ELEMENTS OF

MECHANICAL DRAWING

THEIR APPLICATION AND

A COURSE IN MECHANICAL DRAWING FOR ENGINEERING STUDENTS.

BY

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PREFACE.

Having in charge the instruction of the Freshman Class, Purdue University, in the subject, the writer has compiled the accompanying notes on Mechanical Drawing to facilitate the work of administration.

The intent, throughout, has been to prepare a work embracing those branches of the subject necessary to give the student such knowledge as will prepare him to pursue a course in Engineering, and such practice in drawing as will qualify him to do ordinary commercial draughting.

The work is arranged for students having a knowledge of plane geometry such as is offered in the High Schools, Preparatory Schools, and Colleges.

Acknowledgment is made of many valuable suggestions and criticisms offered by Professors M. J. and Katherine E. Golden, and by Messrs. R. B. Trueblood and A. M. Wilson, co-laborers in the work of administration.

A. P. Jamison

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MECHANICAL DRAWING.

PART I.

CHAPTER I.

ELEMENTARY PRINCIPLES AND DEFINITIONS.

1. **Drawing.**—Drawing is the art of putting one's impressions into visible form, and may be divided into two general classes: (1) the drawing of objects viewed from a finite distance, and (2) the drawing of objects viewed from an infinite distance.

2. **Drawing of Objects as they Appear.**—By the first class of drawing is meant the free-hand work of the artist, drawings of things as they appear to the eye, as they impress one. In such drawing there is but one point of sight *—the observer's eye—and the lines of sight † are straight lines radiating from this one point and extending to the different points of the object or objects, as the case may be. (See Fig. 1.) Paintings of landscapes, portraits, miniatures, the sketch-work of the newspaper artist, etc., are examples of this class of drawing.

3. **Drawing of Objects as they Exist.**—By the second class of drawing is meant the drawing of objects as they actually exist and not as they appear to the eye. Such drawing is called "Mechanical Drawing," and the point of sight being at an infinite distance, the lines of sight are practically parallel and are so

* The point of sight is that point, imaginary or real, from which an object is viewed; we see with two eyes, but only one point of sight is assumed.

† A line of sight is an imaginary straight line connecting any point of the object and the point of sight.

assumed. Fig. 2 depicts the lines of sight for such drawing. Drawings of machinery, bridges, masonry construction, plans for

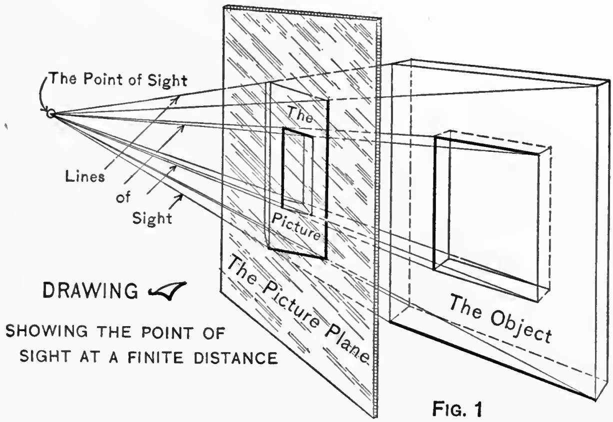


FIG. 1

buildings, etc., are examples of this class of drawing, and this is the kind of drawing with which engineers are concerned.

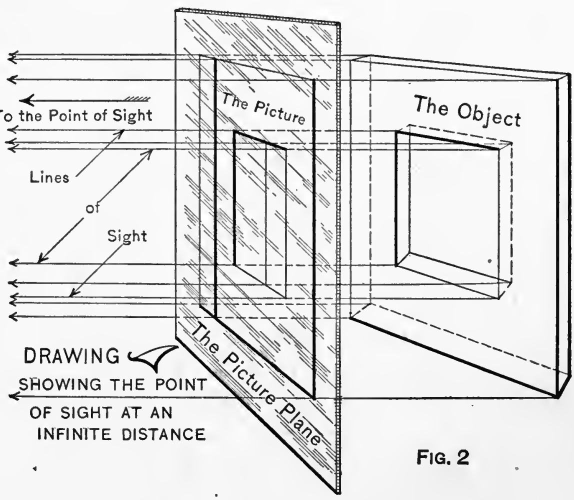


FIG. 2

Mechanical Drawing may, in turn, be divided into two general classes: (1) detail drawing and (2) assembled drawing.

4. Detail Drawing.—To detail means to separate, to "tell" in detail; detail drawing means to separate an object—a machine, for example—into its various parts and to tell of each by a mechanical drawing of it. Detail drawings are used for shop purposes, that is, for "getting out ' the piece—for its manufacture.

5. Assembled Drawing.—To assemble means to collect into one place or body; assembled drawing means to collect the various parts of an object—a machine, again, for example—and to draw it assembled as a whole. Assembled drawings are to "picture" the object as it will appear when complete. Such drawings are mostly used for erection purposes.

Detail and assembled drawing may be subdivided into two other general classes: (1) shop drawing and (2) show drawing, presenting the subject "Drawing" thus:

6. The Divisions of Drawing.

- Drawing.
  - Drawing of objects as they appear, called Perspective Drawing. (The point of sight at a finite distance.)
  - Mechanical Drawing. (The point of sight at an infinite distance.)
    - Detail Drawing.
      - Shop drawing.
      - Show drawing.
    - Assembled Drawing.
      - Shop drawing.
      - Show drawing.

7. Shop Drawing.—A shop drawing is a drawing to facilitate manufacture, and may be a detail or an assembled drawing, or both. It is usually an outline * drawing, very plain and free from ornamentation.

8. Show Drawing.— A show drawing is a drawing calculated to facilitate the sale of an article. It is usually an ornamented drawing,† and is used for catalogue and "show" purposes.

9. Relation of the Lines of an Object.—Every line of an object bears a certain relation to every other line of the same object, and in a mechanical drawing of that object the lines of

* An outline drawing is a single-line drawing of the outline of an object.

† An ornamented drawing is a drawing beautified by the addition of shades and shadows, colors, ornamental lettering, etc.

the drawing must be so arranged as to present this relation to the eye.

For example, consider a cube: all of its edges are straight lines, and are either parallel or perpendicular to one another; therefore, in the mechanical drawing of the cube all of the lines of the drawing must be straight lines either parallel or perpendicular to one another; furthermore, two adjacent edges of the same face are at right angles to each other, and opposite edges are parallel; hence in the mechanical drawing of that face the two adjacent lines must form a right angle and opposite lines must be parallel. From this it is obvious that the mechanical drawing of any one face of a cube is a perfect square.

10. Relation of the Faces of an Object.—To maintain the relation of the lines of an object it is necessary that a separate

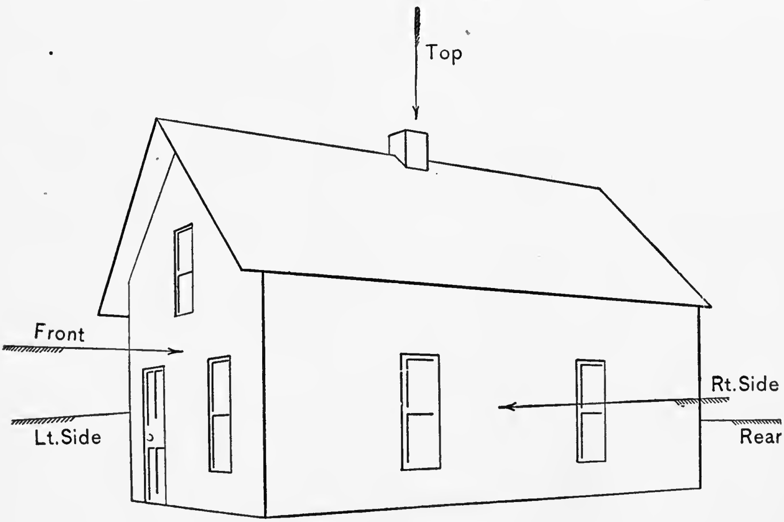


FIG. 3.
A Perspective Drawing.

drawing of every face, or side, be constructed, for, in addition to the relation of the lines of an object, the faces of that object bear a definite relation to one another. To depict the relation of the faces of an object they are referred to one face called the "front face."

11. Choosing the Front Face.—To represent these relations on paper it is necessary that the front face be decided on. In most cases this is readily determined by the objects' use and natural position.

For example, consider the ordinary dwelling-house: it fronts a certain way and has a well-understood front. Facing this end of the building, one views the front face. (Fig. 3.) That face on the right hand is called the right face or side; that on the left, the left face or side; the face at the rear, the rear face; etc.

This reasoning applies to any object as well as to the building in question; but should there be no well-defined front face, the choosing of one is optional with the draughtsman.

12. Relation of Lines and Faces Shown by a Complete Mechanical Drawing of a Cube.—Having determined upon the front face of an object, construct a drawing representing all the lines of that face in their true position and relation with respect to one another. For a cube, as before stated, the drawing of the front face will be a perfect square; likewise, the drawing of all of the faces will be perfect squares. Now to "show" the relation of these various faces:—

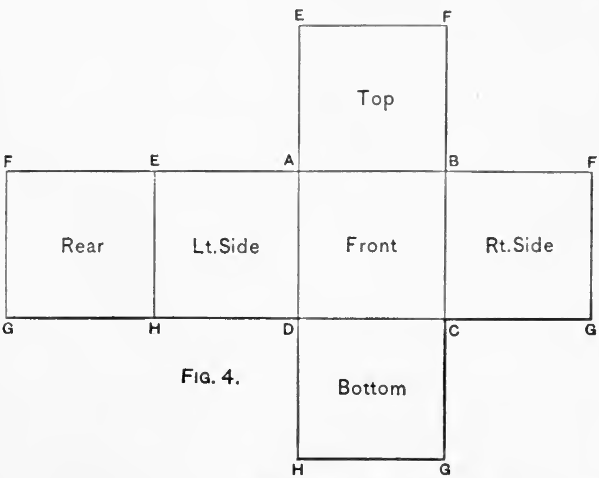


FIG. 4.

A Mechanical Drawing.

(Fig. 4.) Beginning with the front face, *A-B-C-D*, drawn, the right face is at the right side of the front face and is tangent to it, having the line (edge) *B-C* in common with it; the left face is at the left of the front face and has the line (edge) *A-D* in common with it; the bottom is at the bottom and is tangent along the line *D-C*; the top face is at the top and has the line (edge) *A-B* in common with the front face.

The rear face yet remains to be provided for; this face has an edge in common with the right face, one with the left face, one with the top and one with the bottom face. The drawing representing the rear face may be placed tangent to any one of the drawings representing the above faces; the one taken is usually determined by the limits of the paper, but is optional with the draughtsman.

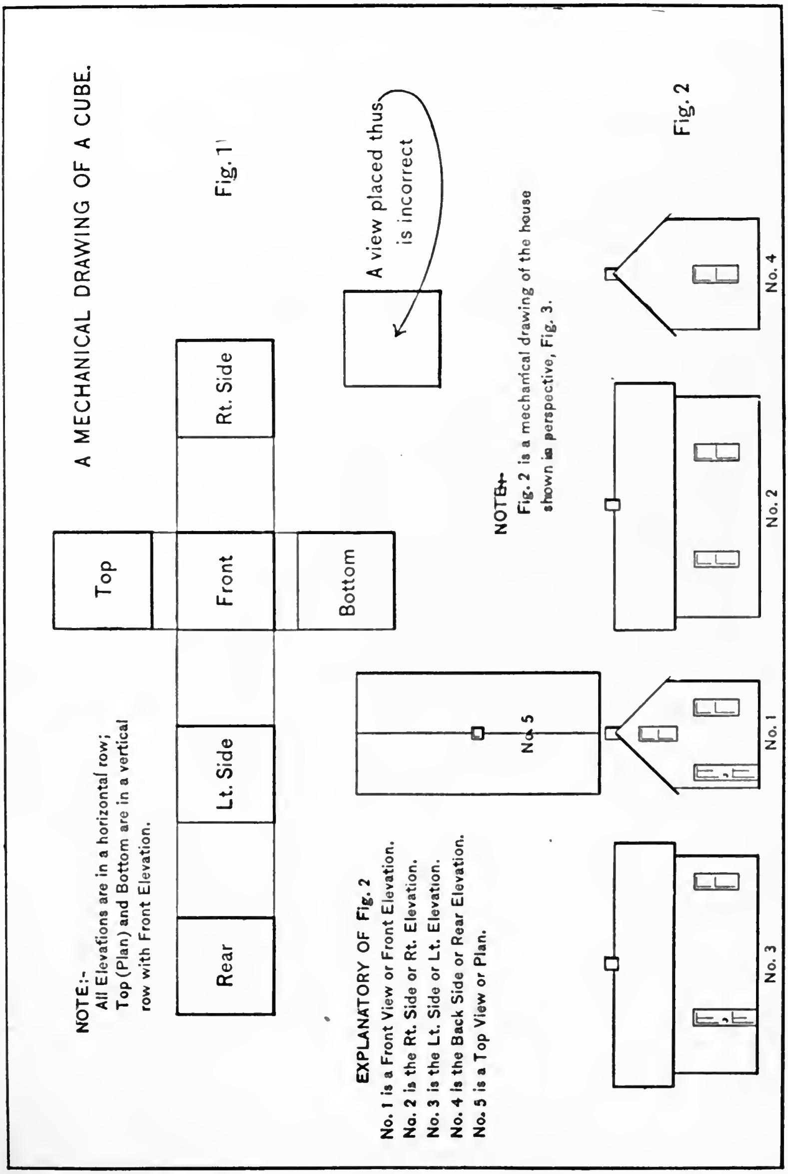
13. **Arrangement of the Drawing.**—Should all drawings be constructed with adjacent sides tangent along common lines the drawings would not admit of the convenient addition of dimension lines, figures, and notes—details necessary to every drawing; also, such an arrangement would only apply to rectangular figures. For the convenient application of the foregoing principles the drawings are separated an optional distance (Fig. 1, Plate No. 1), those at the sides of the front face—the right and left faces—being moved in a horizontal direction only, and those at the top and bottom moved in a vertical direction only.

It will be observed that all of the drawings are contained between two pairs of lines, one pair horizontal and the other vertical; should one or more of the drawings be "out of line" with these two pairs of lines the drawing would be incorrect.

14. **Definition of Mechanical Drawing.**—From the foregoing, a mechanical drawing of an object may be said to be a separate drawing of each face of the object, and these several drawings so arranged as to bear the proper relation to one another.

15. **Naming the Drawings.**—In the explanation mention has been made of the different faces of an object; the several drawings representing these faces are now to be named.

PLATE No. 1.


A MECHANICAL DRAWING OF A CUBE.
Fig. 1
Top
Rt. Side
Front
Bottom
Lt. Side
Rear
NOTE:-
All Elevations are in a horizontal row;
Top (Plan) and Bottom are in a vertical
row with Front Elevation.
A view placed thus
is incorrect
NOTE:-
Fig. 2 is a mechanical drawing of the house
shown in perspective, Fig. 3.
Fig. 2
No. 4
No. 2
No. 1
No. 3
No. 5
EXPLANATORY OF Fig. 2
No. 1 is a Front View or Front Elevation.
No. 2 is the Rt. Side or Rt. Elevation.
No. 3 is the Lt. Side or Lt. Elevation.
No. 4 is the Back Side or Rear Elevation.
No. 5 is a Top View or Plan.

The drawing representing the front face of an object is called a front view or front elevation, and drawings of the right and left faces are called side views, right and left elevations respectively, or collectively side elevations, and the drawing representing the rear face is called the rear view or rear elevation.

16. Elevations.—Elevations are views in which all of the lines of sight are parallel, horizontal lines. Side elevations are at right angles to the front and rear elevations, and vice versa. Elevations should always be between the same limiting pair of horizontal lines. (Fig. 1, Plate No. 1.)

17. Plan and Bottom.—The drawing representing the top of an object is called the top view or plan, and that of the bottom is called the bottom view or bottom. Plan and bottom are views in which all the lines of sight are parallel, vertical lines.

Plan and bottom are at right angles to elevations, and vice versa. Plan and bottom should always be between the same limiting pair of vertical lines with an elevation. The plan may be in line with one elevation, and the bottom view in line with a different elevation and the drawing be correct, though usually they are in line with each other and with the front elevation.

A name has now been given the drawing of each face of an object, though a plan and one or two elevations are quite sufficient to represent simple, solid objects. To represent objects with "interior features," it is necessary to add other views than those given above, views called "sections."

18. Sections.—To section means to separate by cutting, the "section" being that portion cut; in mechanical drawing, a section is a drawing of the cut portion.

Sections may be divided into three general classes: (1) longitudinal sections, (2) transverse sections, and (3) angular sections. These may be divided into full, half, and detail sections.

19. Longitudinal Section.—A longitudinal section is a section in the direction of the length of an object and may be horizontal (cut on a horizontal plane), vertical (cut on a vertical plane), or angular (being cut on a plane at some intermediate angle).

20. Transverse Section.—A transverse section is a section at right angles to a longitudinal section, and may be horizontal, vertical, or angular according to the position of the plane on which it is cut.

21. **Angular Section.**—An angular section is any other than a longitudinal or transverse section.

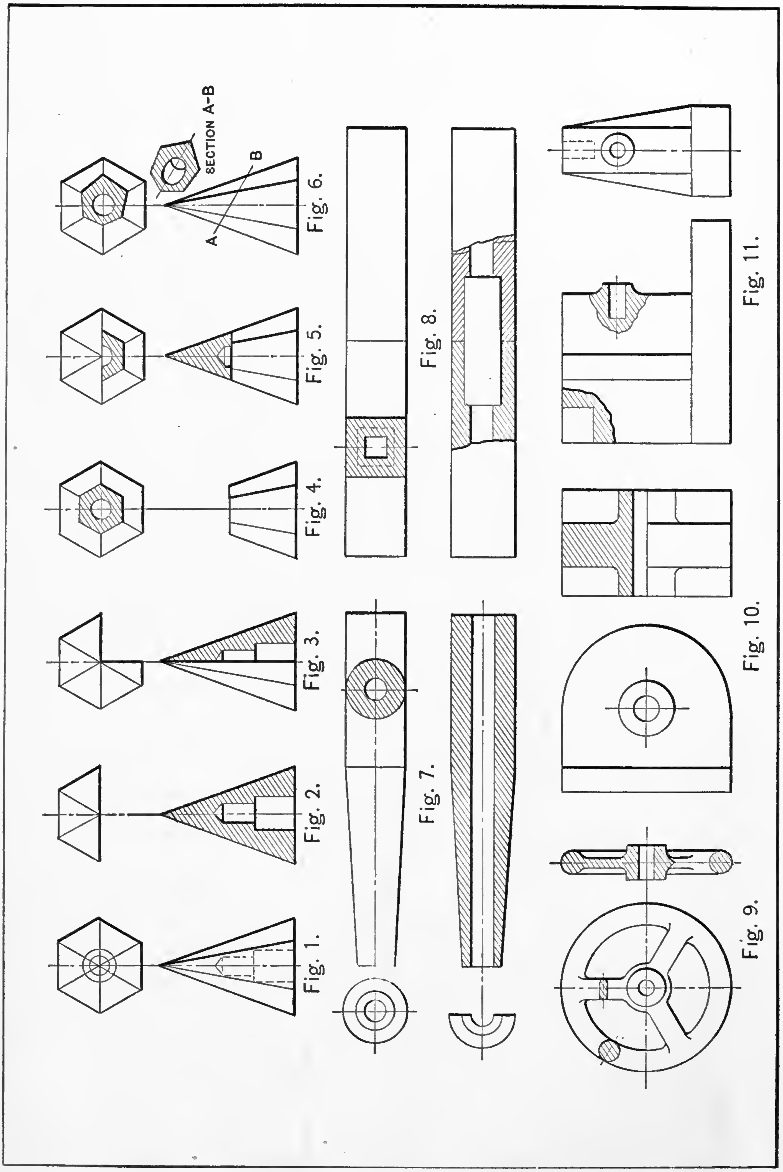
22. **Full Section.**—A full section is a section made by cutting entire and in one plane, that is, by cutting in two.

23. **Half Section.** A half section is a section made by cutting in two planes at right angles, that is, by cutting out one quarter.

24. **Detail Section.**—A detail section is any specially taken section.

25. **Explanatory of Sections.**—Plate No. 2. Fig. 1 is a mechanical drawing (plan and elevation) of a rectangular pyramid, the dotted lines representing a hole in it—"interior features." Fig. 2 is a full, longitudinal section, the drawing being a plan and elevation of one-half of the pyramid and showing only visible lines. Fig. 3 is a similar drawing of a half, longitudinal section of the pyramid. Fig. 4 is a plan and elevation of a full, transverse section, and Fig. 5 a like drawing of a half, transverse section of the pyramid. Fig. 6 is a plan and elevation of a full, angular section, the inclined line (*A-B*) across the elevation indicating the plane on which the section is taken; the view between the plan and the elevation is a drawing of the cut portion and is the conventional method of representing such sections. Fig. 7 is a left and front elevation of a hollow tube, the lined portion in the right end of the front elevation being a conventional method of indicating a full, transverse section. The lower portion of the drawing represents a horizontal, full, longitudinal section and is a front- and end-view drawing. Fig. 8 depicts a full, transverse section, and a full, detail, longitudinal section showing the manner in which the two pieces are held together. Fig. 9 is a front and side elevation of a small, three-armed hand-wheel; the drawing at the right being a side elevation, sectioned, and being cut in two, is a full, sectional elevation; the left figure illustrates the use of detail sections. Fig. 10

PLATE No. 2.


SECTION A-B
A
B
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.
Fig. 9.
Fig. 10.
Fig. 11.

shows a half, sectional elevation, and Fig. 11 another example of detail sectioning.

26. Drawing Sections.—In drawing sections it is customary not only to draw the cut portion, but also all points and lines that are visible when viewing the section; however, it is allowable, and often quite convenient, to draw the cut portion only.

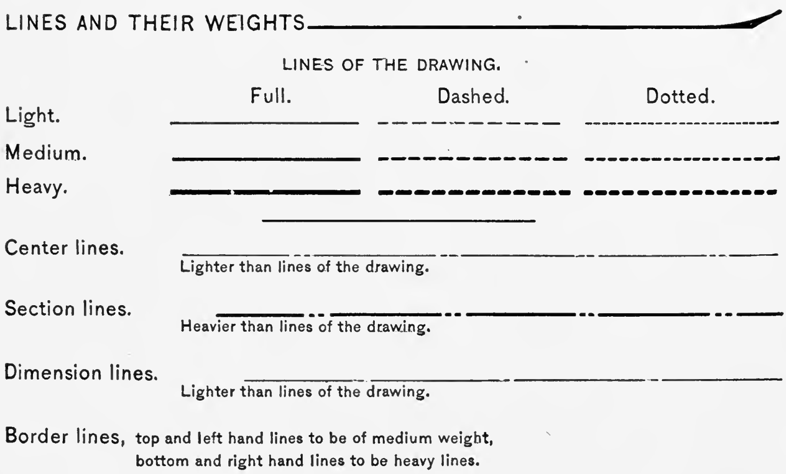
27. Arrangement of Sections on the Drawing.—It will have been noted that the plan, elevations, and bottom view have specially assigned positions on the drawing.. The drawing of sections, in so far as possible, should be placed as follows: All sections taken on a horizontal plane, conventionally indicated by a horizontal line (usually a horizontal center line), should be placed either above or below the view sectioned. All sections taken on a vertical plane, conventionally indicated by a vertical line (usually a vertical center line), should be placed either to the right or to the left of the view sectioned. All sections taken at an angle, conventionally indicated by a straight line drawn through the portion to be sectioned, should be placed at right angles, either way, to the line (plane) on which the section is taken—the general rule being to assume the section as taken, that is, the object as having been cut at the proper place, and calling this a front elevation, to draw a plan, bottom, or side elevation, as the case may warrant, of the cut portion.

Sections are usually indicated as being cut portions by certain conventions applied to the drawing, the most common of which is a process called "cross-hatching."

28. Cross-hatching.—In drawing, to cross-hatch means to rule the drawing with straight lines, usually at forty-five degrees to the horizontal, thus indicating that the drawing is a representation of a cut portion and, at the same time, indicating the kind of material by the arrangement of the lining—different materials being represented by different cross-hatchings. (See Standard Cross-hatchings, page 179.)

When two pieces of the same material are shown together in a drawing, the cross-hatching should have different directions, being usually "hatched" at right angles. When three or more pieces of the same material are shown together, no two pieces should have the same angle and direction. When two pieces of different materials are shown together, the distinction is indicated by the different lining, though it is desirable to make the drawing more readable by changing the direction of the cross-hatching also. When three or more pieces of different materials are shown together, it is best to have a new direction for the cross-hatching of each.

29. **Lines.**—Since drawings consist of different kinds of lines it is well to give a specific name to each kind.



30. **Lines of the Drawing.**—Those lines which go to make up the drawing of an object are called lines of the drawing and may be either full or broken lines, light or heavy, entire or in combinations.

31. **Border Lines.**—Border lines are lines which are drawn about a drawing inclosing it after the manner of a picture-frame, and are usually straight lines forming a rectangle. They vary greatly, however, as border lines are often of original design.

32. **Center Lines.**—Center lines are broken lines drawn through the center of a drawing or drawings, as the case may

be, and are used to "align" the different views—to produce an axis of symmetry. When two center lines are employed, they are usually at right angles, one being horizontal and one vertical. Center lines are used only on such drawings as naturally seem to require them, that is, on drawings of turned work and on those which can be symmetrically divided by such lines. (See Figs. 5 and 6.)

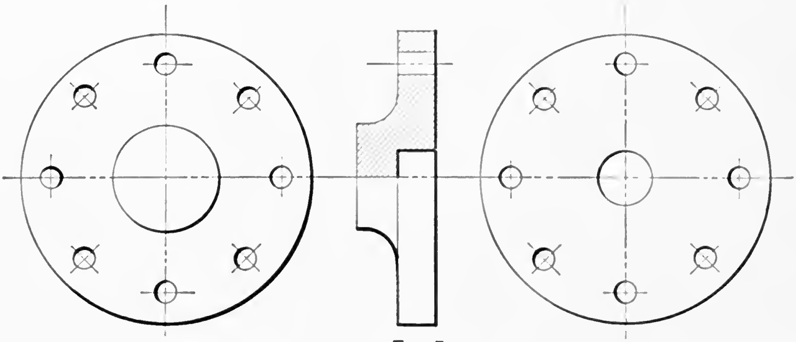


FIG. 5

Such Drawings require the Use of Center Lines.

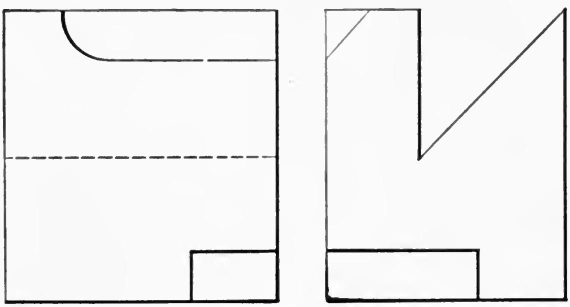


FIG. 6

Such Drawings require no Center Lines.

33. Section Lines.—Section lines are broken lines carried through the drawing to indicate the line (plane) on which the section has been taken—the line on which the object has been cut.

34. **Construction Lines.**—Construction lines are auxiliary lines used in the construction of the drawing and usually do not appear on the finished drawing.

35. **Projection Lines.**—Projection lines are construction lines, usually horizontal or vertical, or both, and are used to project from one view to another. The horizontal limiting lines for all elevations and the vertical limiting lines for plan, elevation, and bottom are examples of projection lines.

36. **Dimension Lines.**—Dimension lines are broken lines terminating in arrow-heads which, together with figures, when added to the drawing enable the observer to read the sizes of the various parts.

37. **Guide Lines.**—Guide lines are light pencil lines used as guides in lettering.

38. **Light and Shade.**—Without light and shade a drawing is merely a flat outline. It is often necessary and at times quite desirable to give the drawing some projection, to cause it to "stand out" from the paper, to give it relief, in which case it is necessary to introduce light and shade; this is called "shading the drawing."

The shading of drawings is rarely resorted to for drawings representing flat surfaces, being most helpful when applied to drawings representing curved surfaces.

39. **Line Shading.**—Line shading is lining the drawing with lines of varying weights and spacings.

In all drawing the rays of light are assumed to strike the plane of the paper at an angle of forty-five degrees, usually taken as coming from the left. If a surface is uniformly covered with light, it is said to be in the light; if uniformly covered by a shadow, it is said to be in the shadow. From the former to the latter there are all degrees of light and shade—from that point at which the rays of light are reflected by the object to the observer's eye, which is called the brilliant point, to that point from which all rays of light are obscured.

40. **Shade or Shadow Lining.**—Shadow lines are lines representing those surfaces of an object which are in the shadow. The

application of shade or shadow lines to drawings is the practical method of "shading" drawings, the convention being as follows: Assume the drawing to be the object itself, and assume the parallel rays of light to extend across the plane of the paper and as coming from the upper left-hand direction, that is, from the top and left sides of the paper; then make those lines heavy which represent

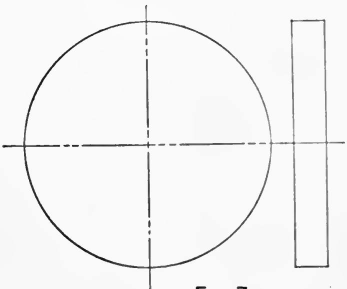


FIG. 7

Lines of Uniform Weight.

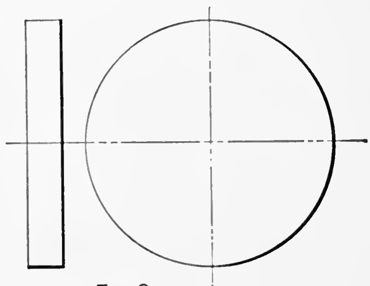


FIG. 8

Shade Lined.

A MECHANICAL DRAWING OF A FLAT PLATE.

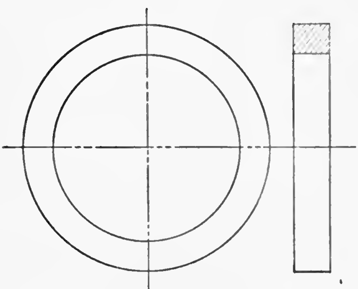


FIG. 9

Lines of Uniform Weight.

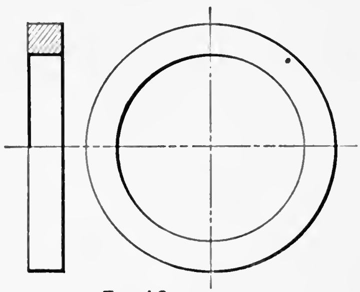


FIG. 10

Shade Lined.

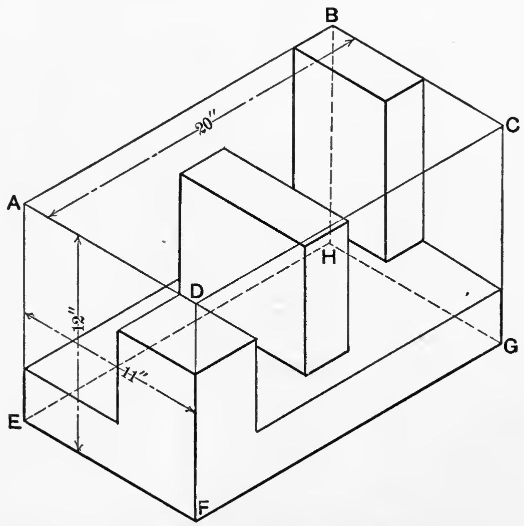
A MECHANICAL DRAWING OF A RING.

surfaces from which the light is excluded—a process which is sometimes called "back-lining." (See Figs. 7, 8, 9, and 10.)

It is obvious that the right-hand and bottom lines, for drawings representing solid objects, and the upper, or top, and left-hand lines, on drawings of interior features—holes, etc.—are the proper lines to shade.

41. **Drawing to Scale.**—In mechanical drawing the drawings are usually drawn to scale, that is, the drawing is made to be of the same size as the object or some proportional size thereof. When possible it is best to make the drawing full size—the same dimensions as the object; in any case, however, it is well to choose such a scale as will make the drawing as large as possible. The usual scales are full size, three-fourths size, one-half size, and one-quarter size for comparatively small objects, and for those of large dimensions one-eighth size, one-twelfth size, one-sixteenth size, one-twenty-fourth size, one-thirty-sixth size, one-forty-eighth size, etc.

42. **Choosing the Scale.**—In choosing the scale for any particular drawing there are three things to be considered: (1) the



THE OBJECT TO BE DRAWN
Fig. 11

dimensions of the object to be drawn, (2) the dimensions of the sheet of paper on which the drawing is to be made, and (3) the number of views to be drawn. With these known we have the full size of the drawing known, not only of any one view alone, but of the several views collectively—the mechanical drawing of the object—and the size of the sheet of paper to receive the drawing; it is then a simple matter to calculate the largest scale possible to fit the conditions.

EXAMPLE.—Let Fig. 11 represent the object to be drawn, let Fig. 12 represent the sheet of paper to receive the drawing—it

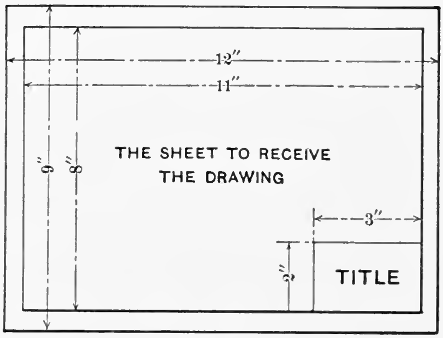


Fig. 12

being the standard sheet for the exercises of the Course—and let it be required to draw three views: (1) a plan, (2) a side elevation, and (3) an end elevation.

Assuming the object to be inclosed within a rectangular box as indicated by the figure *A-B-C-D-E-F-G-H*, note that the plan, or top view, is inclosed within a rectangle which is 20″×11″ in dimensions, that the side elevation is inclosed within a rectangle the dimensions of which are 20″×12″, and that the end elevation is inclosed within an 11″×12″ rectangle. (See Fig. 13.)

As to arrangement, it is fundamental, of course, that the long dimension of the drawing should be placed according to the long dimension of the sheet to receive the drawing; this dimension (of the drawing) is the sum of the length of the side elevation and the width of the end elevation and is 31″. The short dimension of the drawing is the sum of the height of the side elevation and the width of the plan and is 23″. A full-size drawing, then, would occupy a space 31″×23″; the space to receive the drawing is 8″×11″. With these figures known it is simply a problem in arithmetic to reduce the dimensions of the full-size drawing to fit the paper; the largest size possible is

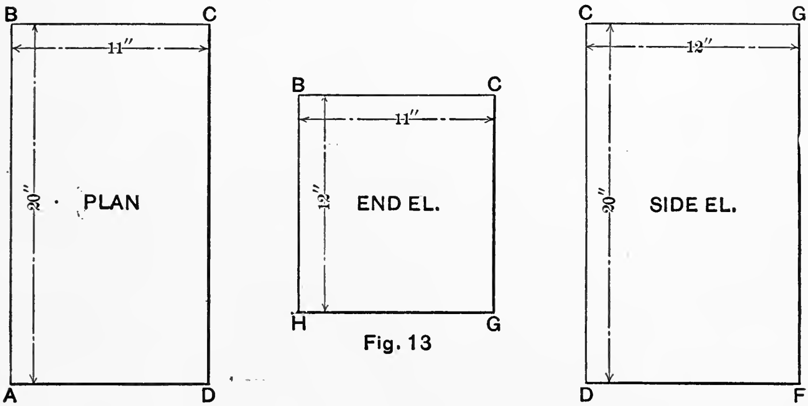


Fig. 13

evidently one-quarter size, $7\frac{3}{4}'' \times 5\frac{3}{4}''$, and to fit the conditions let the drawings be arranged as in *A*, Fig. 14.

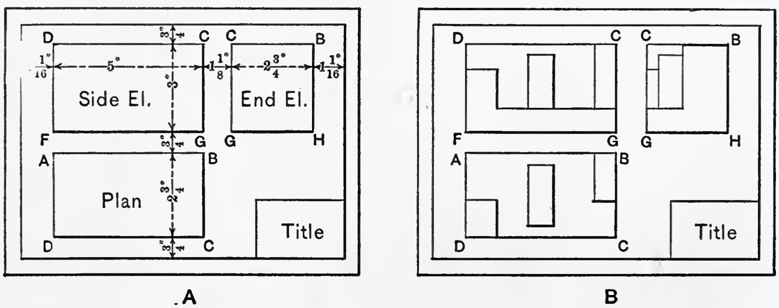


Fig.. 14

43. **Balance and Symmetry of a Drawing.**—A correct mechanical drawing of an object can be made and yet not present a very good appearance. The appearance of a drawing is a large measure of its value, and the draughtsman who would be successful should exercise due care to execute well-appearing, correct drawings.

The essentials for a well-appearing drawing are: a neat, clean-cut drawing of the various views, neat and well-made lettering, the dimensions carefully planned, and the whole so placed on the paper as to present a well-balanced effect with respect to the border lines and with one another, and a symmetry with any and all center lines that may be used on the drawing.

A careful draughtsman will calculate the "balance" of his sheet —the space between views and between the drawing and the border lines—before beginning the drawing, a good general rule for which is as follows: First decide upon the number of views to be drawn; second, decide upon the arrangement of the views; third, calculate the space required for the drawing; fourth, ascertain the dimensions of the sheet of paper to receive the drawing; fifth, subtract the dimensions of the space required for the drawing from those of the space available; and sixth, divide the remainders by the number of the respective spaces to be provided.

EXAMPLE.—Let it be required to calculate the "balance" for the conditions given in the example of section 42. To begin with, the space required for the drawing ($7\frac{3}{4}'' \times 5\frac{3}{4}''$), the space available ($8'' \times 11''$), and the arrangement of the views (*A*, Fig. 14) are known.

An inspection of the arrangement shows that there are three spacings each way (horizontally and vertically) to be provided: (1) a space between views and (2 and 3) a space between the drawing and the border line of the sheet. To get the horizontal spacing, subtract the horizontal dimension ($7\frac{3}{4}''$) of the drawing from the horizontal dimension ($11''$) of the sheet and divide the remainder ($3\frac{1}{4}''$) by three; when the remainder does not divide evenly, as in this case, a compromise may be arranged as is shown in Fig. 14. To obtain the vertical spacing, subtract the vertical dimension ($5\frac{3}{4}''$) of the drawing from the vertical dimension of the sheet and divide the remainder ($2\frac{1}{4}''$) by three.

44. Flexibility of the Drawing.—It seems, at first thought, a strange and very unnecessary procedure that certain rules be given for the proper arrangement of the views of a drawing, as has been done in the first part of these notes, and then to depart from their literal meaning, as is done in Fig. 14.

The arrangement given in Fig. 1, Plate No. 1, is the proper and most clearly understood arrangement, and should be adhered to when possible. In the construction of a drawing, the limits of the paper and reserved spaces—space for title, notes, etc.—are important factors to be considered, and for the most economical use of the sheet the drawing should be so made that it, together with the lettering, the title and notes, will completely fill the sheet and the whole be made to present a full and well-balanced appearance. To do this it is often necessary to violate the given rules and to make the arrangement to fit the conditions—it must be flexible.

A clear understanding of the rule is first necessary, and having the underlying principles well in hand it will always be a simple matter to adjust the drawing to fit any and all conditions and yet fulfill the requirements for a correct mechanical drawing. For this reason the rule is given and should receive due consideration.

The first requirement of a mechanical drawing is to "show" the object, and any arrangement which does this clearly is a correct arrangement.

45. **Dimensioning.**—Dimensioning is one of the most important and widely discussed details of mechanical drawing, each and every shop using that system which works out most satisfactorily for its particular work. Some shops use the decimal system—"engineer's scale" (sect. 100)—giving the dimensions in hundredths parts of the unit used, as .09 of an inch, the inch being the unit.* Other shops use the "architect's scale," giving the dimensions as ½ inch, ¼ inch, ⅛ inch, etc., the inch being the unit used, and this is the system most widely in use. Again, some shops—mostly in boiler-work—give dimensions in inches entirely, as 108 inches, while other shops use feet and inches, as 10 feet 4 inches, which latter system is the one usually used, and this, in turn, is varied when the dimension to be given is an even number of feet, some draughting-rooms—notably those of bridge

* This explanation is with reference to American practice, the inch being the unit adopted in the United States.

and plate works—giving it as 19 feet 0 (zero) inches, and others —manufacturers of machinery—simply 19 feet, no mention being made of the inches. It is universally agreed, however, that all dimensions under three feet should be given in inches, and those greater than three feet to be given at the draughtsman's discretion.

In most shops certain notation is used to indicate feet and inches, some shops using the abbreviations "ft." for feet and "in." for inches; others use one dash, thus ′, for feet, and two dashes, thus ″, for inches, while some shops give all dimensions in inches and with that understanding omit all such notation. Another method is to write "ft." for feet and use the two dashes (″) for the inches. The dashes for both feet and inches is the usual practice.

In putting on dimensions those figures representing the full size of the object are given and a note added as to the scale of the drawing, and not figures representing the size of the drawing unless it be a full-size drawing, when, of course, the dimensions of the drawing and of the object are the same; in any case a note as to the scale used should be on the drawing.

46. Selection of the Necessary Views.—Thus far six views of an object have been dealt with: plan, front, right, left, and rear elevations, and bottom view. Very rarely is this number necessary to show an object: a lesser number being usually sufficient. The selection of the proper views and their number is of primary importance, and it is here that the draughtsman must exercise his ingenuity and knowledge of shop practice. First of all the drawing must tell the story, it must clearly show the object, and the least number of views which does this is the correct number to use.

In the selection of what views should be drawn the draughtsman should consider the purpose of the drawing. If it is for shop purposes—a shop drawing—it should be complete in every detail; for example, if it be a drawing of a single piece of a machine—a detail—the draughtsman should place himself in the shopman's position and should consider just what is necessary to show the piece, what would he have to know to produce it, what views are necessary to portray every feature, what dimensions, what notes, etc. If it be an assembled drawing for erectional purposes, let the draughtsman assume the position of the erecting workman, and consider what drawings, dimensions, notes, etc., would be necessary to carry out the work.

47. **Usual Number of Views.**—For simple objects, a plan, one elevation and a sectional view, or two elevations and a section, properly noted and dimensioned, is all that is necessary to clearly define the object. For complex objects the views range in number from either of the above combinations to a drawing composed of a plan and bottom view, four elevations, and any number of sections.

48. **Use of Dashed and Dotted Lines to Reduce the Number of Views.**—In manufacturing the draughting-room is a means to an end. From the draughtsman's standpoint the number of views constituting a drawing should be as small as possible; from the workman's—the shopman's—standpoint the drawing should be as elaborate and complete as possible. A mean of these two extremes is the usual practice, and to assist the draughtsman he is allowed to use dashed and dotted lines to indicate hidden features.

The compromise is quite satisfactory for comparatively simple objects and oftentimes may decrease the labor of making a legible drawing by one-half; it is, however, very desirable that dashed and dotted lines be reserved for simple drawings, as for the more elaborate ones they prove very confusing; in such drawings they should be omitted and other views and sections added.

49. **Beginning to Draw.**—When a drawing is to be made, the first thing to be considered is the purpose of the drawing; with this well in mind carefully study the object to be drawn and decide upon the least number of views it will be necessary to draw to clearly define the object. Having decided upon the number of views to be drawn, consider the size of the sheet of paper to receive the drawing and, in accordance with section 42, select the largest scale possible under the conditions. With the dimensions of the drawings known, the margin between them

and the border lines and the spaces between one another may be calculated and the drawing balanced without a line being drawn; this done the drawing may be begun. Do all thinking and planning with few preliminary lines, know what to do, how it is to be done, and then proceed with the work.

50. Draughting-room Practice.—In ordinary commercial draughting one meets with two kinds of mechanical drawing: (1) sketches which are used for preliminary purposes—temporary drawings—and (2) the valuable permanent drawings which are placed on file and carefully preserved.

Sketches are usually made in pencil—though pen and ink are sometimes used—and are usually free-hand drawings. The permanent drawings are constructed with a view to reproduction, the usual procedure being as follows:

A pencil drawing is first carefully constructed on some medium grade of paper, and from this pencil drawing a tracing is made in water-proof ink on tracing-cloth, or tracing-paper (the former is preferable), and from this tracing a blue-print is made.

Draughting-rooms are like individuals, each has its own particular method for the accomplishment of its purpose, the purpose of a draughting-room being, primarily, to construct drawings; all, however, agree on a general method of procedure which may be condensed to the following:

Drawings must be clear and concise.

Drawings must be complete.

Drawings should have all dimensions given—total dimensions and of all parts—no addition, division, or subtraction being left to the shopman.

Drawings should be confined to small sheets.

Drawings should be grouped, that is, things of a kind should be placed on a sheet of the kind; as, drawings of pieces to be forged should be placed on a "sheet of forgings"; all brasswork should be together, all cast-iron parts should be drawn by themselves, etc.

Draughtsmen should show a knowledge of the work they propose; how each piece is to be produced; as, holes to be cored should be so marked; holes to be drilled should be marked "to be drilled"; holes to be drilled and tapped should have the size of drill and tap given; surfaces to be finished should be marked "to be finished"; the number wanted of each piece and kind of material should be noted, etc.

51. **The Time Element in Drawing.**—Rapid execution of drawings is demanded by all firms, and the ability to execute a clean-cut, well-appearing drawing within a short time is the measure of a draughtsman's worth. The beginner should remember the value of time in the execution of his work and should strive to produce a legible drawing in the shortest time possible; this, however, not to be at the expense of the quality of the work. Quality without quantity means limited pay and a secondary position; quantity without quality is a similar condition; while quantity and quality is the correct combination and means the highest salary and most responsible position.

In acquiring the art of draughting careful search should be made to find ways, means, and "kinks" with which to expedite the work if possible. Of these "labor-saving devices," besides special tools and other mechanical means, mention may be made of free-hand lettering and of certain conventions, some of which are universally adopted and others which pertain to a particular line of work.

Free-hand lettering being so far in advance of mechanical lettering as regards time required in its execution needs no other argument as to the "why" of its desirability.

The laborious, time-consuming, and erstwhile universal method of cross-hatching sections with lines in certain arrangements to indicate cut portions and kinds of materials is, of late years, being discarded in a large number of shops for other conventions more convenient and rapid of application. Some shops use no cross-hatching whatever, simply marking the drawings C. I. for cast iron, W. I. for wrought iron, S. for steel, etc., and indicating cut portions by darkening that portion of the drawing with a lead-pencil or other quickly applied medium, as by coloring the sections with brush and water colors.

There are a great number of minor labor-saving kinks, many presenting themselves to ingenious draughtsmen, but to the student suffice it to again advise a sharp outlook for these things.

52. Conventions.—To construct every detail of a drawing theoretically exact would consume much valuable time, and to expedite the work certain conventions are adopted. Every class of drawing—bridge drawing, the drawings used in electrical work, etc.—has its particular and peculiar conventions; also, different firms engaged in the same line of work often use conventions peculiar to themselves. There are, however, a large number of simple conventions—fundamentals—such as screw-threads, breaks, methods for indicating sections, the kind of material, etc., that are common, with possibly slight variations in certain cases. A number of these are given in the accompanying drawings and should be noted.

CHAPTER II.

LETTERS, FIGURES, AND LETTERING.

53. **Fundamentals.**—Lettering is to a drawing what clothes are to a man—it makes the appearance, and appearance is of much importance to a drawing. A drawing may be correct in all its details and yet present a poor appearance, but a well-appearing, correct drawing is what manufacturers want and are willing to pay for; therefore the ability of a draughtsman to do good lettering is a measure of his worth. The study of lettering, then, becomes of prime importance to the student of mechanical drawing.

A drawing may be "made or marred" in the lettering, hence great care should be exercised in the lettering of it, and that letter which can be most rapidly made, which looks well when made and in any size, should be selected for the work. A letter to fulfill these conditions must, obviously, be one of simple outline, thus minimizing and expediting the labor of its execution, and being free from ornamentation it presents a clear outline and is readily legible.

The letter most widely accepted as meeting these conditions is what is known as the "Gothic Alphabet." Of this letter there is the upper case, or capital letters, and the lower case, or small letters; these may be vertical or inclined, which gives practically four alphabets and is quite sufficient for all usual commercial draughting.

The Gothic alphabet may be constructed free-hand or with instruments, and may be a single-line letter or a heavy letter made up of heavy lines, several "single" lines in thickness. To construct the letters with instruments—mechanically—consumes too much time for practical work and the beginner should devote his attention to the free-hand alphabet.

To acquire the ability to execute neat and well-appearing free-hand letters, the student should first carefully study the standard proportions and characteristics of the various letters and then practice their construction. Much care and pains must be taken with these preliminaries, as lettering is an art which cannot be mastered in a few hours, but requires perseverance and practice. When the individual letters have been mastered to a degree, the construction of words may be taken up.

The spacing of the various letters which go to make up a word now enters into the subject and is a very important factor. The letters should be placed as near one another as is consistent with clearness (about one-sixteenth to one-sixty-fourth of an inch apart), thus giving the arrangement a well-grouped and compact appearance. Each letter should be of the same alphabet—upper or lower case, vertical or inclined—of the same size (initial letters excepted) and uniformly spaced. Much consideration of the dimensions of the various letters, together with spacing and a large amount of practice, is necessary at this point.

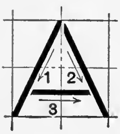
Having acquired the ability to execute words in a rapid, neat, and well-appearing manner, the student is ready to execute sentences, and now the spacing of words demands attention. Words should be placed according to the space they are to occupy; ordinarily, however, they should be from one-eighth to one-quarter of an inch apart, the letters of each word being so grouped that the words are quite compact, and this small space between words sufficient to cause them to stand out and be easily read.

In all lettering much care should be exercised to produce a regular and uniform effect, that is, the individual letters of words should be neither cramped nor isolated, enlarged or decreased in size, but the whole so constructed as to secure a well-balanced and uniform word. This matter of regularity and uniformity is the "secret" of good lettering and applies not only to words but to entire sentences and groups of sentences as well.

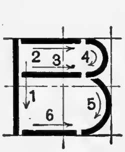
After the student has acquired a working knowledge of the foregoing fundamental requirements, from thence on his lettering becomes a matter of practice, and as "practice makes perfect" too much time cannot be devoted to it.

54. **A Study of Letters.**—Taking up the upper-case Gothic Alphabet, attention should be given to the proportions and characteristics of each letter, together with the manner of its construction. The most popular style of this alphabet is the "square" letter, so called because the major portion of the alphabet may be constructed within a square.

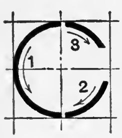
The vertical type of the upper-case, square Gothic alphabet is used for illustration, though the remarks given apply, also, to the inclined type of the same alphabet.



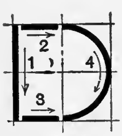
The letter A, constructed in the manner indicated—the arrows indicating the direction of the stroke and the figures the order in which the strokes are made—has equal width and height for proportions, and is characterized by the horizontal bar, stroke 3, which is below the horizontal center line through the square. In the inclined letter, alphabet No. 3, Plate No. 3, note that stroke 2 is vertical.



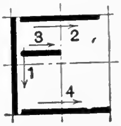
Proportions, the height equals the width; characteristics, bars 2, 3, and 6 are horizontal, the upper part of the letter is smaller than the lower part—stroke 3 is above the center of the square—and arcs 4 and 5 are arcs of circles. In the inclined letter strokes 4 and 5 are elliptical arcs.



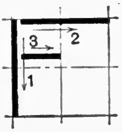
Proportions, the height equals the width; characteristics, all of the arcs are circular arcs, and the lower terminus of the letter extends farther to the right than the upper terminus, thus giving the letter a kind of base. In the inclined letter the arcs are elliptical.



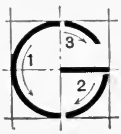
Proportions, the height equals the width; characteristics, bars 2 and 3 are horizontal, and stroke 4 is the arc of a circle. In the inclined letter this stroke is the arc of an ellipse.



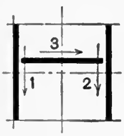
Proportions, the height equals the width; characteristics, three horizontal bars, the bottom bar slightly longer than the upper bar—to give the letter a base—and bar 4 is above the center of the square and from one-half to two-thirds the length of the top bar.



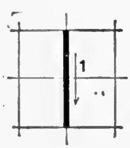
Proportions, the height equals the width; characteristics, bars 1 and 2 are equal in length, and bar 3 is above the center of the square and from one-half to two-thirds the length of bar 2.



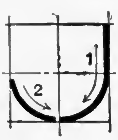
Proportions, the height equals the width; characteristics, the arcs are arcs of circles, bar 2 is on the horizontal center line and extends a trifle to the right of the terminus of arc 3. In the inclined letter the arcs are elliptical.



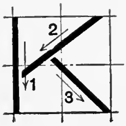
Proportions, the height equals the width; characteristics, the side lines are parallel, and the cross-bar is above the center of the square.



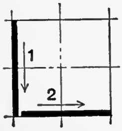
Proportions, the height equals the height of the square; the width equals the width of the line. (Note that I is the first letter in which the height and the width are unequal.) Characteristic, it is a simple straight line. The upper-case I is not dotted.



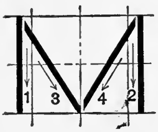
Proportions, the height equals the width; characteristics, the arcs are the arcs of a circle, and the left terminus does not extend quite up to the center line. The letter J is often misconstructed, being sometimes turned backwards; also, one is apt to make it too narrow and thus spoil its proportions; care should be exercised not to extend the left-hand terminus, stroke 2, above the center line, else the letter will be confused with the letter U. In the inclined letter the arcs are elliptical.



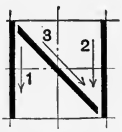
Proportions, the height equals the width; characteristics, bar 2 extends from a point not quite to the corner of the square to a point below the intersection of the center line of the square and the vertical bar. Bar 3 joins bar 2 above the center and extends to the lower corner of the square.



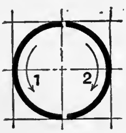
Proportions, the height equals the width; characteristics, bars 1 and 2 are of equal lengths and occupy two sides of the square. This letter is sometimes made backwards. Note the proper way of drawing bar 2.



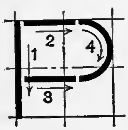
Proportions, the width is from one-fourth to one-third greater than the height of the letter, making M the widest letter thus far; characteristics, the side lines are parallel and the diagonals, 3 and 4, are of equal lengths. This letter is often made as the letter W would appear if inverted, and when so constructed is incorrect.



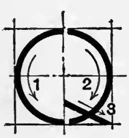
Proportions, the height equals the width; characteristics, the side lines are parallel and the diagonal extends from the upper left-hand corner of the square to the lower right-hand corner.



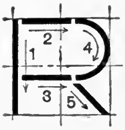
Proportions, the height equals the width; characteristic, it is a complete circle. In the inclined letter it becomes an ellipse.



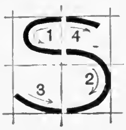
Proportions, the height equals the width; characteristics, strokes 2 and 3 are horizontal, the lower one, 3, is below the center of the square, and the arc is the arc of a circle. In the inclined letter the arc is elliptical.



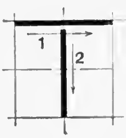
Proportions, the height equals the width; characteristic, it is a complete circle, same as the letter O with the addition of stroke 3. In the inclined letter the circle becomes an ellipse.



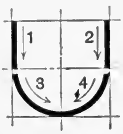
Proportions, the height equals the width; characteristic, it is the same as the letter P with the addition of stroke 5. The letters P and R are two of the "hard" letters to construct; do not fail to note the two horizontal bars, the lower one being below the center of the square.



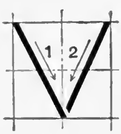
Proportions, the height equals the width; characteristics, the arcs are the arcs of ellipses, and the upper part of the letter is smaller than the lower part. The letter S is the "hardest" letter to construct, and is often turned backwards; note the proper "turn" and that the upper part of the letter is smaller, in two directions, than the lower part.



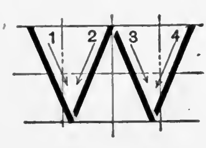
Proportions, the height equals the width; characteristics, the two bars are of equal length—equal to the length of a side of the inclosing square—and the vertical bar, 2, is in the center of the square.



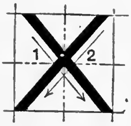
Proportions, the height equals the width; characteristics, the side lines are parallel and the arcs are arcs of a circle. Care should be exercised to always make the letter of full width, as the tendency is to construct a letter of "under width." In the inclined letter the arcs are elliptical.



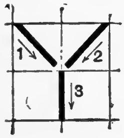
Proportions, the height equals the width; characteristic, it is the same as the letter A inverted; note the full width at the top—equal to the width of the square—do not make it less. In the inclined letter stroke 1 is made vertical.



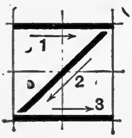
Proportions, the height equals the height of the square and the width is from one-half to three-fifths greater than the height of the letter —the letter W is the widest letter in the alphabet; characteristic, alternate lines are parallel—it can be said to be made up of two V's. The letter M is often inverted for the letter W; this is incorrect. In the inclined letter strokes 1 and 3 are drawn vertical.



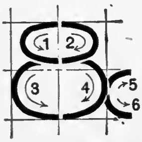
Proportions, the height equals the width; characteristics, the width at the top is slightly less than the width at the bottom of the letter and the bars cross above the center of the square.



Proportions, the height equals the width; characteristic, the three bars unite at the center of the square. Note that the full width of the square is necessary at the top; do not make it less.



Proportions, the height equals the width; characteristics, the two horizontal bars are of equal lengths, and the diagonal, 2, extends from the upper right-hand corner of the square to the lower left-hand corner. The letter Z is often made backwards, bar 2 being turned the wrong way; note the correct slant.



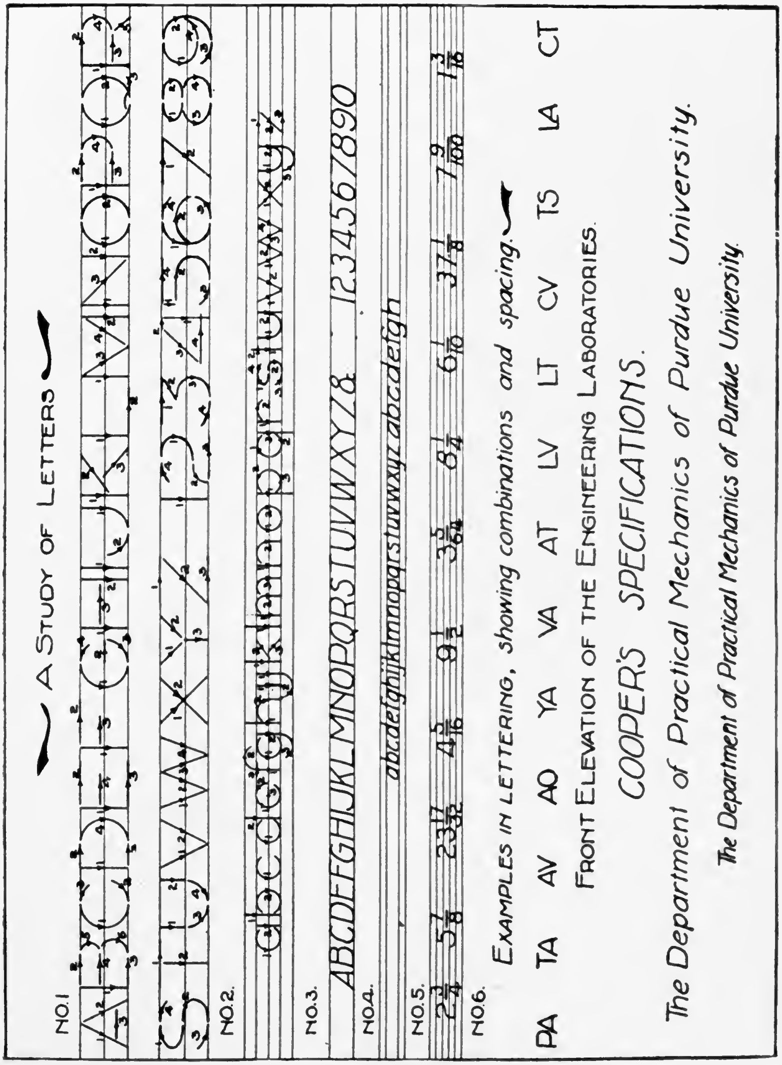
Proportions, the width is about one-fourth greater than the height; characteristic, it is the same as the figure 8 with the addition of strokes 5 and 6.

