Mechanical Drawing

by

John S. Rooke

Text Book

OF

Mechanical Drawing,

BEING

An Explanation of the Principles of Geometry and Ortho=
graphic Projection, the Helix, and Toothed Gearing as
they are applied by Mechanical Draughtsmen,
with Rules for Screw Cutting.

Compiled with Original Illustrations

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PRINTED FOR THE AUTHOR.

SPANGLER & DAVIS, PRS., PHILA

Introduction.

The purpose of this book is to aid pupils in the study of the principles underlying mechanical drawing. It is not intended to make the study easy, for the pupil cannot be benefited in that way. For that reason, though the drawings are made sufficiently accurate to serve as illustrations of the text, they are not so accurate or complete as to permit their use as flat studies to be merely copied without disclosing the copyist's ignorance of the principles intended to be taught. Nor are the explanations made so full and complete as to relieve the pupil of the necessity of thinking. In short, this book by its text and illustrations, will enable the earnest pupil to study the art and get a firm grasp upon the principles of projection, but it will be of no use to the careless pupil who seeks to skim over his studies and make nothing more than a show of understanding.

The subject is presented in a way that is likely to be interesting, and the problems set are of great practical value. The study is not an easy one—if it were it would be of less value than it is—but those who give it serious attention will soon find that what at first seemed hard to understand has become quite simple, and that they have been prepared by a thorough mastery of principles to understand and make the most complex mechanical drawings. This is the end in view. Copying from flat drawings is useful only as an exercise with the pen and other instruments; the mastery of the principles of projection gives the pupil the key to original work.

JOHN S. ROOKE.

Philadelphia, August, 1894.

Orthographic Projection.

Our first illustration is intended to show what is meant by orthographic projection; the pupil will hereafter have to imagine these planes represented by glass.

In fig. **h** we have a rectangular prism placed within a case of plates of glass upon which the projections of the prism are made. These plates of glass represent the planes of projection, and can be revolved about the axes **a b** and **b c**, until all are in one plane as in fig. **b**, which is called the plane of the paper. $\mathbf{h}^h$ is called the horizontal plane, a^v the front vertical, and c^v the side vertical. Suppose $\mathbf{c}^v$ to be revolved about **b c** until it is in the same plane as a^v, and that c^v and $\mathbf{a}^v$ are revolved about **a b** until they are in the same plane as $\mathbf{h}^h$, then we have fig. **b**.

The projections from all points of an object perpendicular to these planes of projection are called orthographic projections. The projection on $\mathbf{h}^h$ is called the top or plan, on $\mathbf{a}^v$ the front elevation, and on c^v the side elevation. It can readily be seen without any reference to the planes that these views are arranged as common sense would suggest, bringing the top to the top, the front to the front, and the side to the side.

In the illustrations the small letters h and v are used with all other letters to indicate in one case the horizontal and in the other the vertical planes.

Fig. h

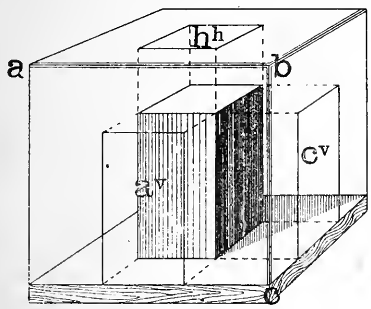
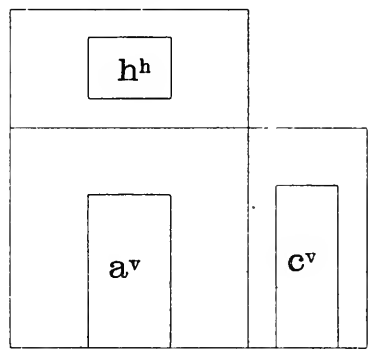


Fig. b



General Instruction.

The drawings should be made on sheets of paper 17 x 22 inches with margin lines ½ inch from the edge of the paper, which will make the measurement inside the margin lines 16 x 21 inches. The paper should be fastened on the drawing board with thumb tacks. One in each corner will be sufficient, care being taken to have the paper put on the board square, and as tightly stretched as possible.

The T square should be used with the head against the left edge of the drawing board (unless the person is left-handed) and the pencil be sharpened to a flat point, similar to a thin wedge, and always kept sharp. The pencil for the compass must be sharpened in the same way.

The drawing and compass pens must also be kept sharp and perfectly clean. Never lay them down or put them away without first cleaning them. A small piece of chamois is very good for this purpose.

All horizontal lines should be drawn with the T square, and all vertical lines with the triangle set against the upper edge of the T square.

All drawings should be made in pencil first, with as much care as though they were not to be inked. If a drawing is not penciled accurately and neatly, it cannot be expected to be neat after it is inked. Do not leave superfluous lead pencil lines on the drawing, but erase all except those to be inked.

The drawing having been finished in pencil, proceed to ink in. Fill the drawing pen with ink; then on a small piece of paper the same as that used for the drawing, try the pen until it makes such a line as is desirable for the work. Then with the straight edge about $\frac{1}{32}$ inch from the pencil line on the drawing, proceed with the inking, holding the pen as nearly vertical as possible. The pen should always be tested on the extra piece of paper, after filling, before it is used on the drawing.

All lines forming the object should be black; all construction and dimension lines, fine red. These red lines are shown on the plates by two dots and one dash, but on the drawings they are to be full lines. The centre lines should be fine blue lines. They are shown on the plates by one dot and dash, but on the drawings are to be full lines. Any part of the object outside of a cutting plane will be drawn with a long and short black dot.

All arcs should be inked first, as it is easier to draw a straight line to an arc, than to draw an arc to a straight line.

All figures and arrow points should be made in black ink with a fine writing pen.

The shape of a draughtsman's scale is such that when it is laid on the paper, the lines forming the divisions of the scale will come down to the paper, which enables the draughtsman to mark the dimensions directly from the scale. Dimensions may thus be marked off more quickly and accurately than by setting the dividers to the scale, and besides that the scale is thus preserved from being injured by the sharp points of the instruments.

Plate 1.

Fig. 1 represents full black lines to be drawn ¼ inch apart. The pupil will be careful to draw them off accurately and ink in carefully.

Fig. 2 represents full black lines to be drawn to the measurements given, using care to have them accurate.

Fig. 3 represents lines which the pupil will lay off to the measurements given. The first three lines represent a fine black line as used in drawing. The next three lines show how fine a red or blue line should be drawn. The first and last of the three should be drawn in red, and the middle one in blue. The next three lines represent shade lines, and should be drawn in black. The next three represent a fine black dotted line. The next three represent long and short dotted lines, and will be used to indicate parts of a figure which are cut off.

Fig. 4 is an exercise in section lining to represent cast iron, and is to be drawn in black.

Fig. 5 represents wrought iron. The section lining is to be in blue, three lines being drawn then a space left, followed by three more lines and a space, and so on until the drawing has been finished.

Fig. 6 represents steel. It is to be in blue, and drawn like fig. 5, except that the middle line should be dotted.

Fig. 7 represents brass, and the section lining is to be done in red, with two lines instead of three, and a space.

The lines forming the outlines of all of these figures will be in black ink.

Plate. 1

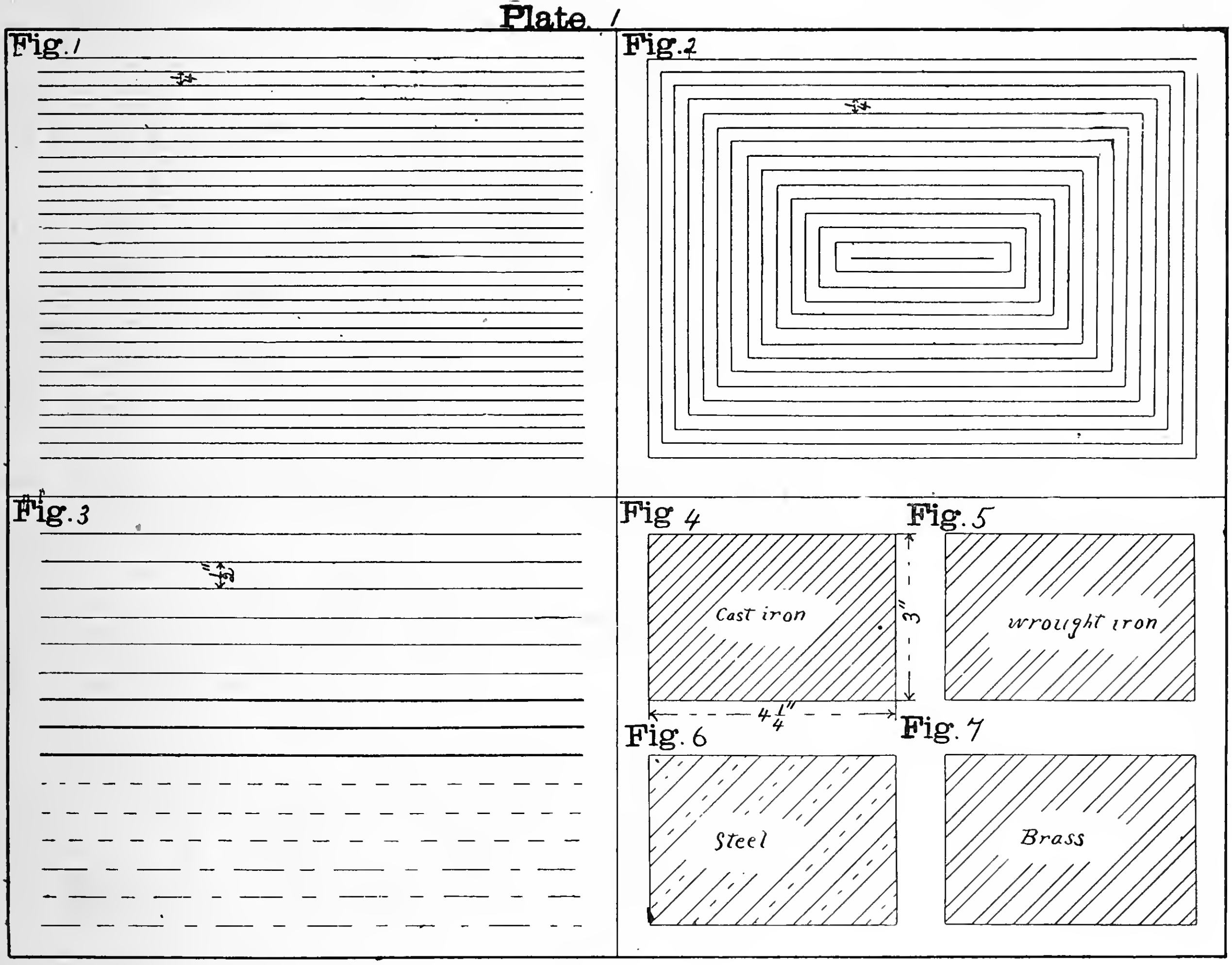


Fig. 1
Fig. 2
Fig. 3
Fig 4
Fig. 5
Cast iron
wrought iron
3"
4 1/4"
Fig. 6
Fig. 7
Steel
Brass

Plate 2.

Fig. 8. To bisect a straight line. Let **a b** be the straight line; then with **a** and **b** as centres, and any radius greater than one-half of **a b**, draw the two arcs **c** and **d**. A line through **c d** will bisect **a b**.

Fig. 9. To bisect an arc of a circle **a b c**. Join **a c** with a straight line, and proceed as in fig. 8.

Fig. 10. To draw a tangent to the arc of a circle when the centre is not accessible. Let **a** be the point on the given arc **d a c**. Lay off equal distances upon the arc from **a** to **c** and to **d**. Join **c** and **d**. From **d** as a centre, and radius **d a** draw arc **a g**; then with same radius and **a** as a centre, draw arcs **d b**, **c e**. Then make **d b** and **c e** equal in length to g **a**. A straight line through the points thus found will be tangent to **a**.

Fig. 11. To erect a perpendicular to a line **a b** from a point **a** or near its end. With **a** as a centre and any radius, draw the arc **d c**. With **d** as a centre and same radius cut **d c** in **c**. With **c** as a centre and the same radius, draw an arc over **a**. Then draw a line through **d** and **c**, producing it to meet the last arc in **e**. A line from **a** to **e** will be the perpendicular.

Fig. 12. To divide a straight line **a b** into any number of equal parts, say four. Draw **a c** at any angle with **a b**. Lay off on **a c** four equal spaces. Join **b** to the last point on **a c** and draw three other lines parallel to this line. They will cut **a b** into the required number of equal spaces.

Fig. 13. To bisect any angle as **a b c**. With **b** as a centre and any radius, draw arc **a c**, then with **a** and **c** as centres and any radius greater than one-half **a c**, draw arcs intersecting in **d**. Draw **b d**.

Fig. 14. To construct an angle equal to a given angle **e b c**. Draw any line as **d e**. With **b** as a centre and any radius, cut the sides of the given angle in **c** and **e**. With **d** as a centre and same radius, draw arc **e b**. With **c e** as a radius and **e** as a centre, cut arc **e b** in **b**. Join **d** and **b**.

Fig. 15. When two straight lines, as **a b c d**, cross each other, the opposite angles are equal.

Fig. 16. To divide a circle **a b** into twelve equal parts with the T square, and 30° x 60° triangle. Draw **a b** with the T square. Next draw **e e** with the short side of the triangle on the T square, and the next longest side directed to the centre of the circle. Draw **c c** and **g g** with either of the long sides of the triangle on the T square, and the other directed to the centre of the circle. Draw **d d** and **f f** with the shortest side of the triangle on the T square, and the longest side directed to the centre of the circle.

Fig. 17. To draw this square draw the circle first, then with the T square and triangle draw horizontal and vertical lines tangent to the circle.

Fig. 18. To draw a hexagon with the T square and triangle. Draw the circle first, then with 30° x 60° triangle and T square, draw lines tangent to the circle.

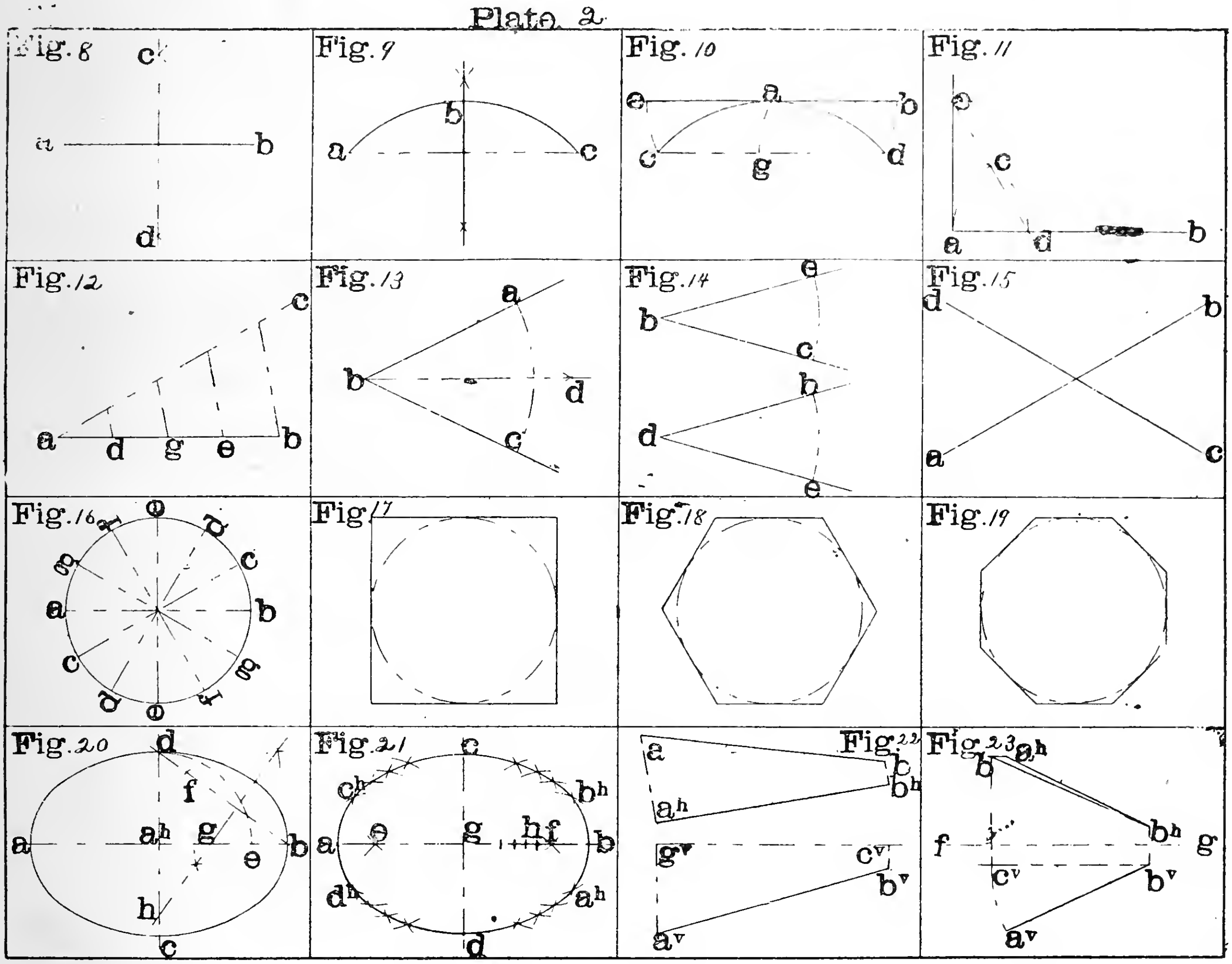
Fig. 19. To draw an octagon with T square and triangle. Draw the circle first, then with 45° triangle and T square, draw lines tangent to the circle.

Fig. 20. To draw an approximate ellipse. Let **a b** be the major axis and **c d** the minor axis of an ellipse. With $\mathbf{a}^h$ as a centre and radius $\mathbf{a}^h$ **d**, draw arc **d e**. Join **d b**. Make **d f** equal to **b e**. Bisect **b f** according to fig. 8, plate 2. Then **g b** will be the radius for the ends of the ellipse, and **h d** the radius for the sides.

Fig. 21. To draw an ellipse. Let a b be the major axis and d c the minor axis. With d as a centre and radius g a, draw arcs cutting a b in e and f which are the foci. Between g and f and g and e take any point as h, and with f and e as centres and radius h b, draw arcs as at a^h b^h d^h c^h, then with the same centres and h a as radius, draw arcs intersecting those first drawn. Take any other points between f and g and g and e, and repeat the operation as is shown. Through the intersections of these arcs draw the curve of the ellipse.

Fig. 22. To find the true length of a line when its projections are at an angle with both planes of projection. Let a^v b^v be the vertical projection of a line at any

Plate 2.



convenient angle, and a^h b^h the horizontal projection at any angle. Draw the horizontal line g^v c^v; project b^v to c^v and a^v to g^v. Draw b^h b and a^h a perpendicular to a^h b^h, then make b^h b equal to b^v c^v and a^h a, equal to a^v g^v. A line from a to b will be the true length of the line. If a line is paralled to one coördinate plane and oblique to the other, its projection on the plane with which it is parallel is equal to the true length of the line in space.

Fig. 23 is another method to find the true length of a line. Let a^v b^v, b^h a^h be the projections of a line. Draw the horizontal lines f g and b^v c^v. With b^v as a centre revolve a^v to c^v, then it will be parallel with the horizontal plane. Project c^v to b on a horizontal line through a^h. Then b b^h is the true length, and is its projection on the plane with which it is parallel.

Plate 3.

Fig. 24. To make a mechanical drawing of a block 4″ high by 3″ wide and 1¾″ thick.

NOTE.—When an object revolves parallel with a plane, its projections on that plane are in their true length, but when it makes an angle with the plane, its projections on that plane will not be in their true length. Therefore the first view of the object must be on the plane with which it is parallel, but as all the views in fig. 24 are parallel with all the planes, we can draw any of them first. In a case of this kind however, it would be well to draw the top or plan first.

Then let g^h g^h and f^v f^v be the axes about which the planes of projection revolve. Draw the plan to the dimensions given. Project a^h to a^v in the front elevation and produce it to b^v, making a^v b^v 4″ long and project d^h to d^v produced to c^v. Connect a^v d^v, c^v b^v, thus completing the front elevation. Now project a^h to f, and e^h to d, in f^v f^v. With centre g and radius g f, draw the arc f c; now with the same centre and radius g d, draw arc d a. Then c projected to the side elevation and intersected by the projection of the top of the block a^v d^v in the front elevation, will locate a^v in the side elevation, and a^v produced to intersect the projection of a will give e^v. The projection of the bottom of the block intersected by the projection from c and a, will give b^v g^v. Connect the points and complete the drawing.

Fig. 25. This is a drawing of the same block inclined at an angle of 30° with the side vertical plane. Here it will be oblique to the horizontal and side vertical planes, therefore we cannot draw either of these views first. But as it revolves through this angle it remains parallel with the front vertical plane, therefore it is on this plane we must draw the first view. Having found which plane to draw first, proceed to draw the block in full as shown in the front elevation. Then lay off the thickness in the plan and side views to the dimensions given, and from the corners in the front view project to the plan and side views, as a^v to a^h, and b^h and a^v to a^v and b^v. Follow the instructions of fig. 24 and complete the drawing.

Figs. 26 and 27 represent the same block in different positions and are drawn by the principles illustrated in figs. 24 and 25.

