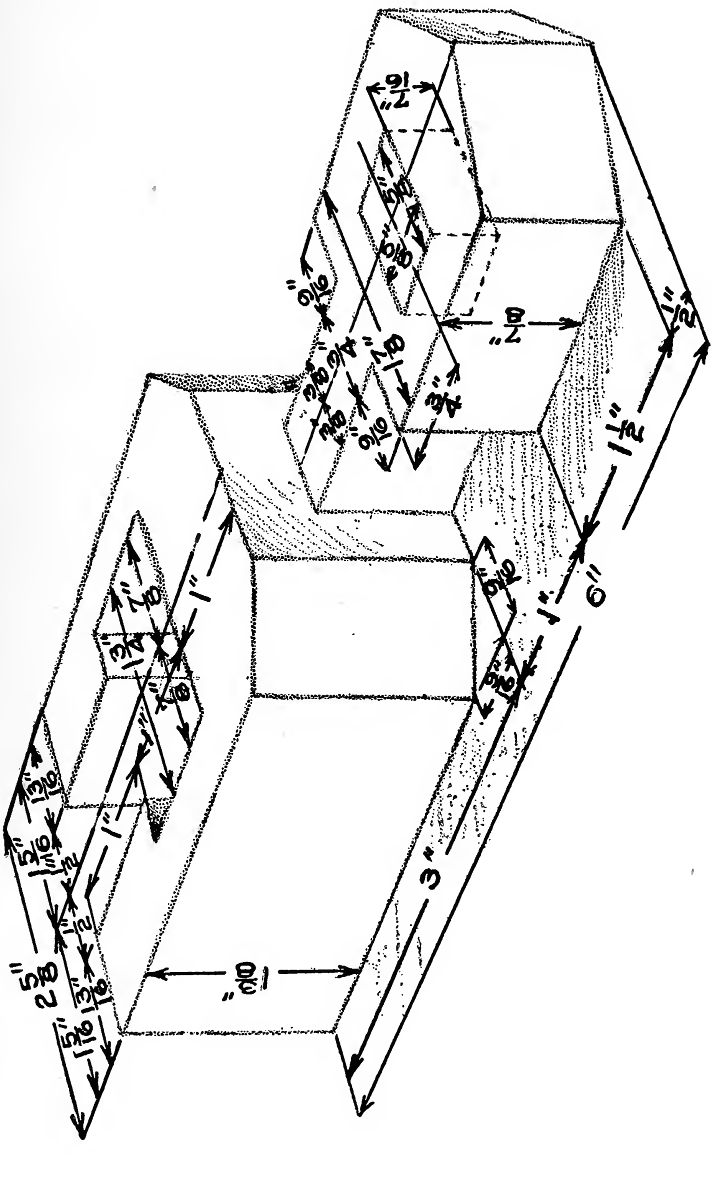


9. Detailed directions for penciling and inking Exercise No. 4.

Draw the plan view first, laying out the center line, scaling the length over all, and the width of the view. Next, lay off the shorter horizontal distances, preferably upon the center line, marking continuously from the scale, then the vertical measurements, either side of the center line at the point marking the horizontal distances. Line in the view, horizontal lines first and then vertical lines.

Lay out the elevation in the same manner as the plan. Put on limiting lines, arrow heads and figures in the order named.

In inking, rule the horizontal outlines of all the views first, beginning at the top and going down. Rule the vertical outlines next, including dotted lines or invisible edges. Rule the limiting and dimension lines next, and lastly put in arrow heads and dimension figures in the order named.



EXERCISE No. 4

10. Detailed directions for pencilling and inking Exercise No. 5.

Draw the plan view first, laying out center line, scaling the length over all and the width of each end, then enclosing by lines. Draw the elevation next, and then either end. After this put on the dimension lines, limiting lines and arrow heads, lastly the dimension figures.

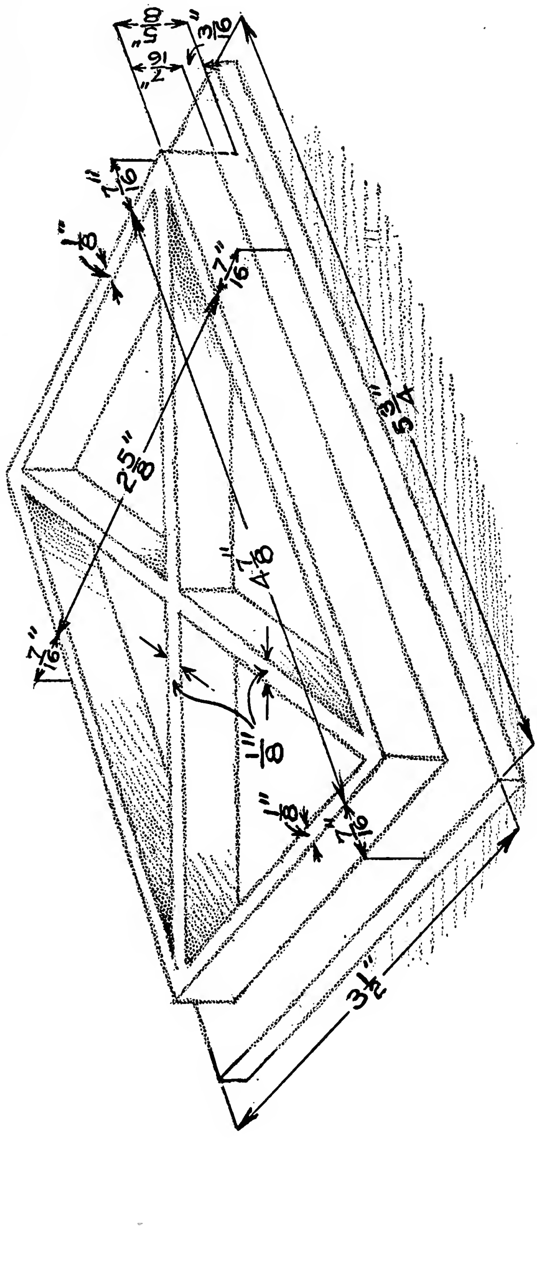
In inking, rule the horizontal lines of all the views first, beginning at the top and going down. Rule the vertical outlines next, finally the oblique lines. Next, rule the dimension and limiting lines, then put in arrow heads and dimension figures.

11. General directions.

Detailed directions were given for laying out and for inking exercises Nos. 1 to 5 inclusive. This was done because method of execution is important, a certain procedure being economical of time and effort in the drawing and more likely to result in accuracy. It is now time to discuss this matter a little more minutely.

The preceding exercises show a symmetry upon a center line. It is best to regard this symmetry in the construction of the drawing, that is, to lay out the main center lines of forms first and then measure either side of these center lines, saving a duplication of measurements.

Again, to avoid drawing superfluous lines, it is best to mark first the sizes of areas that are to be enclosed with lines, these sizes will aid in stopping the lines at the right places. Again, always size and enclose the larger areas first, the smaller features are then most likely to be right, and they are, moreover, better seen in their proper



Exercise No. 5

places, when the larger things upon which they depend are there with which to compare them. It is a part of the training of the draftsman to acquire the judgment necessary to execute a drawing economically of time and effort. Such details as have been given will hereafter be omitted and only those processes outlined which differ from the preceding.

CHAPTER II.

CURVES AND STRAIGHT LINES COMBINED, AND SECTIONS.

12. Handling of the compass, dividers and bows.

There is a difference between geometrical and mechanical drawing. Geometrical drawing is drawing by the methods of geometry, constructing everything geometrically, parallel lines, lines at various angles to each other, and so on. The geometrical drawing instruments are the compass and the straight edge or ruler. All other tools, including the dividers, the T sq., triangles, etc., are mechanical drawing instruments for accomplishing the same purpose.

The compass and dividers are similar to each other, but the use of the compass should be cultivated more than the dividers. The compass is for describing circles and measuring angles, and also for transferring measurements from one place to another. The dividers are used to approximately subdivide linear distances and for transferring measurements from one place to another. It is, many times, a more convenient tool for doing these things, and one of the habits to cultivate is to minimize the use of the dividers. It is an excellent tool in its place, but it is not as safe to depend upon as the scale.

In changing the marking legs of the compass, use care to pull or push the attachment longitudinally of the leg, and not to twist it or move it laterally, it might strain the members. The instrument is easily injured, and accuracy of action is necessary.

The needle point of the compass should have a shoulder on it to prevent sticking too deep in the paper; it should be adjusted to fit the pen attachment and always be kept so. In working with the pencil leg then, and as it wears down, extend the lead to meet properly the needle point adjustment. The pencil in the compass should be sharpened always to the double-edged chisel.

The proper position for the needle point is slightly in advance of the marking point, depending upon the degree of sharpness and the length of the point. At no time should the point more than hold in the paper. And when stuck in to this degree, the bisector of the angle of the compass legs should be perpendicular to the line connecting the two points. This is very important in making small circles.

The compass should be held with one hand only, for obvious reasons, apparent after experience. To open the compass at first, press the thumb and first finger against the bevelled partion near the head. To hold the compass when opened, control the needle point leg with the thumb and third finger, the marking leg with the first and second fingers, held, generally, the former upon the outside, the latter upon the inside of the leg, so as to move the leg in and out with a controlled motion. The tightness of the head should be just sufficient to hold the compass in place during use; such an adjustment will not render it difficult to change the angle between the legs easily with the fingers as described.

If the hand is unsteady, it may be found convenient to use one hand for putting the needle point in the proper center, either by taking hold of the end of the needle point leg or by resting the leg against the finger while putting it into place; the latter is the better way.

Curves should be drawn continuously and always in the same direction, clockwise. In drawing a complete circle, start the marking point at the lowest part of the circle, or even a little to the right, and it will be found possible to swing the whole circle without change of handling, by rolling the head in the fingers during rotation. It should not be necessary to change the handling at any time, or the position of the hand or the instrument. Held correctly, it should always be ready for drawing. It is a very common fault to hold the compass with two hands.

Further, it should be held so that the head is slightly in advance of the marking point in the direction in which the curve is being made, to aid the marking point to remain in contact with the paper. But do not bear any more pressure on either leg than is necessary to make the curve and to keep the needle point in contact with the paper; in ink work, the weight of the instrument, as in the case of the ruling pen, should be sufficient to make the desired line.

Do not overlap a circular curve in inking; there is a chance of a change of adjustment, and even if this is not the case, it is likely a line twice drawn over will spread out, making a noticeable junction.

There is a hairspring attachment put on some compasses and dividers. It has merits in enabling one to make a very delicate change of adjustment, but the author thinks the value of this feature is very much over estimated, for, with experience, comes sufficient skill that, handled as above described, the desired adjustments are made more rapidly than they could be by a hairspring attachment, taking as it does two hands for manipulation. Of the two instruments, however, the hairspring is of more value upon the compass than upon the dividers.

There is a certain point reached in the spreading of the legs of the compass when it is very desirable to bend the ends of both the needle point leg and the marking leg at the proper joint, always provided, so that both come down perpendicularly to the paper. This point, for a six-inch compass, is in the neighborhood of a three-inch diameter. It is easy to see that if the needle point is inclined to the paper appreciably, it will, when swung around, gouge a larger hole, and similarly considered, the nibs of the pen attachment would not touch the paper together; the outer one might rise sufficiently to make a ragged line.

A lengthening bar is used for circles beyond the capacity ordinarily of the compass, but it is an inconvenient thing to use, makes an unsteady tool, and if much work is to be done on large radii it is well to use a beam compass, built especially for this purpose.

The dividers are held in the same manner as the compass. If a given distance is to be divided into a certain number of equal parts that do not correspond to any scale divisions, the dividers can be used to do it by successive approximations. In stepping off such equal spaces, the tool should be swung alternately over and under, so that the holding need not be changed, no matter how many successive distances are to be made. Moreover, but slight pressure should be exerted on the tool, so that the points make no noticeable hole in the paper. To locate a pick of the divider leg for further reference, put a small free-hand circle about the point, not much over a sixteenth of an inch in diameter; this calls attention to the region in which the point lies. Large holes in a drawing are unsightly and are really inaccurate. Sometimes, also, an ink line going into a large hole will give rise to a blot.

The bow instruments are very convenient, small and accurate tools for doing the same kind of things that the compass and dividers will do. The adjustment of needle to marking point in the bow pen and pencil should be even more carefully made than in the compass, because of the small circles for which they are used. On account of their accuracy and positive adjustment, the bows in practical work are used wherever they can be, but since there is nothing distinctive to be learned about them, the beginner is advised rather to favor the use of the latter so that he may get as much practice with them as possible, and acquire the proper handling, which does not generally come naturally at first.

The small circles upon commercial drawings are not infrequently omitted in pencilling, only the centers being located, but a caution is extended to the beginner not to resort to this form of short-cut for obvious reasons, but to pencil in everything very completely and accurately. The omissions of construction should be left to the judgment of the skillful draftsman.

A caution is also here extended regarding the bow dividers. Their particular use, in fact, their only economical use, is to lay off a succession of equal measurements. It is so much trouble to set them to transfer a single measurement that the dividers are better for this purpose. But since, if any mistake is made in the setting, it will increase the error by arithmetical progression, as successive measurements are laid off, it can be seen that the scale is after all the safer tool if it is possible to use it. The value of the bow dividers is apt to be much over estimated. It could be left out of the ordinary set of instruments without any serious drawbacks.

As a practical point in handling, it should be noted that if a decided change is to be made in the adjustment of the bows, it is less wear on the instrument and also more economical of time to take the strain off the legs by pressing them together with one hand while the thumb-screw is twirled around with the other until near the proper adjustment.

13. General directions for the treatment of Exercises No. 6 to No. 9, inclusive.

Draw the center lines first and next the centers of arcs and curves tangent to straight lines; that is, make the outline or contour forms (except in the case of very small curves or fillets, as in Exercises Nos. 8 and 9) determined by the curves to which they are tangent. In construction, the exact location of these centers may be very important. After the centers are located and the curves drawn, enclose the remaining part of the views by the straight lines, and so on to the finish.

It is important to be exact in the tangency of curves to straight lines and of curves to each other; therefore observe that the marks in the paper made by the needle point centers are as small as possible.

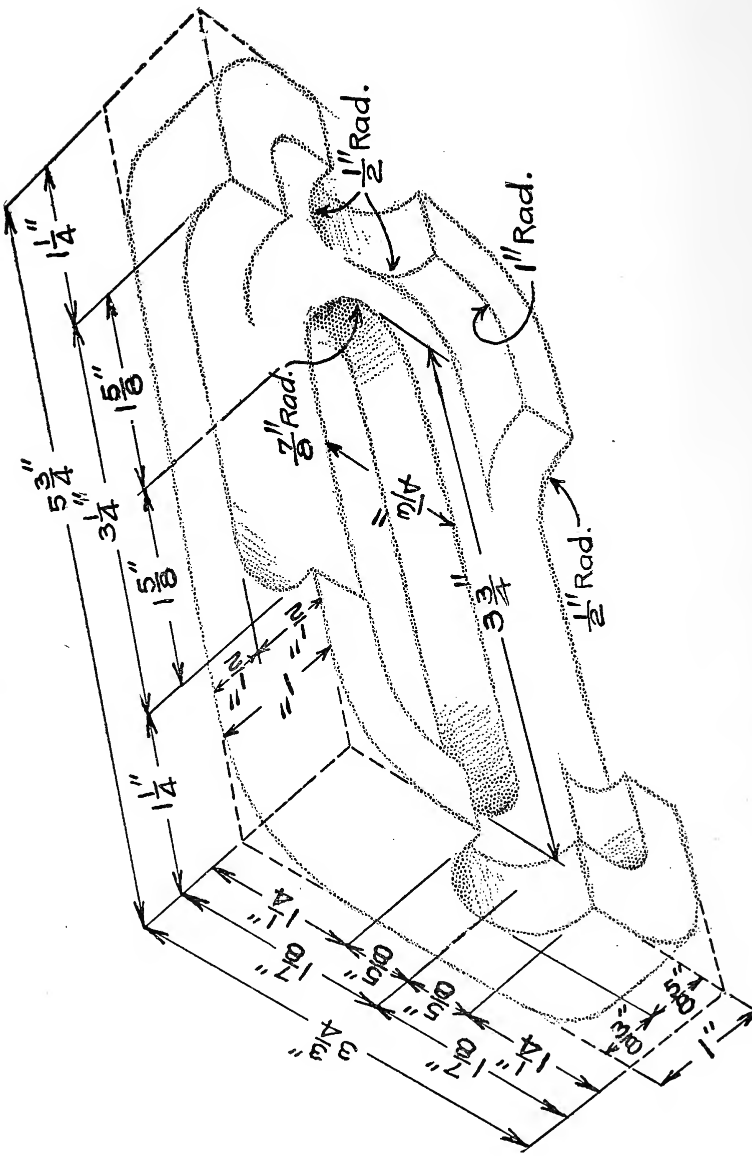
The centers for all arcs, other than very small ones like fillets, should be indicated by at least two center lines crossing each other at right angles at the center, say $\frac{1}{4}$ of an inch long.

In inking, it is also important to observe tangency, and since it is found practically very difficult to copy a pencil line in ink accurately, hence more difficult to make a curve tangent to a straight line than it is to make a straight line tangent to a curve, it is customary to ink in all circular arcs and circles first, going from the smaller curves to the larger ones, so as to be sure of the capacity of the bow pen to do its part.

A word is here in order about dotted lining. Dotted lines can be made quite explanatory of forms and they can also be made quite obscure, depending upon the treatment. The thickness of a dotted line should be no greater than that of the solid outlines, in fact, it is well to make it slightly lighter, for the short dots are likely each to be thicker than a continuous line made with the same setting of the pen. Even in the absence of this (in the case of fine lines) the dotted line may attract more attention than a solid line and should be made lighter to offset it.

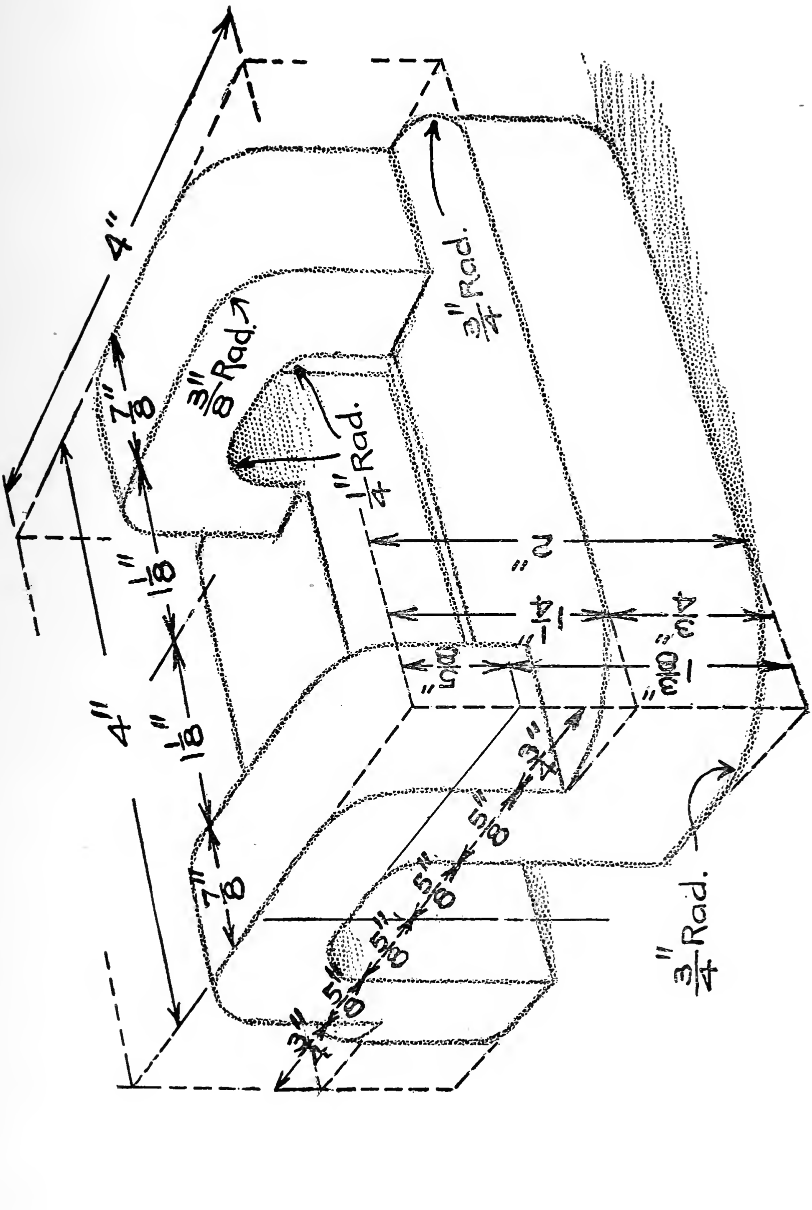
Again, a dotted line is not ideally composed of dots, but of short, uniform and evenly spaced strokes. The uniformity of dotting is a thing which makes it look well on a drawing. Dotted construction should look intelligible always. To effect this, several points need be observed:

(a). The angles of sharp corners should be connected strokes. (b). Where the dotted line crosses solid lines, and is not related to them by identity of form or material, the dots should not stop at, but may cross, these lines. (c). Where dotted lines properly end at solid lines, the dots should touch the lines. (d). In the dotted lines in either of the above



EXERCISE NO. 6

EXERCISE No. 7



cases, the dots marking the angles, or those crossing solid lines or meeting to end at solid lines, can well be made longer than the dots of the rest of the line, even by twice the length. Dotting, in brief, should clearly define the forms by accentuating with larger dots the salient things to be brought out.

The detailed directions for laying out and inking any one of the preceding exercises apply also equally well to any one of the Exercises Nos. 6 to 9. But some special directions connected with them are here introduced.

14. Special detailed directions for drawing and inking Exercise No. 8.

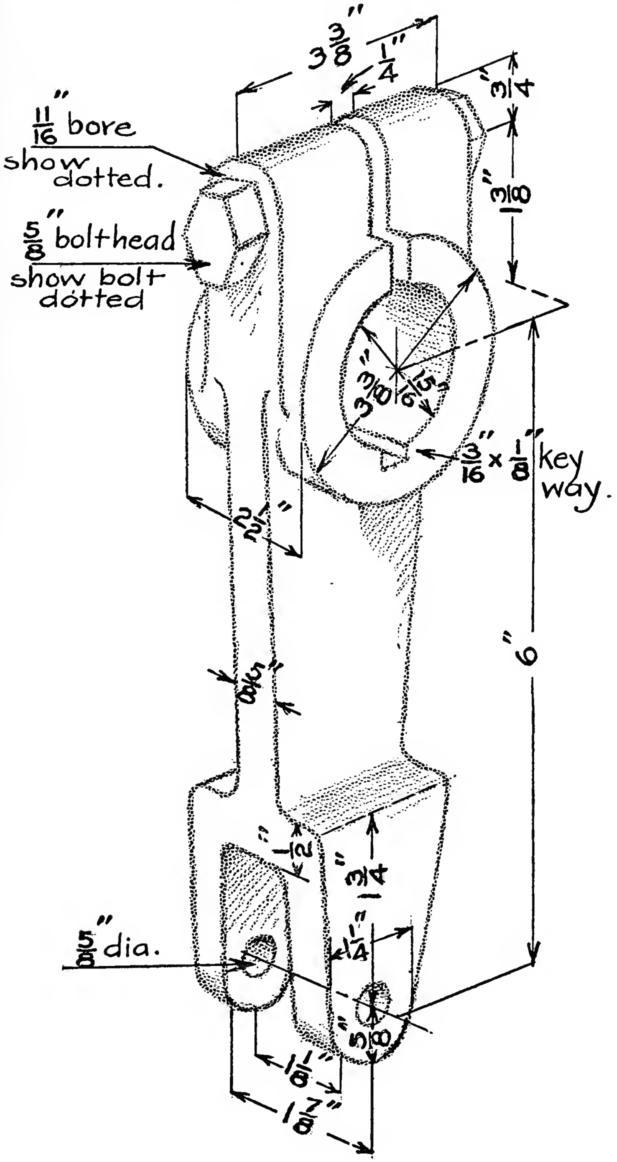
For the sake of clearness, we will call the front view of this a view looking along the rocker shaft, and the end view the one looking into the fork.

This is a form illustrating the advantage, which will be more apparent with greater experience, of developing parts of several views simultaneously. The front view, including the split collar and what is below, is best drawn first; that which is above the split collar, including the tightening bolt, should be drawn in the end view first.

The views should be drawn at first ignoring the small rounded edges or fillets, these put in afterwards by carefully located centers, and left perfectly clear in form.

Note that the bolt should have two rectangular faces of the head and nut horizontal planes. The bolt head and nut as shown are not what are called finished forms. They are so drawn to be easy. The finished forms will be discussed later.

EXERCISE NO. 8



15. Special detailed directions for drawing and inking Exercise No. 9.

Let us call the front view the one looking along the shaft, and the side view the one looking transversely of the shaft. The front view should be drawn first. As before stated, it is easier to draw a straight line tangent to a circle than it is to draw a circle tangent to a straight line.

Where, as in Exercise No. 8, cylindrical forms show ends in both views, then it is desirable to develop parts of both simultaneously, drawing the component parts in that view first which is the more easily drawn.

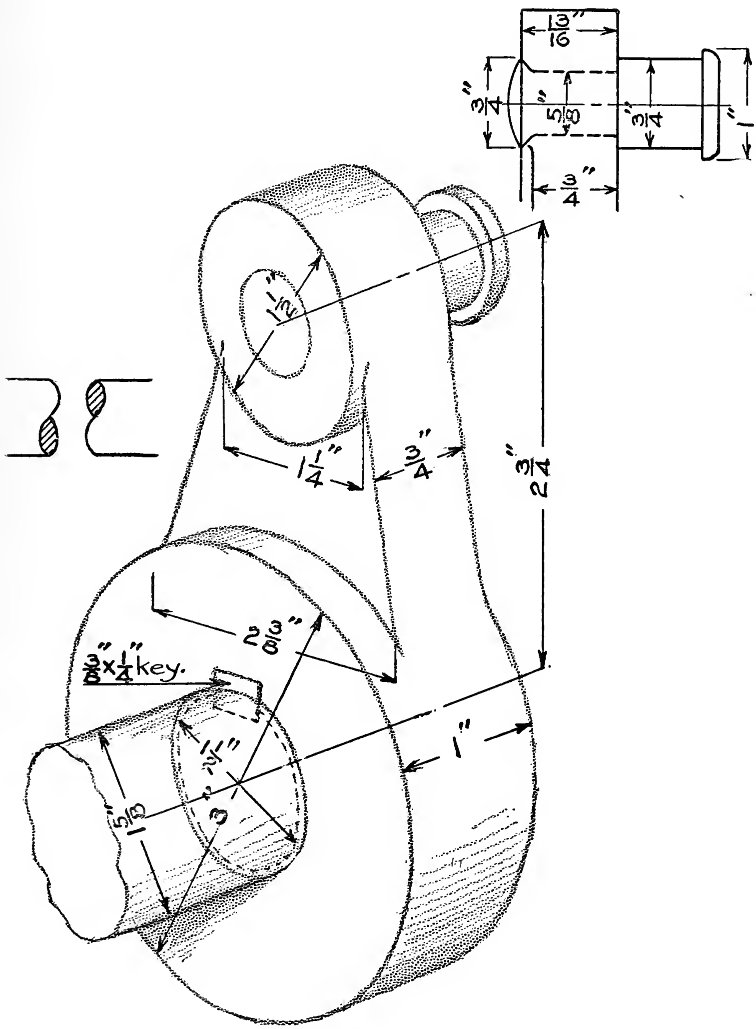
The key-way should be drawn after the circles are struck, and, of course, in the front view first.

Note the conventional method of showing a broken shaft in side view, as given by the small detail to the right of Exercise No. 9. The curved part is sometimes made with the curved rule, but since it is to represent an irregular break, it may with equal propriety be represented by a free-hand pen line, not too ragged. The sectioning, or conventional method of showing the cut surface, should in all cases be ruled in by equally spaced lines somewhat lighter than the general outlines, and in the case of this exercise, slightly less than one-sixteenth of an inch apart.

16. Detailed directions for penciling and inking Exercise No. 10.

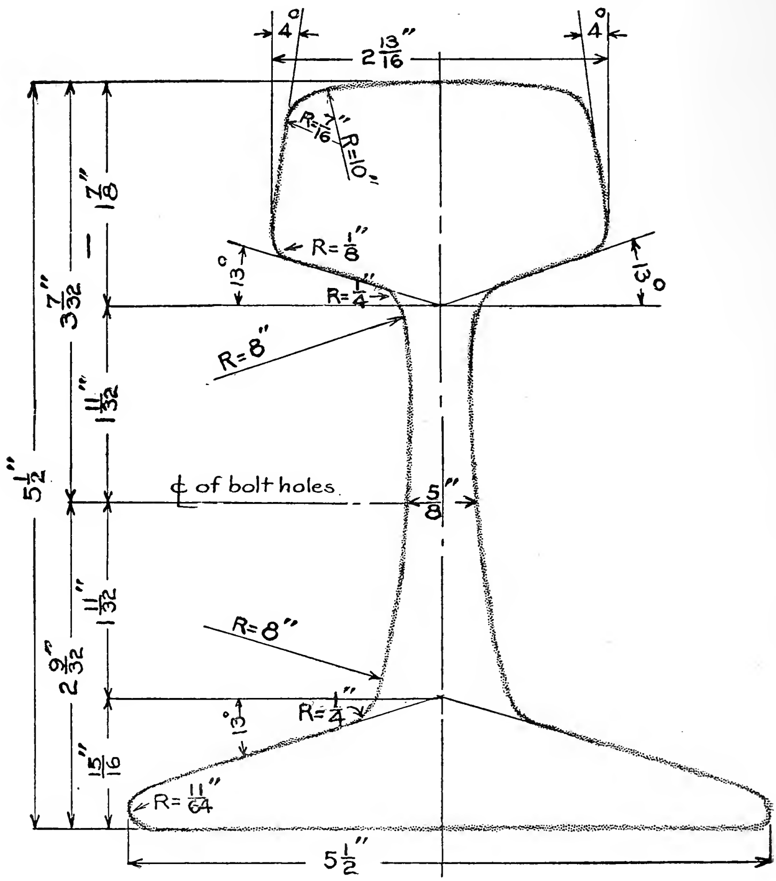
This is an exercise in the tangency of circular arcs. It is a cross section of a P. R. R. standard 100 ℔ rail. Draw the view as sketched making it carefully full size, using the scale for laying out the sizes.