55. Modifications.—The letters A, C, G, O, Q, V, and Y if made on the "square" plan will in some words appear to be smaller than other letters similarly constructed and require to be slightly modified to eliminate the optical illusion, in which case the following is recommended:

Make the letter A to extend slightly above the other letters and to have a width at the bottom a trifle greater than the width of the side of the square. The same modification is given for the letter V, i.e., the width of the letter should be greater than that of the other letters, and it should extend below them. The letters C, G, O, and Q may be made slightly elliptical in shape, having a greater width than the side of the square. The letter Y may be given increased width across the top.

The letters M and N are also susceptible to modification, though not for the same reason given above. To construct these letters as given and secure good results, much care has to be exercised in drawing the diagonal lines, as any slight variation from the correct slant is at once apparent. The modification

PLATE No. 3.


A Study of Letters
No. 1.
No. 2.
No. 3.
ABCDEFGHIJKLMNOPQRSTUVWXYZ& 1234567890
No. 4.
abcdefghijklmnopqrstuvwxyz abcdefgh
No. 5.
No. 6.
Examples in Lettering, showing combinations and spacing.
PA TA AV AO YA VA AT LV LT CV TS LA CT
Front Elevation of the Engineering Laboratories.
COOPER'S SPECIFICATIONS.
The Department of Practical Mechanics of Purdue University.
The Department of Practical Mechanics of Purdue University.

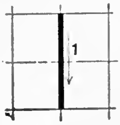
of these letters given in alphabet No. 3, Plate No. 3, is recommended, being a style somewhat more easily constructed and looks well if not quite exact in all its lines. Care should be taken with the letter N not to make the diagonal bar too nearly a horizontal line, else the letter will become confused with the letter H.

56. Suggestions.—It is recommended that the square letter be used for all practical and usual lettering, the modifications being introduced at the draughtsman's discretion. In cases where the square letter does not seem to meet the requirements, as, for example, when it is desired to occupy a large elongated space with a few words or when it is required to place a large number of words in a comparatively small space, letters other than the square alphabet may be used to advantage—an "extended" letter being recommended for the former case and a "condensed" type for the latter case. (See pages 33 (bottom) and 181.)

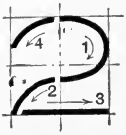
57. Combinations and Spacings.—As has been stated, to make printing "stand out" and be easily read, it is first necessary to make the words compact; second, the spacing must be uniform; and third, the letters must be of the same height—be even along the top and bottom. Some letters, because of their shape, when made and spaced in the usual way give an "open" appearance to words; to obviate this and to secure compactness, examples of various combinations of letters are given in Plate No. 3; also, examples of spacing—these should be carefully studied.

58. Figures.—At the same time attention is being given to the upper-case alphabet some study should be given to the proportions and characteristics of figures, since figures are essentials of drawings. A drawing poorly figured—dimensioned—is like a drawing poorly lettered—the appearance is marred; however, figures and letters go hand in hand, and a drawing poorly lettered is usually poorly figured, and vice versa; a draughtsman with the ability to do good lettering will usually do good figures.

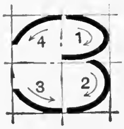
Like the letters the square type of figures is the most popular type, the standard proportions and characteristics being as follows:



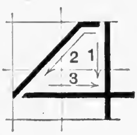
The figure 1 made in the manner indicated has proportions, the height equals the height of the square, the width equals the width of the line; characteristic, it is a simple straight line.



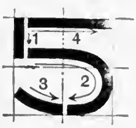
Proportions, the height equals the width; characteristic, the upper portion of the figure is larger than the lower portion.



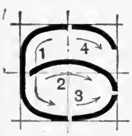
Proportions, the height equals the width; characteristic, the upper portion is smaller than the lower portion of the figure.



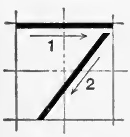
Proportions, the width is about one-fourth greater than the height; characteristics, the short horizontal stroke at the top and the bar below the center of the square. The usual tendency is to make the figure of "short width"—it should be wider than it is high; also, the stroke 3 is often made too high: note that it is half way between the horizontal center line and the bottom of the square.



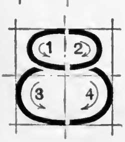
Proportions, the height equals the width; characteristics, the upper portion of the figure is smaller than the lower portion, and the arcs 2 and 3 are elliptical.



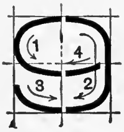
Proportions, the height equals the width; characteristics, the lower portion of the figure occupies over one-half of the square and is an ellipse; the upper part is parallel to the top line of the ellipse.



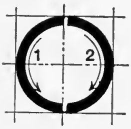
Proportions, the height equals the width; characteristic, bar 2 does not extend out on the left even with bar 1.



Proportions, the height equals the width; characteristic, the figure is made up of two ellipses, the upper ellipse being smaller than the lower one.



Proportions, the height equals the width; characteristic, the same as the figure 6 inverted.



Proportions, the height equals the width; characteristic, it is a complete circle, the same as the letter O.

As in lettering, there is the vertical and inclined type of figures, and the remarks on combinations and spacing given for lettering obtains for figures also.

The extended figure—one in which the width is greater than the height—is a close rival of the square type, being easily constructed and quite clear in outline. For some cases a condensed figure is found convenient; it is well, therefore, for the student to acquire the three [(1) square, (2) extended, and (3) condensed] types of figures.

59. Fractions.—Examples of figures arranged into complex numbers are given in Plate No. 3, and should be carefully studied.

In mechanical drawing always use "mechanical" figures—those given above—and in fractions make the dividing line between the numerator and the denominator to be a straight line in line with the dimension line. To insure clean-cut fractions, be sure to separate the figures so that they do not touch one another, particularly do not permit either the numerator or the denominator to touch the dividing line. In complex numbers the whole number may be made from two-thirds to three-fourths of the height of the fraction.

60. Lower-case Alphabet.—Thus far the upper-case alphabet has been discussed—figures being rated as of the upper case—and as these have to do with but titles and sub-captions, a letter is yet to be adopted for the notes of explanation which are necessary on drawings, and these notes usually represent the major portion of the lettering.

For this work there are two very popular letters: (1) an upper-case alphabet of small dimensions, and (2) a lower-case alphabet, Fig. 15, the latter being somewhat more widely in use because of its ease and rapidity of execution. Of this letter there are the several styles, square, extended, condensed, vertical, and inclined.

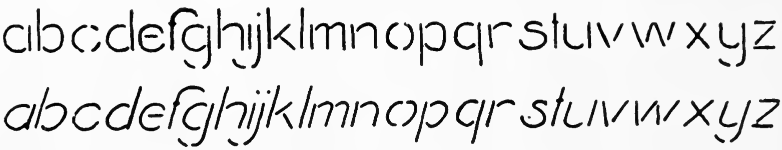


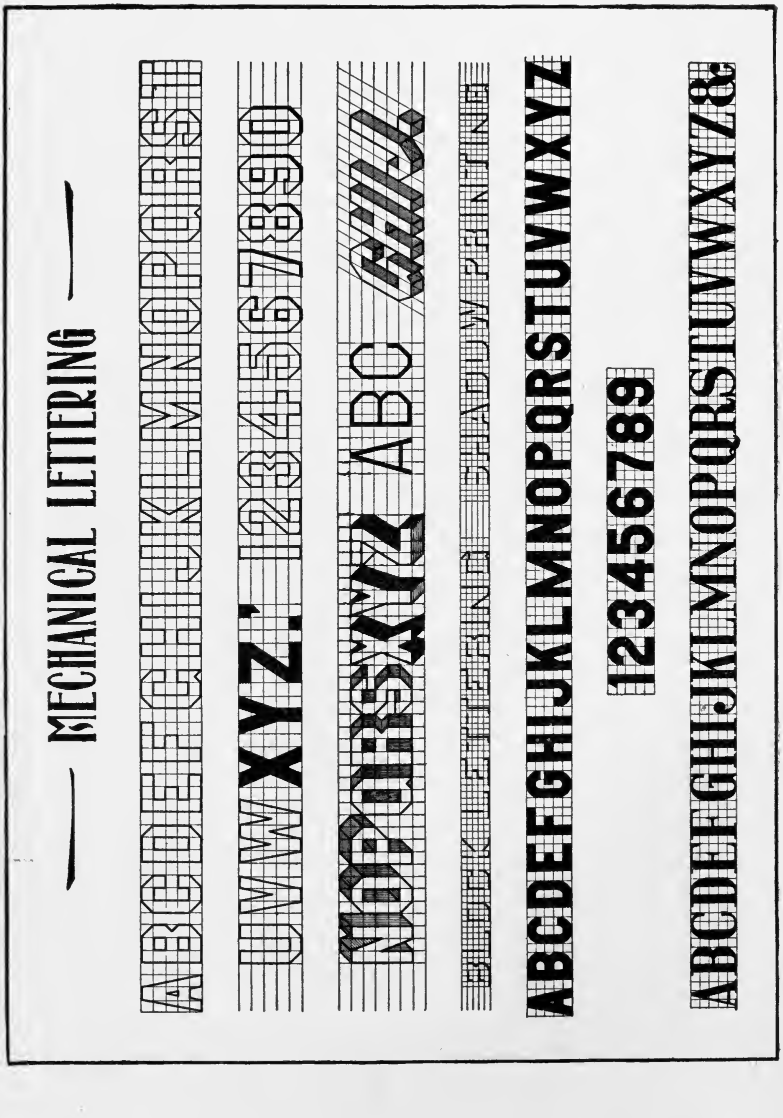
Fig. 15.

The proportions, characteristics, and manner of construction may be studied from alphabet No. 2, Plate No. 3. The general remarks on lettering, combinations, spacing, etc., apply to the lower-case alphabet, and lettering of this alphabet should be made accordingly.

For the beginner it is best to first draw construction lines—guide lines—in pencil to block out the space for the letters, or to use coordinate ruled paper for his practice, and later to use only top and bottom guide lines, doing the spacing and proportioning "with the eye."

61. Mechanical Letters.—Plate No. 4 delineates the usual mechanical letters—letters made with instruments. The plain "block" letter (that shown in the top row) is the style most used and is the basis for nearly all plain and ornamental mechanical lettering. The plate is self-explanatory—adding here that the light construction lines should not appear in finished lettering—and should be given due consideration and study.

PLATE No. 4.



CHAPTER III.

PROJECTION.

62. Scenographic Projection.—To project means to plan, to scheme, to delineate, to draw the outline of a thing. In Fig. 1, explanatory of the drawing of objects viewed from a finite distance, the lines joining the several points of the object and the point of sight—there called lines of sight—may be said to project the image of the object on the retina of the observer's eye (one eye only being used, since but one point of sight is assumed), and the lines themselves, said to be lines of projection or projecting lines. If these lines be intersected by a plane and the points in which they pierce the plane be connected by straight lines, a drawing of the object will be obtained which is said to be projected onto that plane; such a drawing—called a projection—is an example of scenographic projection.

If the intersecting plane be a plane perpendicular to the horizontal—a vertical plane—the drawing projected on such a plane is called a "perspective drawing" (Fig. 3). For example, let the student station himself before a window overlooking a street scene; then stretch a sheet of transparent paper over the glass, and choosing a point of sight—a view-point—look through the paper onto the scene; the picture will then seem to be projected onto the paper, and if the lines be traced in with pencil or ink, the drawing thus obtained will be a perspective drawing, and the scene said to be shown in "perspective."

In ordinary mechanical drawing objects are but rarely shown in scenographic projection or perspective.

63. Orthographic Projection.—In mechanical drawing, as has been noted, the point of sight is assumed as being at an infinite distance from the object, and the lines of sight to be practically parallel. Following the same line of reasoning as given for scenographic projection, if the lines of sight be intersected by a plane, and the points in which the lines of sight pierce this plane be joined, a drawing of the object will be obtained which is said to be projected onto the intersecting plane. If the intersecting plane be in a position which is perpendicular to the lines of sight, the projection on that plane is said to be an "orthographic projection," Fig. 2.

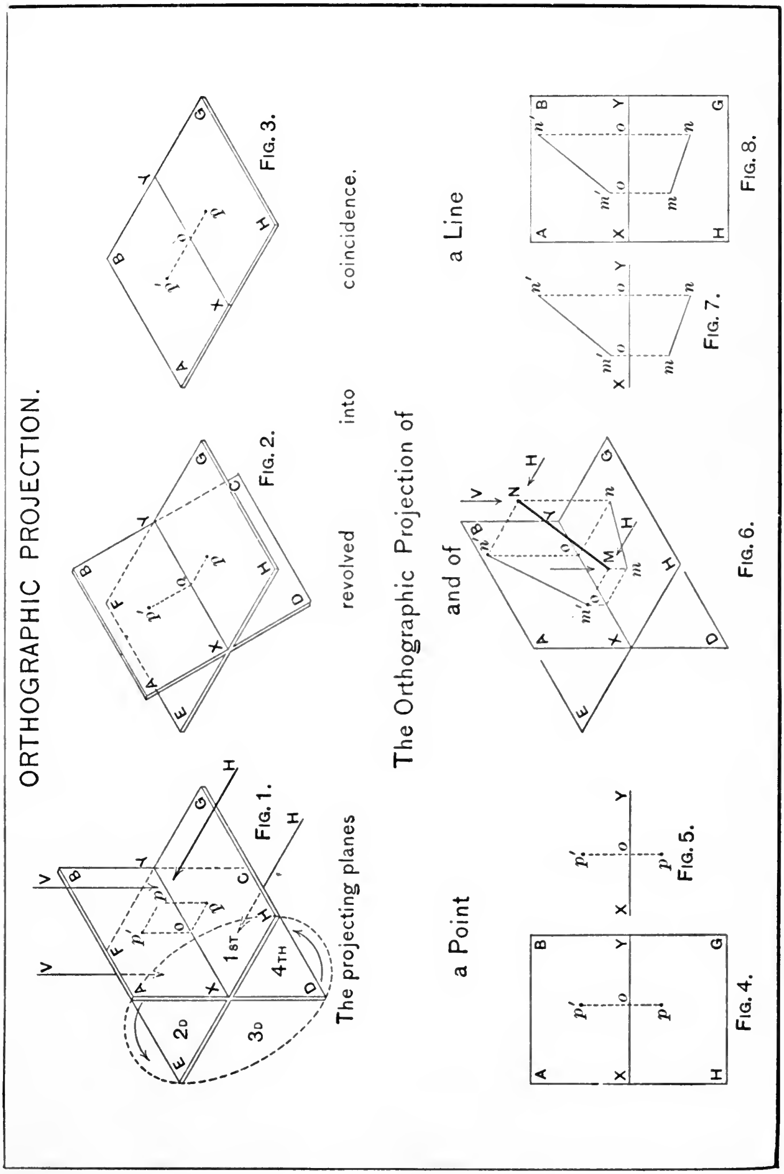
Orthographic projecti n is the more useful to the student in engineering, and will now be taken up in detail.

64. The Planes of Projection.—Thus far we have treated of but one plane of projection—the intersecting plane. To apply orthographic projection in mechanical drawing, it is necessary to have more than one plane of projection, since, in such drawing, it is required to draw more than one view of the object; also, the position of a point, or object, in space cannot be fixed, save with reference to the one plane only which is insufficient for the purpose of use in mechanical drawing. All orthographic projection, then, is reckoned with reference to two planes of projection, two planes being the least number for practical work.

The two planes assumed are (1) a horizontal plane, called the horizontal plane of projection, conventionally designated by the letter *H*, and called "plane *H*," and (2) a vertical plane, called the vertical plane of projection, conventionally designated by the letter *V*, and called "plane *V*." These two planes of projection are assumed to be of infinite expanse, to intersect at right angles, and to divide space into four equal parts, called the "four quadrants."

65. The Four Quadrants.—Let Fig. 1, Plate No. 5, represent a limited portion of each of the two planes of projection (the drawing shows the planes to be of some thickness: the planes assumed, however, are mathematical planes and of infinitesimal thickness—practically of no thickness), *A-B-C-D* being the vertical plane of projection, *V*, *E-F-G-H* the horizontal plane of projection, *H*, and *X-Y* the line in which the two planes

PLATE No. 5.


ORTHOGRAPHIC PROJECTION.
The projecting planes revolved into coincidence.
The Orthographic Projection of
a Point and of a Line
FIG. 1.
FIG. 2.
FIG. 3.
FIG. 4.
FIG. 5.
FIG. 6.
FIG. 7.
FIG. 8.

intersect, being the "ground line"—conventionally designated by the letter *G*. With the planes viewed as shown, the four quadrants are numbered counter-clockwise, that in front of the vertical plane and above the horizontal plane of projection being the first quadrant, that behind the vertical plane and above the horizontal plane the second quadrant, that space below *H* and behind *V* the third quadrant, and that below *H* and in front of *V* the fourth quadrant.

It should be noted that the planes of projection are viewed from two positions only: (1) looking down as indicated by the arrows *V*, *V*, and (2) looking horizontally as indicated by the arrows *H*, *H*. With reference to *H* and *V*, the projecting lines used for projecting points and lines onto these planes are respectively parallel to these two directions of sight; that is, one looks vertically down upon and projects perpendicularly onto the horizontal plane, and looks horizontally upon and projects perpendicularly "against" the vertical plane of projection.

66. The Projection of a Point, with the Planes V and H at Right Angles.—Let *P*, Fig. 1, Plate No. 5, represent a point in space; to find its horizontal projection, drop the perpendicular *P-p* to the horizontal plane, and the point *p*, in which this perpendicular pierces the plane, is the horizontal projection of the point *P*. To find its vertical projection, erect the perpendicular *P-p'* to the vertical plane, and the point *p'*, in which this perpendicular pierces *V*, is the vertical projection of the point *P*. These two projections, *p* and *p'*, fix the position of the point *P* with reference to the planes *V* and *H*; for, given *p* and *p'*, by erecting perpendiculars to the planes *V* and *H*, the two perpendiculars will intersect at *P* and thus define the position of the point.

The student should also note that the perpendicular *P-p* to the plane *H* shows on the vertical plane as the line *p'-o*, for to obtain the projection of a straight line it is but necessary to project any two points of the line and join their projections. In this case the two points taken are the two extremes, *P* and *p* (this is the usual method of projecting a definite portion of a line), p' being the vertical projection of P, and o the vertical projection of p; also, the horizontal projection of the projecting line P-p' is p-o. It is obvious that p-o and p'-o are perpendicular to each other, being adjacent sides of the rectangle P-p-o-p'.

67. The Planes V and H Revolved.—If compelled to construct all projections with the planes V and H in their true positions—V, vertical, and H, horizontal—the task would be entirely too laborious and time-consuming for practical use. That the art may become practical, the vertical plane is assumed to be revolved into coincidence with the horizontal plane, thus forming but one plane; and assuming the plane of the paper to be a limited portion of this plane, the problem is solved.

Explanatory.—Plate No. 5. Let Fig. 1 represent a limited portion of the planes V and H, and let the plane V (A-B-C-D) be revolved in the direction of the arrows (counter-clockwise) until it becomes coincident with the plane H (E-F-G-H). Fig. 2 represents an intermediate position of V in its revolution, and Fig. 3 the coincident position. Now, assume the planes as depicted in Fig. 3 to be picked up and "squared about," presenting themselves as shown in Fig. 4. Considering the first quadrant, it will be noted that the vertical plane falls above the ground line and that the horizontal plane falls below the ground line. The first quadrant, only, is considered in the following discussion.

[To facilitate his conception of the following projections, the student is advised to construct a pasteboard or wooden model of the planes V and H, capable of being revolved. Take two pieces of pasteboard about six or eight inches square, cut a straight slot half way across the middle of each and put the two pieces together, slot to slot, and press "home"; this will give a model which revolves into one plane, approximately.]

68. The Conventional Projection of a Point.—Plate No. 5. Referring again to Fig. 1 depicting the projection of the point P, it is obvious that the figure P-p-o-p' is a rectangle whose plane is both perpendicular to the planes V and H, and to their intersection, X-Y. Now as the planes of projection are revolved into coincidence, note the revolution of the projections of the point *P* (Figs. 2, 3, and 4) and it is seen that the two projections are in the same straight line perpendicular to the ground line. The student should also note that the distance of the point *P* from the vertical plane is shown on the horizontal plane by the perpendicular *p-o*; also, that the distance of the point *P* from the horizontal plane is shown on the vertical plane by the perpendicular *p'-o*; from which we deduce, the distance of a point from the vertical plane of projection is measured on the horizontal plane, and the distance of a point from the horizontal plane of projection is measured on the vertical plane.

As has been stated, the planes *V* and *H* are assumed to be of infinite expanse, and instead of considering definite portions of these planes, as has been done thus far, for practical work the planes are assumed by simply drawing the ground line *X-Y*, and when considering the first quadrant only—as is here done—understanding that all the space above *X-Y* represents the vertical plane, *V*, and all of the space below *X-Y* represents the horizontal plane, *H*. The conventional projection of the point *P*, then, is shown by Fig. 5.

69. The Conventional Assumption of a Point.—Plate No. 5. A point is assumed by its two projections (one projection does not fix the position of the point, two are necessary); also, these two projections always lie in the same straight line, perpendicular to the ground line.

Let it be required to assume a point *P*, four inches from the vertical plane of projection, and ten inches from the horizontal plane. (Fig. 5.) First draw the ground line *X-Y* (the ground line is always drawn as a horizontal line) and erect the indefinite perpendicular *p-o-p'*; now, since the distance of a point from the plane *V* is measured on *H*, lay off, from the ground line, a length *o-p*, equal to four inches—the distance of the given point from *V*—and the extremity, *p*, of this length represents the horizontal projection of the point. In like manner, to obtain the vertical projection of the point, lay off, from the ground line, a length *o-p'*, equal to ten inches—the distance of the point from the horizontal plane—and the extremity, p', of this length represents the vertical projection.

The student should make it a point to clearly understand all points connected with the assumption and projection of a point before going farther, as a clear understanding of all subsequent projections is dependent upon a clear conception of the projection of a point.

Corollary.—From the foregoing it is obvious that the vertical projection of a point which lies in the horizontal plane is in the ground line, as the vertical projection of the point p, Fig. 5, is o, a point in X-Y; also, that point p', in the vertical plane, is horizontally projected in (o) the ground line.

70. The Projection of a Straight Line.— Plate No. 5. To obtain the projection of a straight line, it is necessary to project but two (any two) points of the line, and then join the projections with a straight line. Let M-N, Fig. 6, be a line in space; the two points projected are the two extremes of the line, M and N (this being the usual practice when dealing with a line of definite length), M being horizontally projected at m, N horizontally projected at n, and m-n the horizontal projection of the line. It is obvious that m'-n' represents the vertical projection of the line. Fig. 7 represents the conventional projection of M-N.

Corollary.—It is evident from the foregoing that the projection of curved lines is obtained in a similar manner, that is, by projecting a number of points of the curves, and joining the projections of these points by curved lines.

71. The Projection of a Line which is Parallel to One of the Planes of Projection.—Plate No. 6. Let Fig. 1 represent the projection of a line M-N which is parallel to the horizontal plane of projection, m-n being its horizontal projection, and m'-n' its vertical projection. Since the line is parallel to H, all of its points are at the same distance from the horizontal plane, hence the vertical projection is parallel to the ground line—the distance from H being measured on V; also, since in the figure M-N-n-m M-m equals N-n, and the angles M-m-n and N-n-m are right angles, the figure is a rectangle and M-N is parallel and equal to m-n. Therefore:

A line which is parallel to one of the planes of projection has for its projection on that plane a parallel line of equal length, and for its other projection a line which is parallel to the ground line. (A line is projected in its true length only on a parallel plane.)

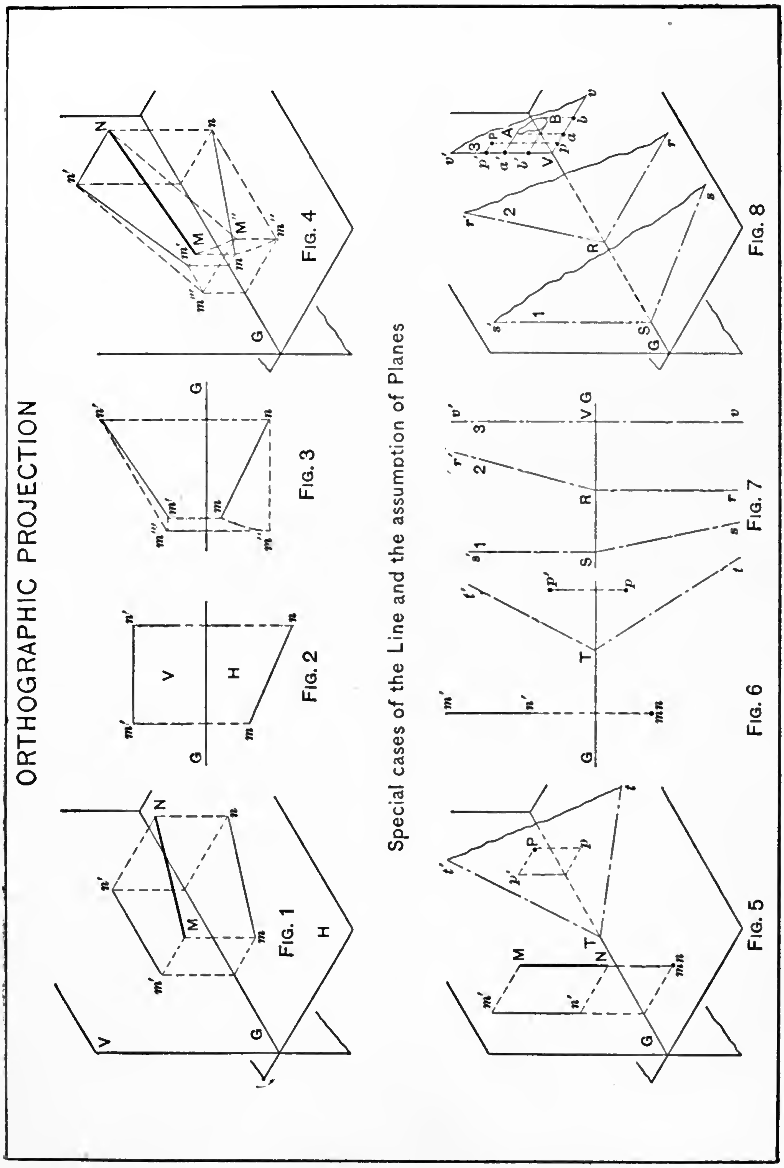
Fig. 2 is the conventional method of drawing the above projection.

72. To Find the True Length of a Line.—Plate No. 6. Having demonstrated that a line is projected in its true length on a parallel plane, it is obvious that, to show the true length of a line which is oblique to the planes V and H, it is necessary to revolve it about some point as an axis—usually one extreme if a definite line—until it becomes parallel to one of the planes of projection, when it will be projected on that plane in its true length.

Let M-N, Fig. 4, represent a line in space which is oblique to both V and H, and let it be required to find the true length of the line by revolving it parallel to the vertical plane of projection. In the revolution, it must be understood, the position of all of the points of M-N are unaltered with respect to plane H; that is, if the point M, for example, be three inches from H in its original position, the point M must be three inches from H in the revolved position: the position of the line is altered with respect to V, only. Let the line be revolved, in accordance with the above, from the original position, M-N, about N as an axis, until it occupies a position M''-N, parallel to V, when its projections are m''-n on the horizontal plane (note that this projection is parallel to the ground line) and m'''-n' on the vertical plane of projection; the line m'''-n', then, represents the true length of M-N.

The conventional procedure is illustrated by Fig. 3. The line M-N is assumed by its two projections m-n and m'-n', the horizontal and vertical projections respectively. To find the true length by revolving into parallelism with the vertical plane, with the point n as a center and a radius n-m describe the arc m-m''; now, since the distance of the point m is unchanged with reference

PLATE No. 6.



ORTHOGRAPHIC PROJECTION
Special cases of the Line and the assumption of Planes
FIG. 1
FIG. 2
FIG. 3
FIG. 4
FIG. 5
FIG. 6
FIG. 7
FIG. 8

to the horizontal plane, the vertical projection of the arc m-m'' is the straight line m'-m''', parallel to the ground line. The point n, being used as a center of revolution, remains fixed, hence its vertical projection remains unchanged and the vertical projection of the revolved line is m'''-n', the true length of the line.

73. The Projection of a Straight Line which is Perpendicular to one of the Planes of Projection.—Plate No. 6. Let *M-N*, Fig. 5, represent a line in space which is perpendicular to the horizontal plane; it is obvious that all of its points are horizontally projected in the same point, and that the projection of the line on *H* is simply a point, while its vertical projection is a line m'-n', perpendicular to the ground line; therefore, a line which is perpendicular to one of the planes of projection is projected on that plane as a point, while its other projection is a straight perpendicular line to the ground line; the conventional projection is shown in Fig. 6.

74. The Assumption of Planes.—Plate No. 6. A point and a line are assumed by their two projections; a plane is assumed by its "traces." In Fig. 5 the triangle t-T-t' represents a portion of a plane which is oblique to the planes of projection; the line *t-T* represents the intersection of the given plane—conventionally designated by the letter *T*, and called plane *T*—with plane *H*, and the line T-t' represents the intersection of *T* with *V*. These lines of intersection are called the "traces" of the plane. It is obvious that the traces of a given plane, as plane *T*, intersect in the ground line; also, that when the traces of a plane are once assumed, the position of the plane becomes fixed; hence a plane is assumed by its traces.

Fig. 5 illustrates, also, the projection of a point *P* which is in the plane *T*, the projections p and p' being obtained by dropping perpendiculars to *H* and *V* respectively.

Fig. 6 depicts the conventional method of assuming plane *T*, and the projection of point *P* in the plane.

The student is advised to provide himself with two pasteboard planes (one piece to be cut in the shape of a rhombus and the other to be rectangular) to facilitate his conception of the following remarks:

Fig. 8 is a drawing illustrating (1) a plane which is perpendicular to H and oblique to V, (2) a plane which is perpendicular to V and oblique to H, and (3) a plane which is perpendicular to both H and V. The student should note that the vertical trace of 1 is perpendicular to the ground line, G, that the horizontal trace of 2 is perpendicular to the ground line, and that both traces of 3 are perpendicular to the ground line. Fig. 7 is the conventional method of representing the above planes.

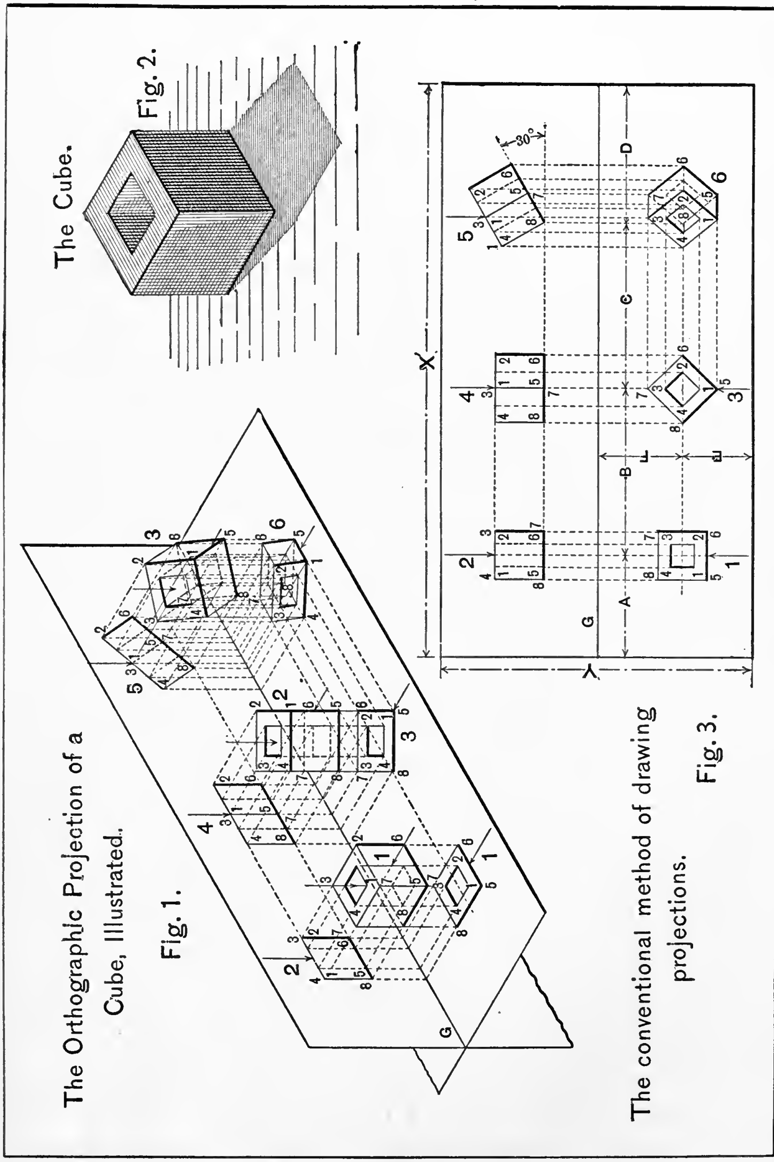
In 3, Fig. 8, let P represent a point in the plane; also, let A-B represent a plane figure in the plane; it is obvious that all such points, lines, and figures within the plane are projected in the traces of the plane—the line a'-b', for example, represents the vertical projection of the closed curve A-B.

As a further exposition of the subject, and to demonstrate its practical use in mechanical drawing, the following representative problems in projection are elucidated:

75. PROBLEM 1. **To Draw the Projections of a Hollow Cube when in Three Different Positions.**—Plate No. 7. Let the first position be with all of its faces either parallel or perpendicular to the planes of projection, as 1, Fig. 1. Now, as a point is assumed by its two projections, so is an object assumed by its two projections; hence, to assume the cube, draw 1, Fig. 3, which is the horizontal projection—the same as a plan of the cube,—then draw 2, the vertical projection—the same as an elevation—of the cube. The projections are drawn in this order, that the hole through the cube may be projected from 1 to 2, in which it is indicated by dashed lines. These two projections drawn, the object is assumed in its first position.

For the second position of the cube, let it be assumed to be revolved, about a vertical axis through its center, through an angle of 45°, without altering its position with respect to the horizontal plane; that is, the cube does not move either up or down along the axis of revolution; 2, Fig. 1, illustrates this new position of the cube. 3, Fig. 3, represents the conventional

PLATE No. 7.


The Orthographic Projection of a Cube, Illustrated.
Fig. 1.
The Cube.
Fig. 2.
The conventional method of drawing projections.
Fig. 3.

horizontal projection (plan) of the cube when revolved; to find its vertical projection, number all of the corners of the cube, when the problem becomes the projection of points, for, since the position of the cube remains unchanged with respect to the horizontal plane, the height of the projection of the various points on the vertical plane remains unchanged, and as the two projections of a point are always in the same perpendicular to the ground line, the vertical projection of the points may be obtained by projecting horizontally from 2 and vertically from 3, when it is evident that the intersection of the projections from the like numbered point will be the new position of that point—its vertical projection. Having projected all of the points, join them by straight lines, and the vertical projection of the revolved cube is obtained.

For the third position of the cube, let its position be altered with reference to the horizontal plane only; this is done by assuming the point numbered 8 to remain fixed, then revolving the object about this point through an angle of 30°. 3, Fig. 1, shows the cube when in this last position, and 5, Fig. 3, represents its conventional vertical projection. To obtain the horizontal projection, since the position of the points are not changed with reference to *V*, and since the two projections of a point must lie in the same perpendicular to the ground line, project horizontally from 3 and vertically from 5, and the drawing numbered 6—the horizontal projection of the cube when in its third portion—is obtained.

REMARKS.—Drawings 1 and 2, Fig. 3, are original projections; drawing 3 is a copy of drawing 1, turned through an angle of 45°; 4 is a projection; 5 is a copy of 4, tilted 30°; and drawing 6 is a projection.

76. Problem 2. To Draw the Projections of a Hexagonal Nut when in Two Different Positions.—Let the first position of the nut be when the plane of its base is parallel to the vertical plane of projection, as shown by position 1, Fig. 17. To draw the conventional projection of the nut when in this position, draw 1, Fig. 18, the vertical projection, or elevation, of the nut, then project 2, the horizontal projection, or plan, of the nut (the drawings are constructed in this order, that the corners of the hexagon

THE ORTHOGRAPHIC PROJECTION OF A BLANK HEXAGONAL NUT.

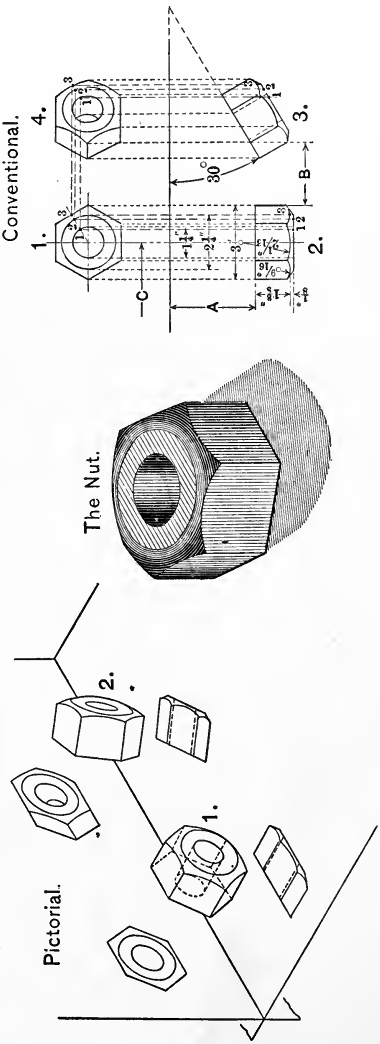


FIG. 16. FIG. 17. FIG. 18.

may be projected from 1 to 2); these two drawings complete, the object is then assumed (by its projections) in its original position.

As a second position, let the position of the nut be changed with reference to the vertical plane only, by changing its position from the parallel one to one of 30° with the vertical plane, as shown by position 2, Fig. 16. To obtain the conventional projection of the nut when in this position, draw 3, Fig. 18, its horizontal projection (which is a copy of 2, turned 30° to the ground line); then to draw its vertical projection proceed as follows:

To find the projection of the outline of the nut, number all of the corners, that is, number every point of 1 and 2 (the same point having the same number in all of its projections) and transfer the numbering of 2 to 3, when, by projecting vertically from 3 and horizontally from 1, the fourth position of the points is defined by the intersection of the projections from correspondingly numbered points; these points being then joined by straight lines give the vertical projection of the straight lines of the object. For the curved lines of the object, a number of points in each curve must be projected and their projections joined by curved lines. For example, take the curved edges of the front face of the nut; three points will be necessary, the two extremes and the middle point; this latter point is indicated by the figure 3 in Fig. 18, and the method of its projection shown.

To project the circles showing on the front face of the nut, each circle should be divided into a number of points (twelve points, equally spaced, being a good working number), these points numbered, and then carried through the four drawings. (The point numbered 2 on the large circle, and the point numbered 1 on the small circle illustrate the method of procedure.) To obtain that portion of the small circle showing at the rear of the nut—the position of the nut being such that the observer can see through it,—the projection of the points of the small circle in 1 are projected onto the rear of 2 (the line nearest the ground line), then copied on the rear of 3, and from there projected vertically to intersect with the horizontal projections from the same points of 1; the intersections are then connected by a curved line. Observe that the projections of the circles of 1 show as straight lines in 2 and 3, the straight-line projections being because the plane of the circles is perpendicular to the horizontal plane; also note that, for a similar reason, two of the curved sides of the front face of the nut project in 4 as straight lines, the plane of each curve being perpendicular to *V*.

77. PROBLEM 3.— **The Projection of a Small Hand-wheel.** This projection is given to illustrate the application of the foregoing principles to ordinary mechanical drawing. Let the hand-wheel to be projected be such a one as is illustrated by Fig. 19. Now, suppose one has a front elevation of a machine drawn, in which the hand-wheel shows on the right side as the rectangle *D*-5-5-*B* (*A*, Fig. 20), at 45° to the horizontal, and is required to draw the right side elevation of the machine, necessitating the projecting of the hand-wheel to this new position.

To Project the Rim.—First, draw the full section of the wheel within the elevation—a sectional elevation—as is indicated by the dashed lines in *A*, Fig. 20, then on the front line of the elevation, *D*-5, as a center-line, lay out one-half of a "square view" of the wheel, as indicated by the dotted portion of the drawing. Next let the vertical center line, 5-5 (*B*), represent the position of the center line for the hand-wheel in the side elevation drawing, and at some point along it—preferably some distance above a horizontal line through the top point, 5, of *A*, or just below a horizontal line drawn through the bottom point, *D*, of *A*—construct a similar drawing to the dotted portion of *A*; the projection may now be begun.

In Fig. 20 the projected figure is but half complete, being an amount sufficient to illustrate the method of procedure; the dotted-half views are, however, all that is required to construct a finished projection.

In such a projection as the one in hand it is best to consider but one "feature" of the object at a time, and to complete the projection of this one feature before taking up a second one, thus minimizing possible confusion. With this suggestion in mind, divide the hand-wheel into the hub, the rim, and the arms, and first consider the projection of the outside of the front face of the rim—the straight line 5-*D* of the *A* elevation, shown also as the dotted circle 5-*D* of the same figure. To project this circle, first divide it into a number of points, as 5, 4, 3, 1, then project

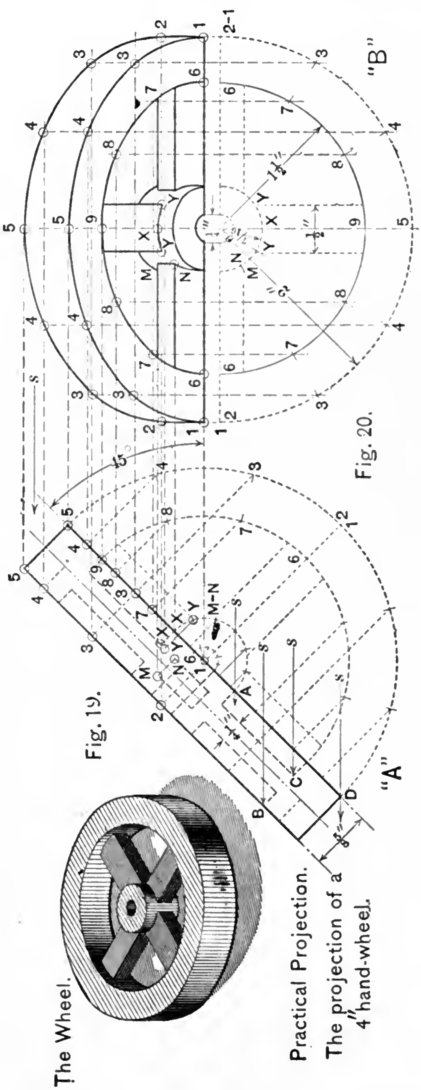


Fig. 19. Fig. 20.
The Wheel.
Practical Projection.
The projection of a 4" hand-wheel.

these points, perpendicularly, onto the straight line 5-*D*, and number them that they may be easily followed. Next, locate the outside circle of the dotted drawing of *B*, and divide it into a number of arcs, equal to those of the same circle in *A*, and number each point to correspond with the same point in *A*. Since the projected view is at right angles with the original position of the wheel, it is evident that the extreme point 5 of *A* is the center point 5 of *B*, and that the center point 1 of *A* constitutes the two extremes of *B*, a fact which renders the numbering of the other points an easy matter. In the drawing, the circles are divided into a number of equal arcs corresponding to twelve equal divisions in a complete circumference: this is in accordance with the usual practice, which is to divide the circumference into an equal number of equal arcs, for when thus divided a circle presents duplicate divisions when viewed from first one position, and then from a position at right angles to the first one. With the points in each drawing properly numbered, project vertically from *B* and horizontally from *A*, and the intersection of the projections from the same numbered point will be the new position of that point; the points being then joined by a smooth curved line, give the side view of the outside of the front face of the rim.

Next, consider the projection of the inside line of the front face of the rim—the dotted circles 9-8-7-6—and proceeding by projecting a number of its points as explained above, the curve 6-7-8-9, etc., of *B* is obtained—the side view of the inside of the front face of the rim.

The inside and outside lines of the front face of the hub of the wheel are projected in the same manner as directed for the lines of the rim.

Now let the arrows *s*, *s*, *s* represent lines of sight directed against the front elevation *A*, the point of sight being at an infinite distance to the right; and having the figure well in mind, consider just what lines of the front elevation will be visible in the side view. Referring to the rim, it is evident that the outside and inside lines of its rear face will appear at top and bottom, respectively, in the side elevation, the method of projection being clearly shown in the drawing. It is also evident that the outside line of the rear face of the hub will be partly visible in the side view.

To Project the Arms.—From a previous explanation, it is evident that the center arm—that shown as a rectangle in *A*—will be shown as horizontal in *B*, extending to the extremes, right and left, and that the other two arms of *A*—the two extending to the extremes, top and bottom—will show on the vertical center line of *B*. First consider the upper arm of *A*, an inspection of which shows three points to project; *X*, the intersection of the center line of its front face with the hub, and *Y*, the intersection of its side face with the hub. (Note the projection of these points from the dotted drawing of *A* to the front line of the sectional elevation of the arm.) By projecting horizontally from these points to an intersection with the vertical projection from the dotted position of the same points in *B*, three points are obtained—one central point and two extremes—through which the full-line curve *Y-X-Y*, representing the intersection of the arm with the hub, may be drawn, and the points *Y*, *Y* being established, the projection of the arm is completed by drawing vertically from these points to the inside line of the front face of the rim, the intersection of the arm with the rim being hidden. It is obvious that the curve of intersection, *Y-X-Y*, of the arm and hub is parallel to the same portion of the outside line of the hub.

To project the horizontal arms of *B*, it is evident, from an inspection of the sectional elevation, that there are two sides or faces—the top and front—to project, the work being clearly shown by the drawing.

It will have been observed that, because of the even number of arms in the hand-wheel, the drawings become symmetrical, and a number of the points project simultaneously. If the hand-wheel had an uneven number of arms, say five, the dotted half views would have to be complete views, and each arm projected separately, the circles being projected as explained.

78. PROBLEM 4.—**Projections of a Frustum of a Hexagonal Right Pyramid and its Development.**—Let the pyramid be assumed as resting on the horizontal plane, and let its position

with reference to the vertical plane be such as is defined by the drawings 1 and 2, Fig. 22—its horizontal and vertical projection respectively. The pyramid is first assumed as a whole, the

The Orthographic Projection of the frustum of a pyramid.

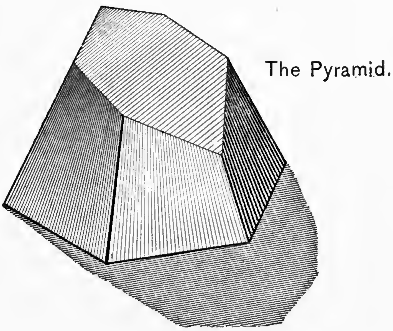


FIG. 21.

"frustum" not, as yet, entering into the problem. The drawings are constructed in the order numbered, that the edges of 2 may be projected from 1. Now that the pyramid is fixed, let

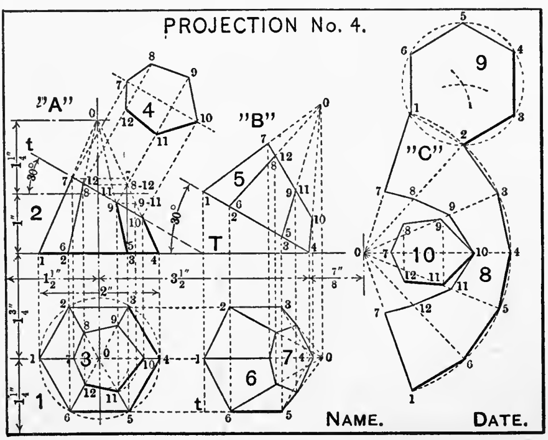


FIG. 22.

the upper base of the frustum be formed by cutting the pyramid with a plane, *T*, which is perpendicular to *V* and at 30° with *H*, and let the cutting plane intersect the vertical center line of the pyramid at a point one inch above its base. The plane of the upper base of the frustum is, of course, in the cutting plane, and this being perpendicular to *V*, the plane of the base is perpendicular to *V*, and is there projected as the straight line 7-10, one inch up the center line and at 30° with the horizontal, as shown in 2. The frustum is now assumed, but the upper base shown only in its vertical projection. Now to obtain its horizontal projection:

The pyramid has six edges, and each edge has a point of intersection with the upper base; that is, to form the upper base, each edge has been cut by a plane. Now, each edge is shown in its two projections, and since the points of intersection of the edges with the plane of the upper base must be horizontally projected in some point on the horizontal projection of the edges, and since the projections of a point are always in the same perpendicular to the ground line, it is evident that the horizontal projection of the points of intersection of the edges with the upper base is the intersection of the projection from the vertical intersections with the horizontal projection. For example, consider the point 12 of 2: 12 is on the edge 6-0; the horizontal projection of this edge is the line 6-0 of 1; the horizontal projection of the point must be on the line 6-0 (1) and must lie in the perpendicular through 12 (2) to the ground line; therefore the horizontal projection of the point is the intersection of 6-0 (1) and the perpendicular 12-12. The other five points of the upper base are projected from the vertical to the horizontal in a similar manner, and these points being joined by straight lines, as indicated in the drawing, represent the horizontal projection of the upper base.

Let it be now required to show the true size of the upper base of the frustum. It is obvious that since the plane of this base is at an angle with *H*, the projected base in 1 does not represent the true size of the base. To show the true size, the base must be projected onto a plane which is parallel to it. In drawing 4, let the line 7-10, parallel to 7-10 of 2, represent such a plane; the projection is then made on this plane, and to "show" it, the plane is revolved into the vertical plane of projection, the practical solution being as follows:

Draw the line 7-10 (4) parallel to and at an optional distance from the line 7-10 (2), then draw the indefinite perpendiculars 7-7, 8-8, etc. It is obvious that the true length of the base is defined by the intersections of the perpendiculars 7-7 and 10-10 with the line 7-10 (4). The true widths of the base are shown in its horizontal projection (1), for it is evident, since the plane of the base is perpendicular to *V*, a straight line joining the points 8 and 12, for example, is parallel to *H*, and being parallel, will there be projected in its true length. Combining these "true widths" with the "true lengths" of drawing 4—using the line 7-10 as a center line—a drawing representing the true size of the upper base of the frustum is obtained.

Let the frustum now be tilted on the point 4 of the lower base, until the plane of this base is in a position 30° with the horizontal plane, without changing its position with reference to *V*, and let it be required to draw the *H* and *V* projections.

To draw the *V* projection, copy drawing 2, tilted to 30° with the ground line, as drawing 5, *B*. Now, since the position of the frustum with reference to *V* has not been changed, and since the two projections of a point must lie in the same perpendicular to *G*, the *H* projection is obtained by projecting horizontally from 1, *A*, and vertically from 5, *B*. This will give a complete projection—upper and lower base, and all edges; the drawing, however, shows a second method of projecting the upper base, by projecting the pyramid as a whole and locating the upper base by projecting the *V* intersections of the edges with this base to the horizontal projection of the edges—the same method as given for the first projection of this base.

Development.—To develop means to unfold, and assuming the frustum to be hollow—made of sheets of pasteboard or metal—let it be required to develop it. It is evident that in the development each base and every side will show in its true size and length. The true size of the two bases is known (the lower base being in the horizontal plane, and projected in 1 in its true size), now to obtain the true length of each of the six sides.

Since the pyramid is a right pyramid, all of its edges are of equal length; the drawing, however, shows the edges of unequal lengths: four of them, being oblique to both *V* and *H*, show a length less than the true length, and two, being parallel to *V*, show on that plane in their true length. The true width at the bottom of each face of the pyramid is known, this line being in the horizontal plane (1). To draw the development proceed as follows:

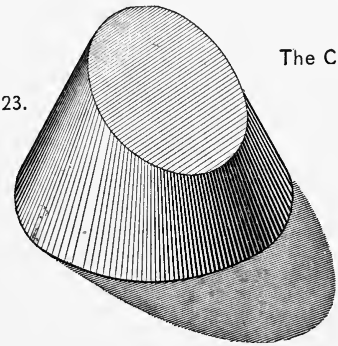
With o (*C*) as a center, and a radius equal to the slant height of the pyramid—the true length of an edge—describe the indefinite arc 1-2-3, etc.; now use the line o-4 as a center line, and from its intersection with the arc, with the true length of the base of a side of the pyramid as a unit, lay off (both above and below the center line) on the arc the lengths 4-3, 3-2, etc., and join these points with each other, and with the center, o; the resulting drawing will represent the development of the sides of the pyramid. To obtain the development of the sides of the frustum, find the true lengths of the various edges and transfer these lengths to drawing *C*.

Let the frustum be cut—for development—along the edge 1-7; this edge being parallel to *V* (1) shows its true length on *V*; also, the edge 4-o is there projected in its true length for the same reason; these lengths, then, may be taken directly from 2. To obtain the true length of the other four edges, each in turn must be revolved about o as a center (1), until parallel to *V*, when their true lengths will be there projected, showing in the drawing (2) as the lengths 4-9, 4-8, etc., on the slant height 4-o. These lengths are then laid off on the proper line of *C*, and the points 7, 8, etc., thus obtained, when joined by straight lines, give the development of the line of intersection of the sides and upper base, completing the development of the sides of the frustum.

In the development, the upper base should be attached to some point of the line of intersection of the sides with this base, and the lower base should be attached to the line of intersection of the sides with the lower base. These two figures, 10 and 9, are copied from 4 and 3 respectively, and placed as shown (*C*) for balance. With *C* completed, if cut out along the full-line outline and folded together, it would give the object illustrated in Fig. 21.

79. PROBLEM 5.—**Projections of a Frustum of a Right Cone of Revolution, and its Development.**—Figs. 23 and 24. Let it be required to draw the projections of a frustum of a right cone of revolution, and to develop the frustum, the cone to be assumed and projected the same as the pyramid given in Problem 4.

Fig. 23.



The Orthographic Projection of the frustum of a cone.

This problem is solved by dividing the circle of the base of the cone into an equal number of equal arcs, and joining these points of division with the apex of the cone, thus giving a number of elements of the cone—working lines—which are projected through the several drawings in the manner described for the six edges of the pyramid, with the exception that, instead of joining the projected points with straight lines, curved lines are used. There are, however, two elements which cannot be thus projected, i.e., the center elements, *C* (*V*) and 4-*C*, 10-*C* (*H*); in locating the points through which the *H* projection of the curve of the upper base of the frustum is to be drawn, it is necessary to find the points *X* and *Y*—the projection of the intersection of the elements 4-*C* and 10-*C* with the plane of the upper base. To locate these points, since any section parallel to the plane of the lower base is a circle, if a plane *X*-*Y* be passed perpendicular to *V* and parallel to *H*, through point *C*, it is obvious that the

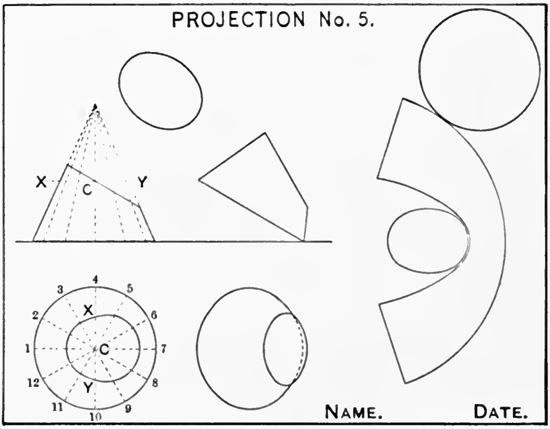


Fig. 24.

distance from the center of the cone to point *C* on the surface is equal to the radius *C*-*X* or *C*-*Y* of the circle cut by the plane *X*-*Y*; hence take the distance *C*-*X* or *C*-*Y* and lay it off on the line 4-*C*-10, as *C*-*X* and *C*-*Y*, which gives the required points.

80. Problem 6. **To Draw the Projections of the Intersection of Two Right Cylinders of Revolution, and to Develop the Cylinders.**—Plate No. 8. Let the cylinders be assumed as shown by drawings 1 and 2, Fig. 5, and the first position of Fig. 1.

To solve the problem, select a number of elements in each cylinder to use as working lines; with this in mind, pass a number of planes, *t*-*T*-*t*′, which are perpendicular to both *V* and *H*, cutting the smaller cylinder, *S*, in a number of elements, and since the two cylinders intersect at right angles, these same cutting-planes also cut elements of the large cylinder, *L*. These planes are passed through *S*, because all such planes intersect both cylinders.

In drawing (Fig. 5), the method of procedure is to divide the small circle (1) into an even number of equal arcs, and through these points of division to draw the vertical lines as shown.

The first position of the cylinders is one in which the elements of *S* are parallel to *H* and perpendicular to *V*, and the elements of *L* are parallel to *V* and perpendicular to *H*. Throughout the problem, *L* is assumed as resting on *H*.

The view marked 4 presents a side view of 1, and is obtained by first constructing drawing 3, which is a copy of drawing 2, turned 90°, and then projecting vertically from 3 and horizontally from 1, and locating the intersection of the projections of the elements cut by the same plane.

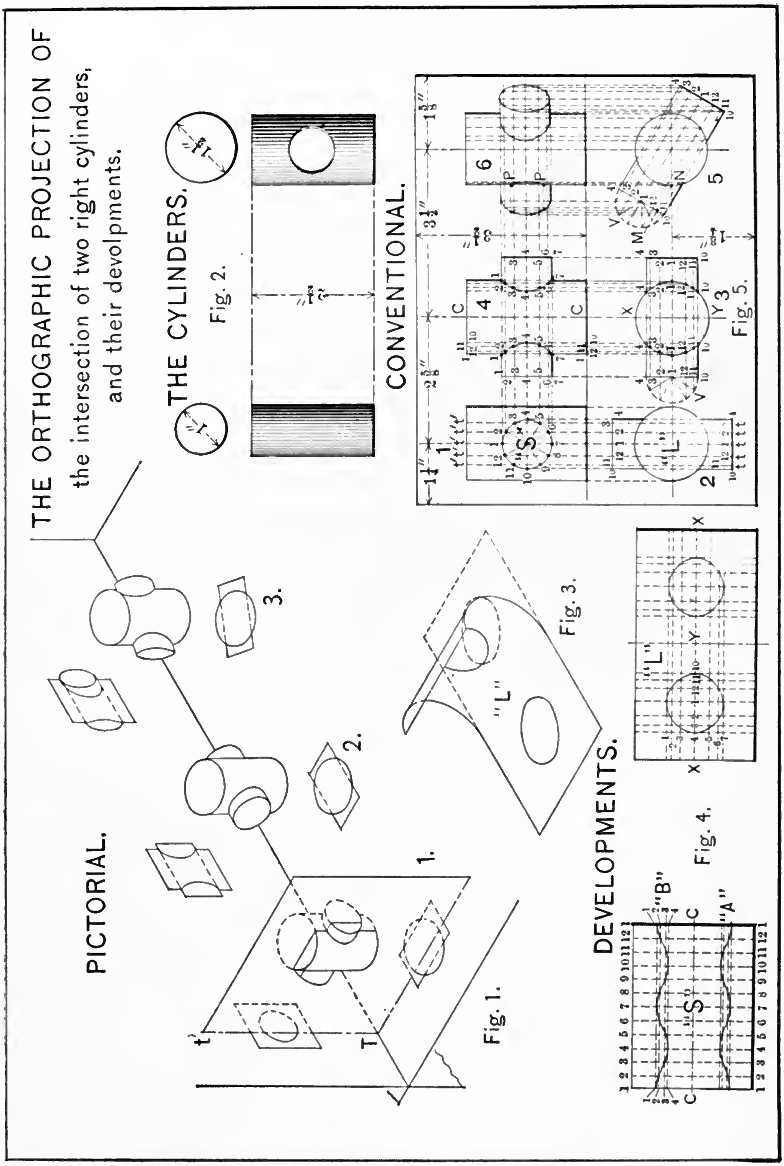
The view marked 6 is an angular, side view of 1, and is obtained by first constructing 5, which is a copy of drawing 3, turned 30° to the ground line, then projecting vertically from 5 and horizontally from 4. The location of the points *P* and *P* (6) require special mention.