Plate 3

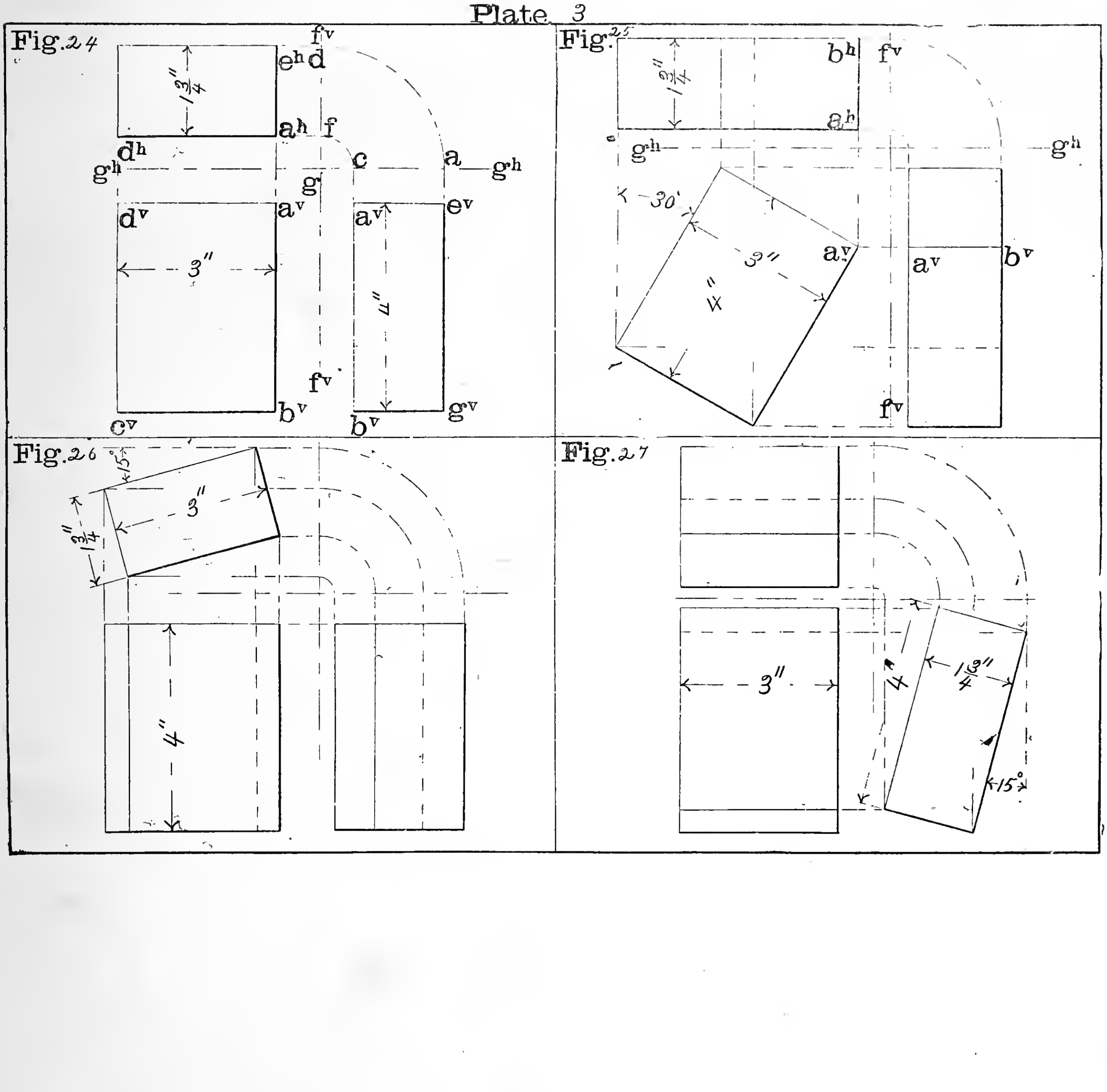


Plate 4.

Figs. 28 and 29 are drawings of a block to be drawn as shown from the instructions on figs. 24 and 25, plate 3.

Fig. 30. This is the same block revolved so as to make an angle of 15° with the side vertical plane. But a^v b^v in this revolution will remain the same distance from the front vertical plane, therefore it follows from what has been said respecting fig. 25 that the front elevation must be drawn first. Make a^v b^v, fig. 30, equal to a^v b^v, fig. 29, at an angle as shown. Then make a^v f^v, fig. 30, perpendicular to a^v b^v, fig. 30, and equal to a^v f^v, fig. 29. The distance a^v g^v, etc., is equal to a^v g^v, etc., fig. 29. From these points draw lines parallel to a^v b^v, also from b^v parallel to a^v f^v. To draw the plan: From a^v, g^v, etc., project fine lines which will pass through c^h, f^h, a^h, g^h. Now take the distances from the axis g^h g^h, fig. 29, to c^h, f^h, a^h, g^h and lay off these distances from the axis g^h g^h, fig. 30, on the lines already projected. They will locate the corresponding letters in fig. 30, and the points being connected will give the top of the block. The bottom is found in the same way. The side elevation can be projected from the views already drawn if c^h be projected to the axis f^v f^v, and from the intersection of f^v f^v with g^h g^h as a centre, we revolve c^h to g^h g^h. Project c^h down until it intersects c^v, projected from the front elevation, which will locate c^v in the side elevation. All other points are located in the same way.

Fig. 31. In this figure the block makes an angle of 15° with the front vertical plane. From what has already been said we see that the side view must be drawn first. Draw c^v e^v at an angle of 15° and equal to c^v e^v, fig. 30. Then draw a perpendicular c d and also a perpendicular a b from c^v e^v, fig. 30, about midway between c^v e^v. Make the distance from c^v e^v to a^v b^v, etc., measured on c d equal the corresponding distances in fig. 30. The distances from c d to c^v a^v, etc., are the same as from a b to c^v a^v, etc., fig. 30. Project c^v a^v, etc., to the front view and make the distance from f^v f^v to c^v a^v, etc., in the front view, fig. 31, the same as from f^v f^v to c^v a^v in the front view, fig. 30. The bottom is found the same way. The top view can be projected from the front and side views as the side view was projected in fig. 30.

Plate 4

Fig. 28

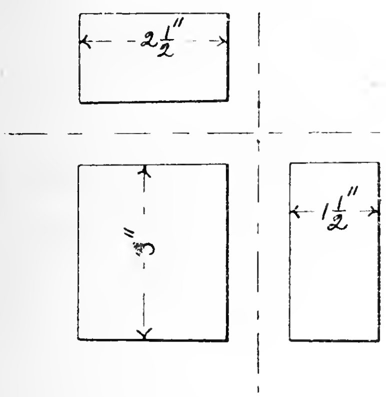


Fig. 29

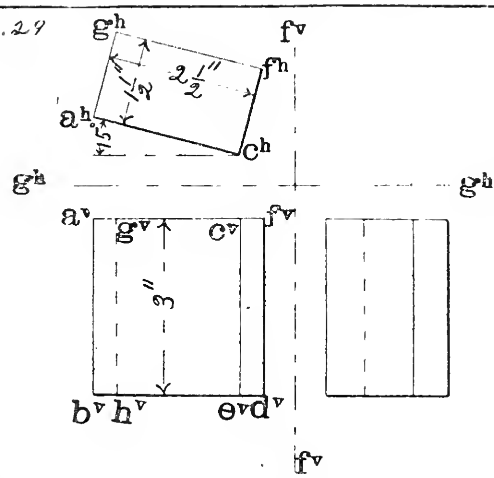


Fig. 30

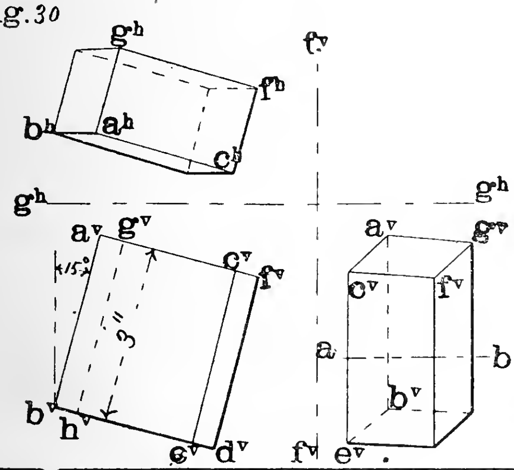


Fig. 31

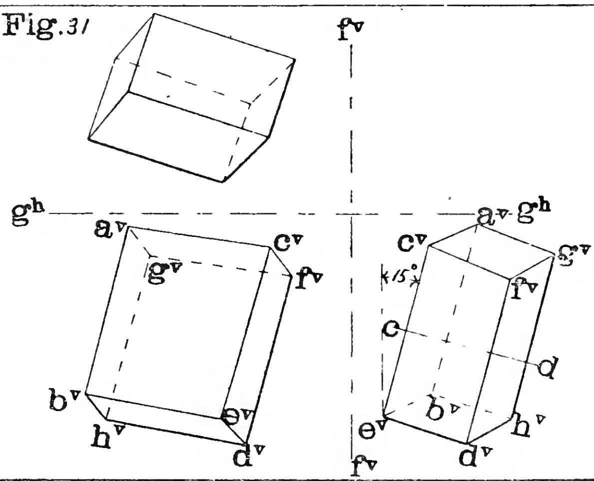


Plate 5.

Fig. 32. This is a drawing and development of a vertical cylinder, cut by a cutting plane at an angle of 45° as shown. The only explanation required is instruction for drawing the oblique view and the development. To draw the oblique view, draw parallel with a^v b^v the trace a^h b of the central vertical plane a^h b^h. Now the points a^v b^v can be projected to the trace a^h b perpendicular to a^v b^v. The distances on each side of a^h b will be the same as the distances of the vertical planes from a^h b^h. Now pass a number of auxiliary traces in the plan as shown, and where they intersect the circle of the cylinder project them down to the base in the front elevation and draw traces as shown. Then project their intersection with a^v b^v to the oblique and side views. Lay off from a^h b and e^v d^v the distances from a^h b^h to where the same traces intersect the circle of the cylinder. Through the points thus found draw traces in the oblique and side views, and where they intersect the traces which were projected from the front elevation will be points to draw the ellipse of the top end in the oblique view, also for the side elevation, which latter will be a circle. The ellipse in the oblique view is the true size of the section made by the cutting plane. The ellipse of the base in the oblique view is found in the same manner. To draw the development, which is the surface unfolded into one plane, draw a horizontal line in length equal to the circumference of the cylinder by calculation. Then divide it into as many parts as the circle is divided in the plan. From each one of these points erect perpendiculars the height of which will be equal to the corresponding lines in the front elevation. Draw the curve through the points thus found.

Fig. 33. This should be drawn without any further explanation. The corners of the prism will answer without any additional traces.

Plate. 5

Fig. 32

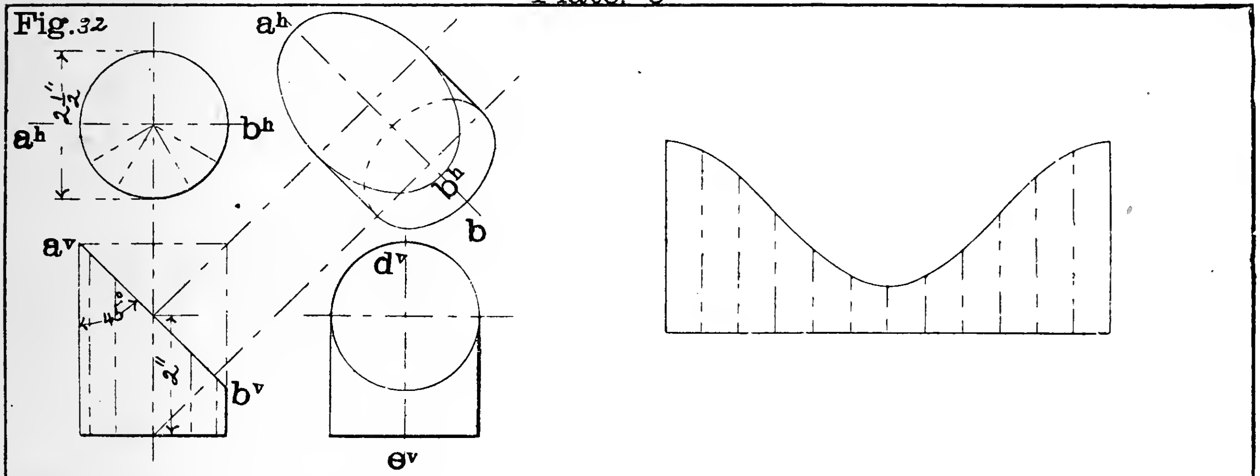


Fig. 33

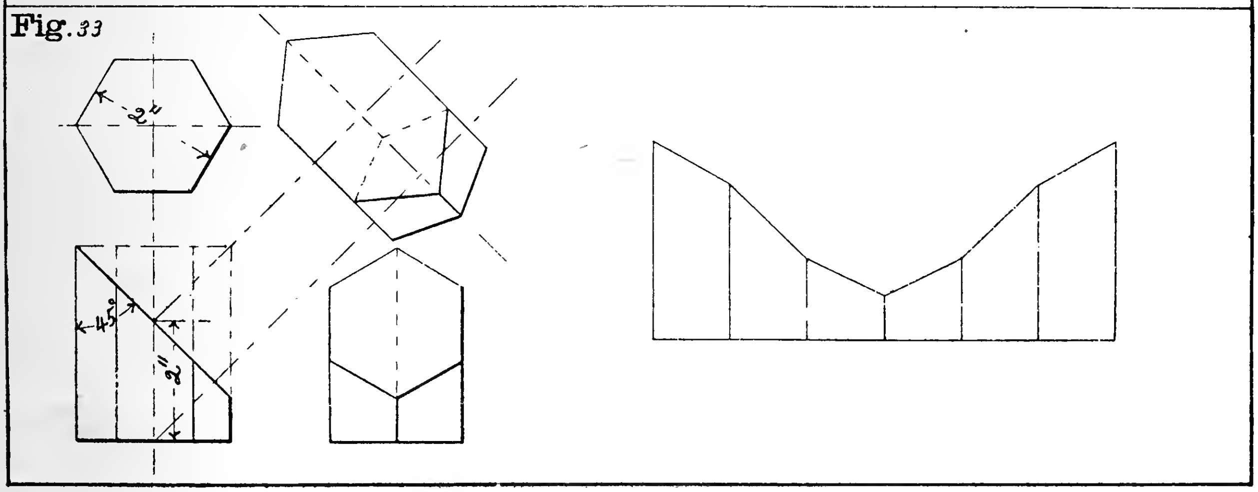


Plate 6.

Fig. 34. This is a drawing of a vertical cone of the dimensions given, drawn to locate the points c and **b**. Draw the plan and front views first. Now draw $\mathbf{a}^{v1}$ $\mathbf{b}^{v}$ which will be a trace of the central vertical plane $\mathbf{c}^{h}$ $\mathbf{b}^{h}$, parallel with the side of the cone, and will also be on a plane parallel with the side of the cone. Next draw the ellipse as instructed in fig. 32, plate 5. Then project the apex to $\mathbf{a}^{v1}$; from a^{v1} draw a trace through the apex of both cones and produce it until it intersects the base produced, as at $\mathbf{a}^{v}$. Project a^{v} to $\mathbf{a}^{h}$. From a^{h} draw a trace tangent to the base of the cone as at c^{h}. Project $\mathbf{c}^{h}$ to c^{v}. Then $\mathbf{c}^{v}$ projected to the ellipse in the oblique view will give c and **b**, and these are the points to which the sides of the cone a^{v1} c, $\mathbf{a}^{v1}$ b are to be drawn.

Fig. 35. This is a drawing of a hexagonal prism to the dimensions given. From what has already been said, the pupil should not have any trouble in being able to tell which view to draw first, and should also be able to finish the drawing without further instructions.

Fig. 36. This is a drawing of a vertical pyramid with a pentagonal base, cut by a cutting plane as shown. Draw the base in the plan as in fig. 36; then from each corner of the base draw lines to the apex **h**, which will be the corners of the pyramid. Draw a horizontal line $\mathbf{e}^{v}$ $\mathbf{d}^{v}$ which will be the base in the front elevation. If all the corners of the base in the plan are projected to the base in the front elevation as $\mathbf{e}^{h}$ to $\mathbf{e}^{v}$, the corners will be located in the front elevation, and lines from these points to the apex $\mathbf{a}^{v}$ will be the corners of the pyramid in that elevation. Now pass the cutting plane, and if the points where this trace intersects the corners of the pyramid be projected back to the corresponding lines in the plan as c^{v} to c^{h} all the points can be located in the plan except $\mathbf{f}^{h}$, which can be taken from the side elevation after it is drawn. Next draw $\mathbf{a}^{v}$ $\mathbf{a}^{v}$ in the side elevation, which will be a trace of the central vertical plane g^{h} g^{h}. The distance that $\mathbf{b}^{v}$ is from the central vertical plane $\mathbf{a}^{v}$ $\mathbf{a}^{v}$ is the same as the distance that b^{h} is from g^{h} g^{h}. All other points are found in the same way. From these points, draw lines to the apex. From the point where the cutting plane intersects the corners of the pyramid in the front elevation project to the corresponding line in the side elevation as c^{v} from the front to c^{v} in the side elevation. Now if the distance from $\mathbf{a}^{v}$ $\mathbf{a}^{v}$ to $\mathbf{f}^{v}$ be laid off from g^{h} g^{h}, the point $\mathbf{f}^{h}$ will be located. Connect all the points and finish the drawing.

Fig. 37. This is a drawing of a vertical pyramid from with an oblique view and should be drawn without further instructions.

Plate 6

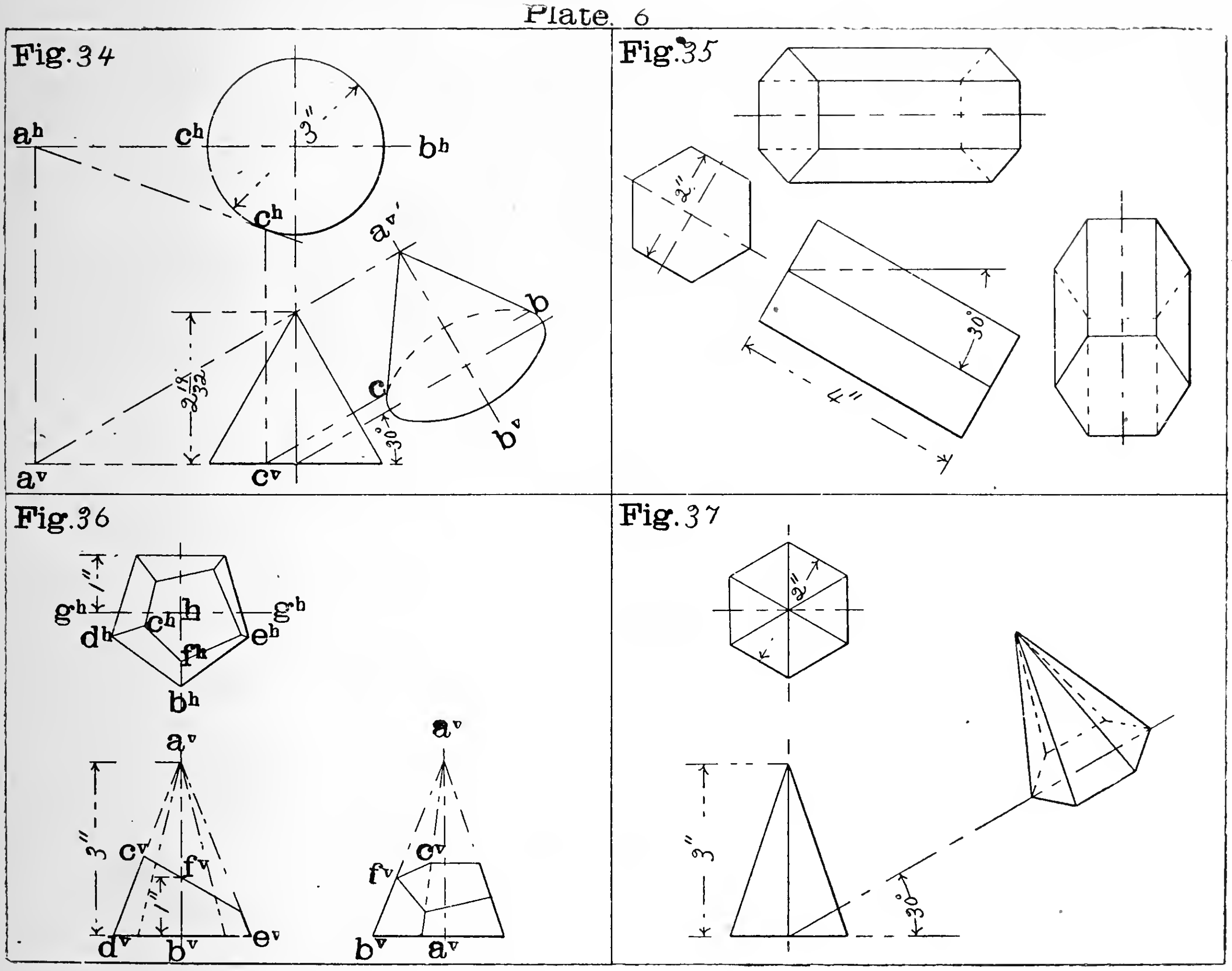


Fig. 34
aʰ
cʰ
bʰ
3"
cʰ
aᵛ'
b
c
bᵛ
2 19/32
30°
aᵛ
cᵛ
Fig. 35
2"
30°
4"
Fig. 36
1"
gʰ
cʰ
h
gʰ
dʰ
eʰ
fʰ
bʰ
aᵛ
3"
cᵛ
fᵛ
1"
dᵛ
bᵛ
eᵛ
aᵛ
cᵛ
fᵛ
bᵛ
aᵛ
Fig. 37
2"
3"
30°

Plate 7.

Fig. 38. This is a drawing and development of a vertical pyramid with a hexagonal base, cut by a cutting plane a^v b^v at an angle of 30° with the horizontal plane. In this figure all the points in the front elevation made by the cutting plane a^v b^v can be projected directly to the plan by projecting each point to the corresponding line, and similar projection may be made to the side elevation. If the pupil will make an oblique view of the top, parallel with the cutting plane a^v b^v, the true size of the section will be obtained. To make the development take the length of the corner e^v f^v as a radius, and with centre a in the development draw an arc. Lay off three times on either side of the central line the length of one side of the base taken from the plan and connect these points with straight lines. Then from these same points, draw lines to the apex a. As the line e^v f^v is the true length of the corners of the pyramid, and is the radius used for the development, all other measurements must be taken on the same line. With the **T** square project c^v d^v a^v to the line e^v f^v. Then the distance from the apex e^v to each one of these points, on the line e^v f^v, if laid off from a, on the development, will give the points from which to complete the figure.

Fig. 39. This is a drawing and development of a vertical cone cut by a cutting plane at an angle of 30° with the horizontal plane. All that is necessary here is to pass a number of auxiliary planes, and treat them exactly as the lines forming the corners of the pyramid, fig. 38. The length of the arc a^v b^v is equal to the circumference of the base of the cone, found by calculation. Follow the instruction in fig. 38 and complete the drawing.