EXERCISE NO. 9



Draw the vertical center line first, then the centers for the arcs designating the web, then the crown of the rail, and

EXERCISE NO. 10



the base and so on, locating centers in the penciling carefully by free-hand circles around the intersections of the construction lines. Put the dimensions on practically where shown on the sketch.

When ready to ink, put in the small arcs with the bow pen, then the larger with the compass and lastly the straight lines. Show the plane of the section by regularly spaced lines at 45° to the horizontal and about $^1/_{16}$ of an inch apart at the very least, the weight of line to be slightly lighter than the outline.

17. Detailed directions for penciling and inking Exercise No. 11.

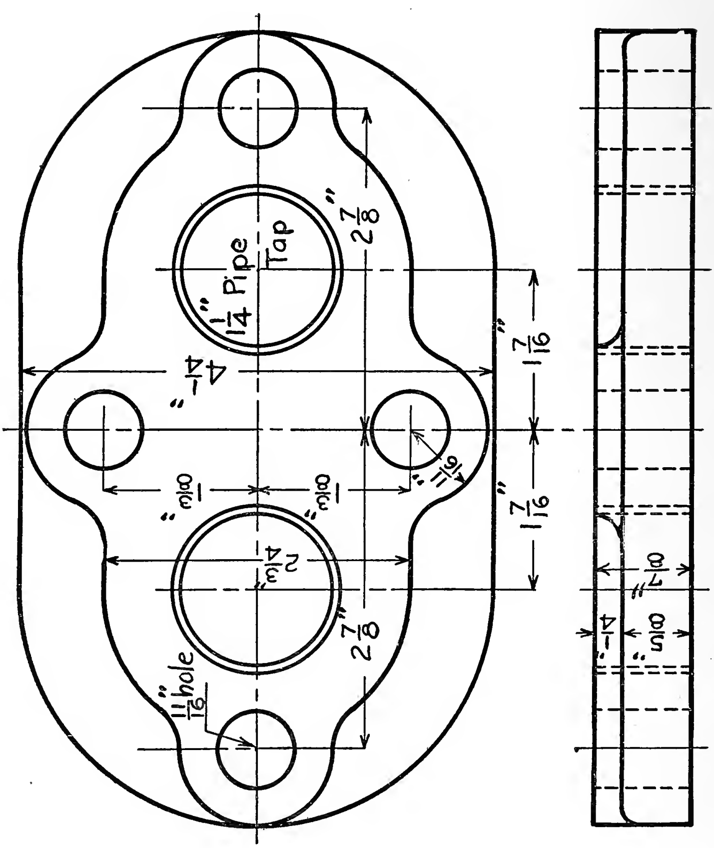
This is an exercise in the tangency of circular arcs. It is a small detail of a riveting machine, a flange for outlet and inlet pipes; the pipes screw into the holes shown. Draw the views as sketched; making it carefully full size, using the scale for laying out the sizes.

Draw the main center lines of the upper or plan view first, continuing the vertical one down to the elevation. Next draw the minor center lines of the plan, then close in the plan, smaller circles first then larger and the straight lines last. Draw the elevation from the plan, making the upper and lower horizontal limiting lines first, then projecting down from the plan. Put the dimensions on practically where shown on the sketch.

When ready to ink, put in the small arcs with the bow pen, then the larger with the compass, and lastly the straight lines. Put in the dimension lines and figures the very last.

18. Detailed directions for penciling and inking Exercise No. 12.

This is an exercise in the tangency of circular arcs. It is a stop lever. Draw the proper views from the sketch,

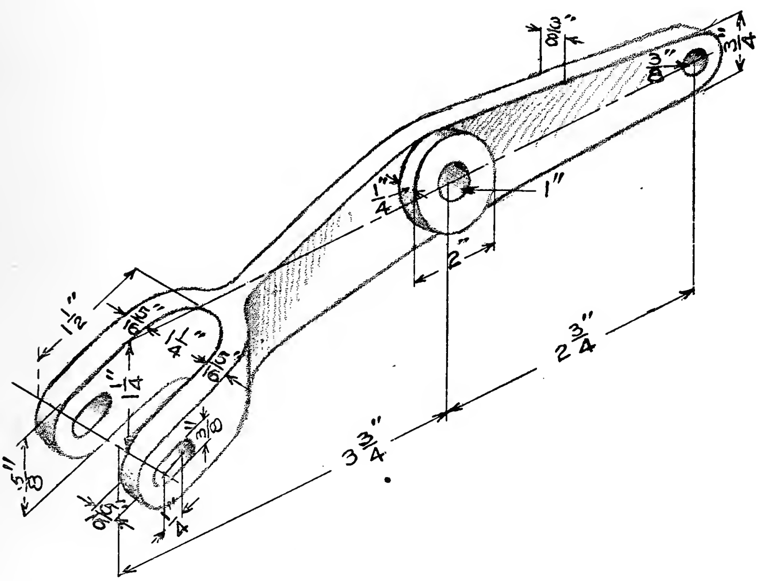


EXERCISE NO. 11

making them carefully full size, using the scale for laying out the sizes.

Draw the horizontal and oblique center lines of both views first. Next draw the central boss and left hand end of the lower view or elevation. Then draw the fork of the

EXERCISE No. 12



plan view and project down to the elevation. Finish the elevation, then the plan. Put the dimensions on practically where shown on the sketch.

When ready to ink, draw the circular arcs first, then the horizontal, vertical and oblique lines in order. Put in the dimension lines and figures the very last.

19. Further points about drawing materials and instruments.

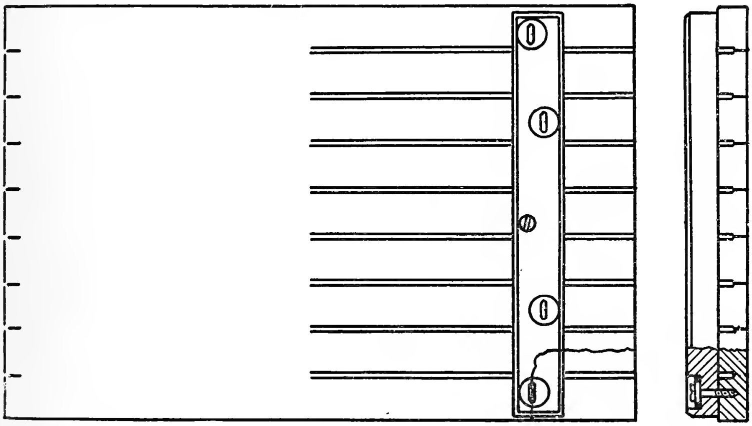
If you want to do good work, you should have good tools. If it happens that an excellent workman does good work with very indifferent tools, it only means that his work is done in spite of, not by the aid of, his poor tools. It is not to be doubted that the poor ones are more or less of a hindrance. Nor is it the opinion of the writer that beginners should have any poorer instruments for work than the experienced man upon the score of his inexperience, and the likelihood that he will spoil his first tools by improper handling. A student's first lesson to learn and a teacher's first duty is to teach the proper use and care of tools. With this lesson learned, it should be possible for the beginner to work safely with the best appliances.

Again, the inexperienced workman, of whatever craft, will bear witness to the statement that the very best appliances are never too good, better tools are continually being constructed and go into immediate use. It is the purpose now to say something about the different tools and their proper care and handling.

Drawing boards: The best drawing boards are made of well seasoned pine, of uniform grain, narrow strips glued together, the whole being finished at the two opposite ends at right angles to the strips by narrow pieces tongued and grooved and glued to the board, to prevent warping. Fig. 3 shows one of these boards.

In large boards, of first class construction, battens are fastened to the back of the board so as to permit of expansion, and contraction of the board with changing temperature, but not of warping. This is effected by fastening a batten rigidly at one point near the middle, and at two or more other points by screws rigid in the board but working in slots in the batten. In order to still further lessen the tendency of the board to warp, saw cuts or grooves are made about two inches apart, longitudinal of the strips of which

Fig. 3



the board is constructed and of a depth of about half the thickness of the board.

It is not absolutely necessary that all four edges of a board should constitute a true rectangle, they ought to be straight. Only one edge of a board, the left hand edge, should be used upon which to rest the T sq. head, the triangles should be used for vertical lines.

The under side of a battened drawing board may conveniently be used to cut paper on, but it should never be done on the working side, and care should be exercised that the working side and the edges of the board be kept clean and in all respects in good order.

Tee squares are made in various forms. They should be of well seasoned wood of uniform grain. The blade may be sunk in the head or screwed on top and glued. A frequent source of trouble in T sqs. is that the part of the head just under the blade swells under the action of the moisture in the glue when it is made, becomes set, and causes the head to rock against the edge of the board when in use. The bulge in the head can be seen by placing a straight edge against it. An excellent form of T sq. is made of mahogany, with a very narrow edging of ebony. The latter is particularly hard, it relieves the edge by its strong contrast with the color of the paper. Sometimes a celluloid edge is used. This seems to have growing favor because of its transparency, permitting partial sight of the work underneath. If T sqs. are large, they are tapered as before mentioned, so that the upper edge is the only one that can be and which always should be used.

Some T sqs. are made with a swivel head so that the angle of the blade can be adjusted and they have their value sometimes. It may be said that one should be in a well equipped drafting office, but that for ordinary use it is not necessary. Steel T. sqs. are made but are not favorites with draftsmen because of their weight and the danger of injury to the drawing by denting, etc.

Triangles are made of the same materials as the T sqs., solid triangles, however, are not good as they will warp. Triangles are made also of vulcanized rubber and of celluloid. The former have the advantage of contrasting well with the color of the paper, but they have the disadvantage of being non-absorbent, consequently they transfer dirt from one part of the drawing to another and smear it.

The inside edges of a triangle may have depressions cut in them to facilitate picking up from the paper. This may seem an advantage to some; it is certainly no drawback.

A 30° and 60° triangle and a 45° triangle are the only ones in common use except those especially made for mechanical lettering. Some other angles may be struck by using the triangles together and adding their angles, 15°, 75°, etc. The accuracy of triangles is important, they may be proved by reversing operations with them, means hardly worth while describing at length, or by using a protractor, to be shortly described.

Paper for drawing upon comes of various kinds and quality, suited more or less to different kinds of drawing. A moderately heavy, smooth hard surface is to be desired for mechanical drawings. A yellow or manilla paper is much used for pencil drawings when the resulting drawing is to be traced. It is called detail paper. Bond paper has also come quite into use, and it has distinct advantages. The drawing is penciled and inked on the paper and from it blue prints can be readily made. Paper should if possible never be rolled, particularly rolled small as it cannot be satisfactorily flattened again.

Tracing cloth is in almost universal use in drafting rooms for permanent drawings, as blue prints can be so readily made from it. Either the rough or the smooth side can be equally well used for drawing in ink. Frequently the original pencil drawing is made upon the rough side of the cloth and inked over. It furnishes a very good surface for this purpose. The smooth side is impractical for pencil drawings but takes ink like a highly calendared surface. Special precautions, which will be mentioned shortly, have to be observed in working upon it. There is but one recognized grade and make of tracing cloth, the "Imperial."

Stretching of paper, as it is called, is resorted to where any water color brush work is to be done. It consists of pasting the edges to the board and shrinking until it is quite taut. It takes a little experimenting to get facility in doing this, but every one ought to know how to do it when occasion arises, hence the following directions are appended.

*"To stretch paper tightly upon the board, lay the sheet right side up—which side is presumably the one which shows correct reading of the water mark when held to the light—place a rule with its edge about one-half inch back from each edge of the paper in turn, and fold up against it a margin of that width. Then thoroughly dampen the back of the paper with a full sponge, except on the folded margins. Turning the paper again face up, gum the margins with strong mucillage or glue, and quickly but firmly press opposite edges down simultaneously, long sides first, exerting at the same time a slight outward pressure with the hands to bring the paper down somewhat closer to the board. Until the gum sets so that the paper adheres perfectly where it should, the latter should not shrink; hence the necessity for so completely soaking it at first. The sponge may be applied to the face of the paper provided it is not rubbed over the surface, so as to damage it. The stretch should be horizontal when drying, and no excess of water should be left standing on the surface; otherwise a water mark will form at the edge of each pool."

The drawing instruments that have already been mentioned, the compass, dividers, etc., constitute the simple

* F. N. Wilson's Theo. and Practical Graphics, P. 14.

universal kit, and probably the majority of draftsmen have little else. Of course there are a number of other tools made, chiefly for special uses. The use of these is not universal, however, chiefly because the time saved with a special tool is usually offset by the time consumed in handling and cleaning, for each special tool comes in generally for but occasional and brief use. Somewhat similar reasons explain why various special attachments to the simple kit are not popular universally, like hair spring legs in compass and dividers, spring catch ruling pens, micrometer adjustment to needle point, etc.

Beam compasses are instruments to strike large circles, consisting of a needle point leg and marking point leg, each separate and adjustably mounted upon a bar of metal or wood. Every large drafting room is likely to have one for occasional use, but the individual hardly needs to go to the expense of one unless its use is demanded frequently.

Follower pens, in which the pen is swivelled in the handle, are used to make irregular curves. The pen automatically adjusts itself properly to the ruling edge. It has but occasional use.

A bow pen is made, chiefly for special professions, which has a fixed needle point leg with a marking leg sliding freely upon it. It is handy for striking a large number of circles of small diameter, but it is a tool for that special purpose.

Dotting wheels are instruments to do what the name implies, make dotted lines. They also have occasional use but are a trouble to care for and easily get out of order.

Proportional dividers, consisting of double pointed legs, pivoted between the ends, and adjustable so as to give a range of relation between the opposite angles formed, are a very useful tool indeed upon those rare occasions when a drawing is merely to be copied to a different size regardless of scale. Where scale is to be observed it is not safe as a tool nor is it much handier than the scale direct.

A parallel straight edge is made which replaces the T sq., A rule, of the length of the board, is held at the ends by sliding on a wire cable and moves into parallel positions. Theoretically it is excellent but lack of sufficient rigidity is its chief drawback in the opinion of many.

The protractor is a semi-circular disc segment of celluloid, bone or brass with degrees marked upon it. The center is marked on the straight edge of it. It has use where angles have to be struck of varying sizes and other than those the triangles can be used for.

There is a machine on the market known as the *Universal Drafting Machine*, which has very meritorious features. It combines the functions of the T sq., triangles and scale and, when specially adjusted, the protractor.

It consists essentially of two straight edges with scales upon them and with a common point of attachment. They can be set rigidly at any angle to one another and the whole moved in any direction over the board through the medium of hinged arms, rigidly attached to the upper left hand corner of the drawing board. Straight edges having any of the standard scales upon them may be attached to the frame.

There is also a Paragon Drafting Instrument accomplishing much the same purpose. It is attachable to a parallel ruler previously mentioned or it can be attached to a T sq. blade. The fixed center is the point of attachment and the ruling edges, two in number, can be swung around it at any angle, replacing triangles and protractor, and also having variously scaled edges.

20. Sectioning.

It is not always possible to show all the facts of a subject by use of the elevation and plan heretofore spoken of, and even where possible, convenience frequently calls for a shorter way to attain the information. A cutting open of the subject, showing the interior is what is resorted to. This is known as sectioning; the views of the cut portion are called sectioned views or simply sections.

A section, in its simplest form then, means to cut any thing as with a saw and to show by some conventional or commonly understood means the plane of the cut and what lies beyond this plane when looking perpendicularly at it.

The conventional or commonly understood means for showing the plane of the cut is to cover the parts cut through with evenly spaced parallel lines. They are not intended to represent or suggest a tinted surface, hence to distinguish it as a sectioned surface the hatching lines, as they are called, are ruled diagonally of the edges of rectangular forms. If the edges of a sectioned surface are vertical and horizontal, the most common condition to be met with, the sectioning is done generally with the 45° triangle resting on the T sq. Contiguous parts are sectioned lined in opposite directions. In any position whatever of the contour lines of the sectioned surface, the section lines are generally made at an angle of 45° with them; for example, where the contour lines are at 45° to the horizontal, the section lines may be horizontal or vertical.

The weight of the lines used in sectioning should not exceed those of the outline, they look rather better, generally, if made slightly lighter. Considerable judgment can be displayed in the adjustment of space and weight of section lines. Consulting practical drawings or the illustrations to this book will be helpful. The effect should never be coarse but pleasing, even, and not too obtrusive.

Fig. 4 gives an example of sectioned surfaces. It can be seen that if nerrow spaces are sectioned by relatively widely spaced lines, the effect is coarse. If on the other hand, the spacing is too narrow the effect will be that of a dark tone obscuring the outlines and any errors in spacing are more noticeable. Again, the larger the surface to be sectioned the wider can be the spacing of the lines. Long narrow pieces should be sectioned by heavy lines closely spaced and large areas by light lines widely spaced.

Draftsmen generally have a maximum and minimum of spacing of section lines that are not very far apart, nor do they use many different spacings because it is economical of effort if sectioning can be made more or less mechanical. One authority fittingly says: *" When a few lines have been done in section an unconscious rythmic action, as it were, is established, just as one beats time to slow or fast music without thinking, and the manipulation becomes mechanical. For this reason,' he goes on to say, 'a drawing to be inked should never be sectioned in pencil first, otherwise the result is likely to be as bad as if one were to write his name with a pencil and then try to go over the lines with ink.' "

Hence it can be seen that this rythmic action comes more readily when the eye is accustomed to a very few different sizes.

* G. W. McCord, Mechanical Drawing, P. 6.

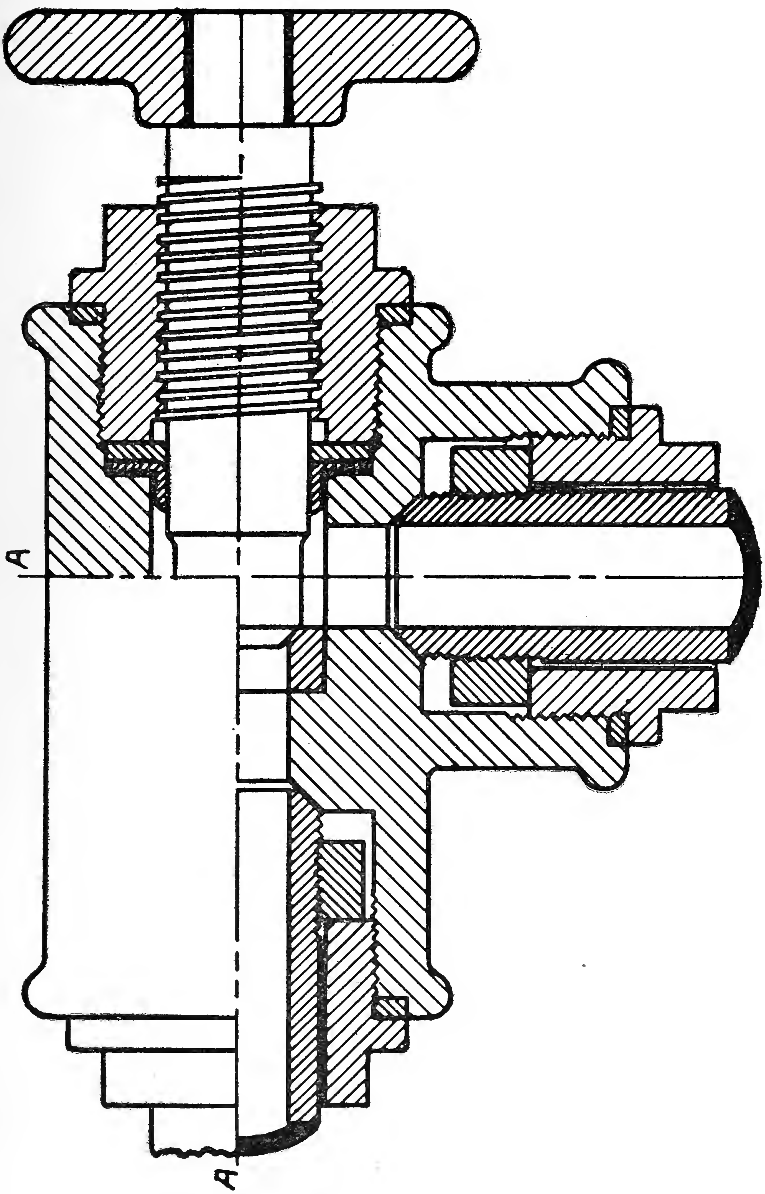


Fig. 4

Where more than two surfaces are contiguous to one another it is customary to use 30° or 60° lines to distinguish the third surface, but these angles are not resorted to unless it is necessary.

Sometimes contiguous surfaces, especially when large, are distinguished from one another by having the section

Fig. 5.

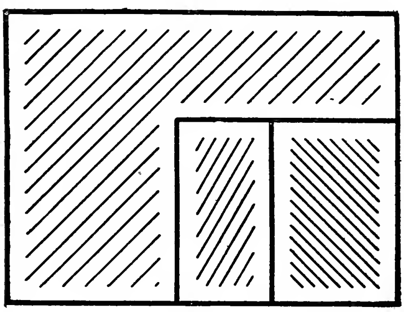


Fig 6.

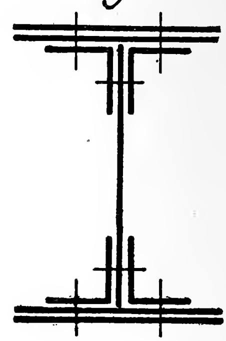
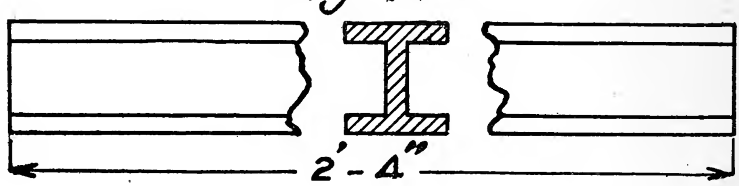


Fig. 7.



lines fall uniformly short of the limiting lines of the surface by a small distance, say $^1/_{32}$ or $^1/_{16}$ of an inch as shown in Fig. 5. A section may be designated as a longitudinal or transverse section according to whether the plane of the section is parallel to the long axis of the subject or at right angles to it.

If the plane of a section is horizontal, it is called a *sectional plan*, if vertical, a *sectional elevation*, or in other directions it may be called simply a *sectional detail.* If a sectional plan, its place is above or below the elevation, according to the angle used in projection and it may take the place of a plan when it is not necessary to have the latter present. When it is, then the sectional plan may be placed either above or below the regular plan according to the angle of the projection, or if there is not convenient room for this, it may be placed to the right or left, orthogonally projected from the plan. Again, sometimes, according to circumstances, the section is placed independently of the regular projection views in any convenient place on the sheet. The importance of the section view and its value in giving data for construction determine the latter mentioned choice of positions.

Again, if the view is a sectional plan, a broken line, for which the convention is a variable, is drawn across the elevation showing the position of the theoretical saw cut, and the ends of this line are lettered A—A or B—B, and so referred to in designating the sectional view (see Fig. 4). The broken line may consist simply of very heavy, short lines just entering upon and on opposite sides of the elevation, to call attention sharply to the place.

While a section is theoretically a saw cut, subjects are not always continuously cut through. Only a portion may be sectioned or the plane of the section may for convenience or economy of views, be in reality two or more parallel planes cutting through two or more parts of the subject; very rarely are the planes made non-parallel, although such a condition is not prohibited by any written or unwritten laws. A very usual device is to represent a portion, say one half, of an elevation as in section. This, if the subject be symmetrical upon a center line, will save the drawing of one view.

If the plane of a section moves from one place to another as just explained, some conventional line, usually that for center lines, is used to divide the planes or the sectioned from the non sectioned parts. The plane then terminated by this limiting line has no other limits. A solid limiting line is not used unless the material sectioned through actually ends at this place, and a new piece begins beyond it.

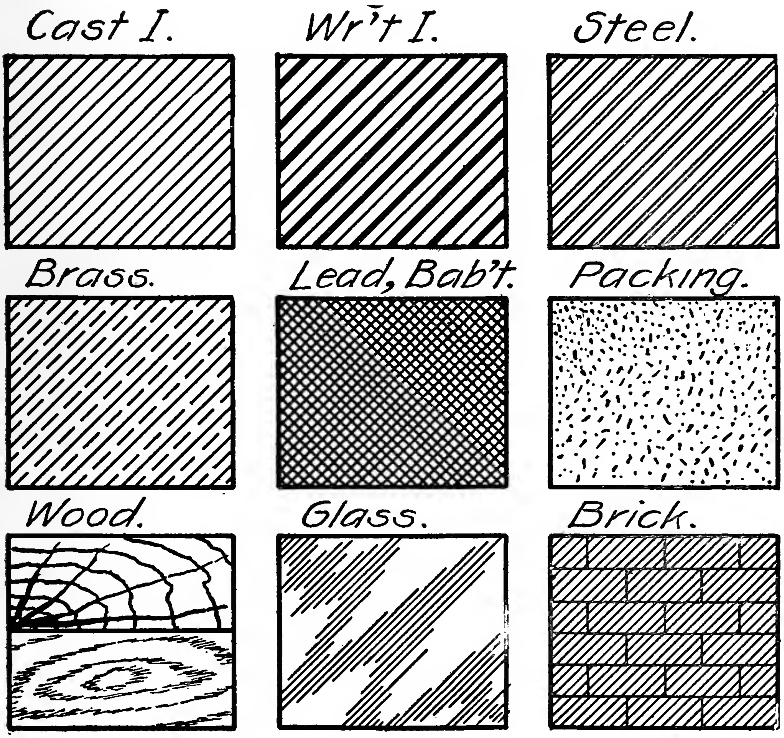
Where different pieces are sectioned in a subject in the same sectional plane, considerable taste can be displayed in distinguishing parts one from another. Where the same piece reappears as cut through in the plane of the section it should be treated by section lines identical in weight and spacing so as to preserve, in other words, the continuity of material.

Attempts have been made to standardize section lining by the adoption of certain weight and spacing of lines to be used as representing different materials, steel, wrought iron, cast iron, brass, etc. But, while a well known series has had wide publicity, that approved by the A. S. M. E., and in use by the Government drafting offices, still its use is not at all universal. Each drafting office has its own way of treating sectioning. Some use no conventions, others use a certain few of the more important ones selected from the above mentioned series.

There are insurmountable difficulties in the use of standard section lining which has prevented its universal adoption. It takes considerable extra time, to render the conventions; it is also difficult, and next to impossible, to harmonize the effects of an intelligent drawing, the proper distinguishing of sectioned parts with the conventions advocated, that is, materials cannot be made to stand out from one another in a desirable manner when the draftsman is confined invariably to a certain kind of line and spacing.

However, a book on drawing which did not present for its readers the standard conventions before mentioned would

FIG. 8



be considered very much out of place, therefore Fig. 8 is given for the benefit of those who wish to familiarize themselves with them.

The illustration shows a spacing and weight of line that are practical. Of course these are more or less governed by the area to be treated, varying with it.

In the wrought iron the groups of lines should be separated from each other simply by a little wider space than are the lines of the group, the same of steel.

The convention for glass is an attempt to illustrate the play of light one sees now and then upon looking into a room from the outside through a window; the several masses of tinting, which by the way should be expressed by lines more closely spaced than in sectioning, are irregular in their contour shape yet grouped together. The arrangement of this convention is after all a matter of the taste of the draftsman.

Leather, sand, or packing material are expressed by about the same convention. It is made with the writing pen, touching the paper irregularly and spreading the nibs; for packing the strokes may take the shape of irregular lines like short threads.

In place of a conventional section lining, materials may be lettered W. I., C. I., S., etc., on the surfaces, to show what they are made of, or else a designating number may be used. The number may lie between limits which by arbitrary agreement stand for a certain material; for example, Nos. 1 to 200 for cast iron, 200 to 300 for wrought iron, etc.

A sectioned view should always show in full line that which lies within the plane of the section, all that is beyond this should also be shown in full line which is not covered by the surface sectioned. If it is desirable to show what is covered it should be dotted as in any other hidden construction. Of course nothing should be shown of that part supposed to have been removed when the subject was cut through.

Sectioned views are not used in working drawings unless it cannot be avoided or unless their use is economical of views, and consequently of time, and when not sacrificing clearness. They are used less as a vehicle for dimensions, also, than they are to show form, what is solid and what is hollow, what is continuous in the various materials. They are not desirable as a vehicle for dimensions because of the interference of the section lines with the dimension lines and figures. When dimensions have to be put across a dimensioned surface, space is left at least for the figures, sometimes for the dimension lines and the arrow heads. Aside from legibility, the presence of a dimension should be at once apparent through its prominence on the drawing.

21. Some practical points about sectioning.

Section lining should be done directly in that material in which the drawing is to be left, and the spacing calculated with the unaided eye. To do this well will require a little practice; a few hints which follow may be found helpful.

In the first place it is convenient in penciling, which is to be inked, to sketch the sectioned surfaces roughly freehand to show which are sectioned and which are not, and to show what direction of section lines to use.

When possible hold an arm of the triangle, one edge of which is guiding the section lines, by the thumb and first or second fiugers so that the triangle may be made to creep along as was suggested for the T sq. blade. Use the edge of the triangle only for an approximate adjustment of spacing, let the pen point give it more accurately. It will be noticed that with practice the pen can be tilted a little out of plumb and nearer to or farther from the ruling edge without sacrificing quality of line, and that this little is sufficient to change the approximate adjustment of the ruling edge to the accurate place of the line to be drawn. It is very desirable to attain this proficiency and in this way.

Mechanical devices called section liners have been invented for spacing lines evenly but they are not in general use by draftsmen. They fail in just the respect mentioned. The pen cannot be held so invariably the same way with respect to the ruling edge that the section liner can be depended upon entirely to space automatically.