When looking against the vertical plane, as view 6 is taken, one cannot see that portion of the large cylinder beyond a section parallel to *V* through its center, in the drawing, beyond the extremes of the horizontal diameter through the point *N* (5). An inspection of the drawing shows no element-cutting plane through this point; to project this point, then, let an auxiliary element-cutting plane be passed through the point, and the projection made in accordance with the drawing.

Assuming the cylinders to be hollow and with open ends, let it be required to develop them, to roll them out flat, as shown by Fig. 3.

The Development of the Small Cylinder.—Lay off the perpendicular line 1-1 (*S*, Fig. 4) equal to the true length of the small cylinder, and draw the indefinite horizontal lines 1-1. Now take the cord of arc 1-2 (1, Fig. 5), which is contained twelve times in the circumference of *S*, and lay it off twelve times on either of the horizontals 1-1, or the center line *C-C*, and through the twelve points thus obtained draw the twelve perpendiculars 1-1, 2-2, 3-3, etc., completing the development of the small cylinder. It is obvious that the greater the number of arcs in *S*

PLATE No. 8.


THE ORTHOGRAPHIC PROJECTION OF
the intersection of two right cylinders,
and their devolpments.
THE CYLINDERS.
Fig. 2.
CONVENTIONAL.
Fig. 5.
PICTORIAL.
Fig. 1.
Fig. 3.
DEVELOPMENTS.
Fig. 4.

(1, Fig. 5), the smaller the cord of the arc, and the more nearly accurate the development.

In addition to developing *S*, let it be required to show the line of its intersection with *L*. There are already lines on the development representing the elements of *S*; also, drawing 4 shows these elements when parallel to *V*, and hence in their true length. The short method of showing the lines of intersection referred to is as follows: Working from the center line *C-C* of drawing 4 (Fig. 5), take the lengths showing the horizontal distance of the various points of the intersection 1, 2, 3, etc., from this center line and transfer them to the development as the lengths *C*-1, *C*-2, *C*-3, etc., and draw the horizontal lines as shown, giving the points through which the curve representing the line of intersection is drawn.

To Develop the Large Cylinder.—Lay off the vertical length *X'* (*L*, Fig. 4), draw two horizontal lines of indefinite lengths through its extremities, and draw the center line *X-Y-X*. Now, let the cylinder be cut along the element *X* (3, Fig. 5), and taking the lengths of the chords of the arcs, *X*-4, 4-3, 3-2, etc., until again coming to the point *X*, transfer them to the development as shown and erect the dotted perpendiculars, which represent those elements of *L* cut by the cutting planes and concerned in the intersection. In drawing 3, the elements of this cylinder are perpendicular to *H* and parallel to *V*, and hence are projected on *V* in their true length. The short method of showing the development of the intersection is as follows: Working with the line 4-4 (4, Fig. 5) as a center line, take the lengths representing the perpendicular distances of the various points of the intersection 1, 2, 3, etc., from this center line and transfer them to the development as the lengths 4-1, 4-2, etc., and draw the horizontal lines as shown, giving the points of intersection through which the two ellipses, representing the holes to receive the small cylinder, are drawn.

With the two developments complete, if cut out along the full lines and rolled into cylinders, it will be found that the two can be fitted together the same as is illustrated by Fig. 1.

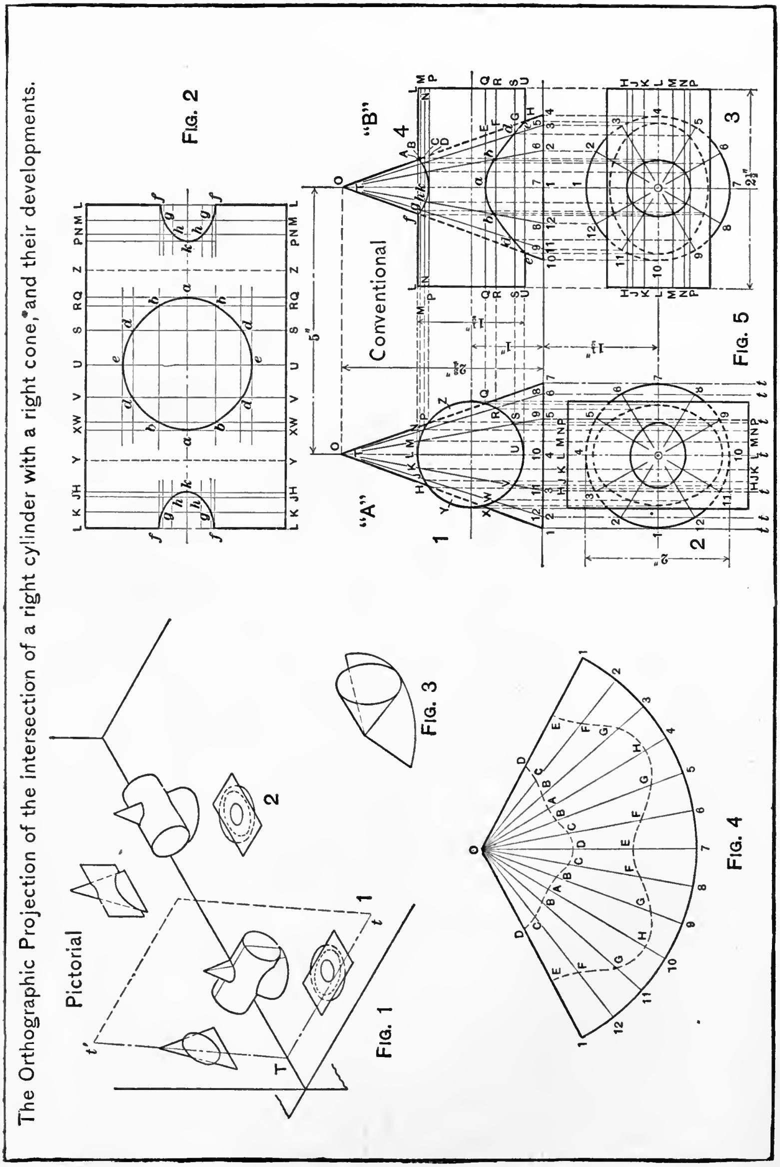
81. PROBLEM 7. **To Draw the Projections of the Intersection of a Right Cone of Revolution with a Right Cylinder of Revolution, and to Develop Both.**—Plate No. 9. Let the objects be assumed as by drawings 1 and 2, Fig. 5, and drawing 1, Fig. 1. To solve the problem select a number of intersecting elements in each figure and project these elements as in the previous problem.

To select the elements to be projected, pass a number of planes, *t*-1-*T*, *t*-2-*T*, etc. (Fig. 5), perpendicular to *V* and at various angles with *H*, through the apex of the cone and intersecting the cone and cylinder along elements, the practical method being to divide the circle of the base of the cone into an equal number of equal arcs, to project these divisions to the vertical projection of the base and then to join these points of division with the apex. These lines, then, represent the projections of the elements of the cone which are to be dealt with; the elements cut from the cylinder by the same intersecting planes are clearly shown by the drawing.

To horizontally project the intersection of the two figures (the two ellipses shown in 2), project, vertically, from the points of intersection of the circle of the base of the cylinder with the different elements of the cone (1) to the horizontal projection of the elements of the cone—the radial lines of 2—as in Problem 5. It is obvious that the small ellipse represents the visible portion of the horizontal projection of the intersection and the large ellipse the hidden portion; the case in hand is one of penetration—the cone penetrating the cylinder.

Drawing 3, Fig. 5, is a copy of drawing 2, turned 90°, and drawing 4 is obtained by projecting horizontally from 1 and vertically from 3, the lines of intersection being obtained by projecting horizontally from the intersection of the circle of the base of the cylinder with the different elements of the cone (1) to the various elements of the cone as shown in 4. The horizontal projection of the intersections (3) are obtained by projecting vertically from the points of intersection shown in 4 to the horizontal projections of the elements of the cone—the radial lines.

PLATE No. 9.



The Orthographic Projection of the intersection of a right cylinder with a right cone, and their developments.

To Develop the Cylinder.—Drawings 1 and 4, Fig. 5, show an end and side view of the cylinder, respectively, the elements showing in their true lengths in the side view; to develop the cylinder, draw the vertical line *L-L*, Fig. 2, and draw the two indefinite horizontal lines *L-L*. Now, working from the circle of drawing 1, Fig. 5, and assuming the cylinder to be cut along element *L*, take the length of the chord of the arc *L-K* and lay this length off on the development as the horizontal length *L-K*; next take the chord of the arc *K-J* and transfer it to the development in the manner shown, and so on, taking each chord in turn until again at the point *L*, when the length of the horizontal line *L-L* will be determined and is approximately equal to the distance around the cylinder—the circumference. It should be noted that the arcs *H-X* and *P-Q* are bisected, rendering the length of the development more nearly equal to the length of the circumference of the cylinder than if the chords of the above arcs had been used.

Each point of division along the horizontals *L-L* represents the locus of an element of the cylinder, which, when connected by the perpendiculars *L-L*, *K-K*, etc., locate the elements required to find the development of the lines of intersection, the points of intersection being found as follows: Take the true lengths of *L-f*, *M-g*, etc., from drawing 4, transfer them to the development as shown, and connect the points thus obtained with a curved line.

To Develop the Cone.—With o (Fig. 4) as a center and a radius o-1 (1, Fig. 5) equal to the slant height of the cone (the true length of the elements), describe the indefinite arc 1-1. Now the base of the cone has been divided into twelve equal arcs, and since the length of the arc 1-1 must equal the length of the circumference of the base of the cone, take the chord of one of these arcs and step it off twelve times along the arc 1-1, then join these points of division with the center, o; this gives a drawing representing the development of the cone.

To show the line of intersection of the cone with the cylinder, the true length of each element from the base or from the apex of the cone to its point of intersection with the cylinder must be taken from either drawing 1 or 4 by horizontally projecting each point of intersection onto the slant height—a short method of revolving parallel to V—as in Problem 5, and transferred to the development as shown.

82. PROBLEM 8. **To Find the Intersection of Two Right Cylinders of Revolution which Intersect at an Angle.**—Fig. 25. This problem is met with in the drawing of pipe fittings, boilers, etc., wherever it is required to represent the intersection of two cylinders.

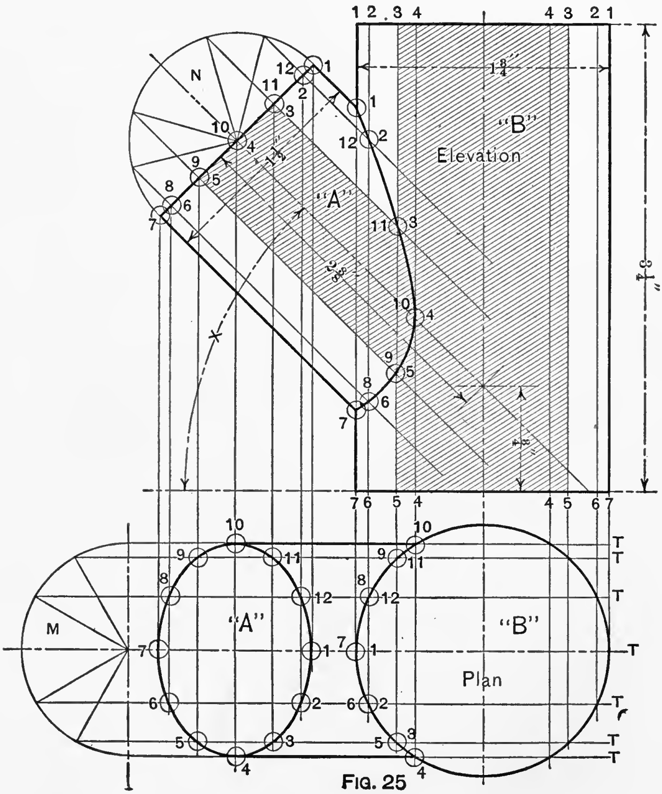


FIG. 25

Analysis.—Intersect the two cylinders with a system of planes, T, T, T, etc., which cut elements from both cylinders (as indicated by the ruled section) and find the intersection of the elements of each cylinder cut by the same plane; these points, when joined by a curved line, represent the line of intersection of the cylinders.

Solution.—Draw the semicircles *M* and *N* and divide them into an equal number of equal arcs; through these points of division draw the lines 1-1, 2-2, etc., parallel to the elements of cylinder *A*. From the points of intersection of these lines—elements—with the circle of the large cylinder, *B* (the plan drawing), project to the elevation to an intersection with the elevation of the same elements and join the points thus obtained, as shown.

The developments are made as in Problem 6.

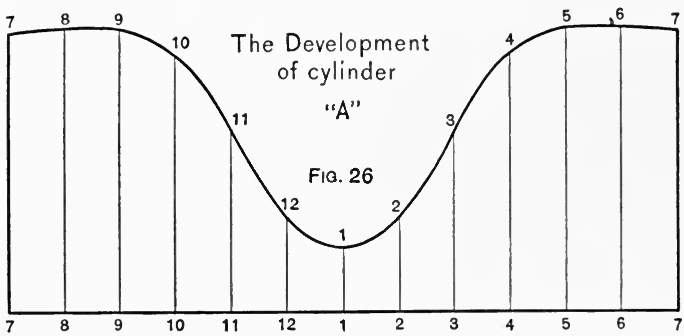


FIG. 26

83. PROBLEM 9. **To Construct a Conical Paper Shade for an Ordinary Incandescent Lamp.**—Let the drawing for the proposed shade be that given in plan and elevation, Fig. 27.

Analysis.—If the sides *D-A* and *C-B* of the shade be projected to an intersection at *O*, the shade becomes a cone, which, when developed and a proper allowance made for lap, may be cut from the paper and rolled into the required shade.

Solution.—Produce the lines *D-A* and *C-B* as suggested, and with the length *O-A* as a radius, and with *O*, Fig. 28, as a center, describe the indefinite arc *B-B′*. Now divide the circumference of the plan of the base of the cone into an equal number of equal arcs; take the chord of one of these arcs and step it off along *B-B′* the same number of times it is contained in the circumference of the plan of the base; from the two extremes of the thus deter-

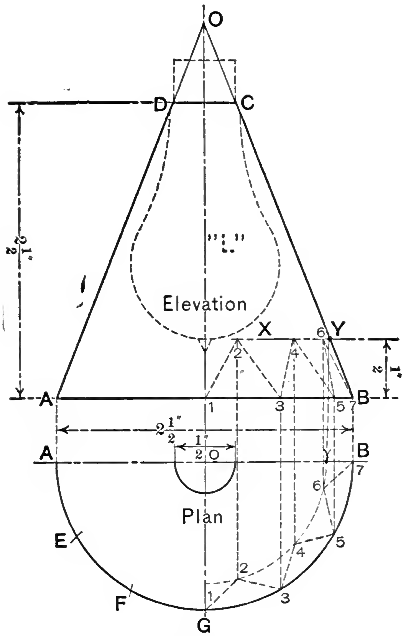

O
D
C
"L"
Elevation
X
Y
A
B
Plan
E
F
G
1
2
3
4
5
6
7

FIG. 27.

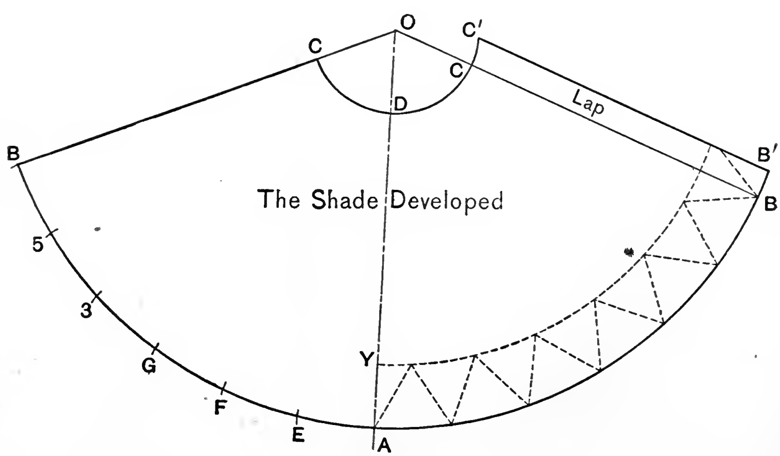

O
C
C′
C
D
Lap
B
B′
B
The Shade Developed
5
3
G
F
E
Y
A

FIG. 28.

mined arc draw lines to the center *O*. Now take a radius equal to *O-D* of the elevation drawing and describe the arc *C-C*, terminating in the radial lines from the center to the extremes of arc *B-B'*. To allow for lap, produce the arcs *C-C* and *B-G* as shown, and terminate them with a line parallel to *C-B* at the required distance; cut out along the heavy line outline (other lines being construction lines), fold up, and paste or pin the lap; that is, securely fasten the ends with *C-B* and *C-B* coincident, and the shade is finished.

84. First and Third Quadrant Projections.—In mechanical drawing, it is often convenient to draw the plan of an object below the elevation—a procedure which is in strict accordance with the principles of projection, and a correct one in every way.

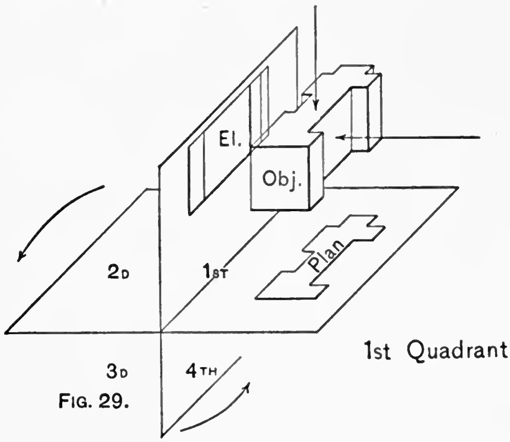


FIG. 29.

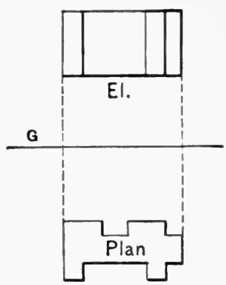


FIG. 30.

Referring to Figs. 29 to 32, inclusive, Fig. 29 illustrates the first quadrant projection of an object, Fig. 30 representing the conventional projection. It will be noted that in this drawing the plan is below the elevation. Now assume the object to be transferred to the third quadrant as in Fig. 32 and here (Fig. 31) the plan is above the elevation; hence when the plan of an object is drawn above the elevation the object is assumed to be situated in the third quadrant and the drawing said to be a third-angle drawing or projection; when the plan is drawn below the elevation, the drawing is a first-angle drawing or projection.

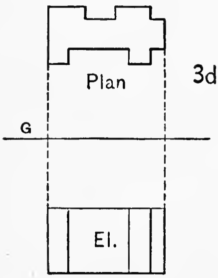


FIG. 31.

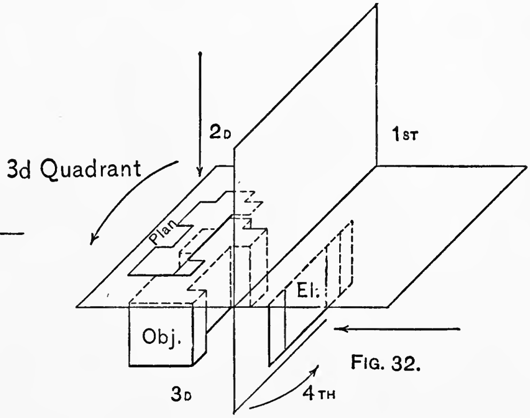


FIG. 32.

85. Isometric Projection.—In the orthographic projections treated of thus far the objects projected have been so situated relative to the planes of projection as to project but one face of the object on each plane, and this is the usual practice. It is, however, often desirable to project two or more faces of an object onto one plane of projection, that a general conception of the object may be obtained from the one projection or drawing. To construct a scenographic projection, which is obtained mechanically from and after the usual orthographic projections have been constructed, requires much time and labor, and because of the complicated arrangements occurring in machinery is practically useless for such work. There is, however, a method of assuming objects to be so situated with respect to the planes *V* and *H* as to orthographically project two or more of its faces on each plane; such an arrangement may be called an "oblique" orthographic projection.

There is a special case of oblique orthographic projection, called "isometric" projection, which portrays three faces of an object, is comparatively easy of construction, and is well adapted to the representation of fairly simple objects; particularly is it convenient and specially adapted to the representation of rectangular objects or objects in which the principal lines are straight, parallel lines, as in the frame of a building. Having three faces to depict, there are three dimensions to be considered: (1) length, (2) breadth—both horizontal dimensions—and (3) height—a vertical dimension.

Let it be required to construct an orthographic projection of a cube, the projection to show equal amounts of three adjacent faces. It is evident that to portray equal amounts of three adjacent faces of the cube, it must be assumed to occupy a position relative to the plane of projection, such that one of its diagonals will be perpendicular to the plane. Fig. 33 is a representation

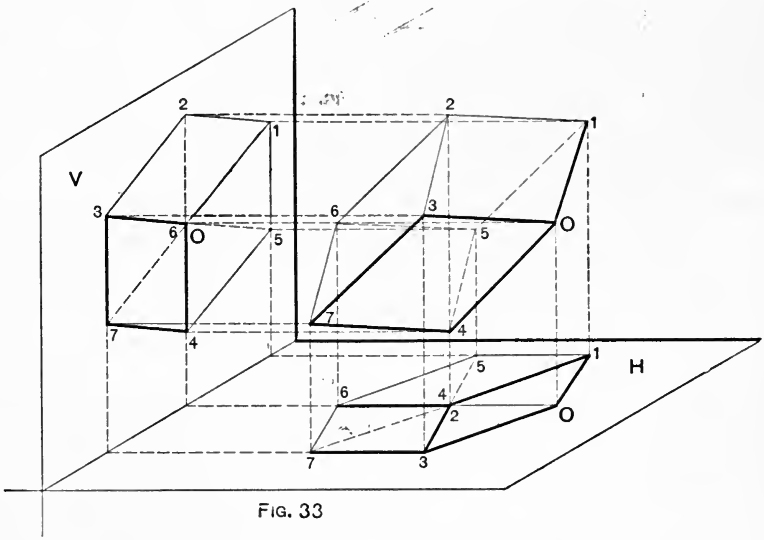


FIG. 33

of the proposed arrangement. Having three faces projected, the projection on but one plane is all that is necessary to "tell the story." The vertical plane is the one adopted. Fig. 34 is a mechanical drawing of the arrangement, *A* being a side view of the cube and *V*-*V* a side view of plane *V*. It will be observed that the line 6-O—a diagonal of the cube—is perpendicular to the plane of projection. The drawing marked *B* is a front view of the plane *V*-*V*, showing the orthographic projection of the cube when thus assumed, and is now called the "isometric" projection of the cube.

It will have been noted in orthographic projection that a line is projected in its true length only when parallel to the plane of projection. It is evident in the above case that the lines—

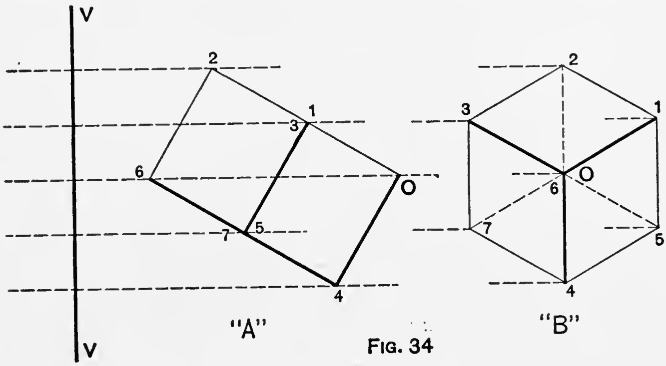


FIG. 34

edges—O-1, O-3, and O-4 make equal angles with the plane *V-V*, and making equal angles, will be projected on that plane in equal lengths, which lengths, however, are somewhat less than the true lengths, being foreshortened (equally) in projection. The angle noted is an angle of 35°-16′, and the projected length is proportional to this inclination, being approximately equal to .8 of the true length.

Referring to Fig. 34 again, and remembering that the three adjacent edges O-1, O-3, and O-4 of the cube form right angles, it will be noted that the projected angles between these lines are equal—equal to 120°. These three lines form the basis of operation in isometric projection and drawing and are called the "coordinate axes." The perpendicular diagonal of the cube is called the isometric axis and the common point of intersection, O, is called the origin. Fig. 35 is a representation of the coordinate axes, showing an optional notation for the three dimensions of isometric projection and drawing.

There is a distinction between isometric "projection" and isometric "drawing," which can be illustrated by the case of the cube. Fig. 34, *B*, is an isometric "projection" of the cube, and, as has been explained, the length of the sides of the projection are but .8 of the true length of an edge of the cube; in an isometric "drawing" it is customary to draw the lines represent-

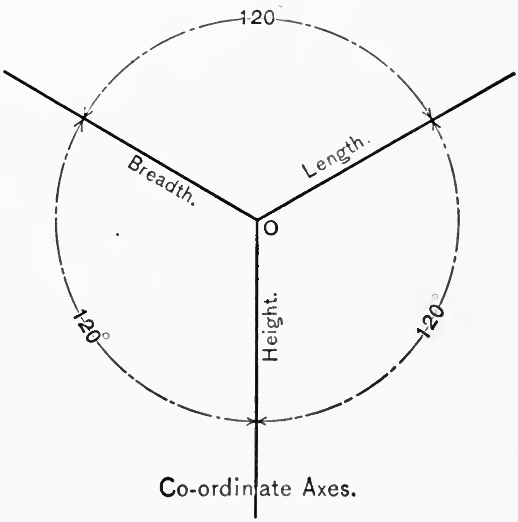


FIG. 35.

ing the edges of the cube of a length equal to the true length of an edge; as, for example, suppose one has a 1-inch cube to project and to draw, the lines of the projection will be .8 inch long, while the lines of the drawing will be 1 inch long.

To illustrate the application of the principles of isometric projection to practical draughting—the construction of isometric drawings—let it be required to construct an isometric drawing of an object the mechanical drawing of which is shown in *A*, Fig. 36. Having three faces to show, there are three dimensions: l = length, b = breadth, and h = height. Now assume the object to be inclosed by a rectangular box, as is indicated by the dotted lines, the three dimensions of the box corresponding with the three extreme dimensions of the object—l, b, and h.

Having such an assumption in mind, the isometric drawing of the object may be begun, the first step of which (Fig. 36) is to draw the coordinate axes and assume one line to represent length, *l*, one to represent breadth, *b*, and one to represent height, *h*. The second step is to lay off on the co-ordinate axes *l*, *b*, and *h* lengths corresponding to *l*, *b*, and *h* of the mechanical drawing, after which complete the isometric drawing of the inclosing box by drawing lines from the extremities of these three lengths parallel to the co-ordinate axes, as shown. The third step of the drawing is to draw those lines visible in some one face of the box. In Fig. 36 this "one face" is the top face; in like manner the fourth and fifth steps are executed by drawing those lines visible in the front and right faces, respectively. The sixth step is to draw all other visible lines, and the seventh step to erase all construction lines, giving a finished isometric drawing.

To Dimension an Isometric Drawing.—Mechanical drawings are dimensioned in two directions, (1) horizontal and (2) vertical; in isometric drawing the dimensions are drawn parallel to the coordinate axes. An isometric drawing is rarely used for shop purposes, that is, as a working drawing having all dimensions given, etc., except for representing very simple rectangular objects, being most useful as a drawing for illustration and not for direction or instruction.

An isometric drawing intended for shop purposes should be completely and properly dimensioned and noted, eliminating all possible necessity for the workman to "scale" the drawing; however, should it be required to scale an isometric drawing, the scaling must be done in the direction of the coordinate axes.

Isometric Scales.—As has been described, the usual and practical method of constructing isometric drawings is to draw the lines of the drawing of the same, or some standard proportional length of the line of the object each represents, remembering that the "isometric dimensions" are measured in directions parallel with the direction of the coordinate axes; however, for some special reason one may have occasion to construct an isometric projection of an object. To construct such a drawing it is first necessary to construct an isometric scale—a scale on which all the dimen-

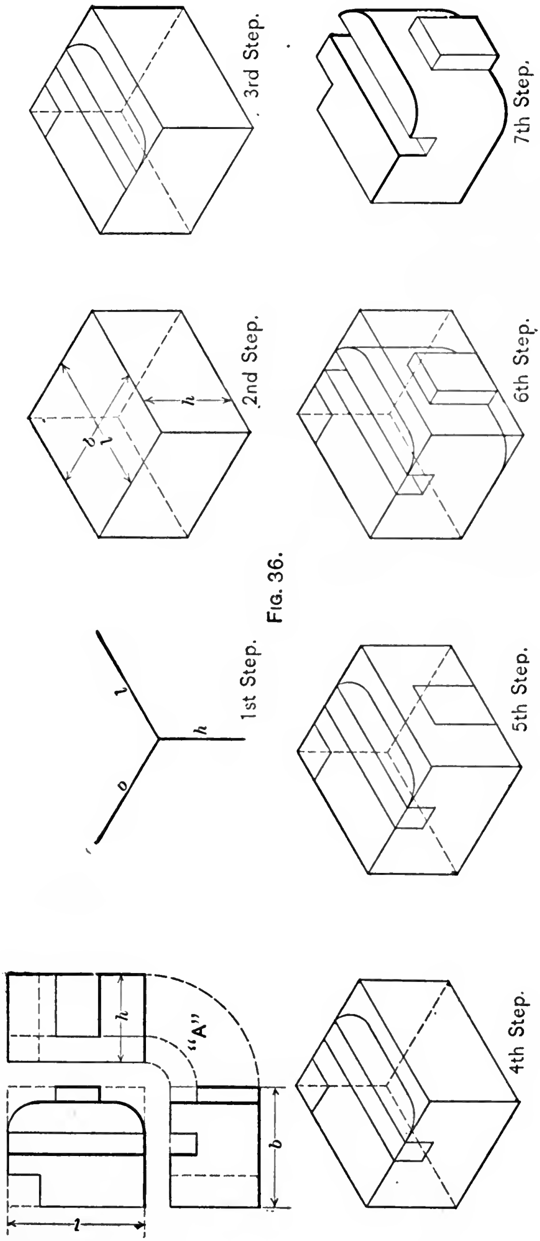

3rd Step.
7th Step.
2nd Step.
6th Step.
1st Step.
5th Step.
4th Step.
"A"
h
l
b

FIG. 36.

sions are properly foreshortened, as 1 inch will be represented by a length .8 inch long. The scale is constructed by laying off the scale *B*, Fig. 37, the left side of which is graduated into full-length inches and subdivisions, then projecting horizontally to scale *A*, the right side of which is the foreshortened isometric scale.

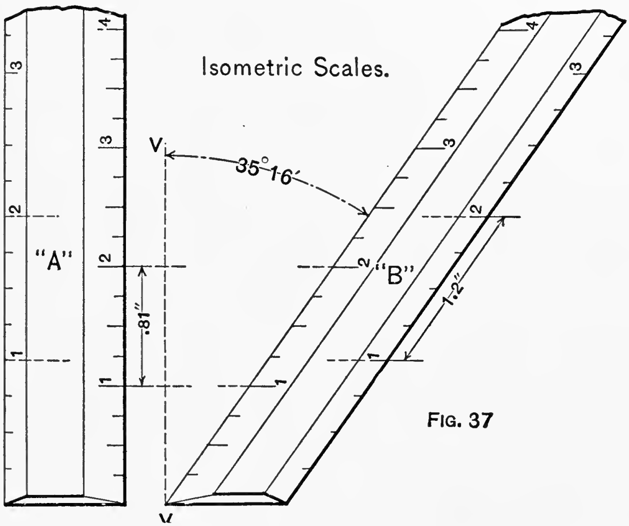


FIG. 37

To use scale *A* for the construction of isometric projections, the object is measured with the left side of the scale—the full-length scale—and the projection constructed with the right side of the scale.

By referring to Fig. 37 again it is seen that the full-length inches of *A* (those on the left) when projected horizontally to the right side of *B* are 1.2 inches long; hence an isometric "drawing" is 1.2 times the size of the object.

These isometric scales have no practical use and are given only as a matter of information in case one should ever wish to employ such a scale.

86. Elementary Examples.—Let it be required to construct an isometric drawing of a cube each of whose faces contains a circle of the same diameter as the dimension of the cube. Let the drawing of the cube be constructed in accordance with the instructions already given (Fig. 38). Now to draw the circle within the top face, *A-B-C-O*, since it will be tangent at the middle point of each side of the rhombus *A-B-C-O*, locate this point of

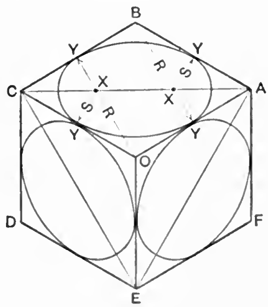


FIG. 38.

each side, and with a center at *B* and a radius, *R*, equal to the distance from *B* to *Y* (the middle point of the opposite side of the rhombus) draw the arc *Y-Y* (the long one), then with the point *O* as a center, and with the same or equal radius, *O-Y*, describe

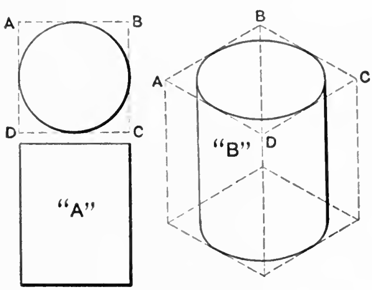


FIG. 39.

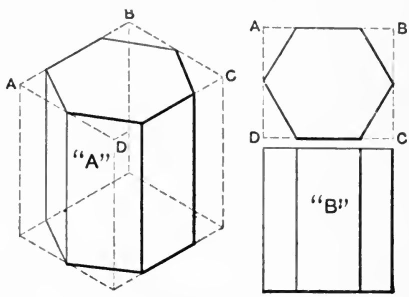


FIG. 40.

the second long arc *Y-Y*; next draw the diagonal *C-A*, and with the points *X*, *X*—the points in which this diagonal cuts the lines *B-Y* and *O-Y*—as centers, and a radius, *S*, equal to the distance from *X* to the points *Y*, *Y*, complete the ellipse *Y-Y-Y-Y*—the isometric drawing of the circle in the top face of the cube.

The ellipses of the right and left faces are drawn in like manner. This is the method of constructing all circles and circular arcs in isometric drawing, i.e., to first inclose the circle within a square, then to draw the square in isometric, then the circle as directed.

Examples of simple isometric drawings are given in Figs. 39 and 40, and in the various Plates.

CHAPTER IV.

DRAWING TOOLS AND MATERIALS.

87. Introductory.—As all drawings consist of either straight or curved lines, entire or in combinations, and since in mechanical drawing these lines must be exact, the student in draughting must provide himself with a number of mechanical devices, technically termed "instruments," calculated to facilitate his labor and precision.

In draughting, as in all manual labor, the skill, natural or acquired, of the "operator" is a potent factor in securing results; however, in the selection of instruments this factor should be disregarded and the best instrument selected that can be afforded; for granted a skilled draughtsman may execute a fair drawing with inferior instruments, how much better work might he do with the very best; for the unskilled it is obvious the "very best" is none too good. The beginner should not think "anything will do to begin with," promising himself to provide an A1 outfit when he shall have acquired a fair degree of proficiency. Accuracy is one of the first requisites of a mechanical drawing and cannot be secured with poor tools.

Having recognized the necessity of proper equipment, the question "What 'make' of instrument is the best" confronts the prospective purchaser. Of all of the numerous "makes" on the market, there may be said to be two general classes: (1) the instrument of triangular section and (2) the instrument of circular section. (See Figs. 48 and 49.) Consultation with experienced draughtsmen will elicit the information that there is a characteristic of instruments called the "feel" of the instrument, meaning the sensation produced on the nerves by the handling of the tool, one draughtsman preferring the first class of instrument because of its "feel," its "touch" when in his hand, and another draughtsman preferring the second class of instrument for the same reason, it being simply a case of what the man is accustomed to.

The selection of instruments, then, becomes a question as to details of construction, and is a matter of finance and choice with the buyer, he being "safe" in purchasing a good quality of any of the standard makes.

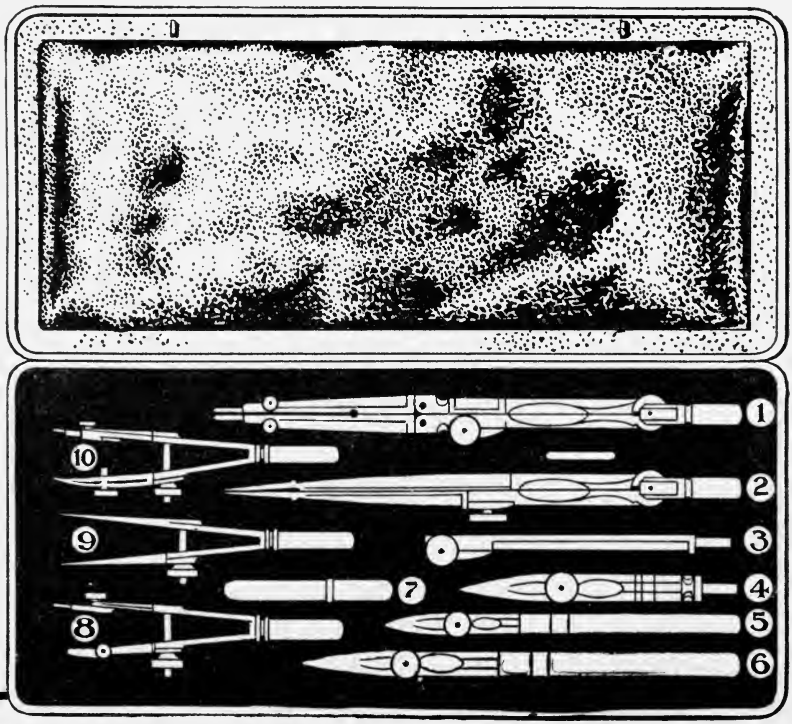


FIG. 41.

1. Compass with pencil-leg and needle-point. 2. Hair-spring dividers. 3. Lengthening-bar. 4. Pen-leg. 5, 6. Ruling-pens. 7. Lead-box. 8. Bow pencil. 9. Bow dividers. 10. Bow pen.

"Just what tools are necessary, what to buy," is the next question, and is one of much latitude, since there are tools and devices to be had by the score. As in every question, there are two sides to be considered: (1) what can one get along with, and (2) what ought one to have?; the answer to the first being instruments for drawing straight and curved lines, representing few tools and a minimum outlay, while for the second question it might be said that many tools were desirable, representing a maximum outlay. Of these two extremes a mean is taken, and the following list names the articles that should comprise a good, practical "outfit":

1. A case of instruments, to consist of
   - 2 ruling-pens, 1 large, 1 small.
   - 1 compass, with pen and pencil-legs and extension-bar.
   - 1 pair dividers, with hair-spring adjustment.
   - 3 bow-instruments: (1) pen, (2) pencil, and (3) dividers.
   - 1 box leads, hard and medium grades.
2. Drawing-board.
3. T square.
4. 2 Triangles: (1) 45° and (2) 30°–60°.
5. Irregular curve.
6. Architect's scale.
7. Thumb-tacks.
8. Pencil, hard lead—HHHHHH.
9. Pen and penholder.
10. Erasers—pencil and ink.
11. Ink, black.
12. Rag for cleaning instruments.
13. Blotter.
14. Soapstone pencil.

The instruments named under item 1 can be secured separately; the "trade," however, provides a neat and convenient case (Fig. 41) for the tools, and as the additional cost of the case is small when compared with the cost of new instruments, it is advisable to purchase a case; the tools will then have a proper receptacle, and with ordinary care this will minimize the necessity of purchasing new tools.

88. The Ruling-pen.—Since the major portion of most drawings is composed of straight lines, the ruling-pen easily becomes the instrument of prime importance. The first requisite of a good ruling-pen is that the temper shall be just right; it must not be too soft, rendering frequent sharpening necessary; neither must it be hardened to a degree rendering it brittle and susceptible to fracture. The "temper" is a quality which cannot be recognized by the eye alone because of the high polish given the tool; the instrument must be given a trial and if not of the proper degree of hardness it may, provided the stock be right, be retempered.

Apropos of further discussion, let the student acquaint himself with the names of the various parts of the ordinary instrument (Fig. 42).

FIG. 42.

The handle is usually of bone, wood, or metal, and can be homogeneous with the nibs, or separate and fastened thereto, as is usually the case, in the which the handle should always have a firm and secure fit, as any slight looseness will tend to render the work of the pen inaccurate.

The nibs are the "pen," and in the ordinary instrument are fashioned with a tendency to spring apart, a tendency for the pen to remain "open"; that they may be brought together, the thumb-screw is employed, only one nib being threaded, the other having a smooth-bored hole.

The thumb-screw should have a knurled head (the edge cut into small points) that it may be easily operated, and its shank should be threaded to the head, or otherwise so fashioned that when in position it is capable of bringing the nibs exactly together. The thread of the screw should never be allowed to become corroded, but should be frequently oiled with gun or bicycle-oil. The fit of the screw in the nibs should be snug and even; there should be no "binds" or "play."

The "business end" of the pen, for ordinary work, should be slightly rounded as *A*, Fig. 43, not like *B*; the nibs should be exactly of the same length, ground to a knife-edge—not a point—and free from "burrs" inside and out. A new pen is usually ready for use, and the student will do well to carefully note the shape and sharpen of it.

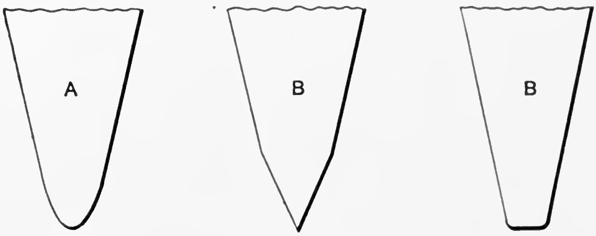


FIG. 43.

A pen "in condition" and properly handled should rule a smooth and even line (1, Fig. 44) of uniform width and with clean-cut sides; also, the pen should produce lines varying in thickness from a light "hair" line to a heavy line of one-sixteenth of one inch, or greater, in width. Since the best pens cannot for a great while, in use, maintain an edge sufficiently fine to produce the hair line, it is well, having two pens, to reserve the small pen for light lines and the larger pen for heavy lines.

A pen "out of condition" will rule, if at all, rough, ragged, and intermittent lines. Some of the common causes for such results are: one nib may be longer than the other, the pen may

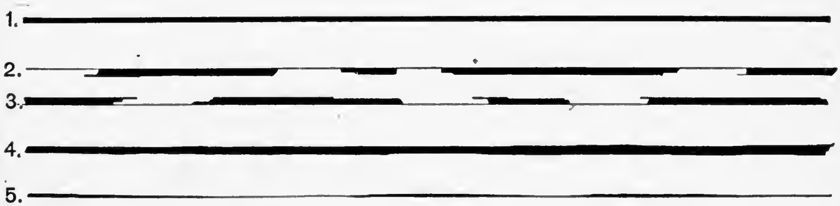


FIG. 44.

be too pointed, there may be burrs or rough places on the points, and above all the pen may not be held properly. In testing a pen, a ruling edge should always be employed.

When a pen produces a line like 2 or 3, Fig. 44, one of the nibs will be found to be longer than the other; a line like 4 indicates that the pen-points are not smooth—a small nick may be broken out. These are usually the troublesome features encountered when only heavy- and medium weight lines are desired; the hair line is more difficult to draw and requires the clever manipulation of a pen in the best condition. To rule very fine lines the pen must be sharpened to a nicety; a line like 5 is the product of a dull pen, and is the result of attempting a finer line than the pen, as sharpened, will rule. When such results are obtained, let the draughtsman stand with his back to the light, and holding the pen lengthwise and in line with the eye, look directly onto the points of the pen—the points of the nibs—and he will observe two "bright spots"; the finest line that can be ruled with the pen is a line whose width is the sum of the widths of the two bright spots, and the pen being closed, the ink must flow by convection around the points and not through or between them as it should, and the flow being irregular, produces a line as shown.

The lines depicted in 4 and 5 may also be caused by a dirty pen; ink may have been allowed to dry on the points; a thorough cleaning is the remedy. No. 5 may also result from undue pressure on the pen in the ruling. In ruling fine lines the pen should be well cleaned after every charge of ink has become exhausted.

When a pen is "out of condition," the remedy is to regrind it—sharpen it. The manufacturers of instruments maintain a department for the sharpening of pens, repairs, etc., but should one send his pen to the factory every time it needed regrinding, he would justly forfeit his title of "Practical Draughtsman." Every draughtsman should be able to keep his instrument in first-class condition, for while there are some general instructions which may be given for the proper handling of the pen, draughting is like writing; no two men will hold the pen in exactly the same position, and the pen must be sharpened to suit the user.

To sharpen a pen, close the nibs until they have contact, and with a fine-grained oil-stone at hand, round off the points until they are even and in shape, comparing with *A*, Fig. 43, not *B*. Now note the bright spots; these must be ground away, the pen must be really sharpened—the same as a knife-blade—not pointed. To do this, open the nibs, and taking them one at a time, consider it as a chisel or knife-blade to be sharpened on but one side—the outside—and by moving it back and forth, turning it slightly from side to side, grind the points until no bright spots are visible. Great care must be exercised in the operation, else the point at which the "spots" disappear be passed and the nibs become of uneven lengths, necessitating another trial of the entire operation. A careful procedure should produce a pair of nibs of even length, truly and smoothly shaped and sharpened on all sides; should any burrs occur, however, at a point that cannot be treated with an oil-stone or oil-slip, they may be removed by the use of very fine emery-cloth.

To try the pen, secure a piece of drawing paper and a straight-edge, and having thoroughly wiped all oil and dirt from the nibs, screw them together until about $\frac{1}{16}''$ to $\frac{1}{32}''$ apart, and charge the pen with ink in such quantity as will fill it for about one-quarter of an inch from the point (Fig. 45). (To charge the pen, take the tool in the left hand, if right-handed, and taking the stopper from

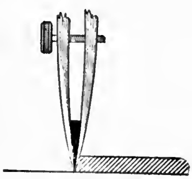


FIG. 45.

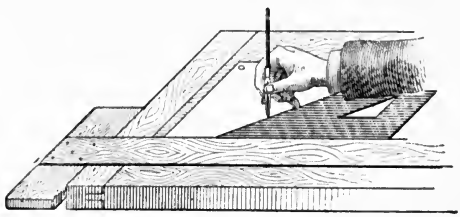


FIG. 46.

the ink-bottle in the right hand, insert the point of the quill between the nibs, when the ink will run into the pen.) The pen being charged, transfer it to the right hand and manipulate the straight-edge with the left hand; hold the pen with the thumb-screw on the outside—away from the hand—and in such a position that the screw may be operated by the thumb and second finger, and holding the pen perpendicularly, place it against the ruling-edge as in Figs. 45 and 46. It will be noted that in this position the curvature of the instrument throws the pen-point well away from the straight-edge (this is important); also that the nibs are parallel to the ruling-edge; maintaining this position, move the pen along the ruler, drawing from the body, with just sufficient downward pressure to secure smooth and even contact with the paper and a pressure against the straight-edge sufficient to maintain the guide. Varying the weight of line by increasing or decreasing the width between the nibs by means of the thumb-screw operated by the thumb and second finger, rule a number of lines and note their contour. Should any of the before-mentioned "faulty" lines result, the cause can be recognized and the fault eradicated.

In the trial for the very fine lines, much care should be exercised not to screw the nibs so tightly together as to cause them to "flare" out at the point, as in Fig. 47.

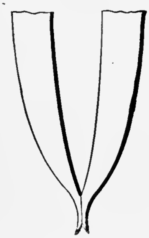


FIG. 47.

With the pen in first-class condition, the ruling of lines becomes a matter of practice. Much care must be exercised to maintain the original position of the pen—that depicted in Figs. 45 and 46—when drawing it along the guide, for should it be changed by throwing the handle out and the point in and against the guide, the ink will be drawn under the guide and cause a blot; the small space between the straight-edge and the pen-point must be maintained. Furthermore, should the position of the pen be altered in any way changing the original space between the point and the guide, the line will not be a right line—all of its points will not lie in the same direction—and as mechanical drawing is an exact art, it is obvious such lines will not answer.

Blotting will be the first trouble experienced by the beginner, and will tend to augment the inaccuracy of his lines; in trying to secure sufficient space between the pen-point and the ruling-edge he will assume a position, to begin with, other than in a perpendicular, and as the ruling proceeds and the hand gets farther from the body, the tendency will be to "straighten" up the pen.

While a perpendicular position of the pen is recommended, good results may also be obtained by slightly leaning the pen in the direction of the line, keeping it, however, in a vertical plane parallel with the straight-edge.

89. The Compass.—Fig. 48. The compass—an instrument for drawing circles—is next to the ruling-pen in importance, and consists of five pieces: (1) the compass proper, (2) the pen-leg, (3) the pencil-leg, (4) the extension-bar, and (5) the center-point.

All the joints in the instrument should have a firm, even bearing, and should be free from all binds and play. In purchasing a new instrument, all the parts should be placed together, the joints inspected, and the fits noted. With the pen-leg in position, the instrument should be closed and the center-point set with its point slightly in advance of the pen-point; if the center-point be fashioned with a shoulder, this should come flush with the pen-point. When the center-point is once set for the pen, it should never be changed; the pencil-point must always be adjusted to the center-point.

The remarks on the ruling-pen apply also to the pen of the pen-leg; the pencil-point will be treated of in the discussion of lead-pencils and leads.

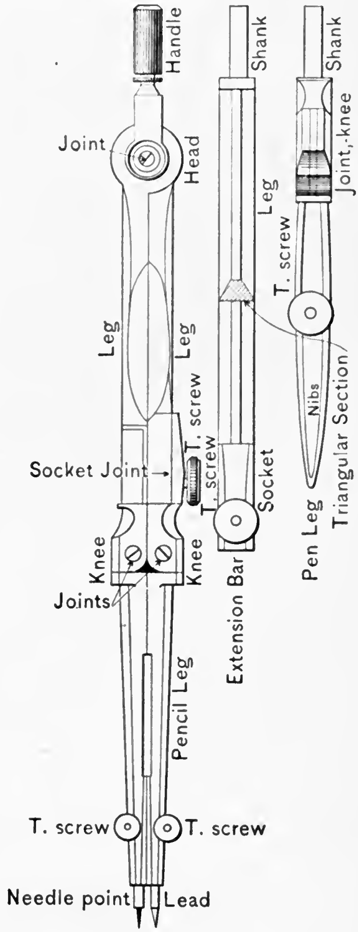


FIG. 48.

The accuracy of the construction of the tool may be remarked by closing the instrument and noting the position of the points, which should lie in a plane perpendicular to the axis of the head and passing through the center of each leg, or should the instrument be broken at the knees (to the same degree) and the points brought together, they should coincide.

To use the compass, the points should be brought to the proper adjustment and the instrument broken at the knees—each knee to the same degree—until the legs of the tool are parallel; now place the center-point on the point about which the circle is to be drawn and press it "home" if the point is "shoulder" fashioned, otherwise give it only such pressure as to cause the point to prick the paper to a depth sufficient to fix it. Do not punch large holes in the paper or the work will be inaccurate and the paper unsightly.

With the center-point fixed, erect the instrument to a position such that a line dropped from the center of the head will be perpendicular to the plane of the paper, and if the adjustment be correct, it should pierce the plane of the paper at a point bisecting a line joining the two points of the compass. From this first position, slightly incline the instrument in the direction in which it is desired to draw the circle—usually clockwise, from left to right—and with a downward pressure, only sufficient to maintain the center-point where fixed and to secure a light contact between the paper and the ruling-point, turn the instrument in the direction of its inclination until the circle is described; should any part of the line be dim or incomplete, go over it again in the same manner until the line is clean-cut; never reverse the order and run "backwards" over the line.

The compass should be used only for the larger-sized circles, those of small diameter being drawn with the bow-pen or bow-pencil. When a circle of greater diameter than the instrument just described will "span" is to be drawn the extension-bar must be used. To use the bar, remove the ruling-point and insert the shank of the bar in the socket of the compass-leg vacated by the shank of the pen-leg, and the latter shank in the socket of the extension-bar, and secure all joints; next break the knees of the instrument until the two legs are parallel, then proceed as above described. With the extension-bar in use, a line through the head of the tool and perpendicular to the plane of the paper will pierce the paper at a point nearer the center-point than the ruling-point, in which case it is well to steady the long leg with the free hand; when possible, however, it should be a "one-hand" operation.

The compass is a very delicate instrument and to preserve its accuracy should be very carefully handled and cared for.

90. The Dividers.—Fig. 49. The dividers are used to lay off divisions and to transfer distances from one point to another, as in copying drawings, and should be provided with a hair-spring adjustment for very fine work. This instrument is even more delicate than the compass, the legs being tapered to needle-points, and should be very carefully handled, else the points be destroyed and the accuracy of the tool impaired. Should one or both of the points become broken or blunted, they can be repointed by grinding on an oil-stone.

To test the accuracy of the instrument, close the tool, when the legs should be of equal length and the points exactly in line and in a plane perpendicular to the axis of the head and passing through the center of each leg.

To use the dividers, say to lay off a given line from a given point, hold the instrument near the top with the thumb and first finger and insert the second and third fingers between the legs of the tool. With the instrument thus in hand it can be opened and closed with the one hand. Now set one leg with its point at one extreme of the line and open the dividers to a width closely approximating the length of the given line, then bring the width between the points to exactly equal the length of the line by adjusting the hair-spring; next transfer the tool to the given point and place one point exactly on it; then, with the other leg in the desired position, bring its point in contact with

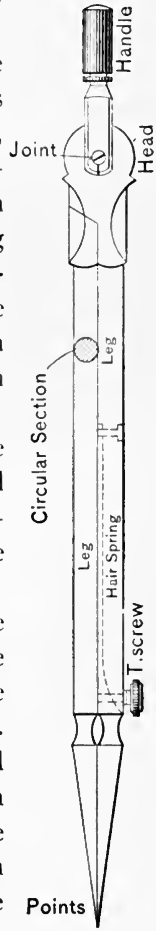


FIG. 49.

the paper and either mark the point with a pencil or raise the instrument, with the point fixed, until the leg is perpendicular to the plane of the paper; then slightly prick the surface. In no case should the prick-marks puncture the paper, as it renders the paper unsightly and the work inaccurate.

The dividers are to be used where the work is comparatively large and the lengths variable. The joint at the head should be quite firm, smooth, and even, and free from all binds and play.

91. The Bow-pen.—Fig. 50. The bow-pen is a small compass with the pen-leg only, the joint at the head is done away with, and the tool so fashioned that the legs tend to spring apart. The essentials of a good bow-pen are: the temper of the pen-point should be that necessary in a good ruling-pen, the spring of the instrument should be quite stiff, the threaded member should be smoothly and truly cut, and the thumb-screw should be capable of bringing the points exactly together.

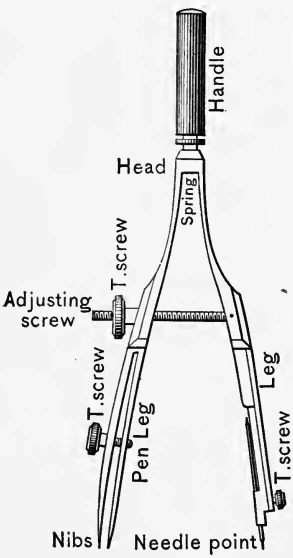


FIG. 50.

To adjust the instrument, it should be closed by means of the thumb-screw and the center-point set slightly in advance of the pen-point, when, if the instrument be well and accurately made, the points will lie in line with each other and in a plane passing through the center of each leg.

To facilitate the use of the instrument and to minimize the "wear and tear," instead of opening and closing the tool by means of the thumb-screw, it is well to proceed as follows: To close the pen, hold it between the thumb and the first finger of the right hand, press the legs together by means of the left hand, and with the second finger of the right hand turn the knurled nut to the proper position. To open the instrument, hold it as for closing, and with the left hand "stay" the legs, and operate the nut with the thumb of the right hand; when the nut is approximately at the desired position, permit the legs to spread gently until the nut prevents further movement. This operation requires much caution to prevent the legs from slipping from the grasp of the left hand and violently springing against the nut, an accident several of which might spoil the threaded members of the tool and render it unfit for use.

The remarks on sharpening the ruling-pen are applicable to the sharpening of the bow-pen; as a special caution, however, it may be added the center-point should be removed during the operation.

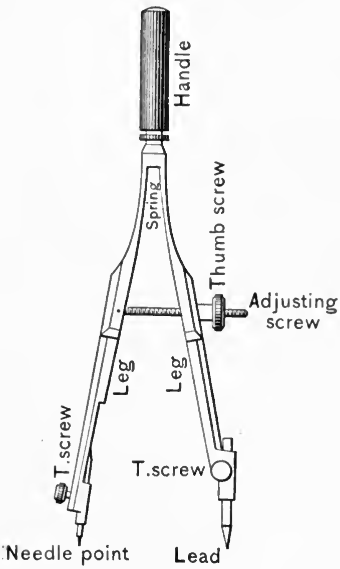


FIG. 51.

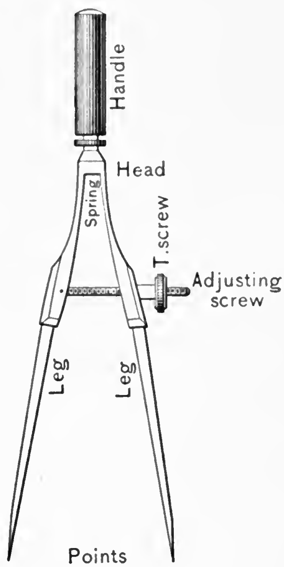


FIG. 52.

The bow-pen should always be used on small work, and in fact wherever possible, as it is easier of manipulation than the compass.

92. The Bow-pencil.—Fig. 51. The bow-pencil is a small compass with the pencil-leg only, and is covered by the remarks on the bow-pen, the method of manipulation, adjustment, etc., being the same for both tools.

93. **The Bow-dividers.**—Fig. 52. The bow-dividers are small dividers and are used in the same manner as the other two bow instruments. Other specific points are covered by the remarks on the large dividers.

The bow-dividers are used for small work or wherever possible, as the tool has the advantage over the larger instrument in that it is not liable to variation when once set. The principal use of the tool is for the laying off of a large number of equal divisions.

94. **The Box for Leads.**—Fig. 41. The box for leads should contain leads of various degrees of hardness and of a shape and size to fit the instruments.

95. **The Care of Instruments.**—Draughting instruments are instruments of precision and should be carefully handled and cared for. When through with a tool, it should be carefully cleaned with an old linen or cotton rag or chamois-skin, then at once placed in the case. Ink or other foreign substances should never be allowed to dry on the tools. After considerable handling, even with the best of care, a slight corrosion will make its appearance, particularly on the ruling-pen; this is due to contact with the moisture of the hands and cannot be eliminated, save to a degree.