Plate. 7

Fig. 38

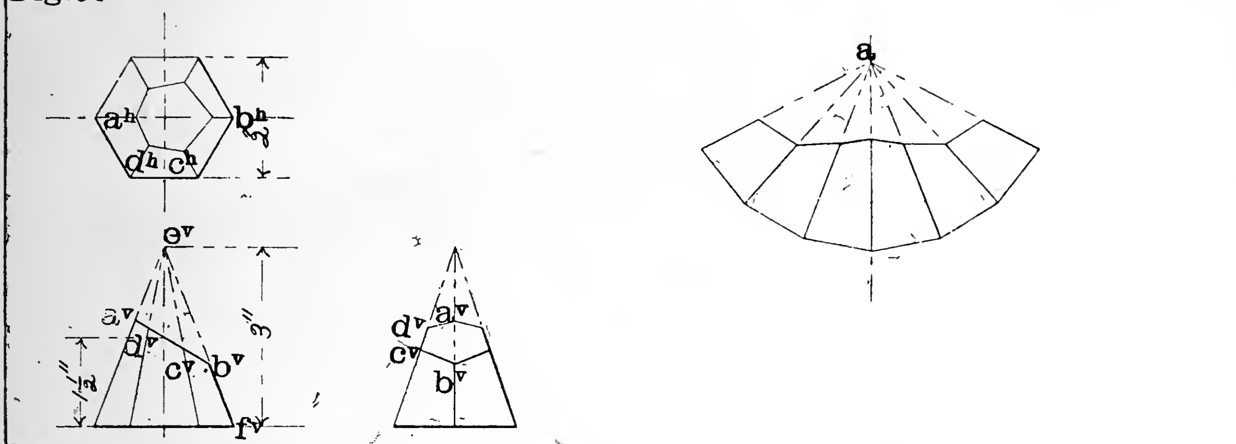


Fig. 39

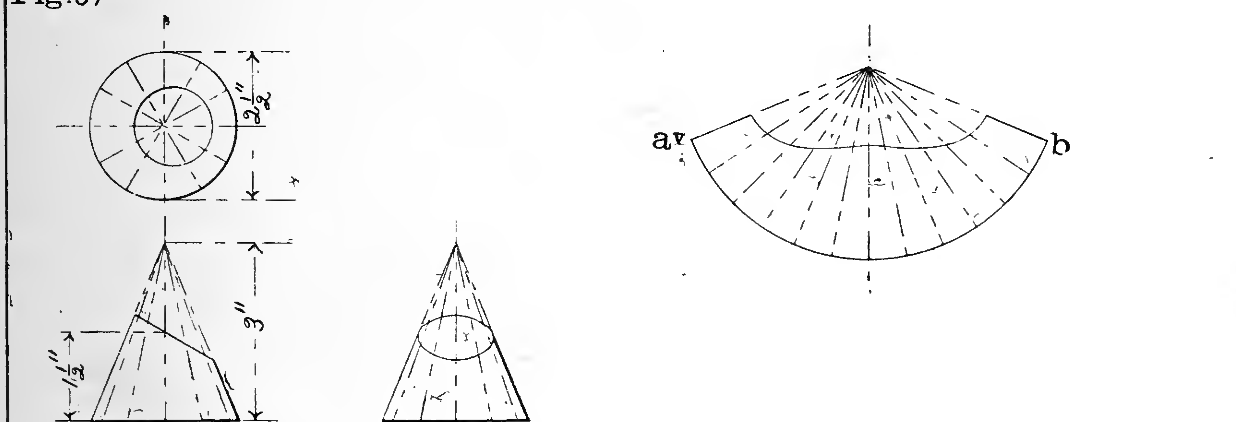


Plate 8.

Fig. 40. This is a drawing and development of a vertical cone of the dimensions given, cut by a plane parallel with the base. From what has already been said the pupil should be able to draw the three views. The development is made by taking the side of the cone a^v b^v as a radius, and drawing the arc a b. The length of the arc is to be made equal to the circumference of the base of the cone. Connect a and b with a^v, and with radius a^v c^v from the same centre as before, draw arc e^v d^v, thus completing the development.

Fig. 41. This is a drawing and development of a vertical cone of the dimensions given, cut by a vertical plane ½″ in front of the axis. The section in the front elevation made by this plane will be bounded by a curve, and in order to find this curve we must pass auxiliary planes. In this case they will be horizontal as shown by the traces in the front elevation, but will be circles in the plan. To find these traces in the plan project b^v to b^h, and with centre g^h and radius g^h b^h draw the trace a^h b^h. Where that trace intersects the line c^h d^h will be points to project back to the trace a^v b^v and will give c^v d^v, which are points in the curve. All other points are to be found in the same way. Through these points draw the curve, which will be a hyperbola.

To draw the development, draw traces as shown in the plan view, which will be the traces of vertical planes where they intersect the circle of the base. Project down to the base in the front elevation, and from these points draw traces to the apex which will be traces of the same vertical planes. Where these traces intersect the curve in the front elevation, project the intersection to the outside of the cone, which is the line g^v h^v. Draw the development as directed in fig. 40. On each side of the centre line in the development, lay off the arcs h^v f^v, etc., equal to the arcs h^h f^h, etc., and from these points draw lines to the apex, which will be traces of the same vertical planes. The points where the curve intersects these same traces in the front elevation are already projected to the outside of the cone g^v h^v. From g^v to each one of these points in g^v h^v will be the distance to lay off from the apex on the corresponding trace in the development. Through these points draw the curve of the development and thus complete the drawing.

Figs. 42 and 43 are drawn in the same way.

Plate. 8

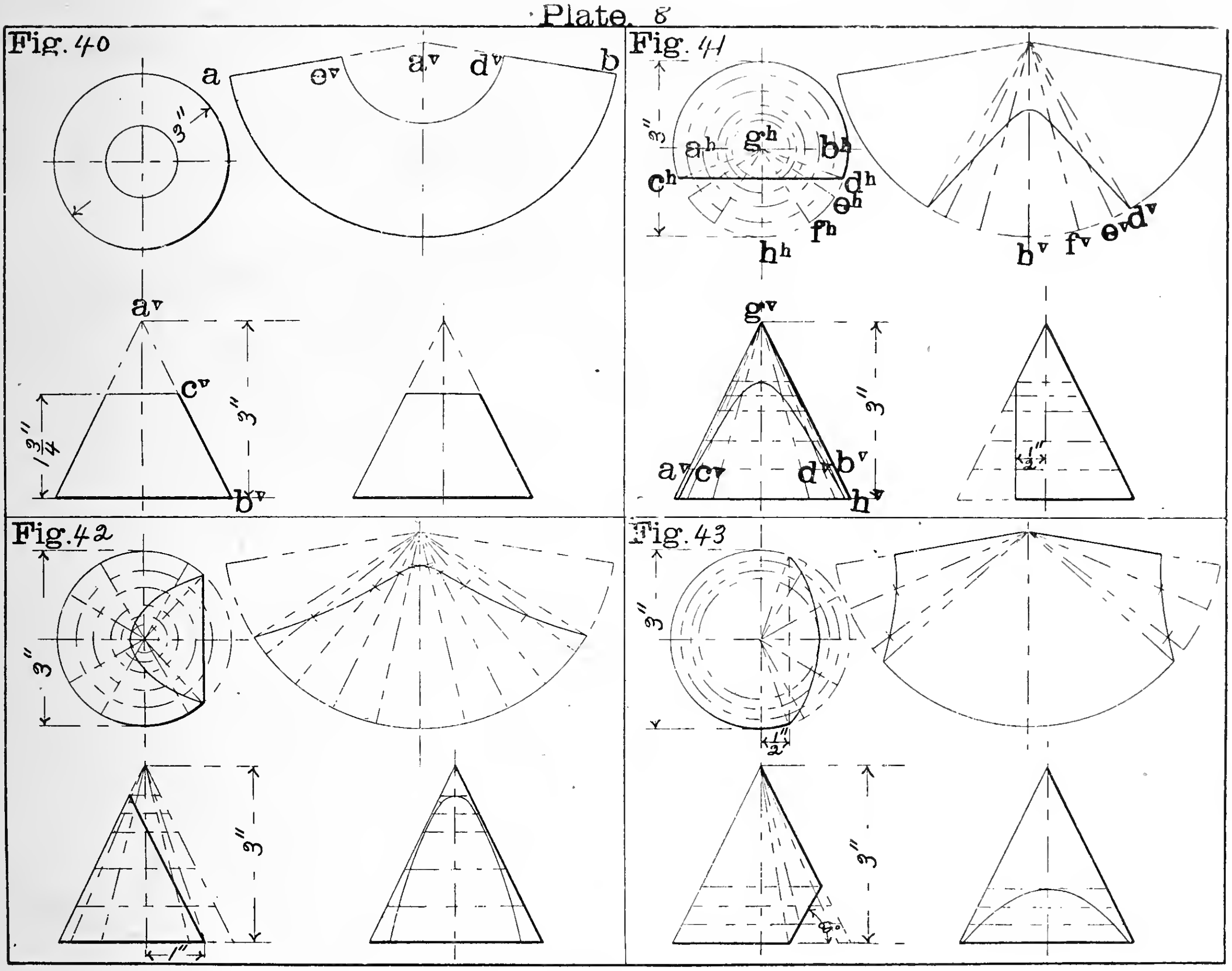


Fig. 40
a
eᵛ
aᵛ
dᵛ
b
3"
aᵛ
cᵛ
1 3/4"
3"
bᵛ
Fig. 41
3"
aʰ
gʰ
bʰ
cʰ
dʰ
eʰ
fʰ
hʰ
bᵛ
fᵛ
eᵛ
dᵛ
gᵛ
3"
aᵛ
cᵛ
dᵛ
bᵛ
hᵛ
1/2"
Fig. 42
3"
3"
1"
Fig. 43
3"
1/2"
3"

Plate 9.

Fig. 44. This is a drawing of a vertical cone to the dimensions given, and is drawn the same as the figures on plate 8. The oblique view is on a plane parallel to the cutting plane in the front elevation.

Fig. 45. This is a drawing illustrating the same principles as fig. 41.

Fig. 46. This is a drawing of a vertical cone intersected by a horizontal cylinder. To do this draw all three views in full first. Then in the side elevation draw traces a^v b^v, a^v d^v tangent to the cylinder. The distance from the central vertical plane to b^v laid off perpendicular to the central vertical plane in the plan will give the point b^h in the plan. Draw trace b^h a^h. Project b^h to b^v in the front elevation and draw the trace a^v b^v. Then c^v in the side elevation projected to the corresponding trace a^v b^v in the front elevation will give the point c^v, which is one point in the curve, and projected to the same trace in the plan will give c^h. All other points are found in the same way by projecting the intersection of the traces with the cylinder in the side elevation to the corresponding traces in the other views.

Fig. 47. This is a drawing of a vertical pyramid with a square base, intersected by a horizontal cylinder as shown. Draw the trace a^v b^v in the side elevation tangent to the cylinder. Then a^v b^v in the front elevation will be a trace of the same vertical plane. Draw as many more traces as are needed to find the curve of intersection, and proceed as in fig. 46.

Plate. 9

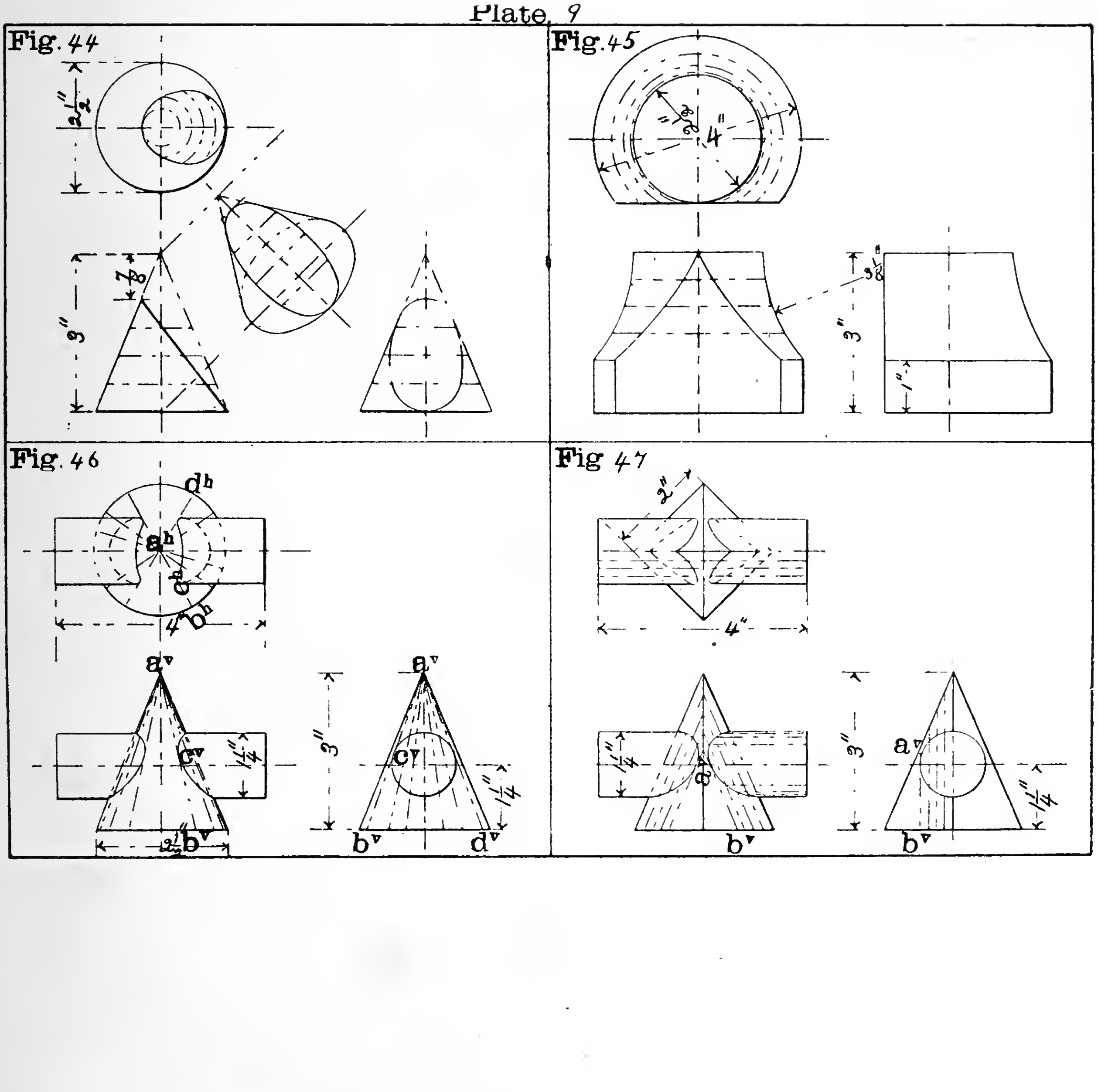


Plate 10.

Fig 48. This is a drawing and development of a vertical cylinder intersected on the right by a horizontal cylinder, and on the left by another horizontal cylinder as shown. If we draw a circle to the right in the plan to represent the end of the horizontal cylinder, and divide that circle into, say twelve equal parts, and through these points draw horizontal lines and produce them to the left until they intersect the vertical cylinder as shown, these lines will be traces of vertical planes, and a^h b^h will be at b^v c^v, a^v d^v in the front elevation. Where the same trace intersects the vertical cylinder in the point c^h, project c^h to the front elevation, which will intersect b^v c^v in c^v and a^v d^v in d^v, then c^v d^v are points which are common to both surfaces, and, therefore, points of intersection of the cylinders. All other points for both cylinders are to be found in the same way.

To draw the development, make the line e^v e^v in length equal to the circumference of the vertical cylinder, and e^v e^h equal to the height. Connect e^v e^v, e^v e^h, etc. Make e^v g^v equal to one-fourth of the circumference of the vertical cylinder, by making e^v h^v equal to f^h c^h and h^v c^v, etc., equal to c^h g^h, etc. From the points thus found erect perpendiculars as shown, and as many on the left of g^v, as there are on the right. The distance g^v a^v is equal to g^v e^v. All other points in the curve are found in the same way. Make g^v f^v equal to one-half of the circumference of the vertical cylinder. If the pupil understands what has already been said, there should be no difficulty in finishing this and drawing the other developments of the horizontal cylinders.

Fig. 49. This is a drawing and development of a vertical cylinder intersected on the right by a cylinder oblique to the horizontal plane, and parallel with the vertical plane of projection. It can be drawn by a close study of fig. 48.

Plate. 10

Fig. 48

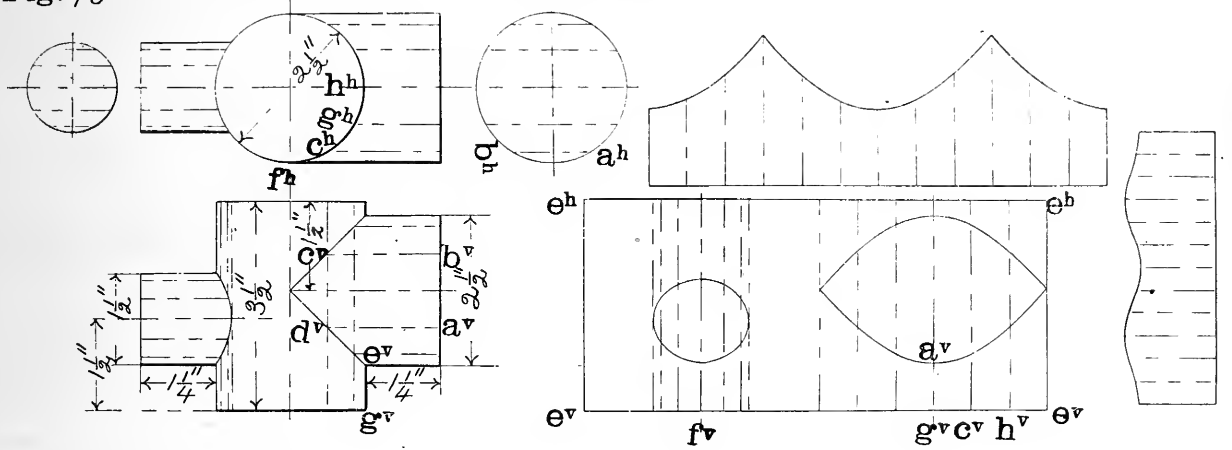


Fig. 49

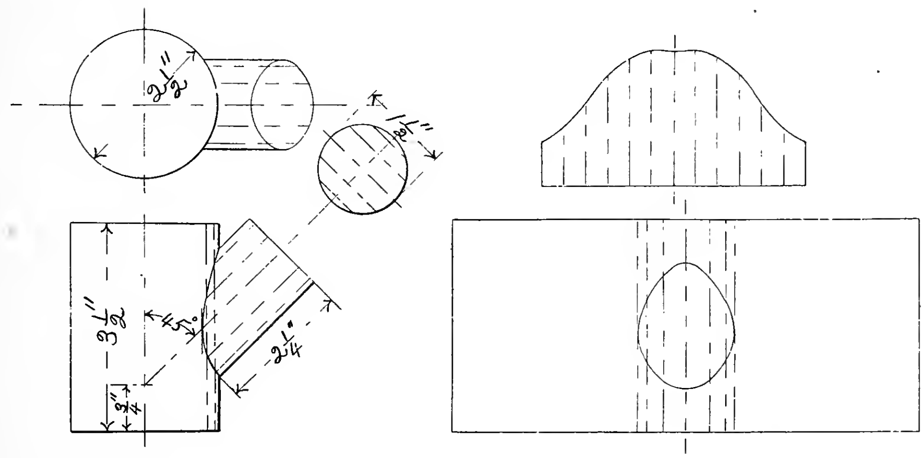


Plate 11.

Fig. 50. This is a drawing and development of a horizontal cylinder intersected by two vertical cylinders. The axis of the 2 inch vertical cylinder is ¼ inch in front of the axis of the horizontal cylinder, and 1½ inches from the end. The axis of the 1½ inch cylinder is ¼ inch behind the axis of the horizontal cylinder and 1½ inches from the end. By attentive study of this plate in connection with the explanation of plate 10, there should be no difficulty in making this drawing and the developments.

Plate. 11

Fig. 50

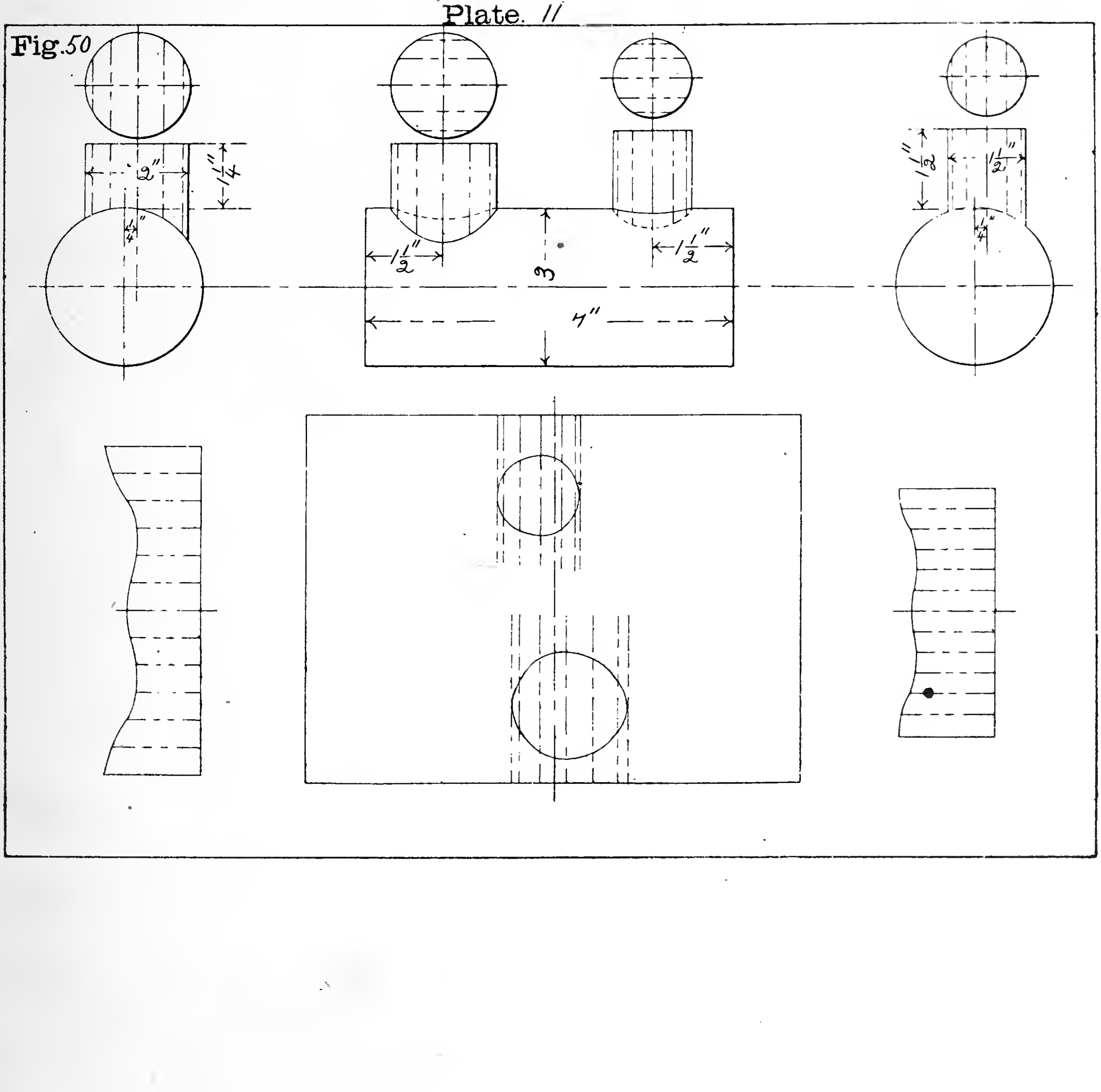


Plate 12.

Fig. 51. This is a drawing and development of a vertical cylinder cut by a cutting plane making an angle of 60° with the central vertical plane, and of dimensions and in positions shown. Divide the distance between the traces at the top and bottom of the cylinder in the plan into, say two equal parts, and draw the trace as shown. Divide the height into the same number of equal parts and draw the trace as shown. Make the projections to the front and side elevations, and through the points thus found draw the curves. To draw the development :—Draw traces in the plan of a number of vertical planes, say twelve, and project them to the front elevation. These traces are not shown, but by referring to the development, and turning back to fig. 32, plate 5, the pupil should have no difficulty in finishing the drawing.