If a surface to be sectioned is broken up so that the lines in all places cannot be drawn continuously across it, as in a transverse section of a hollow cylinder, a line may be followed along from its beginning to its end across the subject before going on with the next one, or a group of lines may be treated in one place and afterwards in another on the opposite side. The latter is the method much to be preferred if certain precautions are followed, for it is exceedingly difficult to maintain an accurate holding of the pen with respect to the ruling edge when the pen has to be lifted and lowered again in another place. If two opposing groups of lines are to be united farther along, each may be drawn readily and separately if one is stopped just short of uniting and the remaining space, which should be sufficient to contain four or five lines, is calculated rather carefully by eye, and any inaccuracy in the alignment of the groups adjusted before they meet. This method requires less care and can probably be done more rapidly than the first one mentioned.

In the section view of features which wrap around one another like a valve with its stem, gland and body, it is desirable, if possible, in the penciling, to begin with the innermost parts and develop outward from them because it will save erasure of parts which are covered up by those on the inner side.

Sometimes labor is saved, in hurried work, by not section lining entirely across relatively large surfaces but by sectioning only around the edge, stopping the section lines along imaginary lines parallel to the edges successively of the surface to be sectioned.

Sometimes forms are cut through which cannot be accurately represented by a surface hatched with lines. Such a form is the cross section of an I beam or a built up girder, the latter form being shown in Fig. 6. Such a thing as this is difficult because the surfaces cut through are so narrow that it is impossible to represent them to scale by a double line, in fact the ordinary line on a drawing might itself be far too heavy to represent this thickness. Scale in thickness of material then has to be sacrificed for effect in showing construction. Where it is possible, accurate scale should be adhered to. It is only in such subjects as the above where the error is apparent without explanation that the rule of accurate drawing should be broken.

Long members of uniform cross section like I beams, etc., sometimes cannot be shown their true length in a drawing without reducing too much their transverse dimension. To overcome this they are assumed to be broken as shown in Fig. 7. The over-all dimension is given and, to save a separate view, the exact shape of the cross section may be shown on one of the pieces, as if the plane of the section were turned through an angle of 90°.

As the rules of orthographic projection are violated in working drawings so, in sections, things are done which are not strictly projective or follow the theoretical saw cut. This is because clearness of construction is paramount.

For example, it is of no use to section longitudinally through a bolt or nut, nothing is gained in clearness, in fact something is lost. The identity of the bolt or nut is not as readily distinguished. So, for this reason, it may be said that we never section longitudinally bolts, washers, shafts, rods, or other solid pieces having a relatively long axis proportional to their diameter.

We do not, in sectioning a wheel with spokes, cut through a spoke longitudinally if it should happen to come within the plane of this section. The rim and hub are the important features, the spoke is but a relatively narrow connecting link between the two. If sectioned it is apt to give the impression of a wheel with a web or diaphragm connecting rim and hub. It does not make the forms clear. In this way, in other subjects, we arbitrarily skip over features which obviously come within the plane of the section.

It may be set down, therefore, as a general rule that a rib, an arm of a pulley, or any comparatively thin piece should not be sectioned by a cutting plane which is parallel to its longest bounding surfaces.

As a further illustration, when materials are sectioned through, the surface of the cut is not interrupted merely for the sake of showing a fastening or some other minor feature. For example, if sectioning longitudinally through a cylinder and its head, and if the bolts fastening body and head should, some of them, happen to come within the plane of the section, they would not be sectioned, but either omitted or shown in dotted where they passed through the sectioned material, and in full line elsewhere.

On the other hand, if we have a sectioned side view of any thing having radially placed holes, and the plane of the section does not pass through one or more of them, nor is their arrangement clearly shown in another view, one hole should be cut through, and at its true radical distance from the center, to furnish information lacking elsewhere.

A key-way in a collar should not be sectioned longitudinally with the collar, but should be shown with a dotted line.

It is hardly worth while to multiply instances of violation of projection in sections; new cases are likely to arise continuously. Suffice it that features are not shown in section where no information would be gained thereby, no matter whether they come within the plane of the saw cut or not.

Sectional details are placed either near the part to which they are related or grouped together in any convenient place on the drawing, there is no rule governing. If placed near the principal form they are generally made projective with it, except that the sectional projection may be made on a supplementary plane not corresponding to the co-ordinate planes. Sometimes the section is revolved into a co-ordinate plane about a line as axis which designates, on the view, where the section is taken and it may be revolved from the actual position of the section or moved along the designating line to a free place on the sheet. For example, the shape of the spoke of a wheel may be shown by a detail section on the spoke, limited by its limiting lines, or to one side on the line which shows where the section is made. See Fig. 10.

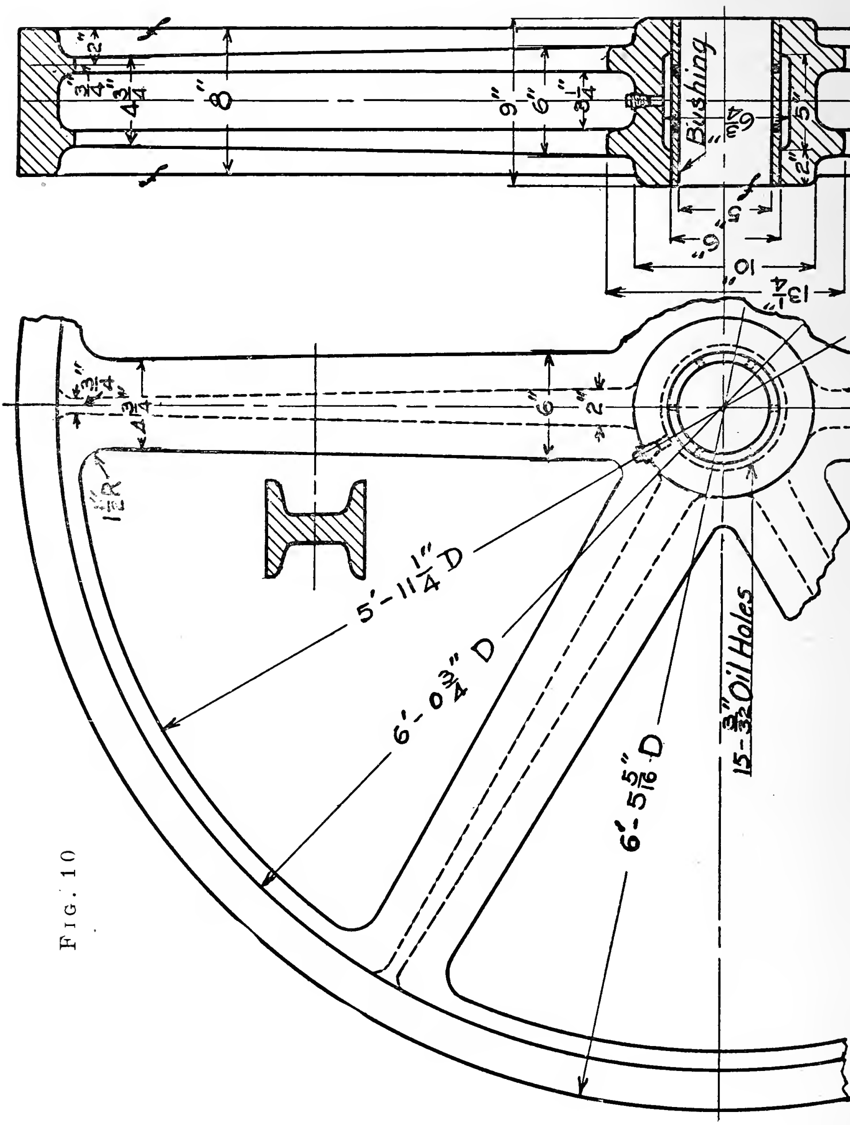

Bushing
5'-11 1/4" D
6'-0 3/4" D
6'-5 5/16" D
15-3/32" Oil Holes
1 1/2" R
8"
9"
6"
10"
13 1/4"

FIG. 10

22. Some practical points about and the care and handling of drawing instruments.

Drawings can be cleaned of the dirt which usually gets on them, with the soft pliable erasers, the needed rubber, the sponge rubber or stale bread crumbs rubbed over with a cloth, or with the hand, if it is not in too hot weather. But the readiness with which the cleaning can be done should not lead to carelessness in the penciling work, for it makes unnecessary work, gives an unfavorable impression, as it should, to onlookers, and there is always the chance of injuring the lines somewhat by the cleaning process. The liquid drawing inks will stand very little erasure with the pencil eraser without loss of blackness in the lines. To keep a drawing, in good shape, as the work progresses, cultivate early the habit of keeping the T sq. and triangles clean, using a piece of paper where possible over parts of the drawing not in immediate use, and, finally, keeping the hands off the work when they also are not in active service.

A caution is here extended which will, if followed, aid in this respect. Cultivate the habit of standing erect at a drawing board, putting all the strain upon the back instead of saving it at the expense of the drawing board, giving an indolent appearance and endangering general physical comfort.

Drawing instruments should be handled as little as possible consistent with necessary use. A fault is all too common, especially among beginners, of nursing instruments in the hand when not in use. Observe that the workman in any craft will always lay a tool down when he is done with it, even temporarily, and moreover, he lays it down where it is the least trouble to find it again.

It is also equally desirable to be scrupulously careful to use the tools only for the purposes for which they were intended. Violations of this are to be found in using the T sq. as a hammer to put in tacks, the dividers as compasses to describe arcs, sticking the divider points into the board so the dividers will stand alone, etc., all of which tend to injure the tools.

The tools should be at all times handy. With the T sq. always on the board, the triangles above it on the board and other tools in predetermined places from which they can be picked up without much, if any, hunting, and while the eyes are engaged on the drawing, will conduce to rapidity and accuracy of work. Time is a very serious quantity to be reckoned with in drawing.

When finished with a drawing instrument for any appreciable length of time it is well to wipe it off with a cloth free of any moisture and dirt from the hand. A chamois skin is not the best thing for this purpose because it absorbs moisture freely from the atmosphere and gives it to the instruments, nor is it a good thing in which to wrap the instruments. Of course it is possible to prevent more or less discoloration of the German silver in instruments in the course of time but rust should never be expected or allowed to appear, for it indicates carelessness.

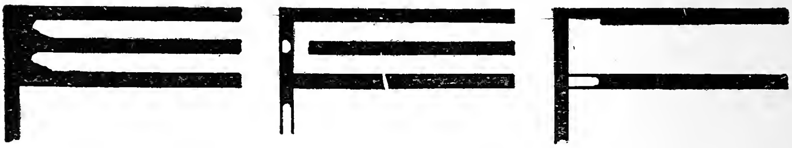
Facility in the use of the ruling pen is eminently desirable as it leads to the proper use of the other tools, so a few more practical directions about it are in order.

The proper holding of the pen has been minutely described. It remains to give more in detail the reasons for these directions. The pen is sharpened in approximately a parabolic curve, the legs are bowed, and when held perpendicularly to the paper the minimum of opening touches it. If tilted sidewise a thicker line is apt to result, or if not noticeably thicker the way is open for a large amount of ink to flow out, and this is what happens when a very heavy line is described, sometimes completely emptying the pen and making a blot. Again, it is easier to see the place and length of the line to be drawn when the pen is held vertical.

The greater care at all times should be exercised the thicker the line used or the fuller the pen is with ink. The beginner should carry less ink in the pen than after he becomes expert. When occasion arises to use the pen for long lines or many close together, with the least interruption for refilling, a considerable amount of ink can be carried in the pen if the following directions are observed: Head the pen to start, the point very close to but not touching the paper; when ready, touch the pen to the starting point and instantly move on the line uniformly and rapidly, the more rapidly the fuller the pen. Stop and lift the pen in the same instantaneous way. It is possible, in this way, to carry so much ink in the pen that if it is held stationary against the paper the ink would run all out at once. These same precautions hold when making a very thick line with the pen; the thicker the line the less ink can be carried.

In drawing lines to go from or to a heavy ink line or border still greater care has to be observed that the border does not draw the ink out of the pen and cause a blot. The situation is illustrated in Fig. 10. It shows a series of lines close together where the edges of the lines are apt to break down and the lines run together. In cases of great danger, every other line or so may be begun late as shown in the figure and afterwards filled out when the ink dries. In patching these open spaces set the pen to make a finer line, matching only one edge of the line drawn, then by tilting the pen probably the requisite increase can be made if not with accuracy in one stroke, then in two or more; a line can

FIG. 10



be added to easily but it cannot be reduced in size except by erasure first and then redrawing.

A similar difficulty is presented in ruling a series of lines to meet or cross at a common point. Where possible it is best to draw the lines towards the meeting point, for there is less likelihood of the ink running out of the pen in lifting from than there is in lowering to the paper.

If a pen fails to work it may be due to several causes. (a). It may be set so tight that the ink cannot flow out between the nibs. In this case it is better to open the pen liberally to a coarser line than desired and set it by trial towards the finer. It is found by experience that this saves time.

(b). The ink may have dried at the ends of the nibs, if not farther, and clogged the flow. The best thing to do is to at once clean and refill. The use of a blotter or a piece of paper drawn through between the nibs is to be deprecated as only a poor substitute for poor conditions for working.

(c). Owing to the presence of grease, or for other reasons, the ink, on first filling, does not run down to the point. Proper running may here be facilitated by opening the nibs a little and shaking gently, over a blotter or something it will not injure if it blots, until the ink settles or drops out. If the latter, it may be found necessary to wipe the nibs free of overflow before using the pen to rule with.

(e). The pen point may be actually out of order, a little broken or one nib a little longer than another. This of course demands that they be sharpened; but the pen should be tested for all of the other difficulties first. An injured pen will either not mark at all or it will make a ragged line; the line, moreover, may be ragged on one or both edges. If the pen is merely uniformly dull, it will refuse to make a fine line, the line will simply fail entirely if the nibs are brought close together.

A pen can be sharpened and tested in the following manner: A fine oil stone should be used for this, an Arkansas stone seems to be preferred. Bring the nibs of the pen together as for drawing a very fine line, and hold for the rubbing at a small angle to the stone, 30° or less, and with the broad face of the nibs towards the stone. Rub to and fro in the direction of the handle with at the same time a slight rocking of the pen in order to round the point. If too pointed it tends to cut into the paper and will not hold sharpness so long. To test for sharpness, drag it on a piece of paper as if making a line; it ought not to scratch roughly or glide too freely, but bite slightly, that is, resist motion. If it seems to act as it should, clean thoroughly and then try with ink. Properly sharpened, the pen should make a very fine black hair-line without breaking and a broad line of sharp edges, even if the pen is tilted five or six degrees out of plumb in a plane perpendicular to the ruling edge. Try for a broad line first with this test in order to see if both blades are of equal length. If they are not, that side of the line at which the nibs are shortest will show ragged. If this test is successful and the line drawn is perfectly sharp and clear on its edges, test for fineness of line, by working from a wide line towards a narrow one. If it happens that the sharpening has proceeded too far and the pen bites too deeply into the paper, or if one nib is slightly longer than the other, the pen may be dulled or the long nib be worn down by rubbing it on the stone with a rotary motion when the broad nibs of the pen are perpendicular to the plane of the stone.

To determine the place of a line the ruling edge should furnish a rough approximation and the marking point the exact place as mentioned in Sec. 21. It is one of the important points in handling to be learned early. The nibs of a ruling pen, for example, being bowed will touch the paper slightly in advance of the ruling edge. If the pen is incorrectly tilted until the nibs touch the paper at the ruling edge, a blot is almost sure to result, for the ink will touch the ruling edge.

It may sometimes happen, when a number of lines have to be drawn which run in a variety of directions that waste of time is threatened in waiting for ink to dry. The ruling edge can be held slightly free of the paper and over the wet lines by using the thumb and first or second finger as a cushion underneath it or one ruling edge may be rested on and slightly overhanging another. In small work one triangle may be put with its open space over the lines to be drawn, and the other triangle rested upon it, crossing the gap. A method of inking will be shortly discussed which overcomes some difficulties of waiting for ink to dry.

Errors in an ink drawing can be corrected so that the repairs are practically invisible. A knife will not do this unless used in conjunction with the ink eraser. In fact, cutting or scratching with a knife is so risky that it is safe to adopt the custom of never using it except under extreme circumstances.

If an error occurs, take up as much ink as possible with a blotter, but do not use it under any ordinary circumstances to dry a line because it pales the ink. Then use the ink eraser, rubbing rather lightly and rapidly, not in one direction or with one part of the eraser, but in all directions and changing the point of contact, because the rubber will heat and not work so well. Every vestige of the mistake should thus be removed, although it blurs a certain area around the error. Erasing shields are quite handy in restricting the area erased. A shield is a piece of sheet brass with various shaped holes in it. Next clean off all the sand by using the pencil eraser. If the surface of the paper is very much disturbed it may be necessary to burnish it with a piece of ivory or smooth metal. The difficult part of correcting errors now comes in putting back the ink lines. A line made upon an erased space is quite apt to spread a little and show larger than on the fresh paper, although the difference is very slight, therefore the pen should be set for a slightly finer line, and this added to by successive strokes. If in spite of all precautions, the place erased be treacherous, use two exceedingly fine lines as limits or walls, the distance apart of the thickness of the line to be drawn, and which, when dry, will prevent the filling ink from percolating into the rough paper. In case of a very wide line, the retaining walls may have to be built up gradually. In repairing also it is necessary to overlap the correct part of the line sufficiently to include all that has been affected by the erasing. A very good hard drawing paper ought to permit several, say three or four, corrections over the same spot if skillfully managed. Corrections upon the rough side of tracing cloth are very easily made with the ink eraser and no burnishing is necessary. On the smooth side, however, erasing is difficult and quite apt to irreparably injure the surface of the cloth. The greatest of care must be used by rubbing lightly to prevent trouble from this cause. A knife is almost sure to take off the surface, and if it does, burnishing will not repair the injury.

A knife comes of service now and then in one of two ways, first to scratch off the crust of large blots or very wide lines, without attempting to remove the ink entirely, second to cut out an extremely small spot of ink or a slightly overlapping line. In the case of the latter, the knife should be run along the edge of the correct portion to cut it away sharply from the incorrect, then the error may be scratched free without leaving the correct line ragged.

The scale is one of the indispensable tools of the draftsman which has not yet been discussed. There are a number of kinds of scales made, divided broadly into flat and triangular and again, into civil engineer's and architect's or mechanical engineer's. The civil engineer's scale is one in which the divisions of inches are by even decimals, tenths, twentieths, thirtieths, etc. The flat scale may contain two, four or eight scales, according to the way in which its edges are divided, and is a convenient tool because of its flatness. The triangular scales usually contain twelve different scales and, because of this wide range, are probably the favorites for all round general use. The civil engineer's decimated scale may be used in place of the mechanical engineer's scale by assigning certain values to the divisions which will be described shortly. A description of the mechanical engineer's triangular scale and its use will suffice for the flat scales also.

In engineering, when scale is mentioned, it generally means so many inches or a certain fraction of an inch to the foot, or so many inches or a fraction of an inch will stand for a foot of the actual thing drawn. To take a concrete case: On one face of the triangular scale, the edge is divided into 3-inch major divisions, identified by numbers on the flat surface, the edge is also divided into $1\frac{1}{2}$ inch minor divisions, identified by numbers on the curved part of the scale. At the right a three inch space is divided into twelve major divisions to stand for inches and each of these again into 8ths. At the left a $1\frac{1}{2}$ inch space is similarly divided, except that each space standing for one inch is divided into quarters. Hence by overlapping we have two scales to an edge. To lay off a dimension the three inch scale we read the even feet to the left of the zero mark and the inches or fractions to the right.

Certain points in the handling of the scale deserve to be carefully noted. It should be used as a scale, never as a rule, and the edge should be brought as close to the line to be scaled as it is possible to get it. With a sharp and round pointed pencil make a short straight stroke, not a dot, at the scale division and perpendicular to the edge, a length, say, of $^1/_{32}$ of an inch. Transfer measurements with the scale itself where possible, not with the dividers or compass, that is, indicate the size by scale measurement then set the compass to the marks made if it is necessary to strike an arc of that radius. It is a common fault and has been even advocated in books on drawing that the compass or dividers be set to size directly by holding to the scale edge. It is very undesirable in several ways and should be studiously avoided.

It leads to economy of time, and certainly to greater accuracy, if the scale is used in place of the dividers. And again, what is very important, where possible, successive measurements should be laid off with one setting of the scale, for in this way any error in one measurement will not be communicated to all the others as it would if the scale were reset after each measurement.

The problems arising in the use of the architect's or mechanical engineer's scale group themselves under three heads. (1). To make a drawing a given fraction of the original in size. (2). Given the scale used to determine the fraction of size which the drawing is of the original. (3). Given the size of the space in which a drawing must be made to fit, to determine the scale to be used to get this reduction from the original.

(1). To illustrate: Suppose it is desired to make a drawing one quarter the size of the original; $\frac{1}{4} \times 12 = 3$; therefore 3 inches is the scale or size per foot to be used.

(2). To illustrate: Suppose a drawing is made to a scale of one quarter of an inch to the foot, then, as $\frac{1}{4} : 12$ so the drawing is to the original or $^1/_{48}$ the size.

(3). In solving this problem the fraction of size must first be determined by getting the ratio of the size of the drawing to the size of the original. This fraction of 12 inches will give the scale to be used. To illustrate: Suppose a subject 3 feet long is to be reduced in drawing to $1\frac{1}{2}$ inches, the length being the determining dimension, then $1\frac{1}{2}: 36\times 12=\frac{1}{2}$, or the scale is $\frac{1}{2}$ inch to the foot.

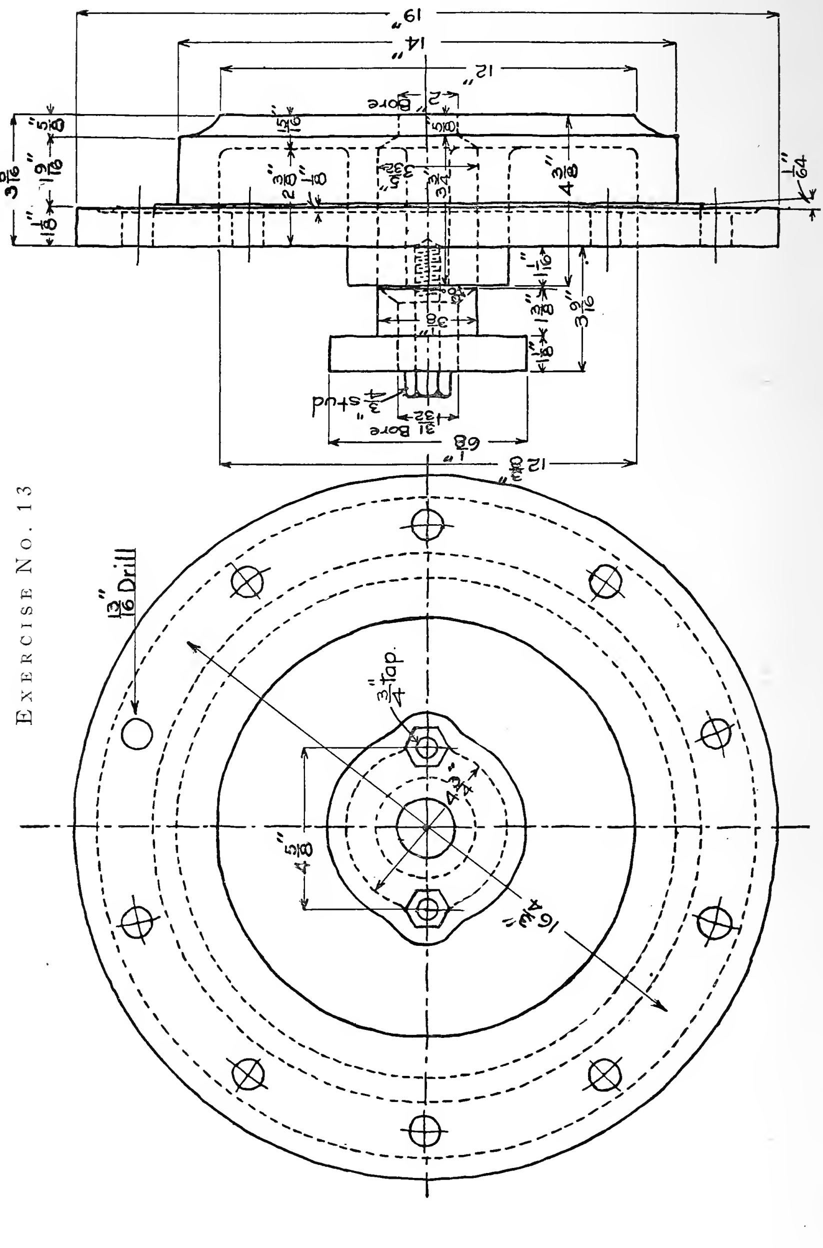
When problems do not come out as even as these, the nearest available scale is taken.

A very common error arises from mixing up scale with fraction. A quarter scale drawing means a drawing made $\frac{1}{4}$ inch to one foot, while a $\frac{1}{4}$ size drawing means a drawing made 3 inches to a foot. In other words when we speak of a fractional size we do not mean that fraction as the scale but that fraction of 12 inches, the foot being the unit.

There is a special and popular form of scale made for mechanical engineering work which differs in divisions from the ordinary scale. The inch and not the foot is made the unit for subdivisions. The scales shown are for half size, quarter size and eighth size. The half size, for example, has a half inch divided again into halves, quarters and eighths, to represent those fractions respectively of an inch.

It now and then happens that a purely arbitrary and exact scale is required, and has to be constructed. It can be readily done by a method based upon the geometrical principle that lines parallel to one side of a triangle divide the adjacent sides into proportional parts (see Fig. 11).

The civil engineer's or decimated scale is mainly a scale for use when the reduction is relatively large so that from 10 to 100 feet will be represented by an inch, for it has divisions of 10ths, 20ths, 30ths, 40ths, and 50ths, of an inch. It can also be used in the same way as the mechanical engineer's scale. To illustrate: The twentieths scale can be used for $\frac{1}{4}$ inch to the foot, five divisions being equivalent to one foot, two and one-half to 6 inches, etc. The thirtieths can be used for six inches to the foot, five divisions then



EXERCISE NO. 13

equalling one inch. By thus assigning arbitrary values to the divisions, any ordinary mechanical engineer's requirements can be fulfilled with the trouble only of interpolation for some of the smaller measurements.

23. Exercise No. 13. Sectioning.

Make a sectional elevation complete of the cylinder head. Show the stuffing box gland as just about to enter the head. Show the one stud bolt in place beyond the plane of the section. Draw section lines a little over $^1/_{32}$ of an inch apart.

NOTE: This may be done in pencil only or inked as directed.

24. Exercise No. 14. Sectioning.

(a). Make a longitudinal section of the outboard bearing for a heavy duty engine as shown, and through the center. Show a few principal dimensions only, overalls, diameters, distances between centers, etc.

(b). Make a longitudinal section of the outboard bearing for a heavy duty engine as shown, and through the bolt holes of the sole plate. Show a few principal dimensions only, overall, diameters, distances between centers, etc.

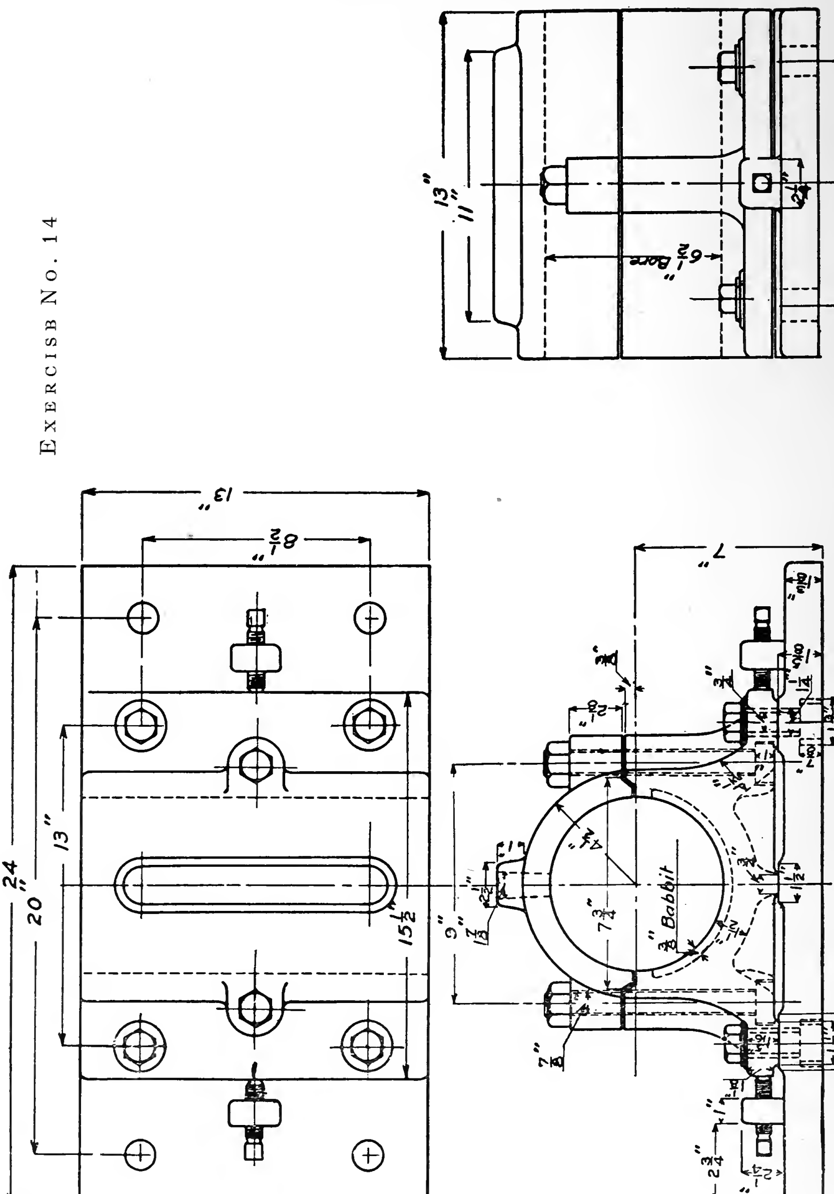
NOTE: These two exercises may be done in pencil only or inked as may be directed.

25. Exercise No. 15. Sectioning.

Make a longitudinal section through the bench vise in the drawing room, taking it through the middle of the jaw.

Show only a few of the principal dimensions.

Exercisb No. 14



NOTE: The same general type of vise is shown in the Scranton Correspondence series on mechanical drawing.

This may be done in pencil only, or inked as directed.