96. **Drawing-boards.**—The trade has a large variety of drawing-boards, adjustable tables, etc., on the market; it is well, however, for the beginner to first provide himself with some simply constructed board, such as is shown in Fig. 53. The stock should be of well-seasoned, clear, soft pine, such as is used for pattern-making; the warping tendencies of the material should be minimized by saw-cuts on the back and with cleats well secured to the board. The top face should be given a smooth, even finish and one end face trued and jointed to this face. The planed surface is the "working-face" and the jointed edge is the "working-edge." With the working-edge at the left hand and the working-face up, the edge farthest from the observer is the top of the board and that edge nearest him the bottom. The

student should fix these features of the board in mind, as they will be used in further discussions.

97. **The T-Square.**—The T-square is a device used as the basis of construction for all accurate drawing, and derives its name from its shape and use, being fashioned like the letter T, and used as and like a square. Fig. 53 illustrates the ordinary T-square, the short piece being the "head" of the square and the long piece the "blade."

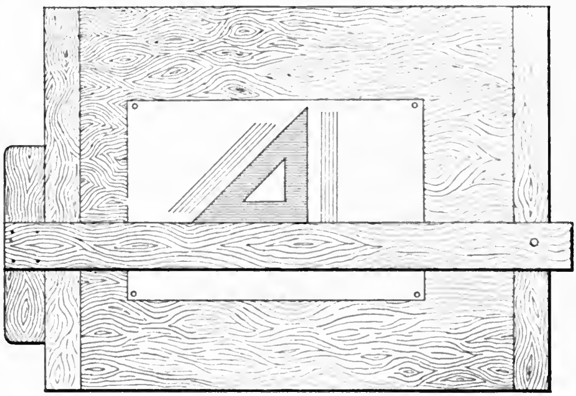


FIG. 53.

T-squares are made of various materials, the more common of which are wood, rubber, amber, and metal, and with solid and adjustable heads and various attachments. A good working-square, one answering all practical purposes, is made of straight-grained hard wood, with adjustable head and a blade with amber edges. The advantages possessed by such a square are its greater range of usefulness because of the adjustable head, which renders it more than a simple square, and the advantage of a transparent edge. For very fine work a metal square is the best, being free from warping tendencies and capable of maintaining the most accurate straight edge, while its greater weight makes it the most stable, and with ordinary care slippage is eliminated. The objections to the metal square are its excessive first cost and susceptibility to corrosion.

In purchasing a T-square, the size of the drawings to be made should be considered and a square selected which has a blade of even length with the board required for the work. The working-edge of the head should be a true plane surface, jointed with the top face; the blade should be planed true on all sides and the faces jointed.

The T-square is used to square the paper on the drawing-board, and as a guide for the ruling-points for drawing horizontal lines, and for the triangles. To use the square, place it on the board and bring the working-edge of the head against the working-edge of the board, then draw along the working-edge of the blade with pen or pencil. The square should be operated with the left hand and the drawing done with the right hand, if right-handed. The head of the square should be held near the center in a firm though not a strained grasp, and having drawn a line, the square may be shifted up or down and any number of parallel lines drawn. In shifting the square, much care should be exercised to grasp the head at the same point and with uniform force, else the lines will not be parallel.

The blade of the square should be preserved as a ruling-edge and never used as a guide for a knife or other edged tool when cutting paper; if limited for straight edges, one edge only (the upper) may be reserved as a ruling-edge and the other edge used as a "cutting-edge." Should the ruling-edge become untrue, if the square be a wooden one, it is an easy matter to remove and true it by planing.

98. Triangles.—Fig. 53. Having provided for the accurate ruling of horizontal lines with the T-square, it is then necessary to provide means for drawing perpendicular and angular lines, an end secured by the use of triangles.

Triangles of various sizes and angles may be had of wood, rubber, amber, metal, and a number of other materials, of which the triangle made of amber is the most desirable because of its transparency and cleanliness. The objection to the amber triangle is its susceptibility to heat, an exposure of some time to the sun's rays often causing the triangle to warp; however, should such a triangle become warped, it may be straightened by reversing it and again exposing it to the sun. The objection cited is not of great moment, as there is no good excuse for leaving one's triangle thus exposed.

As to the size of a triangle, it should be of ample dimensions for the work in hand; one engaged in constructing large drawings should have a large sized triangle, while for small work the smaller sizes are more convenient.

The angle of a triangle is a much discussed subject, though draughtsmen unite in recognizing the desirability, almost necessity, of being provided with angles of 90°, 45°, 30°, and 60°. The manufacturer meets this requirement with two triangles: one called the 45° triangle, which has one angle of 90° and two angles of 45°, and a second one called the 30°-60° triangle, or simply the 60° triangle, which has an angle of 90°, one of 60°, and one of 30°; with these two triangles and the T-square, a circle may be divided into twenty-four equal parts, which gives a division every fifteen degrees.

That a drawing may be exact, it is necessary that the triangles be absolutely true. To test a triangle for the 90° angle, place it against the working-edge of the T-square, with the right angle up and draw through a given point a vertical line; now reverse the triangle—turn it over from left to right or vice versa—and through the same point draw a second vertical line; if the two lines coincide, the angle is correct, otherwise the inaccuracy will show as diverging lines, becoming more and more apparent as the lines recede from the point. A test of any other angle may be made by first drawing a circle, then with the angle against the working-edge of the T-square draw a line through the center of the circle and intersecting the circumference; now reverse the triangle and draw a second line through the center of the circle and intersecting the circumference; if the angle is correct, a horizontal line through one of the points of intersection on the circumference will pass through the other point.

Should the edges of a triangle become nicked or otherwise injured, or should the angles be untrue, the triangle is practically useless and should be discarded, though a skilled workman may eliminate the faults by planing.

It has been noted that the T-square should be used for all horizontal lines; the T-square and triangles should be used for all perpendicular lines and all other lines of known angles. The triangles should never be used "free-hand" (without the T-square), as such a procedure is time-consuming and inaccurate. As a last word, it may be added, never use a triangle as a guide for a knife-edge in cutting.

99. **Irregular Curves.**—Fig. 72. Irregular curves are devices used as a guide for drawing all arcs other than the arcs of circles. They are made of various materials, shapes, and sizes. In purchasing a curve, one adapted to the work in hand should be selected, as curves to fit all usual figures are to be had. The best curve, like the triangles, is one made of amber.

The manner of using the curve is set forth in Sect. 197, and requires much practice to attain proficiency.

100. **The Architect's Scale.**—As all mechanical drawings are drawn proportional to the object, it is necessary to "lay off" the drawing to scale. Scales for this purpose may be had of various materials, principal among which are ivory, boxwood, and metal, and graduated to any denomination. There are two denominations in general use, (1) a graduation of tenths of an inch, and (2) a graduation of sixteenths of an inch. A scale graduated in tenths inches is called the "Engineer's Scale," and the scale with $\frac{1}{16}''$ divisions is called the "Architect's Scale."

The engineer's scale is used mostly in government work, mapping, surveys, etc., while the architect's scale is the one of general usage, the common scale being of boxwood and known as the "architect's tringular scale," the word "triangular" signifying three-sided (Fig. 54).

The ordinary architect's scale contains eleven separate scales: (1) A full-sized scale which is 1 foot in length, the foot is graduated into inches, and the inches into sixteenths inches. This scale is designated by the figure 16 under the 6-inch division of the scale, or in some cases at one end of the scale. In using this scale, the drawing is laid off inch for inch of the object drawn. The next scale for drawings is a scale of three-fourths size, or $9'' = 1'$. To construct a drawing to this scale, the dimensions are reduced mentally, or otherwise, to three-fourths of the original and the drawing laid out with the full-size scale. Half-sized drawings, or a scale of $6'' = 1'$, which is the next usual scale for draw-

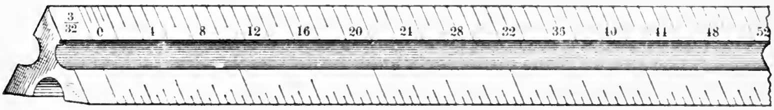


FIG. 54.

ings, are constructed in a similar manner. Should it become necessary to lay off a division smaller than $\frac{1}{16}''$, say $\frac{1}{32}''$ or $\frac{1}{64}''$, this may be done by using the full-sized scale and bisecting the $\frac{1}{16}''$ division with the eye for thirty seconds and quartering the $\frac{1}{16}''$ division for sixty-fourths; with a little practice very accurate divisions may be made.

(2) The next scale is a scale of one-fourth size, or $3'' = 1'$. This scale is found on the "flat" of the tool adjacent to the full-sized scale, on the zero end, and is designated by the figure 3 stamped at the end. A length of $3'$ is given on the scale, the divisions being marked in the groove. One foot of the scale is graduated into inches and these into halves, quarters, and eighths, each division on the scale representing $\frac{1}{8}''$. For dimensions smaller than $\frac{1}{8}''$, approximations may be made as already described.

(3) A scale of one-eighth size, or $1\frac{1}{2}'' = 1'$, is the next smaller scale, and is given on the same flat with the $3''$ scale, the designing figure, $1\frac{1}{2}$, being at the opposite end. This scale is graduated to $5'$ in length, the figures being stamped on the flat of the rule; $1'$ is graduated into inches and these into halves and quarters. Smaller divisions may be approximately as above.

With the foregoing explanation as a key, and remembering that when viewing a scale, if it is on the right-hand end of the rule the foot divisions are stamped in the groove, and if on the left-hand end, the figures are on the flat of the rule, the remaining eight scales may be interpreted. They are:

(4) Scale of $1''=1'$, $=\frac{1}{12}$ size, smallest divisions of which $=\frac{1}{2}''$.
(5) " " $\frac{3}{4}''=1'$, $=\frac{1}{16}$ " " " " " $=\frac{1}{2}''$.
(6) " " $\frac{1}{2}''=1'$, $=\frac{1}{24}$ " " " " " $=1''$.
(7) " " $\frac{3}{8}''=1'$, $=\frac{1}{32}$ " " " " " $=1''$.
(8) " " $\frac{1}{4}''=1'$, $=\frac{1}{48}$ " " " " " $=1''$.
(9) " " $\frac{3}{16}''=1'$, $=\frac{1}{64}$ " " " " " $=1''$.
(10) " " $\frac{1}{8}''=1'$, $=\frac{1}{72}$ " " " " " $=1''$.
(11) " " $\frac{3}{32}''=1'$, $=\frac{1}{128}$ " " " " " $=2''$.

The scales given are the usual scales; however, should an odd scale be required, one may be constructed as follows: Let it be required to divide $1''$ into sixths (*A*, Fig. 55). The nearest division

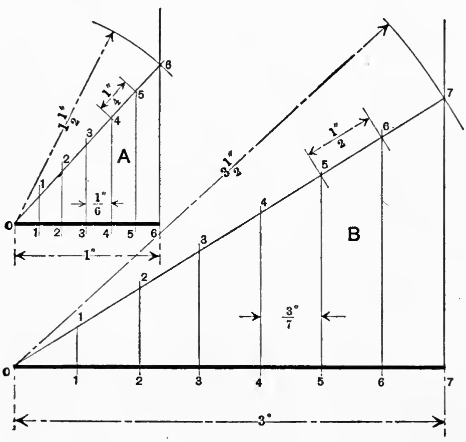


FIG. 55.

given on the scale is the $\frac{1}{4}''$ division of the full-sized scale; to use this, erect a perpendicular at one extremity of the $1''$ line, and with an inch division of the scale on the other extreme, radiate the scale from this latter point until a division $1\frac{1}{2}''$, or $\frac{6}{4}''$ away from the inch division, coincides with the perpendicular, or, better, with the perpendicular drawn, take a radius of $1\frac{1}{2}''$ on the bow-pencil, and with the free end of the line as a center, describe an arc intersecting the perpendicular in a point; joining this point and the center gives a line $1\frac{1}{2}''$ long. Now on this line lay off $\frac{1}{4}''$ divisions, which gives six divisions; dropping perpendiculars through these six points of division to the $1''$ line will give six equal divisions on the line, sixths of an inch. "*B*" illustrates a $3''$ length divided into seven equal lengths by a similar method.

The mistake should not be made of attempting to use the scales $\frac{3}{4}'' = 1'$, $\frac{1}{2}'' = 1'$, etc., for laying out three quarter- and half-sized drawings respectively, as an inspection of the scale will show the graduations to then read $\frac{1}{2}''$, $\frac{1}{4}''$, $\frac{1}{12}''$, $\frac{1}{24}''$ for the $\frac{3}{4}''$ scale and $\frac{1}{2}''$, $\frac{1}{4}''$, $\frac{1}{12}''$ for the $\frac{1}{2}''$ scale, which divisions are odd and seldom used. Any scale may be doubled, tripled, quadrupled, etc.; for example, double the $1'' = 1'$ scale; this changes the smallest division from $\frac{1}{2}''$ to $\frac{1}{4}''$ and gives a scale of $2'' = 1'$, or one-sixth size.

The architect's scale is one of the "fine" tools, the graduations being accurate, and in using it much care should be exercised to preserve the sharpness of its edges and the clearness of the graduations.

To properly use the scale, lay it flat on the paper, with the scale in use from the body and in good light, and lay off the divisions with a fine-pointed pencil or metal point, being careful not to bring a pressure on the pencil sufficient to dent the surface of the paper, or using the metal point, do not puncture the paper to a depth which would mar the surface. Do not use metal points on the scale, or use it as a guide for ruling or cutting.

101. Thumb-tacks. — "Thumb-tack" is the name given a large-headed small tack specially designed for temporarily fastening paper or cloth to wood; they are used in drawing to fasten the drawing-paper or tracing-cloth to the drawing-board. The one essential of a satisfactory thumb-tack is that it have a head of sufficient area to prevent it tearing through the paper or cloth, and that it be so fashioned as not to be an obstacle to the free movement of the T-square and triangles over the surface of the drawing.

The ordinary tack-head is about $\frac{1}{32}''$ to $\frac{1}{16}''$ thick and is more or less troublesome; to minimize the difficulty, 3-oz. or 4-oz. common tacks may be used, driven flush with the surface of the drawing-board; the objection to this practice is that the small head of such a tack is not of sufficient area to retain the paper. As the student becomes more and more expert in the manipulation of his tools, the average thumb-tack ceases to be troublesome.

102. Pencils and Leads.—A drawing is always first constructed in pencil, then finished in ink. "What is the best drawing-pencil" is a question on which every draughtsman has his own private opinion. The degree of hardness of lead best adapted to the work is largely dependent upon the nature of the surface to be penciled on; generalizing, paper is best worked with a hard lead and cloth with a soft lead. For paper a 6-H (trade name) pencil is recommended, while for cloth good results are obtained with a 2-H pencil.

Penciling a drawing is like laying the foundation of a house: it is the basis upon which the building is done, and any inaccuracy in the penciling will appear in the finished drawing. In penciling all lines are made practically of the same weight, which weight is a line just sufficiently heavy to stand out clear and distinct.

To secure nice, clean-cut lines, the pencil-point should be given careful attention, never being allowed to become rough or dulled. There are several styles of points given leads, the three most prominent being (1) the round or needle point, (2) the flat or chisel point, and (3) the bevel or one-sided point.

(1) The round or needle point is the most common and has the widest range of usefulness, being fairly well adapted for all ordinary drawing; it is, however, especially convenient for marking points and for all free-hand work, such as free-hand lettering, dimensioning, etc. To fashion the needle-point, begin at a point about $1\frac{1}{4}''$ from the end, and with a sharp knife bring it (the pencil end) to a neat and true cone, from the apex of which the lead projects about $\frac{1}{4}''$; now bring the lead to a uniformly tapered needle-point, and finish by spinning the pencil-point in a

cloth held about it, thus removing all roughness and producing a fine, smooth point. This pointing of the lead is best accom-

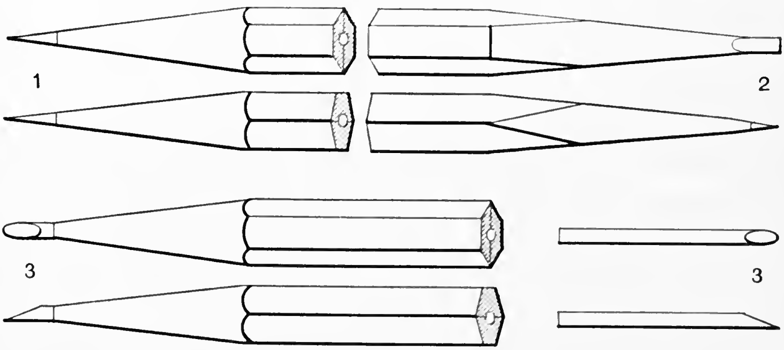


FIG. 56

plished with the aid of a piece of fine sandpaper or emery-cloth (the latter is the better), by drawing the pencil-point over the surface of the paper or cloth and turning it at the same time until ground to a point. In any case the point should be "polshed off" with a rag, as described.

To facilitate such use of sandpaper or emery-cloth, it should ibe stretched over a flat surface and securely fastened. A good arrangement is obtained by making a small paddle of wood and gluing the abrasive to its faces, or, better, as the paper and cloth soon become dull and unfit for further use (in the order named), it is well to make a pad of the material, then as one sheet becomes dulled it can be removed and a new, sharp sheet is presented.

(2) The flat or chisel-pointed lead is restricted to the drawing of very fine lines, and is for accurate work, being especially adapted to the graphic solution of problems. To fashion the chisel-point, begin at a point about 1½″ from the end, and with a sharp knife bring two sides to a smooth and even bevel, with the lead extending about ¼″ from the end of the bevel; next bring the remaining faces of the pencil to a smooth and true bevel to within about ⅛″ of the end of the lead, and then with knife or pad continue the first two bevels until the lead is very sharp, and finish with a cloth, slightly rounding (lengthwise) the point.

To have the needle and chisel-points always at hand, it is well to "double end" the drawing-pencil, one style point on each end. The two points described are primarily for the pencil-point only, though leads used in the compass and bow-pencil may be similarly fashioned, in which case the chisel-point should be adjusted in the instrument with a broad side next to the center-point.

(3) The bevel or one sided point is especially designed for the lead points used in the instruments, and is fashioned by beginning at a point about $\frac{1}{4}''$ from the end of the lead, and with knife or pad making a smooth, true bevel on one side only and entirely across the lead; the point is then finished with a cloth. The lead is adjusted in the tool with the center of the straight side next to the center-point.

When ruling, the pencil should be held in a manner similar to that described for the ruling-pen, and especial attention given to maintaining one position throughout, that the lines may be exact, right lines.

103. Pens and Penholders.—The selection of a pen is largely a matter of preference for some particular brand, though the "style" of pen is determined by the nature of the work to be done; for etching and for all small, fine work a lithographic crow-quill pen is the best, for all ordinary work, as lettering and sketching, any ordinary fine-pointed pen will answer, and for heavy work, as large lettering for titles, a ball-pointed or other heavy pen is recommended. From the first to the last are many points of various degrees of fineness, and that pen best suited to the work in hand is readily determined after a short experience.

The one requisite for a good penholder is that it be of a size and shape to fit the hand without cramping; avoid all very small penholders. The pen should be firmly secured in the holder.

The beginner should provide himself with at least three pen-points: (1) a crow-quill, (2) a common writing-pen, and (3) a ball-pointed pen; with these he will be equipped for this course and for all usual drawing. A new pen will always prove more or less troublesome, as the ink will not flow freely, and requires to be "broken in."

The pen is one of the draughtsman's tools, and as such should receive proper care and attention; do not treat it roughly because it is "just a common pen" and is cheap. To have a good pen it must be first broken in, then preserved. The pen should always be carefully wiped with a rag free from lint or fuzz before laying it aside; never lay a pen down without wiping it off.

104. Erasers.—In constructing a drawing a large number of pencil-lines are drawn which are not to appear on the finished drawing and must be erased; also, errors may be made in inking-in a drawing, necessitating an erasure; alterations on a finished drawing may be desired, which involves erasures, etc.; thus it is that a drawing outfit is incomplete without some means of erasing pencil and ink lines.

An outfit should contain at least two erasers: (1) a pencil eraser, and (2) an ink eraser; a combination eraser, one end for pencil and one end for ink, will answer. The pencil eraser should be of soft rubber and possessed of a property which enables it to "take hold" on the paper; an eraser that is hard, gritty, or that has a glazed surface is unfit for erasing pencil-lines.

An ink eraser should be hard and gritty, but should be pliable. All erasers after a time become hard and stiff and lose their erasive properties; an eraser should be much handled and "worked."

For simply cleaning a sheet of paper, a third eraser known as a "sponge eraser" is very efficient and is a valuable addition to an outfit.

105. Ink.—Until recent years it was customary for draughtsmen to prepare their own ink from a stick of India or Chinese ink, by rubbing it in a specially designed saucer containing a small quantity of water. A very superior ink is thus produced, but the operation is quite laborious and time-consuming.

The market of to-day affords a number of prepared inks, and from these a draughtsman's ink is usually selected. There are but two colors of ink much used in drawing: (1) black ink, and (2) red ink.

Black drawing-ink differs from ordinary writing-fluid in that it is heavier and less fluent. It is a form of carbon in suspension, and when applied to paper or cloth, leaves a deposit of carbon which is at once fixed and distinct. Drawing-ink is easily erased because of this deposit, as it is "on" the paper and not "in" it if the paper be a good drawing-paper

A good drawing ink has the carbon in perfect suspension, is smooth and even flowing, with no granular precipitation whatever, and will produce clear and lasting lines.

The red ink is more fluid than the black drawing-ink and requires great caution in its use, as it has a tendency to "run" from the pen onto the paper and under the edge of the T-square and triangles and cause blots. If a drawing is to be permanent, red "drawing ink" should be used (not a writing-fluid), as this, like the black ink, has the pigment in suspension and leaves a deposit on the paper. The objection to the use of red ink on drawings is that all red ink is more or less susceptible to the light and in time will fade; also, it is less opaque than the black ink and is not "printable," save to a degree, a fact which is sometimes taken advantage of in blue printing to render center lines and dimension lines lighter than lines of the drawing.

106. Rag and Blotter.—A rag for cleaning instruments and wiping pens should be free from lint and fuzz and very absorptive. The cloth most acceptably fulfilling these requirements is an old linen or muslin rag.

An ordinary blotter is an often needed article when drawing; not to blot the lines, however, as these must be allowed to dry, but to assist in removing blots.

107. Horn Center.—The horn center is a device of some transparent material, designed to be fixed over a center-point and to receive the needle-point of the instrument when drawing a large number of concentric circles, thus avoiding a puncture of the paper. Such marring of the surface of a drawing is avoided without the use of a horn center with ordinary care, and they are only needed when a handsome, line-shaded drawing is attempted.

108. Section-liners.—"Section-liner" is the name given a machine for accurately cross-hatching surfaces. It is a convenient but costly device, and as cross-hatching is done in a number of abbreviated forms and is not required to be accurate a section-liner is not a necessity to the draughtsman.

109. **Erasing-shields.**—This is a device of thin material, amber and various metals, with various shaped and sized openings, designed to mat out portions of a drawing to be erased.

110. **Protractors.**—A protractor is a device graduated in degrees, and is used in laying off angles not obtainable with the triangles and T-square. Protractors may be had of various materials, the best being of metal.

111. **Scale-guard.**—A scale-guard is an attachment for the triangular scale and is of use when one scale only is in constant use, as it enables the draughtsman to keep that scale always before him.

112. **Proportional Divider.**—The proportional divider is a double-ended pair of dividers provided with an adjustable clamp which enables the draughtsman to set one end of the tool at full size, and by means of the adjustment the other end is made to be some proportional size, as $\frac{1}{2}$ size, $\frac{1}{4}$ size, etc. Their use is obvious.

113. **Erasing-knives.**—Erasing-knives are a valuable addition to a drawing outfit; but as most draughtsmen are possessed of a pocket-knife, such a knife, well sharpened, answers all practical purposes.

114. **Soapstone Pencil.**—Soapstone is used to resurface the surface of tracing-cloth after an erasure has been made.

115. **Paper.**—Having discussed ways and means of constructing drawings, it now becomes necessary to select some material on which to construct the drawings. For this purpose any smooth surface will answer, shopmen often using the shop floor, a board, the wall, a blackboard, etc., for rough, free-hand, temporary sketches; however, the draughtsman's work is supposed to have finish, accuracy, to be permanent, in short, to be valuable, and for his purposes the field is limited to cloth and to paper.

All sketches, preliminary draughts, etc., are nearly always made on paper, cloth being reserved for the finished drawing, especially when the drawing is to be duplicated, as by blue printing.

The selection of the quality of paper and its dimensions is determined by the nature of the work to be done. Broadly speaking, if the paper be intended for preliminary work, a cheap, low-grade paper will answer; while if the work is to be a finished and permanent article, an expensive, high-grade paper should be used. For the greatest permanency, a high-grade paper mounted on cloth is recommended.

A good drawing-paper should be of a color to cause the lines to stand out sharply (in contrast) and the color should be permanent, the light having no effect upon it. It should have a hard, smooth, and even surface, taking pencil and ink lines sharply, the latter without any tendency to spread or blot, and should take erasures to quite an extent. Added to this, it is quite desirable, for all usual purposes, that the paper should have some body—be rather stiff—thus minimizing any tendency to wrinkle or to buckle.

The paper most nearly fulfilling the above requirements is a pure rag or linen, hot-pressed paper, white in color. It should be understood this applies only to paper for good, permanent, inked drawings; for pencil work and work that is to be traced, any paper that has body and will take erasures will answer.

As has already been noted, the size of the paper is determined by the size of the work to be done. Paper is furnished by the trade in two forms, (1) sheets and (2) in rolls, the dimensions being for sheets:

Medium	17″×22″
Royal	19″×24″
Imperial	22″×30″
Double elephant	27″×40″

While rolls of almost any length and from 2 ft. to 6 ft. wide may be had, only the finer grades of paper are offered in sheet form, though any roll paper will be cut to order. Sheet paper is sold at so much per sheet, ream, and quire; roll paper at so much per yard of certain width, and some grades by the hundred pounds.

In draughting-rooms, where all work is traced, it is customary to use roll paper of suitable width, the draughtsman tearing off such amounts as needed.

If sheet paper is to be used, that size should be selected which reduces waste to a minimum. For example, let it be required to furnish paper to cut into $9'' \times 12''$ sheets; the Royal, $19'' \times 24''$, sheet will be found to four-fold into $9\frac{1}{2}'' \times 12''$, giving four sheets of these dimensions, each sheet having $\frac{1}{2}'' \times 12''$ waste, an amount which when divided in two will give $\frac{1}{4}''$ waste at the top and bottom of the sheet, sufficient to cut out the thumb-tack holes; this is the size of paper required for the drawings of this course.

116. To Make Erasures on Paper.—The quality of the paper being right, the labor of neatly removing pencil lines is directly dependent upon the character of the penciling. For the best results, the penciling should be done with a fine-pointed, hard lead, and the lines made very light, just sufficiently heavy to be clean-cut and clear. To do this the pencil must be handled very lightly and no crease made in the surface of the paper, a case wherein the pencil-mark may be removed, but not the crease. To make the erasure, lightly rub the pencil eraser over the line until it disappears, and then with a cloth dust off the paper. When working on high-grade paper, this last item is of great importance, for if the paper be not dusted and the erasure be permitted to remain on the surface, it will soon become ground into the paper and cannot then be clearly removed.

To make ink erasures on paper, it is best to use the ink eraser and with considerable pressure rub the line to be removed until it is quite indistinct, then dust off the surface, and finish, as above described, with the pencil eraser and again dust off; such a treatment well applied should leave a surface uniform with the remainder of the sheet, and one that will again take ink without any resurfacing of the spot. If the line to be removed be a heavy one, it will facilitate the operation if the erasing-knife be first applied. To do this, hold the knife-blade in a plane perpendicular to the line and lightly scratch the ink deposit until it becomes quite dim, then proceed with ink and pencil erasers. Great care must be exercised when using the knife not to dig into the paper or to scuff the surface.

117. Profile and Cross-section Paper.—These are specially ruled papers, much used for plotting and for sketch-work.

118. Tracing-paper.—Tracing-paper is comparatively thin paper, specially treated to render it transparent, and is used as a substitute for tracing-cloth, because of its lesser cost. Transparent profile and cross-section paper may be had of the trade.

In most paper there is a right and a wrong side to it; that side which presents the smoothest surface should be used.

119. Blue-print Paper.—This is a specially prepared paper used for reproducing drawings, for making blue-prints, a white line on a blue background. The paper is coated with a solution of certain salts which are susceptible to the sun's rays, an exposure thereto causing the prepared surface to undergo a change.

Prepared paper may also be had which will give blue lines on a white background, and several other contrasts.

Blue-print paper is, comparatively, a cheap commodity, and is supplied by the trade in various qualities, sizes—usually in 10-yd. rolls of variable widths—and degrees of sensitiveness, from the extra-rapid printing to the five- and ten-minute paper.

The paper can be bought, ordinarily, cheaper than it can be made, and when thus obtained is of uniform quality; however, should it be desired to prepare some paper, the following formula is recommended: Dissolve 5 oz. (avoirdupois) of red prussiate of potash in 32 oz. (fluid) of rain-water, permit it to stand for two or three days, then filter. When ready to use, for every 200 sq. ft. of paper dissolve 1 oz. (avoirdupois) of citrate of iron and ammonia in 4¼ oz. (fluid) of rain-water and mix the two solutions in equal volumes. Any paper with a smooth, hard surface may be used and the solution applied with a sponge, care being taken to give the surface a smooth and even coating, or the paper may be floated on a basin filled with the solution and thus coated. If both sides are to be prepared for printing, the paper can be dipped in the solution. After the surface has been coated, the paper should be hung up in a dark place to dry, and when dry is ready for use. It is obvious the paper must be protected from the sunlight until ready to use.

The above solution, for the best results, should be given three or four minutes in a bright sunlight.

Linen fabric is also prepared for printing purposes.

120. Tracing-cloth.—Tracing-cloth, or tracing-linen, is smooth, thin, linen cloth which has been treated with "size," one side being finished with a glazed surface and the other in the rough. It is very transparent and is used for tracing drawings, the common practice of the day being to trace all permanent work, the cloth being less destructible than paper, and being transparent, the drawing can be reproduced by blue-printing.

"Which side of the cloth is the best for use" is a much discussed question, each side having its advantages. The smooth side takes erasures the better, that is, erasures may be made on this side more easily than on the rough side; the smooth side is a trifle the better for free-hand work, such as lettering, dimensioning, etc., but when drawings are made on this surface, the cloth has a tendency to curl up, a very troublesome feature. The major arguments for the preference of the rough side are: It takes the ink better, can be penciled on also, and the tendency to curl up is a minimum. With a little practice and care, erasures can be readily and neatly made on this side of the cloth, and for general purposes, the writer advocates the use of the rough surface.

To use the cloth, stretch it taut, smooth, and even over the drawing to be traced and proceed as when inking on paper. Should the ink have a tendency to skip or be ragged, the cause may be removed by rubbing chalk dust over the surface and then polishing it off.

121. To Make an Erasure on Tracing-cloth.—To erase ink from tracing-cloth, use the erasing-knife as described for erasing on paper until the line is quite dim; then the ink eraser, followed by the pencil eraser; then resurface the spot erased by rubbing the surface with soapstone and polish with a cloth. The tracing-cloth can then be again inked on without any tendency to blot.

To remove pencil-lines and to clean tracing-cloth apply a rag saturated with gasoline or benzine.

No water should be allowed to get on the cloth, as it destroys the surface and renders it unfit for use.

Tracing-cloth is supplied by the trade in the form of rolls of various lengths and widths.

CHAPTER V.

THE REPRODUCTION OF DRAWINGS.

122. **Introductory.**—Mechanical drawing is an art to facilitate manufacture. No longer is the construction of a bit of mechanism, a machine, a dwelling-house, a bridge, etc., a "cut and try" operation; rather, have such undertakings become "exact sciences" because of drawing and design. When such works are now proposed, the entire scheme is worked out beforehand to the smallest detail; drawings of all the parts or works are made, forming what is called the "plans" for the undertaking, which, together with any necessary additional information, called the "specifications," forms a safe, accurate, and complete guide for the work.

Let it be assumed that a machine is to be produced; the design having been worked out, accurate mechanical drawings of the machine as a whole, and of its component parts, are drawn to scale; these drawings are to be the "guide" for the artisan in his work; that is, the shopman must have "something to go by." Should the original drawings be sent into the shop it is quite probable that they would soon become soiled and illegible in the grimy hands of the workman and the design lost. The production of the drawings has cost the manufacturer a considerable sum of money and he can ill afford to have original drawings go into the shop; the universal practice is to furnish a duplicate drawing to the workmen and to keep the original on file in the draughting-room.

Besides the reason cited above, the manufacturer must preserve the drawings as a "receipt" for the undertaking in case of future orders for the same design; also, the drawings may be needed at different points at the same time; for these and many other obvious reasons it is necessary that original drawings be duplicated and the originals preserved.

An exception to the foregoing is the occasional practice of mounting original drawings on cardboard, sheet iron, wood, etc., protecting the drawings with a glass cover, a coat of varnish, shellac, etc., then sending them into the shop. Such a practice is limited, and is usually employed where the work is standard—tables of standards, shop-cards, etc.—and the drawings are needed permanently in one place.

Drawings may be duplicated in various ways, principal among which are by blue-print process, by photography, by the hectograph and similar processes, and by the mimeograph, being named in the order of their importance for practical purposes.

123. **Blue-printing.**—Blue-printing is the almost universal method of reproducing drawings for practical purposes, the drawings being made on tracing linen. By this method an unlimited number of duplicates may be made, the most serious objection to the practice being that good sunlight is required for the printing, an erstwhile, very serious objection when it is remembered that during the winter months the sun does not shine for days at a time; however, this objection is eliminated by the present-day practice of printing by electric light, and minimized to quite a degree by rapid-printing paper which will print in a comparatively short time on the darkest of days. The operation is a very cheap one, and a good blue-print is both beautiful and clear to the eye; it does not show dirt and is admirably adapted for use in the shop.

To duplicate a drawing by this process requires the use of some such printing-frame as is depicted on page 188, the procedure being as follows: With the back of the printing-frame removed, place the drawing (tracing) in the frame with the inked side next to the glass; next place the prepared paper in the frame with the prepared side next to the tracing, close the frame by putting the back in position, and see that it is well secured by the springs and catches; this done, carefully inspect the drawing- and print-paper (through the glass front) and see that they have good contact with each other and with the glass and are free from folds and wrinkles; when the arrangement passes inspection expose the frame to the sun in a position as nearly at right angles to its rays as is possible and for a length of time suitable to the paper, then remove the paper (not the tracing) and wash it (the paper) for three or four minutes in a bath of clear water and then hang it up to dry.

The explanation of the phenomenon is, the paper is sensitized with a preparation which is susceptible to the sunlight, and when the printing-frame is exposed, all parts of the print-paper exposed to the sun are affected by its rays. Not so with those portions of the paper directly beneath the lines of the drawing; these are protected from the sun by the opaque deposit of ink on the tracing cloth and this leaves a design on the paper—the duplicate of the tracing—unaffected by the sunlight. Should the printing proceed beyond the proper time exposure, the sun's rays will gradually pierce the lines of the drawing and the entire surface of the paper will become affected, presenting a uniform field and no "print"; also, should the exposure not be of the proper length of time, the paper will not be acted on by the sunlight long enough to produce sufficient contrast and again give a uniform field and no "print."

From the above it is evident that there is a limited exposure necessary for good results; also that it is then necessary to in some manner "fix" the print, rendering it immune to further exposures; this is done by the water-bath, the water "fixing" the exposed surface and dissolving the preparation from the unexposed design. The paper used for the production of the process paper is originally a white paper; when sensitized, a dull-gray or greenish color; when exposed, a deep gray, and when washed, a shade of blue, from light to dark according to the length of the exposure. The protected parts remain the original dull-gray or greenish color, and when washed present the white paper beneath, thus giving white lines on a blue background, the ordinary blue-print.

124. Exposure.—If an exposure results in an entire very deep-blue field, the exposure has been too long, or else the lines of the drawing were transparent, the ink used unfit for printing purposes; if the result be a light, milky-looking print, the exposure was of too short duration. "The newer the paper the longer to print and quicker to wash; the older the paper the quicker to print and longer to wash."

125. Washing.—The washing of the prints is a very particular step in the process, as a too long washing will have a tendency to wash out the print, ultimately dissolving all of the preparation and presenting the original white paper; a short bath does not give sufficient time for the water to completely dissolve the preparation from the unexposed parts of the paper, and when again exposed to light (in use) the print will soon succumb to the sun's rays and the design fade away.

Prints may be kept in a dark place for quite a length of time before being washed, though it is preferable to wash them soon after printing.

126. Drying.—For drying prints, the best results are obtained by "hanging up"; a good arrangement is a frame containing a number of "clip" fasteners—spring clothes-pins. When dry the print will be more or less "curled up"; to straighten, draw it over a sharp table-edge two or three times, or take it down while yet a little moist and place it in a press.

A print when once made is a permanent "job" and any corrections or alterations should be made on the tracing and a new print made. However, if the desired change be not of much import and not requiring much labor, the print may be marked on with a solution of common washing-soda and water.

After some experience one is able to judge of the proper exposure for a paper by the change in color of the preparation. When using such a frame as shown on page 188, the paper may be inspected by raising one part of the two-part back and noting the change in color; if under-exposed, the frame can be closed again and the exposure continued, the tracing and paper having been held in position by the closed half of the back. If no such frame is to be had, a test piece of paper may be placed in one corner of the frame and exposed along with the tracing, and when this is of the proper color the paper should be removed and washed.

127. Photography.—The art of reproducing by photography is a branch of the "trade" of photography. Under this heading is also included the various photogravure processes by which plates are produced for press-printing. This is the method employed by the publishers of text-books, technical papers, magazines, etc., and while of vast importance in this field, it has a small place in the field of manufacture.

128. The Hectograph.—The hectograph process of duplicating drawings is a process much used by architects and others when but a limited number of copies are required. It has the advantage of producing drawings in colors. The drawing is made on smooth paper with specially prepared aniline inks, and is then copied on the hectograph—a slab coated with gelatin—by pressing the drawing on its surface, thus transferring part of the ink from the drawing to the gelatin of the pad, where it is retained after the original has been removed. To make a copy, blank paper is pressed on the surface of the hectograph and well rubbed so that the contact is perfect, when the gelatin, giving up part of the ink deposit, gives an exact copy in colors of the original drawing. The copy is then removed from the pad and when dry is ready for use.

129. The Mimeograph.—The mimeograph has no commercial rating as a copying process for mechanical drawings for shop purposes, but is valuable as a means for duplicating notes, small and fairly simple diagrams, etc. A very large number of copies are to be had by this process. The drawing or copy is made on a specially prepared paper by moving a pointed stylus, as in drawing or writing, over the paper when on a finely grooved steel plate, thus tracing the copy in a series of minute perforations. The stencil is then suspended in a special frame, and by means of an ink-roller, ink is forced through the perforations onto blank paper placed beneath the stencil, producing a fac-simile of the stencil. Stencils may also be made on a typewriter.

CHAPTER VI.

PATENT-OFFICE DRAWINGS.*

130. **Introductory.**—Draughtsmen are often called upon to execute drawings for presentation to the United States Patent Office, and that the requisites of that office and method of procedure may be known, the following remarks are taken from the "Rules of Practice in the United States Patent Office."

131. **Drawings.**—The applicant for a patent is required by law to furnish a drawing of his invention whenever the nature of the case admits of it.

132. **Requisites of Drawings.**—The drawing may be signed by the inventor, or the name of the inventor may be signed on the drawing by his attorney in fact, and must be attested by two witnesses. The drawing must show every feature of the invention covered by the claims, and the figures should be consecutively numbered if possible. When the invention consists of an improvement on an old machine the drawing must exhibit, in one or more views, the invention itself disconnected from the old structure, and also in another view so much only of the old structure as will suffice to show the connection of the invention therewith.

133. **Three Editions of Drawings.**—Three several editions of patent drawings are printed and published: one for office use, certified copies, etc., of the size and character of those attached to patents, the work being about six by nine and one-half inches; one reduced to half that scale, or one-fourth the surface, of which four are printed on a page to illustrate the volumes distributed to the courts; and one reduction—to about the same scale—of a selected portion of each drawing for the Official Gazette.

* Extract from "Rules of Practice in the United States Patent Office."

134. **Uniform Standard.**—This work is done by the photo-lithographic process, and therefore the character of each original drawing must be brought as nearly as possible to a uniform standard of excellence, suited to the requirements of the process and calculated to give the best results in the interests of inventors, of the office, and of the public. The following rules will therefore be rigidly enforced, and any departure from them will be certain to cause delay in the examination of an application for letters patent:

135. **Paper and Ink.**—(1) Drawings must be made upon pure white paper of a thickness corresponding to three-sheet Bristol-board. The surface of the paper must be calendered and smooth. India ink alone must be used, to secure perfectly black and solid lines.

136. **Size of Sheet and Marginal Lines.**—(2) The size of a sheet on which a drawing is made must be exactly ten by fifteen inches. One inch from its edges a single marginal line is to be drawn, leaving the "sight" precisely eight by thirteen inches. Within this margin all work and signatures must be included. One of the shorter sides of the sheet is regarded as its top, and measuring downwardly from the marginal line a space of not less than one and one-quarter inches is to be left blank for the heading of title, name, number, and date.

137. **Character and Color of Lines.**—(3) All drawings must be made with the pen only. Every line and letter (signatures included) must be absolutely black. This direction applies to all lines, however fine, to shading, and to lines representing cut surfaces in sectional views. All lines must be clean, sharp, and solid, and they must not be too fine or crowded. Surface shading, when used, should be open. Sectional shading should be made by oblique parallel lines, which may be about one-twentieth of an inch apart. Solid black should not be used for sectional or surface shading.

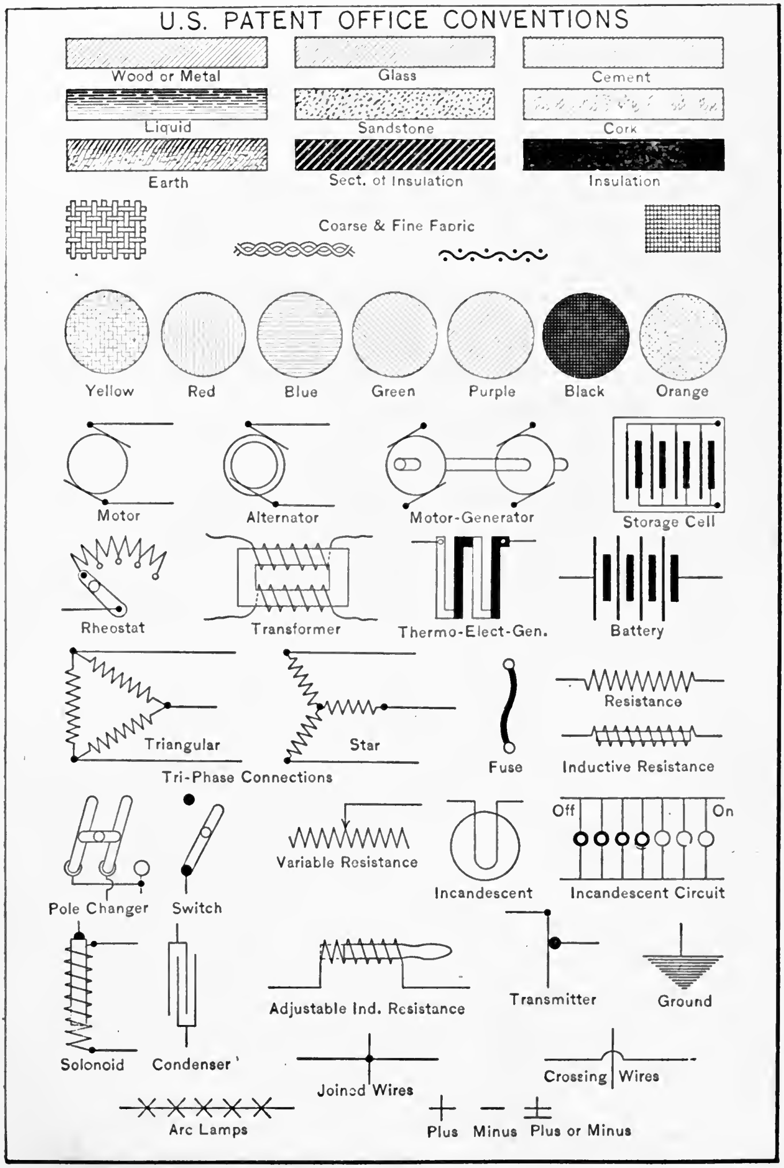
138. **Few Lines and Little or No Shading.**—(4) Drawings should be made with the fewest possible lines consistent with clearness. By the observance of this rule the effectiveness of

the work after reduction will be much increased. Shading (except on sectional views) should be used only on convex and concave surfaces, where it should be used sparingly, and may even there be dispensed with if the drawing is otherwise well executed. The plane upon which a sectional view is taken should be indicated on the general view by a broken or dotted line. Heavy lines on the shade sides of objects should be used, except where they tend to thicken the work and obscure letters of reference. The light is always supposed to come from the upper left-hand corner at an angle of forty-five degrees. Imitations of wood or surface graining should not be attempted.

139. Scale of the Drawing.—(5) The scale to which a drawing is made ought to be large enough to show the mechanism without crowding, and two or more sheets should be used if one does not give sufficient room to accomplish this end; but the number of sheets must never be more than is absolutely necessary.

140. Letters of Reference.—(6) The different views should be consecutively numbered. Letters and figures of reference must be carefully formed. They should, if possible, measure at least one-eighth of an inch in height, so that they may bear reduction to one twenty-fourth of an inch; they may be much larger when there is sufficient room. They must be so placed in the close and complex parts of drawings as not to interfere with a thorough comprehension of the same, and therefore should rarely cross or mingle with the lines. When necessarily grouped around a certain part, they should be placed at a little distance, where there is available space, and connected by short broken lines with the parts to which they refer. They must never appear upon shaded surfaces, and when it is difficult to avoid this, a blank space must be left in the shading where the letter occurs, so that it shall appear perfectly distinct and separate from the work. If the same part of an invention appear in more than one view of the drawing it must always be represented by the same character, and the same character must never be used to designate different parts.

PLATE No. 10.


U.S. PATENT OFFICE CONVENTIONS
Wood or Metal
Glass
Cement
Liquid
Sandstone
Cork
Earth
Sect. of Insulation
Insulation
Coarse & Fine Fabric
Yellow
Red
Blue
Green
Purple
Black
Orange
Motor
Alternator
Motor-Generator
Storage Cell
Rheostat
Transformer
Thermo-Elect-Gen.
Battery
Triangular
Star
Tri-Phase Connections
Fuse
Resistance
Inductive Resistance
Pole Changer
Switch
Variable Resistance
Incandescent
Off
On
Incandescent Circuit
Solonoid
Condenser
Adjustable Ind. Resistance
Transmitter
Ground
Joined Wires
Crossing Wires
Arc Lamps
Plus
Minus
Plus or Minus

141. Signatures of Inventor and Witnesses.—(7) The signature of the inventor should be placed at the lower right-hand corner of each sheet, and the signatures of the witnesses at the lower left-hand corner, all within the marginal line, but in no instance should they trespass upon the drawings.

142. Title.—The title should be written with pencil on the back of the sheet. The permanent names and title will be supplied subsequently by the office in uniform style.

143. Large Views.—When views are longer than the width of the sheet, the sheet should be turned on its side, and the heading will be placed at the right and the signatures at the left, occupying the same space and position as in the upright views, and being horizontal when the sheet is held in an upright position; and all views on the same sheet must stand in the same direction. One figure must not be placed upon another or within the outline of another.

144. Figure for Gazette.—(8) As a rule, one view only of each invention can be shown in the Gazette illustrations. The selection of that portion of a drawing best calculated to explain the nature of the specific improvement would be facilitated and the final result improved by the judicious execution of a figure with express reference to the Gazette, but which might at the same time serve as one of the figures referred to in the specification. For this purpose the figure may be a plan, elevation, section, or perspective view, according to the judgment of the draughtsman. It must not cover a space exceeding 16 sq. ins. All its parts should be especially open and distinct, with very little or no shading, and it must illustrate the invention claimed only, to the exclusion of all other details. When well executed, it will be used without curtailment or change, but any excessive fineness, or crowding, or unnecessary elaborateness of detail will necessitate its exclusion from the Gazette.

145. Drawings to be Rolled for Transmission.—(9) Drawings should be rolled for transmission to the office, not folded.

146. No Stamp, Advertisement, or Address Permitted on the Face of Drawings.—An agent's or attorney's stamp or advertisement or written address will not be permitted upon the face of a drawing, within or without the marginal line.

147. **Drawings for Designs.**—In certain cases these rules may be modified as to drawings for designs.

148. **Drawings for Reissue Applications.**—All reissue applications must be accompanied by new drawings of the character required in original applications, and the inventor's name must appear upon the same in all cases; and such drawings shall be made upon the same scale as the original drawing, or upon a larger scale, unless a reduction of scale shall be authorized by the Commissioner.

149. **Defective Drawings.**—The foregoing rules relating to drawings will be rigidly enforced. Every drawing not artistically executed in conformity thereto may be admitted for purposes of examination if it sufficiently illustrates the invention, but in such cases a new drawing must be furnished before the application can be allowed. The office will make the necessary corrections at the applicant's option and cost.

150. **Drawings Furnished by Office.**—Applicants are advised to employ competent artists to make their drawings.

The office will furnish the drawings at cost, as promptly as its draughtsman can make them, for applicants who cannot otherwise conveniently procure them.

CHAPTER VII.

GEARING.

151. Introductory.—A gear-wheel is a wheel with teeth spaced around its circumference, and is used to transmit motion by rolling contact with other toothed wheels. Gear-wheels are much used in the construction of machinery, the planning for which means that they, like other details, must be worked out and pictured by the draughtsman-designer.

The subject "Gear-wheels and Gearing" is one of much magnitude, there being several systems of forms of gear-teeth, many kinds of gear-wheels, and an endless arrangement of the various wheels. It forms a part of the study of "Mechanism"; however, as the draughtsman often has occasion to draw gear-wheels without any reference whatever to the "design," the study of the usual forms of teeth is properly a part of this work. It is the purpose of these remarks to treat the subject from the draughtsman's standpoint, and, eliminating as much of the theory as is possible, to acquaint the student with the several forms of teeth and kinds of gears, and to instruct him how to draw them.

152. Fundamental Curves.—As a preliminary, the student must acquaint himself with the elementary curves used to form the tooth curve and the manner of their construction. These curves, for the usual forms of teeth, are four in number, and are (1) the cycloid, (2) the epicycloid, (3) the hypocycloid, and (4) the involute.

The Cycloid.—Fig. 57. If a circle be rolled along a straight line, every point in its circumference will describe a curve known as the cycloid. For example, assume a buggy-wheel rolling along a level road, the travel of any particular point on the rim is a cycloid.

To construct the curve, draw the indefinite straight line *A-B* as a base line, then draw the circle at the left of the diagram and divide its circumference into a number of equal arcs—twelve

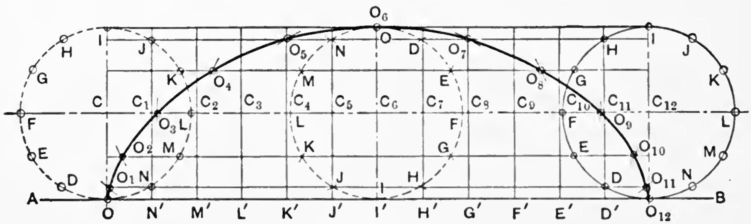


FIG. 57.

being a good working number, though the greater the number the more nearly accurate the work becomes—as *O-D*, *D-E*, etc. Next lay off the lengths *O-N′*, *N′-M′*, etc., equal to the length of the arc *O-D* and erect the perpendiculars *O-C*, N'-C_1, etc. [It will be noted that the circle is divided into an equal number of equal arcs; this facilitates the construction, as the lengths dealt with are uniform, and the curve may be laid out symmetrically with a center line (I'-O_6). However, the circle may be divided in any manner, provided the various lengths be used properly.] Lastly, draw the lines *I-I*, *J-H*, etc., parallel to the base line *A-B*. Now assume the circle to roll to the right; when the point *N* has reached *N′*, the center of the circle, *C*, has traveled to C_1; with this point as a center and the proper radius—that of the rolling circle—by describing an arc intersecting the line *N-D*, the point *O* is found to be at O_1—the point *O* is the point taken for the example. By proceeding in this manner until the circle has traversed its circumference, and using the successive positions of the center-point, *C*, a series of points, *O*, O_1, O_2, O_3, etc., are obtained through which the cycloid is drawn.

The Epicycloid.—Fig. 58. If a circle be rolled around the outside of a fixed circle, every point in the circumference of the rolling circle will describe a curve known as the epicycloid.

To construct the curve, draw the fixed circle *A-B*, then draw the rolling circle *O-D-E*, etc. (the circle at the extreme left of the diagram), and divide its circumference into an equal number of equal arcs, as *O-D*, *D-E*, etc.; next lay off the arcs *O-N′*, *N′-M′*, etc., on the circumference of fixed circle *A-B*, equal to the arc *O-D* of the rolling circle, and draw the radial lines through these points; lastly, draw the circular arcs through the points of division on the circumference of the rolling circle and through its center. Now assume the circle to roll to the right; when the point *N* has reached *N′*, the center of the circle is at C_1, and with this point as a center and with the

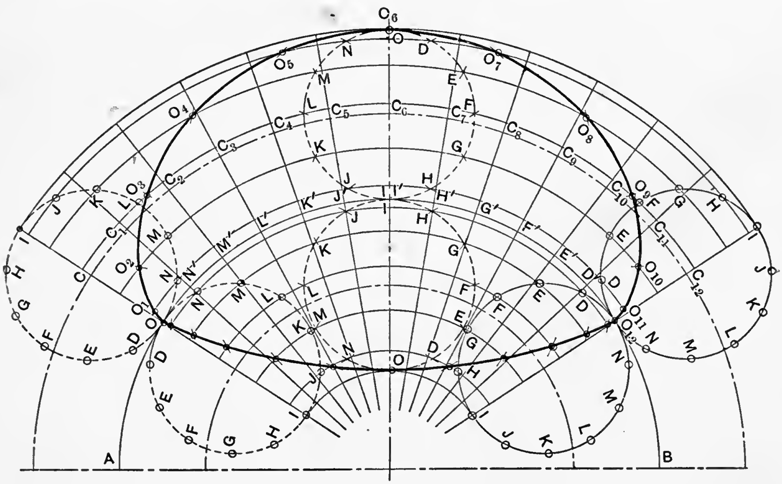


FIG. 58.

proper radius—that of the rolling circle—by describing an arc intersecting the circular arc *N-D*, the point *O* is found to be at O_1. By thus rolling the circle to the right for a complete revolution, locating the successive positions of the center-point, C_1, C_2, C_3, etc., and describing the proper arcs, a series of points, O, O_1, O_2, etc., are obtained through which the epicycloid is drawn.

The Hypocycloid.—If a circle be rolled around the inside of a fixed circle, every point in the circumference of the rolling circle will describe a curve known as the hypocycloid.

The manner of constructing the curve is identical with that given for the epicycloid, as is clearly evident from Fig. 58.

The Involute.—Fig. 59. If a straight line, or to be consistent, a circle of infinite radius be rolled around the outside of a fixed circle, every point in it will describe a curve known as the involute. A common illustration is to wind a string about a cylinder, then keeping the string taut, unwind it; the end of the string will describe an involute.

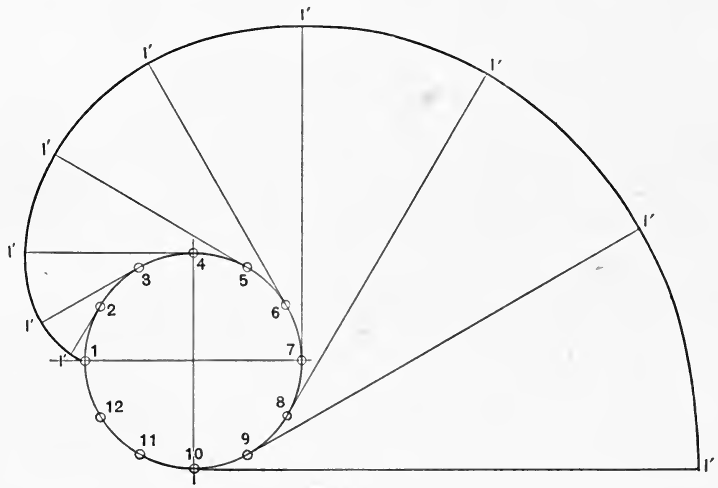


FIG. 59.

To construct the curve, draw the circle 1-2-3, etc., and divide its circumference as shown; at each of these points of division draw a tangent to the circle, then lay off the lengths 2-1′ equal to the arc 2-1, 3-1′ equal to the arc 3-1, etc.; that is, beginning at a certain point, the length of the tangent at any point must be equal to the length of the rectified arc between that point and the starting-point.

153. Glossary of Terms.—The projections around the periphery of a gear-wheel are called the *teeth* of the gear; the blank spaces between the teeth are called the *spaces*. The width of a tooth plus the width of a space, measured on a certain circle called the *pitch-circle*, is called the *circular pitch* of the gear.

The engaging surface of a tooth projecting beyond the pitch-circle is called the *face of the tooth;* the engaging surface within the pitch-circle is called the *flank of the tooth.* That face of a tooth first coming into contact is called the *front of the tooth;* that face coming into contact later is called the *back of the tooth;* thus we have the front and back face of a tooth, and the front and back flank of a tooth. The point where the pitch-circle cuts the front of a tooth is called the *pitch-point* of the tooth. The outer end of a tooth is called the addendum end, and a circle, concentric with the gear, drawn through it is called the *addendum-circle;* the inner "end" of a tooth is called the *root* of the tooth, and a circle, concentric with the gear, drawn through it is called the *root-circle.* The space between the addendum-circle of one gear and the root-circle of the gear with which it engages is called the *clearance* of the gears; a circle defining the clearance of a gear is called the *addendum-circle.* The *depth of a tooth* is the distance, measured radially, between the addendum- and root-circles of the gear. The *fillet* is the rounded part of the flank, fashioned so as to give the tooth strength. The *pitch-diameter,* or simply *diameter* of a gear, is the diameter of its pitch-circle; the *diametral pitch* of a gear is the ratio of the number of teeth to the pitch-diameter. The gear to which the power is applied is called the *driver;* the one with which it engages is called the *follower.*

Gears are designated in two general ways: (1) by giving the pitch-diameter of the gear and number of teeth, as a 10″ gear having 40 teeth; (2) by the pitch-diameter and diametral pitch of the gear, as (for the same gear) a 10″ four-pitch gear.

154. Usual Proportions for Teeth.—The dimensions of the teeth of a gear are determined in two ways: (1) by making them proportional to the circular pitch, and (2) by proportioning them to the diametral pitch. Both methods are much used; also, there are several proportions in use. For the draughtsman a good method is to draw the addendum .3 of the circular pitch, measured radially out from the pitch-circle; the dedendum .3 of the circular pitch, measured in a like manner in from the pitch-circle;

the clearance to be .1 of the circular pitch; the width of tooth and space to be equal and equal to one-half of the circular pitch.

155. Development of Formulæ.

Let D = the diameter of the gear.

C = the circumference of the gear $= 3.1416 \times D = \pi D$.

N = the number of teeth.