Fig. 52. This is a drawing and development of an inclined cylinder with the base and top parallel with the horizontal plane, the axis making an angle of 60° with the horizontal plane and parallel with the front vertical. This will be left to the pupil to finish.

Plate 12

Fig. 51

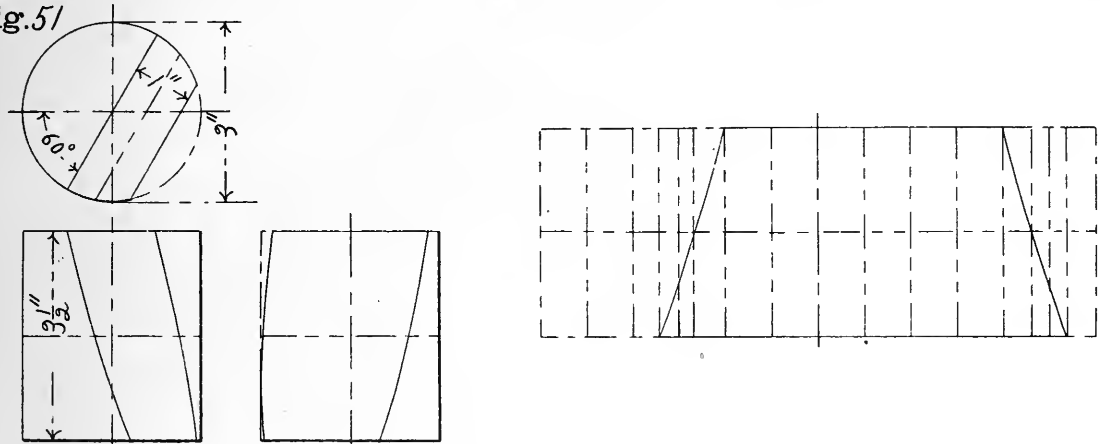


Fig. 52

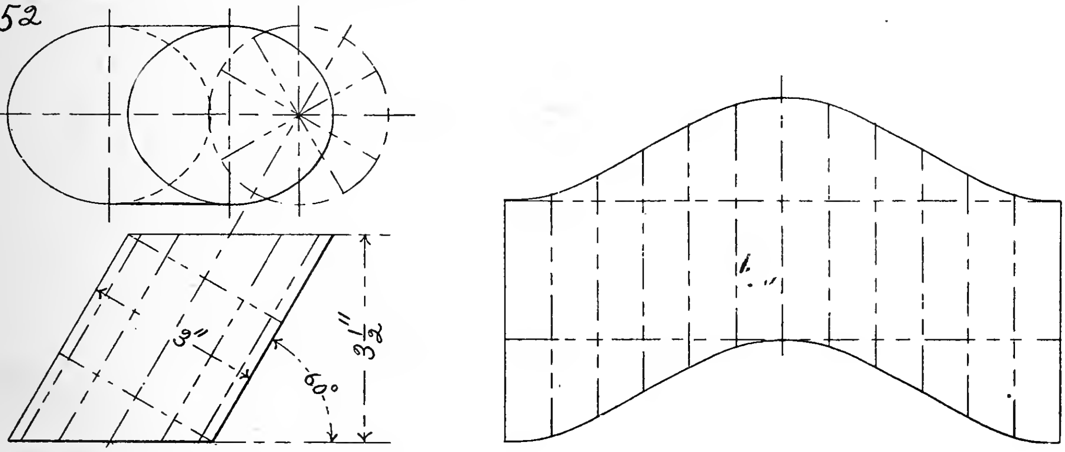


Plate 13.

Fig. 53. This is a drawing of a vertical hexagonal pyramid intersected by a horizontal cylinder. Draw all three views in full first. Divide each side of the base into four equal parts. From these points draw traces to the apex, which will be traces of vertical planes. Project their intersection with the base, to the base in the front elevation. From these points in the base draw traces to the apex, which will be traces of the same vertical planes. The traces in the side elevation will be the same distance from the central vertical plane a^v b^v as they are from the central vertical plane a^h b^h in the plan. Where these traces in the side elevation intersect the cylinder, project that intersection to the corresponding trace in the front elevation and plan as c^v c^v, c^v c^h, and complete the drawing.

Plate. 13

Fig. 53

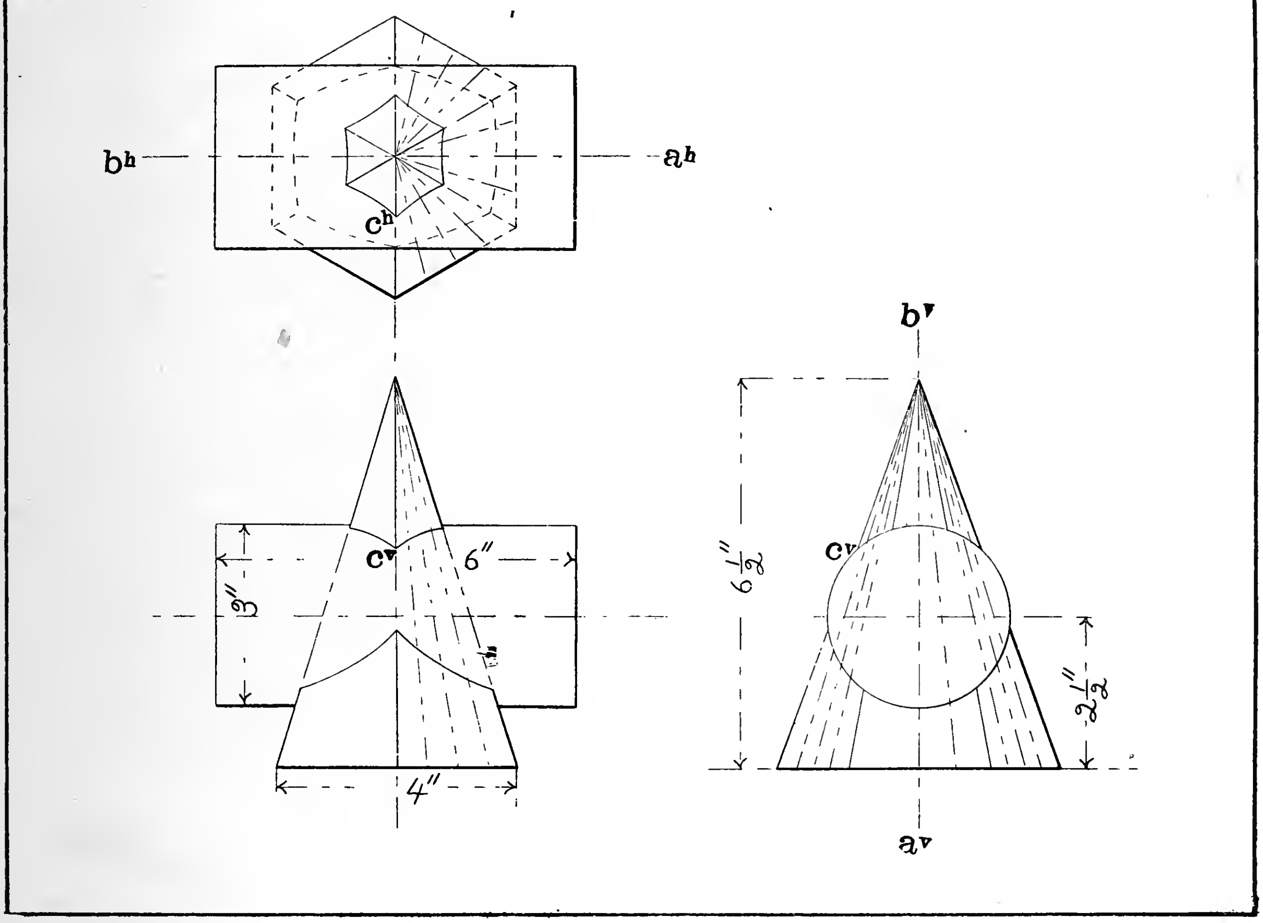


Plate 14.

Fig. 54. This is a drawing and development of a vertical hexagonal pyramid intersected by a cylinder. The axis of the cylinder is parallel with both planes of projection and ¼ inch in front of the axis of the pyramid. Draw all three views in full, and proceed as instructed in fig. 53, plate 13, except the trace a^v b^v, which is tangent to the cylinder in the side elevation. a^h is the same distance from the central vertical plane as $\mathbf{a}^v$ is from $\mathbf{f}^v$. The point c^v in the side elevation can be found by drawing a line through the centre of the cylinder and perpendicular to b^v $\mathbf{a}^v$. Then if it is projected to the same trace in the front elevation it will give c^v, and projected to the plan will give c^h. To draw the development of the pyramid, with b^v $\mathbf{h}^v$ as a radius and centre b^v in the development, draw an arc. With a distance equal to one side in the plan, lay off six spaces, connect these with straight lines, and also draw lines to the apex b^v, now these lines are equal in length to b^v h^v in the side elevation, and are also the corners of the pyramid. If the points where the lines which represent the corners of the pyramid intersect the cylinder be projected to b^v h^v, the distance from b^v to these points will be the distance to lay off on the corresponding lines in the development from b^v. On account of the curve in the development it will be necessary to draw lines in the development midway between those already drawn, which will be the same as the traces in the plan midway between the corners. Now b^v $\mathbf{h}^v$ is the true length of the corners, because it is parallel with the plane on which it is projected, therefore b^v $\mathbf{e}^v$ is the true length of b^h $\mathbf{e}^h$ and all other lines midway between the corners. If the points where the curve of intersection intersects these traces in the front elevation be projected to b^v e^v, the distance from b^v to these points will be the distance to lay off on the corresponding line in the development from b^v. The line g^h c^h is the distance in the development that c^v is from b^v, and is found by making g^h b^h equal to c^v $\mathbf{f}^v$ and perpendicular to b^h a^h. Connect g^h c^h, draw curves through the points in the development and complete the drawing.

Plate 14

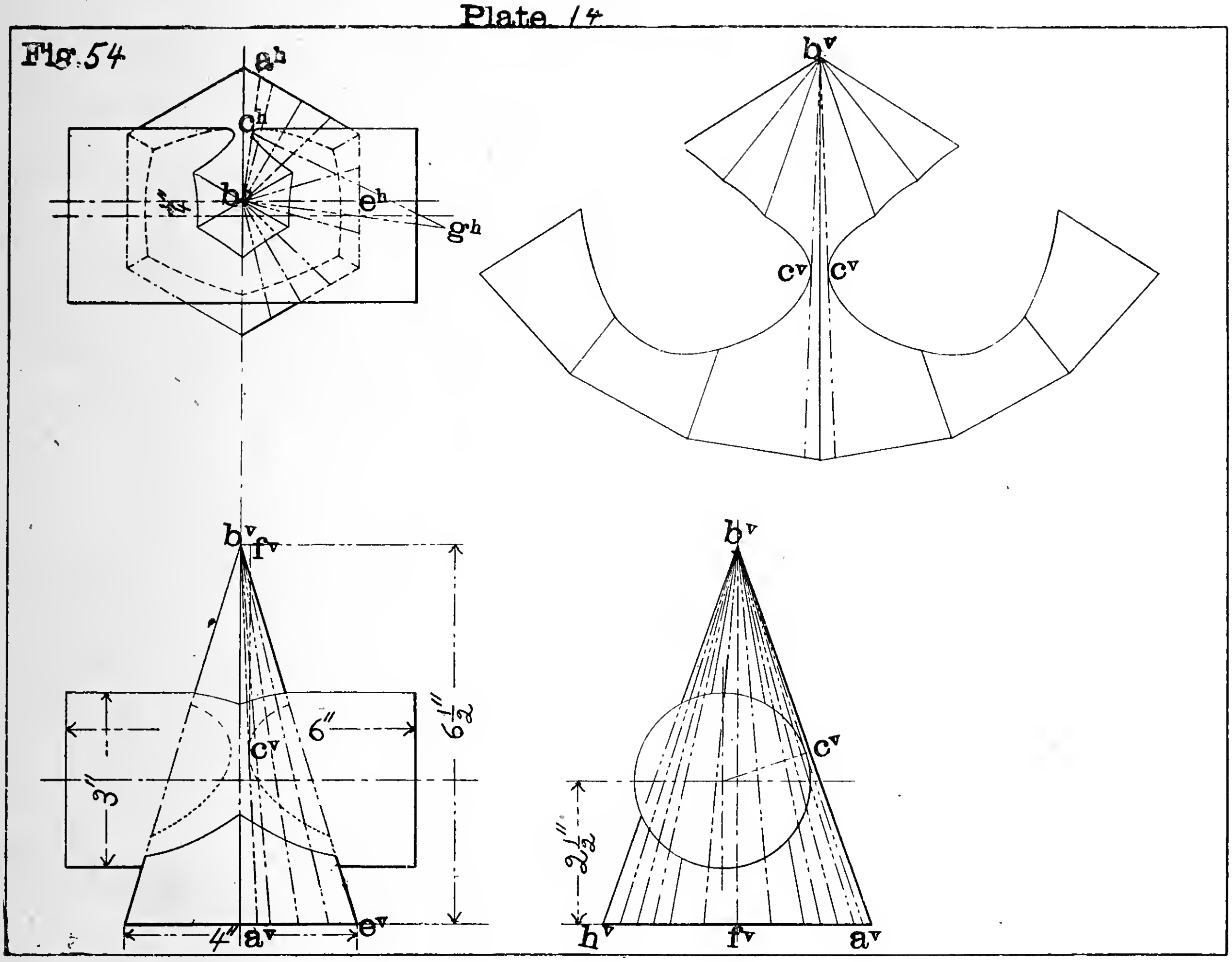


Fig. 54
a^h
c^h
b^h
e^h
g^h
b^v
c^v
c^v
b^v
f^v
c^v
6″
$6\frac{1}{2}''$
3″
4″
a^v
e^v
b^v
c^v
$2\frac{1}{2}''$
h^v
f^v
a^v

Plate 15.

Fig. 55. This is a drawing of a vertical pyramid with a triangular base, and the front side making an angle of 15° with the front vertical plane, intersected by a triangular prism with its axis parallel with both planes of projection, the front side making an angle of 15° with the front vertical plane and drawn to the dimensions given. If we use the line $f^v g^v$, which is the top corner of the prism, as the trace of a cutting plane, it will give a triangular section in the plan as $a^h b^h c^h$. Where the traces of this section intersect the line $f^h g^h$ (which is the same corner of the prism) will be points of intersection of the two solids, because $f^h g^h$ and $a^h b^h c^h$ are in the same plane, and these points $d^h e^h$ projected back to $f^v g^v$, will give the points $d^v e^v$ in the front elevation. All other points are found in the same way, except where the left corner of the pyramid is cut. Use the line forming the corner of the pyramid as the trace of a cutting plane, and where it intersects the lines of the prism project to the corresponding lines in the plan, which will give a section of the prism in the same plane as the corner of the pyramid is. Where the traces of this section intersect the corner of the pyramid will be the required points of intersection, and if projected back to the front elevation, will give the points there. The pupil should study these principles, as he will have many cases of their application.

Plate. 15

Fig. 55

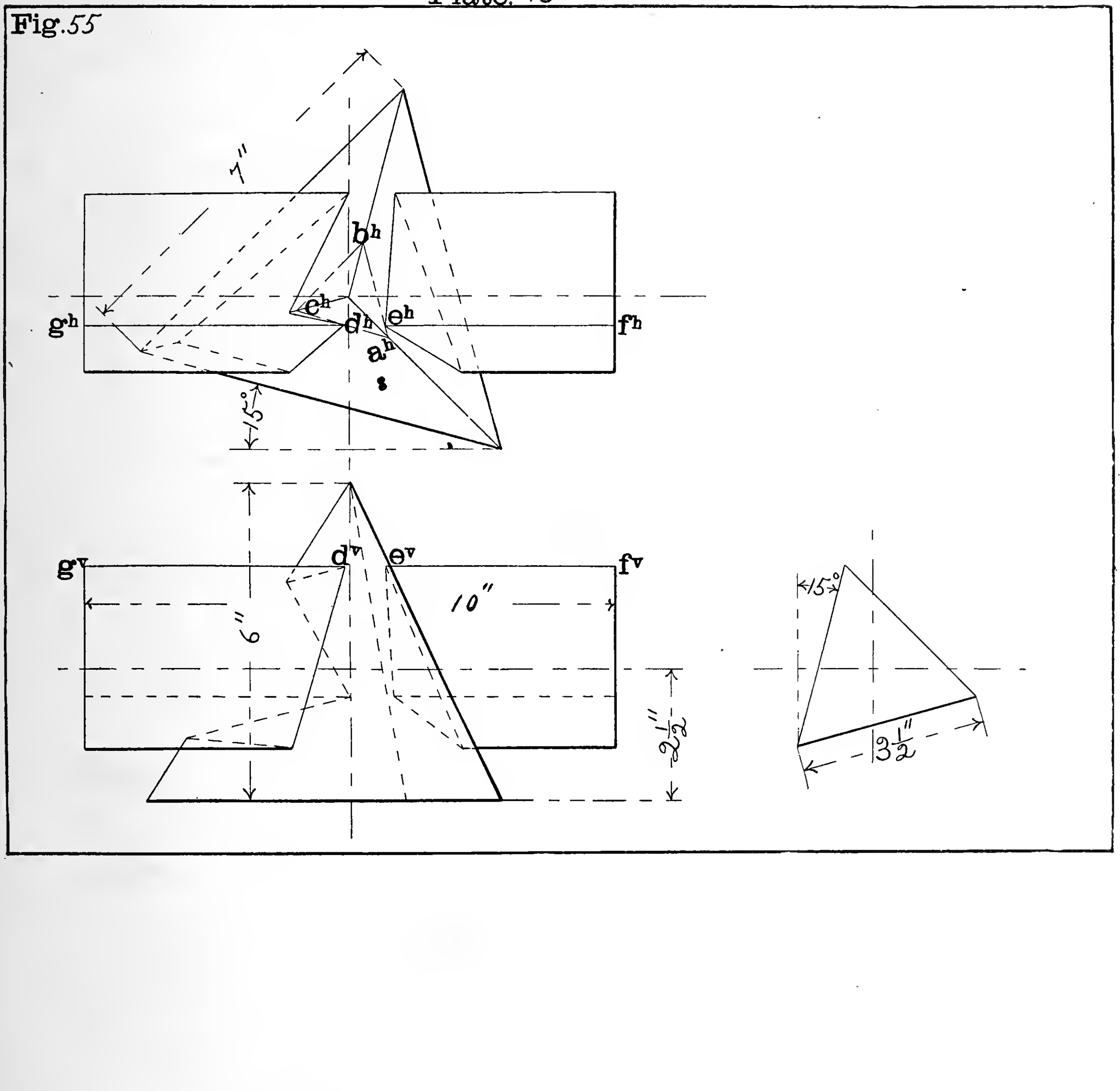


Plate 16.

Fig. 56. This is a drawing of a vertical pyramid with triangular base, making an angle of 15° with the side vertical plane, intersected by a triangular prism, the axis of which is parallel with the vertical plane, ½ inch in the rear of the axis of the pyramid and making an angle of 30° with the horizontal plane. The bottom side makes an angle of 15° with the horizontal plane. The intersection of these two solids can be found in the same way as fig. 55, plate 15, but there are other ways, and it would be well if the pupil would use other lines as traces of cutting planes. Suppose we use the line a^h b^h as the trace of a cutting plane. Where that trace intersects the base of the pyramid in the plan it should be projected to the base in the front elevation, and where the same trace intersects the front corner in the plan it should be projected to the corresponding line in the front elevation. Draw traces from that point to the points already found in the base, and where these traces intersect a^v b^v will be the required points of intersection, because they are in the same plane. If the pupil will have patience to find one point at a time in making these drawings, any of them should be handled without difficulty.

Plate. 16

Fig. 56

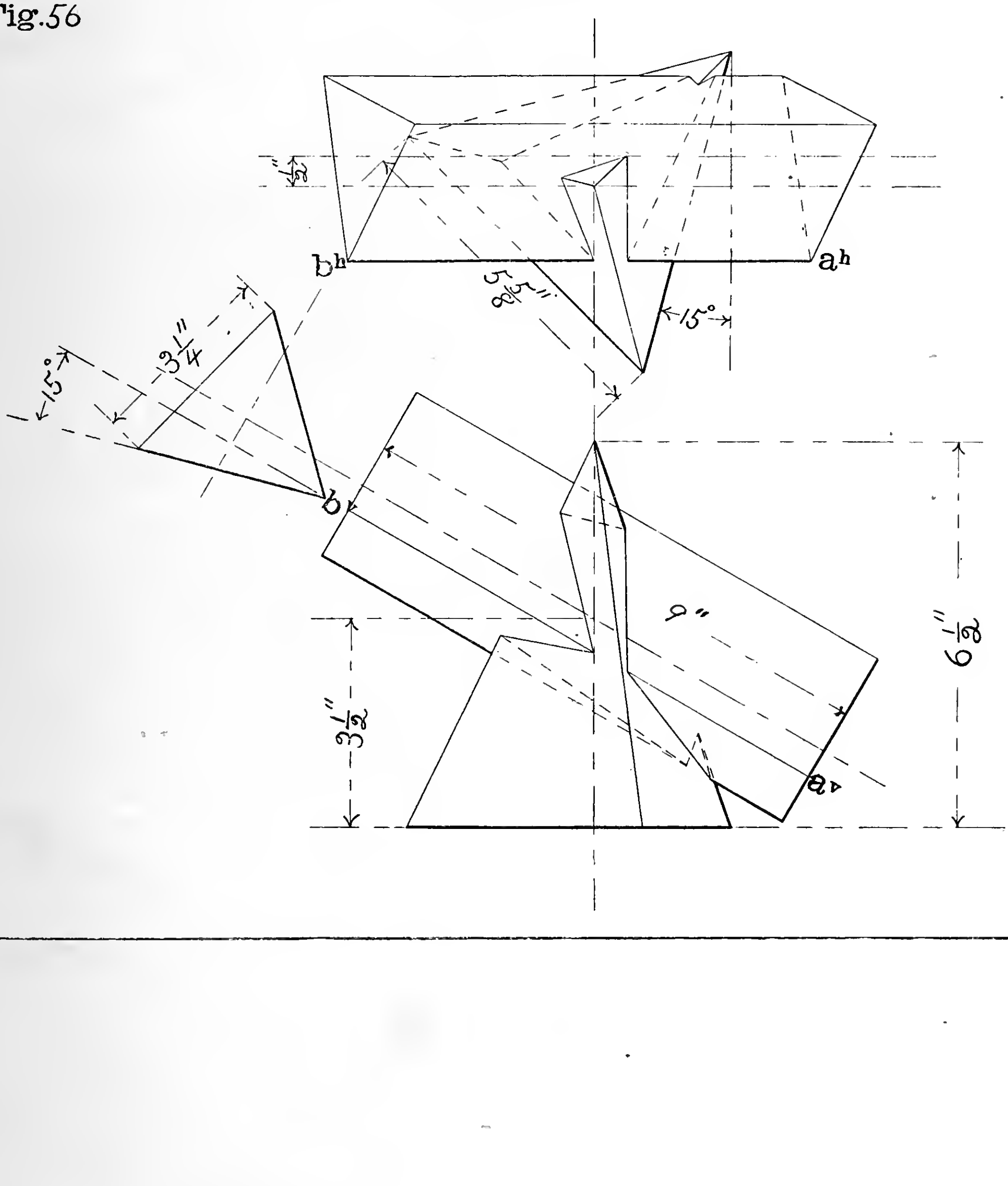


Plate 17.

