SHOP AND FOUNDRY PRACTICE

PREPARED FOR STUDENTS OF THE

INTERNATIONAL CORRESPONDENCE SCHOOLS

SCRANTON, PA.

Volume I

READING WORKING DRAWINGS

ARITHMETIC

MEASURING INSTRUMENTS

LATHE WORK

WITH PRACTICAL QUESTIONS AND EXAMPLES

Second Edition

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PREFACE.

The need of a work on Shop and Foundry Practice for the use of apprentices and journeymen, dealing with the subject from the workman's point of view, has long been apparent. That such a work has not heretofore appeared has been due to a number of causes, perhaps the chief of which has been the immense field to be covered and the great expense involved. The modern trend toward specialization and the constantly increasing list of special tools and appliances has tended to develop journeymen who are not all around workmen; that is, they are not able to run any machine in the shop or to perform all the operations pertaining to their trades. Every journeyman (and apprentice) desires to obtain a knowledge of all that relates to his trade, and it was in the hope of assisting him in this respect that the present treatise has been prepared. The subjects treated include Machine-Shop Practice—embracing a description of Machine Tools and their operations, Toolmaking, Bench, Vise, and Floor Work, and Erecting—Patternmaking, Molding and Foundry Work, and Blacksmithing and Forging.

Owing to the practice of furnishing drawings and blueprints to workmen, we have prepared a special paper on the subject of Reading Working Drawings. We are not aware that any paper similar to this has heretofore been published. A careful study of it, together with a little practice, should enable any one to read a drawing without difficulty. This paper is followed by three small papers covering the subject of Arithmetic up to and including decimals. It is essential that the machinist have a knowledge of arithmetic equivalent to this, in order to calculate problems relating to change gears, pitches, indexing, tapers, etc. These papers are followed by a paper on Measuring Instruments, in which are described verniers, micrometers, micrometer calipers, protractors, gauges and other instruments of precision, with directions for using them.

In preparing the papers relating to machine-shop practice, every effort was made to secure information regarding the latest practice. Many of the leading establishments in the East and West were visited by our representatives and unusual privileges were extended to them; valuable information was given them and permission was accorded to take photographs of anything desired. Credit has been given in many places in the work where tables or other special matter that has been furnished, appear. A large number of the devices and processes described appear herewith for the first time in print. We desire to acknowledge our indebtedness to the following firms for courtesies extended: E. P. Allis Co., Milwaukee, Wis.; Fraser & Chalmers, M. C. Bullock Manufacturing Co., Whitcomb Manufacturing Co., Gates Iron Works, The Western Electric Co., The Standard Pneumatic Tool Co., and The Chicago Pneumatic Tool Co., Chicago, Ill.; Laidlaw-Dunn-Gordon Pump Co., The Fay & Eagan Co., Lane & Bodley Co., and Goyne Pump Co., Cincinnati, O.; Brown Hoisting and Conveying Machine Co., Warner & Swasey Co., and Cleveland Twist Drill Co., Cleveland, O.; Dickson Manufacturing Co., Dickson Locomotive Works, Scranton Stove Works, and Scranton Bolt and Nut Co., Scranton, Pa.; Schenectady Locomotive Works and General Electric Co., Schenectady, N. Y.; Norton Emery Wheel Co., Plunger Elevator Co., Worcester Polytechnic Institute, and T. E. Reed Co., Worcester, Mass.; Newton Machine Tool Works, Bement Miles & Co., and Wm. Sellers & Co., Philadelphia, Pa.; Stilwell-Bierce & Smith-Vaile Co., National Cash Register Co., and New Era Iron Works, Dayton, O.; Hill, Clark & Co. and Rivett-Dock Co., Boston, Mass.; Beaman & Smith and Brown & Sharpe Manufacturing Co., Providence, R. I.; Baush Machine Tool Co., Springfield, Mass.; Jones & Lamson Manufacturing Co., Springfield, Vt.; Manning, Maxwell & Moore and Garvin Machine Co., New York, N. Y.; Pratt & Whitney Co. and The Whitney Manufacturing Co., Hartford, Conn.; Niles Tool Works Co., Hamilton, O.; Arcade File Works, Anderson, Ind.; Pond Machine Tool Co., Plainfield, N. J.; Landis Tool Co., Waynesboro, Pa.; Westinghouse Machine Co., Pittsburg, Pa.; Chas. A. Strelinger & Co., Detroit, Mich.; Morgan Engineering Co., Alliance, O.; The Thomas D. West Foundry Co., Sharpesville, Pa.; Deane Steam Pump Co., Holyoke, Mass.; W. & L. E. Gurley, Troy, N. Y.; Morse Twist Drill and Machine Co., New Bedford, Mass.; American Engine Co., Bound Brook, N. J.; L. S. Starrett & Co., Athol, Mass.; Stow Manufacturing Co., Binghamton, N.Y.; New Process Twist Drill Co., Taunton, Mass., and many others who have shown courtesies to our representatives and have sent catalogues, drawings, or other material for use in preparing these volumes.

We also wish to extend our thanks to the American Machinist, Machinery, and Engineering Magazine for information gleaned from their files and for courtesies extended.

The various papers constituting these volumes have been prepared in accordance with the system originated by us of teaching subjects relating to technology by correspondence. The descriptions of the machines in use have been confined to one or two leading types of each class, and the space thus gained has been devoted to imparting general information that would be applicable to all machines of the class considered, regarding their operation, care, and management. For each paper there has been prepared a series of questions, which serve to bring out the student's knowledge of the text; and solutions to those questions requiring an arithmetical calculation are given at the end of each volume.