P = the circular pitch $= \dfrac{C}{N}$. . . . . (1)

P' = the diametral pitch $= \dfrac{N}{D}$. . . . . (2)

Then, with the diameter and circular pitch given, to find the number of teeth,

$$N = \frac{C}{P}. \qquad (3)$$

With the diameter and diametral pitch given, to find the number of teeth,

$$N = P'D. \qquad (4)$$

Placing the two values of N equal to each other,

$$\frac{C}{P} = P'D.$$

Substituting πD for C,

$$\frac{\pi D}{P} = P'D.$$

Hence

$$P' = \frac{\pi}{P}. \qquad (5)$$

$$P = \frac{\pi}{P'}. \qquad (6)$$

$$\pi = PP'. \qquad (7)$$

156. Kinds of Gears.—Of the several kinds of gears met with in practice, three have been chosen and will be discussed as being representative of those most frequently confronting the draughtsman. 1. A *spur-gear* is a gear whose teeth are on the outside of the gear. 2. A *rack* is a spur-gear whose radius is infinity; here the pitch-circle becomes a *pitch-line*, the addendum-circle the addendum-line, etc. 3. An *annular or internal gear* is a gear whose teeth are on the inside of the gear.

157. Systems of Teeth.—Like the kinds of gears, there are several systems of tooth outline; of these but two are widely in use: (1) the cycloidal system, and (2) the involute system.

The form of the tooth curve adopted for the rack is the determining basis for the systems. If the tooth curve is composed of cycloidal curves, the resulting system is called the *cycloidal system;* when the tooth curve be omes a straight line the resulting system is called the *involute system.*

In the cycloidal system the tooth curve is described by certain circles, called *describing-circles*, rolling on the pitch-circle of the gear; in the involute system the tooth curve is formed by the involute to a certain circle, called the *base-circle*, drawn tangent to a certain straight line, called the *line of action*, drawn through the common pitch-point of the two gears, and a radial line drawn from the origin of the involute.

158. Interchangeability.—Gears are largely made to work in sets; for this reason it is necessary that the teeth be so fashioned that the gear will be interchangeable within certain limits.

In the cycloidal system, if the gear is not to be one of a set, a good general rule is to make the diameter of the rolling circle equal to three-eighths of the diameter of the pitch-circle in which it rolls; if the gear is to be one of a set, a universal rule is to make the rolling circles for the set of a uniform diameter, this diameter to be equal to the radius of a gear with twelve teeth of the circular pitch of the set, the fundamental for all interchangeability being a uniform circular pitch.

In the involute system the gears must have a common line of action and a uniform circular pitch.

159. Methods of Drawing the Tooth Outline.—There are several practical methods for drawing the tooth curve; to treat of all of them is beyond the scope of this work, and the discussion will be limited to the two methods most widely in use. 1. The "*exact method*" is the term applied to the procedure when the true theoretical tooth curve is drawn. 2. The "*approximate method*" is the term applied when the true tooth curve is approximated.

160. Spur-gears. Exact, Non-interchangeable Cycloidal.— Let it be assumed that the draughtsman is required to furnish

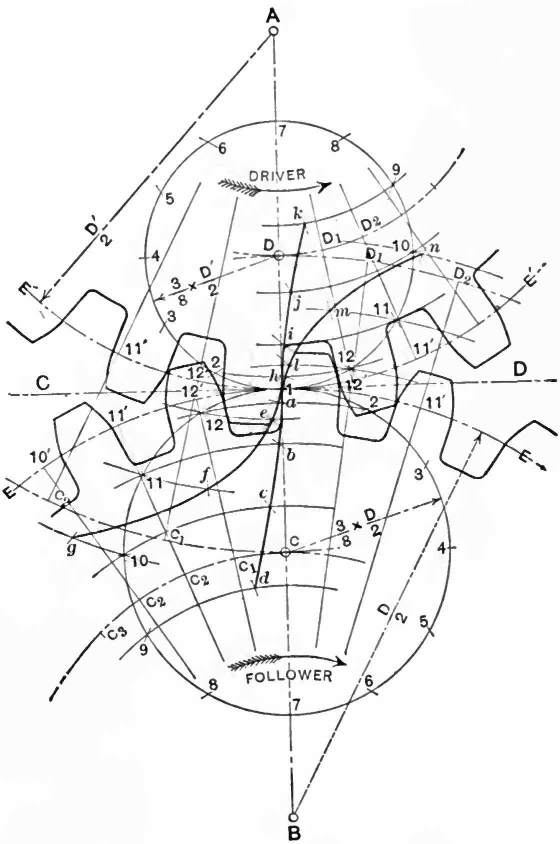


FIG. 60.

the pattern-maker with a templet for laying out the exact tooth outline for certain gears, and let Fig. 60 represent the conditions. This pair of gears is not part of a set, simply designed to work together; note also that the gears are spur-gears and that the teeth are of the cycloidal system.

To draw the teeth, draw the line of centers, *A-B*, properly locate the centers and draw the pitch-circles *E-E* and *E′-E′*; draw the describing-circles as shown, and of a diameter equal to three-eighths of the diameter of the respective pitch-circles. Now roll the describing-circle of the driver to the right and inside of the *E′-E′* pitch-circle and describe the hypocycloid 1-*h-i-j-k* (Sect. 152); this curve forms the flank of the teeth for the driver. Again roll the same describing-circle to the right and this time on the outside of the *E-E* pitch-circle and describe the epicycloid 1-*l-m-n* (Sect. 152); this curve forms the face of the teeth for the follower. Next roll the describing-circle of the follower to the left and inside of the *E-E* pitch-circle and describe the hypocycloid 1-*a-b-c-d;*—this curve forms the flank of the teeth for the follower. Rolling the same describing-circle to the left again, and this time on the outside of the *E′-E′* pitch-circle, obtain the epicycloid 1-*e-f-g*, which curve forms the face of the teeth for the driver. The tooth curves drawn, draw the addendum, dedendum, and root-circles for the gears according to the usual proportions (Sect. 154), the circular pitch having been computed by formula 1, Sect. 155. Starting at the common pitch-point, 1, step off one-half of the circular pitch around the pitch-circles, and with a templet of the proper curve—an irregular curve properly marked—through these points draw in the outlines of the teeth as shown.

Exact, Interchangeable Cycloidal.—Assume that the follower of the above example is to form part of a set of gears, and let it be required to draw the exact tooth outline. As previously explained (Sect. 158), the diameter of the describing-circle is predetermined—found by substituting the known values in formula 1 and solving for *D*; the diameter of the rolling circle equals one-half of *D*. Let Fig. 61, showing the follower in gear with the smallest gear of the set, represent the conditions.

The describing-circles drawn, the method of procedure is identical with that given for the non-interchangeable gear; it will be noted, however, that the hypocycloid obtained by rolling the describing-circle inside the pitch-circle of the driver is a straight line passing through the center of the pitch-circle, making the flanks of the teeth of that gear to be radial lines.

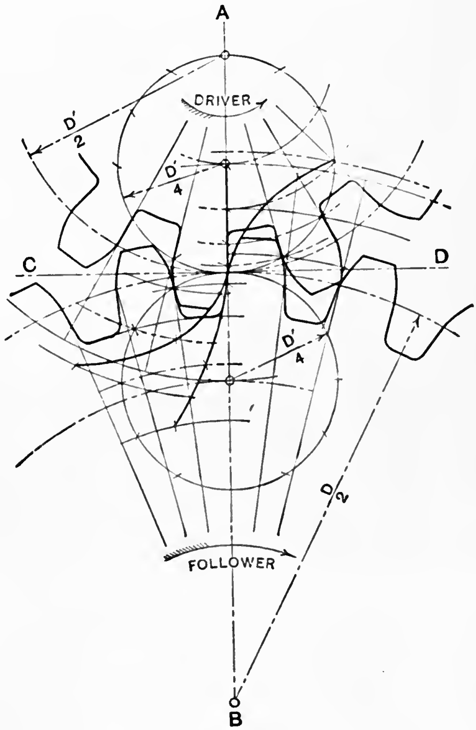


FIG. 61.

Exact Involute.—Let it be required to draw the above gears with exact involute teeth, and let Fig. 62 be the diagram. To draw the teeth, draw the two pitch-circles as before, then draw the line of action, *X-Y*, as shown, and the base circles, *m-n* and *p-p*, tangent to it. Next draw the involutes 0-1-2-3, etc., and 0′-2-3′, etc., to the *m-n* and *p-p* base circles, respectively; these curves form the face and part of the flank—that part between the pitch-circle and the base circle—of the teeth of the respective gears, the remainder of the flanks being drawn as radial lines.

With the depth of the tooth defined, and the width of the tooth and space laid out on the pitch-circles, the tooth outline is drawn in as shown by means of templets to the involutes.

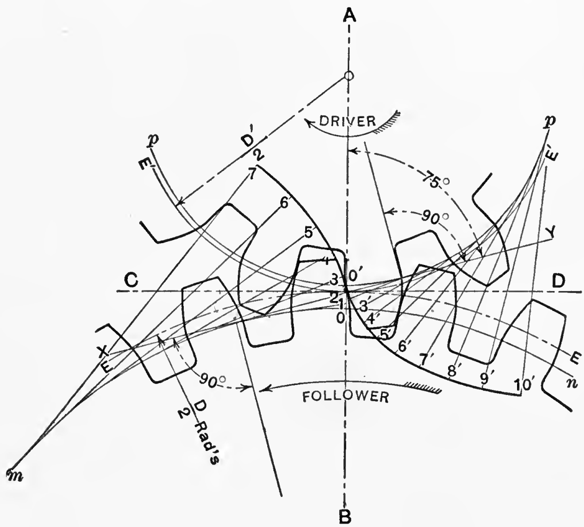


FIG. 62.

The construction of the exact tooth curve is both laborious and time-consuming; in fact so much so that there has been a number of methods evolved for approximating the curve. Of the various methods in use, that of approximating the tooth curve with circular arcs is the most widely used. The methods known as "Grant's Epicycloidal and Involute Odontographs" (see tables), the invention of George B. Grant, are taken, by permission of the author, from "Grant's Treatise on Gearing." They have nearly supplanted previous devices for the purpose in this country.

The use of the tables is explained by the following examples:

Approximate Cycloidal.—Fig. 1, Plate No. 11. Draw the pitch-, addendum-, dedendum-, and root-circles of the gears and lay off the width of tooth and space, as previously explained. With either the diametral or circular pitch, and the number of teeth known, to apply the table look in the column of teeth for

GRANT'S TABLES FOR DRAWING GEAR-TEETH.*

(Standard Interchangeable Series.)

GRANT'S INVOLUTE ODONTOGRAPH.

Centers on Base Line.

Teeth.	Divide by the Diametral Pitch.		Multiply by the Circular Pitch.	
	Face Rad's.	Flank Rad's.	Face Rad's.	Flank Rad's.
10	2.28	.69	.73	.22
11	2.40	.83	.76	.27
12	2.51	.96	.80	.31
13	2.62	1.09	.83	.34
14	2.72	1.22	.87	.39
15	2.82	1.34	.90	.43
16	2.92	1.46	.93	.47
17	3.02	1.58	.96	.50
18	3.12	1.69	.99	.54
19	3.22	1.79	1.03	.57
20	3.32	1.89	1.06	.60
21	3.41	1.98	1.09	.63
22	3.49	2.06	1.11	.66
23	3.57	2.15	1.13	.69
24	3.64	2.24	1.16	.71
25	3.71	2.33	1.18	.74
26	3.78	2.42	1.20	.77
27	3.85	2.50	1.23	.80
28	3.92	2.59	1.25	.82
29	3.99	2.67	1.27	.85
30	4.06	2.76	1.29	.88
31	4.13	2.85	1.31	.91
32	4.20	2.93	1.34	.93
33	4.27	3.01	1.36	.96
34	4.33	3.09	1.38	.99
35	4.39	3.16	1.39	1.01
36	4.45	3.23	1.41	1.03
Interval				
37–40	4.20		1.34	
41–45	4.63		1.48	
46–51	5.06		1.61	
52–60	5.74		1.83	
61–70	6.52		2.07	
71–90	7.72		2.46	
91–120	9.78		3.11	
121–180	13.38		4.26	
181–360	21.62		6.88	

* Taken, by permission, from "Grant's Treatise on Gearing."

GRANT'S CYCLOIDAL ODONTOGRAPH.

Number of Teeth in Gear.		For One Diametral Pitch. For any other Pitch, Divide by that Pitch.				For One Inch Circular Pitch. For any other Pitch, Multiply by that Pitch.			
		Faces.		Flanks.		Faces.		Flanks.	
Exact.	Intervals.	Rad's.	Dist.	Rad's.	Dist.	Rad's.	Dist.	Rad's.	Dist.
10	10	1.99	.02	−8.00	4.00	.62	.01	−2.55	1.27
11	11	2.00	.04	−11.05	6.50	.63	.01	−3.34	2.07
12	12	2.01	.06	Infinity	Infinity	.64	.02	Infinity	Infinity
13½	13–14	2.04	.07	14.50	9.43	.65	.02	4.60	3.00
15½	15–16	2.10	.09	7.86	3.46	.67	.03	2.50	1.10
17½	17–18	2.14	.11	6.13	2.20	.68	.04	1.95	.70
20	19–21	2.20	.13	5.12	1.57	.70	.04	1.63	.50
23	22–24	2.26	.15	4.50	1.13	.72	.05	1.43	.36
27	25–29	2.33	.16	4.10	.96	.74	.05	1.30	.29
33	30–36	2.40	.19	3.80	.72	.76	.06	1.20	.23
42	37–48	2.48	.22	3.52	.63	.79	.07	1.12	.20
58	49–72	2.60	.25	3.33	.54	.83	.08	1.06	.17
97	73–144	2.83	.28	3.14	.44	.90	.09	1.00	.14
290	145–300	2.92	.31	3.00	.38	.93	.10	.95	.12
Infinity	Rack	2.96	.34	2.96	.34	.94	.11	.94	.11

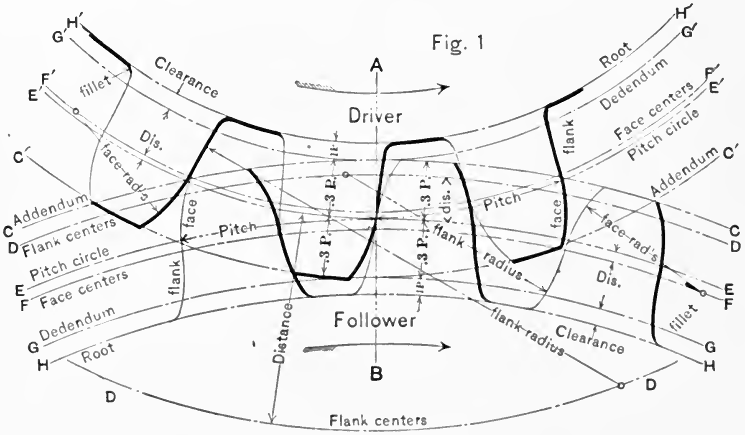
the number corresponding to the number of teeth of the gear to be drawn; this found, follow across to the column headed "Face, Dist." (diametral or circular pitch, as the case may be), and applying the instructions (to divide or to multiply) given in the table, lay off the length obtained as shown, and draw the circle of face centers. Going back to the column of teeth number in the table, find the corresponding "Rad's" number, and in accordance with the table instruction, compute the face radius; this found, with centers on the face radius circle, draw the face curve of the teeth. The circle of flank centers and flank radii are computed from the table in a similar manner and the flank curve of the teeth drawn as shown.

Approximate Involute.—Fig. 2, Plate No. 11. The table for involute teeth is applied similarly to that for cycloidal teeth, with the exception that all centers are on the base circle.

161. Rack and Pinion. Exact, Non-interchangeable Cycloidal.—Fig. 63. This is identical with the same conditions given for spur-gearing (Sect. 160), the rack being a spur-gear of in-

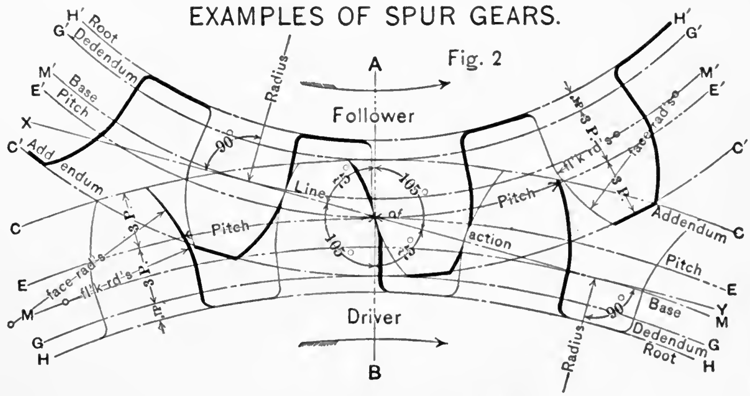
PLATE No. 11.

GEARING
DIFFERENT SYSTEMS.
Approximate method.



1. CYCLOIDAL SYSTEM.
(By Grant's Cycloidal Odontograph.)

EXAMPLES OF SPUR GEARS.



2. INVOLUTE SYSTEM.
(By Grant's Involute Odontograph.)

finite radius and its describing-circle a straight line *E-E*. By rolling the describing-circle of the pinion on the inside of the

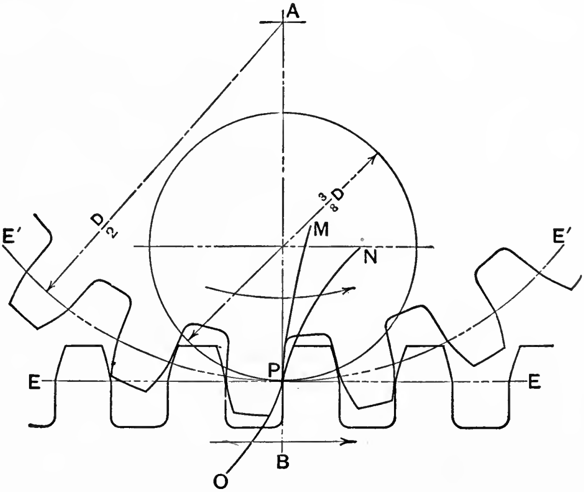


FIG. 63.

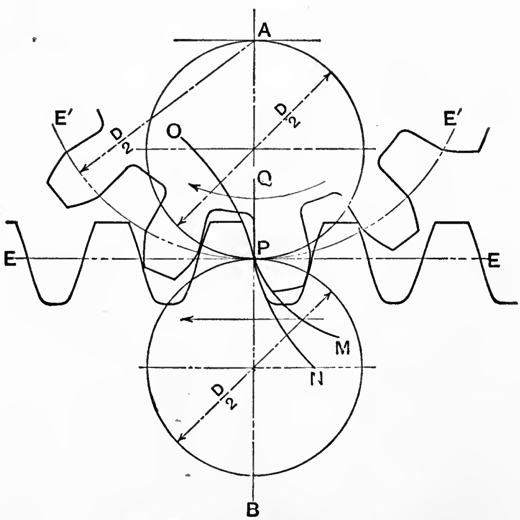


FIG. 64.

pitch-circle, the hypocycloid *P-M*, forming the flanks of the pinion teeth, is obtained; by rolling the same circle along the pitch-line, the cycloid forming the faces of the rack teeth is obtained; by rolling the line *E-E* around the pitch-circle the involute forming the faces of the pinion teeth is described; the flanks of the rack teeth are drawn perpendicular to the pitch-line.

Exact, Interchangeable Cycloidal.—Fig. 64 illustrates the ap-

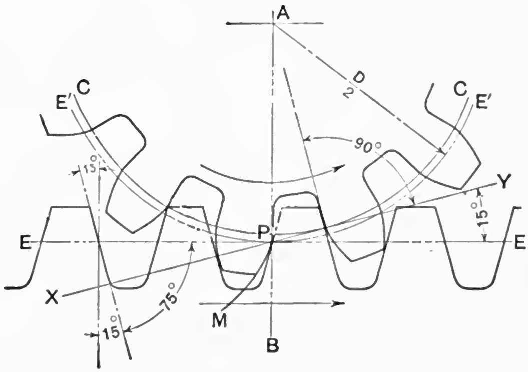


FIG. 65.

plication of the uniform rolling circle of a set of gears, and the procedure is identical with that given in Sect. 160.

Exact Involute.—Fig. 65. Here the tooth curve of the rack

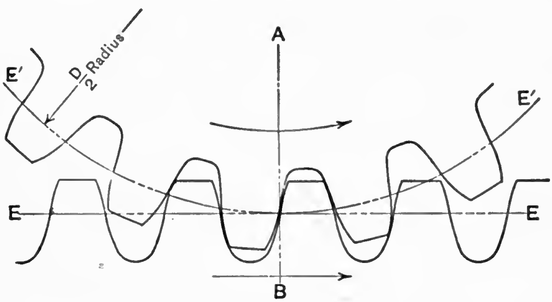


FIG. 66.

is a straight line; the base circle and involute *P-M* for the face of the teeth of the pinion are obtained in the usual manner and the teeth drawn as in Sect. 160.

Approximate Cycloidal.—Fig. 66. Apply the cycloidal table as for spur-gears, the face and flank center circles for the rack becoming straight lines parallel with the pitch-lines.

Approximate Involute.—Fig. 67. Draw straight lines for the

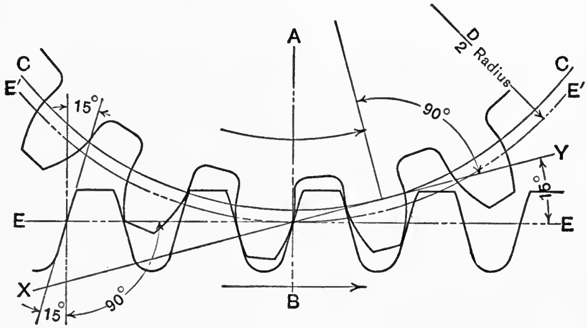


FIG. 67.

tooth curve of the rack teeth, and for the tooth curve of the pinion apply the involute table as for spur-gears, Sect. 160.

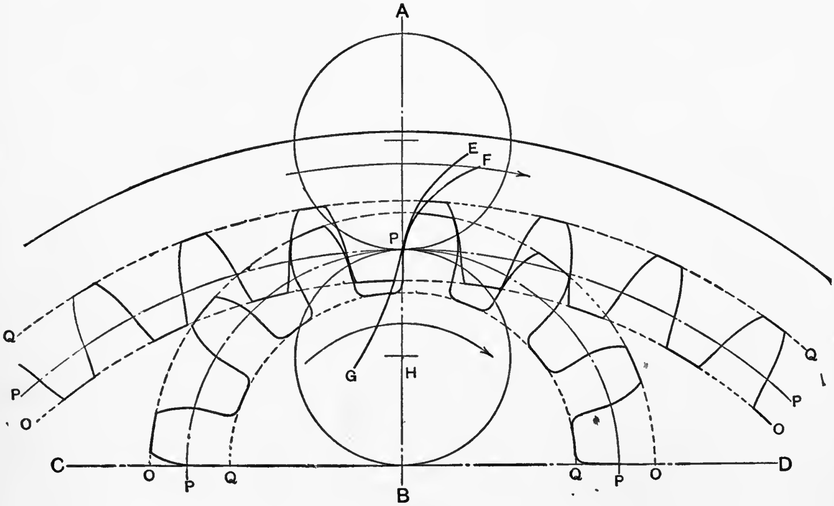


FIG. 68.

162. Internal Gears. Exact Cycloidal.—Fig. 68. To draw the teeth, draw the two pitch-circles tangent at the common pitch-point, *P*; draw the addendum- and root-circles of the usual proportions, and the describing-circles as shown. Rolling the describing-circle on the outside of the large pitch-circle generates the epicycloid *P-E*, which defines the flank curve for the teeth

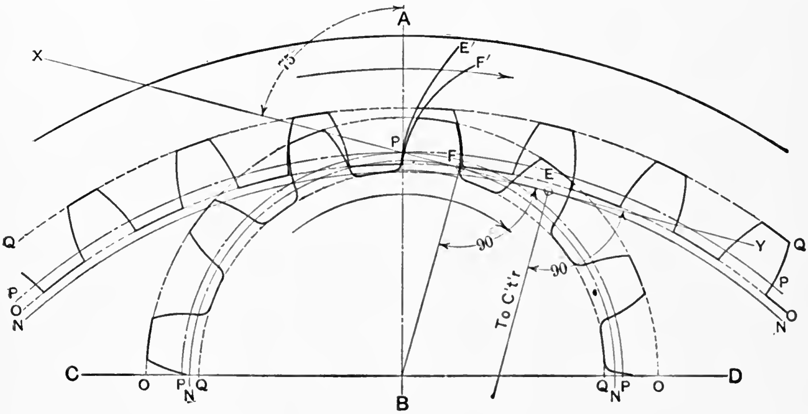


FIG. 69.

for the annular wheel; rolling the same describing-circle on the outside of the pitch-circle of the pinion generates the epicycloid *P-F*, which defines the face curve for the teeth for the pinion.

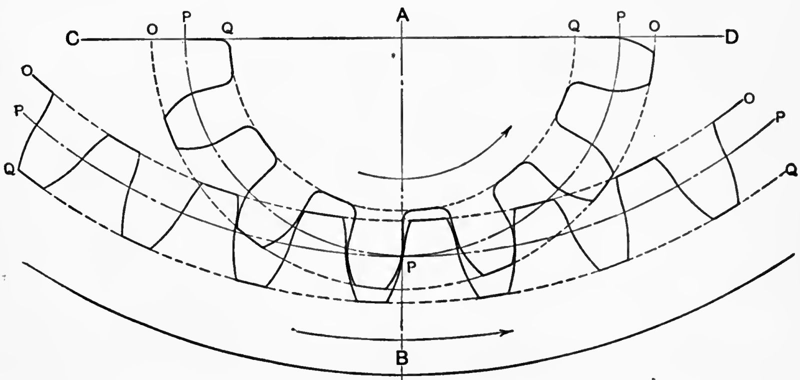


FIG. 70.

Rolling the describing-circle on the inside of the pitch-circles generates the hypocycloids *P-G* and *P-H*, which form the face curve of the teeth for the wheel and the flank curve for the teeth of the pinion, respectively. The tooth curves defined, the teeth are drawn by means of a templet.

Exact Involute.—Fig. 69. Draw the two pitch-circles and the line of action as shown; draw the addendum-circle of the pinion and the root-circle of the wheel as usual. The addendum-circle of the wheel is determined by the point *F*, and the root-circle of the pinion by the usual clearness. To draw the teeth, the base circles are drawn as for spur-gears, the involutes to them, *P-E′* and *P-F′*, described, and the teeth drawn as shown.

Approximate Cycloidal.—Fig. 70. The pitch-, addendum-, and root-circles are drawn in the usual way and the cycloidal table applied as for spur-gears.

Approximate Involute.—Fig. 71. The pitch-circles, the

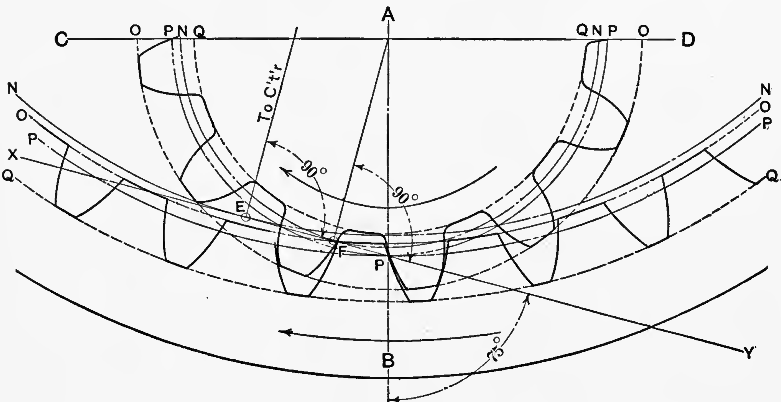


FIG. 71.

addendum of the pinion, and the root-circle of the wheel are drawn in the usual way, and the addendum-circle of the wheel and the root-circle of the pinion, as in the exact example. These drawn, apply the involute table as for spur-gears.

CHAPTER VIII.

COLOR WORK.

TINTING.

163. Introductory.—Tinting is the art of applying colors to drawings, and as a "touch of color" added to most things enhances their beauty, so does the art of tinting assist in the production of handsome drawings. The art is much used in the preparation of drawings for catalogue illustrations, this particular kind of work being a trade in itself and known as "wash drawing." The art of tinting is, however, of some importance to the ordinary engineer-draughtsman, being much used by the architectural engineer for coloring plans and perspectives of buildings, and by others for expediting the drawing of sections, the sectioned part being colored as a substitute for cross-hatching.

164. Outfit.—The outfit needed for the course as herein embodied is as follows:

(1). Two small beakers for holding water.

(2). Two sable or camel's-hair brushes, or, if preferred, one double-ended brush, one end for color, the other for clear water. The brush should be thick in the body, tapering rapidly to a fine point.

(3). A nest of six cabinet saucers in which to mix the colors.

(4). A bottle of library paste for mounting the paper.

(5). A small hand sponge or rag with which to sponge the paper.

(6). A six-inch square of ordinary fly-screening.

(7). A tooth-brush or other small, stiff-bristled brush.

(8). One-half pan (trade term) of Chinese white.

(9). A small stick of Chinese or India black ink.

The paper best adapted for tinting differs from a good drawing-paper in that it is comparatively rough of surface.

165. Making a Stretch.—Since the tints are applied in a liquid form, there is more or less of a tendency for the paper to "blister"; the moisture causing it to stretch and the corners being fixed, the paper blisters in proportion to the amount of the liquid applied. To meet this tendency, the paper is usually "stretched" on the board. This is done as follows:

To make a stretch, first select the surface of the paper to receive the drawing, then lay the paper, with this side up, on a drawing-board and "square" the top edge of the paper with a T-square; next slide the square down for about $\frac{1}{4}''$ and turn up this $\frac{1}{4}''$ strip of paper against the edge of the T-square blade; then remove the square and fold the paper back; in this manner turn up and fold back a strip of about $\frac{1}{4}''$ at each side of the sheet, turning the top side first, then one end, then the other, and lastly the bottom side; with the paper thus prepared, turn it over and with a sponge or rag apply a liberal wash of clear water, being careful to keep it off the upturned edges, and allow it to soak for two or three minutes; this expands the paper (should a very "tight" stretch be desired, the paper may be moistened on both sides; for the exercises of this course, moistening on the under-side will suffice); next turn the paper over on the drawing-board, squaring the last turned edge with a line drawn on the board, then rub the paper down; the moist surface will adhere to the board for a short time; now apply a liberal coating of paste to the turned-up strips, being careful to keep it off the surface to be drawn upon, and taking them in the reverse order as turned up, fold them back and rub them down until perfect cohesion is obtained; when the paper is pasted on, and while the paste is yet moist, the paper should be drawn taut with the finger-tips; this gives an additional stretch to the sheet, which, being yet moist, is now permitted to dry, thus contracting the expanded sheet, and the pasted parts being fixed, the paper is stretched.

166. Mixing the Colors.—To mix the stick ink, rub the stick with considerable pressure in a saucer containing a small quantity of water until the desired tint is obtained. To mix the Chinese white, moisten the tip of the camel's-hair brush and apply it to the surface of the color, rubbing briskly and turning the brush until a quantity of the color is absorbed; then transfer the coloı to a saucer containing more or less water, according to the quantity and degree of color wanted. If the color is to be used in the ruling-pen, the pen may be charged directly from the brush-tip.

167. Flat Wash.—A "flat wash" is the term applied to the application of a uniform tint. In applying the color, the brush should be well filled and a small "puddle" of color made on the surface to be colored; this puddle is washed over the surface, then picked up with a dry brush. This applies to fairly large surfaces; if the surface be small, the brush may contain but little color and the surface be "painted."

The tints, if permitted to stand on the paper, will dry in a very short time, especially along the edges, and when washed over and the sheet allowed to dry, they will appear streaked; for this reason it is important to keep all parts of the wash moving—the minimum speed is quickly ascertained in practice—until the wash is finished. If one cannot work with sufficient rapidity, the drying tendency may be minimized by first moistening the surface with clear water. Such a procedure is advantageous also as a vehicle for carrying the wash into intricate parts of the drawing, since the water can be applied slowly and with the necessary caution to preserve the lines; however, when so doing, care must be exercised to produce a uniform tint, as the added water will tend to lighten it.

168. Shading.—There are a number of methods for shading with tints, principal among which are the following:

1. To shade by means of flat tints, lay on a light tint flat wash for a short space, then soften off the edge with a clear, moist brush-end; when dry, begin as before, and this time carry the wash a little greater distance, then soften off the edge as above; in this manner apply a number of coatings, each successive one covering all the others—a process which causes the

first applied wash to become darkest and grades from it to the last wash. The objection to this method is the great amount of time consumed in its application.

2. A second method of applying shades is to mix the color to correspond to the deepest shade and make a puddle of this at the top of the surface; then pick up a quantity of clear water with the brush and add this to the color on the sheet, washing it down for a short distance; then add more water and wash it down, etc., adding clear water each time, thus thinning the tint and grading the wash from dark to light. This method requires much practice to determine the exact amount of water for a uniform grading of the tint.

3. A third method is to begin as in the second method, with a puddle at the top, but this time thin the color off the sheet, in the saucers, then apply it. In these two methods it is important that a fair-sized puddle be maintained on the paper, thus insuring a more even thinning of the color and a uniform grading of the tint. Too much water will produce a streak, too little no perceptible change of tint.

4. In this method first wash the surface to be shaded with a wash of clear water; do not apply enough water to cause it to stand on the surface, but just a quantity sufficient to cause the paper to "glisten" unifo mly, and while yet wet apply the color—which should be quite da k—to the part which is to be darkest and draw the color from here to the high lights by streaking the surface with bands of color varying in width and spacing; to execute the shade, begin at the high light with a clean, moist brush-tip, and moving the brush back and forth at right angles to the direction of advance, work through the bands of color to the darkest part. Should the shading be streaked or otherwise irregular while the surface is yet moist, begin again at the high light with a clean brush and again work through the shade. The advantage of the method is that as long as the surface is moist, the work may be gone over and bettered.

In applying the bands of color, care should be exercised to have just the right quantity of the liquid in the brush-tip, else the color will run; if too much is applied, or if too little is added, the shade will be "pale." The color should be quite thick—heavy—and the brush should contain that quantity which remains after wiping the brush-tip a few times on the edge of the saucer.

The clean brush should contain a quantity of water remaining after gently squeezing the brush-tip between the fingers—a fairly "dry" brush. If the brush contains too much water, the tint will be thinned too much and the shade will not be marked; if there be too little water, the brush will pick up the color and the shade will be streaked.

5. When the surface is comparatively small, a fifth method may be used to advantage. In this, apply a small amount of the heavy tint, then with a clean, moist brush draw the color out, and as it is carried over the surface it will become thinned and the color graded from the original dark to light. The exact amount to first apply is a matter of practice.

To minimize a tendency to dry too rapidly in the first, second, third, and fifth methods, clear water may be first applied, though the surface must be allowed to dry to a point where the "glisten" of the water disappears from the surface of the paper, else the color will follow the water and cannot be controlled.

STIPPLING.*

169. Introductory.—To "stipple" means to shade by means of dots. If the surface to be stippled is small, the work is usually done with a pen-point; if the surface is of some size, such a method is too time-consuming and difficult where good results are desired. For stippling such surfaces, there are several mechanical methods which may be used; that method to be followed in this course will be treated of as being typical of these processes.

If a piece of ordinary wire fly-screening be held over a sheet of paper and a stiff brush—such as a tooth-brush—containing a liquid be brushed over the upper surface, it will throw dots of

* Also called "spatter drawing."

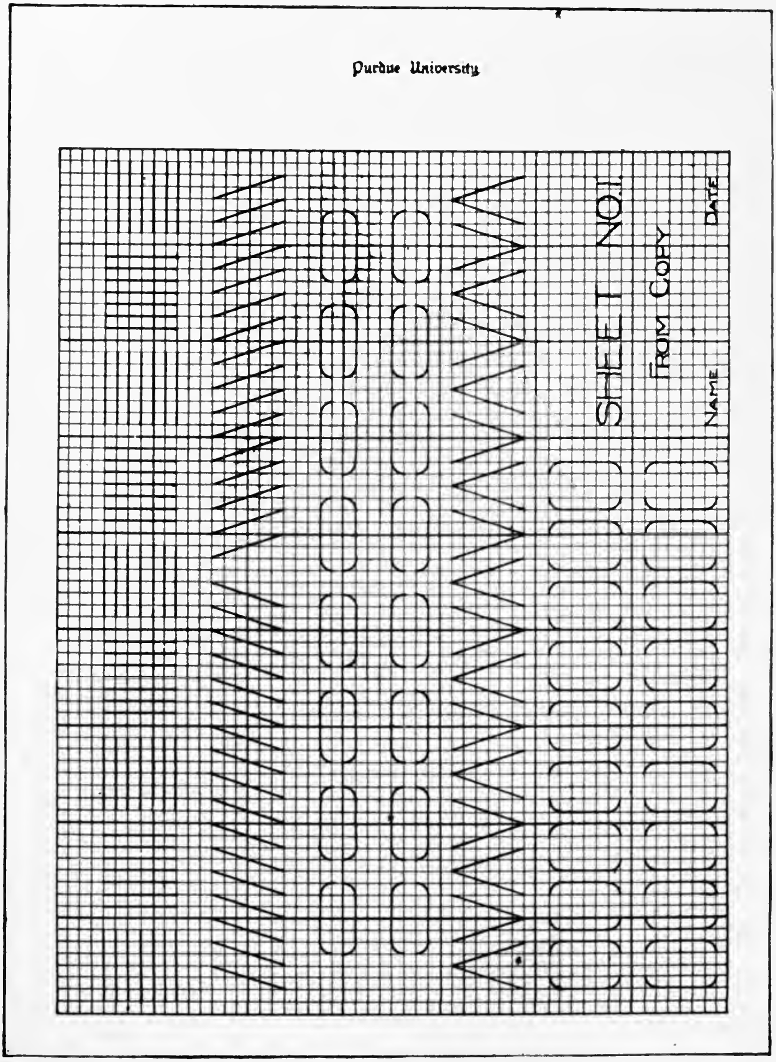
the liquid onto the paper. This simple procedure is the method to be followed in executing the exercises in stippling.

170. Method of Procedure. — For good results the paper should be stretched as for tinting, though if the amount of surface to be stippled is small, and the degree of shade comparatively light, the paper may be secured with thumb-tacks as in ordinary drawing. The color is mixed as for tinting; however, no very light tints are used, as the light shade is here produced in a different manner. The figure to be "drawn" is executed on a sheet of fairly stiff paper—not the finished sheet—and is then prepared for stippling by cutting out the various surfaces; that is, make a templet for the figure, then lay this on the paper, matting out all other parts, and throw the dots on the exposed area.

To stipple, dip the brush in the color, shake it until quite dry, then brush it across the screen. If the brush contains too much color the dots will not be clean-cut and often will run together and blur and blot.

To shade lightly and uniformly, hold the screen some distance away—three or four inches—from the paper; as the screen is moved closer to the paper the shading may yet be uniform, but will grow darker. Large surfaces are stippled by moving the screen about, and shades are intensified by holding the screen in one place and close to the paper.

PLATE No. 12.



PART II.

CHAPTER IX.

SKETCHING.

171. Introductory.—The "course in mechanical drawing" as embodied in these notes is divided into two parts: (1) sketching, and (2) mechanical drawing. The work in sketching is a preliminary to the mechanical execution of the copies given, and is intended to thoroughly acquaint the student with the fundamentals of mechanical drawing.

The sketches are to be drawn in pencil, on a specially ruled paper, with the aid of a compass, straight-edge, and scale.

172. Sheet No. 1.—The first exercise, Plate No. 12, is an exercise in straight-lining and is to be copied free-hand, exactly as set forth; the lettering is to be of the same size and style given, except where the words "Name" and "Date" occur the student is to print his name and the date of completing the sheet.

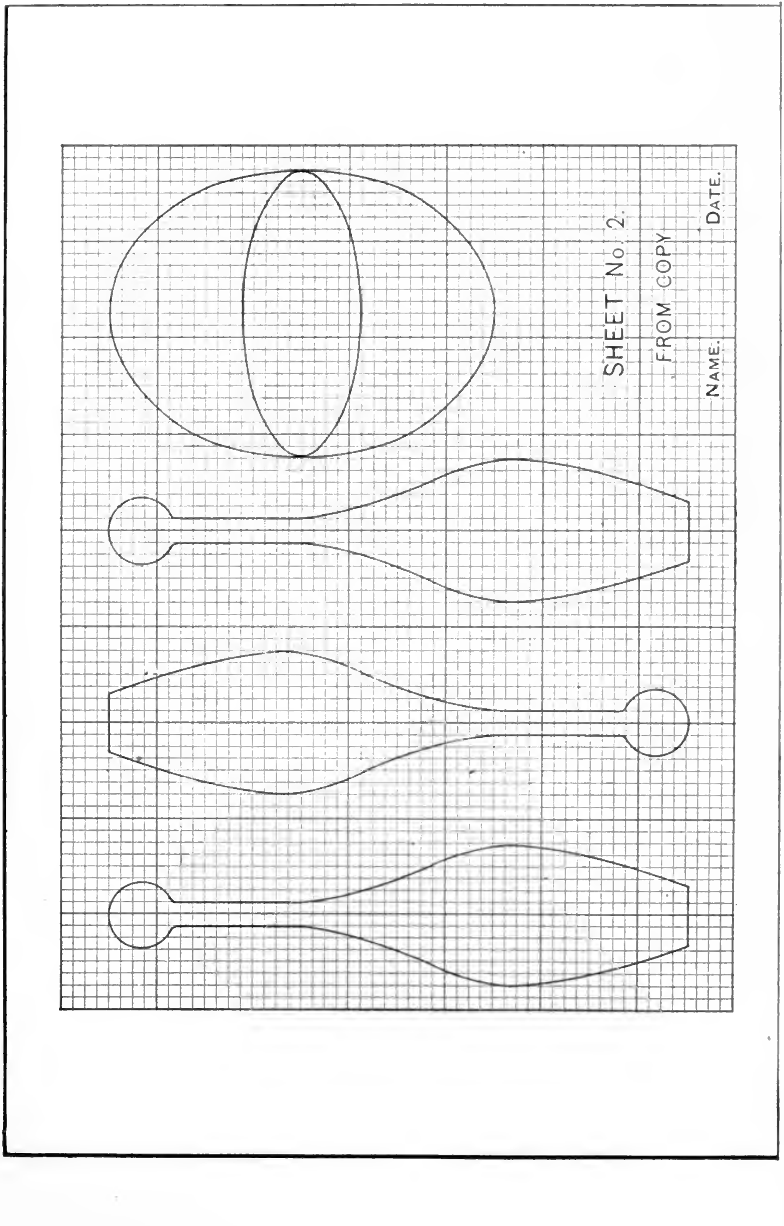
The paper is to be placed as for writing, and with the hand in the natural relative position, the sheet is to be executed without either turning the paper or altering the position of the body; great care should be taken to make the lines of uniform weight and as straight and free from waves as possible.

When completed, the sheet is to be submitted for inspection and acceptance before proceeding with the next exercise.

173. Sheet No. 2.—Sheet No. 2, Plate No. 13, is an exercise for the training of the eye to recognize regular curves in balance—symmetry; it is a free-hand exercise and is to be drawn as follows:

Locate the center lines and work to them by checking the

PLATE No. 13.



cross lines every half inch or less, and measure the distance of the points at which the curve of the copy crosses these cross lines; then lay these distances off (by counting spaces) on the corresponding cross line of the drawing, mark the points, and draw the curve through these points, making the lines very light until satisfactory; then trace them until distinct.

174. **Sheet No. 3.**—Sheet No. 3 is an exercise in the free-hand construction of letters and figures. As a preliminary for this sheet, Chapter II should be carefully digested.

To draw the sheet, use Plate No. 3 as a copy and construct the following alphabets:

1. Alphabet No. 1, making the letters and figures $\frac{1}{2}''$ high. Note the copy is the square alphabet.
2. Draw alphabet No. 1, $\frac{1}{4}''$ high.
3. Draw alphabet No. 3, $\frac{1}{4}''$ high.
4. Draw alphabet No. 2, the guide-lines to be $\frac{1}{8}''$ apart.
5. Draw alphabet No. 4, the guide-lines to be: center space $= \frac{1}{8}''$; the space above and below this $= \frac{1}{16}''$.
6. Draw a number of miscellaneous fractions proportioned in accordance with copy No. 5.

Reserve a space $2'' \times 3''$ in the lower right-hand corner of the sheet for the following title:

SHEET NO. 3.

Letter-sheet No. I.

Name. *Date.*

NOTE.—Begin one space from the top of the sheet and one space in from the left border line, and allow one space between letters and two spaces between rows.

When complete, submit the sheet for inspection.

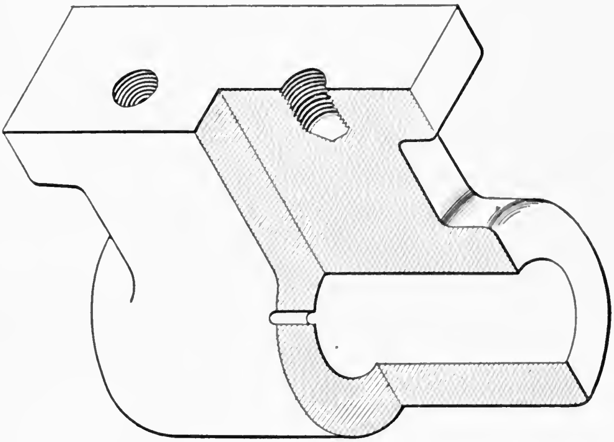
175. **Sheet No. 4.**—Use Plate No. 3 as a copy and draw two copies of No. 6—entire lower half of the plate; the student is to make a choice of size, spacing, and balance for the lettering, and is to space the following title in the usual letter space:

SHEET NO. 4.

Letter-sheet No. 2.

Name. *Date.*

176. **Sheet No. 5.**—Sheet No. 5, Plate No. 14, is a mechanical drawing, front and right elevations and bottom view, of a lathe detail (Fig. 70), and is to be executed exactly like the copy, using the compass and straight-edge.



THE DETAIL

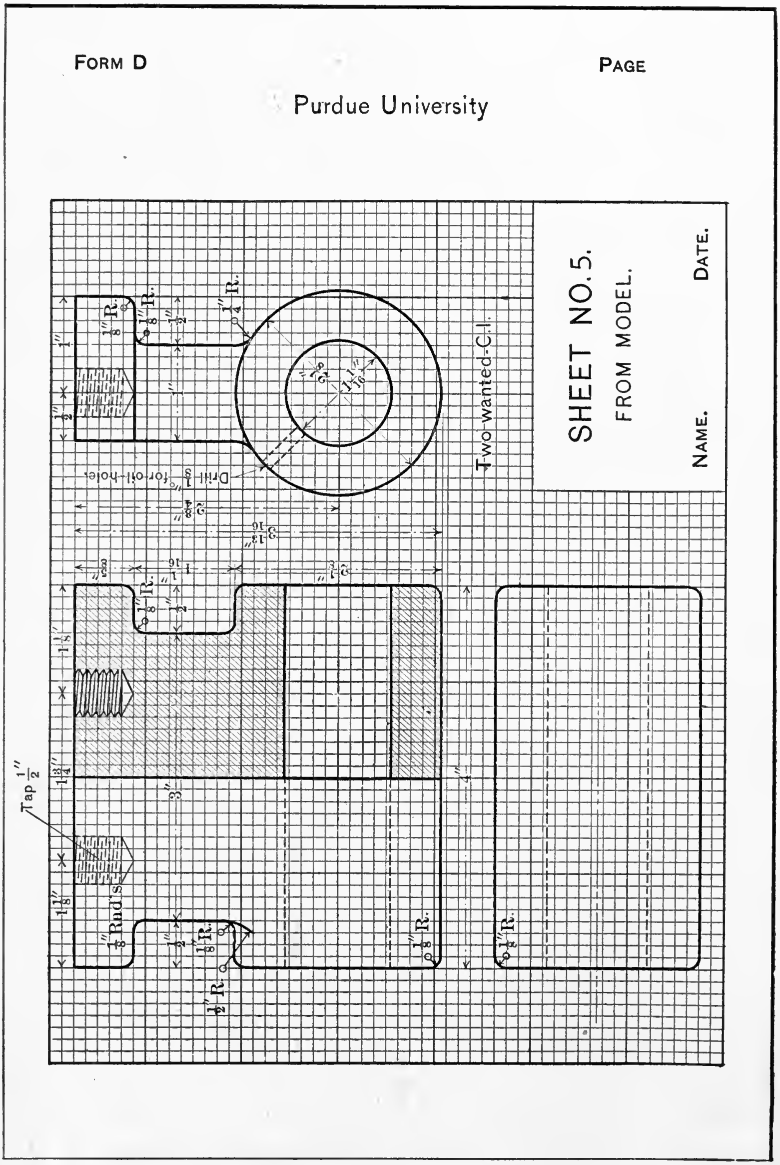
FIG. 70.

177. **Sheets Nos. 6 to 20, Inclusive.**—These sheets are to be scale drawings from models, such as could be taken into a shop, and with the drawing as a guide, the piece could be produced.

In these drawings care should be exercised to produce a well-balanced sheet, to place the views so as to bear the proper relation to one another, thus rendering the sheet easily legible, and to give all necessary dimensions and notes. Reserve the standard letter space—2″ × 3″—for a title.

To illustrate the character of these fifteen drawings, the following examples are given, and in the absence of models from which to draw, they may be used as a copy; the intention of this part of the course, however, is to give the student practice

PLATE No. 14.



Form D
Page
Purdue University
Sheet No. 5.
From Model.
Name.
Date.
Two wanted C.I.
Drill 5/16" for oil-hole.
Tap 1/2"
1/8" Rnd's

in original drawing, and to this end the following models, which are universally obtainable, are named as being representative:

Hammers,	Bicycle parts,
Wrenches,	Stove parts,
Pipe-fittings,	Ink-bottles, etc.
Valves,	Spools,
Machine parts,	Boxes.

The notes on these drawings illustrate a common shop practice, that of numbering the pattern for an object, so that should duplicates of the piece be wanted at any time, in place of supplying the shop with a new drawing, one has but to say "Use pattern No. —." The notes as to the number wanted, finish, etc., are in accordance with Sect. 51.

The name of the piece given in the letter space represents real practice; for the course the title of the sheet may be simply the consecutive "SHEET NO. —."

178. Sheet No. 21.—Draw the projections of a 2″ cube with a 1″ square hole through its center, and assume the cube to rest on the horizontal plane. (Reference, Sect. 75.)

Use Fig. 3, Plate No. 7, as a copy, with the following dimensions: X and Y=standard sheet, 7″×9″; $A=1\frac{1}{4}''$, $B=2\frac{5}{8}''$, $C=2\frac{1}{2}''$, $D=2\frac{5}{8}''$, $E=1\frac{3}{4}''$, $F=1\frac{3}{4}''$. Execute a full-sized drawing, drawing the figures as numbered. Omit all dimension lines and letter the sheet as in Fig. 21.

179. Sheet No. 22.—Execute a full-sized drawing of the projections of a blank, hexagonal nut, Fig. 17, the nut to rest on the horizontal plane. (Reference, Sect. 76.)

Draw the figures in the order numbered, using the following dimensions: $A=1\frac{1}{2}''$, $B=1\frac{1}{2}''$, C (the distance of the center line from the left border)$=2\frac{3}{8}''$; ground line to be in center of sheet. Omit all dimensions.

180. Sheet No. 23.—Execute a full-sized, well-balanced drawing of Fig. 20, completing the projection B; all working lines to be very light and to show on the finished drawing. Omit all dimensions. (Reference, Sect. 77.)

PLATE No. 15.

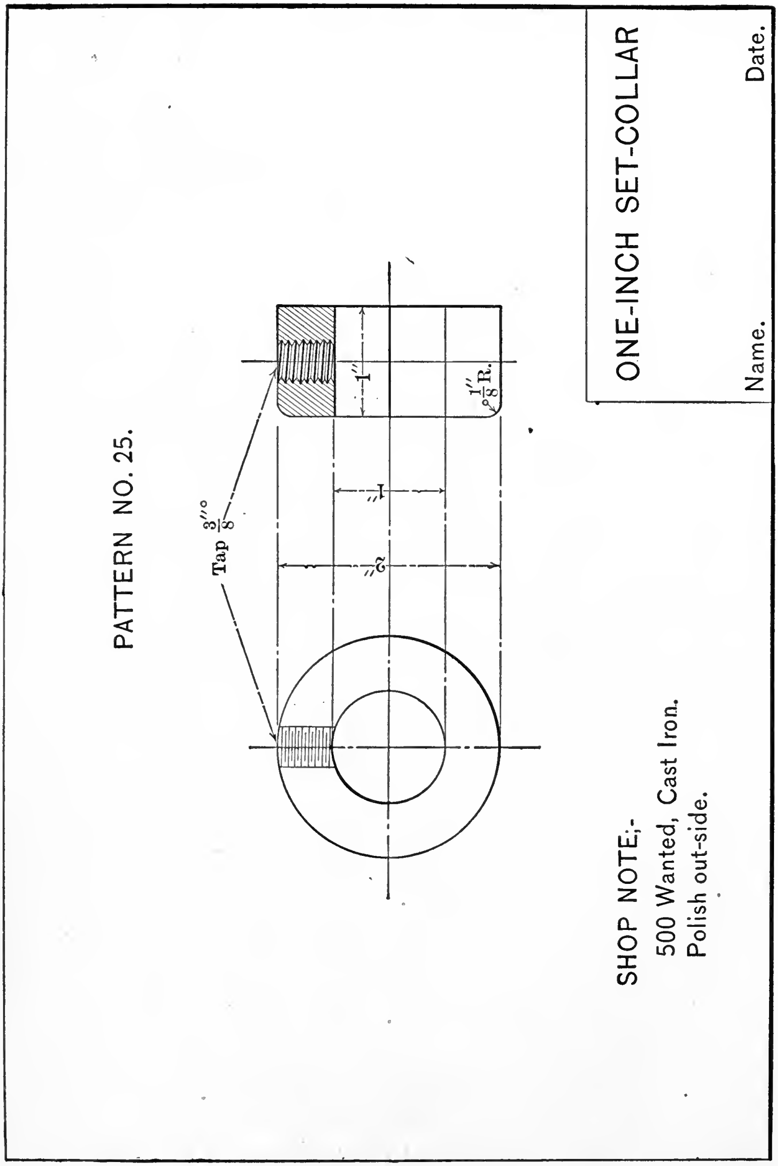

ONE-INCH SET-COLLAR
Name.
Date.
PATTERN NO. 25.
Tap 3/8″
1″
1″
2″
1/8″ R.
SHOP NOTE;-
500 Wanted, Cast Iron.
Polish out-side.

PLATE No. 16.

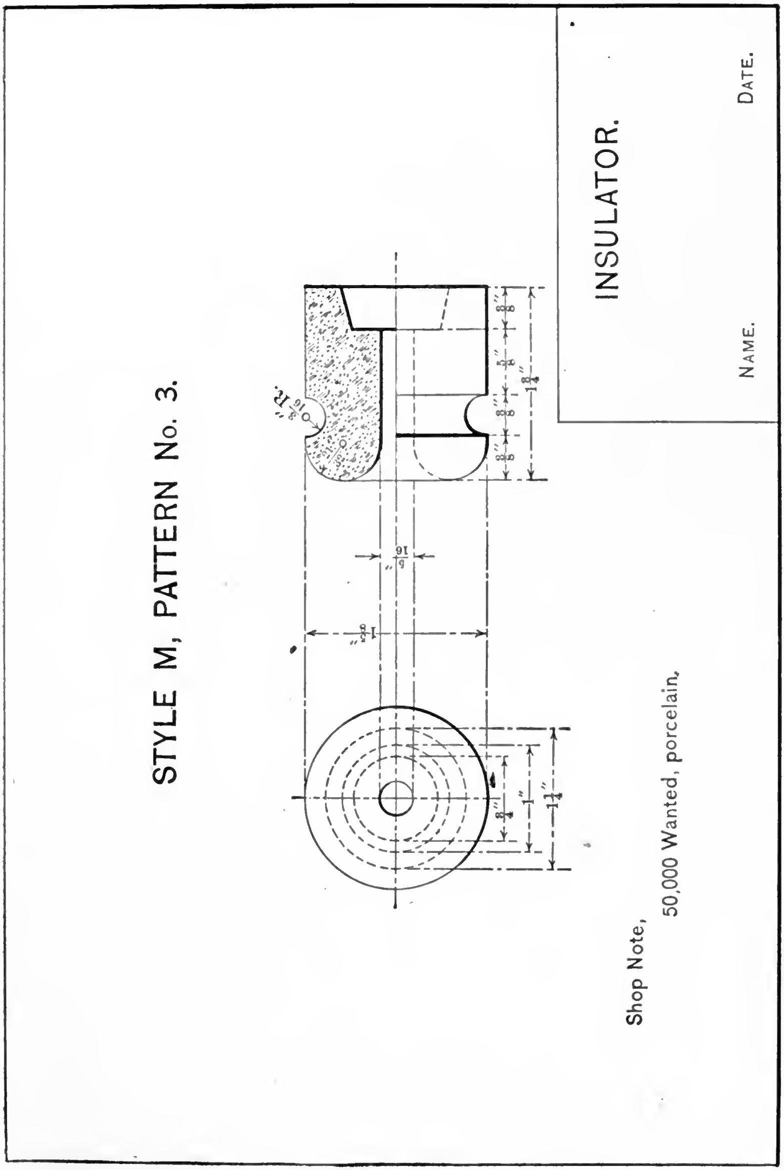

STYLE M, PATTERN No. 3.
INSULATOR.
DATE.
NAME.
Shop Note,
50,000 Wanted, porcelain.

PLATE No. 17.

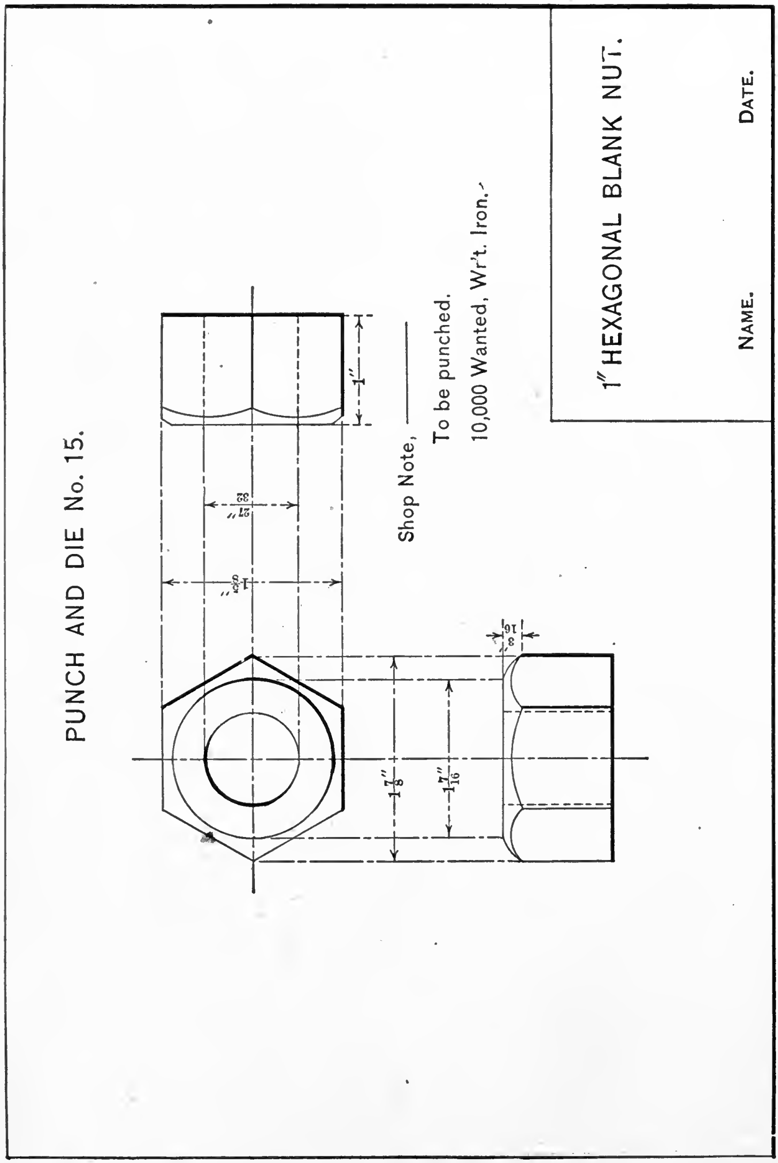

PUNCH AND DIE No. 15.
Shop Note,
To be punched.
10,000 Wanted, Wr't. Iron.
1" HEXAGONAL BLANK NUT.
NAME.
DATE.