Fig. 57. This is a drawing of axes or centre lines oblique to both planes of projection, about which any solid may be drawn very readily. Draw b^v b^v, which will be the trace of a horizontal plane; then f f perpendicular to b^v b^v and a^v c^v at the desired angle (45°) with the horizontal plane, making it of any convenient length longer than the length of the object to be drawn. Draw also c^v c^h any convenient length. Now draw c^h a, making the desired angle with the front vertical plane. From a^h to h^v draw a line perpendicular to c^h a and g^v e^v parallel to c^h a, and any convenient distance from c^h a. Then c^h e^v must be parallel to a^h h^v. Make g^v h^v equal to the vertical distance that c^v is from b^v b^v. Draw d^v d^v through h^v and parallel to g^v e^v, which will be a trace of the horizontal plane b^v b^v. Now draw a line from h^v to e^v, which will be the true length of the axis a^v c^v, and will also be a parallel view of the axis. Here we must draw the object first in its true size. The line c^v f^v may, for convenience in drawing, be equal to c^v c^h. If c^v c^h be produced to intersect a horizontal from a^h as at b, then the vertical distance c^v b, laid off on c^v f^v produced as at c and projected to b^v b^v, will give f^v, and f^v f^v is a side view of the axis.

Fig. 58. This is a drawing of a solid inclined to both planes of projection as shown. The axis must be drawn in full first, as instructed in fig. 57. If it is true that the distance g^v h^v is equal to the vertical distance from c^v to b^v b^v, it is also true that the vertical distance from c^v to any point in the front or side views is equal to the distance from g^v e^v to the corresponding point in the auxiliary view, taken perpendicular to g^v e^v. Draw the auxiliary first as shown. The top view can be projected from the auxiliary view, and the thickness taken from the end view. The front view can be projected from the top, and the vertical distances of all the points found as already explained. The side view is not shown, but must be drawn by the pupil. It can be done by projecting all the corners from the top and front views.

Fig. 59. This is a drawing of a triangular prism of the dimensions shown, and can be drawn from instructions already given.

Fig. 60. This is a drawing of a cube of the dimensions given, and if the others on the plate are understood there will be no difficulty in drawing it. A thorough knowledge of these principles is something that no draughtsman can afford to be without; therefore it is hoped that the pupil will give this plate undivided attention and study.

Plate. 17

Fig. 57

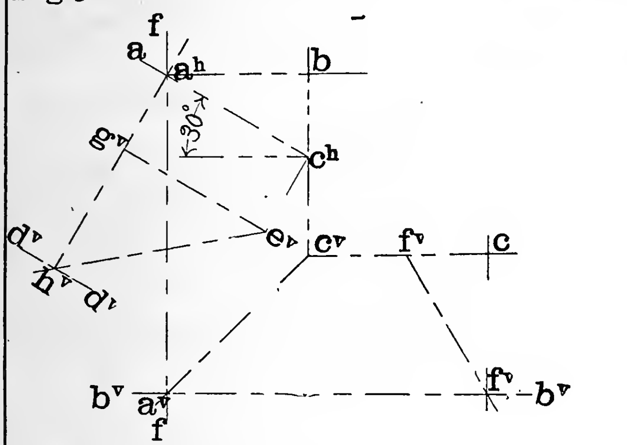


Fig. 58

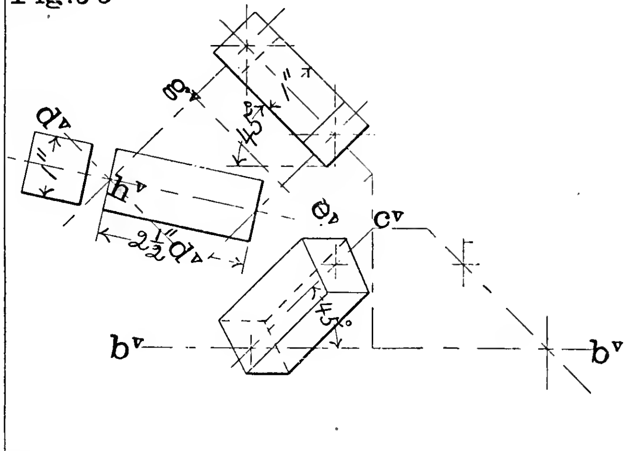


Fig. 59

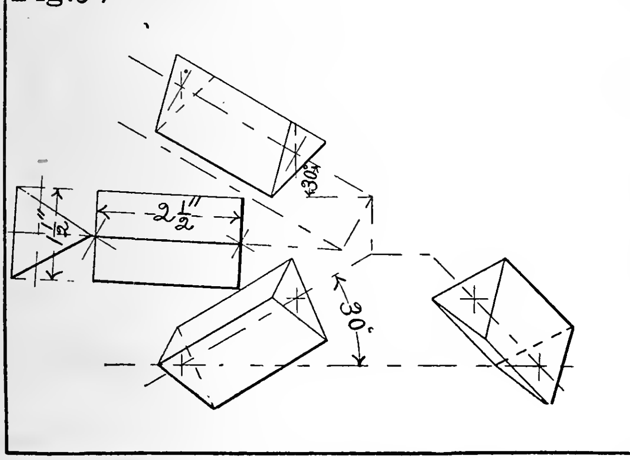


Fig. 60

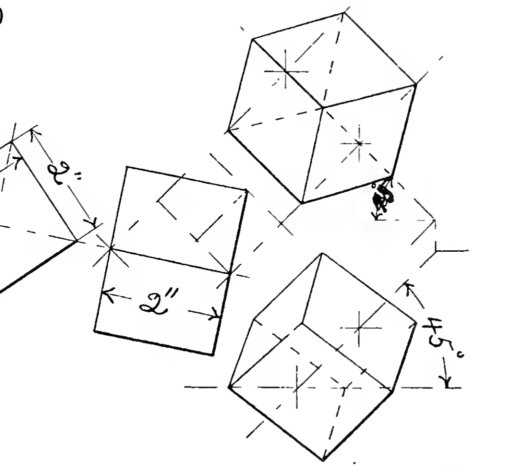


Plate 18.

Fig. 61. This is a drawing of a vertical cone intersected by a vertical cylinder, the axis of which is ¼ inch behind the central vertical plane.

Fig. 62. This is a drawing of a vertical cone intersected by a horizontal hexagonal prism, the axis of the prism piercing the axis of the vertical cone 1¼ inches above its base.

Fig. 63. This is a drawing of a vertical hexagonal prism intersected by a horizontal hexagonal prism as shown.

Fig. 64. This is a drawing of a vertical prism intersected by a horizontal prism as shown.

Plate. 18

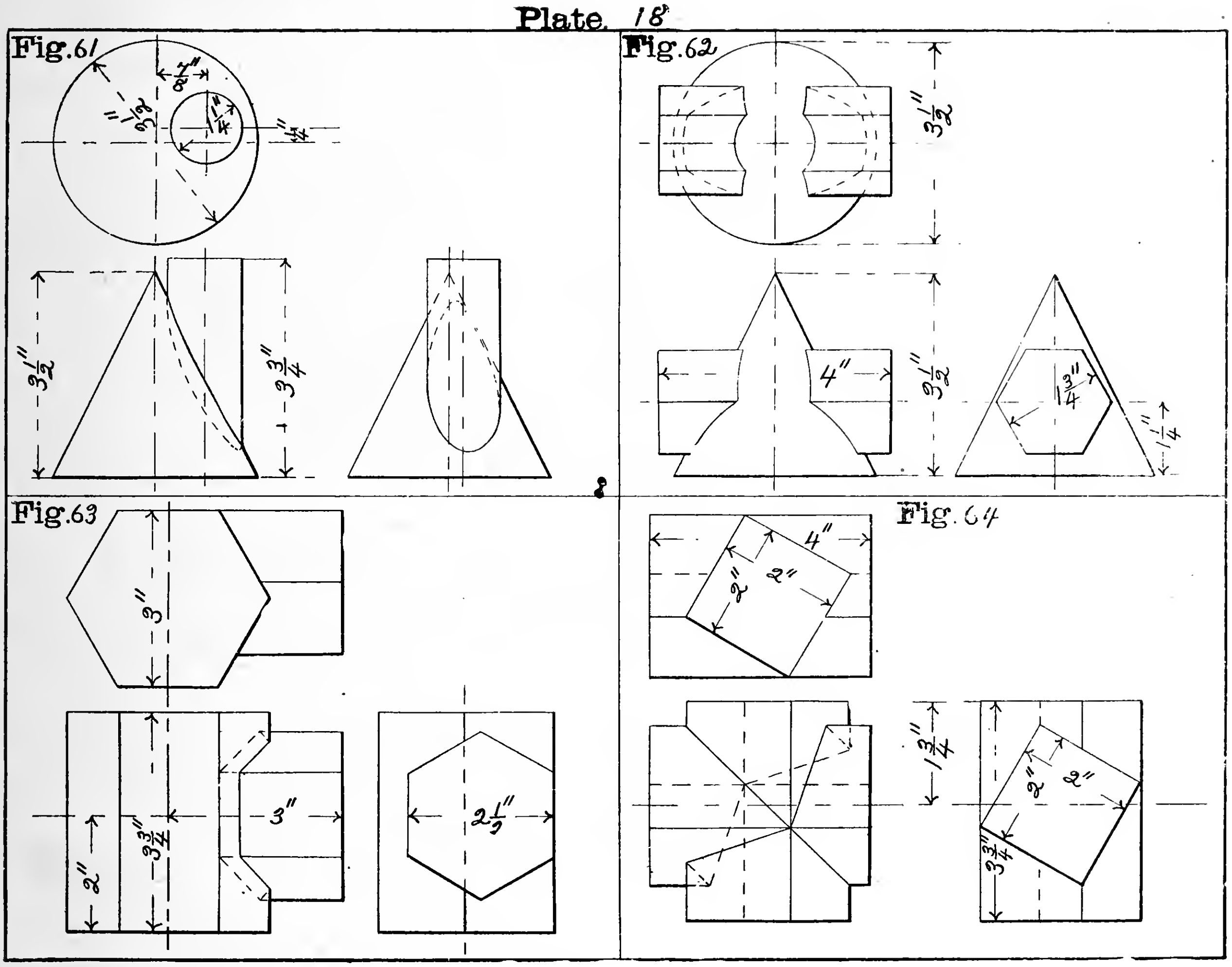


Plate 19.

Fig. 65. This is a drawing of a vertical hexagonal pyramid intersected by a horizontal prism $2\frac{1}{2}$ inches square, the axis of which is 1 inch behind the axis of the pyramid.

Plate. 19

Fig. 65

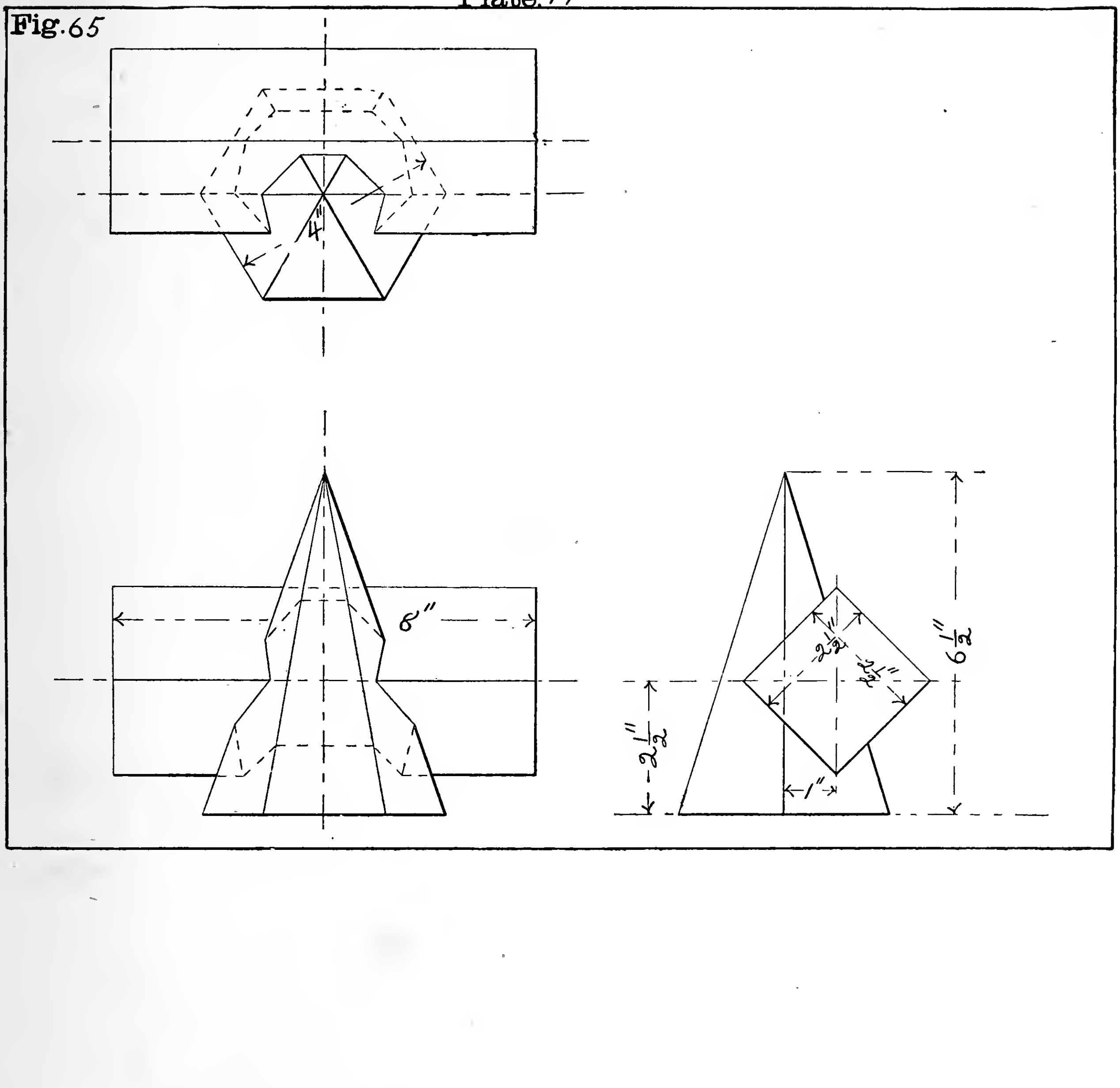


Plate 20.

Fig. 66. If a circle is rolled on the outside of another circle, a point on its circumference will trace a curve which is called an epicycloid. If a circle is rolled on the inside of another circle, a point on its circumference will trace a curve which is called a hypocycloid. To describe these curves, draw the large circle as shown and a horizontal and vertical centre line. Then, setting the spacing dividers to any distance, say $\frac{5}{16}$ of an inch, step this distance on the large circle, starting at the intersection of the vertical centre line with the circumference, and step both ways. Be careful not to change the distance of the dividers. From the centre of the large circle, draw the paths of the centre of the small circles as **a b c d**. From the points laid off on the large circle draw radial lines as shown, and from where they intersect the path of the centres of the small circles as centres, and with radius equal to the radius of the small circles, draw arcs as shown. Now with the dividers at the same distance, step back on each arc from the points on the large circle as many times as the point numbers from the vertical centre line. Then through the last points thus found draw the curve.

If a cord is kept taut while it is unwound from a cylinder, a point at its end will trace a curve which is called an involute. To describe an involute:—With the spacing dividers set at about $\frac{5}{16}$ of an inch, step this distance on the large circle as shown. Be careful not to change the distance of the dividers. From these points draw radial lines and a perpendicular to each of these lines tangent to the points on the large circle. With the dividers at the same distance, step back on each tangent as many times as it is from the vertical centre line. Through the last points thus found on each tangent, draw the curve.

Fig. 67. If a circle is rolled on a straight line, a point on its circumference will trace a curve which is called a cycloid. To describe the curve draw the straight line **h h** and lay off spaces the same as in fig. 66. Through these points draw perpendiculars. A straight line through the centre of the circle will be the path of the centre. The intersection of this path with the perpendiculars will be centres from which to draw arcs with a radius equal to the radius of the circle. With the dividers at the same distance, step back on these arcs as many times as the arc is from **a^v a^v**. Through the last points on each arc thus found draw the curve.

These circles which we have been rolling are called generating circles, and are used to generate the curves of gear teeth. In good practice they are 1.9098 times the circular pitch in diameter, which is the length of an arc of the pitch circle from the centre of one tooth to the centre of the next tooth.

Plate 20

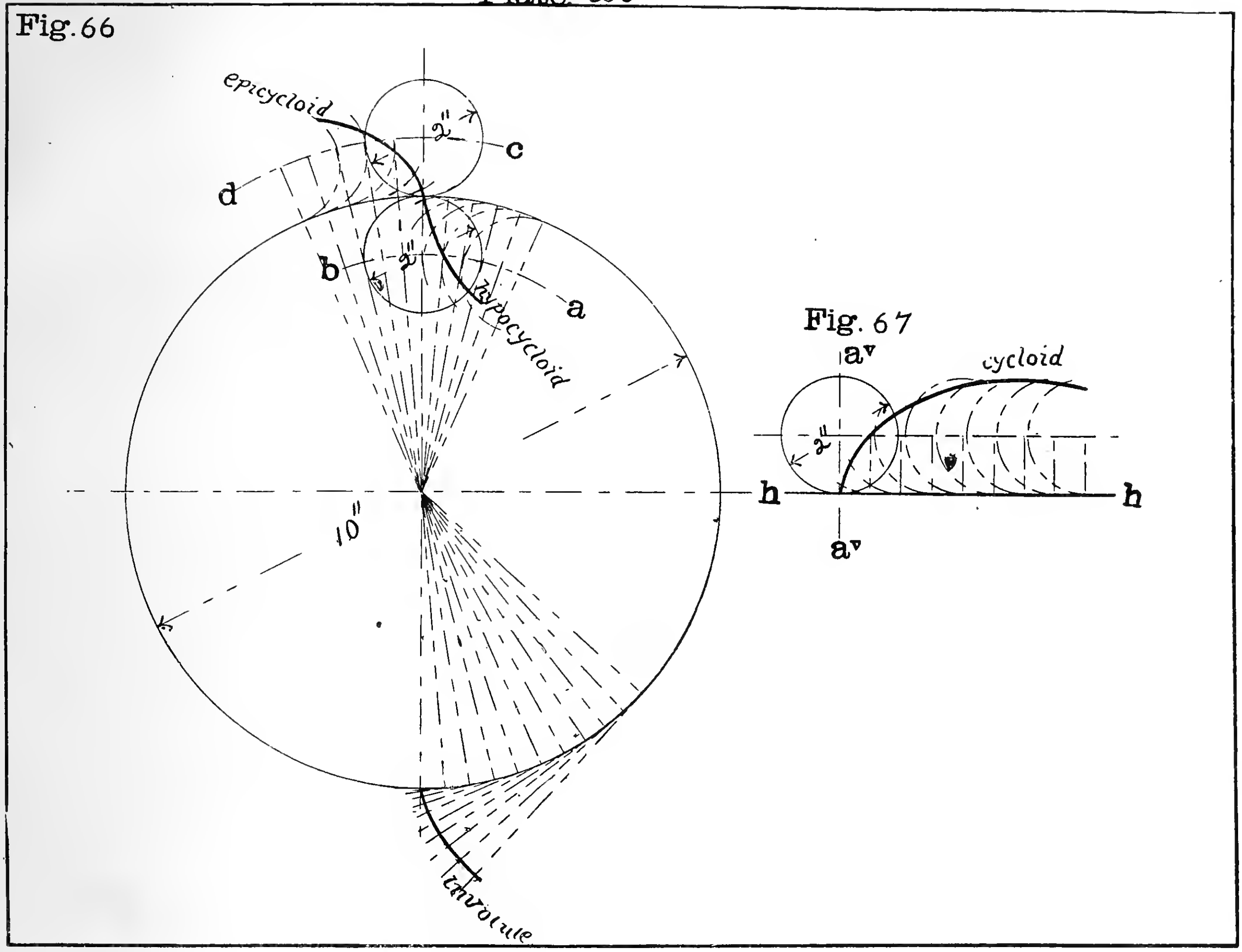


Fig. 66
epicycloid
2"
c
d
2"
b
a
hypocycloid
10"
h
involute
Fig. 67
a'
cycloid
2"
h
h
a'

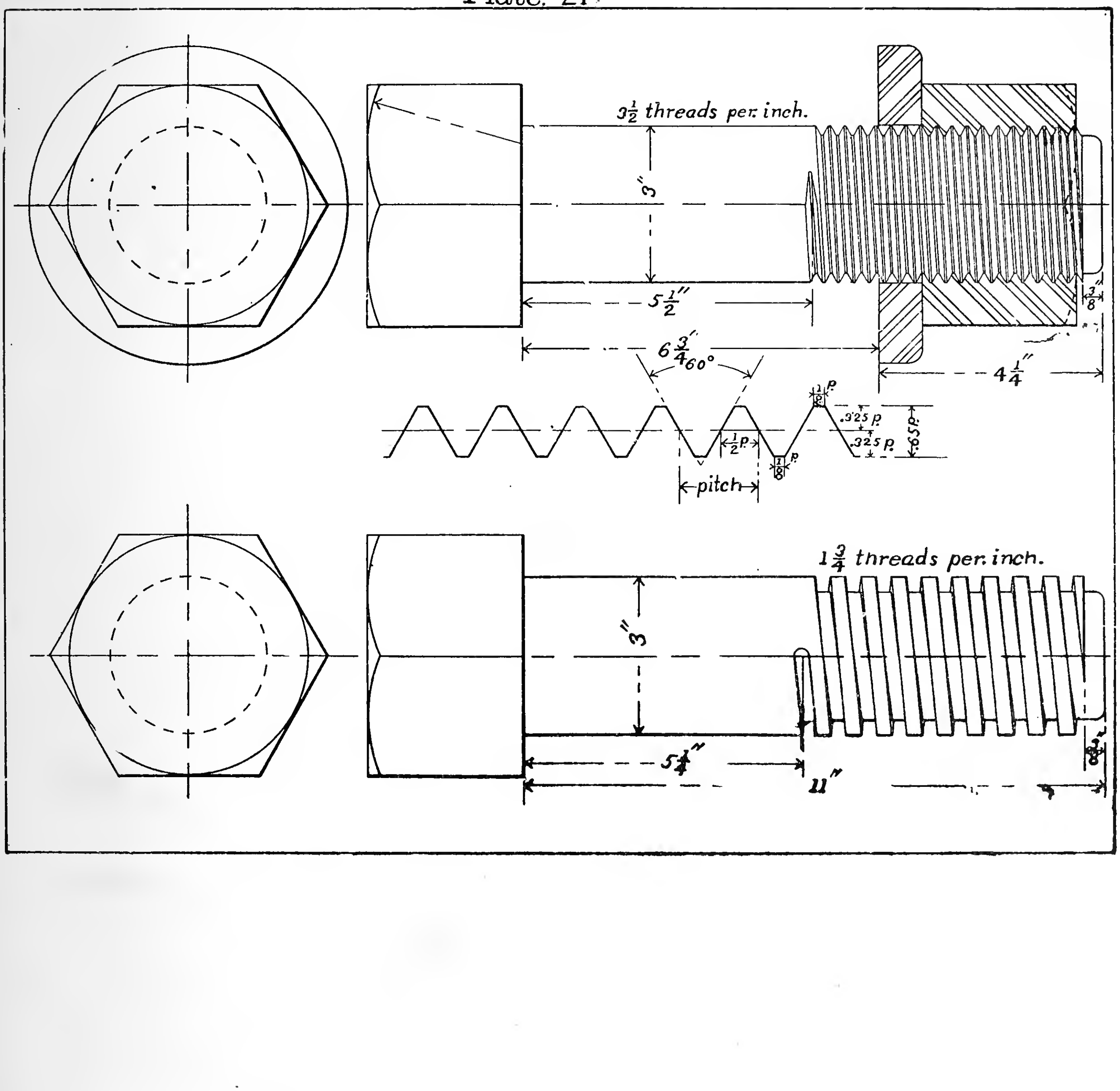
Plate 21.