26. Exercise No. 16. Sectioning.

Make a longitudinal section through the center of the expansion joint, an example of which is to be found in the drawing room. Show only a few of the principal dimensions, the diameters, lengths of the parts, &c.

NOTE: This may be done in pencil only or inked as directed.

CHAPTER III.

IRREGULAR CURVES AND GEOMETRICAL DRAWING.

27. Irregular curves.

Irregular curves are those which cannot be drawn with the compass,they include the 2nd and 3rd degree curves and the higher plane curves. They must be plotted by points and then drawn through these points; the larger the number of points taken, the more accurate the data for the curve. But at least the drawing of them can only be approximate. Points should be plotted closer together in proportion to the sharpness of the curve or to its rate of change of curvature. The points are connected by use of a curved ruler. To use it requires considerable practice and knowledge of handling.

If the hand and eye are true enough, the curve may be drawn most advantageously, after plotting points, first free-hand in pencil, then interpreted in ink. The value of free-hand treatment lies in the rapidity with which an accurate result may be obtained. The eye can be depended upon to detect small inaccuracies; it is a most true instrument. To accomplish the free-hand treatment skillfully, the same methods should be used as those in any other free-hand drawing. Since these may not be well in hand, a few words of direction will be given.

Swing the hand in the direction of the curve and through as many points as possible; when the motion seems to be true for recording the line, make a very light, fine and short stroke through each of the plotted points, giving a suggestion of the direction of the curve; next, if these records look right, put in similar short strokes between the plotted points, obtaining a still more complete suggestion. If the points plotted are fairly close, this suggestion ought to be complete enough to make refinement of the whole curve possible, erasing and truing here and there as needed until it satisfies the eye. When it does this it may be depended upon sufficiently to copy in ink. As before remarked, the eye can be depended upon to detect small inaccuracies better than the instruments.

Of course the above directions are not necessary if the points are fairly close together and the draftsman has sufficient skill to handle the ink line directly with the ruler.

The correct shape for a curved ruler is of importance. There are many curves made that are of very little value, these are the ones which have the maximum of different curves included in the one tool. The curves of value are the ones which have the fewest and simplest curves in one tool. The best type probably for general all around use, is a curve which is uniformly spiral in its characteristics, that is, goes from a relatively sharp curvature to a gradual one, possibly very near a straight line. The curve is applied to the points plotted with the direction of the change of curvature the same in both. It cannot be used successfully, for example, in a case where the curve to be drawn becomes more gradual towards the right, and that of the curved ruler, incorrectly placed, grows more gradual towards the left. Hence a curve ruler that has a double spiral, where the region of change from the one spiral to the other is concealed, will give trouble in matching.

A rule having many different curves will be one scrolled out in the interior, and it is made of more or less fanciful shapes. But the curves in the interior are not valuable because of the difficulty of raising the rule from the wet line without blotting, for in order to remove either a curved or a straight ruler from a line drawn, it should be slid along free of the line first and then lifted.

Any curved ruler can be used to make any curve; a straight edge can even be used to draw any curve by making a large enough number of adjustments, but the ideal condition is, of course, realized when the maximum of the curved ruler will match the curve. Frequency of adjustments in using the ordinary curve is no perceptible drawback to an experienced draftsman beyond the time consumed in making them, any more, in fact, than the effort involved in moving the T sq. up and down, or adjusting a straight edge to successive straight lines.

It is not necessary for a draftsman to have many different curves in his kit. Constant familiarity with a few curves will compensate for the time taken to adapt himself to one with which he is not familiar, but which more closely approximates the curve to be drawn. A thoroughly equipped drafting room, where there are many men working, is likely to be stocked with curves for specific purposes, like railroad curves, ship curves, ellipses, parabolas, etc., whichever are frequently needed.

The drawn curve should be as unbroken as the theoretical curve, and it is the execution of this which is difficult for the beginner. It involves two problems: (a) To match the curves; (b) to conceal the successive segments of the line.

To insure matching the curves, apply the rule to at least three points, more if possible, then draw, not as far as the ruler seems to match the curve, but a little short of it, the amount depending upon how rapidly the ruler departs from the curve to be drawn at the last discernable point. Again, in moving to the next segment, match the ruler to the part already drawn so that it corresponds with it for an appreciable distance back of the last point drawn to.

To connect the segments of the line accurately, handle the pen as previously described for section lining, head the pen first to make a perfect alignment, then start to move on the line, or if drawing up to a line, and just before reaching it, tilt the pen, if necessary, to bring it into the ink line correctly, but do not overlap. It is handier, whenever possible, to draw from, not to, a line, and in this case make the new line just touch the one already drawn, not overlap it, as in so doing the wet line is apt to spread and show the joint.

It is necessary, in using the pen with the curved ruler, to acquire an adjustable handling so that the blades of the pen are at all times tangent to the ruling edge; it involves holding loosely, so the pen can roll between the fingers. At the same time it is desirable not to work on the under side of the rule. Instead of this, either turn the drawing around or use a part of the ruler which will fit it and present an upper edge for lining. A form of pen, before mentioned, is made which adapts itself automatically to the ruling edge, known as a follower pen; it is swiveled into the handle.

Economy of time can be effected by duplicating curves. If a curve is composed of units of similar parts, the rule may be marked on its surface with a pen or pencil, noting where the unit begins and stops, and some other reference point or two to aid in setting the ruler in place. This applies to symmetrical curves like the parabola, hyperbola and ellipse.

In symmetrical curves, care should be observed to match with the ruler for an appreciable distance beyond the axis of symmetry, but also to draw only to the axis.

28. System in penciling and inking drawings.

Successful work of any kind will proceed in a systematic and orderly manner. The workman, through experience, will adopt the shortest and most accurate ways, his most valuable qualifications being accuracy, neatness and speed.

A system in penciling cannot be followed to advantage entirely, because the conditions in the development of a drawing vary quite a little, nevertheless, a general plan can be followed where circumstances permit. The following is given as such a system:*

SYSTEM IN PENCILING.

1. Draw border lines.

2. Draw match lines to guide in replacing the drawing if it is temporarily removed.

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* Cooledge & Freeman, Mechanical Drawing.

3. Block out space for title.

4. Block out space for bill of materials, if any.

5. Block out the views to be placed upon the sheet.

6. Draw main center lines, and where these are to be inked, they may be drawn full light lines.

7. Locate main lines of views.

8. Draw small and inside lines.

9. Put in dimensions and necessary notes.

In inking a drawing there are two imperative conditions determining the most economical way of working: First, delays which are likely to occur in waiting for ink to dry; second, omissions likely to occur in things which should be lined in. Draftsmen are not uniform in their systems, but each one has that which to him seems to commend itself to avoid the difficulties above mentioned. There is, however, a general plan followed by all, and it is the purpose to discuss this general plan in detail.

The following is an order of inking which may be safely adopted and depended upon to fulfill all general requirements:

SYSTEM IN INKING.

1. Ink all small circles and arcs of circles with the bow pen.
2. Ink larger circles and arcs with the compass.
3. Ink irregular curves with the curved ruler.
4. Ink all horizontal lines with the T sq.
5. Ink all vertical lines with the triangle resting on the T sq. edge.
6. Ink all 45°, 30° and 60° lines in groups and in order.

7. Ink other oblique lines not at the above angles, also in groups and in order.
8. Do the section lining.
9. Do the dimensioning.
10. Do the surface tinting and shading.
11. Put in the lettering and descriptive matter.

In large, complicated drawings it may be found quite an arduous task to put in any one of the first seven directions throughout a sheet of drawings, hence it may be well to treat a restricted area, one figure or a group of figures on the sheet, then the next group with the same treatment, and so on until the entire sheet is completed under one heading at a time. Under no circumstances should one figure, or part of a sheet, be completed in every detail before the rest of the sheet is carried through the same stages. This is a fault very apt to be indulged in by the beginner.

Such a series of directions is exceedingly important to follow, and an unconscious adherence to them should be cultivated very early. That the importance may be more fully grasped, an explanation is here offered in detail of the main reasons for undertaking each stage in the order named.

First, in general, it is well to do with a tool all that it is possible to do while having it in hand; changing tools takes time, besides this, the eye and hand become increasingly adapt with use of a tool in performing a certain set operation, and from minute to minute it is found there is perceptible change in facility. Again, in working through one operation at a time there is more certainty that the entire subject will be uniformly treated, and no similar operation on any part of the drawing be omitted.

The bow pen, of course, is limited in range. In taking the small circles first, there is more certainty of doing all that the bows will do than if the compass is used. And, of course, in general, the value of doing curves first at all, is that it is easier to make a straight line tangent to a curve than it is of drawing the curve tangent to the straight line. For a similar reason, the irregular curves are drawn after the compass curves, the latter are, in general, more in evidence, consequently more of them to hunt for on a drawing.

Horizontal and vertical lines, as the enclosing lines of rectangular forms, also are most in evidence, and should be drawn among the first of the straight lines. It is well, if possible, to rule everything in the path of the T sq., as it is moved from the upper to the lower part of the sheet; but where a drawing is much broken up, it may be well to draw the long lines first, then the shorter, or else restrict the work to a certain area, or to one or more figures at a time, as before mentioned; or still further even, to divide the dotted and the center lines from the solid. Some authorities advocate the location of center lines the very first thing—it certainly has arguments in its favor. They are dependable land marks which control the correctness of everything else. But however the tool is handled in this respect, care should be taken to see that no lines it would make are omitted from the series; they should be carefully checked before the next tool is taken in hand. For similar reasons the remaining straight lines are divided into groups.

Section lining and dimensioning may conveniently change places in the series; they are given in the order named because the section lining concerns the construction, and theoretically, construction should be complete before any dimensions are put on. The advantage in making sectioning take second place, is that dimensions have sometimes to go across sectioned surfaces and determination of their place first, provides for their not being interfered with by the section lines.

Dimensioning, itself, being one of the most important divisions of a working drawing, is profitably capable of subdivision because it provides against errors and omissions. Occasionally it is not practicable or necessary to include dimensioning as part of the penciling or preliminary operations, so that both it and the inking of this stage go together. Hence, it may be considered a good plan to go over one figure at a time and record by arrow heads the radii or diameters, then the widths of everything needing specification, then the heights and the oblique dimensions. After these operations are completed upon all the figures, or on the whole drawing, the values of the dimensions, whose place has been determined, can be put down with less risk, that neither the dimensions required or their value will be slighted. In inking the dimensions a similar plan should be followed with this addition, that, when the values are put on with the writing pen, the arrow heads at the terminals of a dimension line should be drawn first. The ommission of limiting arrow heads is a very common source of trouble in dimensioning, so that if the habit is formed of always putting them in at first, one trouble will be overcome.

Surface tinting and shading, which are quite infrequent on working drawings, have reference only to pictorial or graphic interpretation, and should be performed separately as the very last of the operations. The tinting should precede the shading because it and the section lining, while elastic in their character, yet together control the amount, or rather the intensity of the shading. To illustrate: A drawing having much surface area broken up by tinting and sectioning will require a stronger treatment in the shading, that the latter may hold its place than it would were there little or none. It may be here remarked that there is much more possibility for pleasing effect and variety of treatment in a mechanical drawing than is generally supposed. A drawing looks well or it does not when the specific reasons are hard to assign; they may lie in this happy distribution of the masses of lines, somewhat as they do in a free-hand drawing.

The lettering and directions for manufacture, which are listed last, it hardly seems worth while to make comment upon. Their place in the list is a rational one, it not being possible to place them elsewhere with any good reason to support the change. It is always likely, too, that at the last a need may be seen for some fuller explanation of construction.

29. Geometrical drawing.

Use all the mechanical aids that are available to get constructive results in a drawing, provided the processes do not involve too great an expenditure of time. For geometrical processes more frequently by their very multiplicity of steps, open the way for errors, and are practically more likely to result in faulty construction than if mechanical aids were used. But there are a few fundamental processes which every draftsman ought to know well, and there are some mechanical equivalents, also. As for the many geometrical constructions of a more or less simple form, the student is recommended to consult the various hand books.

Parallel lines are more easily obtained by mechanical methods. The T sq. and also the T sq. and triangles taken together, show the simplest cases. For others use either a straight edge and triangle, or two triangles. Place an edge of the triangle to the given line, and the straight edge or the other triangle against either of the other edges. The first triangle moved in either direction will present parallel sides. This is a common expedient for making a drawing when a T sq. is not handy.

Perpendiculars and verticals mean two different things. Perpendicular is a relative term and means that one line is at 90° to the other, or normal, no matter what the direction of either line. Vertical, in a drawing, means a line which is perpendicular to a horizontal one only. In space it is a normal to a horizontal plane, or in other words, to the earth's surface. This distinction should be borne in mind at all times, and neither the terms or the meaning mixed.

Perpendiculars can be made most readily with the triangles and T sq. or straight edge. To draw a perpendicular to a given line, place the straight edge parallel to and at a short distance from the latter; for vertical perpendiculars this can be very easily done with the T sq. In the case of oblique lines, place one triangle against the given line and move it against the other triangle, as for parallel lines, until it is a short distance away, then use the second triangle against the first so that the perpendicular drawn can be made to intersect and cross the first, if necessary.

It is a fault all too common to draw the perpendicular when the first triangle is in contact with the given line. It is not an accurate process, for in the first place it is difficult to set the triangle exactly to the point at which the perpendicular is to be drawn, and in the second place it is not easy to draw the perpendicular down to the first line to touch it; with triangles in which the angles are at all worn, it is next to impossible. A facility in the use of the triangles for these processes is eminently desirable, for the latter one is almost continuously encountered. Sharp angles, where angles are constructed, is imperative in first class work.

Right angles can be divided readily into halves and thirds by means of the 45° and 30° and 60° triangles, either with the assistance of a T sq., or without, by the process just described for perpendiculars and verticals. Hence a circle can be divided into four, eight, or twelve parts, and by bisecting one angle a new base can be obtained for halving all the angles and doubling the number of the above mentioned divisions, for, put a straight edge parallel to this bisector and the triangle can be used as before.

Similar triangles and equal angles may be constructed by the methods given for parallel lines; although if the two equalities are far apart, geometrical process may be found preferable, namely, transfer of measurement by compass.

If a line to be drawn is longer than the edge of the triangle being used, the latter may be extended to continue the line by first moving its edge along parallel to the line, using the other triangle against the parallel edge.

The lengths of the edges of the equal triangle should be transferred preferably by the scale rather than the compass, when possible, as it is more apt to be accurate. The use of the measurement a second time, that is to be transferred from the first triangle to the second, acts as a check upon the size of the first. Whenever processes are gone over twice a check is effected on the work.

Tangency in geometry means identity of direction. Two curves are tangent to each other at a given point when they have the same direction at the point. The same direction also means that the common tangent to the curves is a normal to the radius of curvature of each at the point of tangency.

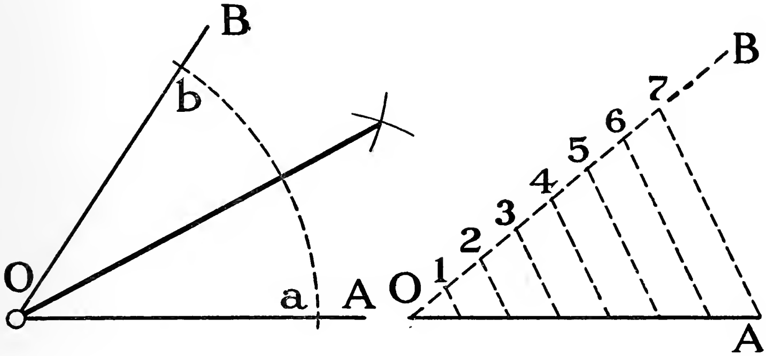
Since in geometry lines have no thickness, it follows that two lines in a drawing that are to be tangent to each other should be made not osculating lines, but identical, that is, the thickness of the lines at the point of tangency should be that of the thickest line only which is used. Osculating means, of course, touching. If this included tangency, it would mean that where a number of curves were tangent at a common point, the thickness of the lines at the tangent point would assume very disagreeable, and perhaps, impossible proportions.

To bisect any angle, as AOB, see Fig. 11. Lay off on its sides any equal distances Oa, Ob from O as a center. Use a and b as centers for intersecting arcs having a common radius, but such, practically, that the arcs intersect normally. Connect the point of this intersection with O, and it will be the bisector.

To draw a circle through three points, as a, b and c: Join the points by lines a—b and b—c; bisect these lines by perpendiculars, and the intersection of the latter will be the center of the desired circle.

To divide a line into any number of equal parts, see Fig. 11. From one extremity of the line OA, as O, draw a line OB making any angle with OA. With the scale, or dividers, lay off any convenient unit from O on OB, as many times as parts into which it is desired to divide OA. Connect the last division with A, as 7A. Then draw lines through the other divisions parallel to 7A; they will divide OA into parts proportional to those on OB. It is based upon the geometrical principle that parallels to one side of a triangle divide the remaining sides proportionally. In practice, this has a

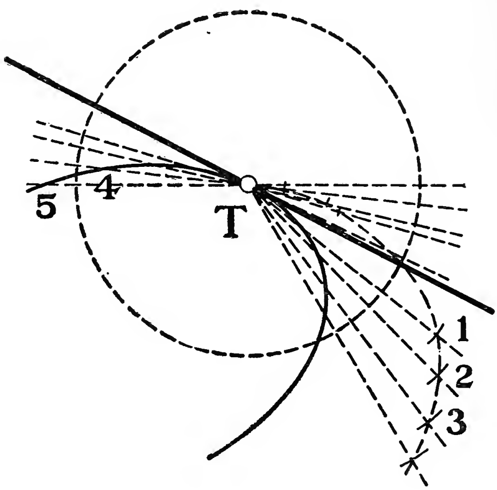
Fig. 11



very ready application. To illustrate: If the distance between two parallel lines is to be divided into equal parts, in order that a number of parallels may be drawn to the first pair of lines, and they lie either horizontal or vertical, take the scale with any convenient unit, swing it so it touches both parallels with the number of parts enclosed between its limits, then locate these parts, and use the triangles, or T sq., to draw the parallels. It is a process very easily accomplished.

To draw a tangent to an irregular curve from a point without, see Fig. 12: Through T, the point of the desired tangent, draw random secants through points on the curve as 1, 2, 3, 4, 5, etc. With T as a center, and any radius, describe an arc to cut the secants prolonged. On each secant lay off, from its intersection with the circle a distance equal to the chord length of the secant within the irregular curve, and measuring on the same side of the cricle as the secant with respect to the point T. Draw a curve through

FIG. 12

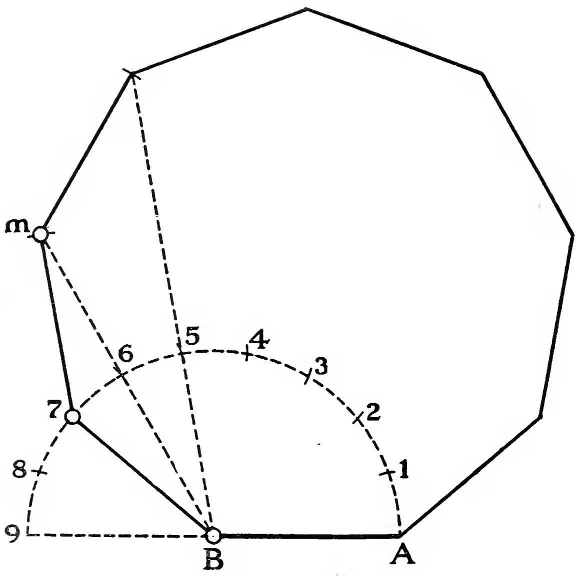


these points. Where this curve cuts the auxiliary circle, is a point in the tangent. For the tangent the chord length will be its minimum value.

To inscribe a circle in any triangle: Bisect any two of the interior angles. The intersection of these bisecters will be the center, and its perpendicular distance from any side will be the radius of the required circle.

To construct a regular polygon of any number of sides, the length of a side being given: Let AB, Fig. 13, be the length of a side, and let the polygon consist of x = 9 sides. With AB as a radius, describe a semicircle and divide it into nine equal parts by cut, and try methods with the compass. Join B with x − 2, or division 7. Join B with 6, 5, 4, 3, etc., prolonging the radii. With 7 as a center and radius AB, cut

FIG. 13

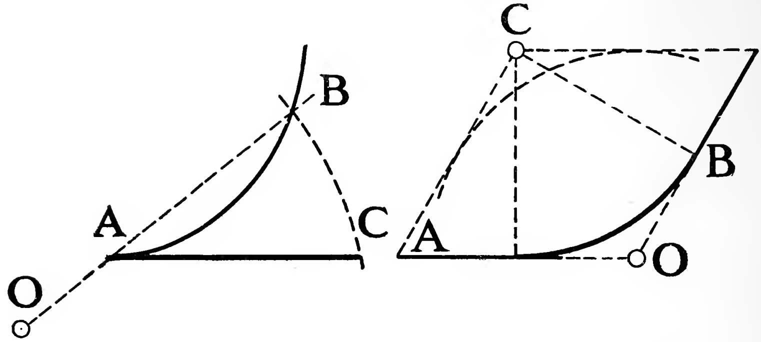


B − 6 prolonged at m, and join m with 7. Using m as a center and same radius, = BA, cut B − 5 prolonged in another vertex of the polygon, and so on.

This solution is based upon the principle that if a regular polygon has x sides, each interior angle $= \frac{180(x-2)}{x}$, and second, that the diagonals drawn from any vertex of a polygon make the same angles with each other as with the sides meeting at that vertex.

To rectify an arc, in other words, to lay off on a straight line the length of a given circular arc (see Fig. 14). Let BA equal the given arc. Prolong AB to O, making OA = AB ÷ 2. With radius OB draw an arc to cut a tangent to the curve at A in C. AC will be the required

FIG. 14



length. This is an approximation, and useful only for short arcs.

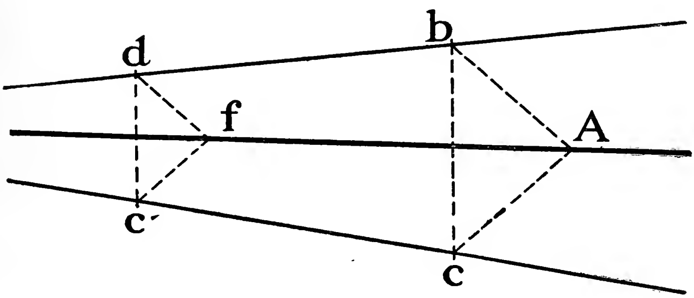
To draw an arc of given radius tangent to two given oblique lines (see Fig. 14): Prolong the given lines to meet at O. With O as a center, and the given radius, describe an arc AB. Parallels to the given lines, and drawn tangent to the arc AB, will meet at C, from which perpendiculars to the given lines give the points of tangency, C being the center of the arc.

Through a given point to draw a line to meet the inaccessible intersection of two given lines (see Fig. 15): Join A, the given point, with any points b and c on the respective lines. At any point on one of the given lines, as d, draw parallels to bc and bA, and from where the parallels to bc intersect the other line in c′, draw a parallel to cA. f, a vertex of the triangle formed, will be another point in the required line.

30. The conics.

The conic sections, or simply conics, as they are called, appear frequently in mechanics and machine construction. They are called conic sections, because they are the contour forms of plane sections of a cone of revolution. A cone of

FIG. 15

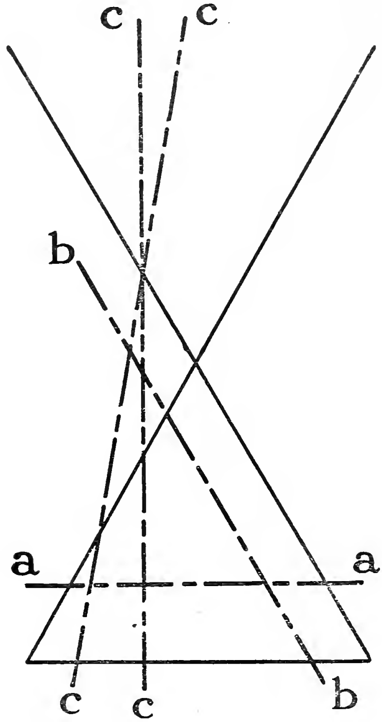


revolution is a cone formed by one line revolving about another, which it intersects, and with which it maintains a constant angle.

If such a cone (see Fig. 16) is cut by a plane perpendicular to the fixed line, or axis, as a—a, the shape of the sectional plane will be a circle. If the cone is cut by a plane parallel to any position of the moving line, as b—b, the shape of the section will be a parabola. If the cone is cut by a plane making a less angle with the axis than that of the revolving line, as c—c, the shape of the section will be a hyperbola. In any other position, the cutting plane would give an ellipse in section.

Ellipses, parabolas, and hyperbolas may be drawn in several different ways. A few of the more common and convenient will be given below:

FIG. 16

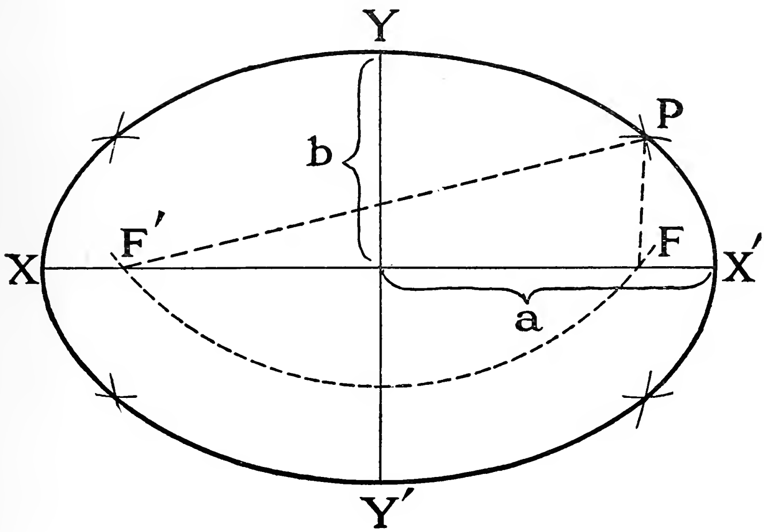


31. To draw an ellipse by the focii method.

To draw it by the principle, in other words, that the sum of the focal radii to any point on the curve is a constant (see Fig. 17). The constant is equal to 2a. The focal radii are F P and F′P, respectively.

When the major and minor axis are given, the focii may be obtained as follows: With a radius equal to the semi-major axis, and a center at either extremity of the minor axis, describe arcs to cut the major axis in points which will be the focii, for FY plus YF′ = 2a. To find any point on the curve, as P, take any radius not less than XF or X′F′, and with center at F, describe an arc of a circle;

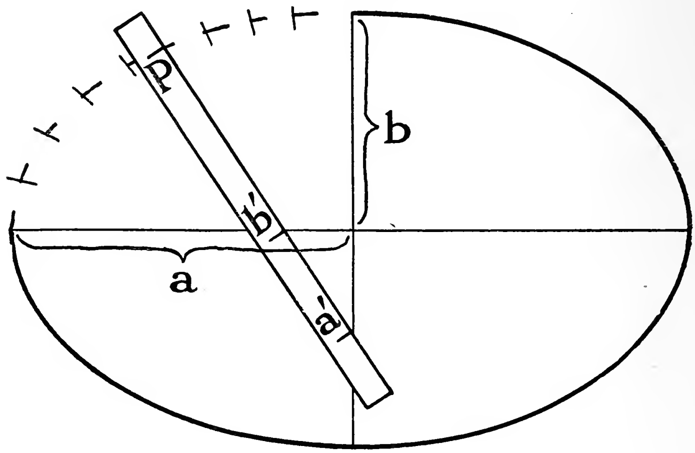
Fig. 17



with a radius equal to the difference between 2a, and the radius just taken, and a center at F′, describe an arc to intersect the first one at P, which will be a point on the curve. There are three other points on the curve in addition to P which are symmetrical with respect to the axis, hence the practical method of procedure is to arbitrarily divide the major axis between the focus and the center of the ellipse into several parts, each to give two radii for four symmetrical points on the curve. With each radius taken the four symmetrical points are obtained by striking arcs from both focii above and below the major axis.

For careful drawing, more points will have to be plotted in the neighborhood of the major axis, than in that of the minor. It is well to find a group of symmetrical points, as just described, complete, before proceeding with any con-

FIG. 18

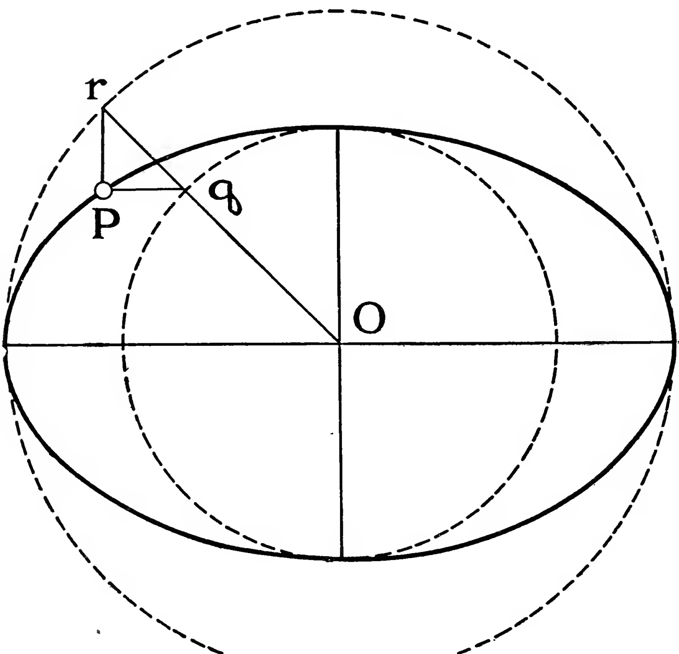


struction for other points. Otherwise, there are apt to be errors in intersecting arcs.

32. To construct an ellipse by the method of the trammel.

The trammel is an instrument for mechanically constructing an ellipse, not very successful practically, because of its lack of adaptability and its cumbersomeness, as well as large cost. It consists, fundamentally, of two tracks or guides at right angles to each other, and which constitute the major and minor axes. A third member, an arm, carries a marking point while two wheels, or lugs, fastened to it rigidly, move in the grooves in the first two members, and hence constrain the moving arm so that its marking point goes in the path of an ellipse. The operation can be more

FIG. 19



readily seen after a description of its practical equivalent (see Fig. 18).