PLATE No. 18.

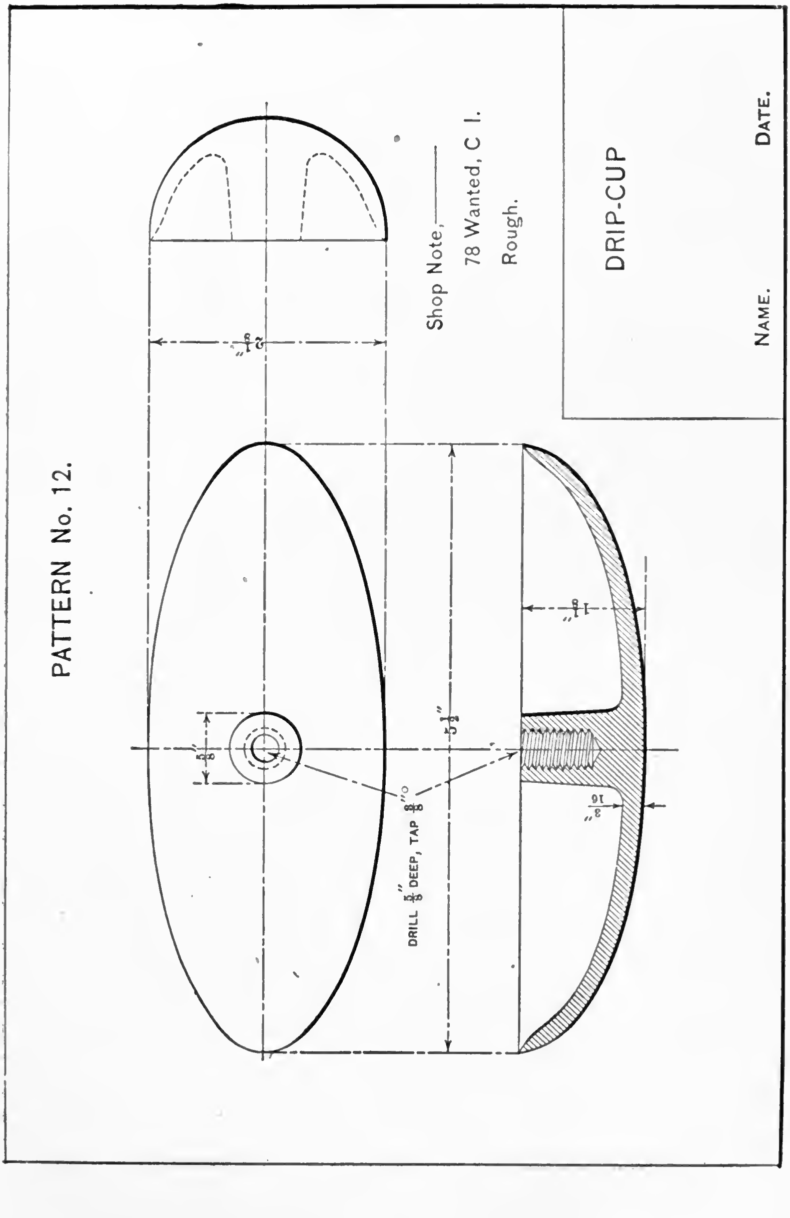

PATTERN No. 12.
Shop Note,—
78 Wanted, C I.
Rough.
DRIP-CUP
NAME.
DATE.
DRILL 5/8" DEEP, TAP 3/8"
5 1/2"

PLATE No. 19.

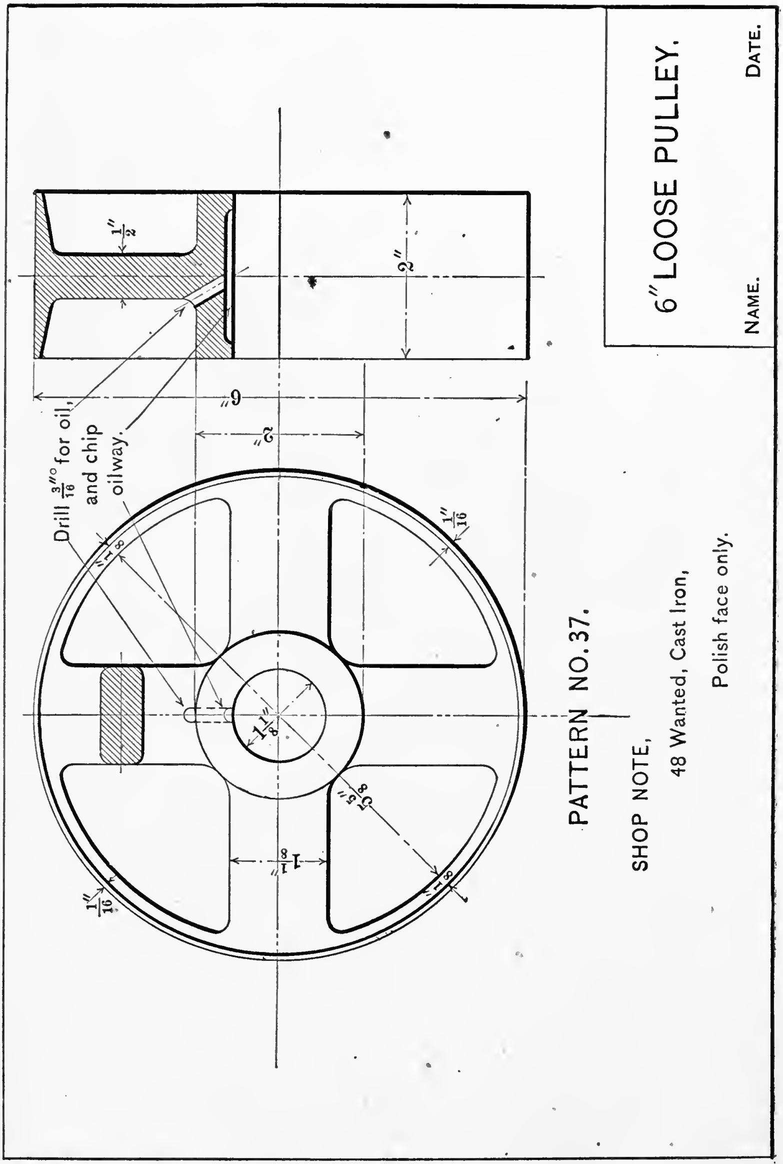

6" LOOSE PULLEY.
NAME.
DATE.
Drill 3/16"○ for oil, and chip oilway.
PATTERN NO. 37.
SHOP NOTE,
48 Wanted, Cast Iron,
Polish face only.

PLATE No. 20.

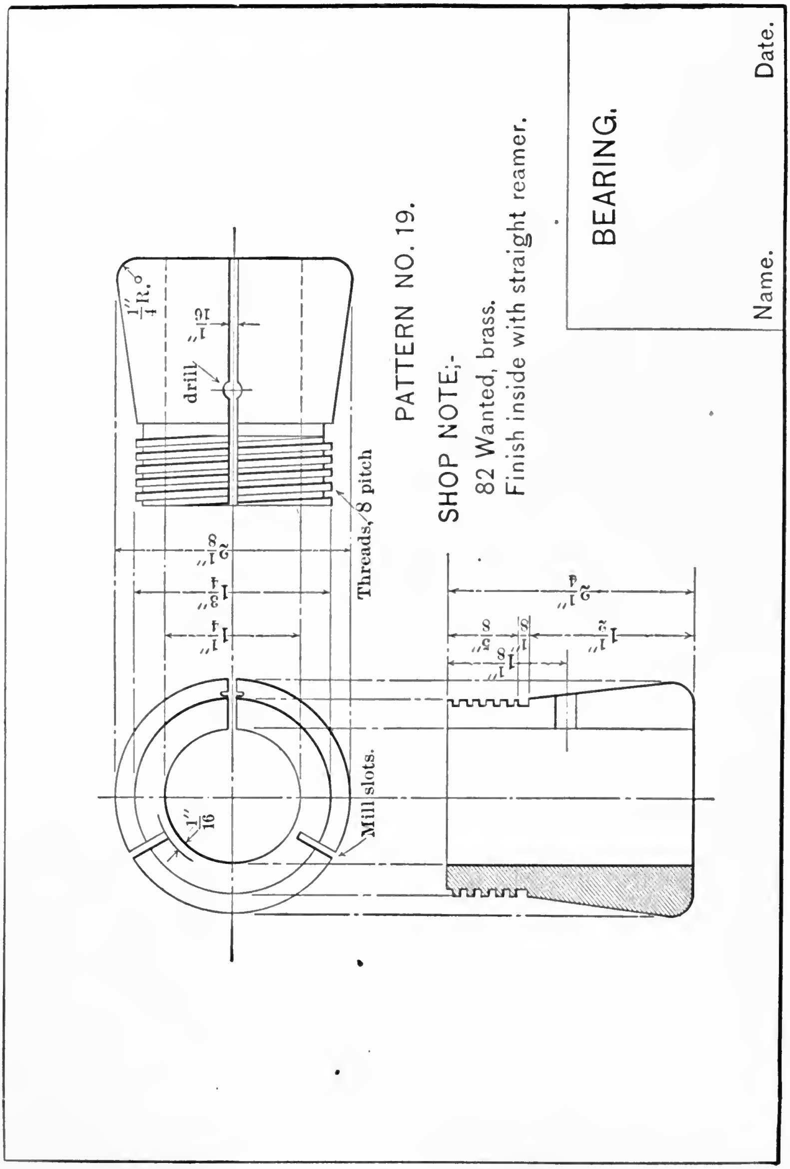

BEARING.
Name.
Date.
PATTERN NO. 19.
SHOP NOTE:-
82 Wanted, brass.
Finish inside with straight reamer.
Threads, 8 pitch
drill
Mill slots.

PLATE No. 21.

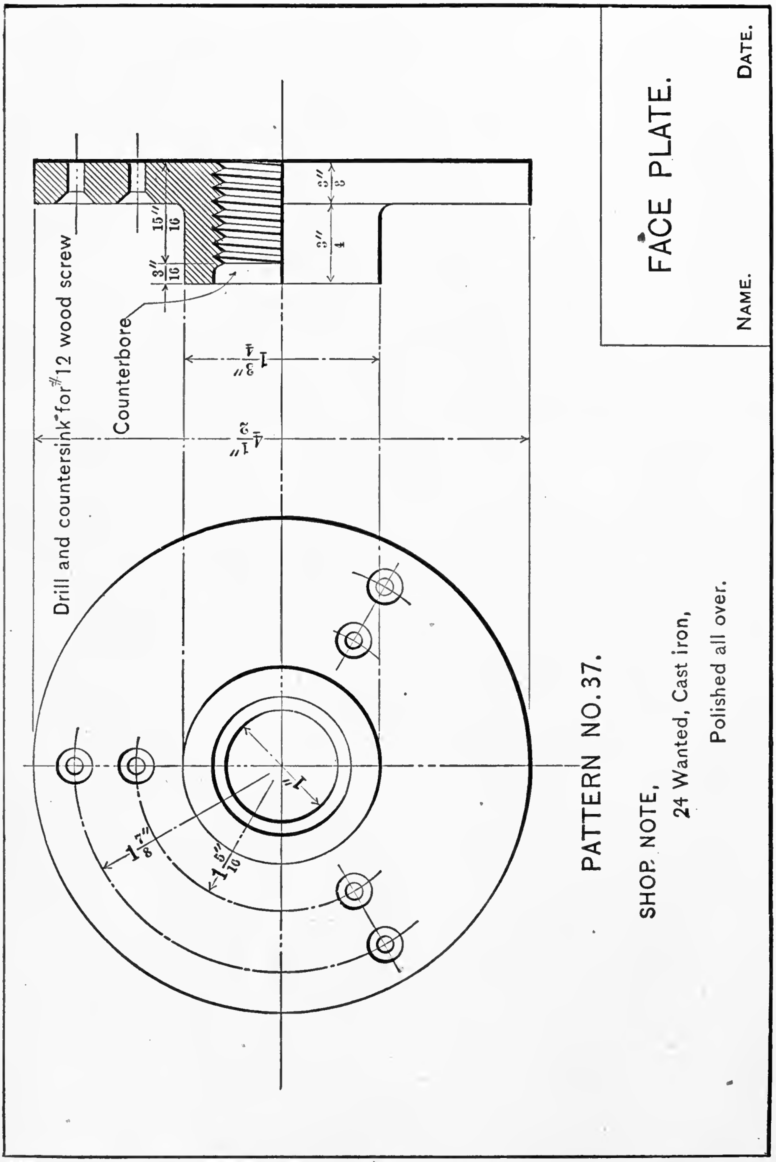

FACE PLATE.
NAME.
DATE.
Drill and countersink for #12 wood screw
Counterbore
PATTERN NO. 37.
SHOP NOTE,
24 Wanted, Cast iron,
Polished all over.

PLATE No. 22.

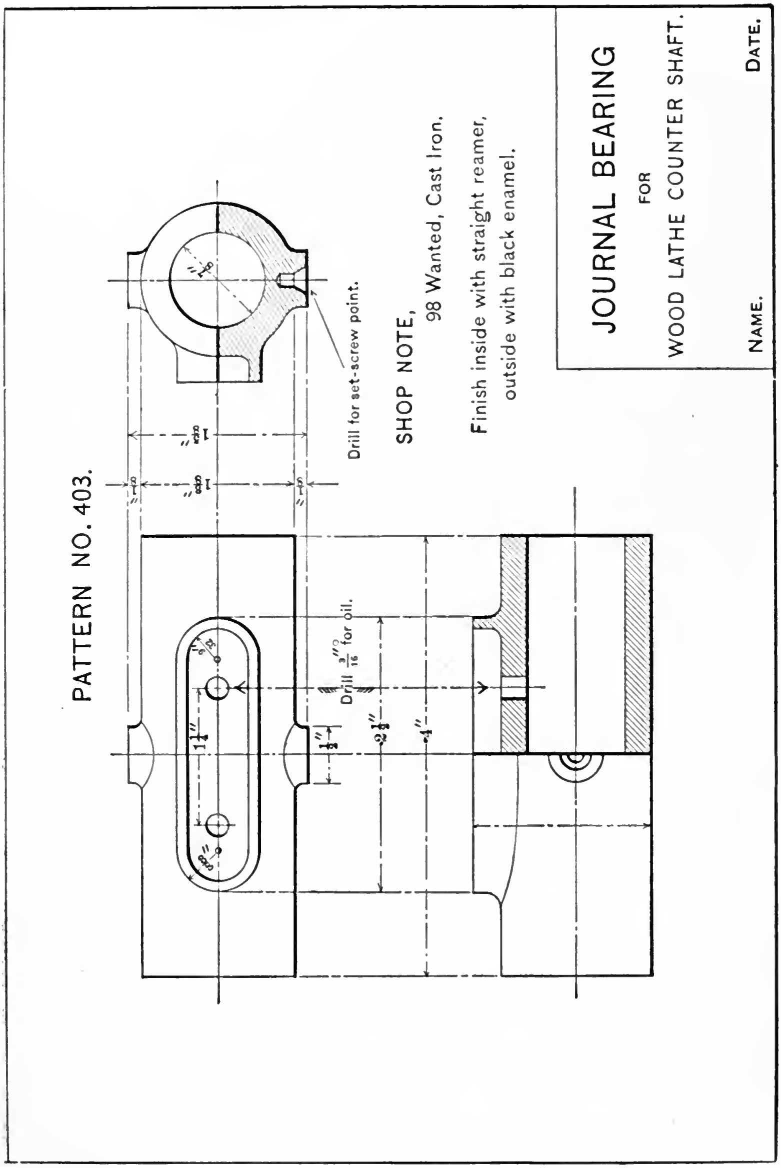

PATTERN NO. 403.
SHOP NOTE,
98 Wanted, Cast Iron.
Finish inside with straight reamer,
outside with black enamel.
Drill for set-screw point.
JOURNAL BEARING
FOR
WOOD LATHE COUNTER SHAFT.
NAME.
DATE.

PLATE No. 23.

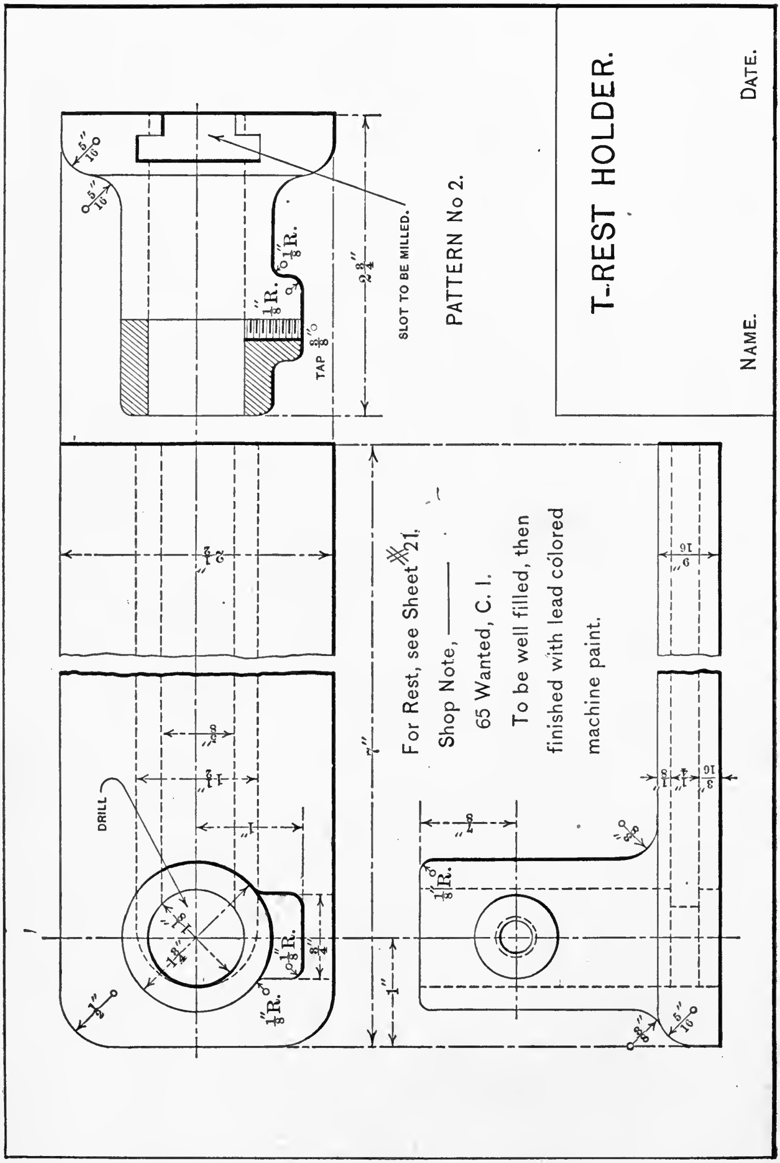

T-REST HOLDER.
NAME.
DATE.
PATTERN No 2.
SLOT TO BE MILLED.
TAP 3/8″
DRILL
For Rest, see Sheet #21.
Shop Note, ——
65 Wanted, C. I.
To be well filled, then
finished with lead colored
machine paint.

PLATE No. 24.

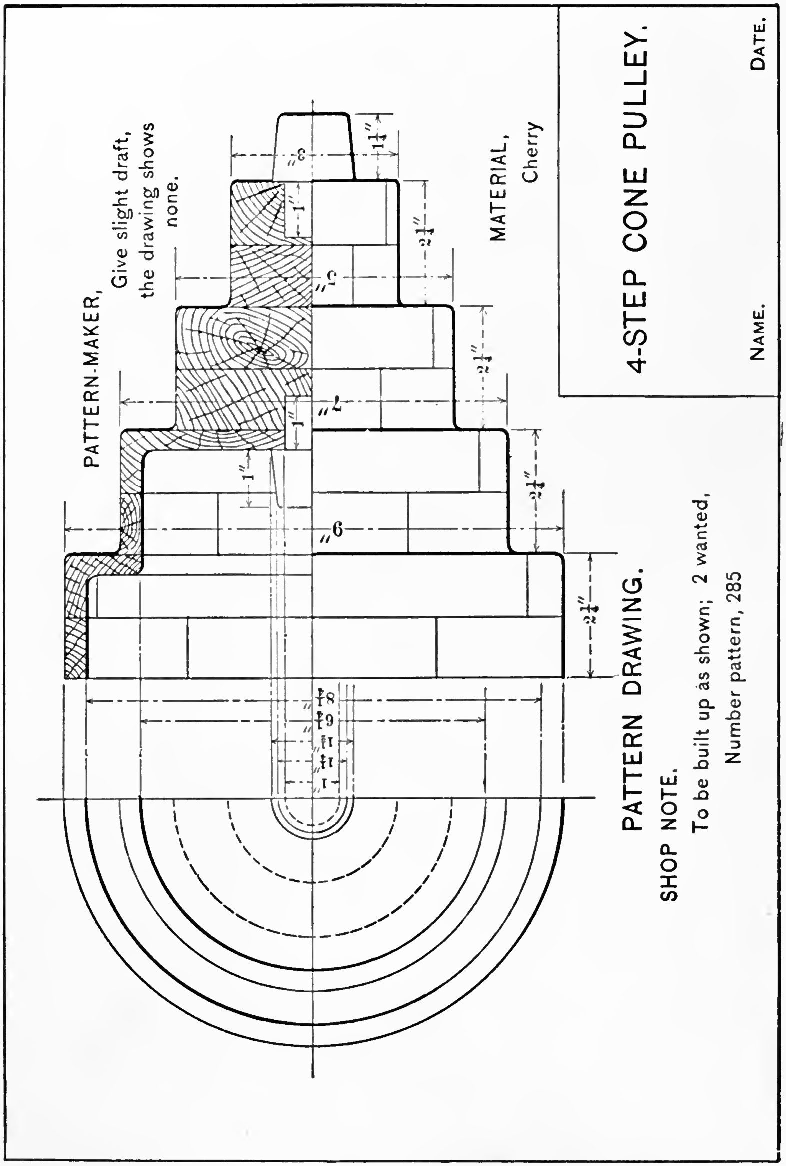

4-STEP CONE PULLEY.
NAME.
DATE.
MATERIAL,
Cherry
PATTERN-MAKER,
Give slight draft,
the drawing shows
none.
PATTERN DRAWING.
SHOP NOTE.
To be built up as shown; 2 wanted,
Number pattern, 285

PLATE No. 25.

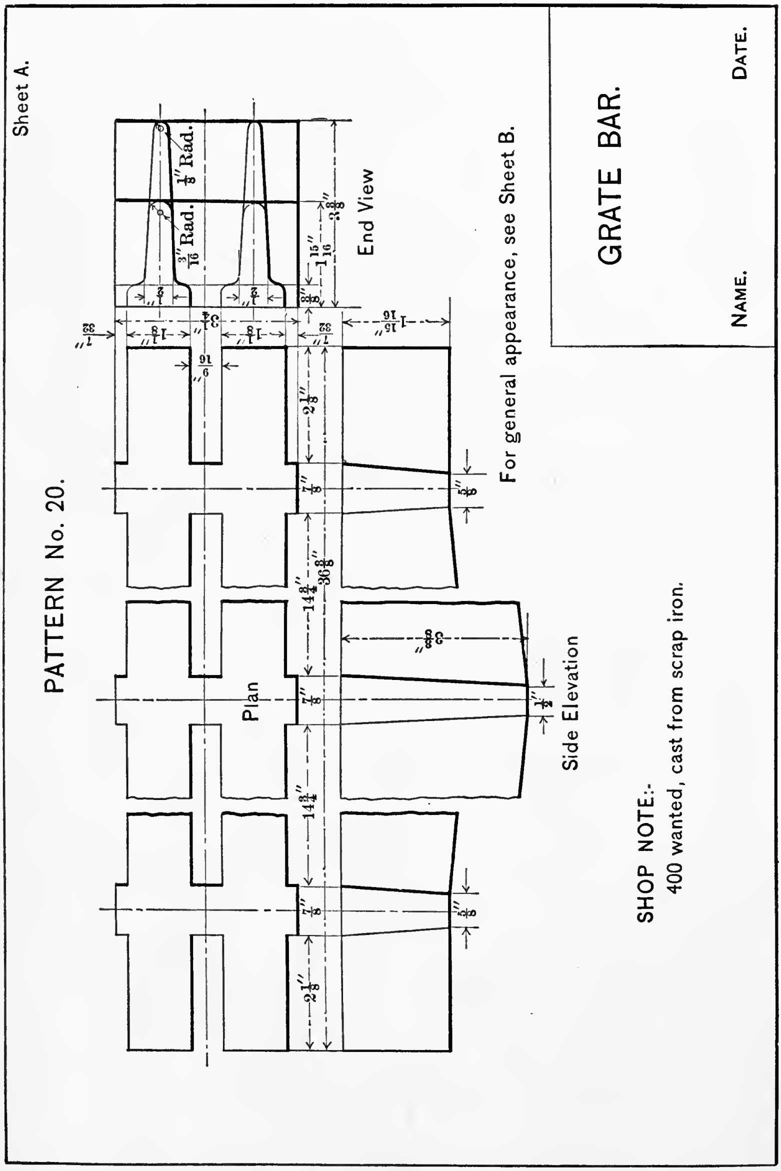
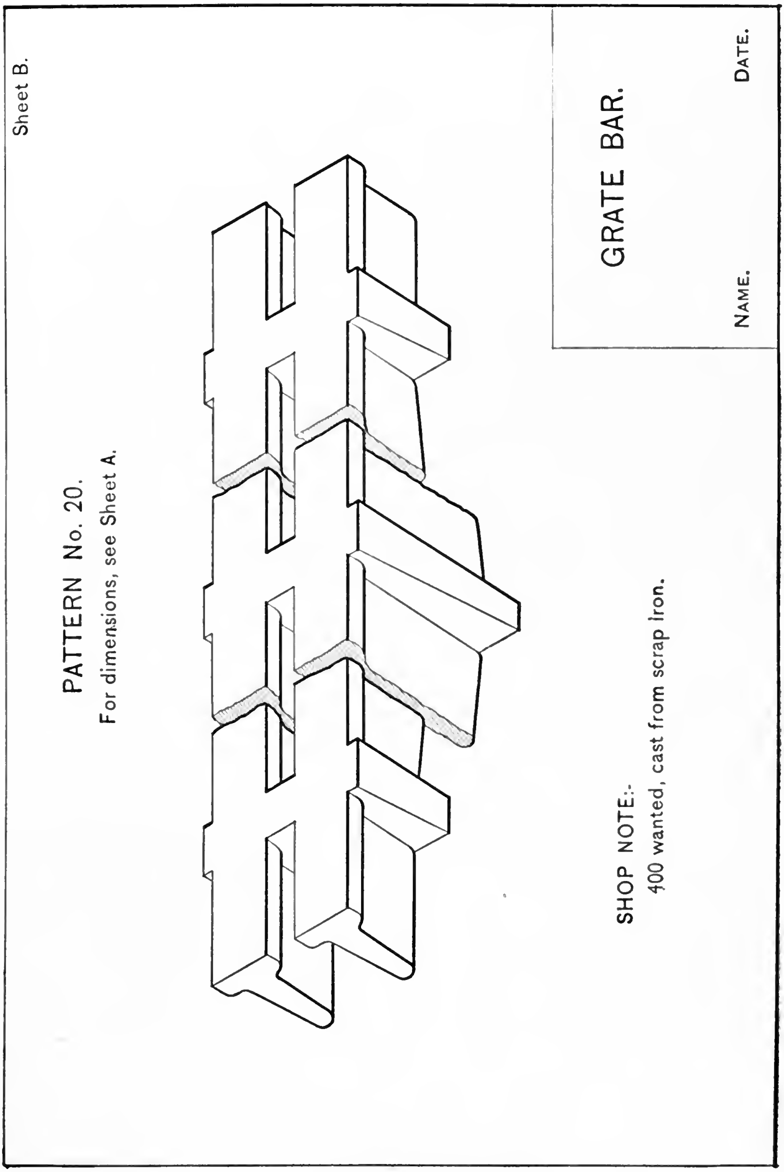

Sheet A.
PATTERN No. 20.
GRATE BAR.
NAME.
DATE.
End View
Plan
Side Elevation
For general appearance, see Sheet B.
SHOP NOTE:-
400 wanted, cast from scrap iron.

PLATE No. 26.


Sheet B.
GRATE BAR.
NAME.
DATE.
PATTERN No. 20.
For dimensions, see Sheet A.
SHOP NOTE:-
400 wanted, cast from scrap iron.

181. **Sheet No. 24.**—Execute a full-sized drawing of Fig. 21, drawing the figures in the order numbered; show all working lines and omit all dimensions. (Reference, Sect. 78.)

182. **Sheet No. 25.**—Execute a full-sized drawing of Projection No. 5, Fig. 24. (Reference, Sect. 79.)

183. **Sheet No. 26, Plate No. 8.**—A. Execute a full-sized drawing of Fig. 5. (Reference, Sect. 80.)

B. Draw the developments of the two cylinders (Fig. 4), the sheet to be well balanced and all working lines to be shown.

184. **Sheet No. 27, Plate No. 9.**—A. Execute a full-sized drawing of Fig. 5. (Reference, Sect. 81.)

B. Draw the developments of the cylinder and of the cone. (Figs. 2 and 4.)

185. **Sheet No. 28.**—A. Execute a full-sized drawing of Fig. 25. (Refe nce, Sect. 82.)

B. Draw the developments of the cylinders, cutting cylinder *A* along the element 4-4 and cylinder *B* along the element 1-7 (outside element).

186. **Sheet No. 29.**—Execute a full-sized drawing of Fig. 27, and let it be required to construct a shade with twelve points around the bottom as indicated by the dotted lines; allow $\frac{1}{4}''$ lap. (Reference, Sect. 83.)

187. **Sheet No. 30.**—Execute an isometric drawing of some simple piece of mechanism, drawing from the model; give all dimensions and balance the drawing; the title space to contain the following:

SHEET NO. 30.

Isometric Drawing No. 1.

From Model.

Name. *Date.*

188. **Sheet No. 31.**—Execute an isometric drawing of some simple piece of mechanism, drawing from the mechanical drawing of the object. (Select drawing from Sheets Nos. 6 to 20, inclusive.) Give all dimensions; letter as above.

189. **Sheet No. 32.**—Execute an original isometric drawing

in accordance with either Sheet No. 30 or 31, omit all dimensions, and shade the drawing.

190. Sheet No. 33.—Execute an original assembled mechanical drawing of some fairly simple machine, giving all dimensions and notes necessary on such drawings. (Read Sect. 51.)

191. Sheets Nos. 34 to 40, Inclusive.—These sheets are what will be known as "working-sketches." They are to be free-hand, detail, and assembled drawings, drawn from the various machines in the different laboratories, and are later to be reproduced as pen-and-ink scale drawings; some of them to be on paper and others to be drawn on tracing-cloth. These sketches must be complete, not with reference to the mere drawing alone, but with reference to dimensions, notes, etc.; in preparing his sketch, the student is to assume he is never again to see the object and must be able, months hence, to construct a drawing from his sketch such that the thing could be reproduced with the drawing as the only "guide."

CHAPTER X.

THE MECHANICAL EXECUTION OF DRAWINGS.

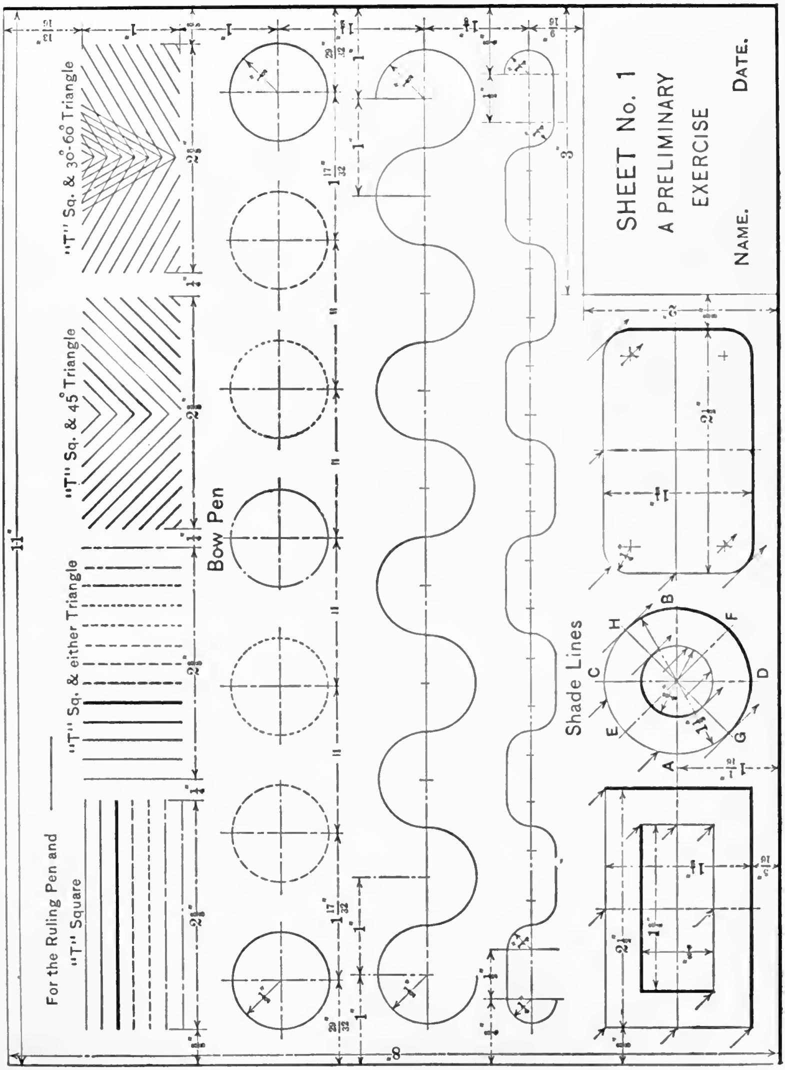
192. Introductory.—Having completed the course in sketching, the student should have a good working knowledge of the underlying principles of mechanical drawing and be prepared to take up the study of drawing-tools and the mechanical construction of practical drawings. With this end in view, Plates Nos. 27 to 57, inclusive, are given as examples in drawing, calculated to further the student's knowledge of the subject, to be his copy for the manual use of instruments, and being representative sheets of every-day practice, to afford him a field for acquiring that proficiency of execution and construction which is required of the practical draughtsman.

In the execution of these copies, the plates are to be accurately reproduced in accordance with the instructions given for each sheet, and with such dispatch as is consistent with clean-cut, neatly finished work. The tools required for the work are such as is given in the "Draughtsman's Outfit," page 85.

193. Sheet No. 1, Plate No. 27.—The sheet of paper given for this and for all of the other exercises is the standard $9\frac{1}{2}'' \times 12''$ sheet and is to finish $9'' \times 12''$; this allows a waste of $\frac{1}{2}''$ to be apportioned, $\frac{1}{4}''$ at the top and $\frac{1}{4}''$ at the bottom of the sheet to be used as "try" paper (to try the ruling-pen, etc., on), and when cut away (when the sheet is completed) removes the thumb-tack hole.

To secure the paper to the drawing-board (Fig. 53) place the paper approximately in the center of the board—the narrow way—and 3″ or 4″ nearer the left side of the board (if right-handed) than the right side; now place the T-square on the

PLATE No. 27.


"T" Sq. & 30°-60° Triangle
"T" Sq. & 45° Triangle
"T" Sq. & either Triangle
For the Ruling Pen and "T" Square
Bow Pen
Shade Lines
SHEET No. 1
A PRELIMINARY EXERCISE
NAME.
DATE.

board as shown, hold the paper with the right hand and with the left hand on the T-square head move the square towards the top of the board until the top edges of the square and paper coincide, turning the paper as is necessary to "square" it with the square; with the paper thus "squared," remove the square and place a thumb-tack in the upper left-hand corner of the sheet; then keeping the paper square, run one hand—with considerable pressure —along the top edge of the paper, stretching it to the right-hand corner, and tack it; these two corners secured, stretch the paper from the center to the two lower corners and tack them.

The paper secured, with the architect's scale lay off the 8″×11″ border and mark the cutting lines; now with the T-square for horizontal lines, and the T-square and either triangle for vertical lines, draw the lines through these points which form the 8″×11″ inclosed space to receive the drawing, then lay out and draw the 2″×3″ letter space.

Working to the dimensions given, lay off a top and bottom line for the row of lines and pencil them in, making all of the lines light, full lines, and when satisfactorily spaced, ink them, showing the different lines.

For the second row of figures, locate the centers for the circles, and with the compass set with the proper radius, the circles may be inked without any preliminary penciling.

The next two rows are to be penciled in as dimensioned, and then inked in Much care is necessary here to produce smooth lines and evenly undulating curves.

The bottom row on the plate is given to introduce the shade line—"back lining" drawings. The small arrows represent the projection of the rays of light, which are assumed to be parallel and to strike the plane of the paper at an angle of 45°. Considering the hollow, rectangular figure on the left, it is evident that the top and left-hand lines of the outside of the figure will be in the light—illuminated—and should be drawn as light lines; also that the bottom and right-hand lines of the outside of the figure cut off the light and represent faces of the object which are in the shadow, and should be drawn as heavy or shade lines.

It should be noted that the shading on the interior of the drawing is the reverse of that on the exterior.

To shade the circular drawing as "called for" by the arrows, draw the diameter *E-F* with the 45° triangle, then draw the diameter *G-H* at 90° with *E-F* and 45° with *A-B*, and cutting *E-F* at a point about $\frac{1}{32}''$ to $\frac{1}{16}''$ from the center; now with the center defined by the intersection of *A-B* and *C-D*, and the proper radius, describe the circles, and to shade them, take a new center—the intersection of *E-F* and *G-H*—and with the same radius used for the circles (see Fig. 71), shade the larger

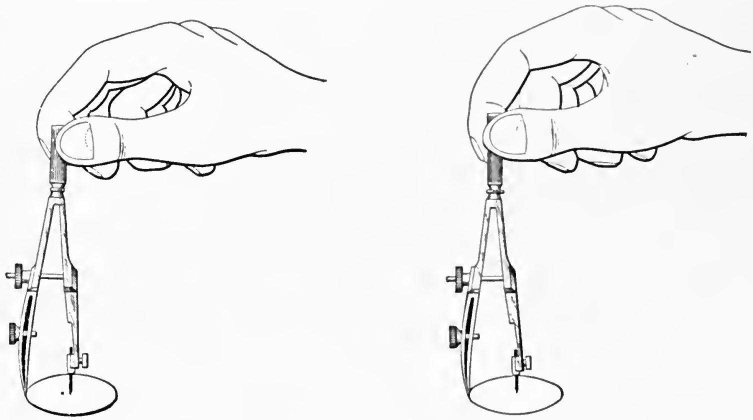


FIG. 71.

one on the lower right-hand side and the smaller circle on the upper left-hand side.

The right-hand figure of the row is to be shaded like the copy.

The drawings completed, draw top and bottom guide-lines for the title lettering, the top row to be $\frac{1}{4}''$ high, the middle row, initial letters $\frac{3}{16}''$ high, other letters $\frac{1}{8}''$ high; name and date, initial letters $\frac{1}{8}''$ high, other letters $\frac{3}{32}''$ high; to be spaced approximately like the copy; pencil in the letters until satisfactory, then ink them in free-hand.

When completed, submit the sheet for inspection and acceptance before taking up Sheet No. 2.

194. Sheet No. 2, Plate No. 28.—This is an exercise for a test in accuracy of manipulating the compass and bow-pen, and is to be first constructed in pencil, then inked in. To draw the sheet, begin with the large central figure by locating the horizontal and vertical center lines intersecting at the center of the sheet; with this point as a center and a 3″ radius, describe the 6″ circle; then with the same center, describe the 3″ circle, and with the points in which it intersects the two diameters as centers, and the same radius used for the 3″ circle, draw the four other circles, then draw the exterior arcs as indicated.

To draw the three small designs, locate the center lines and draw the 2″ and $1^3/_{16}$″ circles; then with the T-square and 45° triangle draw the two diagonal center lines, and with the eight points in which the $1^3/_{16}$″ circle intersects the four center lines as centers and a radius of $1^1/_{16}$″ describe the eight circular arcs as shown.

195. Sheet No. 3, Plate No. 29.—This sheet is given as an exercise for practice in ruling straight lines and to acquaint the student with the standard cross-hatchings most used in drawing.

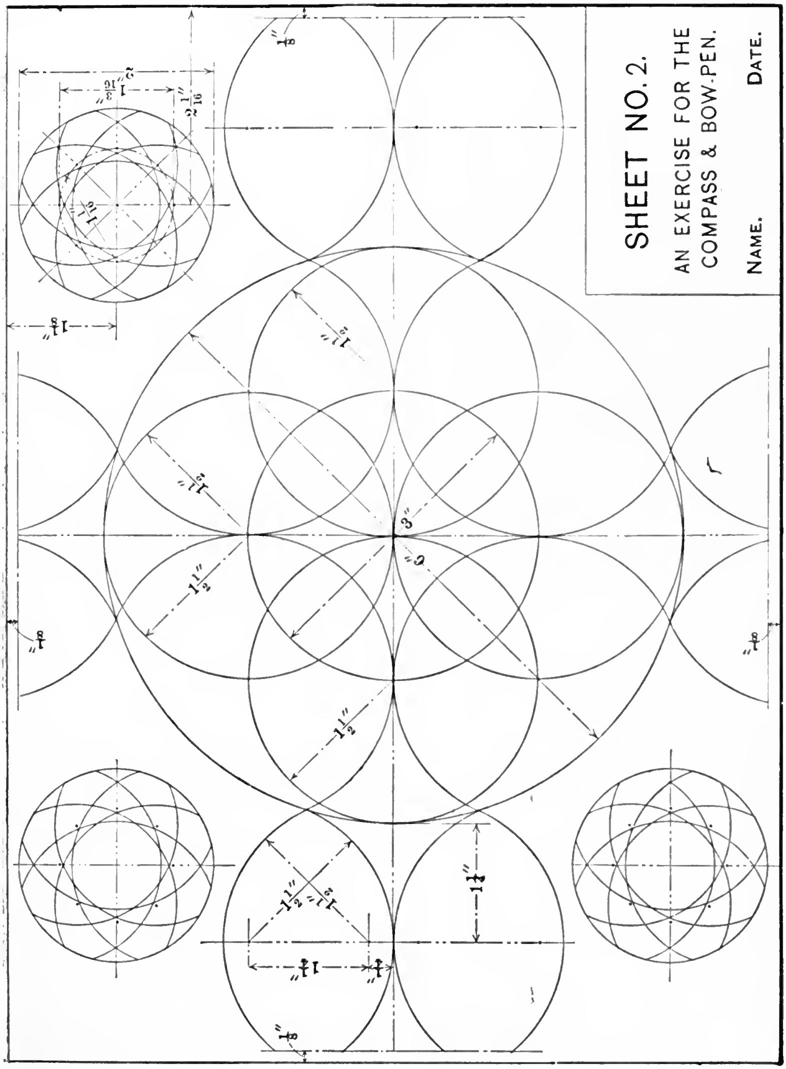
To draw the sheet, pencil in the fifteen rectangles as per dimensions and proceed as follows: For cast iron, from the upper left-hand corner of the rectangle draw a 45° line to the right and on it lay off points $^1/_{16}$″ apart; with the T-square and 45° triangle draw the ruling through these points and when satisfactory, ink it in, inking the border last; this applies to all of the fifteen spaces, i.e., ink the border last.

For wrought iron, draw a 45° spacing line as for cast iron, lay off $^3/_{32}$″ lengths and draw (in ink) the light line; then, using the eye for the spacing, draw a heavy line about $^1/_{32}$″ below each light line.

For steel, use the eye for the spacing and draw two fine lines about $^1/_{32}$″ apart, and space the pairs of lines about $^1/_{16}$″ apart, inking them in without any preliminary penciling.

For brass and lead, use the eye for the spacing (about $^1/_{16}$″) and ink directly.

PLATE No. 28.


SHEET NO. 2.
AN EXERCISE FOR THE COMPASS & BOW-PEN.
NAME.
DATE.
3"
6"
$1\frac{1}{2}$"
$1\frac{1}{4}$"
$1\frac{3}{8}$"
$1\frac{1}{8}$"
$\frac{1}{8}$"
$2\frac{1}{16}$"
$1\frac{3}{16}$"
$1\frac{1}{16}$"

For copper, draw the pencil-lines defining the blank spaces and ink directly, approximating a $^1/_{16}''$ space between lines.

Aluminum and wires are to be inked directly, with approximate spacings.

Brick and stone are to be accurately blocked out in pencil, inked in, then the cross-hatching approximated.

Sand is made free-hand with a writing-pen, dotted in in ink directly.

Earth is first ruled in ink, then "touched up," free-hand, with a writing-pen.

Water is an approximate ruling, and glass is free-hand pen work.

The spacing given, about $^1/_{16}''$, applies to spaces to be cross-hatched of about the size of the rectangles of the plate; if the space to be cross-hatched be greater than this, the space between lines should be increased proportionally; if smaller, it should be decreased.

196. Sheet No. 4, Plate No. 30.—This is to be a free-hand exercise, the letters to be "single-line" letters. To draw the sheet, begin with the upper-case letters, square type, and draw the top and bottom guide-lines and pencil in the alphabet, omitting the numbers and arrows illustrating the number and direction of the strokes; when the letters are properl penciled, ink them in, then proceed with the slanted alphabet, using the top and bottom guide-lines and inking in directly. Complete the upper-case letters, using only top and bottom guide-lines and inking directly.

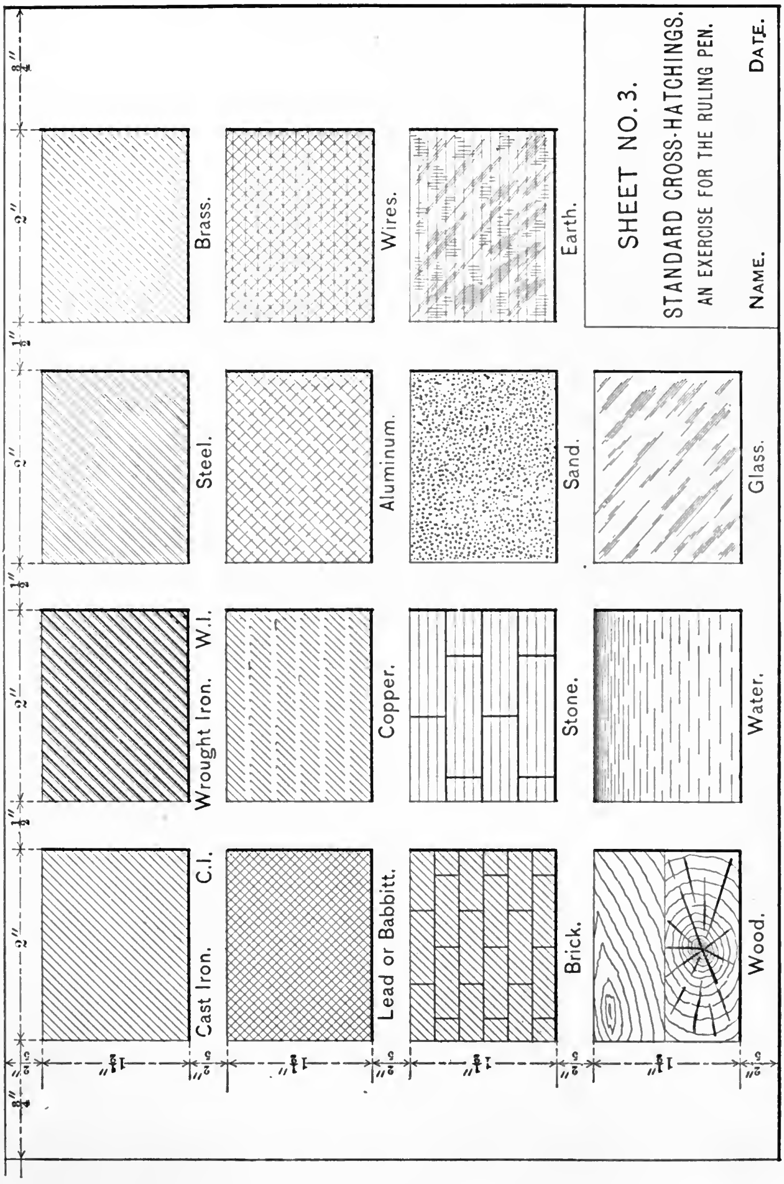
Execute the first row of the lower-case letters, first in pencil, omitting arrows and numbers, then ink them in; proceeding as for the upper-case letters, complete the alphabets.

Put on the headings and title last, then erase all construction lines.

Omit all dimensions.

197. Sheet No. 5, Plate No. 31.—Fig. 1 is an elevation drawing of the "business end" of a twist drill and is a practical example of the helix. To draw the figure, locate the center line,

PLATE No. 29.

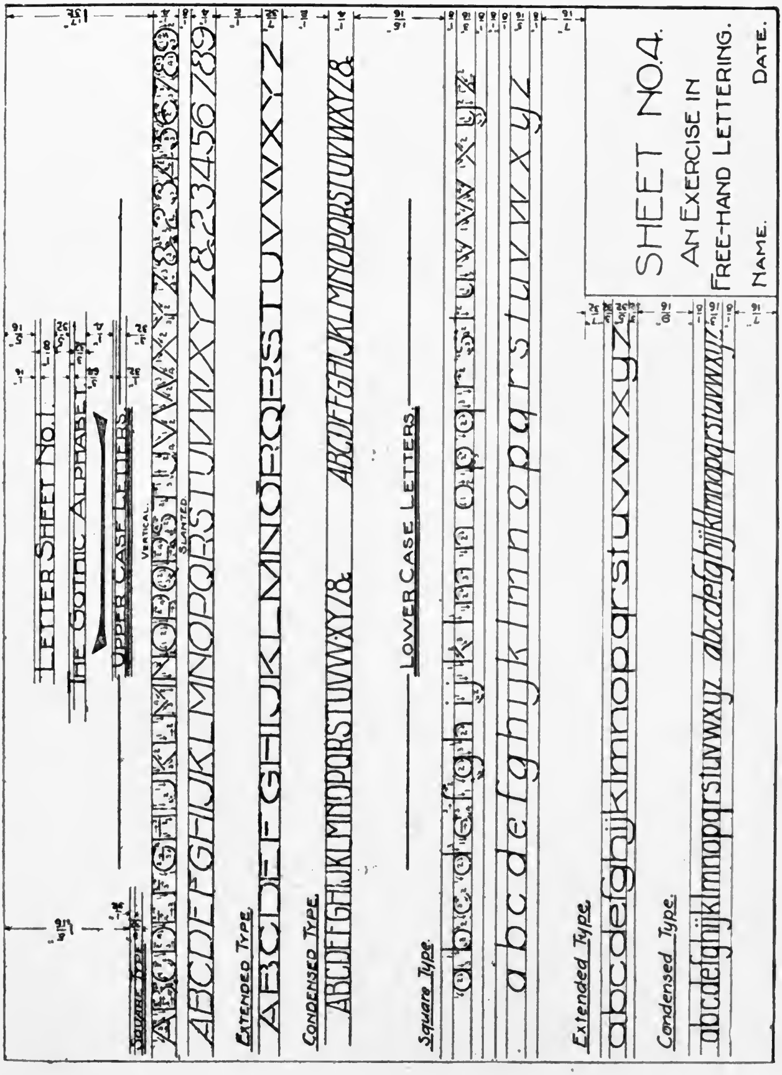

SHEET NO. 3.
STANDARD CROSS-HATCHINGS.
AN EXERCISE FOR THE RULING PEN.
NAME.
DATE.
Brass.
Wires.
Earth.
Steel.
Aluminum.
Sand.
Glass.
Wrought Iron. W.I.
Copper.
Stone.
Water.
Cast Iron. C.I.
Lead or Babbitt.
Brick.
Wood.

describe the semicircle 1-2-3, . . . 7 and divide it into six equal arcs, then draw the rectangular outline and copy the lines of the plate, using the small irregular curve as is suggested by the dotted lines; the curve at the top, representing a broken end, is drawn free-hand. When the figure is accurately drawn in pencil, ink in the drawing by inking the curved lines first; to do this, use the ruling-pen and curve, holding the pen in a vertical position, as shown in Fig. 72, and turning the pen with the curve, thus keeping the edges of the nibs parallel at all points with the guide.

FIG. 72.

Fig. 2 illustrates two methods of drawing ellipses when the axes are at right angles. First method: Locate the center lines and draw the two circles; divide the large circle into twenty-four equal parts (this can be done by means of the T-square and both triangles) and draw a radial line to each point of division. To locate points on the ellipse, consider the radial line 8-*C*; from the point in which this cuts the large circle, drop the perpendicular 8-4, and from the point in which it (8-*C*) cuts the small circle, draw the horizontal 8-8—the intersection of these two lines is a point on the ellipse; the other twenty-three points of the curve are obtained in a similar manner. The points—the locus of the curve—obtained, use the irregular curve as is suggested

PLATE No. 30.


LETTER SHEET NO. 1.
THE GOTHIC ALPHABET.
UPPER CASE LETTERS.
SQUARE TYPE.
VERTICAL.
SLANTED.
EXTENDED TYPE.
CONDENSED TYPE.
LOWER CASE LETTERS.
Square Type.
Extended Type.
Condensed Type.
SHEET NO. 4.
AN EXERCISE IN
FREE-HAND LETTERING.
NAME.
DATE.

by the plate (note the lap of the consecutive positions) and pencil in the ellipse.

Second method: Secure a strip of heavy paper one edge of which is a straight edge, and on this edge lay off from some point, as *A*, a length *A-C* equal to the semi-major axis of the ellipse, then from the same point (*A*) lay off a second length, *A-B*, equal to *B-C*, the semi-minor axis of the ellipse; now with the point *C* on the minor axis (extended) and the point *B* on the major axis rotate the strip of paper (the point *C* moving back and forth along the minor axis, and the point *B* moving up and down along the major axis) about the center, *C*, and dot the travel of the point *A*; the curve is then drawn through these points.

After both curves have been accurately constructed in pencil, trace them in ink with the ruling-pen and curve.

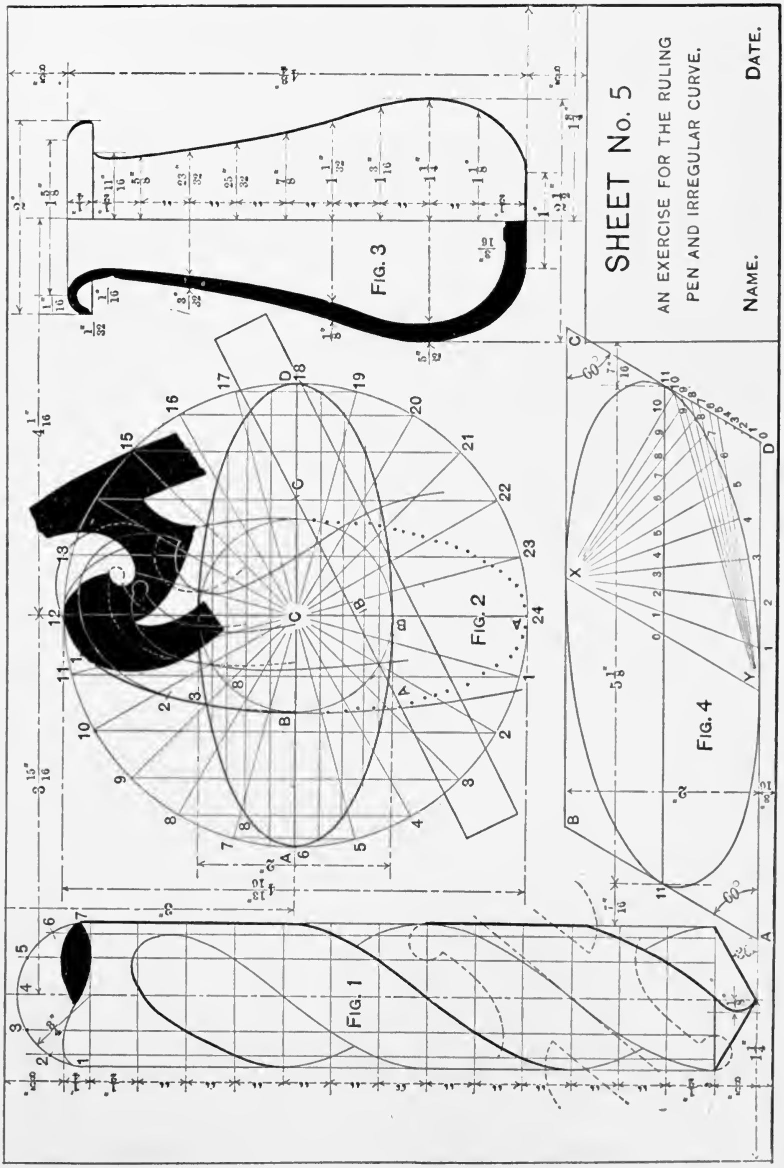
Fig. 3. This figure illustrates a method of constructing any curve. To construct the curve, locate the center line, draw horizontal lines every $\frac{1}{2}''$, lay off on these the lengths given in the copy, and with the curve pencil in the drawing, and when satisfactory ink it in.

Fig. 4 illustrates a method of constructing an ellipse when the axes are not at right angles. To construct the ellipse, draw the rhombus *A-B-C-D* and the major (11-11) and minor (*X-Y*) axis of the curve; divide the semi-major axis (0-11) into a number of equal parts, and the line *D*-11 into the same number of equal parts; draw radial lines from point *X* through the points of division on the major axis, and radial lines from point *Y* through the points of division on line *D*-11; the intersections of the lines drawn to the same numbered point are the points through which the ellipse is drawn.

The plate illustrates the locating of points for but one-quarter of the curve; points for the other three-quarters are located in a similar manner.

198. Sheet No. 6, Plate No. 32.—This sheet is an example of structural iron draughting, and is to be first constructed in pencil, to a scale of $1'' = 1'$, without any letters or figures, and submitted for inspection, then inked in, and the letters and figures

PLATE No. 31.


SHEET No. 5
AN EXERCISE FOR THE RULING PEN AND IRREGULAR CURVE.
NAME.
DATE.
FIG. 1
FIG. 2
FIG. 3
FIG. 4

drawn last. Space the lettering of the title so as to add the line "Scale...... 1″ = 1′."