CONVENTIONAL SCREW THREADS.

The bolt at the top of this plate is a drawing of a U. S. Standard bolt and nut, with the conventional thread. The sides of the thread known as the U. S. S. make an angle of 60° with each other, with a flat at the top and bottom of the thread equal to $\frac{1}{8}$ of the pitch, and have a depth equal to .65 of the pitch. The pitch of a screw is that distance which it travels through the nut in one revolution. To lay out and draw this thread: First, draw the bolt in full (referring to table No. 5 for all dimensions not shown on the drawing) and lay off the depth of the thread and bisect it and draw what may be termed a pitch line as shown in the enlarged thread below the bolt; also draw a line at the root or bottom of the thread. Now it remains to determine the pitch, which is as follows: This bolt has $3\frac{1}{2}$ threads per inch, and $3\frac{1}{2}$ threads are equal to 7 threads in 2 inches, which is equal to $\frac{2}{7}$ pitch. The pitch being determined, lay off 2″ on the lower pitch line and divide into 14 equal parts, then each division will be equal to one-half of the pitch. Lay off as many more of these divisions as may be required for the number of threads on the bolt, and project each one of these points to the pitch line at the top of the bolt. Now with the 30°x60° triangle with the shortest side to the **T** square, draw lines through alternate points on the lower pitch line, then in the opposite direction through the remaining points. The distance between the lines where they intersect the outside and root lines will be the width of the flat at top and bottom, which will be $\frac{1}{8}$ of the pitch. Draw the top side in like manner, care being taken to have the outside of the thread directly opposite the root at the bottom side of the bolt, as shown. Having completed this, connect all points at top and bottom with straight lines as shown in the plate.

The bolt at the bottom of the plate represents the conventional square thread, the depth of which is equal to one-half of the pitch. After the outlines of the bolt have been drawn in full, lay off on the bottom side of the bolt 4″ and divide into 14 equal parts, because $1\frac{3}{4}$ threads per inch are equal to 7 threads in 4″ or $\frac{4}{7}$ pitch. Then each division will be equal to one half of the pitch. Lay off as many more divisions as are required for the number of threads on the bolt, and also from the top and bottom side lay off the depth of the thread equal to one division, and through these points draw lines which will represent the root diameter, also lines through the points in the bottom side of the bolt, from the outside to the root both top and bottom. These lines will represent sides of the threads on the central plane and must be perpendicular to the axis of the bolt. Then connect each point in the top and bottom sides of the bolt with straight lines, the first one at an inclination toward the left equal to one division, and draw all others parallel to this one. They represent the outside of the threads. Then at the same inclination in the opposite direction, draw the short lines on the left of the thread at the top, and on the right of the thread at the bottom, which will be an outline of a portion of the thread on the underside of the bolt. Now from where the lines forming the sides of the thread on the central plane intersect the lines forming the root diameter, draw lines to represent the root of the thread as shown. These are only drawn to the axis, because from this point on they could not be seen, and if drawn would be dotted, which is not desirable.

Plate. 21



3½ threads per inch.
3″
5½″
6¾″
60°
3/8″
4¼″
1/8 P
.325 P
.325 P
.65 P
½ P
1/8 P
pitch
1¾ threads per inch.
3″
5¼″
11″

Plate 22.

THE HELIX.

If we suppose that the line **a b** is parallel to the axis of the cylinder, and a point moving along the line from **a** to **b** at a uniform velocity, while the cylinder makes one revolution about its axis at a uniform velocity, the point, if touching the cylinder, will trace a curve known as a helix. The distance **a b** will be what is termed the pitch of the helix. The pitch of a screw is equal to the axial distance through which the generating point travels in one revolution of the cylinder, both moving at uniform velocities. The helix may be drawn as follows: Draw a cylinder 4 inches in diameter, and 4 inches long, and divide the circumference of the cylinder in the top view into 12 equal parts, subdividing 4 of these into 3 equal parts as shown. Also divide the length of the cylinder into the same number of equal parts, and subdivide as is clearly shown in the plate. This may be done by drawing the straight line **b h** perpendicular to the axis of the cylinder, and in length equal to the circumference, laying off the distances in the top view on **b h**, and from each point drawing perpendiculars as shown. Also draw **h a**, which will be the development of the helix. Then by projecting the intersection of the perpendiculars with **h a**, as is shown in the plate, the length of the cylinder will be properly divided. These traces intersected by projections from the top view, will locate the points through which to draw the helix **a d b**. The inner circle in the top view represents what is termed the "root cylinder" of a screw thread, the helix of which is drawn in the same manner as the above. From the projection in connection with the numbers there should be no difficulty in making this drawing. The angles shown in the plate are the angles which a tangent to the helices makes with the plane of the base of the pitch cylinders. The co-tangent of the angle is equal to the circumference of the cylinder divided by the pitch. The drawing of a quadruple square thread screw to the right of the top view gives the application of the helix to the screw thread.

This being a quadruple screw, means that the pitch is divided into four equal parts, each part being equal to one thread and one space, and is termed "individual pitch," and as the pitch of the helix is 4 inches, the individual pitch will be 1 inch. Make the thickness of the thread, the width of the space and the depth, each equal to one-half of the individual pitch.

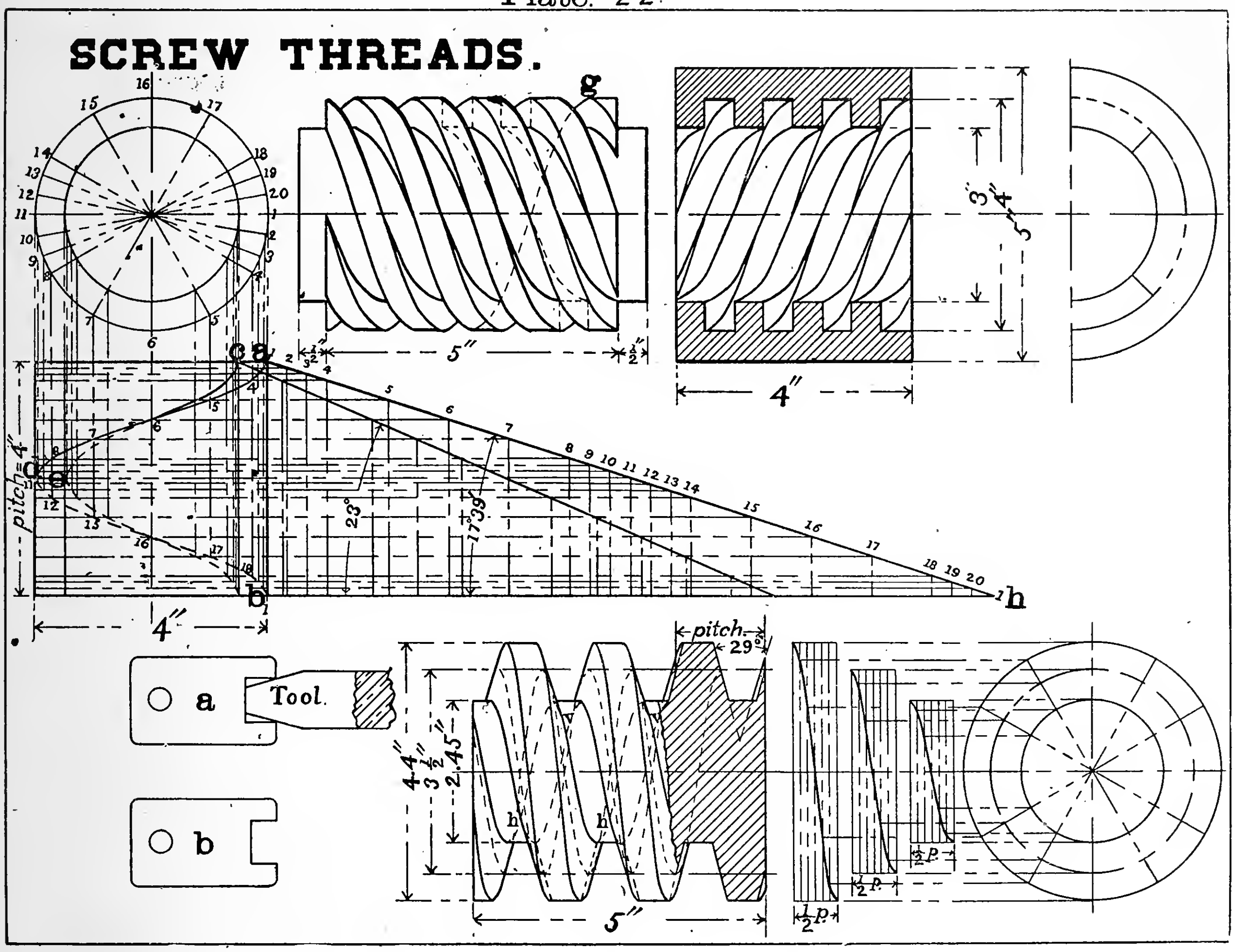
Then from a piece of thin wood make a curve to fit the helices from **a** to **d** and from **c** to **e**, and with these draw the helices of the screw as clearly shown. This being a quadruple screw a thread at the top will be opposite a thread at the bottom.

Lay out and draw the nut with the same curves.

In drawing the helices of a screw it is well to use a bow pen to draw a small portion at the point of tangency, as at **g**.

The drawing at the lower side of the plate is to illustrate the method of drawing the thread usually used for a worm to work with a worm wheel. The helices for this thread are determined in the same manner as explained above. To draw this thread draw the outside, the pitch and root cylinders as shown at the right, and the outside, the pitch and root diameters in the front view. Then lay off on the pitch lines the pitch and thickness of the teeth equal to one-half of the pitch, and through these points draw the sides of all of the teeth as shown in the section and the dotted outline at the bottom side. From the points where the sides of the teeth intersect the outside, the pitch and root cylinders, draw the outside, the pitch and root helices, then straight lines tangent to these helices, will be the visible contour of the thread in the finished drawing, instead of the straight lines drawn first through the pitch points in the central plane. It will be noticed that these tangents at the right of the thread at the top extend to the point of tangency as at v v, and only to the root on the left ; at the bottom this will be reversed, as at h h.

Plate. 22.



After the tool to cut this thread has been filed to the proper angle, file off the end of the tool until a gauge, as at a—which has a width equal to one-half of the pitch and a depth equal to .35 of the pitch—will touch the end and sides of the tool at the same time. It will then be the correct shape to form the thread, if the top side of the tool is in the same plane as the axis of the screw. When the thread is finished a gauge as at b should touch the top and sides of the thread at the same time. This gauge has a width equal to one-half of the pitch, with a depth equal to .3 of the pitch.

The dotted outlines are not to be drawn, as they are only shown in the plate for illustration.

Plate 23.

SPUR GEARING.

When motion is transmitted from one shaft to another, the axes of which are parallel, toothed wheels are used, the pitch surfaces of which are imaginary cylinders. Let two perfect cylinders be keyed fast on shafts whose axes are parallel and such a distance apart that the cylinders are in contact. Then if one cylinder revolves the other will revolve also, and if there is no slipping the two cylinders will have equal velocities at the point of contact. On these cylinders is laid off the pitch, which is the distance from the centre of one tooth to the centre of the next, measured along the pitch circle. It is termed circular pitch. The addendum is generally .3 of the circular pitch, and the space below .35 of the circular pitch, making a total depth of .65 of the circular pitch. The diameter of the pitch circle is equal to the number of teeth multiplied by the pitch, and this product by .3183. Then pitch diameter = number of teeth $\times$ pitch $\times$ .3183. Outside diameter equals pitch diameter plus .6 of the pitch, and the root diameter equals pitch diameter minus .7 of the pitch. The radii of these circles equal the diameters, divided by 2.

Diametral Pitch.—If a wheel has 48 teeth and 6 inches pitch diameter it is 8 pitch. That is, for each inch of the pitch diameter there are 8 teeth on the circumference. Then

$$\text{Pitch} = \frac{\text{number of teeth}}{\text{pitch diameter}} \text{ and}$$

$$\text{Pitch diameter} = \frac{\text{number of teeth}}{\text{pitch}}$$

$$\text{Number of teeth} = \text{pitch diameter} \times \text{pitch}$$

$$\text{The addendum is} = \frac{1}{\text{diametral pitch}}$$

$$\text{Then whole diameter} = \frac{\text{number of teeth} + 2}{\text{diametral pitch}}$$

$$\text{Whole depth of the teeth} = \frac{2.15708}{\text{diametral pitch}}$$

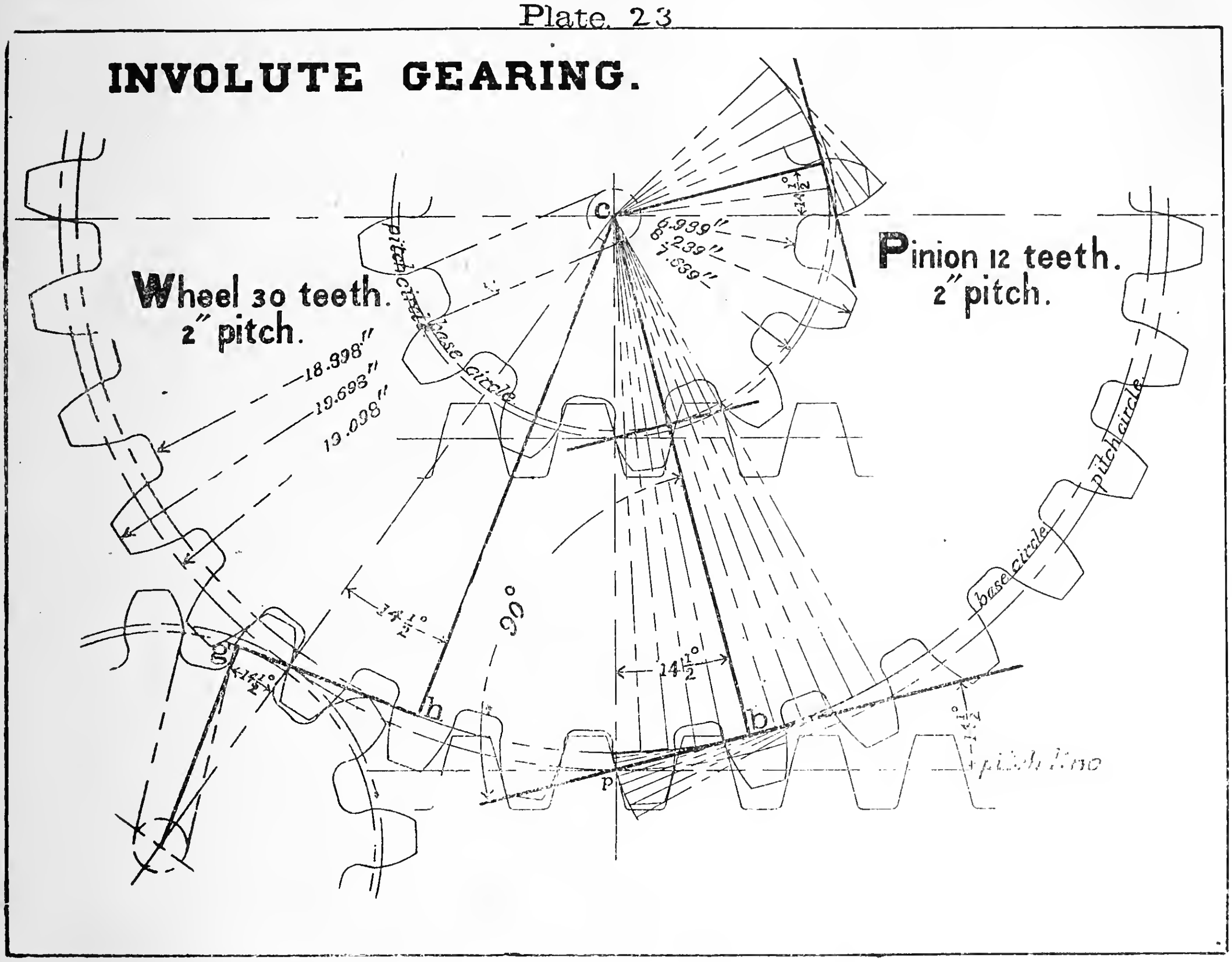
$$\text{Pitch} = 8. \quad \text{Number of teeth} = 48, \text{ then } \frac{48}{8} = 6'' \text{ pitch diameter.}$$

$$\text{And } \frac{48}{6} = 8 \text{ pitch.}$$

$$\text{And outside diameter} = \frac{48 + 2}{8}$$

Involute Gearing.—Compute the diameters as explained for circular pitch, and lay off on the pitch circles of the wheel and pinion the pitch, also the thickness of the teeth equal to one-half of the circular pitch. Then draw through **c** a straight line making an angle of 14½° with the centre line, and perpendicular to this line draw the line of action through the pitch point **p**. The intersections of these two lines will locate the point **b**. With **c** as a centre and radius **c b** draw base circle as shown, and divide **b p** into say five equal parts. Then starting at **b** lay these same parts off on the base circle toward the left. The last point will fall a little to the left of the centre line. Also mark off four or five times from **b** toward the right. Lay the dividers down carefully so that their distance will not be changed. From these points draw radial lines and a perpendicular to each of these, tangent to the points on the base circle. With the dividers which have not been changed, step back on each tangent as many times as it numbers from **p**. Through the last point on each tangent thus found draw the involute which does not extend below the base circle. Find by trial centres from which face and flank curves can be drawn, then through these centres draw circles: which will be circles of centres from which all the curves may be drawn with the same radius. The flanks below the base circle will be radial lines. The radius for the fillet is equal to the product of the constant number for 30 teeth in column No. 5, table No. 3, multiplied by the pitch. The involute for the pinion is drawn in the same manner. The flanks of the teeth are drawn from the base circle tangent to the circle at the centre, the radius of which is equal to the product of the

Plate 23



constant number for 12 teeth, column 4, table No. 3, multiplied by the pitch. Draw a few teeth of the pinion in gear with the wheel as shown at the left hand corner at the bottom. Also the line of action as shown by the heavy lines. The straight line **g h** represents the flexible cord, which being unwound from the base circles generates the involutes. This line is also the path of contact of the teeth, that is the teeth are in contact with each other along this straight line. The rack is a wheel with an infinite number of teeth; the involutes of the flanks are straight lines through the pitch points, perpendicular to the line of action, that is 14½° in opposite directions. The faces of the teeth are drawn with a radius equal to the product of the pitch and the constant number for 150 teeth, column 1, table No. 3, laid off from the pitch point **p** on the line of action produced.

Plate 24.

APPROXIMATE INVOLUTE TEETH.

Compute the pitch, the outside and root diameters of the wheel and pinion as explained in plate 23, and draw the line of action at 14½°, which may be done as follows: **b c** is equal to the cosine of 14½°, and **p b** is equal to the sine of 14½°. As .96815 = cosine of 14½° and .25038 = sine of 14½°, **p c** × .96815 = **b c**, and **p c** × .25038 = **p b**. This is for 14½° only. For 20° it will be **p c** × .93969 = **b c**, and **p c** × .34202 = **p b**, and this can only be used for 20°. The angle of action being drawn, lay off the pitch, and thickness of teeth equal to one-half of the pitch. The wheel has 30 teeth and is 2 inches pitch: find in table 3, column 2, opposite 30 teeth, the constant number, 1.4079, which, multiplied by the pitch, will give the radius with which to draw the face of the teeth. This radius must be laid off on the line of action from the pitch point **p** toward g^v and will give the centre from which to draw the face of the teeth, as **p v**. Through this centre draw a circle which will be a circle of centres from which to draw the remainder of the teeth. Find in table 3, column 3, opposite 30 teeth, the constant number .990, which, multiplied by the pitch, will give the radius for the flanks of the teeth from the pitch circle to the base circle. This laid off on the line of action from the pitch point **p** toward **b** will give the centre from which to draw the flanks. Then a circle through this centre will be a circle of centres from which to draw the remainder of the teeth. The teeth of the pinion are drawn in the same manner, as the wheel. By referring to the table and taking the constant number opposite the number of the teeth desired, a wheel having any number of teeth may be drawn, the teeth of which will be as accurate as the average teeth in actual practice. The rack teeth are drawn in the same manner as in plate 23. The object in rounding the face of the rack teeth is to make them interchangeable with a 12 tooth pinion. The space between the teeth of a 12 tooth pinion below the base circle is almost parallel, being just a trifle wider at the base circle than at the root circle. This is done to facilitate matters in cutting the teeth, and also adds some strength to the teeth. If the flanks below the base circle were made so that the rack teeth would work without rounding the face, (which should not be done), then the space between the pinion teeth would be wider at the root than at the base circle, which would complicate matters in cutting the teeth and also weaken the teeth. Drawing the teeth as they are, not only necessitates the rounding of the faces of rack teeth but all wheels of 150 teeth and over must be drawn with the radius for 150 teeth. By increasing the angle of action to 20° or more this is overcome, allowing all the wheel teeth to be true involutes, and the sides of the rack teeth straight lines, as they should be, but for the reason already explained.

Plate. 24.

INVOLUTE GEARING.