Take a piece of paper as a straight edge, and mark on it a point P. From P lay off a distance, Pa′, equal to a, and also a distance, Pb′, equal to b. Then with b′ touching the major axis, and a′ the minor axis, P will be a point upon the curve. To plot points then, move the straight edge around into as many positions as desired, and for each point plotted, indicate its place by a short stroke along the straight edge, and one perpendicular to it at P. This kind of stroke will identify the points most successfully. This method of plotting an ellipse is an excellent one, because of the ease with which the points can be located, and the ease, also, with which they can be placed where wanted.

33. To draw an ellipse by the aid of the major and minor auxiliary circles. (See Fig. 19.)

Draw the circles, as shown in the figure, upon the major and minor axis, respectively, as diameters. Draw any radius to cut the auxiliary circles in q and r, respectively. Through r draw a line parallel to the minor axis, and through q draw one parallel to the major axis. These lines will intersect in a point, P, on the curve. The points may be plotted, similarly, in all quadrants, or else in one and transferred by measurement to the others.

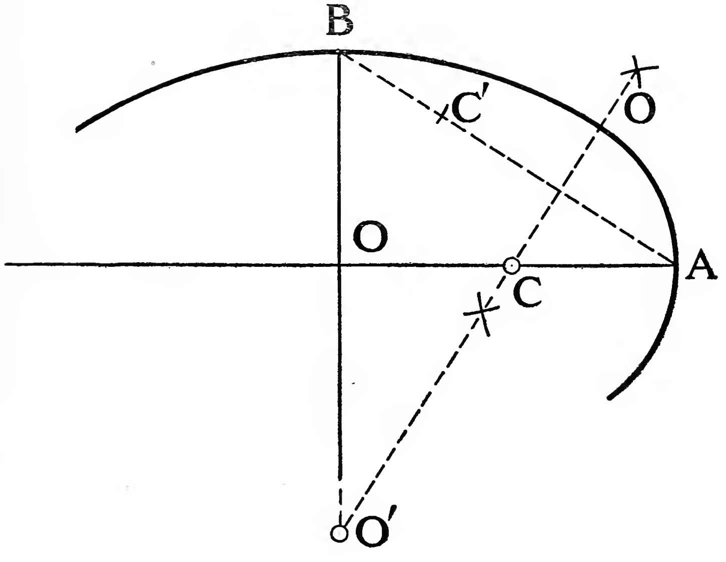
34 To draw an ellipse approximately with the compass. (See Fig. 20.)

This is the method the mechanical draftsman will always use, where possible, and it is a very good substitute. There are two ways, the following being the more common:

Draw the minor auxiliary circle—it will cut the major axis in C. Connect B and A. Lay off on BA from B, the distance BC′, = AC. Next, bisect the line, C′A, and prolong the bisector, O O′, to meet BO′ prolonged in O′. O′ will be the center for an arc of a circle passing through B, which will approximate the ellipse.

From the point in which this arc touches the bisector, O′O, draw an arc of another circle, passing through A, which has its center where the bisector cuts the major axis. To complete the curve, another center may be found on the other side of the major axis, and symmetrical with O′, and

FIG. 20



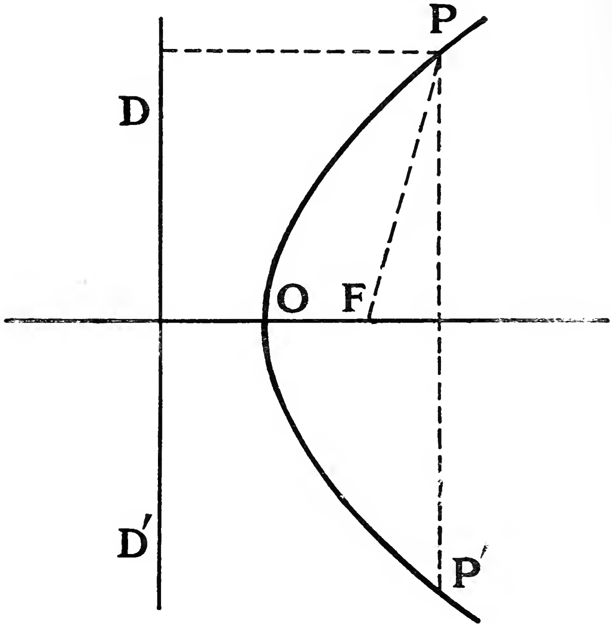
one on the other side of the minor axis, symmetrical with the center C for the arc which goes through A.

This is a method of drawing an ellipse, which, of course, more closely simulates the true curve, the nearer the ratio of the two axes is equal to one. But, in any case, it can easily be detected as composed of compass curves.

The other method of approximation, seldom used, however, uses three centers for each quadrant, instead of two, but it is more or less cumbersome, and if a closer approximation than the above is desired, a cut and try process for the centers is economical of effort and time.

If one has any facility in free-hand work, it is recommended that a quadrant be sketched in roughly, and then

FIG. 21



copied as closely as possible with arcs, and using as many centers as needed for the purpose. The ellipse will not be as true as if plotted by points, but it will be a smooth curve and make a better general appearance than if constructed as first directed. In following this method remember that *tangent circles, or regular curves have a common radius at the point of tangency.*

35. To draw a parabola by means of the focus.

First, a parabola is defined in mathematics, as the locus of a point which moves, so that its distance from a fixed point, called the focus, is equal to its distance from a fixed line, called the directrix.

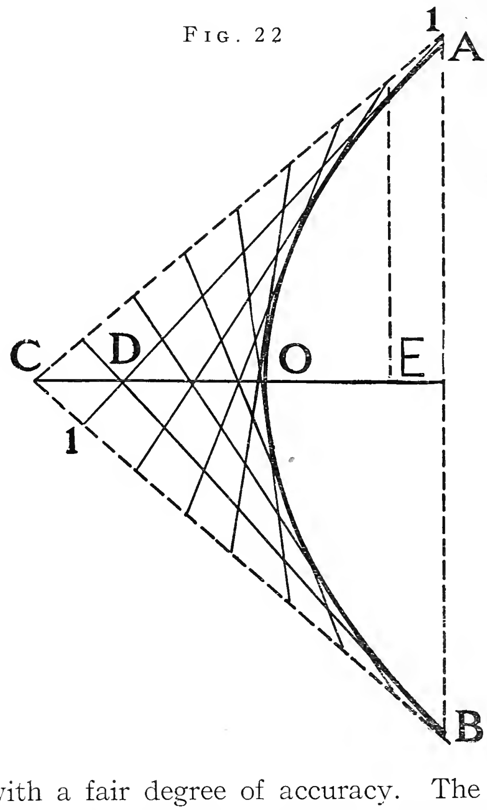
Let D D′ (Fig. 21) be the directrix, and O F at right angles to it, the axis. Let F be the focus. Since the distance of F from any point on the curve is equal to the distance of that point from the directrix, to find any point on the curve as P, draw a line parallel to D D′ at any chosen distance from it. Then with this same distance as a radius, and F as a center, describe an arc to cut the parallel in the point, P. Two such points, P and P′, will be found symmetrical with the axis. One point must lie on the axis half way between the focus and directrix, namely, O, which is called the vertex. The entire curve is symmetrical on its axis.

To plot a large number of points, for a good, smooth curve, divide the axis, arbitrarily, into a number of points starting at the vertex. Through these draw parallels to the directrix. Then with radii equal to these distances from the directrix, respectively, describe arcs from the focus as a center to cut the parallels in points.

36. To draw a parabola by means of its envelope. (See Fig. 22.)

If the approximate spread of the parabola as AB, together with the axis and approximate vertex, O, are known, the method is as follows: Prolong the axis and make the distance from O to C equal the distance from O to the line, AB. Divide the lines, AC and CB, into the same number of equal parts, and connect them oppositely as shown. The parabola will be tangent to these lines, and if a considerable number are drawn, the parabola may be

FIG. 22



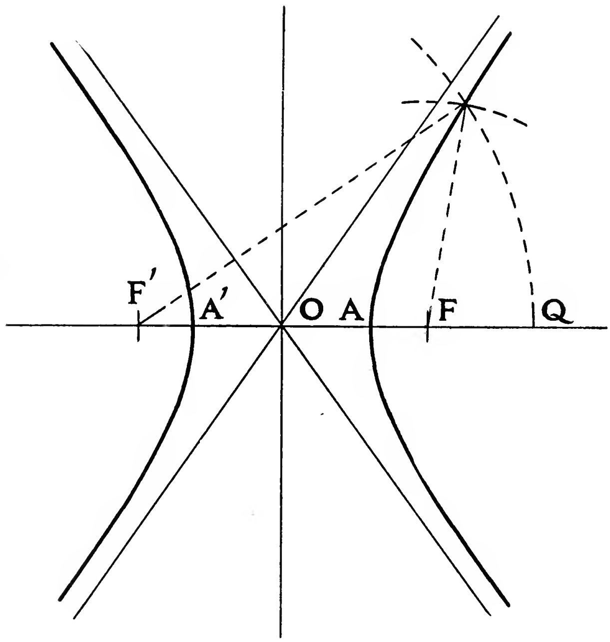
obtained with a fair degree of accuracy. The curve does not exactly go through the points, A and B, although very nearly.

To find the point of tangency, of the curve with any one of the lines, say 1–1, lay off a distance on the axis, OE, equal to OD. At E erect a perpendicular to cut 1–1 in the point of tangency.

37. To draw a hyperbola by means of its focii.

First, a hyperbola is defined in mathematics as the locus of a point which moves so that the ratio of its distance from a fixed point called the focus, to its distance from a

FIG. 23



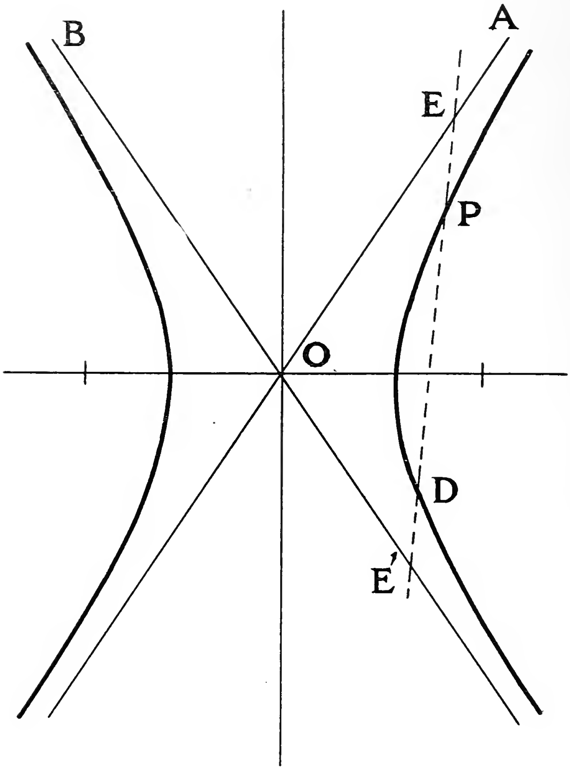
fixed line, called the directrix, is a constant and greater than unity (see Fig. 23).

We shall work the problem, however, by the principle that the difference between the focal radii to any point on the curve is a constant. Let F F′ be the focii, and O the center. Assume the vertices of the curve, A A′, at equal distances from O. A A′ will also be the constant difference.

(8)

Take any point on the axis a distance from F′ greater than F′A as F′Q, and with F′ as a center describe an arc; then, substracting the constant, A—A′, from F′Q, take the

FIG. 24



remainder as a radius, and F as a center, describe an arc to cut the first one in points of the curve above and below the axis.

Now, for a simple illustration, consider that hyperbola, which is formed by a section of the cone parallel to the axis, it can be easily seen that if these two elements of the surface (positions of the moving line), which are parallel to the plane of the section, were projected on the plane of the section, the curve would approach, but never touch them. These two elements are known as the asymptotes of the curve.

38. To draw a hyperbola, given the two asymptotes and any point on the curve. (See Fig. 24.)

This depends upon the geometrical property of the hyperbola that the intercepts on any chord of the curve, between the curve and the asymptotes, are equal.

Let AO and OB be the two asymptotes, and P the given point. Through P draw any chord, PE, lay off the distance, DE, equal to PE′, then D will be a point on the curve. By drawing any other chords through P or D and subsequent point found, as many points may be obtained as necessary with which to draw the curve. But while this is true, geometrically, it is not a very convenient method practically.

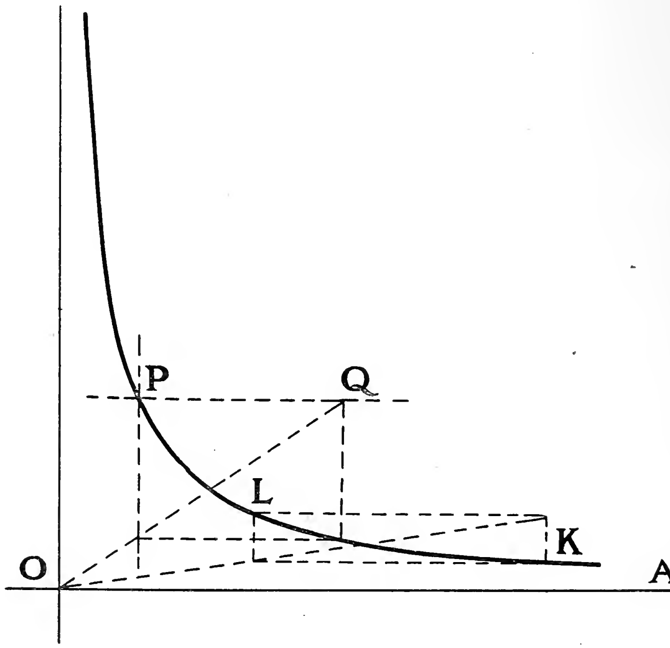
39. To draw a hyperbola by the rectangle method.

This is a method which is associated with certain properties of steam, when its performance in an engine cylinder is plotted in a curve (see Fig. 25).

Let AO and OB be two reference lines at right angles to each other, and let P be a point of the curve. Through P draw lines parallel to OA and OB, respectively; also, draw any line, OQ. From the points in which the line, OQ, cuts the parallels through P to OA and OB, respectively, erect perpendiculars, and these will intersect in a point on the curve, and so for as many points desired.

To find the point, O, given any two points, as K and L, on the curve and one of the reference lines: Draw a parallelogram upon K and L as vertices similar to the one erected at P. A diagonal of the parallelogram will cut the given

FIG. 25



reference lines in the point, O. The latter construction is in common use when applying the hyperbola to indicator cards of engines.

40. The cycloid.

The cycloids belong to a class of curves otherwise known as roulettes. A roulette is the path traced by a point upon a curve which rolls upon another curve, the latter being fixed. The rolling curve is the generatrix, and that upon which it rolls is called the directrix. A cycloid may be described as a curve traced by a point upon a circle, which rolls on a straight line or another circle; although the cycloid, proper, is understood to be that curve traced by a point upon a circle which rolls upon a straight line, and the distinguishing terms, epicycloid and hypocycloid, are used to mean the path of a point upon a circle which rolls upon the outside and the inside of another circle, respectively.

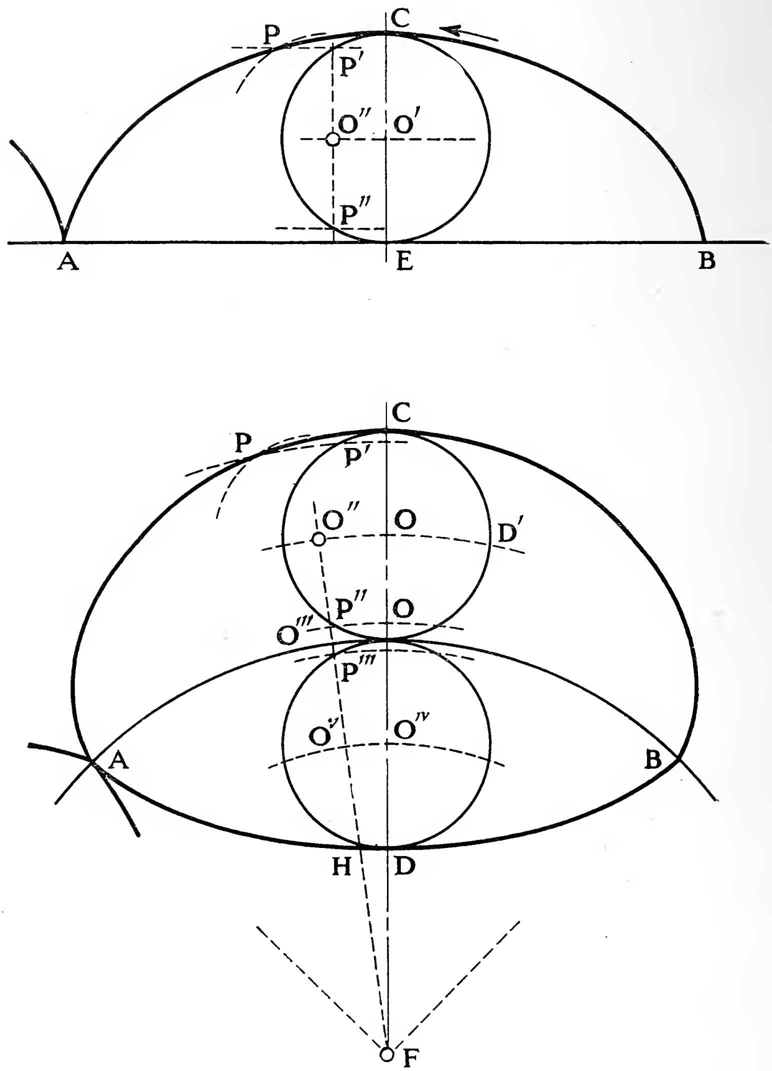
The cycloidal curves are those used extensively for the outlines of gear teeth, and every draftsman should at least be familiar in the beginning with their construction. The aim in the construction of gear teeth is to get rolling contact.

41. To construct the cycloid. (See Fig. 26.)

Let AB be the fixed line upon which the circle, EDC, rolls. Suppose this circle to move in the direction of the arrow. When the circumference has rolled a given fraction of its length upon the line, AB, the center, O′, will have moved a linear distance equal to this, or to O″, that is, O′ O″ = CP′ = EP″. The point, P″, will lie on the directrix and the point, C, will have moved the distance towards the directrix that P′ is from it originally. Hence draw a line parallel to the directrix through P′, and with O″ as a center and radius equal to the given circle, describe an arc to cut this parallel in the point, P, which will be a point of the curve. Repeat this process for as many points as desired.

The curve is symmetrical upon the vertical line, EC. The tangent to the curve at C is parallel to the directrix. The

FIG. 26



tangent at A is perpendicular to the directrix. If the circle continued to roll on AB it would generate another loop, and the point, A, would be a cusp of the curve. In gear design, only a small portion of the curve, in the neighborhood of A or B, would be used for the line of the tooth.

42. To draw the epicycloid. (See Fig. 26.)

The epicycloid, and also the hypocycloid, are the more common curves for gear teeth; the cycloid is limited to the teeth on a rack. The directrix is a circle, AOB, whose center is at F. When the circle, ODC, has rolled through a given circumferential length upon the directrix, O—O‴, the center will have traveled a greater distance, proportional to its distance from the center, F, or O′—O″. Assume the circumferential length to be one-twelfth, the point, P″ will have come down to the directrix, and C will have come nearer the center, F, by as much as P″ moved toward it, or to the position of P′. Hence through P′ draw the arc of a circle with center at F, and an arc of the generating circle from O″ as a center. Where the two arcs cross, will be a point of the curve of the epicycloid.

The curve is symmetrical upon the line, F—O. The tangent to the curve at C is normal to the radius, FOC, and the tangent at A is normal to the directrix, or equal to the radius, FA.

43. To draw the hypocycloid. (See Fig. 26.)

The hypocycloid is similarly constructed to the epicycloid, the generatrix, or rolling circle, moving on the inside of the directrix. The epicycloid is the curve of the face, or upper half; the hypocycloid, the flank or lower half of the tooth outline. The center of the generating circle, it will be seen, travels through a shorter linear distance than the points on the circumference. When the circumference has rolled off a distance, O—O‴, the center will have traveled to O^V; the point, D, will have moved a distance farther from the center, F, equal to the distance of P‴ from the directrix. Hence with O^V as a center, strike an arc of the generating circle, and also draw an arc of a circle through H, whose center is at F. Where these two circles intersect will be a point of the curve. If the circumference of the generating circle will go an even number of times into that of the directrix, there will be that even number of loops, or cusps. If the generatrix does not go an even number of times into the directrix, then the cusps will not close entirely.

Both epicycloid and hypocycloid have a common tangent at the points, A and B, which tangent is a radius of the directrix.

44. Geometrical definitions, terms, etc.

Curves, in a mathematical sense, include straight lines as well as curves. A straight line is a curve of infinite radius.

A plane figure is a plane bounded on all sides by lines. If the lines are straight, the space which they contain is called a rectilinear figure, or polygon, and the sum of the bounding lines is the perimeter of the polygon.

Polygons are named according to the number of their sides as a triangle, quadrilateral, pentagon, hexagon; a heptagon, of seven sides; octagon, of eight; nonagon, or enneagon, of nine; decagon, of ten; undecagon, of eleven;

dodecagon, of twelve. Polygons are supposed to be regular unless otherwise stated.

A diameter of a polygon is any line drawn through the center of a figure, and terminated by the opposite boundaries.

The long diameter of a polygon is the diameter of its circumscribed circle. This is also called a diagonal.

The short diameter of a polygon is the diameter of its inscribed circle.

A polyhedron is a solid bounded entirely by planes.

There are only five regular polyhedrons, viz.:

The tetrahedron, bounded by four equilateral triangles.

The hexahedron, or cube, bounded by six equal squares.

The octahedron, bounded by eight equilateral triangles.

The dodecahedron, bounded by twelve equal pentagons.

The icosahedron, bounded by twenty equal equilateral triangles.

A prism is a polyhedron having two of its faces, called its ends or bases, parallel, and the rest parallelograms.

A parallelopiped is a prism whose bases are parallelograms.

The axis of a prism is a straight line joining the centers of its ends.

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

A right prism, or pyramid, has its axis at right angles to its base.

CHAPTER IV.

WORKING DRAWINGS.

45. The difference between 1st angle and 3rd angle projection.

By angle of projection is meant that diehedral angle between the two co-ordinate planes of projection in which an object is placed. For working drawings the choice, only, is open of either the first angle, or the third angle, for in either the second or the fourth, the plan is quite likely to fall behind or in front of the elevation. If the distances of the elevation and plan from the ground line are made to differ by a sufficient amount, this super-position can be avoided, but an equal difficulty is encountered in not being able to distinguish which is second angle, and which is fourth angle, for the relation of plan to elevation does not, of course, determine it.

Now, in the first angle projection, be it observed, that the object is projected upon the vertical plane from a center of projection, which may be assumed to be on the same side of the plane as the object. This is also true of the horizontal projection. To be consistent, an end view of the object should be that obtained by projecting it from a center on the same side of the plane as the object. For illustration: The view of the left hand end of an object would be placed on that plane which was to the right of the object, and the view of the right hand end would be projected upon the plane at the left. Now, if the same center is used, and an object be drawn in vertical projection in the third angle, it will be projected through the vertical plane, for the center is on the opposite side of the plane from the object. Therefore, to be consistent, the end view should be obtained by use of a center, which is upon the opposite side of the plane from the object. We see that if this is done, the view of the left hand end of an object will lie at the left, and that of the right hand end at the right.

It is manifestly convenient to have this latter condition of affairs in a working drawing, because it conduces to legibility, and (in fact) it has been quite universally adopted. Care should be taken by the beginner not to be thoughtless in the use of either angle at pleasure, and in not mixing the two up in a drawing.

Figures 27 and 28 show the first and third angle projection, respectively.

46. The helical curve and the screw thread.

The ordinary V and square thread screws are based upon a curve known as the helix; we will note something of the properties of the curve first.

If a point moves around the surface of a cylinder at a uniform rate, and at the same time moves at a uniform rate in the direction of the axis of the cylinder, it will generate the helix. It can be seen from co-ordinate geometry that a curve plotted between co-ordinates, which have a directly proportional relation to one another, will be a straight line. The helix is such a curve, and it may be defined as the shortest line which can be drawn upon a cylinder between two

Fig. 27

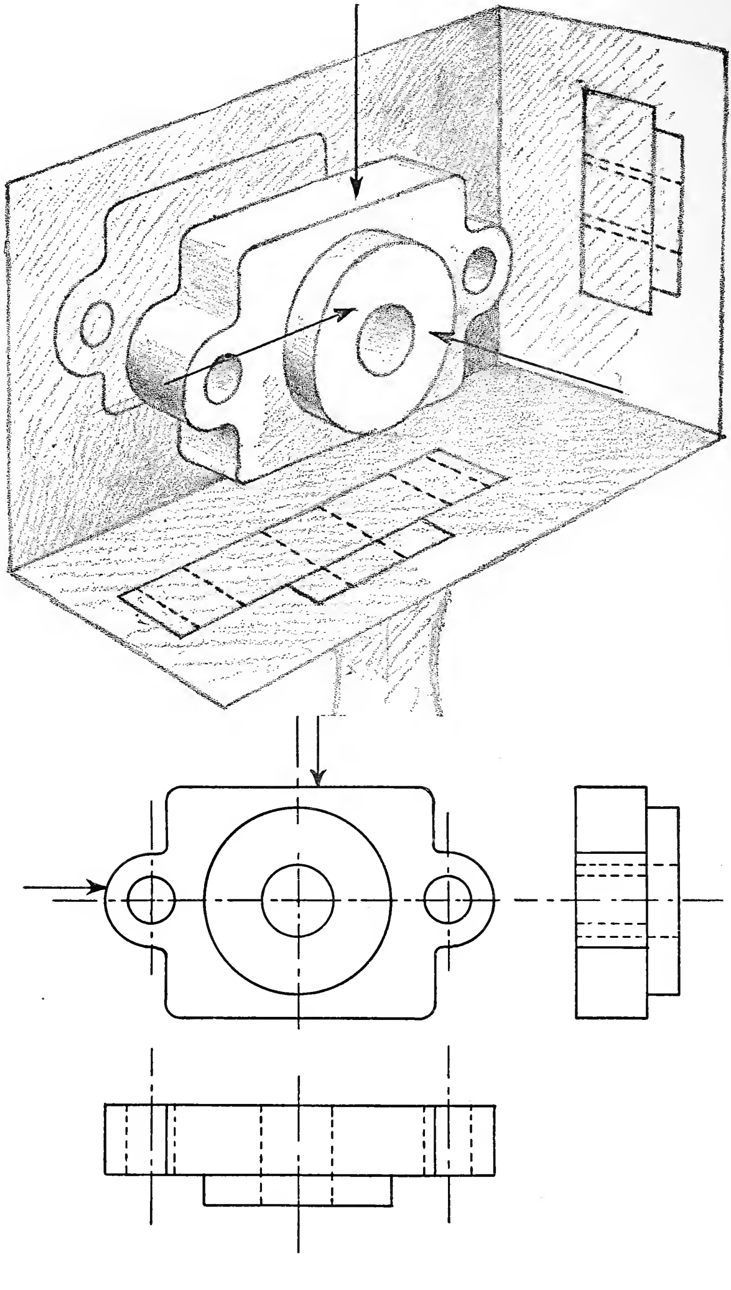
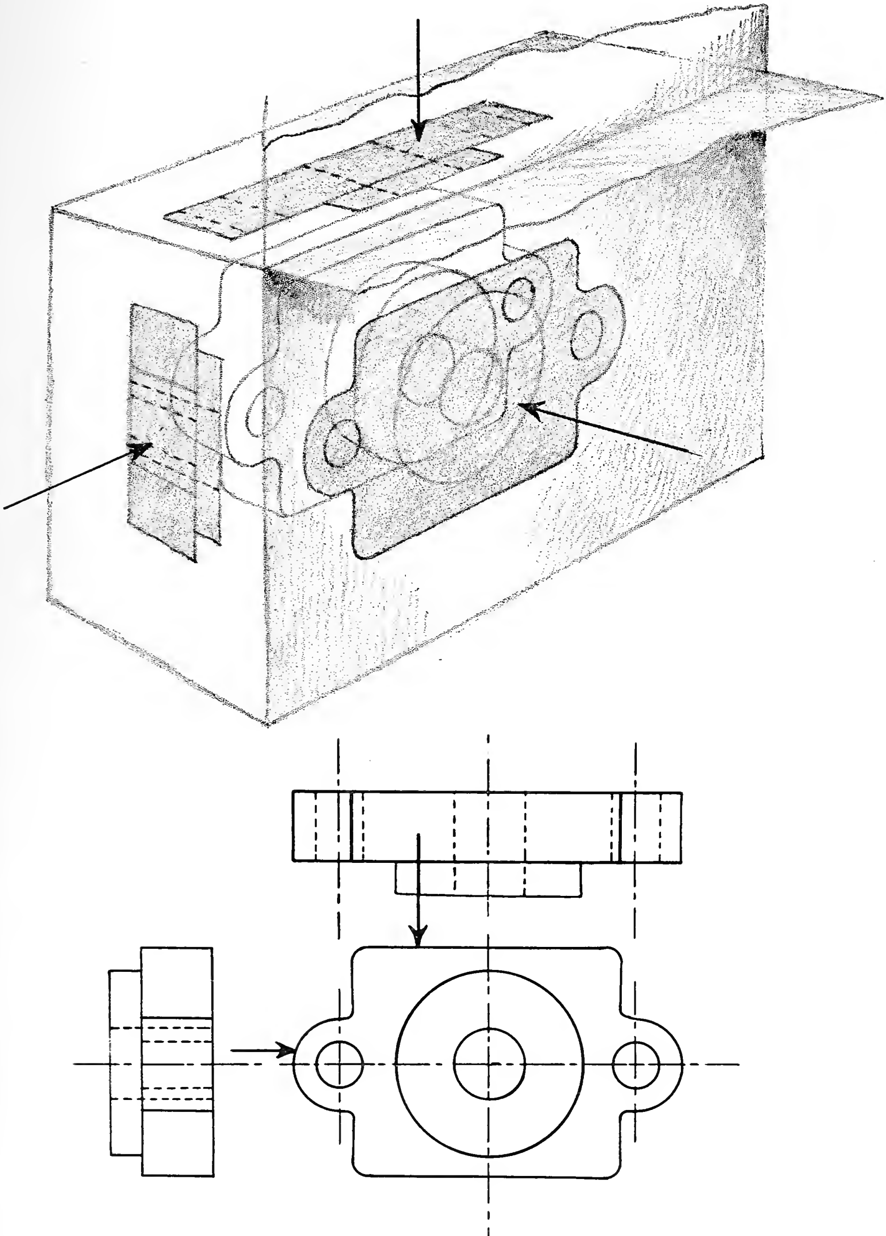


Fig. 28

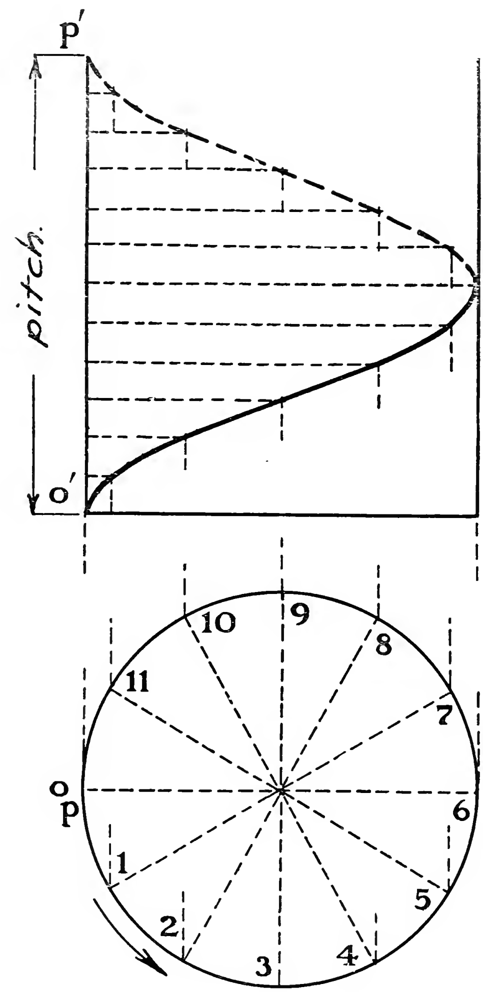


points that lie neither upon the same right section, or upon the same right line element.