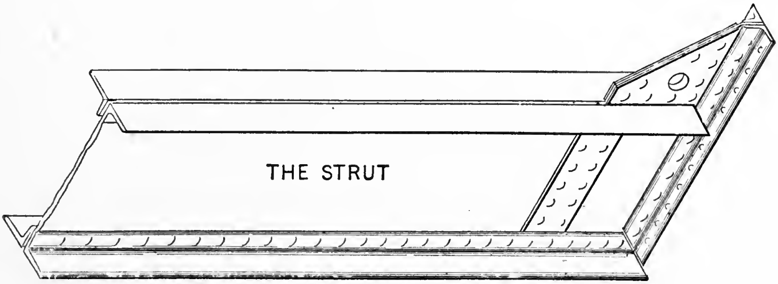
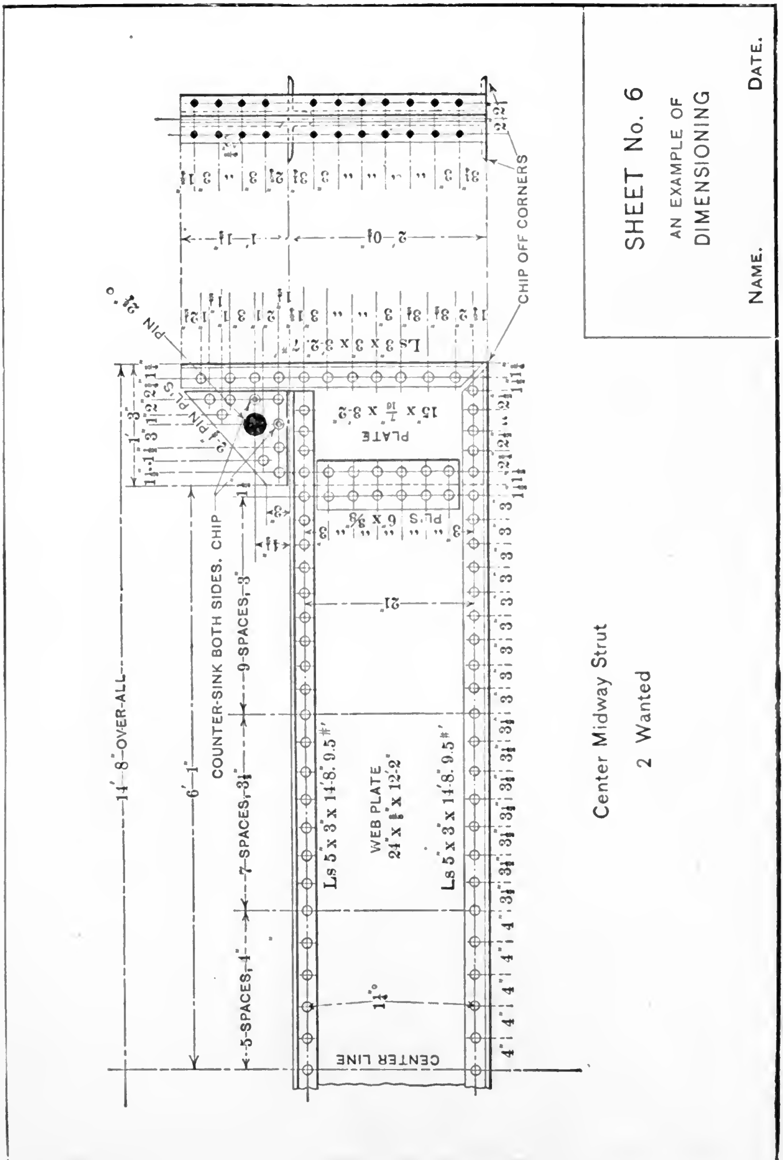


FIG. 73

199. Sheet No. 7, Plate No. 33.—This sheet is given to illustrate methods of representing screw-threads, and as a guide for drawing bolts and nuts. Fig. 1 represents a hexagonal-headed bolt and nut; to draw the figure, locate the center line, and with dimension *D*—the diameter of the bolt—equal to one inch, calculate all other dimensions and proceed as follows: First draw the end view, circumscribing the hexagon about the large circle with the T-square and 60° triangle, then project the side view of the nut and the body of the bolt. To draw the screw-threads, begin on the right-hand side of the outline of the bolt, at a point as dimensioned, and on the continuation of this line lay off $\frac{1}{8}''$ divisions, and with the T-square and 30° triangle draw the V's on this side; now on the left-hand outline of the bolt, beginning at a point $2\frac{1}{16}''$ from the bolt-head—$\frac{1}{16}''$ nearer than on the right side—lay off a number of $\frac{1}{8}''$ divisions, and draw the V's on this side; to end the bolt, with a center at the point of the last V (right side) and a radius equal to the diameter of the bolt (*D*), strike an arc intersecting the center line (see Fig. 2) and with this point as a new center and the same radius, strike the arc of the end of the bolt; finish by connecting the tops and bottoms of each row of V's.

The drawing represents a right-hand V thread, an outside thread on the bolt, and an inside thread in the upper half of the nut; note the direction of the inclination of the threads, also

PLATE No. 32.


SHEET No. 6
AN EXAMPLE OF DIMENSIONING
NAME.
DATE.
Center Midway Strut
2 Wanted
CHIP OFF CORNERS
COUNTER-SINK BOTH SIDES. CHIP
14'-8" OVER-ALL
6'-1"
CENTER LINE
WEB PLATE
PLATE

that the top and bottom of a thread are directly opposite (on opposite sides of the bolt); that is, the nut advances one-half thread in traveling half way around the bolt.

The pitch of a thread is the distance from the point of one thread to the point of the next, in the drawing, shown as $\frac{1}{8}''$, and spoken of as "eight pitch." The figure illustrates a convenient method of representing all V threads, though not always a true representation, as there are various kinds of threads, as single, double, triple, etc.; in such cases a note relative thereto should be added to the drawing.

In addition to the above, there are a number of types of threads, as the American and European standard forms of V threads, square threads, buttress threads, and others, an elaborate exposition of which is reserved for the work in elementary design; however, the simple V thread as given is conventional for all forms of V threads, unless, of course, an accurate representation is desired, and is rendered specific by the addition of a note, as "U. S. standard V, double, 4 pitch."

The V thread is always drawn showing a 60° V, using the T-square and 60° triangle.

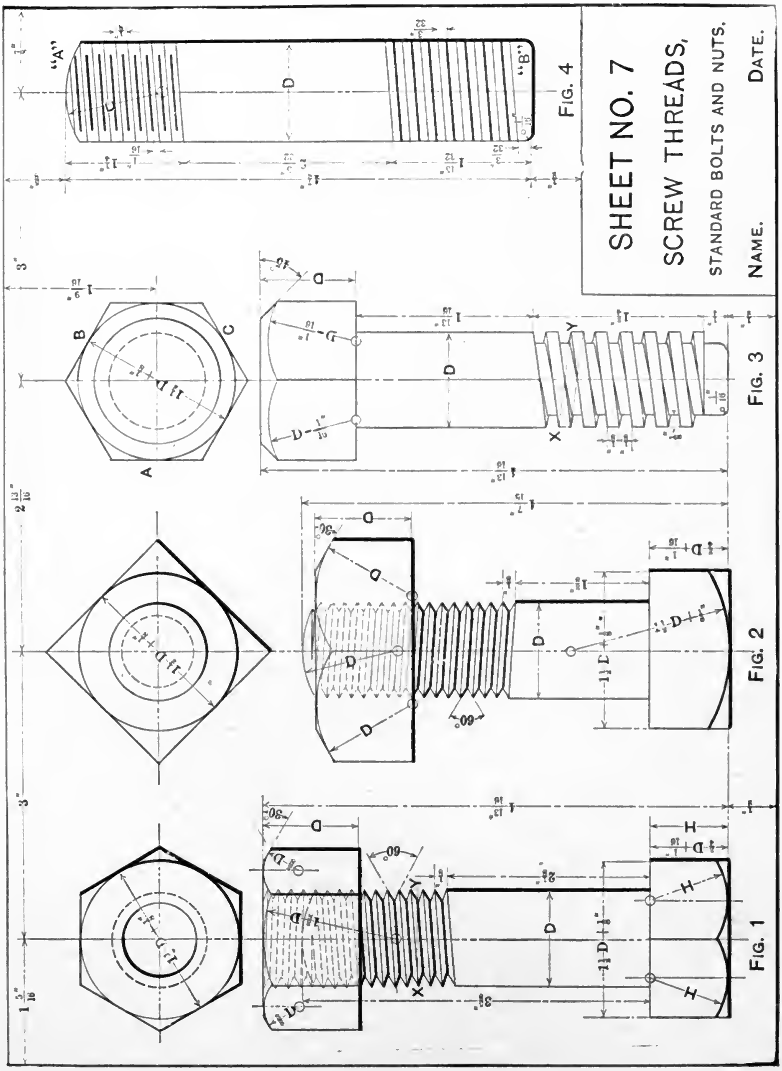
Fig. 2 represents a square-headed bolt and nut, showing a left-hand V thread. The end view is drawn first and the remainder of the figure constructed substantially the same as in Fig. 1.

Fig. 3 represents a chamfered, hexagonal-headed, square-threaded bolt. To draw the figure, locate the center line, draw the end view by first drawing the construction circle *A-B-C* (this circle does not appear in the finished drawing) and circumscribing the hexagon about it, then project the head of the bolt and proceed with the thread, which is analogous with the V thread.

The drawing of this figure is to be shade-lined in accordance with the other drawings of the sheet; the "shade" should be drawn outside of the outline dimensions.

The conventions given for representing screw-threads are at best tedious and difficult, especially so for threads of small diameter. To further expedite the work, the conventions illus-

PLATE No. 33.


SHEET NO. 7
SCREW THREADS,
STANDARD BOLTS AND NUTS.
NAME.
DATE.
FIG. 1
FIG. 2
FIG. 3
FIG. 4

trated in Fig. 4 are often adopted, the end *A* representing a V thread, and the end *B* a square thread, the inclination of the lines being slightly out of a right angle with the side lines and all parallel.

200. Sheet No. 8, Plate No. 34.—This sheet is given as a guide for drawing block-letters and as an exercise in free-hand lettering. The block-letters are drawn with instruments in accordance with the directions given on the sheet; the remainder of the plate is to be drawn by first ruling top and bottom guide-lines in pencil, then executing the lettering free-hand with the writing-pen without any preliminary lettering in pencil. The letters are to be of the following dimensions: Captions, initial letter to be $\frac{3}{16}''$ high, other letters $\frac{1}{8}''$ high; descriptive matter, initial letters, $\frac{1}{8}''$ high, other letters $\frac{3}{32}''$ high; space between lines $\frac{1}{8}''$.

In the free-hand work great care must be exercised to make the letters of uniform height and spacing, the words compact, and the lines of uniform weight. No guide or construction lines are to show on the finished sheet.

201. Sheet No. 9, Plate No. 35.—This plate is a working-

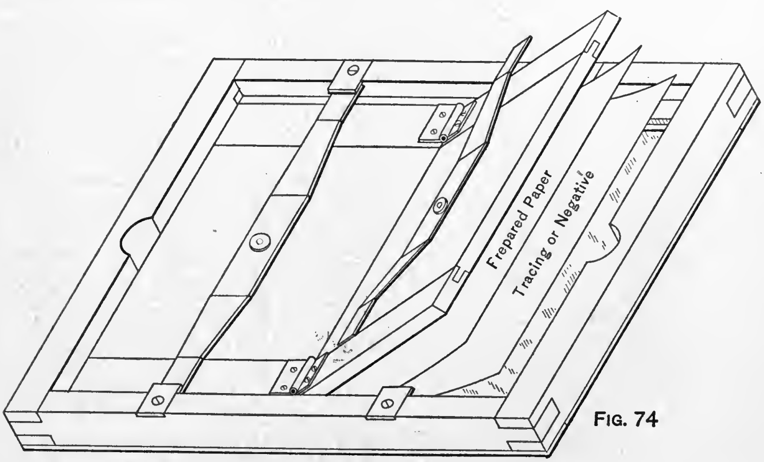
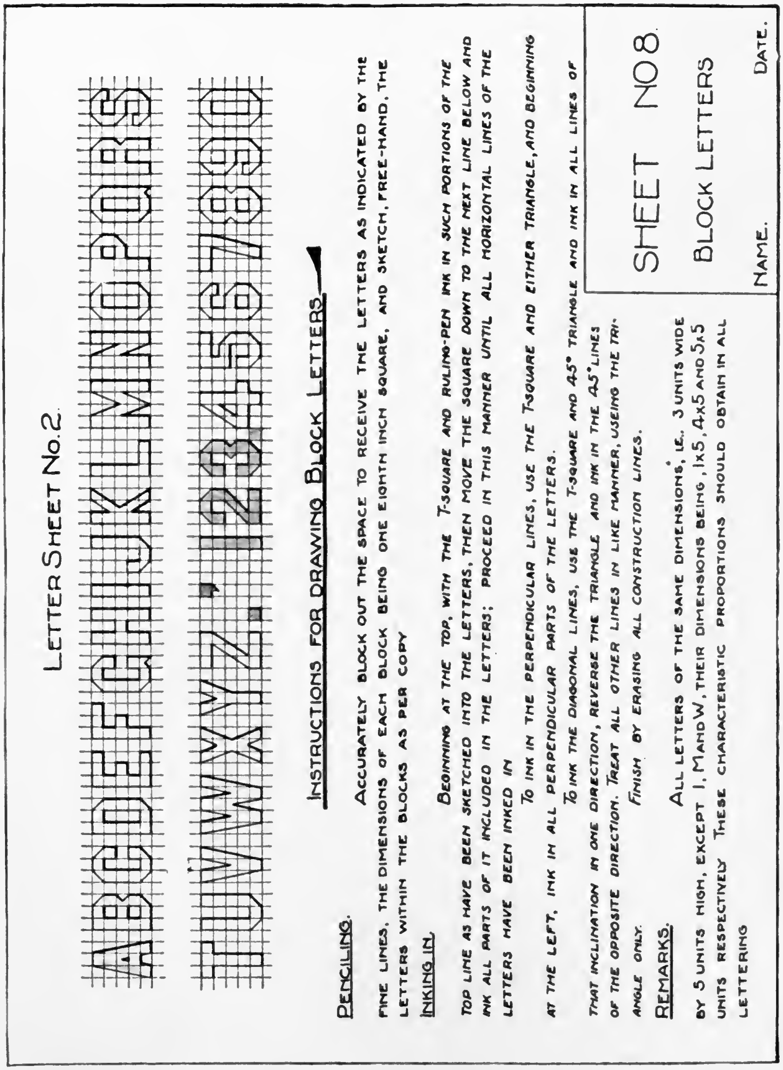


FIG. 74

THE FRAME

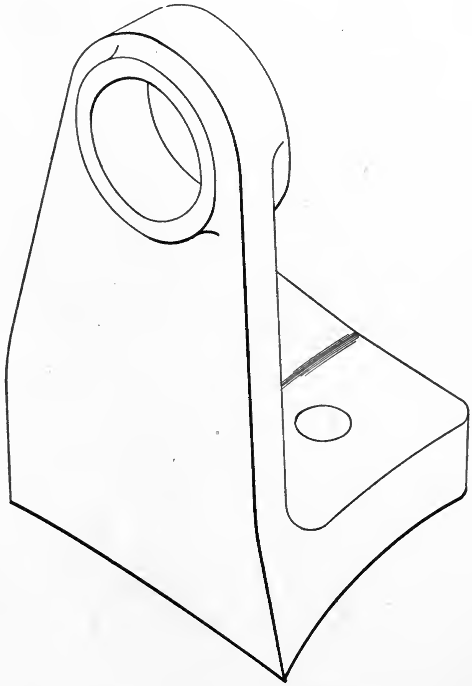
drawing of a simple blue-printing frame of a size to print the standard sheet of this course; i.e., $9'' \times 12''$.

PLATE No. 34.


LETTER SHEET No. 2.
ABCDEFGHIJKLMNOPQRS
TUVWXYZ.' 1234567890
INSTRUCTIONS FOR DRAWING BLOCK LETTERS.
PENCILING.
ACCURATELY BLOCK OUT THE SPACE TO RECEIVE THE LETTERS AS INDICATED BY THE FINE LINES, THE DIMENSIONS OF EACH BLOCK BEING ONE EIGHTH INCH SQUARE, AND SKETCH, FREE-HAND, THE LETTERS WITHIN THE BLOCKS AS PER COPY
INKING IN.
BEGINNING AT THE TOP, WITH THE T-SQUARE AND RULING-PEN INK IN SUCH PORTIONS OF THE TOP LINE AS HAVE BEEN SKETCHED INTO THE LETTERS, THEN MOVE THE SQUARE DOWN TO THE NEXT LINE BELOW AND INK ALL PARTS OF IT INCLUDED IN THE LETTERS; PROCEED IN THIS MANNER UNTIL ALL HORIZONTAL LINES OF THE LETTERS HAVE BEEN INKED IN
TO INK IN THE PERPENDICULAR LINES, USE THE T-SQUARE AND EITHER TRIANGLE, AND BEGINNING AT THE LEFT, INK IN ALL PERPENDICULAR PARTS OF THE LETTERS.
TO INK THE DIAGONAL LINES, USE THE T-SQUARE AND 45° TRIANGLE AND INK IN ALL LINES OF THAT INCLINATION IN ONE DIRECTION, REVERSE THE TRIANGLE AND INK IN THE 45° LINES OF THE OPPOSITE DIRECTION. TREAT ALL OTHER LINES IN LIKE MANNER, USEING THE TRIANGLE ONLY.
FINISH BY ERASING ALL CONSTRUCTION LINES.
REMARKS.
ALL LETTERS OF THE SAME DIMENSIONS, I.E., 3 UNITS WIDE BY 5 UNITS HIGH, EXCEPT I, M AND W, THEIR DIMENSIONS BEING, 1x5, 4x5 AND 5x5 UNITS RESPECTIVELY THESE CHARACTERISTIC PROPORTIONS SHOULD OBTAIN IN ALL LETTERING
SHEET NO 8.
BLOCK LETTERS
NAME.
DATE.

To draw the sheet, locate the center lines of the front view (the large rectangular figure) and working to these, copy the drawing and when complete project the side views.

202. Sheet No. 10, Plate No. 36.—This plate is given in the nature of a problem in drawing, illustrating the relation of the different views of an object; the "problem" is to construct a plan drawing of the object, working from the lines and dimen-



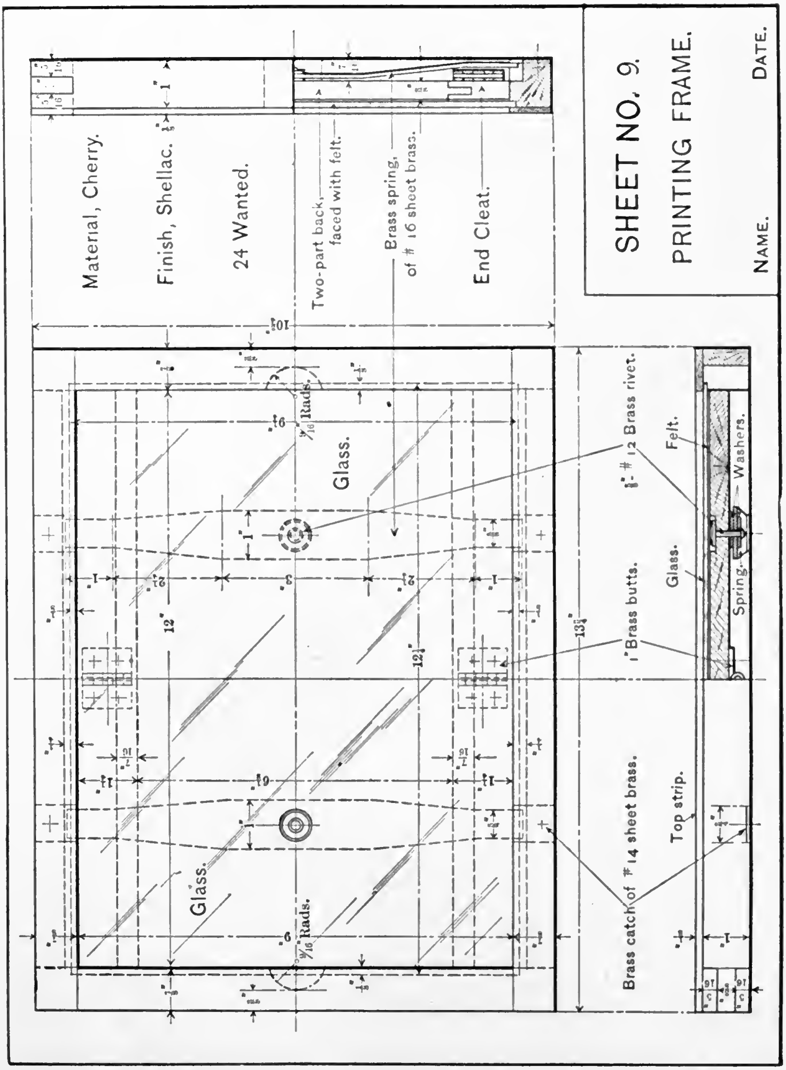
THE SUPPORT

FIG. 75.

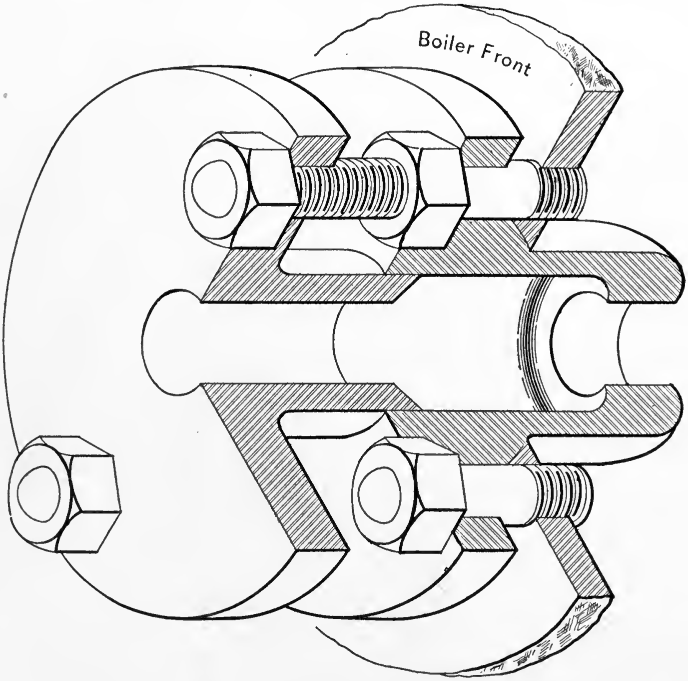
sions presented by the two elevations. The drawing is to be a scale drawing, one-half size, and a note relative thereto inserted in the title space.

To draw the sheet, construct the drawing on the right hand—the right side elevation—first, then project the front elevation.

PLATE No. 35.


SHEET NO. 9.
PRINTING FRAME.
NAME.
DATE.
Material, Cherry.
Finish, Shellac.
24 Wanted.
Two-part back, faced with felt.
Brass spring, of # 16 sheet brass.
End Cleat.
Glass.
Glass.
Rads.
Rads.
Felt.
Washers.
Glass.
Spring.
1" Brass butts.
Brass catch of # 14 sheet brass.
Top strip.

203. Sheet No. 11, Plate No. 37.—This plate presents a working drawing of a locomotive-throttle stuffing-box. To draw the sheet, locate the center lines, construct the front-elevation

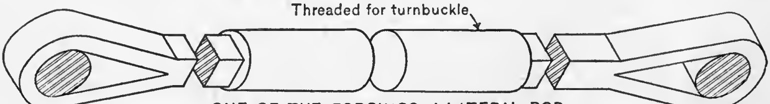


THE BOX

FIG. 76.

drawing first (the figure on the left of the plate), then project the side elevation.

204. Sheet No. 12, Plate No. 38.—This exercise is an example



ONE OF THE FORGINGS, A LATERAL ROD

FIG. 77.

of bridge drawing. The sheet is to be drawn to a scale of $1\frac{1}{2}'' = 1'$ ($\frac{1}{8}$ size); all lettering to be free-hand.

PLATE No. 36.

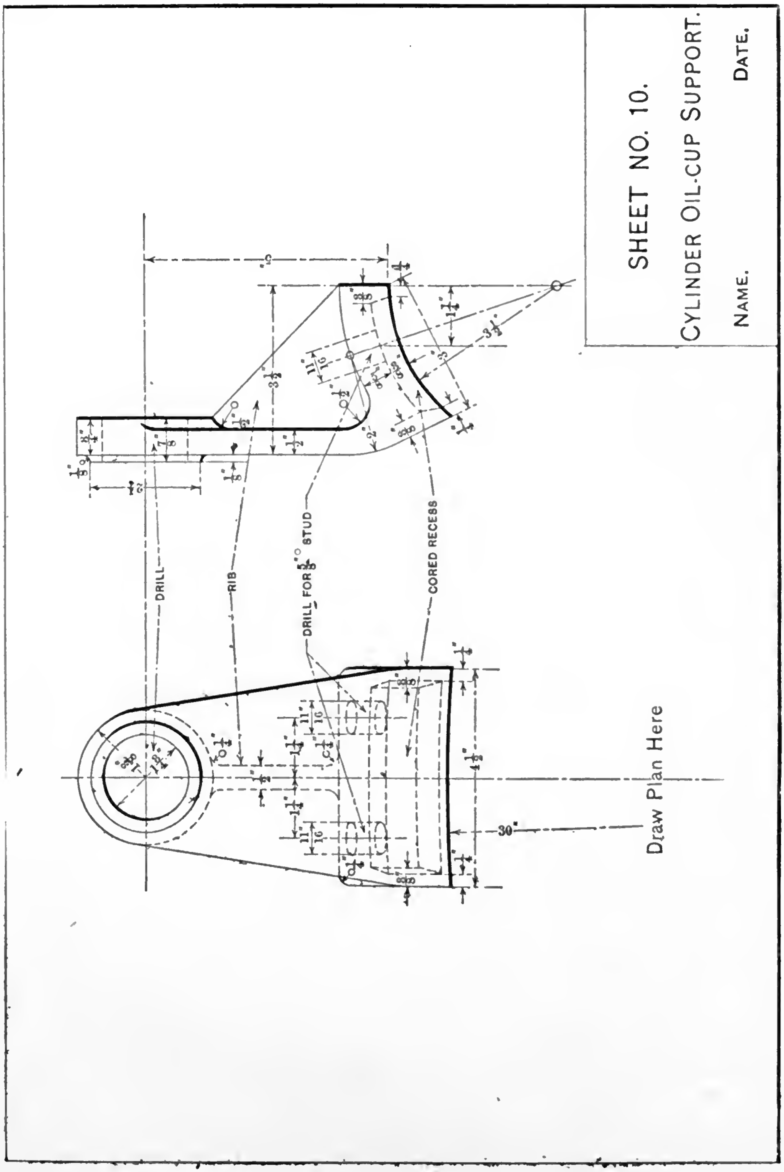

SHEET NO. 10.
CYLINDER OIL-CUP SUPPORT.
NAME.
DATE.
DRILL
RIB
DRILL FOR 5/8" STUD
CORED RECESS
Draw Plan Here

PLATE No. 37.

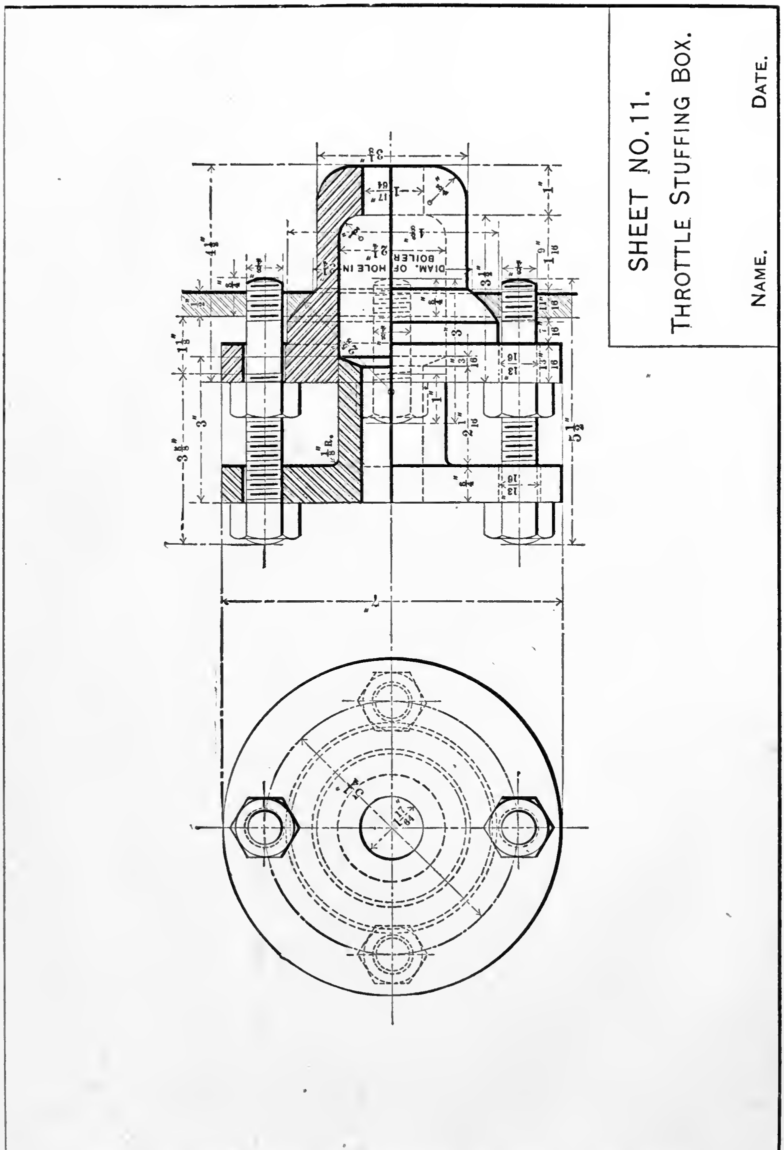
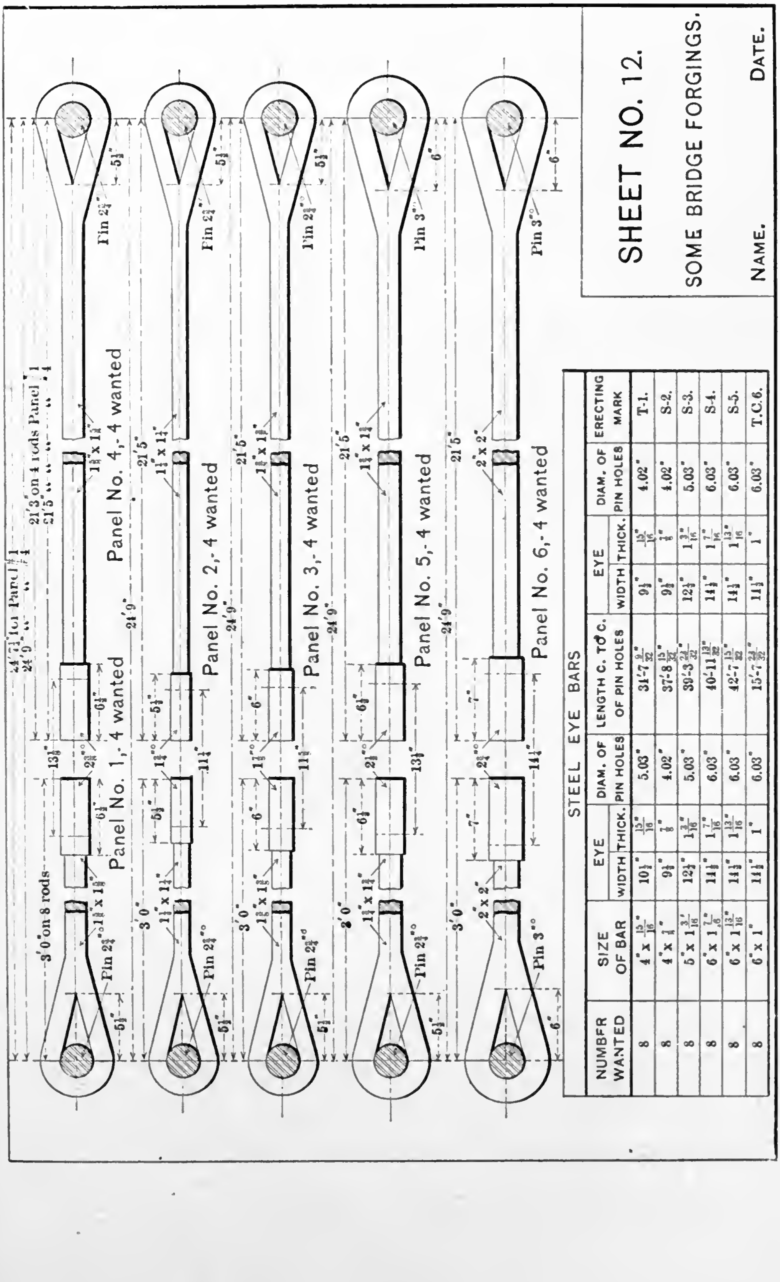

SHEET NO. 11.
THROTTLE STUFFING BOX.
NAME.
DATE.
DIAM. OF HOLE IN BOILER

PLATE No. 38.



NUMBER WANTED	SIZE OF BAR	EYE WIDTH	EYE THICK.	DIAM. OF PIN HOLES	LENGTH C. TO C. OF PIN HOLES	EYE WIDTH	EYE THICK.	DIAM. OF PIN HOLES	ERECTING MARK
8	4" x 15/16"	10½"	15/16"	5.03"	34'-7 9/32"	9½"	15/16"	4.02"	T-1.
8	4" x 1"	9½"	1"	4.02"	37'-8 15/32"	9½"	1"	4.02"	S-2.
8	5" x 1 3/16"	12¼"	1 3/16"	5.03"	39'-3 24/32"	12¼"	1 3/16"	5.03"	S-3.
8	6" x 1 7/16"	14½"	1 7/16"	6.03"	40'-11 13/32"	14½"	1 7/16"	6.03"	S-4.
8	6" x 1 13/16"	14½"	1 13/16"	6.03"	42'-7 15/32"	14½"	1 13/16"	6.03"	S-5.
8	6" x 1"	14½"	1"	6.03"	15'-7 24/32"	14½"	1"	6.03"	T.C.6.

205. Sheet No. 13, Plate No. 39.—This sheet is a drawing for the shop, and is to be drawn to a scale of $3'' = 1'$, or $\frac{1}{4}$ size, and a "scale note" added to the title space.

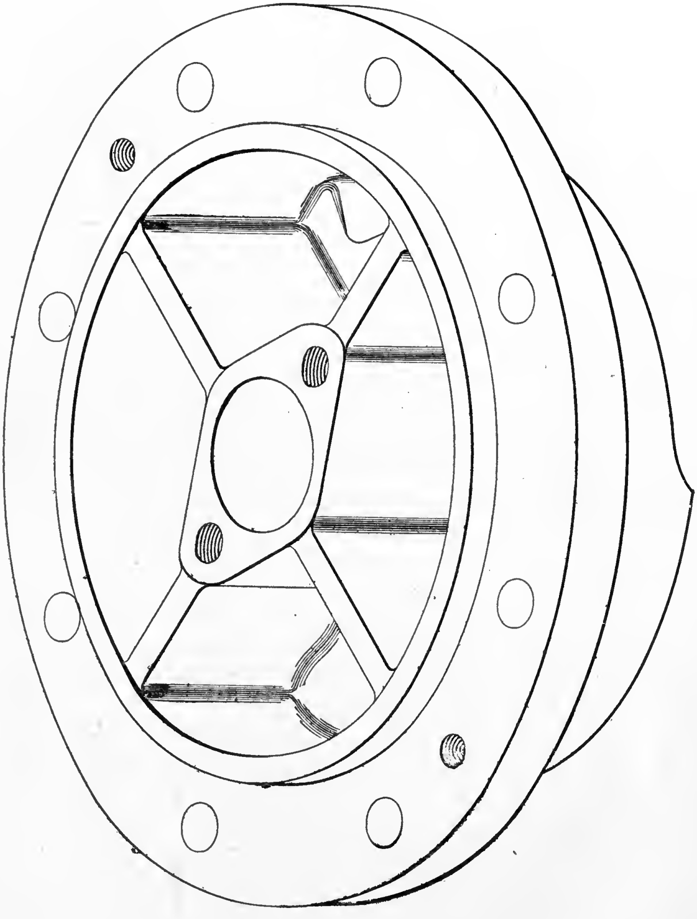
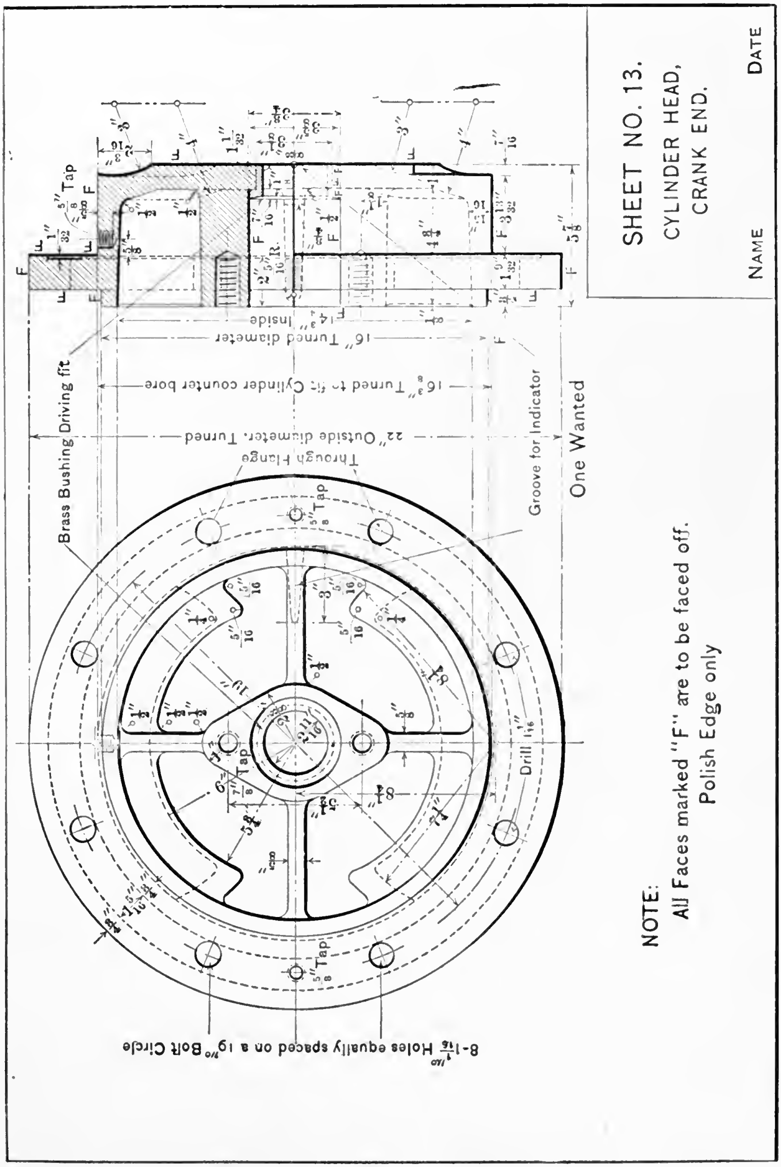


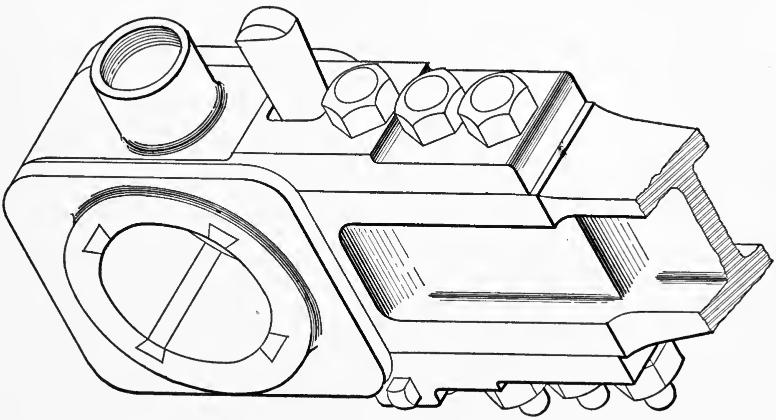
FIG. 78.

206. Sheet No. 14, Plate No. 40.—A second problem in drawing, similar to that of Sheet No. 10, is here introduced. Working with the plan and elevation drawings and to center lines,

PLATE No. 39.


SHEET NO. 13.
CYLINDER HEAD,
CRANK END.
NAME
DATE
NOTE:
All Faces marked "F" are to be faced off.
Polish Edge only
One Wanted
Groove for Indicator
Brass Bushing Driving fit
22" Outside diameter, Turned
Through Flange
16" Turned diameter
Inside
Turned to fit Cylinder counter bore
Tap
Drill
8-1 1/16 Holes equally spaced on a 19" Bolt Circle

construct a right end view drawing of the stub, to a scale of $4'' = 1'$.

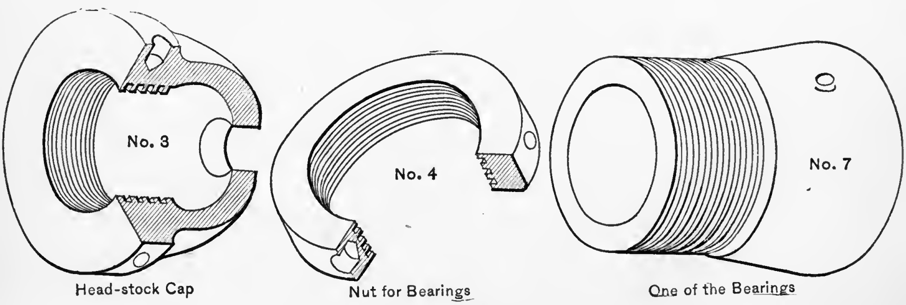


THE STUB

FIG. 79.

In addition to the above problem, the student is to shade line—back line—the entire sheet.

207. Sheet No. 15, Plate No. 41.—This sheet is a detail sheet, detailing four fittings for the head stock of a wood-turning lathe.

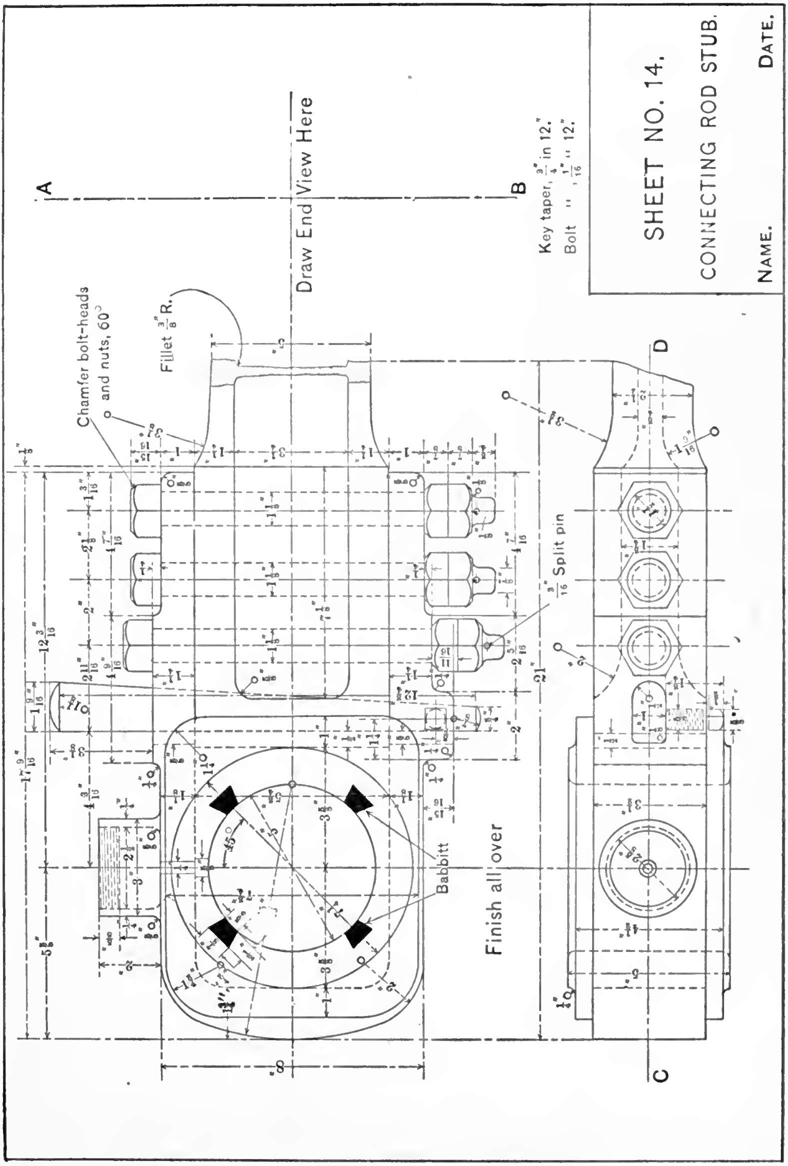


LATHE DETAILS

FIG. 80

The student should note the arrangement and balance of the sheet.

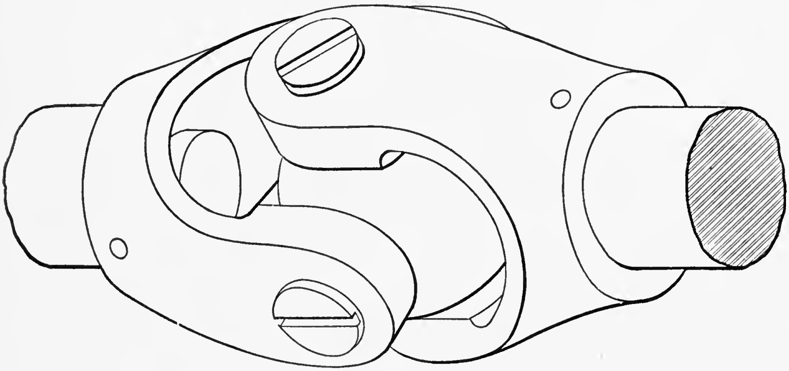
PLATE No. 40.


SHEET NO. 14.
CONNECTING ROD STUB.
NAME.
DATE.
Key taper, 3/4" in 12."
Bolt " 1/16" " 12."
Draw End View Here
A
B
C
D
Chamfer bolt-heads and nuts, 60°
Fillet 3/8" R.
3/16" Split pin
Babbitt
Finish all over

The cross-hatched portions of the top row of figures illustrate the fit of the bearings and the use of the pin which keeps them (the bearings) from turning.

208. Sheet No. 16, Plate No. 42.—This sheet is an exercise in free-hand lettering. The student is to decide the size of letters, spacings, and balance of the sheet.

209. Sheet No. 17, Plate No. 43.—An assembled shop drawing



THE JOINT

FIG. 81

of a universal joint. Construct a full-size drawing and shade the end view.

210. Sheet No. 18, Plate No. 44.—This sheet introduces a third problem in drawing. The sheet is to be drawn to a scale of $3'' = 1'$, and in the two elevations show a half section taken on the line *A-B-C* of the plan drawing—the plan drawing to be drawn like the copy.

211. Sheet No. 19, Plate No. 45.—This sheet is an exercise for practice in line shading, an operation for which the following general rules may be found useful:

1. A surface which is parallel to the plane of projection and in the light is uniformly covered with light; a light line uniformly spaced (1 and 2) illustrates the ruling for such a surface.

2. A surface which is parallel to the plane of projection and

PLATE No. 41.

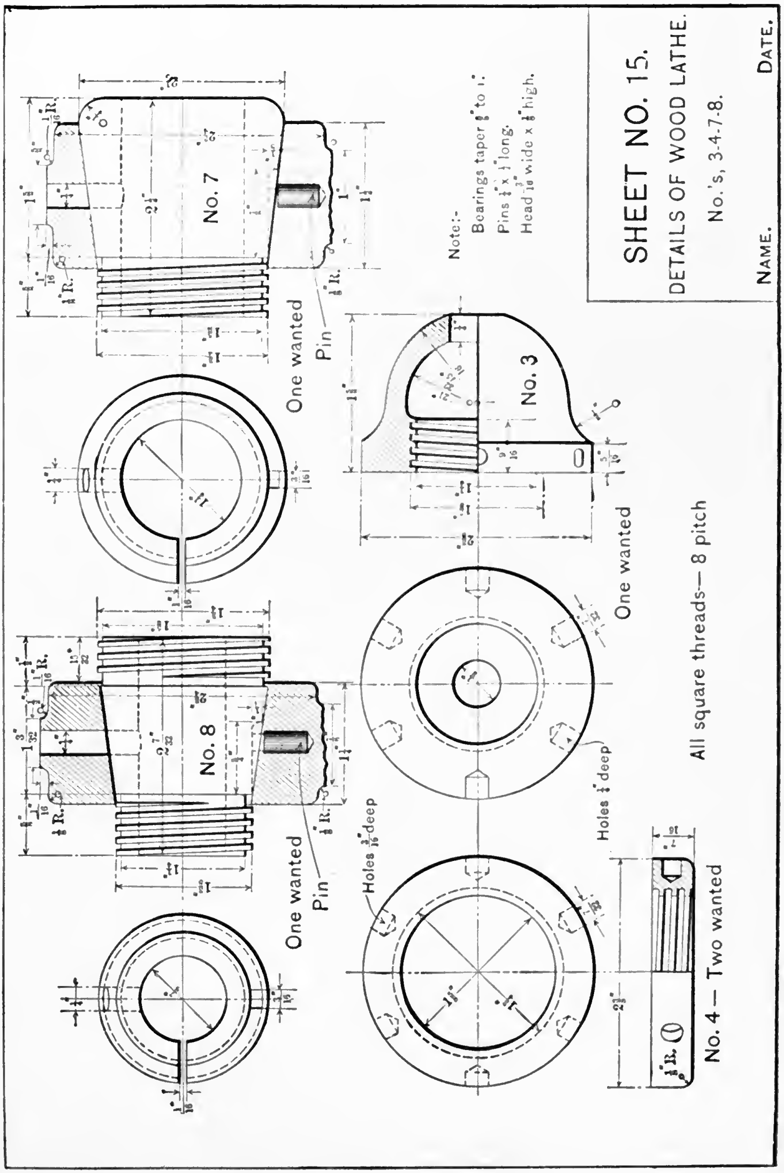

SHEET NO. 15.
DETAILS OF WOOD LATHE.
No.'s, 3-4-7-8.
NAME.
DATE.
Note:-
Bearings taper ⅛" to 1'
Pins ¼" x ⅞" long.
Head 3/16" wide x ⅛" high.
No. 7
One wanted
Pin
No. 3
One wanted
All square threads— 8 pitch
No. 8
One wanted
Pin
Holes ¼" deep
Holes 3/16" deep
No. 4 — Two wanted

PLATE No. 42.

SHEET No. 324-A.

No. 2 CAR-WHEEL BORER.

CLASS "G."

COUNTER-SHAFT WORK.

FOR MACHINE COUNTER.

1—Shaft, $2\frac{1}{4}''$ diameter—finishes $2\frac{3}{16}''$ °, 6'–5" long.
1—Rod, $1\frac{1}{8}''$ diameter, 6'–10" long. Forge draw on one end.
2—16" Drop-hangers, 16" center of rod to center of shaft.
2—Boxes, 8" long, $1\frac{11}{16}''$ hole. Babbitted.
2—28" Friction pulleys, 7" face crowning, $2\frac{3}{16}''$ hole.
1—Cone, steps 18", 22", 26", and 30" with face for 5" belt. Hole $2\frac{3}{16}''$.
1—Shipper sleeve, $2\frac{3}{16}''$ hole.
1— " fork with set-screw
1— " stud " nut and washer.
1—Collar, $2\frac{3}{16}''$ hole.

NOTE:—
FOR PLAN OF COUNTERS SEE SHEET No. 316-B.

FOR CRANE COUNTER.

1— Shaft, $1\frac{7}{8}''$ diameter, finishes $1\frac{13}{16}''$ °, 4'–2" long.
1— Rod, $\frac{15}{16}''$ diameter, 4'–7" long.
2— 10" Drop-hangers, $8\frac{3}{4}''$ center of rod to center of shaft.
2— Boxes, 7" long, $1\frac{1}{4}''$ hole Babbitted
2— 16" Friction pulleys, 5" face, crowning, $1\frac{13}{16}$ hole Hubs project $\frac{1}{2}''$ beyond rims
1— 16" Pulley, 5" face, crowning, $1\frac{13}{16}''$ hole, 2 set-screws. Hubs project $\frac{1}{2}''$ beyond rims.
1— Shipper sleeve, $1\frac{13}{16}''$ hole.
1— " fork with set-screw.
1— " stud " nut and washer
1— Collar, $1\frac{13}{16}''$ hole.

SHEET NO. 16.

SHOP INSTRUCTIONS:

NAME. DATE.

PLATE No. 43.

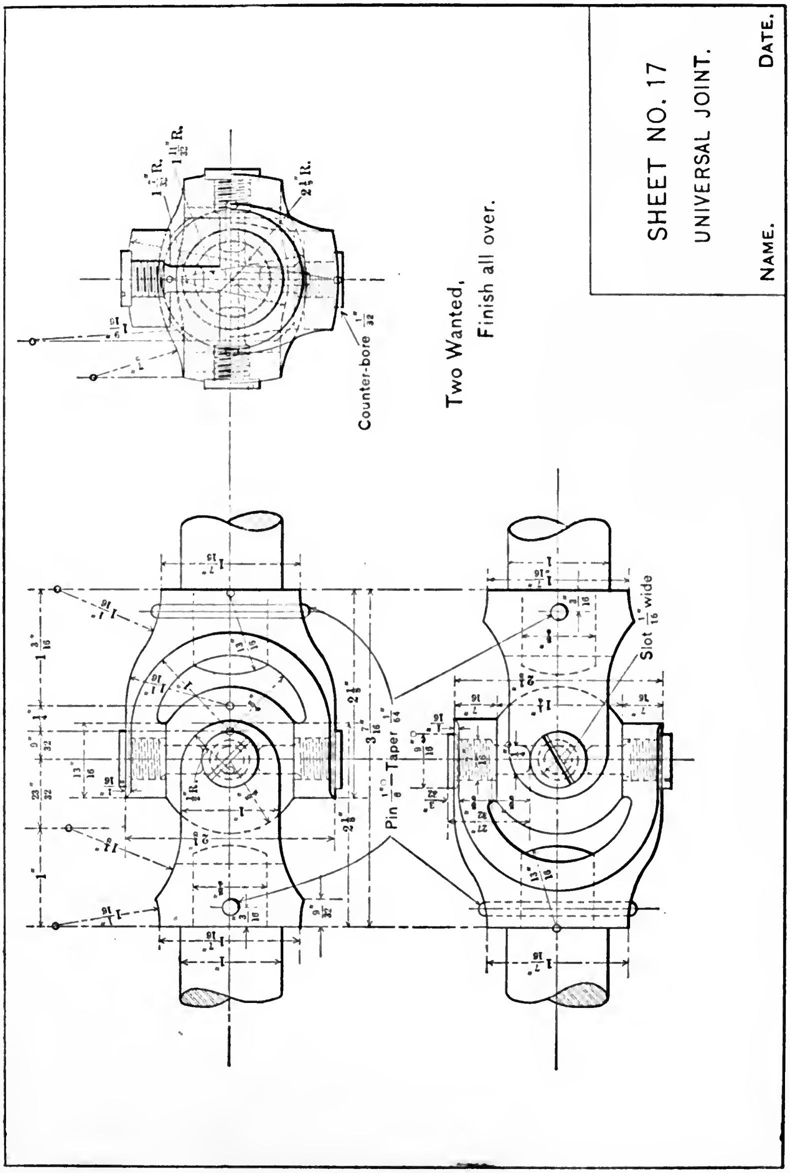

SHEET NO. 17
UNIVERSAL JOINT.
NAME.
DATE.
Two Wanted,
Finish all over.
Counter-bore
Slot 1/16" wide
Pin
Taper

PLATE No. 44.

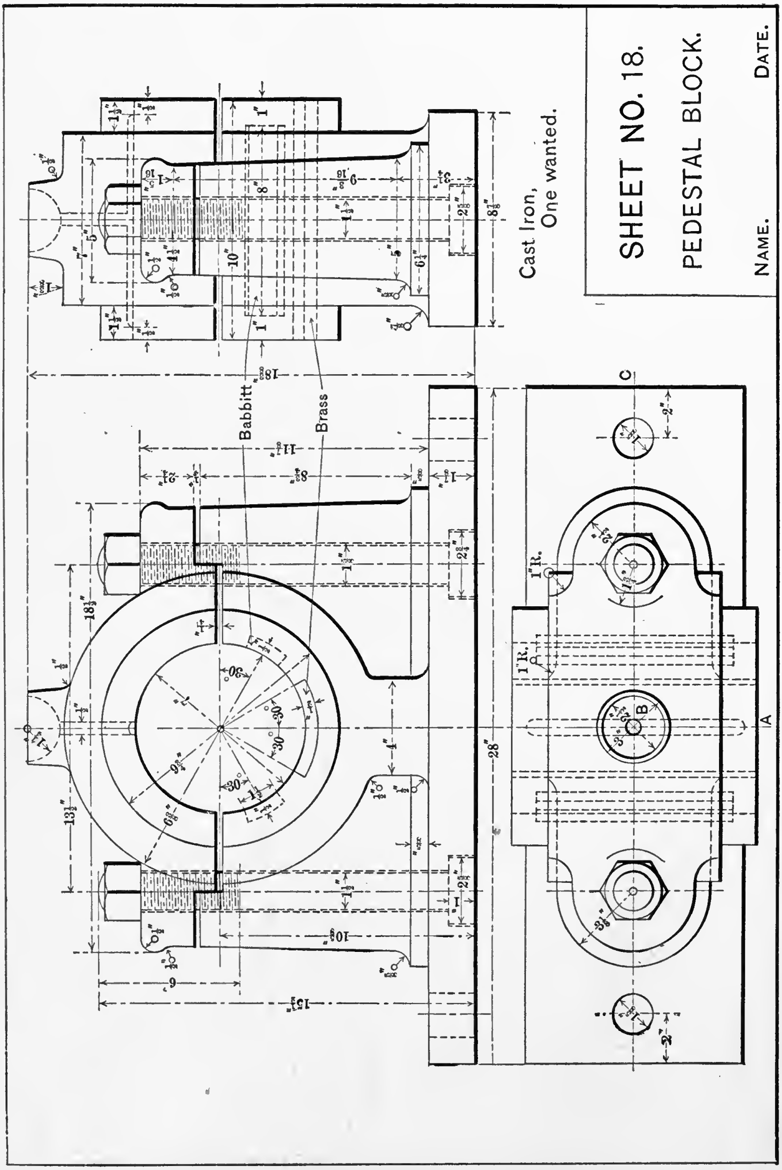
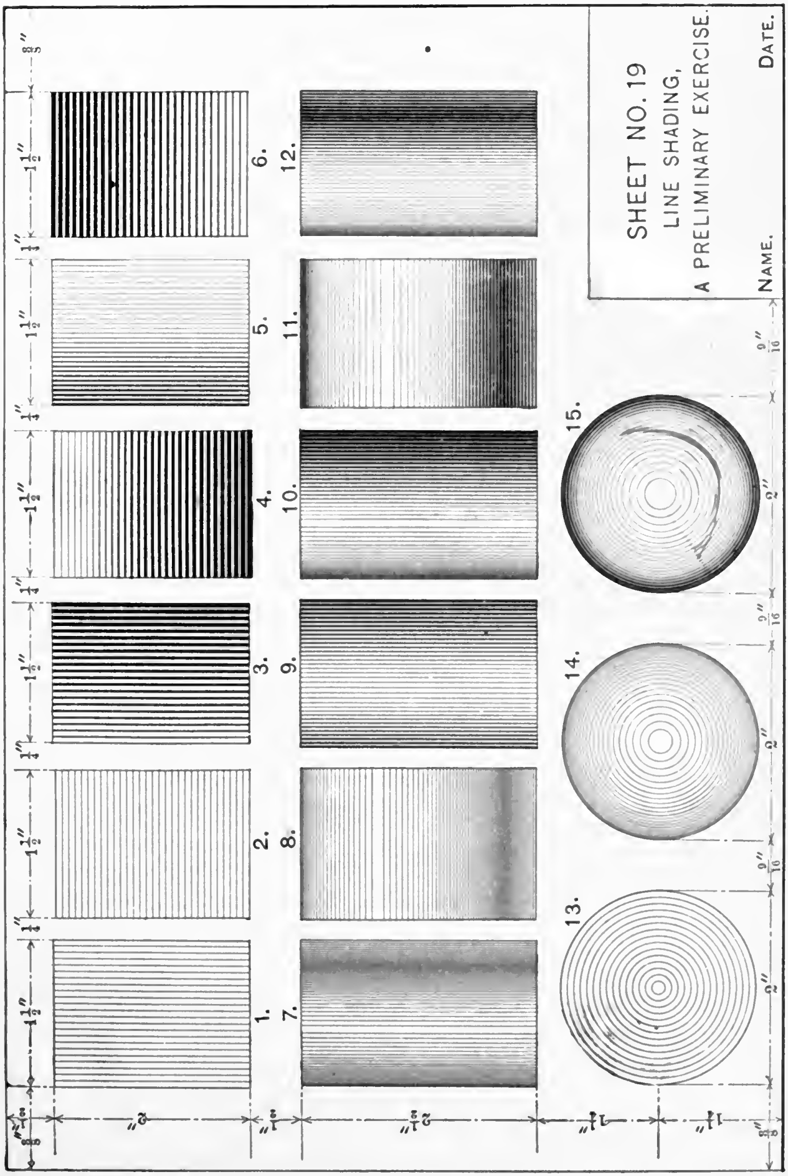
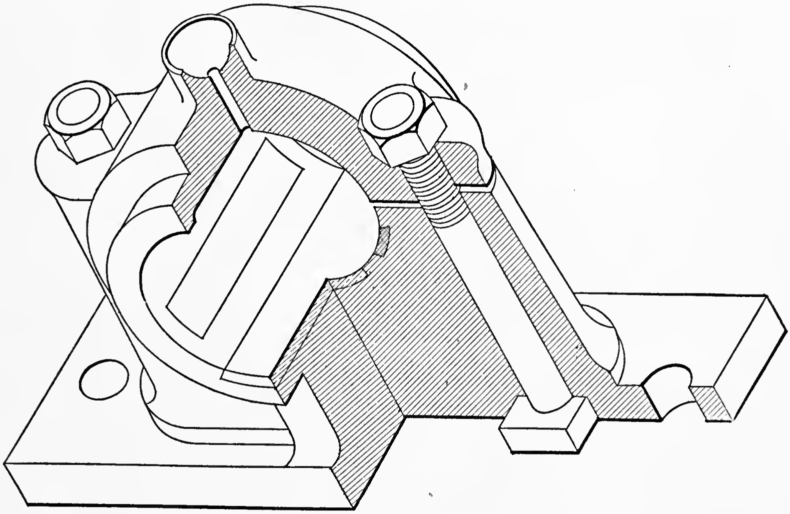

SHEET NO. 18.
PEDESTAL BLOCK.
NAME.
DATE.
Cast Iron,
One wanted.
Babbitt
Brass

PLATE No. 45.