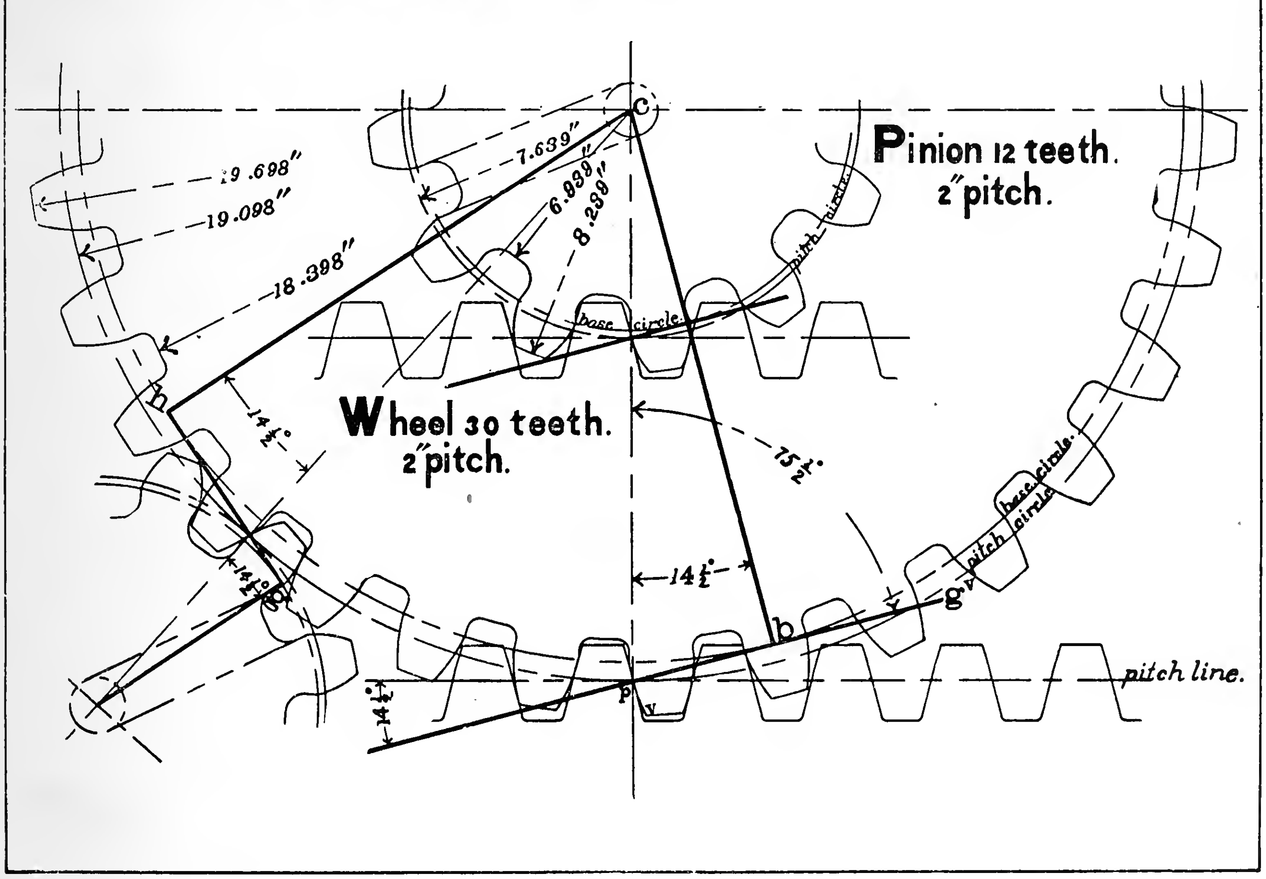


Plate 25.

CYCLOIDAL GEAR TEETH.

As already explained in plate 20, if a circle rolls on the outside of a circle, a fixed point on its circumference will generate an epicycloid, which being on the outside of the circle will be the curve which must be used for the faces of the teeth. If a circle rolls on the inside of a circle, a fixed point on its circumference will generate a hypocycloid, which, being on the inside of the circle, will be the curve which must be used for the flanks of the teeth. And if a circle rolls on a straight line, a fixed point on its circumference will generate a cycloid, which will be the curve for the face and flank of the rack teeth. Compute and draw the pitch, the outside and root circles for a pinion having 12 teeth and a wheel having 30 teeth 1½ inches pitch, also the pitch the outside and root lines for the racks as shown in the plate. Then draw the generating circles tangent to the pitch circles at the pitch points **p** and **p**, and, using the pitch point **p** as the fixed point on the generating circles, generate the curves as explained in plate 20.

The diameters of the generating circles are equal to half the pitch diameter of the pinion, which will make them equal to 1.9098 times the pitch. Then the diameter of the generating circle for a wheel of any pitch, is equal to 1.9098 × pitch. The curves for the rack teeth are generated in the same manner as the cycloid in plate 20. All the curves being generated, lay off the pitch, and the thickness of the teeth equal to half the pitch, and find centres to approximate these curves, and through these centres draw circles, which will be circles of centres from which to draw the curves of the teeth. The path of contact is represented by the heavy arcs **a p**, **p b**, that is as the wheels roll the teeth are in contact along these arcs. By multiplying the proportional figures in the plate the different proportions of the wheel may be obtained. Thus .625 **p** means that the thickness of the rim below the root circle is equal to .625 × pitch, and the rest in like manner. The width of the arms is equal to 1.625 times the pitch at the pitch circle, and enlarged toward the centre .75 in 12 inches. The thickness of the arms at the pitch circle is equal to .4 of the pitch, and is enlarged toward the centre .75 in 12 inches. A normal section of the arms should be an ellipse. The radius of the fillets at the root of the teeth may be equal to .05 of the pitch.

Plate 25.

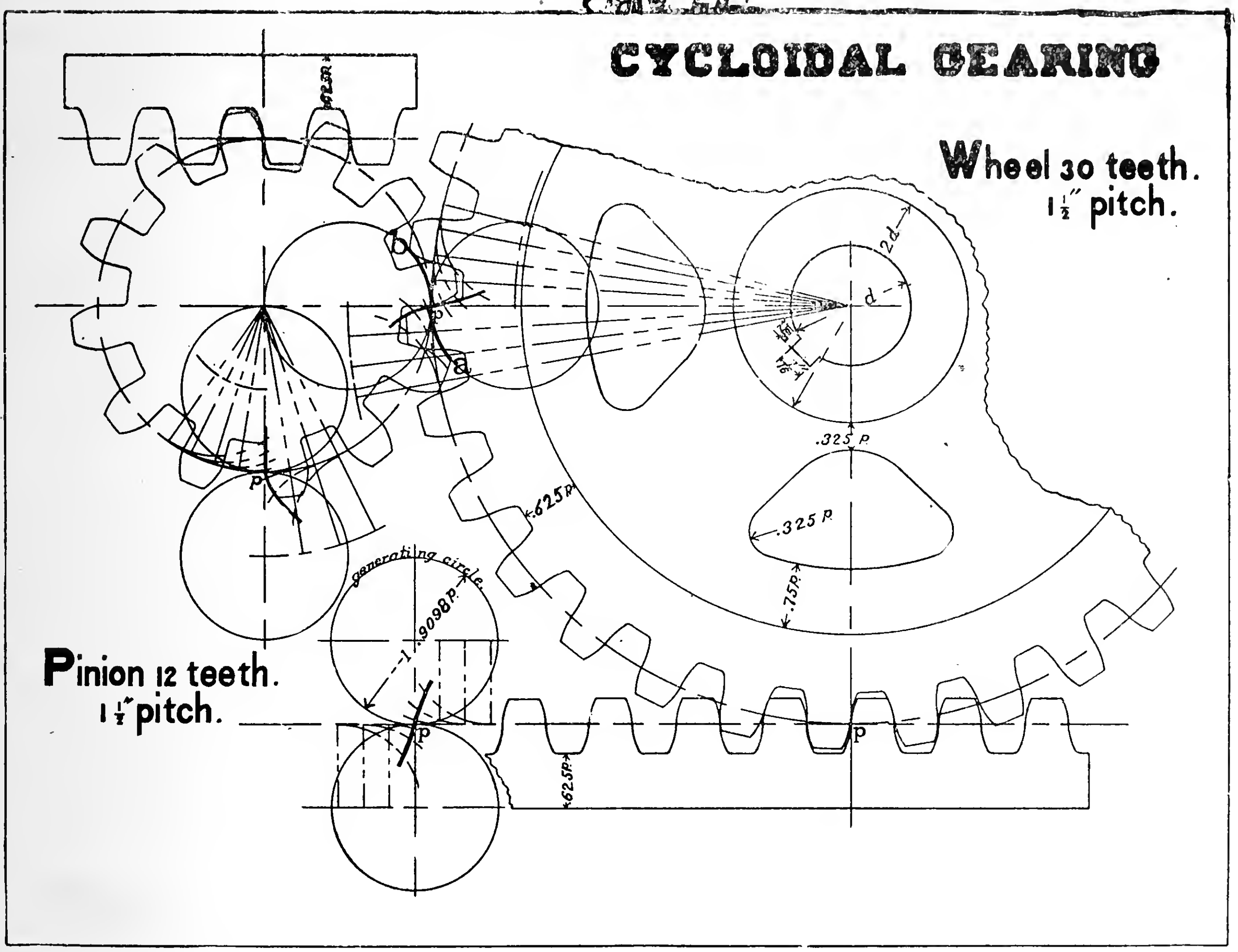

CYCLOIDAL GEARING
Wheel 30 teeth.
1½″ pitch.
Pinion 12 teeth.
1½″ pitch.
generating circle.
.9098 P.
.625 P.
.75 P.
.325 P
.325 P
2d
d
b
a
p
P
.625 P.

Plate 26.

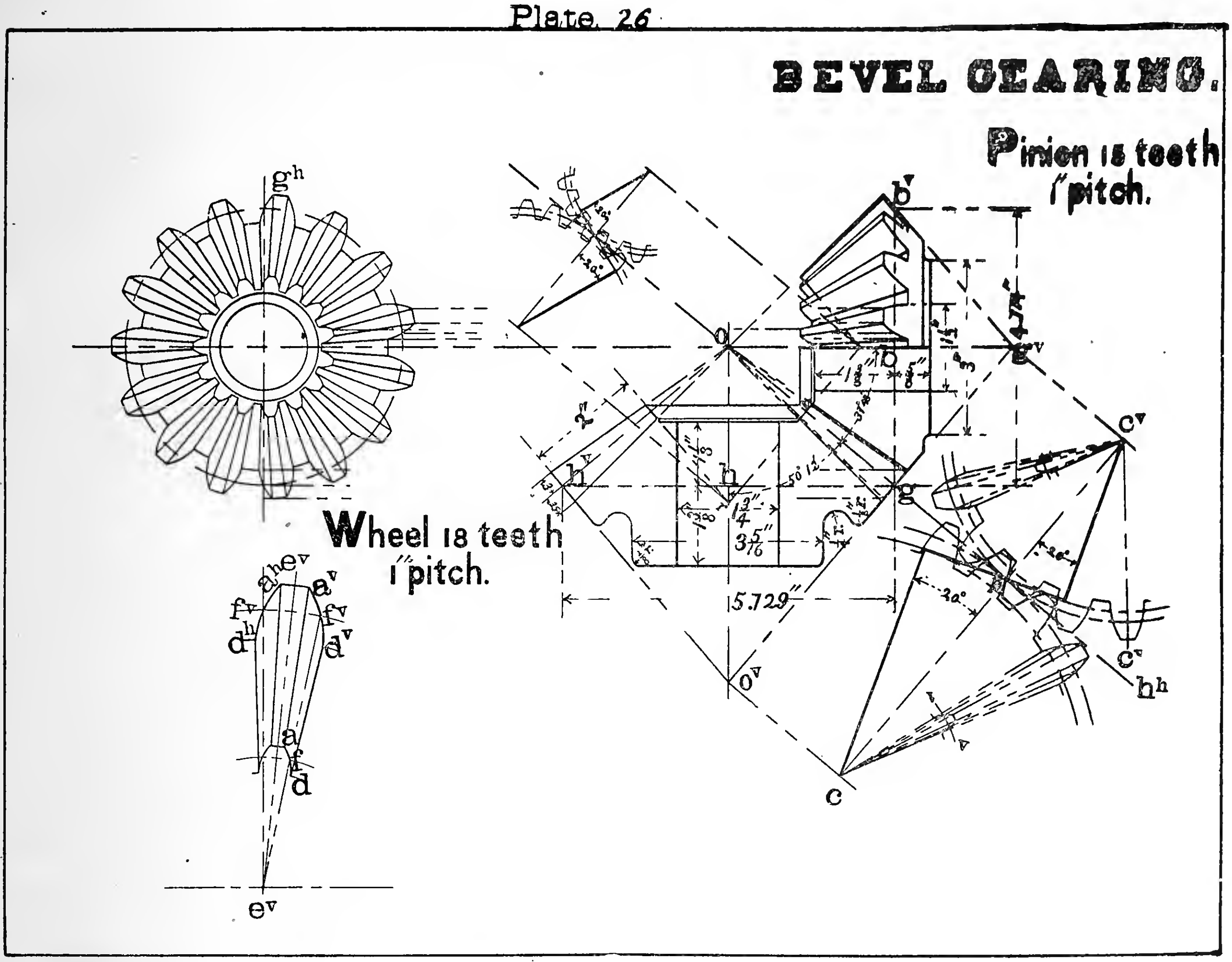
BEVEL GEARING.

It will be readily understood from what has already been said about spur gearing that when motion is transmitted from one shaft to another by such gearing, the shafts must be parallel to each other. When shafts are so situated that the axes of the shafts are in the same plane and at right angles to each other, they will, if produced, intersect each other. Motion is transmitted by wheels whose pitch surfaces are cones, instead of cylinders. They are known as bevel gears, if the cones are unequal; and as mitre gears, if the cones are equal. To draw the bevel gear: First draw the axes at right angles to each other; and lay off from the intersection of the axis at **o** on the axis of the pinion the pitch radius of the gear, as **o b**; and the pitch radius of the pinion on the axis of the gear, as **o h**. Now draw lines through **b** and **h** until they intersect in g and make **b** b^v equal to b g; also **h** h^v equal to h g. Then **g** b^v will be the pitch diameter of the pinion; and g h^v the pitch diameter of the gear. From the points g b^v and h^v draw lines to the point **o**. The angle g **o h** is the centre angle of the gear; and **g o** b the centre angle of the pinion. These angles may be found as follows: When the shafts are at right angles to each other only, divide the number of teeth in gear by the number of teeth in pinion, which will give the tangent of the centre angle of gear. This angle, subtracted from 90°, will give the centre angle of pinion. Now through the points **g** b^v and h^v draw lines perpendicular to g **o**, b^v o and h^v o, and produce them until they intersect the axis as at o^v and g^v. These lines will represent the normal cones to the pitch cones **o** h^v g and **o g** b^v. Lay off on these perpendiculars as shown at h^v the addendum and depth below—which is the same as in spur gearing—and from these points draw lines to o. Then lay off the length of the teeth, 2 inches, and draw lines through these points parallel with the lines forming the outside end of the teeth. If these normal cones be developed the base of each one will be an arc of a circle. The centre of one is o^v and radius o^v g; and of the other the centre is g^v and radius g^v g. Now produce **o g** as to h^h, and from o^v and g^v draw lines parallel to **o** g h^h. Then at any convenient distance draw **c** c^v parallel to o^v g^v. It is here we develop the outline of the teeth. Draw the line of action at an angle of 20°. Now with **c** as a centre and radius **c p** draw arc of pitch circle; and with the same centre and radii found in the same manner as **c p** draw addendum and root circles. The pinion is treated in like manner. Lay off the pitch and thickness of teeth and proceed exactly the same as for spur gearing, with the exception of one thing, which is the number of teeth from which to select the tabular number for the faces and flanks of the teeth. **h g** is the true pitch radius of this gear having 18 teeth of 1″ pitch; but the teeth are laid out on an arc of a circle of a much larger radius, which is **c p**. Then a gear of radius **c p** will contain 1″ pitch more than 18 times. Therefore we must select a tabular number for a gear of a greater number of teeth than 18. And also a cutter to cut the gear for a greater number than 18. This is determined as follows: Multiply **c p** by 6.28 and divide by circular pitch, then we have: Number of teeth $= \dfrac{6.28 \times \mathbf{c\,p}}{\text{circular pitch}}$

Use tabular number in table No. 1, 20° line of action, and proceed in the same manner as for 14½°. The thickness for the small end of the teeth is shown on the arc v v, the radius of which is equal to **r v**. This pitch is also equal to the product of the pitch at the large end and the quotient of **o g** into **o v**. The teeth at the small end are drawn in the same manner as at the large end. The same tabular numbers must be multiplied by the pitch on the arc v v.

To draw the view at the left: Project from the section of the pinion as indicated, and through these points draw the pitch, the outside and the root circles. Next lay off the pitch as many times as there are teeth in the pinion; also the thickness of the teeth, equal to one-half the pitch. Now make projection from the small end of the teeth in the sectional view, in the same manner as from the large end, which will give points through which the pitch, the outside and the root circles of the small end will pass.

Plate 26



To draw the outlines of these teeth: Draw one tooth as at g^h from the explanation of the enlarged tooth below. Bisect the arc f^v f^v with the radial line e^v e^v, and make the distance each side of e^v e^v on the outside, the pitch and the root circles equal to the distance each side of c^v c^v. Through these points draw the outlines a^v f^v d^v; a^h f^v d^h. Then where radial lines through these points intersect the circles at the small end of the teeth, will be shown the outline as indicated on one side by a f d, and also the outside and root of the teeth as a^v a and d^v d. Find, by trial, centres from which arcs can be drawn through a^v f^v d^v and a f d, then circles drawn through these centres will give circles of centres from which the remaining teeth can be drawn through the pitch point. All elements of the teeth of bevel gear wheels must run to the vertex o, of the pitch cone, whatever may be the angles of the shafts to each other. The teeth in the upper half of the pinion are drawn as indicated by the projection.

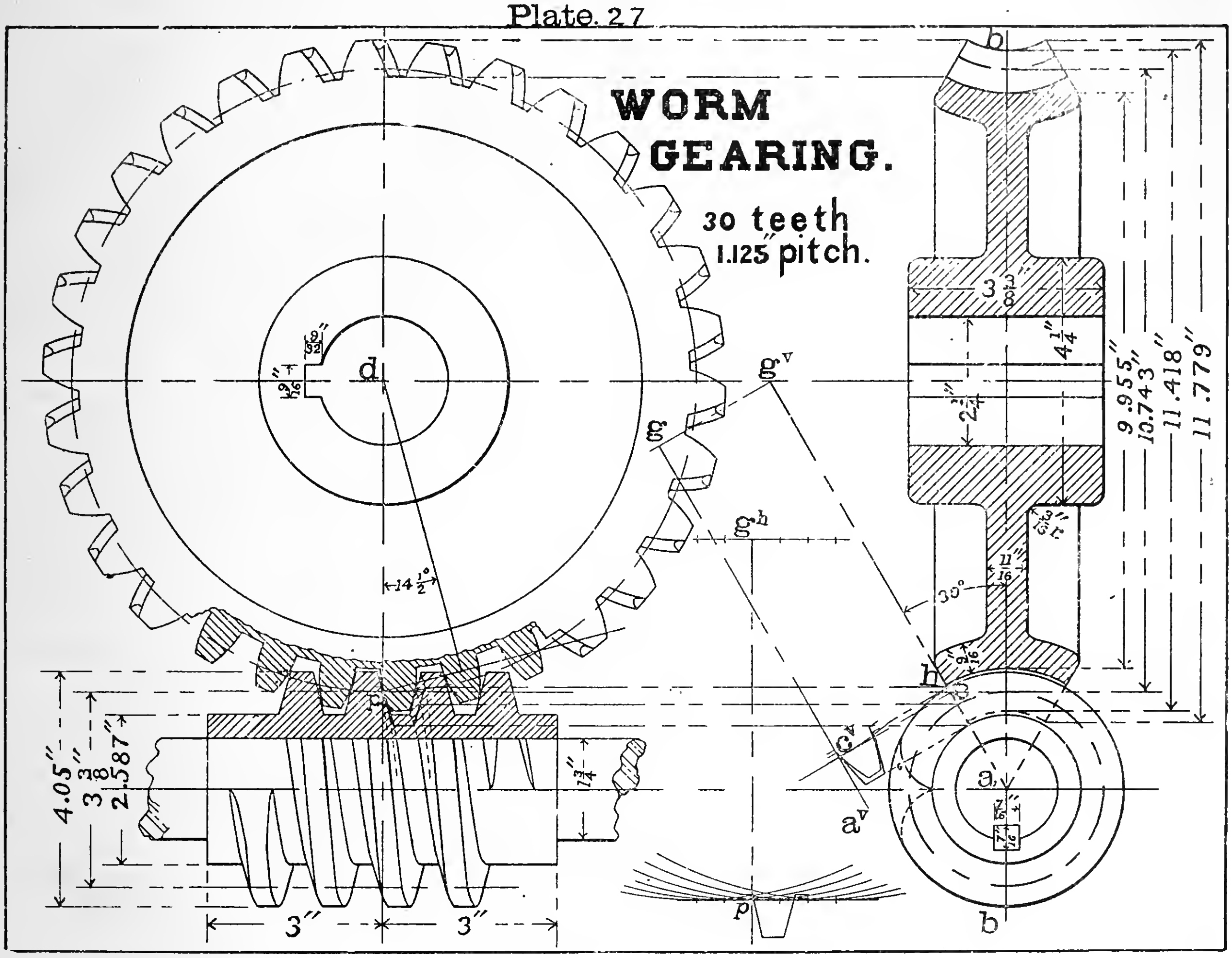
Plate 27.

WORM AND WORM WHEEL.

This gearing is employed when the shafts cross each other but do not intersect, and may be considered as a spur wheel and rack; that is, a section on the central plane **b b** is the same as a rack and spur gear having the same pitch and number of teeth. Therefore draw the pitch circle of the gear; and tangent to it at the pitch point **p** draw pitch line which may be considered as the pitch line of a rack to work with the gear. From this pitch line lay off the pitch diameter of the worm 3.375″. Draw the outside and root diameter of the gear and worm in the manner instructed in plates 22 and 23. Next draw the line of action as shown, and generate the involute in the manner already explained. Next divide the wheel into as many equal spaces as there are teeth, and lay off the thickness of the teeth equal to one-half of the pitch, and draw the outline of the teeth as clearly shown in the section.