To study the curve in projection, draw a cylinder in the first angle (as Fig. 29) with axis parallel to the vertical plane. Assume a point to be at o, and to move around the cylinder in the direction of the arrow through equal distances, 1, 2, 3, etc. Let it move also up the cylinder through any given distance, until, after it has completed one revolution of the cylinder, it reaches a position, P′, directly above o′. The distance, o′P′, is known as the pitch of the curve. Now, as both motions are uniform, the point will travel to 1, which is one-twelfth of the circumferential distance in the same time that it travels one-twelfth of the distance of o′P′ towards P′, and to 2, which is one-sixth of the circumferential length as it goes one-sixth of the distance, o′P′, towards P′, and so on. Hence to plot the curve, divide the circumference of the plan into any convenient number of equal parts, and the pitch into the same number of equal parts. By noting the points of intersection of the perpendiculars to the ground line, through the divisions of the circumference and parallels to the ground line, through the corresponding divisions of the pitch, points of the curve may be found.

Certain peculiarities of the curve deserve notice: (1) It is tangent to the contour elements of the cylinder at points, o′ and 6. (2) It changes curvature at point, 3, midway of the contour elements. The tangent to the curve at 3 shows the angular pitch, which is the ratio of the linear pitch to the circumferential distance. (3) The curve is sharpest at o′, and gradually grows straighter until at 3 it reaches a straight line for a very short distance. (4) It is symmetrical in parts with respect to the axis of the cylinder, and to lines perpendicular to the axis, so that the curve from o′ to 3 is a unit which is repeated throughout the path of the point.

FIG. 29



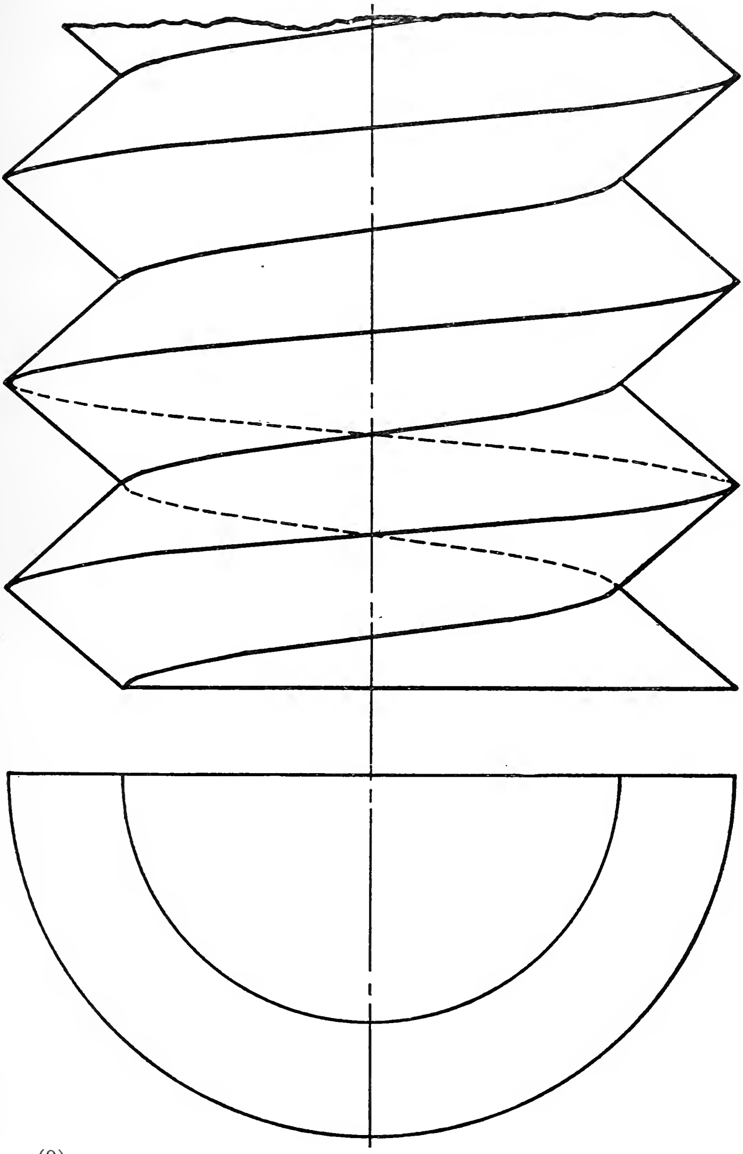
If the pitch is lessened, the curve at the contour elements of the cylinder grows sharper, and at the middle of the cylinder straighter, approaching throughout straight lines oblique to the axis of the cylinder. When in the ordinary screw the pitch is exceedingly small, relative to the diameter of the screw, it is next to impossible to draw the curve correctly. The pitch in the screw means the number of threads per inch of length, or the number of coils of the curve per inch of length.

In the V threaded screw three curves are shown, one theoretically wound around a larger cylinder at the crown of the thread, and two wound around a smaller cylinder, at the base, or root, of the thread. In the square threaded screw are shown four curves, two at the crown and two at the root. The appearance of these two threads is shown in Figs. 30 and 31.

It is to be particularly observed that the coutour lines of the V thread do not meet at the crown of the thread in sharp angles, but each is tangent to the curve of the crown. Again, these lines do not meet at a point which lies on the cylinder upon which the root curve is theoretically wound, but they are tangent to the root curve, and cross one another a little outside of it. These facts are neglected in any practical drawing of the thread, but should be comprehended. They are, unfortunately, too often incorrectly shown in careful drawings of the thread in well known text books.

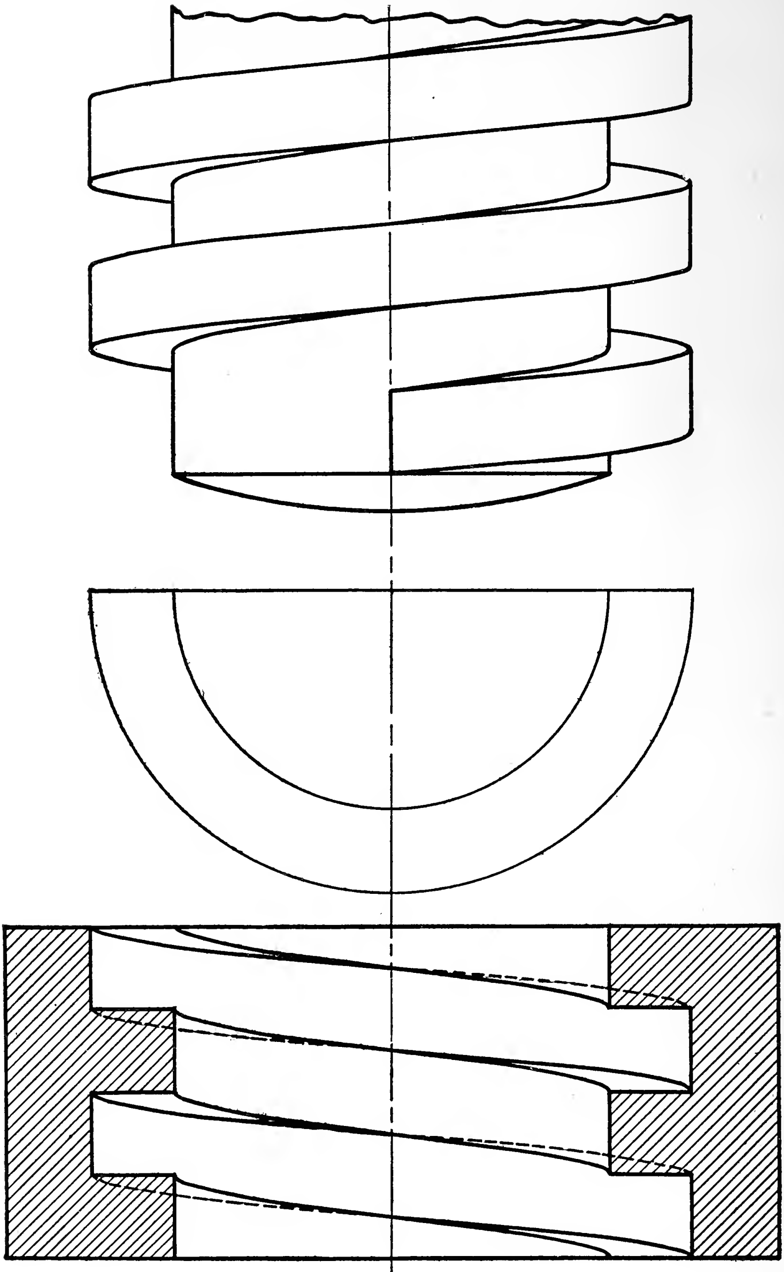
The diameter of a screw, as dimensioned, always stands for the diameter of the crown line of the thread; this does not indicate the strength of the screw. The strength is determined by the diameter of the root curve of the thread,

FIG. 30



(9)

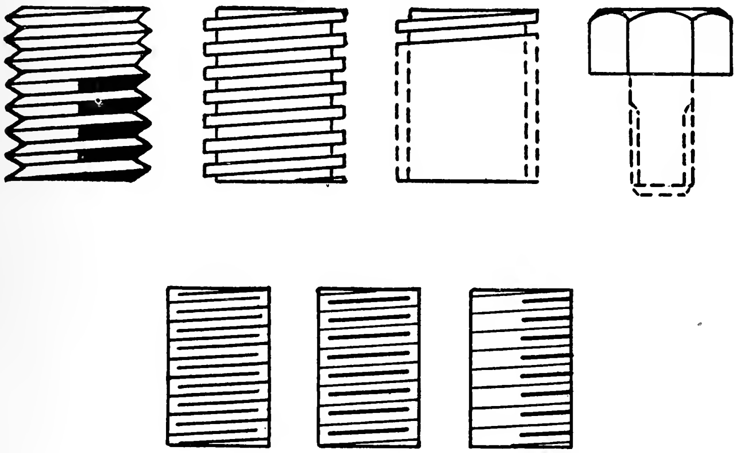
Fig. 31



being the minimum cross section of the material of which the screw is made.

Unless, in exceedingly rare cases, a large screw is to be drawn to show up especially well, a conventional method of showing the thread takes the place of the accurate one.

Fig. 32



The first change from the accurate thread is to make the curves straight (as shown in Fig. 32). The next change to make is, in the case of the V thread, to omit the saw tooth edge, leaving just the longer and shorter lines, as shown, making the limits of the screw a cylinder. Another convention is shown also in the figure, one which suggests, in a way, roundness with a sacrifice of the screw characteristic. Square threaded screws are relatively rare, and there is no particular convention in use to represent them beyond making one thread of full lines and dotted limiting lines for the others as shown. Sometimes this is even done in the V thread.

It will be observed that the lines of the thread have a slight inclination upward toward the right; the direction of the slant of the lines, in all positions of the screw, can be ascertained in this way by looking in the direction of the axis of the screw. For left handed threads, which are rare, the slant is upwards toward the left. The tap for a screw (see Fig. 31), if shown in section, will have its lines the reverse of those in the screw, because it is the duplicate of the curves on the rear half of the screw, which in the latter are not seen.

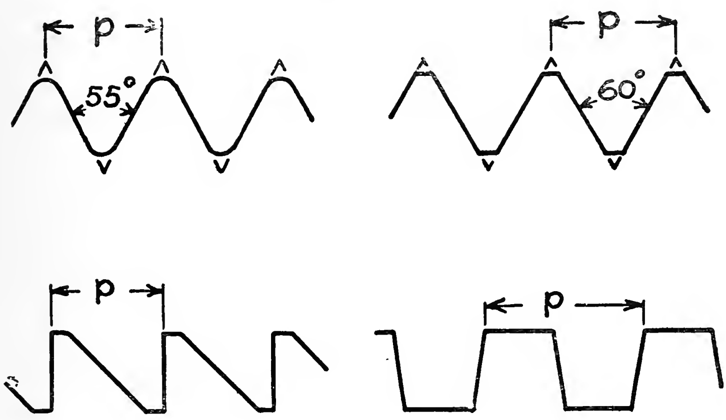
In ordinary drawing, of course the pitch, as conventionally treated in Fig. 32, is not measured but estimated.

The Whiteworth standard has an angle of 55° between the sides of the thread. The crown and root of the thread are both rounded off. The amount taken from the crown, and that added to the root of the thread, being equal to one-sixth of the total depth of the thread. Let D′ = diameter at the bottom of the thread, D = outside diameter of the thread, and N = number of threads per inch; then $D = D' - \frac{1.28065}{N}$ (see Fig. 33).

The U. S. standard proportions, devised by Mr. William Sellers of Philadelphia, has an angle of 60° between the sides of the thread. The crown and root are cut off flat; the amount added at the root being equal to that taken from the crown; the depth of the flattened face being equal to one-eighth of the depth of the thread. Using the notation as given above, $D = D' - \frac{1.299.}{N}$

There are other forms of thread occasionally used besides the V and square thread. The buttress thread, for example, is shown in Fig. 33. It is used where the screw is a transmitter of power in one direction, or where it is used to resist force in one direction. It may here be noted that a screw to transmit motion may have a large or steep pitch in proportion to the speed of the screw. If the speed is rather great, and yet it is desired to keep the screw strong, or

FIG. 33



even for the latter reason alone, it may have a double thread or a triple thread. Thus, for one revolution of the screw it will travel axially two times the pitch, or three times the pitch, etc. An illustration of a screw with steep pitch, to give relatively large axial motion, is shown in the thread on the spindle of some valves. There is even a certain point which can be reached in the pitch of a screw thread, that longitudinal pressure of the screw will turn it. This is illustrated in the self-acting screw drivers.

A truncated V thread is one in which the crown and root have been very materially flattened. It is a kind used in the spindles of some valves, as before mentioned. A form of truncated V thread, known as the Powell thread, is shown in Fig. 33.

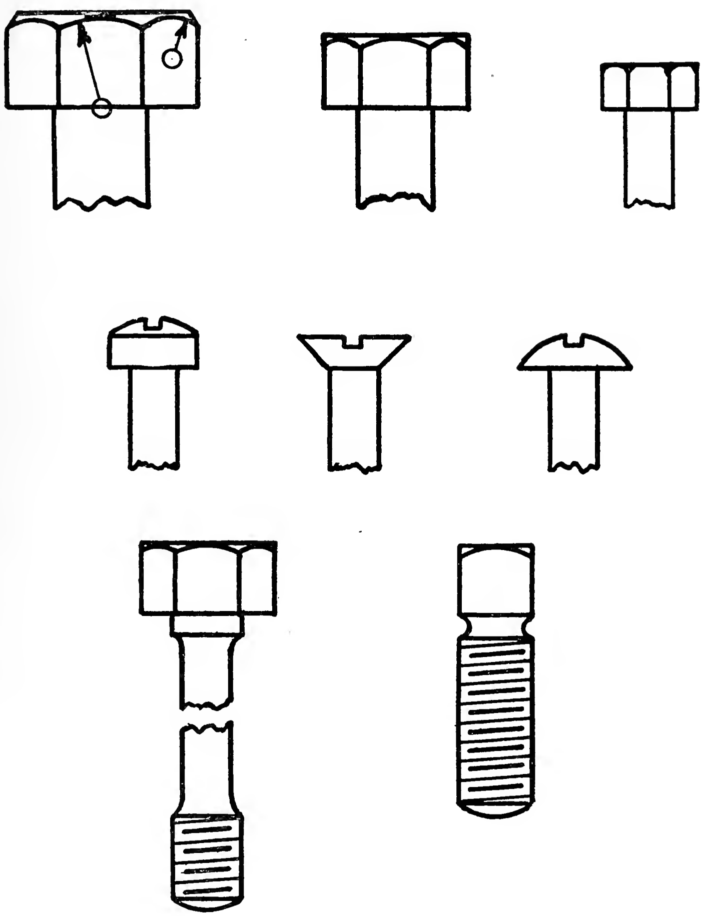
47. The drawing of hexagonal and square-headed bolts.

Bolt heads and nuts are almost universally made of the hexagonal, or the square form, so as to be convenient to grip with a wrench. The hexagonal form is preferable, because in cramped places the hold of the wrench can be changed after turning through an angle of 60° (see Fig. 34).

The sizes of the heads, both hexagonal and square, are universally standard for those in common use. Bolts are either cast, cut, or drop forged. The sizes are determined as follows: Let d = the diameter of the bolt, D the diameter of the head, then the formula is $D = 1\frac{1}{2}d + \frac{1}{8}''$. D is the true diameter of the hexagonal and square forms, namely, the perpendicular distance between the middle of opposite faces. It is taken this way so that the wrench for either will be the same, and so that the quantity may be readily set off with the scale. The diagonal of a hexagon is an awkward quantity to figure out, involving, as it does, a decimal; it is an incommensurable quantity compared with the diameter.

The heads are not left in the prismatic form, exactly, but are chamfered. The underside of the head is left flat. In nuts, both hexagonal faces are sometimes chamfered. A nut that is to tighten down on a flat surface will work better into place without cutting the material, if its corners are rounded. To get the chamfer, the bolt is put in the lathe, and the cutting tool set at 30° to the axis of the bolt, and the head cut until all the edges are removed. The surface of the cut is a cone; the intersection of the plane surfaces of the head with this cone give hyperbolas, very short arcs,

FIG. 34



however, differing so slightly from the circular that never in practice would any draftsman render them accurately, no matter how exacting the work. In finished bolt heads, the dimensions are somewhat less than the formula given, being $D = 1\frac{1}{2}d + {}^{1}/_{16}''$. The height of a bolt head is approximately equal to the diameter of the bolt, in fact, it is different for different diameters.

There is a generally universal method of drawing the chamfer (shown in Fig. 34). The center for the middle face is taken such that the arc, whose radius is equal to d, shall fall just a little short of the top line of the head. The radius for the smaller arcs is taken by cut and try methods, such that the arcs will be level with the larger arc, and cut the larger at its intersection with the edges of the middle face.

In less careful drawings, the curve of the chamfer is made tangent to the upper edge of the head, and the bevel at the right and left may or may not be omitted. In still more hasty work, the angles are just slightly rounded, as shown at the right in the figure—this being done with the writing pen. Or, in still smaller work, the chamfer may be omitted.

In working drawings bolt heads and nuts are always shown in the same positions. The elevation of a square headed bolt will show the one rectangular face. The elevation of a hexagonal bolt will show either two or three faces symmetrically placed with respect to the axis of the bolt. If one view only of the bolt is shown, it will be that of three faces, the point being that the showing of three faces identifies the bolt as hexagonal, and of one face as the square. It is not uncommon in large machinery to see bolts of a size all set the same, that is, their rectangular faces parallel.

Bolts are made with heads shaped differently from the hexagonal and the square. One form is a cylinder with the sharp edges of the upper base of the cylinder rounded off. The diameter of the head varies from 1.3d to 1.4d. A spherical head is also used, really not a sphere or even a hemisphere, but only a segment of diameter about 1.5d, and height, .75d.

Machine screw is a term used to cover all threaded members to screw in metal as distinguished from wood. In a narrower sense, it is used to designate those screws which go by numbers, varying usually by thousanths. The threads are similar to the bolts proper. The fillister head (another name for the cylindrical) is, as shown at the left of the middle row of Fig. 34, a combination of the cylindrical and spherical. The flat head is, as shown at the middle, and the button head, otherwise the spherical shaped head, before mentioned, is shown at the right. These same shapes are used for bolts, also, except that the groove for the screw driver is left out.

There are varieties of bolts named according to the function they perform: The tap bolt, used to fasten two pieces together, running free through one piece and screwing into the second; a stud or stud bolt, a bolt having no head but tapped into a piece, the free end being threaded to receive a nut. It may be used as a point of attachment, or center of motion. A set screw is a screw or bolt which presses on a piece so as to prevent the rotation or sliding of that piece, as the screw which holds a small pulley to its shaft.

The strength of a bolt depends upon the diameter at the root of the thread as well as upon other things. Sometimes the shank of a bolt is made less than the outside diameter of the threaded portion, making of it a stronger bolt, for reasons of machine design, not the province of this work. It is sometimes erroneously called a bolt of uniform strength. Usually, a part of the shank is left of the diameter of the threads, so as to prevent play of the bolt when in place (see Fig. 34).

In ordinary machine bolts when threaded up to the head sometimes a groove is cut next to the head, as shown at the lower right in Fig. 34. It is impossible to cut a thread with a lathe up to the head, so the groove is put in as a finish.

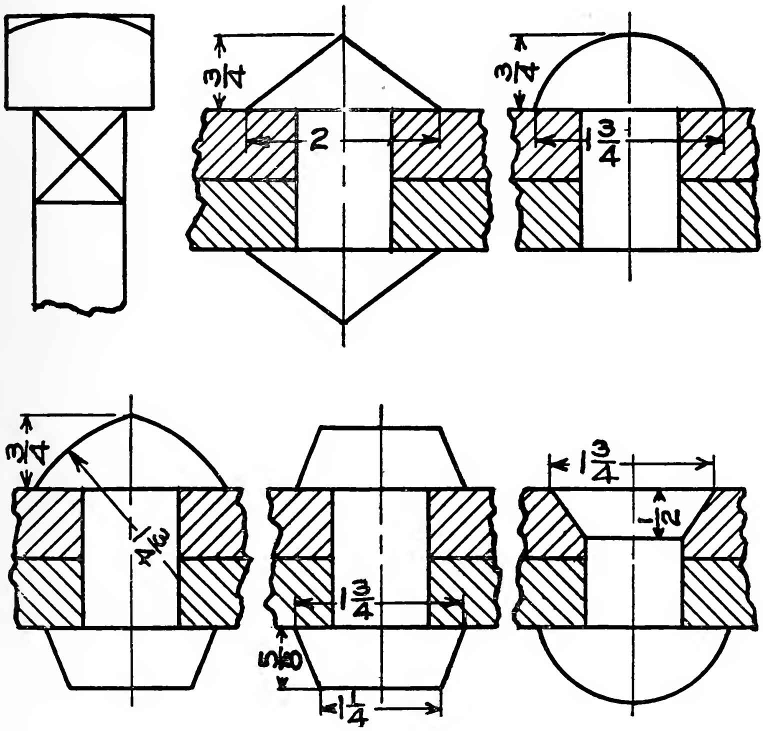
In machinery where a bolt is to go into a piece that is not otherwise smooth finished, frequently a small surface is raised to receive the pressure of the head, called a boss. It is left, in the case of a casting, of sufficient height that it can be cut down with the shaper or planer to a smooth surface.

When a machine bolt, together with its nut, is shown in place in a drawing, to distinguish the square or hexagonal head, from the square or hexagonal nut, the bolt is shown as extending for a short distance, say $1\frac{1}{2}$ threads beyond the nut.

Sometimes bolts have a square shank just at the head to sink into a square hole to keep them from turning. This is conventionally represented as in Fig. 35. The same convention is used for that portion of a shaft which sets in a bearing.

Rivets for permanently fastening two or more thin members together are really short bolts with permanent heads on both ends. The heads of rivets are conical, spherical, cup shaped or pan headed, as shown in Fig. 35. The conical shape is the most common obtained by the use of the ordinary hand-hammer. If the cup head or pan head is desired a different tool has to be used at the last in finishing, known as a 'snap,' or die, and a heavy hammer. A modified form of conical head is shown on the second row

Fig. 35



at the left. The approximate proportions are shown by dimensions on the figures given in terms of d.

The exact interpretation of the dimensions shown is not important in ordinary drawing. The diameter of a bolt or rivet being laid out, the adjuncts can generally be treated with sufficient precision by eye for ordinary use.

48. Orthographic projection and working drawing.

Orthographic projection is the language in which working drawings are written, but a dimensioned orthographic projection of anything does not necessarily constitute a working drawing of that thing.

A working drawing must be simple and plain in its features, easy to be interpreted, yet explicit. While projection calls for a certain set of views to complete the definition of form, the working drawing does not, for if one view of a piece will suffice to tell a workman how to make it, only the one view need be made. On the other hand, however, more views may be required in the working drawing than are required in orthographic projection, for sometimes assembly views are needed to show relation of all parts and detail drawings of each component part in addition. Third angle projection tends to legibility, and is the most usual medium for showing working drawings; it brings the front and end views into intimate relation to one another. The principles of orthographic projection are frequently violated in working drawings wherever modification will aid in legibility or economy of time in drawing. This was pointed out in discussing sections, and it will be again further treated a little later.

There is no way to formulate this difference between the two under rules for there are no fixed ones. Each case has to be treated by itself when the occasion arises. Judgment and knowledge gained through experience are the only reliable aids. The draftsman should, as far as possible, place himself in the position, in imagination, of the one who is going to construct from his drawings, and in that way arrive at a conclusion as to what would be desirable in the way of views. Unless the draftsman does this, he is apt to make his drawings too brief, to economize time and effort at the expense of the workman's time. From the workman's standpoint, many times, drawings are not explanatory enough; he will want them too elaborated with directions. A mean of these two has to be struck. For example, where hidden forms can be expressed by dotted lines, without hampering the workman in his requirements, the draftsman is privileged to use it to simplify his work.

49. Of what a set of working drawings is composed.

If a working drawing is required of a group of mechanisms or subjects somewhat widely separated, a diagram drawing may first be made to determine upon the arrangement or lay out of the various parts. Upon this lay out, also, may depend the character of the forms, so that this is an additional requirement for its being made first. The diagram shows, further, the number of the various elements of the group. As one illustration of this kind of drawing can be mentioned a layout for piping, showing the number of elbows, Tees, valves, etc.

In a diagram the briefest indication of shape is given, and not infrequently special conventional forms are used to stand for the more intricate actual forms. In piping, for instance, a valve is represented by two short lines perpendicular to and crossed by each other, one perpendicular to the line of piping and standing for the entire valve, the other parallel to the line of the piping and standing for the handle. In electrical work, also, there is a very frequent occasion for diagraming, and a very common use of conventions. The particular forms that are used in any case depend partly upon the usage of the company for whom the drawing is made.

Again, as another illustration of the diagram, an outline of a machine may be wanted composed of the main lines, together with the usual center lines. Perhaps, in this, the relation of some of the moving parts is wanted. These may be represented by heavy lines coinciding with the center lines of the members for which they stand, as in a Corliss engine valve gear diagram.

The diagram is the most comprehensive of drawings; next to it comes the assembly drawing of an engine, machine or mechanism. This shows, perhaps in several views, the projection appearance of the entire subject to be treated. It may not show all the features, or parts, only the principal ones; but it gives certain facts not available in any other way. It shows the size of the whole, the place for the different component parts, and the relation between these places, together with certain desirable chief dimensions. The minor features, as remarked, such as bolts, nuts, keys, set screws, etc., are left off. Perhaps their place will be indicated by center lines; perhaps, not even that. In fact, the assembly drawing may be more or less in the form of a diagram itself.

The diagram and the assembly drawing are not always made, but the latter is quite apt to be if the subject is at all complex, and when, in particular, it is manufactured for the first time. The assembly drawing of parts of a subject also may be made.

Next to the assembly drawing comes the details. These may be made together upon a sheet of details, or each may be made on a separate sheet to be more handy in the shops.

Again, the details may be made for the different workmen, according to the process through which the parts are to be put. There are details, for example, for the pattern maker, the blacksmith, or the machinist. The dimensions put on these and the general treatment will be that of interest to the particular workman handling them. Sometimes, however, the detail drawings are made complete enough in all respects to answer for the several above mentioned requirements.

Finally comes the bill of materials. This, of course, is, strictly speaking, not a working drawing, but it is a very necessary accompaniment of it. The bill of materials consists of a tabulation of the stock required, the number and character of the pieces needed. To be specific, it is composed of: (1) An identification mark as a number, which, as before stated, may, by its denomination, indicate the material. (2) Name of the part. (3) Number of the pieces needed to make one of the entire subject. (4) Name of material, if the identification is not complete as above. (5) Further general descriptive matter, like pattern number, dimensions of the rough stock, method of casting, etc. In very small subjects it may not be made a separate tabulation, but written near the separate parts. In other cases it may be a tabulation in one corner of the sheet containing the pieces detailed. When very complicated drawings are dealt with, it may be accorded a separate sheet. It generally indicates the number of parts needed for making one of the combined subject.