SHEET NO. 19
LINE SHADING,
A PRELIMINARY EXERCISE.
NAME.
DATE.
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
14.
15.

in the shadow is uniformly dark and is illustrated by uniform ruling of heavy lines closely spaced.



THE BLOCK, SECTIONED.

FIG. 82.

3. Of two or more surfaces which are parallel to the plane of projection, the surface nearest to the plane is the lightest and the one most remote the darkest.

4. A surface which is inclined to the plane of projection and in the light becomes lighter as it approaches.

5. A surface which is inclined to the plane of projection and in the shadow is dark nearest the plane and becomes lighter as it recedes.

Figs. 1 and 2 show a uniform line uniformly spaced; 3 and 4 show a uniform space, variable line, drawn from light to heavy —"drawn in"; 5 and 6 show the same "drawn out."

Figs. 7 to 12, inclusive, illustrate conventional shadings for representing cylindrical surfaces; 7 and 8 show a uniform line, variable space; 9 a uniform space and variable line, and Figs. 10, 11, and 12 variable space and line.

Fig. 13 is a uniform line uniformly spaced, used to represent

PLATE No. 46.

SHEET. No 20.

LIST OF COMPLETE SET OF DRAWINGS OF SCHENECTADY No 2.

BOILER	451.	EXPANSION PAD	1.
BOILER, FRONT	152.	ENGINE STEP	11.
BUMPER, FRONT	453.	FRAME	446.
BUMPER, BACK	102.	FOOT-PLATE	283.
BELL	52.	FIRE-BRICK	44.
BLOWER	37.	FURNACE-DOOR	11.
CYLINDER-HEAD	284.	FLAG-FIXTURES	20.
" " COVER	95.	GUIDE	279.
" COCK	31.	" OIL-CUPS	74.
" " WORK	221.	" YOKE-SHEET	148.
" " LEVER	1.	GRATE	9.
" OIL-CUP SUPPORT	304.	GAUGE-COCK	309.
CAB	257.	HAND RAIL	6.
" BRACKET	136.	HEAD-LIGHT SHELF	35.
" TOOL-BOX	105.	JACK-SCREWS	2.
" LAMP-STAND	28.	LINK	194.
" DOOR FIXTURE	14.	" OIL-CUP	2.
" HANDLE	449.	PISTON	347.
CROSS-HEAD	160.	PILOT	223.
CONNECTING ROD	328.	REVERSE LEVER	206.
" " STUBS	336.	" SHAFT	216.
" " OIL-CUPS	203.	" SPRING	300.
CRANK PIN	188.	ROCK SHAFT	181.
COMBINATION GLOBE	151.	" " OIL CUP	10.
CINDER POCKET	1.	RUNNING BOARD	257.
DOME CAP	129.	STEAM CHEST	277.
" RING	37.	" " VALVE	189.
" FINISH	144.	" " " YOKE	132.
DRIVING WHEEL CENTER	371.	" " " ROD	127.
" " GUARD	161.	" " CASTING TOP	11.
" AXLE	168.	STEAM PIPE IN SMOKE BOX	237.
" SPRING	351.	SMOKE STACK	228.
DRY PIPE	251.	SAFETY VALVE CASING	8.
DEFLECTING PLATE	342.	" " CHIMNEY	21.
ENGINE TRUCK	19.	SHOE AND WEDGE	29.
" " BOX	12.	SPRING BOX	468.
" " AXLE	5.	THROTTLE	132.
" " CENTER PIN	67.	" LEVER	63.
" " OIL CUP	40.	" STUFFING BOX	1.
EQUALIZER	250.	TALLOW CAN HOLDER	20.
" FULCRUM PLATE	3.	WAIST SHEET	196.
EXHAUST	243.	WASTE-COCK	31.
ECCENTRIC	89.	WHEEL GUARD BLOCK	13.
" STRAP	41.		
" ROD	170.		

NAME. DATE.

flat discs, the ends of cylinders, etc., when parallel to the plane of projection.

Fig. 14 is a uniform line with variable spacing, and Fig. 15 a variable space and line, and illustrate conventions for representing spheres.

212. Sheet No. 20, Plate No. 46.—The sheet is a free-hand sheet; the student is to decide the size of letter, space, balance etc. ("Schenectady No. 2" is the name of Purdue's present experimental locomotive.)

213. Sheet No. 21, Plate No. 47.—Fig. 1 represents a sphere; Fig. 2 a concave surface, the interior of a hollow cylinder; Fig. 3 represents one-half of a hexagonal prism; Fig. 4 a ring which is circular in section. To shade the view on the left, draw a number of fine lines parallel to the sides and "touch up" between them, free-hand, with an etching-pen.

Fig. 5 illustrates two shadings for screw-threads, the upper end being shaded with fine, ruling-pen lines and "touched up," free-hand; the lower end is shaded with the writing-pen alone.

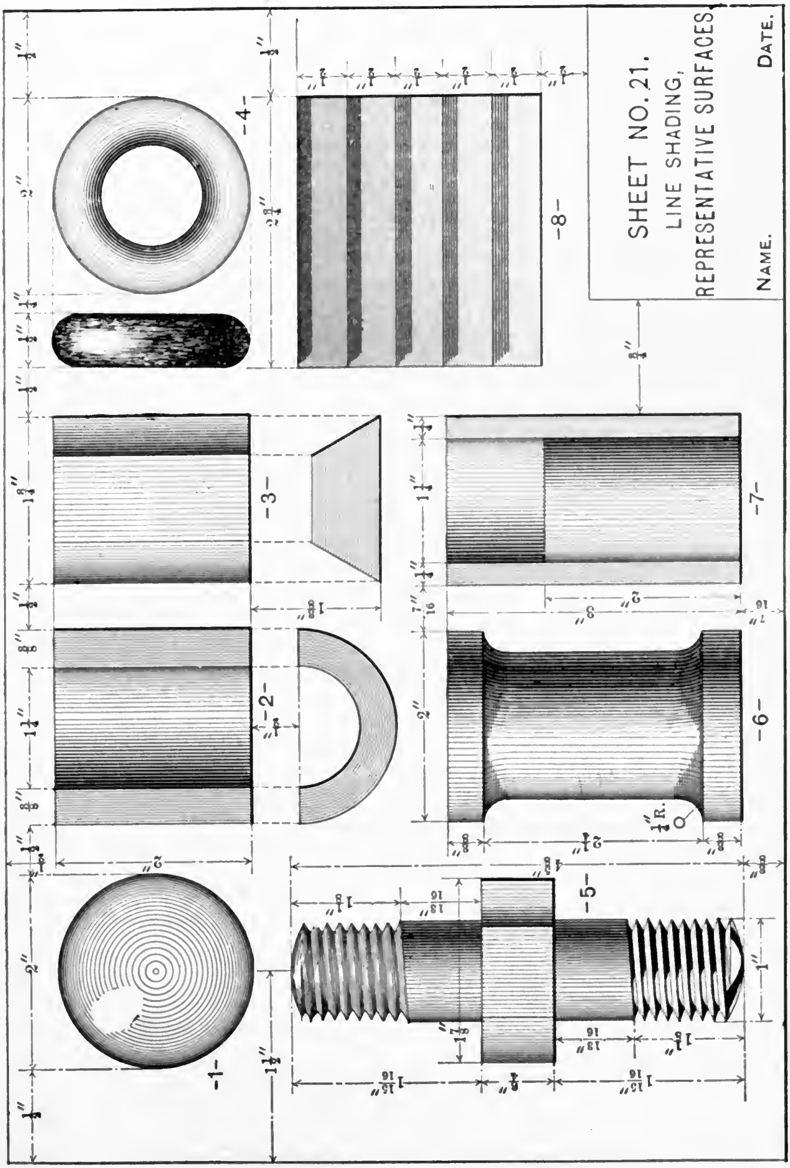
Figs. 6 and 7 represent cylindrical surfaces, Fig. 6 illustrating the "treatment" of double-curved surfaces and Fig. 7 the contrast between inside and outside curves, concave and convex surfaces, respectively.

Fig. 8 represents a number of flat surfaces parallel with the plane of projection, as an elevation of a flight of steps, the several heavy lines at the top of each rise, indicating the shadow of the nose of the step tread.

214. Sheet No. 22, Plate No. 48.—This sheet is given as a preliminary to the drawing of gear-teeth, and is also an excellent exercise for practice in the use of the irregular curve; the chapter on gearing should be carefully read before beginning the drawing.

The sheet is to be a full-size drawing to the dimensions given, and is to be executed in accordance with Sect. 152. All lines, letters, and figures of the copy are to be shown on the finished sheet; omit all dimensions.

PLATE No. 47.


SHEET NO. 21.
LINE SHADING,
REPRESENTATIVE SURFACES.
NAME.
DATE.
-1-
-2-
-3-
-4-
-5-
-6-
-7-
-8-

215. Sheet No. 23, Plate No. 49.—Here is presented a first exercise in the construction of gear-teeth. The sheet is to be a full-size drawing, and is to be executed in accordance with Sect. 160. The finished sheet is to show all lines, letters, and figures, except the dimension lines, given in the copy.

216. Sheet No. 24, Plate No. 50.—This sheet is a second exercise in the construction of gear-teeth, and is to be drawn full size, in accordance with Sect. 161; the finished sheet is to appear like the copy, without the dimensions.

217. Sheet No. 25, Plate No. 51.—The sheet is another exercise in the construction of gear-teeth, and is to be a full-size drawing, to be executed in accordance with Sect. 162; the sheet is to be finished the same as the other sheets of the set.

218. Sheet No. 26, Plate No. 52.—Here we have presented a practical example of the construction of gear-teeth, the drawing being a front and side elevation drawing of a pair of *involute* gears. The sheet is to be a full-size drawing, and is to be executed in accordance with Sect. 160. The finished sheet is to show all lines, letters, and figures, given in the copy.

219. Sheet No. 27, Plate No. 53.—Before beginning this sheet the student should read Chapter VIII. on color work. The exercise is a first exercise for the brush, and is to be executed on a special paper—different from that used for the preceding sheets, in that the surface is not so highly calendered. A cold-pressed paper gives the best results.

The paper should be neatly stretched on the board in accordance with Sect. 165; the ink used should be a "wash ink" prepared by rubbing stick ink in a saucer containing a small quantity of water.

Directions for Drawing.—Lay out the sheet, according to the dimensions, in light pencil, being careful to draw only the lines necessary to block out the rectangles; do not draw lines within these spaces necessitating an erasure, thus bruising the surface, as this would show through the wash. Begin with 1 and wash in the top row of rectangles; it will be noticed that the shade increases in depth; this is accomplished by, after each

PLATE No. 48.

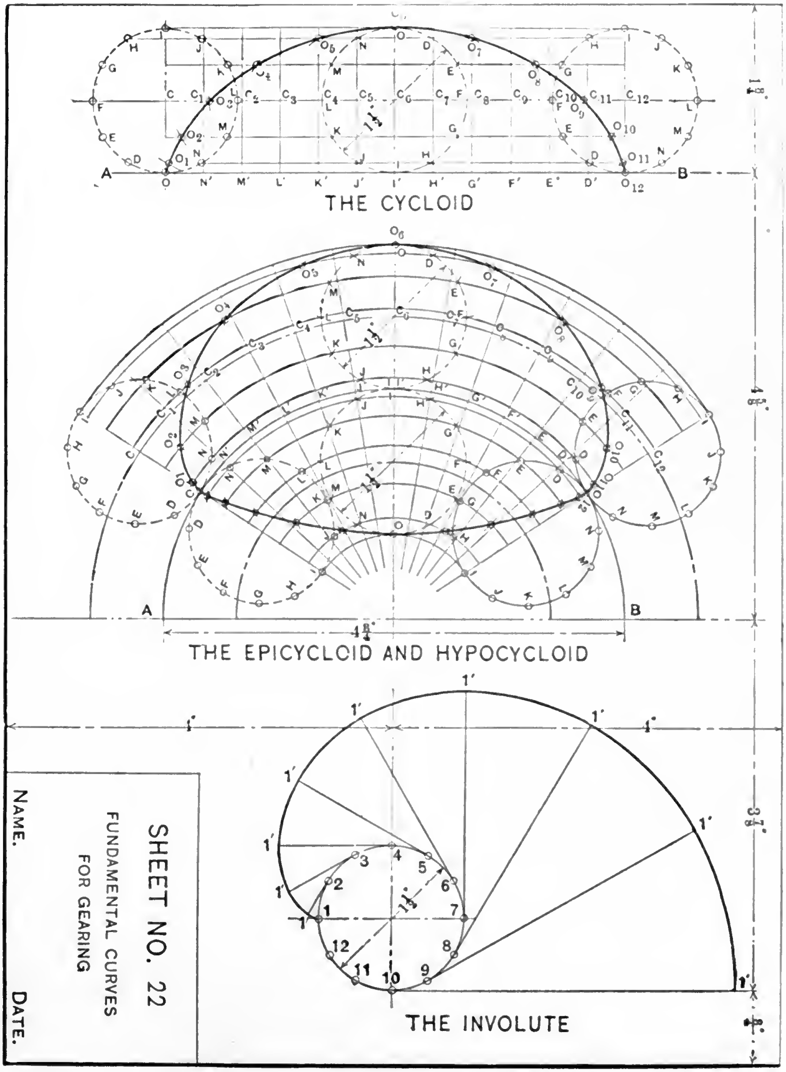

THE CYCLOID
THE EPICYCLOID AND HYPOCYCLOID
THE INVOLUTE
SHEET NO. 22
FUNDAMENTAL CURVES
FOR GEARING
NAME.
DATE.

PLATE No. 49.

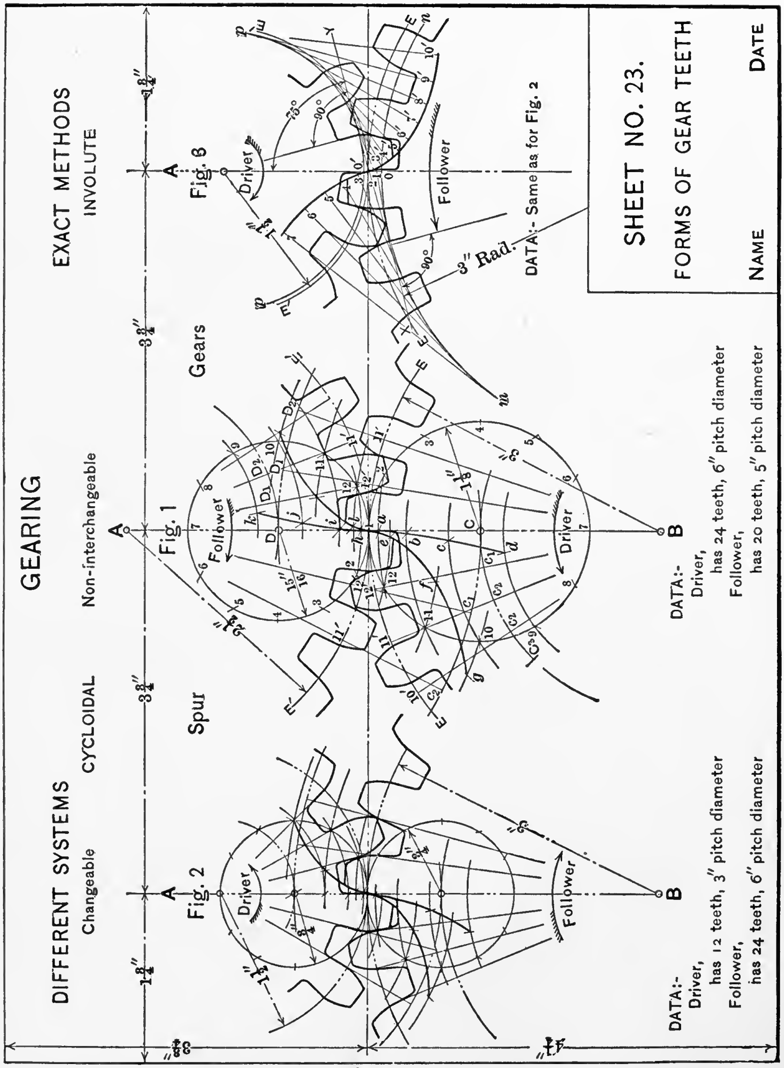

GEARING
DIFFERENT SYSTEMS
Changeable
CYCLOIDAL
Non-interchangeable
EXACT METHODS
INVOLUTE
Spur
Gears
Fig. 2
Fig. 1
Fig. 3
Driver
Follower
3" Rad.
DATA:- Driver, has 12 teeth, 3" pitch diameter
Follower, has 24 teeth, 6" pitch diameter
DATA:- Driver, has 24 teeth, 6" pitch diameter
Follower, has 20 teeth, 5" pitch diameter
DATA:- Same as for Fig. 2
SHEET NO. 23.
FORMS OF GEAR TEETH
NAME
DATE

PLATE No. 50.

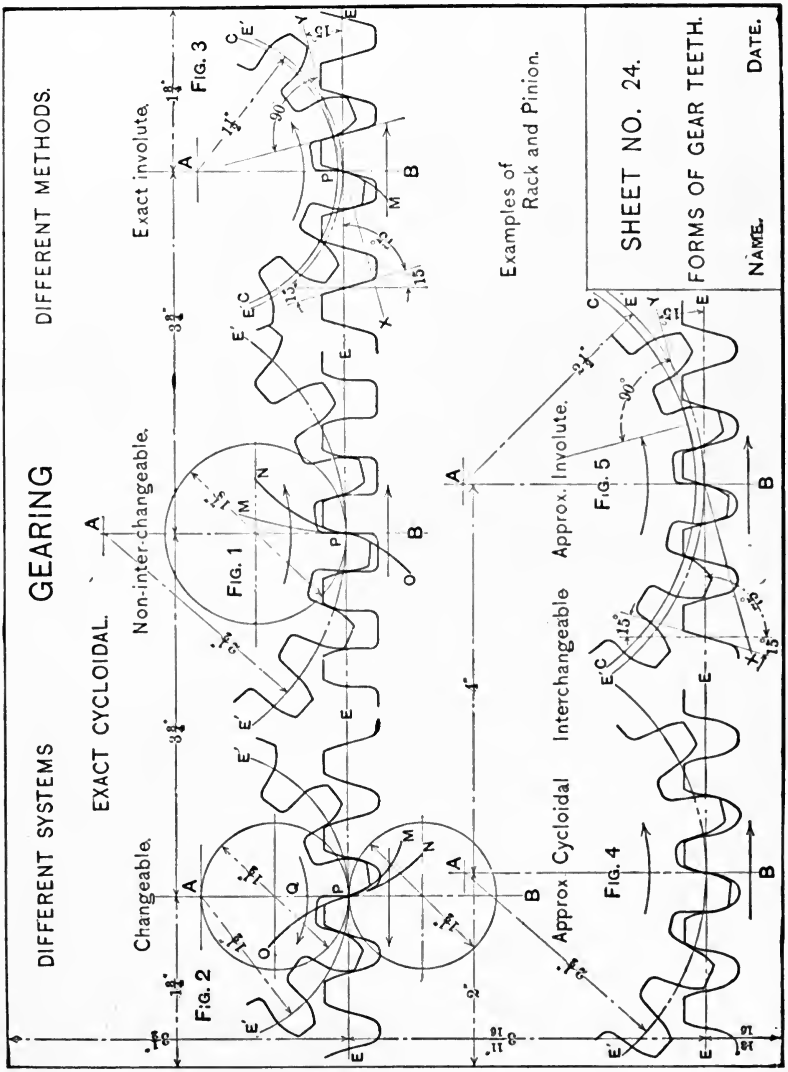

GEARING
DIFFERENT SYSTEMS
DIFFERENT METHODS.
EXACT CYCLOIDAL.
Changeable.
Non-inter-changeable.
Exact involute.
FIG. 2
FIG. 1
FIG. 3
Examples of
Rack and Pinion.
Approx. Cycloidal
Interchangeable
Approx. Involute.
FIG. 4
FIG. 5
SHEET NO. 24.
FORMS OF GEAR TEETH.
NAME.
DATE.

PLATE No. 51.

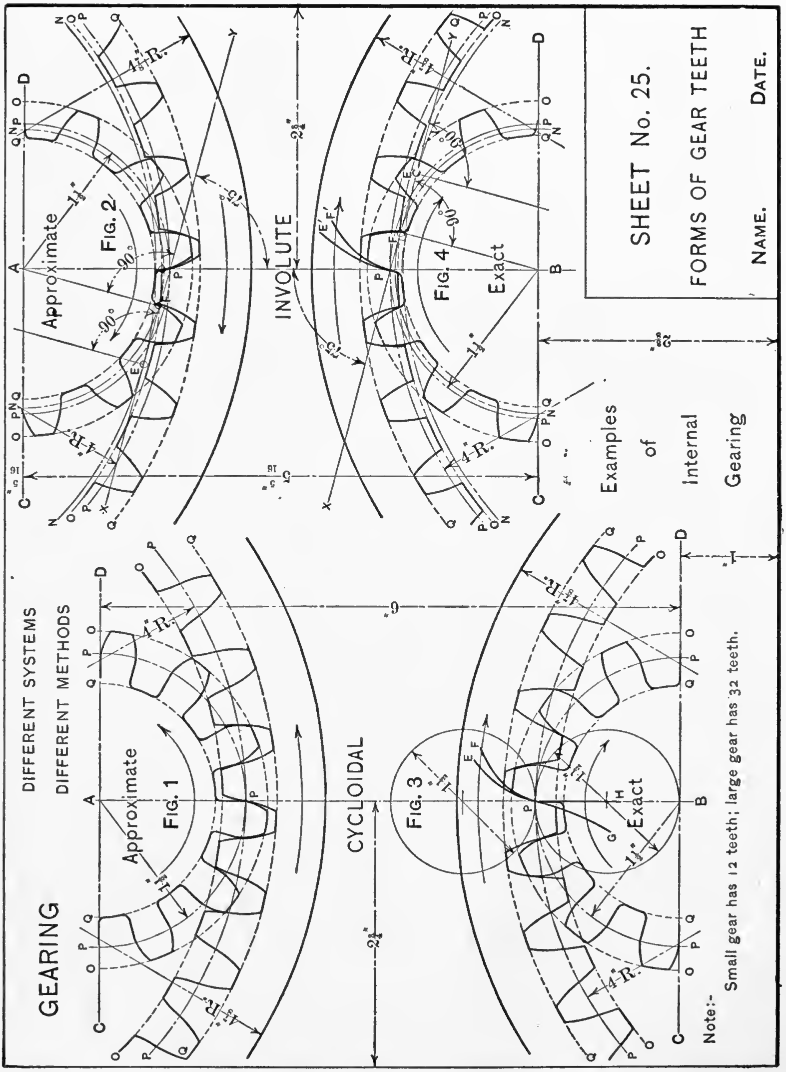
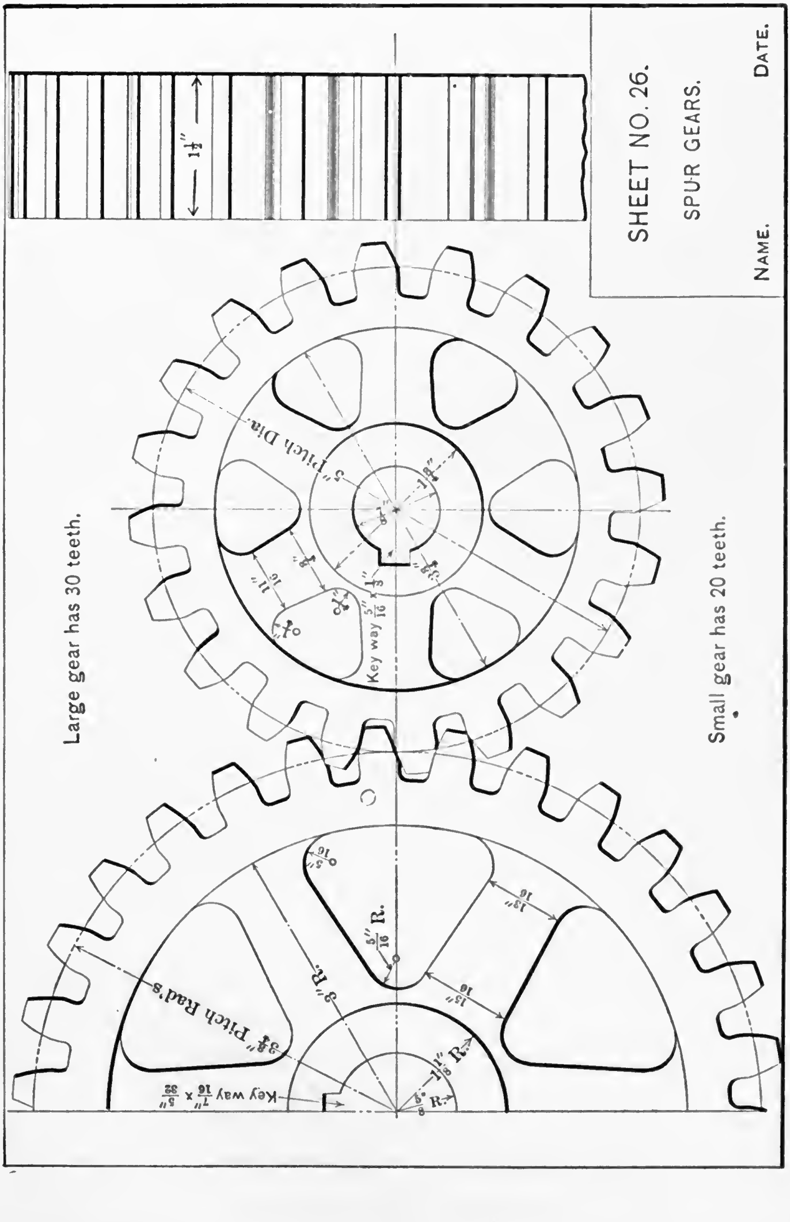

GEARING
DIFFERENT SYSTEMS
DIFFERENT METHODS
CYCLOIDAL
INVOLUTE
FIG. 1
Approximate
FIG. 2
Approximate
FIG. 3
Exact
FIG. 4
Exact
Examples of Internal Gearing
SHEET No. 25.
FORMS OF GEAR TEETH
NAME.
DATE.
Note:- Small gear has 12 teeth; large gear has 32 teeth.

PLATE No. 52.


SHEET NO. 26.
SPUR GEARS.
NAME.
DATE.
Large gear has 30 teeth.
Small gear has 20 teeth.
5" Pitch Dia.
3¾" Pitch Rad's.

wash, rubbing the stick of ink in the saucer; the tint should be inspected by sample on scrap-paper before applying.

The shaded row is washed in in accordance with one of the methods for shading given in Sect. 168. It should be noted that 7-*A* and 7-*B* are alike and are the light washes of the row, that 8-*A* and 8-*B* are alike and are a shade deeper than 7-*A* and 7-*B*, and that 9-*A* and 9-*B* are alike and are the heavy shade of the row.

The tinted row is washed in by first laying a flat wash over the entire rectangle, and when dry applying the shade as above.

In the flat wash (top row) let the paper be first washed with clear water for one or two spaces, that the student may note the effect; the remainder of the sheet may be washed in directly.

In executing the sheet, exercise great care in preserving the outline of the rectangles; should the color run outside, the edges may be straightened with a knife-point and eraser, a procedure, however, which does not add to the beauty of the sheet and is to be avoided if possible.

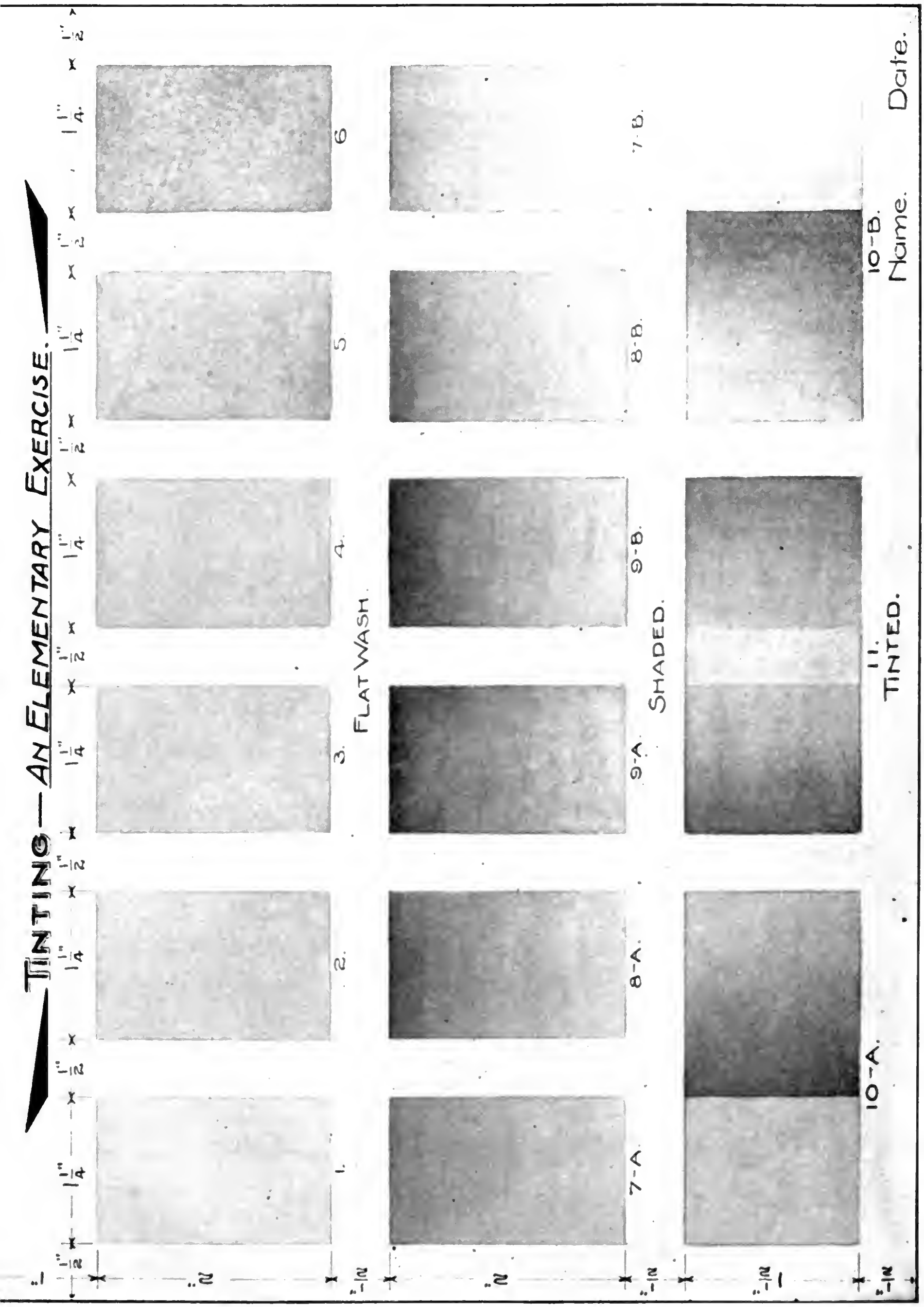
In inking, ink only the border-line of the sheet—not the borders of the rectangles—omit all dimensions, and finish the sheet by lettering the title and name only. When finished, cut the paper from the board with a $\frac{1}{2}''$ margin outside of the border-line on all sides.

Place the sheet number—SHEET NO. 27—in the upper right-hand corner.

220. Sheet No. 28, Plate No. 54.—This sheet is a wash drawing of plane surfaces which are parallel with, and inclined to, the plane of projection, and of concave and convex single-curved surfaces.

To wash Fig. 1, begin on the left with the proper tint and draw it out to the right, washing entirely across the rectangle; do not attempt to define the center edge. When dry, begin at the center with the proper tint and draw it out to the right. For 2, flat wash the parallel face and when dry shade the inclined sides as shown. For 3, lay on a light wash first, then treat each face in order according to the degree of shade. For 4, beginning

PLATE No. 53.


TINTING — AN ELEMENTARY EXERCISE.
FLAT WASH.
1.
2.
3.
4.
5
6
SHADED.
7-A.
7-B.
8-A.
8-B.
9-A.
9-B.
TINTED.
10-A.
10-B.
11.
Name.
Date.

at the left, draw out the tint to the right and entirely across the rectangle; when dry, begin at the right side and draw the tint to the left. For 5, flat wash the flat surfaces first, then shade as in 4.

The next row, representing end views of the figures in the top row, are all flat washes. For 6, flat wash the circular drawing, also the rectangular section, first cross-hatching it with the ruling-pen and the wash ink. The shading of this figure may be done according to the fourth method of Sect. 168. Fig. 7 is a flat wash of three tints. For Fig. 8, the circular drawing is a flat wash of two tints and the rectangular drawing a wash similar to the rectangular drawing of 6.

Directions for Drawing.—Lay out the sheet, according to the dimensions, in light pencil; wash all flat surfaces first, then shade as directed above. In inking, ink the border only, and finish the sheet by lettering the title and name.

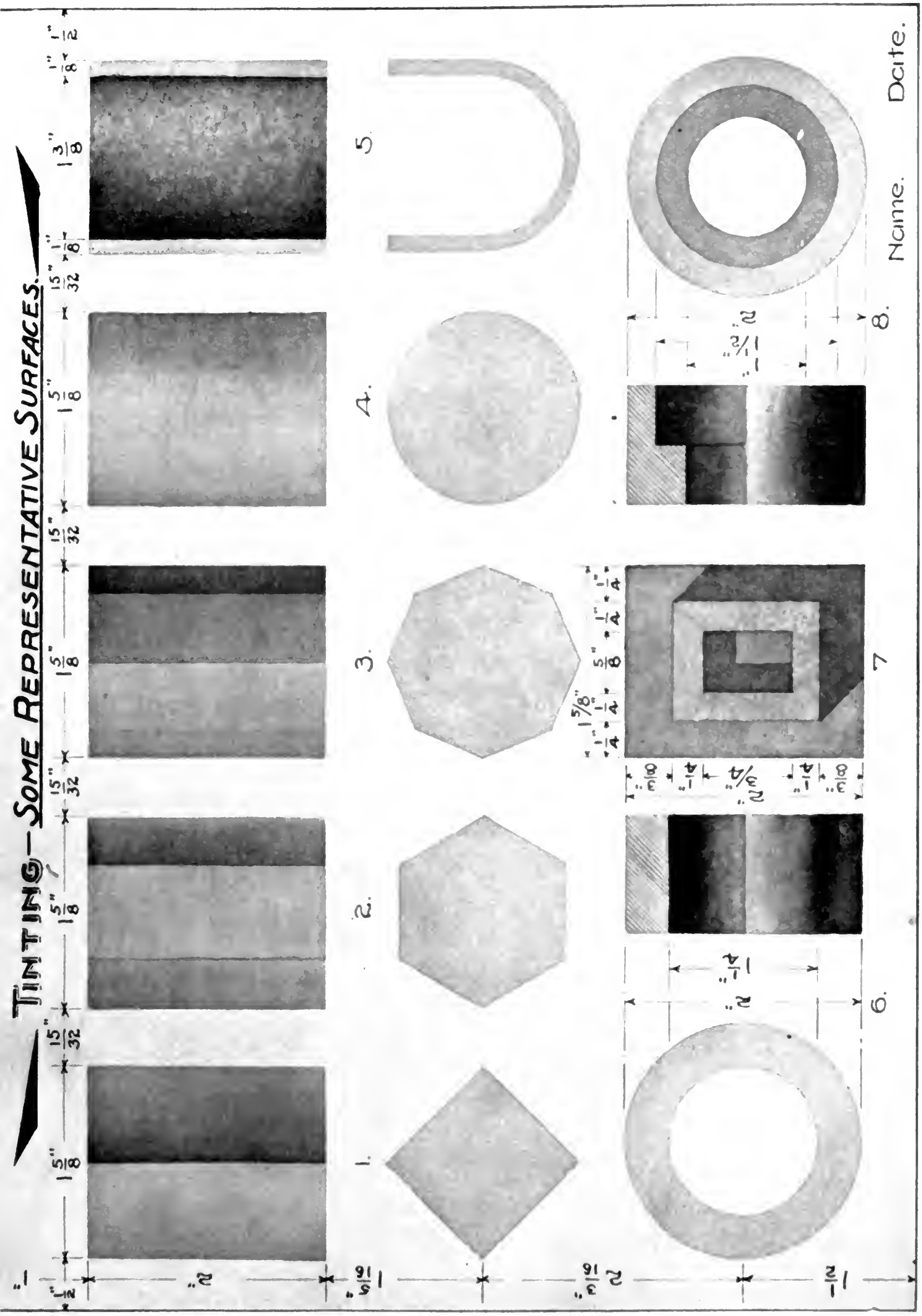
Place the sheet number in the upper right-hand corner.

221. Sheet No. 29, Plate No. 55.—This sheet illustrates certain well-known mechanical details, washed in as for catalogue illustration, and introduces the application of Chinese-white for bringing out the lines. Fig. 1 represents a coil spring, 2 a section of a cylinder disclosing a piston, 3 a portion of a square-threaded bolt, and 4 a hexagonal-headed bolt and nut—5 and 6 are end views.

To shade the spring, cross-hatch the sections with the ruling-pen, using wash ink, then flat wash them; shade the front of the spring first, then the parts showing at the rear. To shade, wash in one curvature at a time, i.e., consider the top wire extending across the front of the spring; beginning at the top, lay on a stripe of the tint all the way across, then draw it down at once; when the surface is dry, begin at the bottom line and draw up at once; again allow the surface to dry, then beginning at the left hand lay on the wash and draw it to the right at once; next, shade the right end in a similar manner.

The cylinder is shaded in a like manner, one curvature at a time. The section is cross-hatched, free-hand, with the tip of the brush, then flat-washed.

PLATE No. 54.



The thread is also shaded one feature at a time.

To shade the bolt and nut wash in all the flat surfaces, then shade as above.

The white lines are ruled in with the ruling-pen and Chinese-white ink; this is done the last thing.

Directions for Drawing.—Lay out the figures according to the dimensions, wash in as directed, and finish the sheet by lettering as shown. All dimensions are to be omitted.

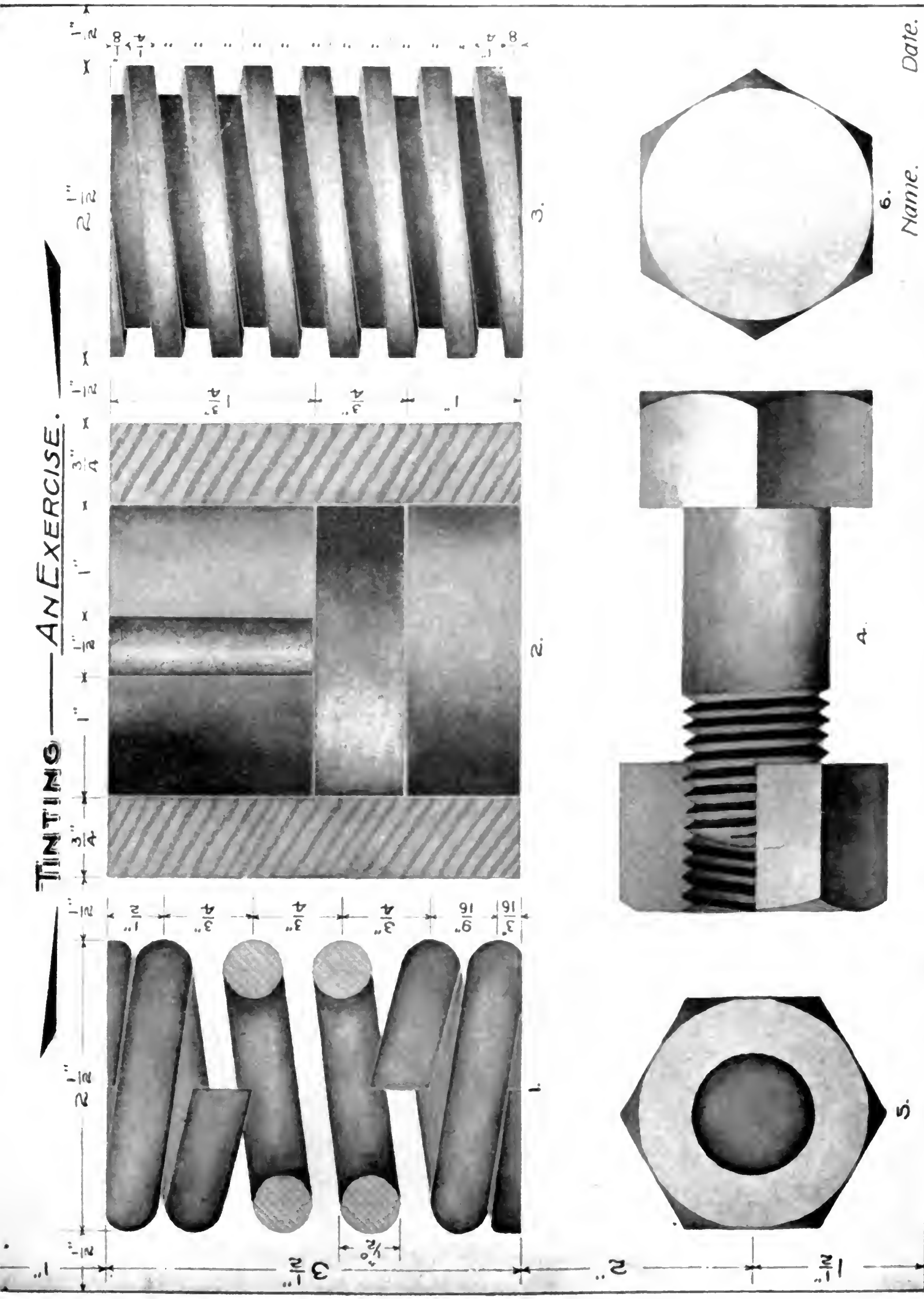
Place the sheet number in the upper right-hand corner.

222. Sheet No. 30, Plate No. 56.—This sheet is a first exercise in stippling—shading with dots. The plate shows a plan and elevation of a hexagonal prism, a hexagonal pyramid, a cone, and a cylinder. The figures are first drawn in outline on a duplicate sheet; that is, the figures are laid out in the same arrangement relative to one another and to the border-line as they will appear on the stippled sheet, and are then cut out as follows:

With a knife-point cut out the plan of the prism, cone, and cylinder (5, 7, and 8). The first and last are flat surfaces and are stippled uniformly by placing the "stencil" on the sheet, border to border, and the dots thrown through the openings as directed in Sect. 170. To shade the plan of the cone (7), mat out, with strips of paper, all of the exposed surface except a small sector in the part to be darkest; stipple this about as for the flat surfaces, drawing the shade at the radii; now increase the area of the sector, then stipple the exposed surface lightly again—this will cause the first shaded portion to grow darker. Continue increasing the size of the sector in this manner until the entire circle is exposed, when the view will have been shaded.

For the plan of the pyramid (6 , cut through the stencil on the lines representing the edges and part way through on the base-lines; with the stencil in position, fold back the lower right-hand triangle and stipple the exposed surface rather dark; now fold back the bottom triangle—the first remains open—and shade the exposed area; next fold back the upper right-hand triangle and shade the exposed surface; proceed in this manner, taking the faces in the order of the degree of shade and shade the

PLATE No. 55.



entire exposed area each time, thus causing the faces to grow darker in the order of exposure.

To shade the top row, 1, 2, 3, and 4, cut out the side faces of the prism and of the pyramid, and the outlines of the cone and cylinder; place the stencil in position and shade the exposed surfaces according to the copy, care being taken to protect each surface after stippling; these shaded, cut out the front face of 1 and 2 and stipple the exposed areas.

Directions for Drawing.—In stippling, it is important that the stencil be protected, that is, when stippling an area, mat out the surface of the stencil immediately about the opening with scrap-paper, thus keeping the moisture off the stencil, which if allowed on would cause it to blister. It is also important that the stencil have good contact with the paper to produce clean-cut lines; good results are obtained by laying small weights about the edges of the opening.

In inking, ink the border-line only, omit all dimensions, and finish the sheet by lettering it as shown.

Place the sheet number in the upper right-hand corner.

223. Sheet No. 31, Plate No. 57.—Here is depicted for "show" purposes a form of insulator (1, 2, and 3) and an ornamental cap (4, 5, and 6). The figures are first drawn on the stencil-paper, then the sheet executed in the following order:

Cut out 1, the interior of 2, the darkest circle of 3, all of 4, the interior of 5, and the center of 6; place the stencil on the sheet, border to border, weight the 1″ center of 1 and 3 in position, and shade the exposed areas according to the copy. Next cut out the section of 2 and 5, the second circle of 3, and all of 6, then shade. Now cut out the ends of 2, all of 3, and the double curved part of 5; mat out with scrap-paper the exposed parts already stippled, then shade; lastly, cut out the groove of 3 and the single curved surface of 5, mat out exposed parts, and shade according to the copy.

Directions for Drawing.—Ink the border-line only, omit all dimensions, and finish the sheet by lettering it as shown.

Place the sheet number in the upper right-hand corner.

PLATE No. 56.

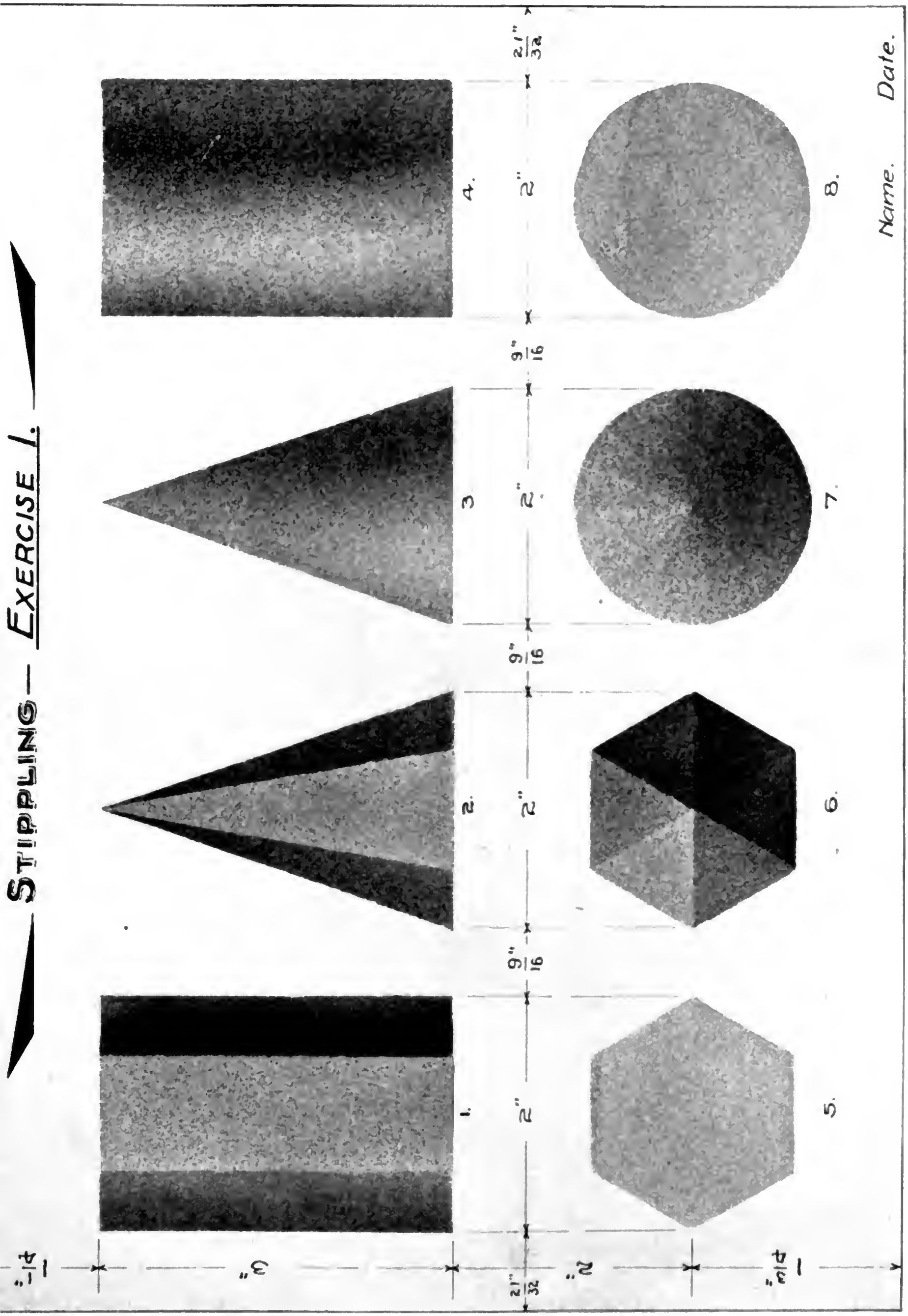
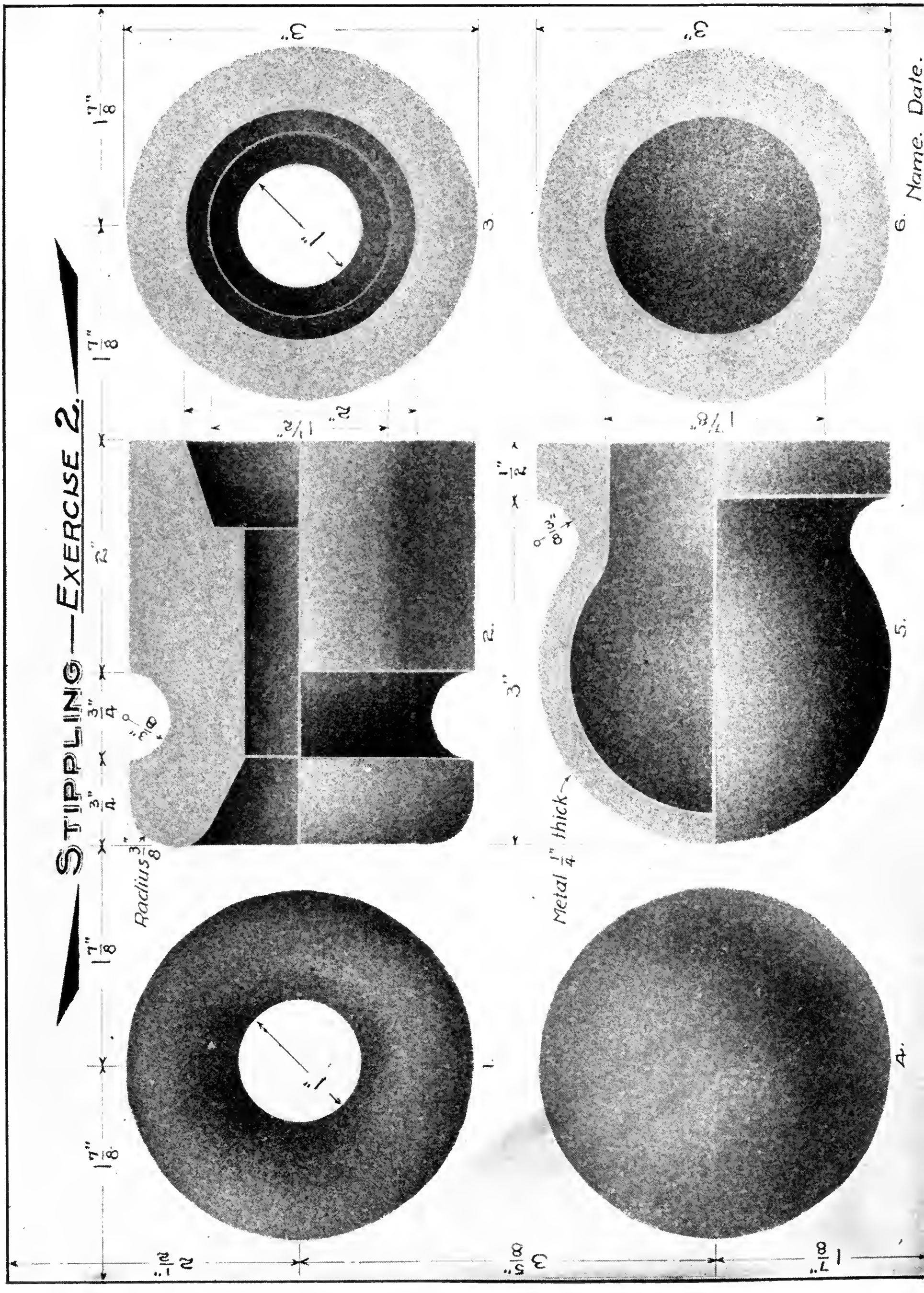

STIPPLING — EXERCISE I.
1.
2.
3
4.
5.
6.
7.
8.
2"
2"
2"
2"
9"/16
9"/16
9"/16
21"/32
21"/32
3"
2"
Name.
Date.

PLATE No. 57.



224. **Sheets Nos. 32 to 36, Inclusive.**—These are to be pen-and-ink scale drawings of the "working sketches" of the work in sketching, constituting what will be termed "shop drawings"—drawings for shop purposes. These drawings are to be prepared in pencil on paper, and then traced in ink on tracing-cloth, and later reproduced in blue-print.

Great care must be exercised in the preparation of these drawings to make them clear and complete in every detail, giving all necessary dimensions, notes, etc.

225. **Tables.**—To work most efficiently a draughtsman should surround himself with tabulated statements of much-used information; if he be a designer, he should have tables of the diameter, circumference, and area of circles, the weight per cubic foot of the various metals, dimensions of standard parts, etc. The student in elementary mechanical drawing, while not needing a complement of such information, often has occasion to know the dimensions of the nut and number of threads per inch for a bolt of certain diameter, the size of tap-drill, etc., the size of steam- and gas-pipe, with the corresponding threading, information for drawing gear-teeth, etc. The following tables are appended for reference in such cases:

STEAM- AND GAS-PIPE.

Normal Size.	Actual Inside Diameter.	Actual Outside Diameter.	Number of Threads per Inch
$\frac{1}{8}$	.27	.40	27
$\frac{1}{4}$	.36	.54	18
$\frac{3}{8}$	.49	.67	18
$\frac{1}{2}$	.62	.84	14
$\frac{3}{4}$	.82	1.05	14
1	1.05	1.31	$11\frac{1}{2}$
$1\frac{1}{4}$	1.38	1.66	$11\frac{1}{2}$
$1\frac{1}{2}$	1.61	1.90	$11\frac{1}{2}$
2	2.07	2.37	$11\frac{1}{2}$
$2\frac{1}{2}$	2.47	2.87	8
3	3.07	3.50	8
$3\frac{1}{2}$	3.55	4	8
4	4.03	4.5	8
$4\frac{1}{2}$	4.51	5	8
5	5.04	5.56	8
6	6.06	6.62	8

Taper of threads $\frac{3}{4}''$ per $1'$.

BOLTS AND NUTS.

Diameter of Screw.	Threads per Inch.	Diameter at Root of Thread.	Distance between Flats, Hexagonal or Square.	Diameter Across Corners, Hexagonal.	Diagonal of Square.	Tap-drill.
1/4	20	.185	1/2	37/64	11/16	3/16
5/16	18	.240	19/32	11/16	13/16	1/4
3/8	16	.294	11/16	51/64	31/32	5/16
7/16	14	.344	25/32	58/64	1 1/16	23/64
1/2	13	.400	7/8	1	1 1/4	13/32
9/16	12	.454	31/32	1 1/8	1 5/16	15/32
5/8	11	.507	1 1/8	1 7/32	1 1/2	17/32
3/4	10	.620	1 1/4	1 7/16	1 3/4	5/8
7/8	9	.731	1 7/16	1 21/32	2 1/32	3/4
1	8	.837	1 5/8	1 7/8	2 5/16	27/32
1 1/8	7	.940	1 13/16	2 3/32	2 1/2	31/32
1 1/4	7	1.065	2	2 5/16	2 27/32	1 3/32
1 3/8	6	1.160	2 3/16	2 17/32	3 3/32	1 3/16
1 1/2	6	1.284	2 3/8	2 3/4	3 3/8	1 9/32
1 5/8	5 1/2	1.389	2 9/16	2 31/32	3 5/8	1 13/32
1 3/4	5	1.490	2 3/4	3 3/16	3 29/32	1 1/2
2	4 1/2	1.712	3 1/8	3 5/8	4 7/16	1 3/4
2 1/4	4 1/2	1.962	3 1/2	4 1/16	4 31/32	1 31/32
2 1/2	4	2.175	3 7/8	4 1/2	5 1/2	2 3/16
2 3/4	4	2.425	4 1/4	4 29/32	6	2 7/16
3	3 1/2	2.628	4 5/8	5 3/8	6 3/16	2 5/8
3 1/4	3 1/2	2.878	5	5 13/16	7 1/8	2 29/32
3 1/2	3 1/4	3.100	5 3/8	6 7/64	7 5/8	3 1/32
3 3/4	3	3.317	5 3/4	6 21/32	8 3/16	3 11/32
4	3	3.566	6	7 3/32	8 11/16	3 19/32

Angle of thread = 60°. Thickness of nut = diameter of bolt. Thickness of head = one-half distance between flats.

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