It now remains to determine the contour and its limits at the edge or end of the teeth, which may be done as follows: From where **a h** intersects the outside, the pitch and the root cylinders of the worm, project to the corresponding helices as shown by the dotted outline in the front view. This will give a foreshortened outline of the worm thread space as shown. Produce **a h** to the axis of the wheel as at g^v, draw a^v g parallel to a g^v, and project c to c^v; also the intersection of the outside and root cylinder with **a h**, which will give the limit of the worm thread space above and below the pitch line c c^v. Then lay off the outline of the section in the same relation to c^v g as the outline of the section in the front view is to p d; this will be a parallel view of the worm thread space. Transfer this view to an extra piece of paper as shown at p g^h, lay off on the pitch line equal divisions each side of p, also the same divisions on the axis of the wheel the same number of times each side of g^h. With g^h p as a radius and the points on the axis each side of g^h as centres, draw arcs tangent to each point on the pitch line as shown, which will represent the pitch circle in different positions as it rolls on the pitch line of the worm. Then on a piece of tracing cloth draw the pitch line of the worm and perpendicular to it a line equal to p g^h; with p g^h as a radius and g^h as a centre draw an arc of the pitch circle; through p on this arc of the pitch circle lay off divisions equal to those on the drawing. Place the tracing on the drawing so that p and g^h on the tracing coincides with p g^h on the drawing, fasten with thumb tacks and trace the section, remove the tacks and revolve the tracing until the pitch circle on the tracing coincides with the next arc of the pitch circle on the drawing, and the next point to p on the tracing coincides with the next point on the pitch line, fasten with the thumb tacks and trace the section again. Repeat this four or five times in each direction, then the envelope of these tracings will be the contour of the wheel tooth on the parallel plane, as seen in the parallel view at c^v. Find centres from which this outline can be drawn and transfer it from the tracing to the parallel view in the same relation to c^v g as it is to c^v g on the tracing. By projecting from the sectional view as shown at the top, the radii of the circles which limit the curves of the teeth at the outside and bottom will be obtained. These circles having been drawn, lay off on these circles and the pitch circle the points through which to draw the left outline of a tooth in the same relation to p d as they are to a^v g in the parallel view, then by making the width at the outside the pitch and the bottom equal to the width at the corresponding circles in the parallel view will give the points through which to draw the other side of the tooth. Then by drawing these outlines in the same relation to all the pitch points the front side of the teeth are finished. The outlines of the rear side are found in the same manner, by first finding an outline of the worm thread space on the rear side of the same space. In drawing these arcs upon which to place the tracing cloth,

Plate. 27



the longer they are the better for accuracy. This is a very difficult operation, therefore great care should be excerised. The outside diameter of the wheel may be determined as follows : The radius of the root cylinder plus the clearance multiplied by the versed sine of 30°, and this product multiplied by 2, then this last product added to what would be the outside diameter of a spur wheel having the same number of teeth and pitch, will give outside diameter of the worm wheel. Versed sin. of $30^\circ = .13397$

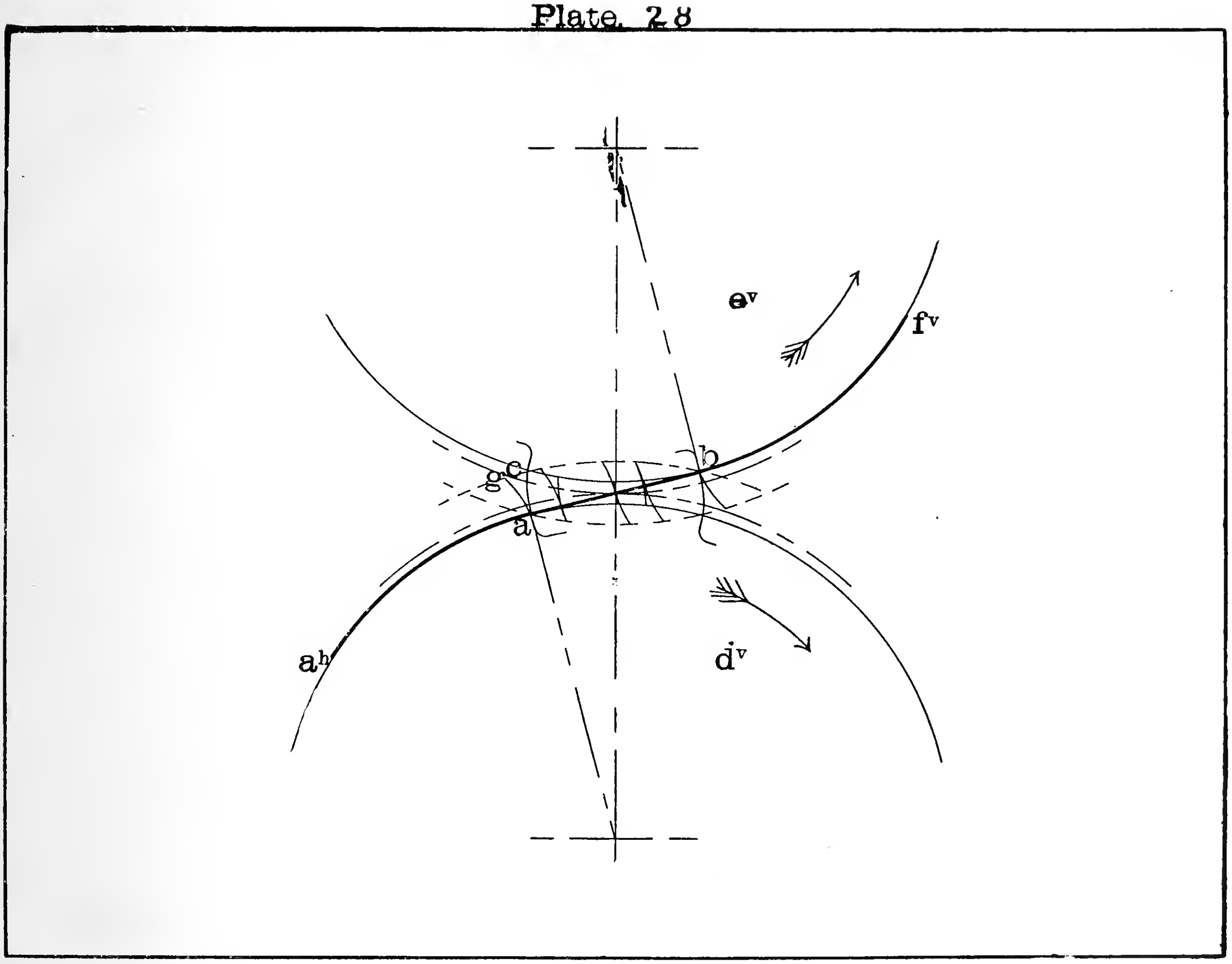
Plate 28.

The statement has been made that the path of contact of involute teeth was along the line of action. It will be well to give this more attention now, as the pupil is better acquainted with the subject, and therefore better prepared for further explanation. Draw the pitch circles of two wheels, and lay off the line of action. Then draw the base circles through a and b, and draw the addendum circle of the wheel e^v through a, and the addendum circle of the wheel d^v through b.

Let the flexible band f^v b a a^h be made fast to the base circles at f^v and a^h, then if e^v be revolved as indicated by the arrow, the flexible band will be wound on e^v and unwound from d^v, and at the same time revolve d^v as indicated by the arrow. Then while the wheels are revolving, a point fastened to the band at a will move along a b, and during this movement will generate the involutes a g and a c. It should be readily seen that the teeth must be in contact along the line of action.

It will also be seen; that the contact begins at a and ends at b, which is the greatest length of the path of contact, and as the addendum circles pass through a and b the full length of contact is made use of.

Plate. 28



SCREW CUTTING.

Rule.—Divide pitch of screw to be cut, by pitch of lead screw. Pitch of a screw is the distance it travels in one revolution. The lead screw is that screw which moves the lathe carriage along the shears of the lathe, and the movement of the carriage per revolution of the work is regulated by gear wheels on the end of the lathe.

To cut 4 threads per inch with a lead screw of 5 threads per inch: Four threads per inch is equal to $\frac{1}{4}''$ pitch; the lead screw 5 threads per inch equals $\frac{1}{5}$ pitch. Then

$$\frac{1}{4} \div \frac{1}{5} = \frac{1}{4} \times \frac{5}{1} = \frac{5 = \text{stud wheel.}}{4 = \text{lead screw wheel.}}$$

But there are no wheels with such a small number of teeth, and to obtain a suitable number of teeth, we may multiply $\frac{5}{4}$ by any number as 10; then

$$\frac{5}{4} \times 10 = \frac{50 = \text{stud wheel.}}{40 = \text{lead screw wheel.}}$$

If the thread to be cut is a certain number of threads and a fraction of a thread in one inch, as $5\frac{1}{4}$ threads per inch, it will be $5\frac{1}{4}$ equals $\frac{21}{4}$, which must be divided into 1 inch to obtain the pitch, then

$$1 \div \frac{21}{4} = 1 \times \frac{4}{21} = \frac{4}{21}$$

pitch or 21 threads in 4 inches, and is similar to the former example. $\frac{1}{4}''$ pitch is 4 threads in one inch, the numerator of the fraction always denoting the number of inches, and the denominator the number of threads, in that number of inches. Then

$$\frac{4}{21} \times \frac{5}{1} = \frac{20 = \text{stud wheel.}}{21 = \text{lead screw wheel.}}$$

If the thread to be cut should be one thread in more than one inch, as one thread in $1\frac{3}{4}$ inches, then $1\frac{3}{4} = \frac{7}{4}$, which is the pitch, and

$$\frac{7}{4} \div \frac{1}{5} = \frac{7}{4} \times \frac{5}{1} = \frac{35 = \text{stud wheel;}}{4 = \text{lead screw wheel;}} \text{ or } \frac{35}{4} \times 4 = \frac{140 = \text{stud.}}{16 = \text{lead screw.}}$$

But there is a great difference between the two wheels, which in most cases will make it necessary to compound, which may be done as follows: Divide $\frac{35}{4}$ by any numbers which will divide them without a remainder, as

$$\frac{35 \div 5 = 7}{4 \div 2 = 2}.$$

Then $\frac{5}{2}$, $\frac{7}{2}$ are the new wheels, and

$$\frac{5}{2} \times 10 = \frac{50}{20} \text{ and } \frac{7}{2} \times 8 = \frac{56}{16},$$

or $\frac{50}{20}$, $\frac{56}{16}$ will do the same work as $\frac{140}{16}$, and will go on the lathe in this manner: Put 50 on the stud gearing in 20, then 56 along side of it, gearing in 16 on the lead screw. 56 and 20 must be keyed to a sleeve which is made to turn on the intermediate stud. The numerator and the denominator must be multiplied by the same number. Any number that may be necessary to obtain a set of wheels from the wheels there may be to select from may be used. Whatever may be the pitch of the screw to be cut, or the pitch of the lead screw, the wheels are obtained as above.

Threads are quite frequently irregular, as $4\frac{3}{4}$ threads in $3\frac{5}{8}$ inches.

$$4\frac{3}{4} = \frac{19}{4} \text{ and } 3\frac{5}{8} = \frac{29}{8};$$

$\frac{29}{8}$ is the length which contains $4\frac{3}{8}$ or $\frac{19}{4}$ threads. The length divided by the number of threads equals pitch, as

$$\frac{29}{8} \div \frac{19}{4} \text{ or } \frac{29}{8} \times \frac{4}{19} = \frac{116}{152};$$

this being large may be reduced without changing its value,

$$4 \left| \frac{116}{152} = \frac{29}{38} = \text{pitch}, \right.$$

which, divided by pitch of lead screw, equals wheels. Let pitch of lead screw be 4 threads per inch, equals $\frac{1}{4}$ pitch, then

$$\frac{29}{38} \times \frac{4}{1} = \frac{116}{38}.$$

$$\frac{116 \div 4 = 29}{38 \div 2 = 19} \times 2 = \frac{58}{38} \text{ and } \frac{4}{2} \times 10 = \frac{40}{20}.$$

Then $\frac{40}{20}$ and $\frac{58}{38}$ are the wheels that will cut $4\frac{3}{4}$ threads in $3\frac{5}{8}$ inches.

To prove a set of wheels, divide the product of the teeth of the driven wheels by the pitch of the lead screw, then this quotient divided by the product of the teeth of the driving wheels will give the number of threads per inch. Or, if there are only two wheels, then the number of teeth in the lead screw wheel divided by pitch of lead screw, and this quotient divided by number of teeth in stud wheel, will give the number of threads per inch.

Table No. 1.

20° LINE OF ACTION, CIRCULAR PITCH.

Note:—This table can be used only for 20° line of action. Multiply tabular numbers by circular pitch to obtain the different radii.

For 20° line of action :

Radius of face curve $= .34202 \times \mathbf{r} + (.2125\ \mathrm{p})$.

Radius of flank curve $= .04125 \times \mathrm{p} \times \mathbf{n}$.

$\mathrm{r} =$ radius of pitch circle.

$\mathrm{p} =$ circular pitch.

$\mathrm{n} =$ number of teeth.

Column No. 1. No. of teeth.	Column No. 2. Radius of face.	Column No. 3. Radius of flank.	Column No. 4. Radius of circle at centre.	Column No. 5. Radius of fillet.
12	.86568	.495	.2	.15
13	.92	.53625	.15	.15
14	.97452	.5775	.125	.125
15	1.02896	.61875	Radial	.125
16	1.1034	.66	"	.125
17	1.1378	.70125	"	.125
18	1.19224	.7425	"	.125
20	1.30114	.825	Curve	.1
22	1.41004	.9075	"	.1
24	1.5188	.99	"	.075
26	1.6277	1.0725	"	.075
30	1.8454	1.2375	"	.05
40	2.38978	1.65	"	.0375
50	2.934	2.062	"	.0375
70	4.0227	2.887	"	.0375
100	5.6557	4.125	"	.0375
150	8.3773	6.187	"	.0375
300	16.542	12.375	"	.0375
Rack				

Table No. 2.

20° LINE OF ACTION, DIAMETRAL PITCH.

Note:—This table can be used only for 20° line of action. Divide tabular numbers by diametral pitch to obtain the radii.

Column No. 1. No. of teeth.	Column No. 2. Radius of face.	Column No. 3. Radius of flank.	Column No. 4. Radius of circle at centre.	Column No. 5. Radius of fillet.
12	2.7193	1.5551	.3148	.4712
13	2.8902	1.6845	.2356	.4712
14	3.0614	1.8142	.1963	.3927
15	3.2323	1.9437	Radial	.3927
16	3.4664	2.0734	"	.3927
17	3.5745	2.2028	"	.3927
18	3.7454	2.3326	"	.3927
20	4.0875	2.5918	Curve	.3141
22	4.4296	2.8510	"	.3141
24	4.7714	3.1100	"	.2356
26	5.1135	3.3693	"	.2356
30	5.7975	3.8877	"	.1570
40	7.5074	5.1836	"	.1178
50	9.2174	6.4779	"	.1178
70	12.6377	9.0697	"	.1178
100	17.7679	12.9591	"	.1178
150	26.3181	19.4370	"	.1178
300	51.9683	38.8773	"	.1178
Rack				

Table No. 3.

$14\frac{1}{2}°$ LINE OF ACTION, CIRCULAR PITCH.

Note:—This table can be used only for $14\frac{1}{2}°$ line of action. Multiply tabular numbers by circular pitch to obtain the different radii.

For $14\frac{1}{2}°$ line of action:

Radius of face curve $= .25038 \times r + (.2125\ p)$.

Radius of flank curve $= .033 \times p \times n$.

$r =$ radius of pitch circle.

$p =$ circular pitch.

$n =$ number of teeth.

Column No. 1. No. of teeth.	Column No. 2. Radius of face.	Column No. 3 Radius of flank.	Column No. 4. Radius of circle at centre.	Column No. 5. Radius of fillet.
12	.6906	.396	.23125	.175
13	.7305	.429	.1982	.1708
14	.7703	.462	.1652	.1666
15	.8102	.495	.1321	.1625
16	.8500	.528	.0991	.1583
17	.8899	.561	.0661	.1542
18	.9297	.594	.0330	.1500
20	1.0094	.660	Radial	.1417
22	1.0891	.726	"	.1333
24	1.1688	.792	"	.1250
26	1.2485	.858	"	.1167
30	1.4079	.990	"	.1000
40	1.8064	1.320	Curve	.0583
50	2.2048	1.650	"	.0500
70	3.0018	2.310	"	.0500
100	4.1972	3.300	"	.0500
150	6.1896	4.950	"	.0500
300	6.1896	9.900	"	.0500
Rack				

Table No. 4.

$14\frac{1}{2}°$ LINE OF ACTION, DIAMETRAL PITCH.

Note:—This table can be used only for $14\frac{1}{2}°$ line of action. Divide tabular numbers by diametral pitch to obtain the radii.

Column No. 1. No. of teeth.	Column No. 2. Radius of face.	Column No. 3. Radius of flank.	Column No. 4. Radius of circle at centre.	Column No. 5. Radius of fillet.
12	2.1696	1.2441	.7264	.54978
13	2.2949	1.3477	.6227	.53658
14	2.4200	1.4514	.5189	.52339
15	2.5453	1.5551	.4151	.51051
16	2.6704	1.6588	.3114	.49731
17	2.7957	1.7624	.2076	.48443
18	2.9207	1.8661	.1038	.47124
20	3.1711	2.0734	Radial	.44516
22	3.4215	2.2808	"	.41877
24	3.6719	2.4881	"	.39270
26	4.0223	2.6955	"	.36662
30	4.4230	3.1102	"	.31416
40	5.6750	4.1469	Curve	.1835
50	6.9266	5.1836	"	.15708
70	9.4304	7.2571	"	.15708
100	13.1859	10.3672	"	.15708
150	19.4452	15.5509	"	.15708
300	19.4452	31.1018	"	.15708
Rack				

Table No. 5.

FRANKLIN INSTITUTE OR U. S. STANDARD BOLT AND NUT PROPORTIONS.

Diameter of Bolt.	Threads per Inch.	Root Diameter=Diameter —1.3 of Pitch.	Width of Flats=.125 of Pitch.	Width over Flats=1.5 Diameter + 1/16".	Long Diameter=Width over Flats × 1.154.	Thickness of Head and Nut=diameter—1/16".	Diameter of Washer=2 Diameters + 1/16".	Thickness of Washer.
1/4"	20	.185"	.0062"	7/16"	.505"	3/16"	9/16"	3/32"
5/16"	18	.240"	.0074"	11/32"	.613"	1/4"	11/16"	1/8"
3/8"	16	.294"	.0078"	5/8"	.722"	5/16"	13/16"	1/8"
7/16"	14	.344"	.0089"	23/32"	.830"	3/8"	15/16"	5/32"
1/2"	13	.400"	.0096"	13/16"	.938"	7/16"	1 1/16"	5/32"
9/16"	12	.454"	.0104"	29/32"	1.046"	1/2"	1 3/16"	3/16"
5/8"	11	.507"	.0113"	1"	1.154"	9/16"	1 5/16"	3/16"
3/4"	10	.620"	.0125"	1 3/16"	1.371"	11/16"	1 9/16"	7/32"
7/8"	9	.731"	.0138"	1 3/8"	1.587"	13/16"	1 13/16"	7/32"
1"	8	.837"	.0156"	1 9/16"	1.804"	15/16"	2 1/16"	1/4"
1 1/8"	7	.940"	.0178"	1 3/4"	2.020"	1 1/16"	2 5/16"	1/4"
1 1/4"	7	1.065"	.0178"	1 15/16"	2.237"	1 3/16"	2 9/16"	5/16"
1 3/8"	6	1.160"	.0208"	2 1/8"	2.453"	1 5/16"	2 13/16"	5/16"
1 1/2"	6	1.284"	.0208"	2 5/16"	2.670"	1 7/16"	3 1/16"	3/8"
1 5/8"	5 1/2	1.389"	.0227"	2 1/2"	2.886"	1 9/16"	3 5/16"	3/8"
1 3/4"	5	1.491"	.0250"	2 11/16"	3.103"	1 11/16"	3 9/16"	7/16"
1 7/8"	5	1.616"	.0250"	2 7/8"	3.319"	1 13/16"	3 13/16"	1/2"
2"	4 1/2	1.712"	.0277"	3 1/16"	3.536"	1 15/16"	4 1/16"	9/16"
2 1/4"	4 1/2	1.962"	.0277"	3 7/16"	3.969"	2 3/16"	4 9/16"	5/8"
2 1/2"	4	2.176"	.0312"	3 13/16"	4.402"	2 7/16"	5 1/16"	11/16"
2 3/4"	4	2.426"	.0312"	4 3/16"	4.835"	2 11/16"	5 9/16"	3/4"
3"	3 1/2	2.629"	.0357"	4 9/16"	5.268"	2 15/16"	6 1/16"	13/16"

These are finished sizes. Add 1/8" for rough sizes instead of 1/16".

DECIMAL EQUIVALENTS.

8ths.

$\frac{1}{8}$ = .125

$\frac{1}{4}$ = .250

$\frac{3}{8}$ = .375

$\frac{1}{2}$ = .500

$\frac{5}{8}$ = .625

$\frac{3}{4}$ = .750

$\frac{7}{8}$ = .875

16ths.

$\frac{1}{16}$ = .0625

$\frac{3}{16}$ = .1875

$\frac{5}{16}$ = .3125

$\frac{7}{16}$ = .4375

$\frac{9}{16}$ = .5625

$\frac{11}{16}$ = .6875

$\frac{13}{16}$ = .8125

$\frac{15}{16}$ = .9375

32nds.

$\frac{1}{32}$ = .03125

$\frac{3}{32}$ = .09375

$\frac{5}{32}$ = .15625

$\frac{7}{32}$ = .21875

$\frac{9}{32}$ = .28125

$\frac{11}{32}$ = .34375

$\frac{13}{32}$ = .40625

$\frac{15}{32}$ = .46875

$\frac{17}{32}$ = .53125

$\frac{19}{32}$ = .59375

$\frac{21}{32}$ = .65625

$\frac{23}{32}$ = .71875

$\frac{25}{32}$ = .78125

$\frac{27}{32}$ = .84375

$\frac{29}{32}$ = .90625

$\frac{31}{32}$ = .96875

64ths.

$\frac{1}{64}$ = .015625

$\frac{3}{64}$ = .046875

$\frac{5}{64}$ = .078125

$\frac{7}{64}$ = .109375

$\frac{9}{64}$ = .140625

$\frac{11}{64}$ = .171875

$\frac{13}{64}$ = .203125

$\frac{15}{64}$ = .234375

$\frac{17}{64}$ = .265625

$\frac{19}{64}$ = .296875

$\frac{21}{64}$ = .328125

$\frac{23}{64}$ = .359375

$\frac{25}{64}$ = .390625

$\frac{27}{64}$ = .421875

$\frac{29}{64}$ = .453125

$\frac{31}{64}$ = .484375

$\frac{33}{64}$ = .515625

$\frac{35}{64}$ = .546875

$\frac{37}{64}$ = .578125

$\frac{39}{64}$ = .609375

$\frac{41}{64}$ = .640625

$\frac{43}{64}$ = .671875

$\frac{45}{64}$ = .703125

$\frac{47}{64}$ = .734375

$\frac{49}{64}$ = .765625

$\frac{51}{64}$ = .796875

$\frac{53}{64}$ = .828125

$\frac{55}{64}$ = .859375

$\frac{57}{64}$ = .890625

$\frac{59}{64}$ = .921875

$\frac{61}{64}$ = .953125

$\frac{63}{64}$ = .984375