50. The development and arrangement of working drawings.

In beginning a set of working drawings of a subject which is entirely new in design, it is quite likely that the small features will be designed first, and the assembly drawings of parts, or of the whole, made afterwards. So there can be no rule for the order in which drawings are made.

The convenient arrangement of a set of drawings is of first importance, and it is something which only experience and knowledge of the business will give adequately. But a few fundamental principles may be laid down to start with.

Differences in manufacture and in the subject control the method of development and arrangement. Principles cannot be laid down applicable to all cases. But some one problem may be considered somewhat in detail, and will serve to show how it is done. About the best illustration that can be taken is an academic exercise, a problem which would be given a student in drawing, a problem of making a set of working drawings of a furnished model. Let the first illustration, for example, be a simple steam engine.

First, let us take a general survey. Determine the chief dimensions or size of the whole, and choose such a scale as is necessary to properly present the assembly drawings, a plan, elevation and end view, upon one sheet without overcrowding the sheet, or on the other hand, making it so small that the character of the subject is not readily seen. Next, take in turn the various parts, and make the necessary working drawings of each. It is best to take a survey of the size of the largest piece and of the smallest, and see of what size they can be conveniently made, for it is desirable that as few different scales be used as possible. Lay out the projections of the larger pieces first, and proceed toward the smaller, then the next smaller, and so on.

It can be seen that in the practical problem of designing a machine the details would be made first, and afterwards, the assembly drawing, partly to see that there was the proper fit among the details when put together.

Second, as to details of construction: Before any drawing is done, a list should be made of all the features needing to be detailed, and the number and kind of views required of each. If this is made a written list, the scope of the work can be gotten better in hand, the room on the sheet or sheets can be planned for, and the scale adopted which is necessary to show the parts to advantage.

It is not always feasible to use only one scale for a drawing throughout. The one for the assembly views needs frequently to be a smaller one than that for the details. But the fewer scales, the better. There is no objection, however, to one for the assembly drawings, one for the larger details, and full size for the smallest features like keys, bolts and screws, etc.

Next, the arrangement of the sheets should be decided upon. In practical work different sized sheets are used for the different parts of the subject; frequently, the assembly views will be made upon a relatively large sized sheet, the main details on a second or medium sized sheet, and the smallest parts on small sheets. Small parts require, generally, finishing or machine work, and it is more convenient in the shop to handle the small sheets, mounted as they often are, on compote board, or some stiff backing, and varnished to preserve them.

In the academic problem, it is sufficient to use the same sized sheets for everything, and use only the number that will show up all the parts advantageously.

If the assembly views can be shown well enough in small size, they may be made upon the same sheet with the principal details. To get the best arrangement of views on a sheet, a free hand sketch treatment should be used first, that is, to an approximate scale, sketch roughly, by very light lines, the space to be occupied by each and all of the views. This will permit of an adjustment in the arrangement, if it does not at first promise to be good.

Next, it is best to begin the careful drawing of the details first, leaving the assembly drawings until later, as the best interpretation and accuracy can be reached in working the assembly from the details.

Draw the views of the bed of the engine first. Do not begin at the top or bottom, and build steadily down or up until finished, but lay out the chief, or the over all sizes, then the next smaller, and so on, to the smallest parts last; also, drawing not one view at a time, but the several of the set; the same feature recurring in the several views should be treated in them all so that there should be harmony of parts.

If a view can be developed by projection from another, it is better to do so than to use the scale and lay it out independently, for it saves time. But the scale relation must be kept in mind and discrepancies noted.

It will be found, perhaps, that the drawing of one view will suggest the forms of the others, or show errors, if there should be such. Accuracy of form is of paramount importance, and anything that conduces to accuracy is in order. It is also certain that, since the various details are related to one another, where possible, lay out the chief sizes of them, so that this relation may be kept in view. In other words, it may be quite possible, in some subjects, to develop all the details together, more or less simultaneously, and where this can be done it is to the advantage of the drawing in accuracy. Where there are dotted forms, no distinction need be made from the solid outlines, etc. They may be done at the same time, and they may really help in the development of the forms, by checking the sizes of things.

The matter of treating the larger features first, then the smaller, and so on, is of such importance that a few further directions about it are in order. The small things depend so directly upon the larger, that if the larger are drawn first there is more chance that the smaller will be right. Or, if done in this way, the process is logical in the same way that if a line is to be divided into a certain number of parts, say 12 in free hand drawing, it is easier to divide it into two larger parts, then these two into two more each, and lastly, each of these into three. Very often some of the smaller features have very accurate requirements, whereas, the larger may not, for the former may be centered openings, or fitted parts, whereas the latter might be the over all sizes of castings which can vary one way or the other in size. Hence their size and location, if the former, can be more accurately ascertained after the larger features have been laid out.

After the engine bed, draw the cylinder, the fly-wheel, the connecting rod, the eccentric and rod, the bearings, the main shaft, the valve gear, if any, and so on, leaving for the last, the bolts, screws, keys and minor fastenings, etc.

As to the place on the sheets for the different views, a certain logical sequence and legibility should be observed. Large details should be put on a sheet by themselves, or else either along the upper part of the sheet, or at the left hand side. The next smaller parts should be put below the first, or to the right, and so on, so that the smallest parts are shown along the bottom, or along the right hand edge of the sheet. If it was a new machine, built for the first time, it is likely that for convenience to the workman in determining fits and locating related parts, assembly details would be used. That is, the connecting rod, for illustration, would be shown complete in the upper part of the sheet, and its various component parts detailed in order below this. To be complete in explaining new forms, a bill of materials should be written alongside of the assembly detail.

Related parts may be in projectively, related positions, provided the subject admits of it, or while not in projectively, related positions they may be so intimately related on the drawing that the connection is apparent at a glance. For illustration: A connecting rod—showing the rod at the top—may have the straps to the left and right of the rod as if they had just been slipped off, their center lines coinciding with that of the rod; the brasses may be shown also to the right and left of the straps as if they had been removed by simply sliding along their center lines coinciding with that of their position in the straps; finally, the keys, and bolts, etc., may be put in the lower part of the sheet in any convenient place, arranged so that the left hand bolts, etc., belong at the left hand end of the rod, and those at the right, to the right hand end of the rod. This may be seen in part in diagram in Fig. 36.

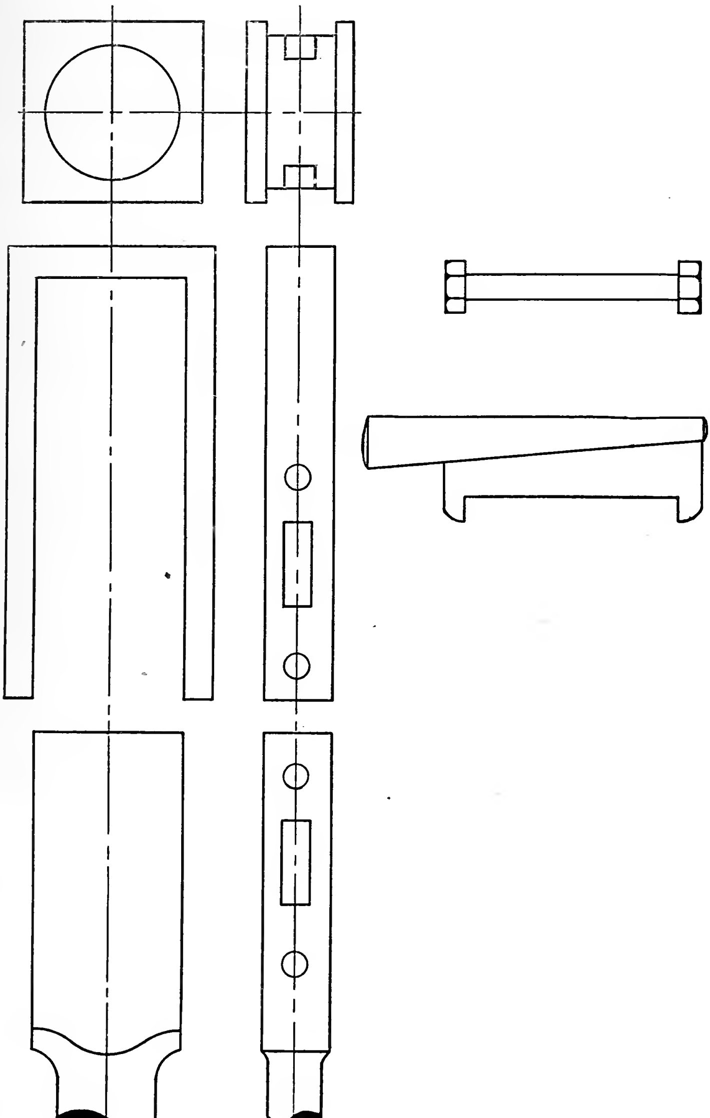
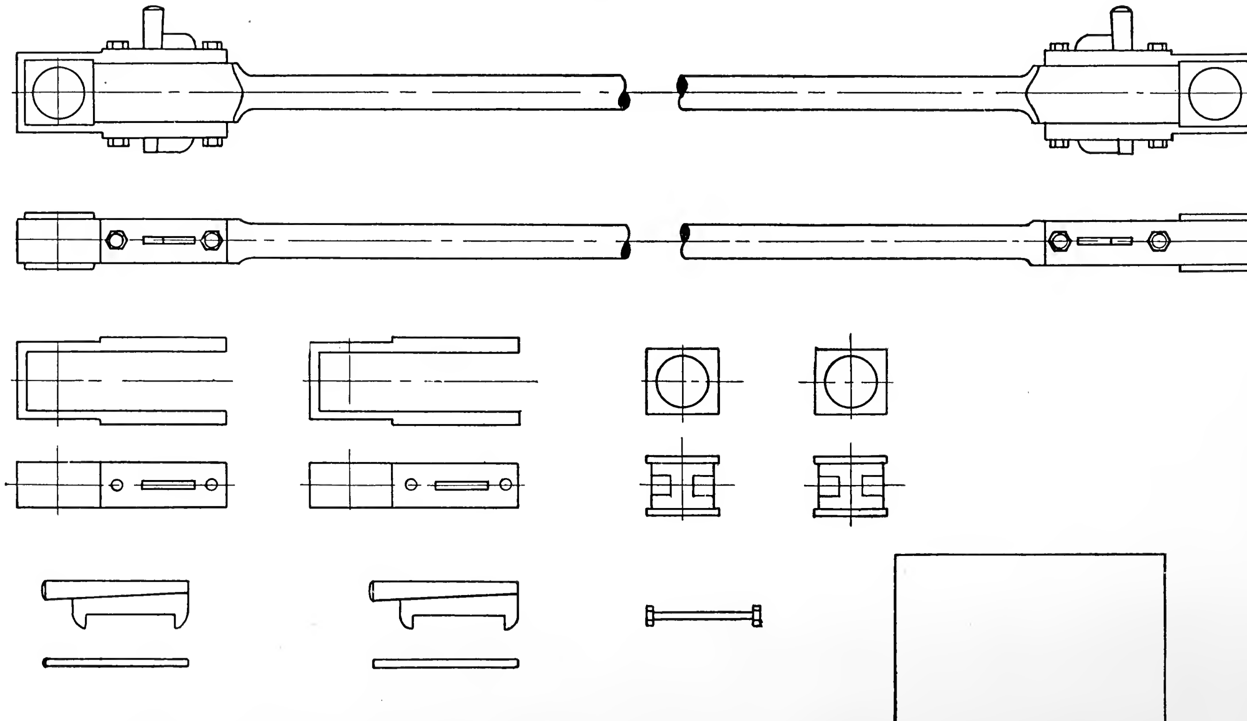


Fig. 36

FIG. 37



Another logical and perhaps better arrangement is shown in diagram, in Fig. 37. Here the principle is followed of placing parts of a kind together, disregarding their exact position in the subject. The straps of both ends are put together at the left, but the upper one belongs to the left hand end of the rod, and the lower one to the right-hand end of the rod, a certain convention of sequence which is quite common. Similarly, the brasses are placed at the right with, again, the left hand brass above and the right hand one below.

The first mentioned plan of arrangement is rather risky, unless the subject be a very simple one, and admits of it without sacrifice of legibility, for of course it would become confusing if there were many pieces to remove from one another.

If the engine were complex, say triple expansion, probably the connecting rods would be put on a sheet with the eccentric rods, or other long turned members, the brasses all together on a sheet by themselves, and the straps also. Even here, however, the rods for the high pressure (H. P.), low pressure (L. P.), and intermediate pressure (I. P.), would follow each other down or across the sheet in a certain sequence, which would be the same as that on the sheet of brasses and straps, etc. It is evident that such an arrangement would aid materially in reading the drawings and finding what is wanted.

If several parts of the engine are put on a sheet, the groups of drawings of them should be separated by a little more space than the several views of a part, so that the identity of the different things is not confused.

Where the projections of related parts cannot conveniently be projectively related on the drawing, they should all line up to an imaginary limit. For illustration, a series of bolts of different sizes may be placed side by side, and the under sides of all the heads in line; this will show at once the size of the bolt, for the length under the head is the usual dimensioned length.

The small adjuncts to component parts of a subject, like bolts, fastenings, etc., may go with the parts to which they belong in the case, for example, in which the connecting rod is treated complete on a sheet by itself. But the best arrangement, perhaps, is to put these small parts on a sheet by themselves, especially where the same kind of thing recurs in various parts of the subject, and is not intimately related to one of the large divisions, like connecting rod or cylinder.

Parts which have to be made upon the same machine, or by similar processes, are often collected on a separate sheet by themselves; for example, there may be a sheet of bolts alone, of screws, of forgings and of castings; but this is done only where a large number of parts are wanted, and where, moreover, processes of manufacture have become somewhat systemmatized.

If it takes more than one sheet to make the set of drawings, keep each sheet as far as possible self-contained, even though on some sheets there may be waste room. The economy of space profits little, nor the even distribution of views over the sheet unless it can be done without any sacrifice. Do not, for example, divide up the small parts, bolts, fastenings, etc., and put some on each of two or three sheets, merely to fill up clear space on the sheet and economize in number of sheets.

Thus, has been laid out a plan of arrangement for a set of drawings. But it must not be taken for granted, as before remarked, that all subjects can be treated the same way. The character of the subject, the extent of the manufacture, and a number of things modify the process one way or another. The accuracy and the legibility of a drawing are the chief things. That development which will lead to accuracy is the best. That arrangement which enables one to read the drawings without trouble, also, is the best. Usage dictates the sequence in a set of drawings so that this is accomplished. Other things being equal, then, the valuable draftsman is he who can, with the least outlay of time and labor, produce drawings that will enable the construction to be carried forward with certainty and dispatch. He should be a master of the principles of projection, but not a slave to them.

51. Dimensioning:

To dimension a working drawing is to do the most important part of the work. Upon it depends everything. If the scale on the drawing and the dimensions do not agree, the latter are assumed to be correct and govern the men in the shop. All that the workman needs to know must be put thereon, either in dimensions or footnotes, the latter being equally as important as the dimensions.

If a drawing is made of a machine already constructed, or that it can be repaired, it may be necessary to take sizes from the original. This should always be done with the foot rule and calipers, never with the scale. The scale should be put as close to the distance to be measured, as possible, and if it is not possible to get close enough for accurate work, then use the machinists' dividers, and apply them afterwards to the foot rule, not the scale, to get the size. The scale is a tool whose edge should be kept sharp and undented, and furthermore, free of any dirt or grease likely to soil a drawing.

The machinists' dividers are used to ascertain sizes of flat surfaces; the calipers, inside and outside, are used to get the diameters of holes and cylindrical forms. After a diameter has been obtained with the inside calipers, one end should be set flush with the end of the foot rule. If convenient, place both against a flat surface. With the outside calipers, rest one of the arms against one of the end faces of the rule. These directions will facilitate the making of rapid measurements. The diameter of a cylinder should be placed on the end view of the cylinder.

While it is true that dimensioning is an accurate operation, still the beginner must appreciate that some things will permit of only approximate dimensions. A knowledge of processes of manufacture will show that it is a waste of effort to measure everything to the thousandths of an inch, as some tight fits, of course, have to be. Rough castings cannot be measured to a sixteenth of an inch with accuracy, and there is nothing gained by trying it. Work that is to be machined may or may not require to be very accurate. A tight fit may call for accuracy to a thousandth of an inch, another kind to a hundreth. Discrimination should therefore be used in dimensioning. As an illustration of the application of approximate and exact measurements, take a line of sub-divided dimensions, which lie, on the one hand, between a finished surface, and the other the end of a casting. The last subdivided dimension at the casting end should be omitted, and in its place an overall dimension should be given. The man who makes the casting will get the measurements he needs, while he who does the machine work and finishing will get those exact sizes he wants, and neither will in any way hamper the other.

The question of what to give in dimensions is an important one. It may be said that everything should be dimensioned. This is only true in a degree. Those dimensions should be put on which are needed in the various processes through which pieces are to be put in making. Some knowledge of these processes is therefore necessary before the matter can be handled skillfully. A few very general directions may be given here.

In the first place all dimensions should be the final working ones, no allowance should be made for shrinkage of castings, etc.

The distance between chief centers, and if the subject is symmetrical upon a center line, the distances also of these centers from the center line is always necessary. They are among the most exact of the dimensions, for centers may, for example, involve fitting of parts bolted together, and unless the centers are right in both pieces fit is out of question. Be sure these are correct before putting in other dimensions depending upon them.

The overall dimensions are, of course, needed in every case. The subdivided ones between depend upon the nature of the work which is to be done upon the particular piece, all the subdivisions may or may not be needed. It frequently happens that there are two or three main subdivisions, like the distances of the sides or ends of a piece from one or two important center lines, and in addition the distances of other smaller parts from these center lines. Where such exist we have three classes of dimensions. They ought generally to be figured up complete in each case to the overall, if for no other reason than that each may be a check upon the other. Aside from this they may be needed in constructing the piece. The three sets should be rather close to one another, the overall the outermost, and the subdivided the innermost of the three. The relation between the three should be at once apparent. As an illustration of this, see Exercise 10. In the absence of any limiting conditions, it is a good safe working rule to put in subdivided dimensions, and to fill in to the overall.

Judgment of manufacturing processes must be exercised as to whether the radius or the diameter is the dimension needed in a particular case. A circle passing through a series of bolts radially placed requires the radius; a turned piece or a bored hole demands the diameter. The latter is designated as, for example, a $1\frac{1}{2}''$ bore.

When a hole is bored to carry a screw it is designated as tapped, for example, for a $1\frac{3}{4}''$ screw, the tool used in making it being known as a tap. Or, if it is a casting, the hole is specified as cored for a sufficiently smaller size to permit of its being tapped out to the required size. These have to be allowed for. If a hole is tapped for a bolt the drawing may or may not show two concentric circles to stand for the base and the crown of the thread. If only one is shown it will be the circle which specifies the diameter of the screw, namely, the crown of the screw thread.

In this connection it may be explained that "to ream" means to finish a hole with a "reamer" for a very smooth close fit. "To bore" means imply to cut out with an ordinary boring tool, while a "core" means a hole made in a piece when cast, by inserting a piece in the mould which which displaces the metal, but is rendered very brittle in the making and falls out readily.

The bolts to go into a tapped hole will, if standard, only require the size or diameter which may be specified as a dimension, or by a note to one side, the length under the head and the length that is threaded, the latter specified generally as a distance from the end of the bolt. If the bolt is not standard it will require in addition to the above dimensions the height and diameter of the head and number of threads per inch. If the end of a screw is rounded, the dimensions of the overall and the length that is threaded should be given to the corner and not to the extreme end.

As before stated, notes should be given, which may be included in the bill of materials, or may be written on the drawing. If the latter, the note will state the material used, how each part is to be finished, and the number of pieces required. Special directions pertaining to making, painting, shipping, etc., may even be given in notes; also, sometimes, notes pertaining to erection are added, like "These rivets are to be field driven."

When bolt holes are spaced equally around a center upon a disc or a cylinder head, for example, a circle passing through all their centers, together with radial lines also passing through the centers, constitute center lines for these forms, and the radius of this bolt circle is given, and also the number of the bolts, or the angular distance apart may be given instead.

It may here be noted that all holes should have center lines, even if only two short strokes at right angles to each other, cutting across the curve of the hole, and cutting each other at the center of the hole. Always make a dash of a center line, cut across centers of forms, and also have dashes cut the principal lines of the drawing.

Angles, if specified, may be given in degrees, or by co-ordinates or by tangents, depending upon circumstances. If in degrees, an arc is struck from the vertex of the angle, the dimension line constituting this arc; if by co-ordinates, any two distances at right angles to each other are used, measuring from each other and the vertex of the angle; if by tangents, it is the length of a perpendicular measured from a base which is one side of the angle of length one, measuring from the vertex of the angle. The measuring by co-ordinates is particularly useful for the pattern makers.

When a surface is machined or finished, an f mark should be placed on that line of the view which represents it as a line, and not on that view which shows it as a surface; moreover, the f should be placed on the line in such a way that the cross bar of the f cuts across the line.

It is sometimes necessary to go farther and specify what kind of finish a part receives as file finish, grind finish, plane finish, which would be stated by a written note near the f.

Special care should be exercised in measuring those portions of any detached pieces which are fitted to other parts. In general, all measurements should be made from center lines, or from finished surfaces.

A few scattered directions about dimensions:

(a) Always show filleted or rounded corners, where an adjoining finished surface does not prevent and give the radius of the fillet, as its size may be important in adding strength to the angle.

(b) Where a number of rivets or small bolt holes are in a right line, the dimensions concerning these should be written between the arrowheads of an overall. It should contain the number, size, distance apart, as well as the distance of centers overall. The distance of the end holes to the end of the piece should regularly be given.

(c) Where a taper is required it should be dimensioned with the taper per foot of length. Occasionally it is specified by giving the dimension at each end of the taper; where this is done the approximate taper ought also to be given.

(d) The dimensions of boards and iron plates should be specified in the order of width, thickness and length, for example a board 14″ x $\frac{1}{4}$″ x 8″. The grain will be parallel to the 8″ edge.

In regard to where to place dimensions, a knowledge of constructive requirements, and a draftsman's judgment are necessary to determine them.

A drawing is made for the workman to follow, and it must give him the information he wants, and give it in a way which it is the least trouble for him to find. This, it will be found, by examining working drawings, has resulted in a certain system in the placing of dimensions, which can only be fully appreciated by such an examination.

In the first place, no open spaces should be left undimensioned which the workman is likely to want, neither should additions or substractions be left for him to perform.

As to placing dimensions upon the inside or outside of a view, practice differs. Other things being equal, dimensions on the outside are to be preferred, but things are not always equal. If a view is large, and there is much small work in the interior, it is not practical to run long limiting lines across the view to reach the outside; it will confuse. Legibility should govern in this matter. Overall dimensions, if possible, should be given the preference of the outside position; diameters should be placed, where possible, diametrically of the part dimensioned, if this does not confuse by making too many lines.

Subdivided dimensions should invariably be made continously on a line, unless it is impossible to find a place where the line can be run without interference. Occasionally, one or two subdivisions have to be removed slightly from the line, but in no case should they be moved far enough to prevent reading the whole line readily.

Center lines should never be used for dimensions, no matter how near to them it may seem desirable to have a dimension placed. Nor should dimension lines cross one another, if it can be prevented. If it cannot, then neither dimension figures should be placed close to the intersection. Nor, again, should a dimension be written across a line of the drawing, or across a center of anything, no matter how insignificant.

The common two-foot rule has undoubtedly been generally adopted for standard, and, therefore, when dimensions are under two feet they should be specified in inches. Two feet should be written 2′–0″, and so on. In some lines of work, boiler work, for example, dimensions of whatever size are given in inches, as 120 inches.

If the drawing is a design, the dimensions should be put on about as fast as the forms are constructed, because at any time a preceding dimension may be needed to find a subsequent one. And, furthermore, it is a check on what is needed for construction, for what is needed to size in making the drawing will be very likely required in making the thing for which the drawing stands.

If the drawing is made from a model, as for study purposes, before mentioned, it is probably best to leave the dimensions until the last, as one thing to consider at a time leads to accuracy.

In constructing a drawing, and in setting off measurements and subdividing distances, use the scale where possible. Use the dividers or compasses only where it is unavoidable.

In dimensioning sectioned surfaces, as before mentioned, which should be avoided, if possible, leave a clear space unsectioned for the dimension figures and for the arrow heads also.

If, again, the drawing is made from a model, and the dimensioning left for the last, as directed, then the following system should prevail: (1) Start at the top of the original, and going down, note all those things requiring horizontal dimensions, and put the same on the views which will need them, or show them to best advantage. (2) Starting at the left, and proceeding toward the right, move similarly, recording the vertical dimensions. (3) Locate all radii, diameters and oblique dimensions. (4) Check everything by going over the whole subject again. These steps should again be subdivided into more. After locating something requiring a dimension, mark simply the place where it is to go on the drawing, by either sketching in the dimension lines and arrow heads free hand, or with the rule. After the place and the full number of all dimensions are located, then the foot rule should be applied, and the value of the several dimensions ascertained and recorded.

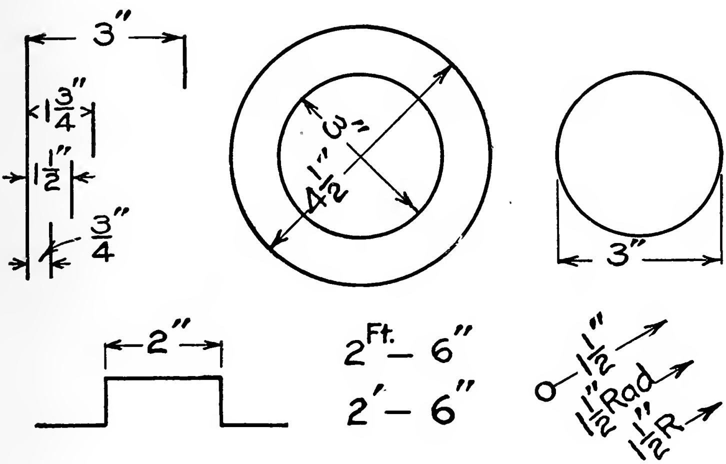
In inking such a drawing, i. e., one made from the model, the same procedure should be gone through with in dimensioning, except that the arrow heads should be put in first, and the dimension figures next. Nothing in the way of precaution to preserve accuracy in dimensioning can be out of place. The inking of the limiting lines for dimension lines should precede the dimension lines, for the same reason that the arrowheads should precede the figures. For, if the former are not done first they are apt to be overlooked.

The practice is common in the better drafting rooms to give accurate dimensions in decimals and approximate in fractions. Structural steel drawings are dimensioned in decimals. When the dimensions are given in decimals, the inch or foot marks should be placed in front of the decimal to replace the whole number. Similarly, in case of dimensioning in feet and inches, and the inches are zero, or less than one, a zero mark with the inch sign over it should always be put in the inches' place, or a zero in front of the fraction.

Dimension lines on drawings are usually not made of any particular convention of line, because they are so varied in length. Generally they are composed of several dashes when long, varying in length according to the distance to be dimensioned. Some drafting rooms use a solid line, but much lighter than any of the other lines of the drawing, and in rendering in ink where blue prints are to be made from it, they are made in red ink with a little black mixed with it to render it opaque, and make it show on the blue print as a very light blue line.

It is better to leave a clear space in the middle of each dimension line for the dimension figures, rather than write them either above or below it, because where a series of

FIG. 41



dimensions are close together, it is difficult to ascertain to which dimension line a figure belongs. Although the practice of writing a dimension figure above the line is common in structural steel work.

But on the other hand dimensions should not be crowded between limits too narrow to receive them. The several ways of specifying linear dimensions are shown in Fig. 41. The several ways of specifying diameters and radii are also shown in the same figure.

When a dimension is to be placed outside a form, limiting lines must be run to the form and perpendicular to the direction of the distance which is to be specified. They should be continuous lines, running just a trifle beyond the dimension line, and to a point just a trifle short of the outlines of the subject, as shown in the figure. They should be of the weight and the treatment of the dimension lines in Fig. 41. The foot and inch marks may be as shown, either way, but the upper of the two is the best because there can be no misunderstanding of the symbol. The dash should always be put between the foot and inch figures, to prevent misunderstanding.

The dash marks when used for the feet and inches should be distinct and easily distinguished from accidental marks. They should go above and to the right of the figures, be about one-eighth of an inch long, thick at the top and pointed at bottom as the writing pen would naturally make them with the spreading of the nibs at the beginning of the stroke.

The arrow heads at the ends of dimension lines should be made with the writing pen, sharp and concave with the sides of the arrow at about an angle of 30° to one another. Care should be exercised to bring the point of the arrow to exactly the limit it is to accentuate. There is no serious objection to having only one side to the arrow, although common practice usually shows the two sides. Where leaders are taken from a point to a dimension, the line can either be ruled or made free hand, entirely according to preference. The neatest appearance is attained when it is ruled.

The greatest of care should be exercised in making the figures of a dimension. They should be printed, not written hurriedly. Figures that are from one to one and one-half times as wide as they are high are the best, because legibility is attained more through an increase in width than by increase in height. Dimension figures need only be about one-sixteenth of an inch high if they are made sufficiently broad. They should not be varied in size in different parts of the drawing, or cramped in places where space is scarce. Ample room should be provided for them under all circumstances. Where fractions occur the fraction line should be perpendicular to the line connecting the two figures, or in other words, horizontal when normally reading the figures. Recent practice puts the numerator exactly above the denominator and omits the fraction line. The position of the figures tell that it is a fraction.

The fraction figures may be made as large as those of the whole number, but also can equally appropriately be made slightly less; the minimum should, however, not be as small as one-half the size of the whole numbers. A good working rule is to make them just a trifle smaller than the whole numbers.

It should be noted that uniformity in all respects is one thing which makes a drawing look well; that is, all figures and letters should be the same height, the same thickness of line, and of style. The same is true of the lines of the drawing, as before mentioned.

52. Working drawings may violate the rules of orthographic projection:

Working drawings, although based upon the principles of orthographic projection, in practice do not bear witness to implicit dependence upon them. Projection is the theoretical side, working drawing the practical application, and as practice modifies theory, always, so working drawings depart from orthographic projection when circumstances warrant.

Custom has sanctioned certain practices more or less universal for making drawings more explanatory with less labor, while there are innumerable short cuts, etc., adopted by different establishments, known only to the individuals having use for them. Some few of the general principals which may be followed will be here touched upon:*

(1) "That in each separate view, whatever is shown at all should be represented in the most explanatory manner."

(2) "That which is not explanatory in any one view may be omitted therefrom, if sufficiently defined in other views."

(3) "The proper position of a cutting plane is that by which the most information can be clearly given."

(4) "It is not necessary to show in section everything which might be divided by a cutting plane."

(5) "Whatever lies beyond a cutting plane may be omitted when no necessary information would be conveyed by its representation."

The views necessary to show a subject do not follow the conventional ones of projection, for if one view is sufficient to tell the workman all the facts, more are superfluous, for example, one view of a bolt is all that is needed when the bolt is standard. The certainty that the workman could not make anything else from the drawings than the thing intended is the controlling condition.

When two pieces differ only in being rights and lefts, it is usually not necessary to draw but one of them, making an

* See McCord Mech. Draw. Part II, Page 3.

explanatory note on the drawing that two are wanted, one right and one left.

Sometimes, although rarely, a section and an elevation are combined on the one view by superimposing the lines of theelevation over those of the section. This saves one view.

Sometimes it happens that lines come so close together, notably, on a small scale drawing, that if put in true projection they could not be distinguished apart. One should either be left out entirely, or else both separated a little for greater clearness.

In drawing gears, a few teeth, perhaps only one, are drawn out in full; the remainder are indicated by dotted circles for their crowns and for their roots, the pitch circle being a dash and dot line, or the usual convention for center line, or it may even be made a solid line.

In sectioned views, continuity of material is not interfered with by the introduction of minor elements in the plane of the section. They are either left out or put in dotted.

Sometimes in the drawing of one part of an object, which it is particularly desired to show, there are other parts connected with it which may be rendered in dotted lines to help show the connection of them all.

And so illustrations may be multiplied, but it is not necessary to go farther. The different illustrations in the book will show some of the short cuts. Judgment and experience will open up others to the thoughtful draftsman, and he will even then occasionally find that there are opportunities for him to improve on past experience.

53. Relative value of tentative and exact processes:

In paragraph 12, page 17, mention was made of the difference between geometrical and mechanical drawing, and the need for accuracy has been dwelt upon. A process which in itself is accurate would seem to promise accurate results; the fact is, however, that sometimes the length of the process and the steps of construction to be gone through with, open the way to errors in greater number and more serious consequence than if approximate cut and try methods were used. That is, each step in a geometrical process may yield a very small, and, in itself, negligible error, but in the aggregate, the several steps may make an error that cannot be neglected. Again, the construction by geometrical methods being accurate in theory, begets confidence in the draftsman, and he is apt to depend upon it and not to use his eyes in detecting errors. Now, the unaided eye is a most accurate instrument for discovering discrepancies, and if it is trusted it will prove an invaluable aid in truing up the drawing.

Of course, the results decided as accurate by the eye must be proven out by measurement before they can be accepted as accurate.

To take a couple of examples of these: (a) To find the center of a circle of given diameter, in other words, to bisect a line, strike an arc of estimated half to intersect the diameter, and with center each end of the diameter; this will leave a space to be further halved in correction, and so on. By adjusting the radius a couple of times or so, as accurate a center can be found as is needed, and more rapidly than by geometrical method.

(b) By a similar method a line may be divided into a given number of equal parts. By striking an estimated unit, a residue will be left which has to be divided into as many parts as the line. By adding an estimated division to the first unit, another try may be made, and generally, but two or three trys are necessary to arrive at quite accurate results.

Practice and experience will show the opportunities for application of approximate methods, and dictate the wisdom of using them. As the draftsman's eye becomes trained to estimate distances, he can depend more and more upon approximations.

54. Checking drawings:

After a drawing is made, a bird's-eye view of it is not a sufficient means of checking it. The checking for accuracy should be done by methodical steps. Broadly speaking, the drawing should be checked through the duplicate of steps by which it was originally made, and each step should be carried carefully throughout before the next step is undertaken. The following is a good series of steps.

(1) Identify every piece of a subject to see if all are fully shown, and to see if the requisite views of each are given.

(2) Note lines of various views for completeness and correctness.

(3) See that all dimensions are given that are needed, also working notes.

(4) Scale every dimension to see if it is correct, putting a check mark alongside of each as checked.

(5) See if they correspond with each other in different parts, in the assembly and the details.

(6) See if arrow heads are anywhere missing.

(7) See if dimensions are well placed.

(8) See if accents for feet and inches are all correct, and fractions or decimals plain.

(9) See if center lines are all in and correctly shown.

(10) Finally check for supplementary notes and directions, including bill of materials, if there is any.

As a draftsman continues to work on a drawing, becoming more and more accustomed to it, his sense of its deficiencies is apt to become somewhat dulled, hence checking is often done by another man, perhaps, two, to make doubly sure of the results. The final checker may be a man who does nothing else, and who is held responsible for the results after the drawing leaves the drafting room.

These directions are subject to modification according to the particular class of work dealt with. Possibly the machine designer, for example, may need to still further check for interference between different parts, "proper clearances," that bolts, screws, pins, and keys are standard," etc.

55. Conventions in common use in working drawing:

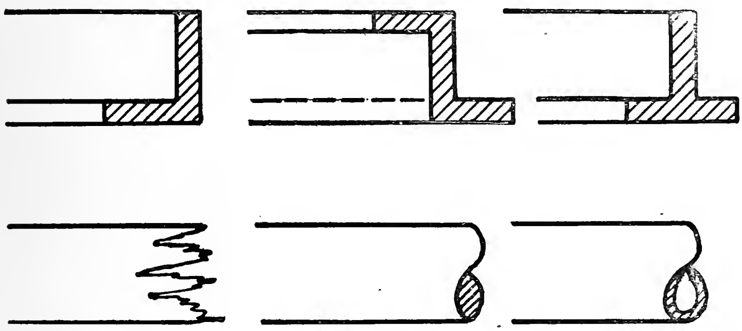
There are a number of conventional methods of representing forms and certain construction, which recur very frequently in working drawing.

When a long thin member like an angle, or T bar, or I bar, etc., is broken for any reason, the approximate shape of the section is shown on the end. Sometimes the accurate shape is given so that one view may do for two. See Fig. 42.

A round shaft or rod is broken, as shown, and if hollow, the approximate thickness of the metal is indicated. The curve of the break may be put in with the curved rule, but it may just as well be shown by free-hand treatment with the writing pen and with saving of time. Wood is shown by representing the splintering that is apt to accompany a break.

Now and then colors in very pale tints are used to represent various materials of construction. They ought only

Fig. 42



to be put in drawings which are stretched to the board. The following are the most important of these:

Cast iron, Payne's grey.
Wrought iron, Prussian blue.
Steel, Prussian blue with tinge of carmine.
Brass outside, Gamboge.
Brass in section, Carmine.
Grained or knotted wood, Burnt Sienna.
Earth, Burnt Umber.
Brick, Light or Venetian Red.
Masonry, wash of India ink with tinge of blue.

More natural effect can be given to other materials like wood, water, etc., according to the artistic skill of the draftsman.

In some elaborate drawings a nice effect is obtained by shading, where possible, with the India ink lines and putting a tint over these of the convention for the material shown.

Since the ability to put on a good flat tint is a necessary accomplishment of the civil engineer, if not for others, the following extracts upon the subject are quoted from F. N. Willson's Theoretical and Practical Graphics.

"The surface to be tinted should not be abraded by sponge, knife or rubber."

"The liquid employed for tinting must be free from sediment, or if the latter is present, it must be allowed to settle and the brush dipped only in the clear portion at the top. Tints, may, therefore, best be mixed in an artist's water-glass, rather than in a shallow receptacle."

"Tints are best prepared from the India ink in cakes, and from other water colors in the pans. The size of the brush should bear some relation to that of the surface to be tinted."

"Since tinting and shading can be successfully done, after a little practice, with only penciled limits, there is but little excuse for inking the boundaries; but if for the sake of definiteness, the outlines are inked at all, it should be before the tinting, and in the finest of lines, preferably of 'water proof ink,' although any ink will do, provided a soft sponge and plenty of clean water be applied to remove any excess that will 'run.' The sponge is also to be the main reliance of the draftsman, for the correction of errors in brush work; the water, however, and not the friction, to be the active agent. An entire tint may be removed in this way if it seems desirable."

"When beginning work incline the board at a small angle, so that the tint will flow down after the brush. For a flat tint, start at the upper outline of the surface to be covered, and, with the brush full, yet not so as to prevent its coming to a good point, pass slightly along from left to right, and on the return carry the tint down a little further, making short, quick strokes, with the brush held almost perpendicularly to the paper. Advance the tint as evenly as possible along a horizontal line; work quickly between outlines, but more slowly along outlines, as one should never overrun the latter, and then resort to 'trimming' to conceal lack of skill. It is possible for any one, with care and practice, to tint to, yet not over, boundaries."

"The advancing edge of the tint must not be allowed to dry until the lower boundary is reached."

"No portion of the paper, however small, should be missed as the tint advances, as the work is likely to be spoiled by retouching."

"Should any excess of tint be found along the lower edge of the figure, it should be absorbed by the brush, after first removing the latter's surplus by means of blotting paper."

"To get a dark effect, several medium tints laid on in succession, each one drying before the next is applied, give better results than one dark one."

"A tint will spread much more evenly on a large surface, if the paper be first slightly dampened with clean water. As the tint will follow the water, the latter should be limited exactly to the intended outlines of the final tint."

56. Tracings:

Quite usually blue prints are made from which to manufacture things. Tracings or tracing cloth are the best for this purpose. The drawings may either be made on manila or detail paper, as it is called, or they may be made directly upon the rough side of the tracing cloth, as before mentioned.

A few directions are necessary upon the handling of the tracing cloth, for it differs quite a little from paper drawing. The penciling, as well as ordinary dirt and soil, can be cleaned off by rubbing with gasoline, ether, benzine, or any highly volatile substance. Before inking on the cloth a little chalk should be rubbed over the surface with a rag, for there is more or less grease apt to be present, and it interferes with the drawing of lines in ink. If the fibres should get at all torn or injured, they may be repaired, partly, by rubbing with soapstone or hard beeswax. The soapstone comes convenient in the form of the soapstone pencil.

Special care has to be noted in inking on the cloth, particularly if the smooth side be used. If it is a very polished surface, the lines made by the pen are apt to be thicker by spreading, the ink flows out much more readily and consequently blots are easy to make. The precautions to be observed are to carry less ink in the pen, than if working on paper, and to be sure that lines are dry before working up against them. Speed in crossing a line, or working from and to lines, is necessary. Mistakes, as before mentioned, are not so easy to correct, hence care should be taken that no errors occur.

CHAPTER V.

MACHINE SKETCHING.

57. Machine sketching:

One of the most important accomplishments an engineer can have, and one which, unfortunately, is somewhat slighted, is the ability to make a free-hand working drawing sketch. It is of constantly recurring usefulness for him to be able to do this. The machine designer finds it invaluable beyond a question, and, particularly, if he is able to do it well enough to turn his sketches over to the junior draftsmen to work up. The junior draftsman finds it valuable if a part of a machine has to be repaired, and temporary drawings made of it, or again, to make a record of construction for future reference. Frequently apparatus has to be standardized; this can be done readily from sketches. If a record of anything has to be taken hurriedly, to be later worked up, the sketch is also invaluable. To quote a very clear statement of the case from C. W. McCord's Mechanical Drawing:

"It is supposed by some that deft handling of instruments of precision alone is required of the mechanical draftsman. This, however, is an error; no matter how expert he may be in the execution of working plans by rule and compass, the measure of his accomplishments is not yet full if he lacks the ability to make good free-hand sketches."

"To the designer of a new machine of any degree of complexity, a fair degree of skill in this direction is absolutely essential. He may have the clearest, possible conception of the relations of the parts and of the general arrangement of the whole, but without some visible record of that conception, to which reference can be made from time to time, he cannot proceed with any certainty of success in the elaboration of details. This record is in the nature of a sketch, though not necessarily wholly free-hand. Sometimes certain absolute dimensions are assigned as a basis, such, for example, as the bore and the stroke in a steam-engine."

"Or, again, definite movements must be provided for, and their elements reduced to settled proportions, as a preliminary; the resulting diagram forming the skeleton of the proposed structure. In either case some use of scale and instruments is, of course, proper, not to say necessary; but the filling out of this skeleton into the complete body is largely dependent upon free-hand work."

"Usually this dependence is direct, the designer at once sketching in the general arrangement, for the sake of having something before him as a guide in subsequent operations."

"In simple cases, however, he may proceed without this, to construct the details, adding them successively to his skeleton drawing, as each is completed. * * * In designing, then, perhaps the skeleton plan may indicate certain pins, which must be connected by a link; it may locate certain journals, and these must be supported by a frame with suitable bearings; it may give the position of certain orifices, which are to be joined by pipes with valves; and so on, in an endless variety of conditions and requirements. * * * Sometimes tentative methods are necessarily adopted, and in most cases there is a choice of ways and means, so that a judicious selection can be made only by comparison; in either event the utility of reasonably accurate sketches is self-evident, and from the nature of things it is equally apparent that they can be made most advantageously with the free hand, whether for the use of the maker, only, or for submission to the inspection and decision of another."

"Not only are the sketches directly made use of for their special purposes, but in the very process of making them and the necessary measurements, the habit of close observation is cultivated, and, in addition, impressions of relative, if not of absolute dimensions, insensibly fix themselves in the mind, and what may be termed a sense of proportion is developed, which, to the designer, is of the greatest value."

The principals of free-hand sketching, however, are so apparently different from those of mechanical drawing, that it is difficult for the beginner to harmonize the two.

We will take up the discussion of free-hand sketching by considering several classes of problems in which it enters and which are likely to meet the student in practical work.

First, to make a complete set of working drawing sketches. It may be the designer's problem, before mentioned, or it may be such a problem as discussed in the making of a complete set of working drawings. For the purpose of being able to set forth clearly a method, let us take a similar problem to the latter, that is, assume a set of working drawing sketches are to be made of a furnished model, or of a machine in the original.

These sketches may go upon the pages of a note book; it is not likely the same care in laying out sheets and grouping of related views will be made as for the regular working drawing. The same planning of necessary views, however, is required before any sketching is done.

Each view may be treated separately as was outlined for the working drawing, or where several related views are to be considered, they can be developed in the sketching even more advantageously, in fact, it is best in every case to take the several projection views of a piece and develop them together. A certain harmony of relation exists, which, in the absence of scaling, can be treated in no other way as well.

A particular scale is not generally a requirement in sketching, but the proper proportion of each view and their sizes relative to each other is, and this is one of the chief requisites of sketching.

Now let us make some observations about sketching in general, and as related to working drawing. A drawing is the record of the approximate relations of things, the relation of width to height, of the length of one line to the length of another, and so on. In setting down a value, it is to be observed that as one value in the subject is to another so should be the relation of the same two values upon the drawing. It is a proportion then of four members.

The fundamental value or data in beginning a sketch may be taken as anything desired; then upon it depends everything else drawn. That is, the length of a subject on a sketch may be assumed at will, and the width of it to be correct must be a certain size in comparison. The length and width over all having been ascertained, these can be taken as units for comparison with other sizes, and so on; as values become established they furnish the basis for the estimate of other values. The correctness of the sketch, then, is the correctness of the relations of the various values. Whatever helps in the establishment of correct values most readily assists the expeditious development of the sketch, and herein lies the problem of the draftsman. How can values be most correctly and expeditiously obtained? If small things are developed from the larger, this will be aided more than if the larger are derived from the smaller. As has before been mentioned, when dividing a line into a certain number of parts it is easiest to divide it first into halves, these halves into halves, making quarters, etc. This is not only expeditious, but if one size is taken wrong it does not affect all the others, as would be the case if a unit were stepped off the required number of times into the total distance to be divided.

The principle used in dividing a line is the same one as that which should be employed in making the whole drawing. The small values should not be treated first, but always after larger values upon which they depend.

Again, the method of getting any one value and in handling the pencil is characteristic of free-hand drawing. The touch in free-hand drawing is very different, indeed, from that in mechanical drawing. In the latter, it is very firm and certain for the rule and scale, etc., to guide the pencil. The pencil should be sharpened to a long tapering and fine point. It should be held well back of the point so as to allow of greatest freedom of motion, and in the beginning, the motion should be pretty nearly an arm motion with very little, if any, motion of the fingers. From the arm motion for larger values and forms, it should proceed to fore-arm motion for smaller values, and to wrist and finger motion for the smallest.

Nor are values everything to be considered. Direction of stroke needs to be studied, and this quite as much as the former, is attained through the free handling explained. A working drawing demands a relatively, clean cut mechanical line for a finish line. A line in free-hand drawing is not abtained by drawing from one point to another with a steady continuous motion, as a line is made in mechanical drawing by the pen or pencil against the rule edge. Certainty of direction without such aids is impossible, and it can only be realized approximately by a step-by-step process.

To draw a line, then, between two points the pencil is swung to and fro between the limits by a free arm motion, or fore-arm motion, if the distance is short, without making any visible record at first. It may be done by whatever holding of the pencil will give greatest freedom of stroke. It may be the arm will be held above the pencil point, may be below. When the motion of the arm seems to be guiding the pencil point fairly well between the limiting points, then a short record is made at these points, and then between giving as a result a suggestion of direction, not in any sense a line. If this record happens to be very far out, it may be erased and another put in. It should be replaced, if it is not fairly suggestive of the true direction. Performing the same operation again, intermediate records can be made to fill out a little more the suggestion, resorting to a free arm or finger motion, if feasible, and distance is short. These records should be very light, barely visible. Skill in drawing implies a control of the pencil, and until the final line is needed there is no virtue in hard dark strokes; on the contrary, there is distinct disadvantage, for if they prove incorrect, they are hard to change. A line should be developed, as described, by a series of approximations closer and closer to the desired line, and proceeding by stages that are similar. This ideal method of development is rarely realized in practice. After two or three approximations have been made it is customary to refine the line by going from one to the other, directly, making it by one final operation as straight and black as desired.

The principal precaution to be observed is to keep the preliminary approximations sufficiently light to permit of changes, if necessary, without spoiling the surface of the paper for additional lines. This can be done by cultivating and adhering to a light stroke; as soon as the approximations become blurred they should be cleaned up or removed to make way for closer ones.

The drawing of one line is not the only thing, however, to be kept in mind at one time. The relation of that line to all the other lines of the drawing is equally important, and this may be realized in the following way: Carry all parts of a figure through the same stage as the line. Lay out the limits of a figure by short approximate strokes; divide these limits into two or three of the principal subdivisions that suggest themselves by similar short approximate strokes, then proceed to smaller subdivisions and smaller in the same way. If subdivisions are not very apparent make arbitrary ones. Included as indicating subdivisions into parts are the center lines. It is a question in sketching whether the outside dimensions and division—where apparent—into smaller forms should precede the indication of center lines or not.

The two ought certainly to go pretty close together. The principal center lines should, of course, be located first, then the shorter and minor ones, and all be preserved clear throughout to furnish landmarks for guidance. If at any time through correction they should accidentally get rubbed out they should be put immediately back. They should be worked from in the sketch as they are in construction, the same is true of finished surfaces wherever they occur. Sometimes a very broken up contour or group of forms may be simplified for preliminary treatment by circumscribing them by one or more simple forms, such as enclosing rectangles.

After chief and minor subdivisions are made proceed to an approximate suggestion of form. But first check the results just obtained, in fact, check from step to step as approximations are made. As each new record is put down see that it harmonizes in every respect with all the other records made. As soon as a discrepancy is observed correct it by whatever change, upon careful survey, seems called for, in order to make it right; even if it should reflect upon fundamental measurements. A constant watch upon the developing drawing and the correct relations of things is the way to proceed. And, of course, the more there is recorded, the more things there will be to compare one with another, and the more accurately can each value be estimated. Each is a unit of measures for the other.

The first suggestion of the shape of the forms will tell much as to the truth of the forms. As each stage is completed the general survey should be made making these comparisons. After this very brief suggestion of shape, a fuller one should follow and then a fuller yet, until forms appear well defined and clear as did the subdivision of parts. So, stage by stage, each one of which is brief, the figures develop to completion. The accuracy of the drawing will depend upon the accuracy of the eye of the draftsman in making true estimates of the values and judgment in what is the important thing to be done at any particular stage of the drawing. It is not a straight-away mechanical operation, but requires discrimination.

The sketching of curved and circular forms will give trouble at first. Let us take a circle, for illustration, as the principles in treating all curves are the same.

It is not to be expected that a circle can be sketched with anything like accuracy. Two records should be made at opposite ends of right angled diameters, then two more intermediate diameters estimated. These sketch records, if nearly right, should give a fair suggestion of the circle. Next swing the hand in the direction of a short arc, not as much as a quadrant, and when it is felt the hand is swinging right sketch in more strokes; do this with an arc diametrically opposite in each of the quadrants, thus getting, at each step, equal balance in all parts; then by the same finishing approximations complete the curve. If time is short, and rapid practical results are desired, a piece of paper may be used to lay off a few points around the center to act as land-marks for the further work. Quite a good circle may be obtained in this way. It shows up especially well when a number of concentric circles are to be drawn, and when pure sketch methods might result in indifferent circles. Irregular curves can be treated in the same way, and generally, perhaps with better results, as we are not as familiar with irregular curves as we are with circles, and the same accuracy is not to be expected.

To get the proper relation of values, i. e., distances and sizes of lines, a certain ratio must be obtained. The ratio in perspective drawing or picture making is a very different problem from that in mechanical drawing. In the former the ratios are between sizes that are not of certain true length, but apparent lengths due to the obliquity of these lines to the observer, or foreshortening, as it is called, while in mechanical drawing these are absolutely being the practical lengths, as a rule, that are in the subject.

Now in almost all cases a sketch, being but roughly approximate, and although in proportion, is not made to scale, else the actual ratio which one dimension is to another might be used as a basis for the ratio maintaining in the drawing. It is rather better for training in seeing proportions and values that this is not the case, that an estimate of the ratio of actual values be made and the drawing adjusted to it by sight, rather than measurement.

Therefore, to obtain a value to record in drawing that is a ratio between two quantities, estimate the value in the original by assigning either a numerical ratio of simple numbers easily transferred, or else, carry a conception of the ratio value in the mind without assigning any numerical value. For illustration, if a certain detail be one-fifth as long as the over all dimension, then that detail in the drawing should be one-fifth as long as the over all. In some cases of rather large subjects it may be advisable to make a space measurement of sizes for comparison. For illustration, if a certain detail is one-fifth the length of an over all, a pencil may be held up between the eye and subject, and covering one end of the detail to be measured with the end of the pencil, and the other end by the finger moved along the pencil, this length may be compared with the over all by noting that it will go into it five times. Therefore, as the pencil unit is to the whole unit stepped off with it, so the detail in the drawing should be to the over all in the drawing. This method can be used where the quantities to be measured do not extend throughout a very wide range of vision, else the foreshortening, before mentioned, will cut a very serious figure and introduce inaccuracies. An eye estimate of values is better than an actual measurement made. After the drawing has all been made, however, its accuracy may be tested by these means very nicely.

It takes consideralbe practice and a faithful adherence to the principles of drawing just laid down to sketch advantageously, but once learned, the accomplishment is invaluable and finds usefulness in many minor ways in all drawing, even the mechanical.

Sometimes sketching may take the form of a hasty drawing or drawings of a model from which afterwards working drawings can be made. It is possible, generally, to get the data into two or three views sufficient to work up at leisure into a complete set of working drawings. In fact, the problem is to choose the fewest views which will accomplish this result, and some discrimination has to be exercised to ascertain what they are. Or it may be that the final drawing is to be one which shows all the constructive facts—without being a working drawing—with the fewest views. Such a problem is illustrated by a patent office drawing.

Sketching may be done upon regular sheets, but more frequently it is put upon scratch paper, or the pages of a note book. Use of a rule and compass is here not feasible. If done on the pages of a note book, the first problem is to adopt such a size that the subject may be treated properly and legibly. It may involve only one view on a page, or it may involve two or more. If there is room for more than one view on a page they should be sketched in the same projective relation to one another that they would be if mechanically drawn, and upon the different sheets of the note book, as far as possible, the views should be sketched in the same position that they would occupy, if drawn mechanically on a sheet; otherwise, a little confusion in reading the sketches may result. Where several views are to go on one page, in the sketching they should be roughly blocked out for proper allotment of space before doing further work upon any one view; where feasible, sketch them together throughout.

In very rare cases a whole view even cannot be put on a sheet. It should be stopped at a conventional line, such as was described in the case of sections where the plane of the section moved from one place to another, and it is furthermore best to sketch the two or more parts on the sheets in the same relative position so that, if called for, they may be cut along the line of their separation and fastened together to make the complete view.

Views of parts should be sketched as occupying the relative position which they would in the machine.

Some further practical points about sketching want to be kept in mind.

(a) Throughout sketching, it is important to observe, carefully, right angles and the rounded corners; the latter may, in the preliminary operations, be made sharp, and only in the final stage rounded off to the desired amount. Be sure that the right angles are always as near right angles as they can be made.

(b) Where forms are symmetrical upon a center or center line, sketch the two or more parts at the same time. This plan of symmetrical development was instanced in the directions given for the drawing of a circle. No other symmetrical form should be treated in any other way. The brief preliminary record made upon one side should be followed by the same record on the other side, and as each stage is gone through with on the one, it should be followed by the same stage on the other. The mistake is quite common to draw one side of thing that is symmetrical on an axis and then copy it faithfully on the other. It is very much more difficult to get symmetry in this way.

(c) The sketches of a subject, if made from a model or the original, should be finished complete before any dimensions are put on, for the problem of sketching does not involve scale or absolute size, it is better if these are not considered. And it is to be observed that the lines of the sketches should be much sharper and blacker if they are to be dimensioned, than if left without, for dimension lines and figures cover up form. When sketches are ready for dimensions these should be taken from the subject in the way heretofore described for mechanical drawings, noting in particular to take only one dimension at a time; do not attempt to deal with more than one.

(d) Sometimes sketches must be made hurriedly, when it is very important to subdivide the time to be used into parts to be given each to certain stages of the drawing. Roughly speaking, about as much time should be allowed for dimensioning as that for making the sketches. Again, the time allotted for sketching may be divided into parts, three of which to be given to the light preliminary work, and one part to finishing up in clear line, for the proportioning and the shape are more important than the character of the line.

(e) If it should happen that time has been improperly allotted, or that a great deal has to be accomplished in a very short time, it may be disirable to cut steps short by leaving out certain things. Where parts are duplicated, for example, they need not be drawn but once. Where forms are encountered which are perfectly understood, like wheels, only a small portion needs to be sketched. Much can frequently be omitted by giving a few written directions explanatory of them; this is true of holes for bolts, fastenings of a similar character, etc.

(f) Where forms are symmetrical upon a center line only one half needs to be sketched; where symmetrical upon a center perhaps only one quarter, a note being used to refer to the omitted part. But these short cuts to save work and time should be confined to the sketch, and not used indiscriminately in the working drawing. It is better to run the chance of being superfluous in the working drawing than to be insufficient, leading to misunderstanding.

(g) It very occasionally may happen that a complicated subject must be drawn in a very compact space, and in short time. There may not be room upon the pages of the note book to develop the forms, either entire or in separate parts, and even proper proportioning is not feasible. It may be necessary to sketch neglecting proportions entirely, or it may be convenient to change one dimension without changing the other. Again, it may be that some parts can be shown in proportion, while others are not, compressing the drawing where needed to make it fit the space. These are practical problems that can easily be solved when they arise. With a knowledge of the principles of sketching, it becomes merely the question of recognizing the limiting conditions of the particular problem in hand. The draftsman who expects to do comprehensive work cannot afford to be without a knowledge of sketching.

58. Blue print process and reproduction:

A mechanical drawing made to be worked from is generally reproduced by blue print, or analogous process. A drawing may be reproduced in photo engraving to furnish a cut for a catalogue.

The following upon the subject of blue prints is taken from F. N. Willson's Theoretical and Practical Graphics:

"A sheet of paper may be sensitized to the action of light by coating its surface with a solution of red prussiate of potash (ferrocyanide of potassium) and a ferric salt. The chemical action of light upon this is the production of a ferrous salt from the ferric compound; this combines with the ferricyanide to produce the final blue undertone of the sheet; while the portions of the paper, from which the light was intercepted by the inked lines, become white after immersion in water."

"The proportions in which the chemicals are to be mixed are, apparently, a matter of indifference, so great is the disparity between the recipes of different writers."

The entire process, while exceedingly simple in theory, varies, as to its result, with the experience and judgment of the manipulator. To his choice the decision is left between the following standard recipes for preparing the sensitizing solution. The "parts" given are all by weight. In every case the potash should be pulverized, to facilitate its dissolving.

No. 1. FROM LE GENIE CIVIL.

SOLUTION.

No. 1.	Red Prussiate of Potash............	8 parts
	Water............................	70 parts
No. 2.	Citric of Iron and Ammonia.........	10 parts
	Water............................	70 parts

Filter the solutions separately, mix equal quantities and then filter again.

No. 2. FROM THE U. S. LABORATORY, WILLETT'S POINT.

SOLUTION.

No. 1.	Double Citrate of Iron and Ammonia.	1 ounce
	Water............................	4 ounces
No. 2.	Red Prussiate of Potassium.........	1 ounce
	Water............................	4 ounces

"The solutions should be dissolved separately, as then they are not sensitive to the action of light. They should be mixed and applied only in the dark room."

"The best American practice is to apply the solution with a flat brush, and to obtain an even coat by stroking first one way, then at right angles. If necessary, a coat of diagonal strokes may be given to secure evenness."

"To copy a drawing, it is placed in a blue print frame made for the purpose, the sensitized paper, with the sensitized surface outermost and immediately back of the drawing. Exposure for about five minutes to the rays of the sun is usually sufficient to get good results, after which the paper is taken out and placed in a bath of water when the superfluous chemicals are washed off."

"White lines can be drawn upon a blue print by using a solution of soda, potash, quick lime, or any alkali with water, adding a little gum arabic to keep the liquid from spreading. It can be applied with the writing pen, ruling pen or brush, according to the area desired to be white."