In the papers on Patternmaking it is assumed that the workman already has a knowledge of the more common hand tools and their uses, and only a short description is given of the machine tools and their advantages. In place of attempting to systematize the various classes of patterns and bring them all to conform to some regular law, they have been divided into broad general classes and a series of practical examples have been given showing how to make patterns for certain classes of castings. A careful study of these examples should enable an intelligent workman to overcome any difficulties ordinarily arising in the work of the pattern shop.

The papers on Foundry Work include not only the molding, but the mixing of sands and loams, the mixing and melting of the metals, general arrangement of the foundry, core making, and all the important questions or difficulties that are likely to arise in conducting the work of iron or brass foundries.

The papers on Blacksmithing and Forging, like the previous ones, are not intended to be exhaustive, but it is aimed to give all the underlying principles of importance, the first paper dealing with iron forging, and the subsequent papers with steel and the methods of handling it. There has also been included a treatment of the subjects of soldering, brazing, sweating, and bending brass and copper pipe.

An examination of these volumes will make evident the fact that the various papers composing them were written by men who are thoroughly acquainted with the subjects on which they wrote and who are capable of taking the places of the workmen engaged in carrying out the practical ideas presented. Besides our regular staff of writers we have been assisted by the following well known gentlemen: Thos. D. West, President American Foundrymen's Association, member of The American Society of Mechanical Engineers, author of "American Foundry Practice," "Molders' Text Book," and "The Metallurgy of Cast Iron," and Manager of the Thos. D. West Foundry Co.; P. S. Dingey, Professor of Patternmaking and Foundry Work in the Chicago English High and Manual Training School, author of "Machine Patternmaking"; Moritz W. Boehm, Instructor of Manual Training, North Side High School, Chicago; W. P. Turner, Instructor in Machine Work, Purdue University; Prof. M. J. Golden, member American Society Mechanical Engineers, Professor of Practical Mechanics, Purdue University, and author of "A Laboratory

Course in Wood-Turning"; H. P. Fairfield, Head Instructor Worcester Polytechnic Institute; G. I. Alden, past Vice President of the American Society of Mechanical Engineers and for twenty-eight years Professor of Mechanical Engineering in the Worcester Polytechnic Institute, now Treasurer of the Norton Emery Wheel Co. and the Plunger Elevator Co., Worcester, Mass.; C. H. Norton, formerly Engineer of the Grinding Machine Department of the Brown & Sharpe Manufacturing Co. and author of their book on Grinding, now Mechanical Engineer of the Norton Emery Wheel Co., Worcester, Mass.; F. M. Davis, Designer of Special Machinery for the E. P. Allis Co., Milwaukee, Wis.; J. S. Lane, M. E., member of American Society of Mechanical Engineers, formerly connected with the Webster, Camp & Lane Machine Co., Akron, O., then General Manager of the M. C. Bullock Manufacturing Co., Chicago, Ill., and later Consulting Engineer in New York, N. Y., and Johannesburg, South Africa. The following members of our own staff have also assisted in this work: J. J. Clark, John A. Grening, A. B. Clemens, D. Petri-Palmedo, F. B. Hamilton, and C. P. Turner, the whole being outlined and edited by H. M. Lane.

The method of numbering the pages, cuts, articles, etc., is such that each paper and part is complete in itself; hence, in order to make the indexes intelligible, it was necessary to give each paper and part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number, it is preceded by the printer's section mark §. Consequently, a reference such as page 29, § 18 would be readily found as follows: Look along the inside edges of the headlines until § 18 is found, and then through § 18 until page 29 is found.

The Question Papers are given the same section numbers as the Instruction Papers to which they belong, and are grouped together at the end of the volumes containing the Instruction Papers to which they refer.

INTERNATIONAL CORRESPONDENCE SCHOOLS.

CONTENTS.

READING WORKING DRAWINGS.

FUNDAMENTAL PRINCIPLES OF DRAWING.

INTRODUCTION.

1. Drawing has been spoken of as the "language of the engineer." In addition, it is also a *universal* language. A drawing made in France or Germany can be interpreted and worked to as readily in the United States of America as can a drawing made in one of the drafting rooms of the latter country, except, of course, that the notes on the former would be in a foreign language, and the units of measurement in a different system. But the drawing proper would be quite intelligible.

2. The object of this section is to teach the student this language of the engineer—to enable him to *read* a mechanical drawing, just as he would have to learn the German language in order to read a book written in that tongue. Much has already been written for the draftsman himself, instructing him how to make a *drawing;* what views to give, how to obtain them correctly, and how to arrange them; what conventions to observe; how to handle his instruments, with hints regarding the preparation of his materials, ink, paper, pencils, etc.; and also how to make prints. This section, however, is written with a view to rendering the meaning of a drawing intelligible when put into the hands of a person having no previous knowledge of the object pictured. While a thorough knowledge of reading drawings can be obtained by a careful study and a subsequent application of the principles underlying the conventional representation of objects on paper, the beginner must not expect that as soon as he is able to read a drawing correctly he will also be able to read it as rapidly as a person that has spent many years in reading drawings and working from them. Actual practice alone will enable a person to read a drawing rapidly, as this may be likened to printed matter, which no one can read rapidly without practice.

DEFINITIONS.

3. In order to understand what a drawing really is, it is necessary that the following definitions and explanations should be thoroughly mastered.

A **surface** may be defined as the *outline* of a solid; it has the shape of a solid, but is without thickness. For example, when a pattern lies in its mold, that part of the pattern that comes in contact with the sand is called the **surface of the pattern.** Again, as we all know, a soap bubble is very thin; it has air inside of it and its outside is also in contact with air; that part touched by the air inside is called the **inside surface,** and the part touched by the air outside is called the **outside surface.** Now, if the thickness of the bubble could be diminished indefinitely until there was absolutely no thickness at all, there would of course be no bubble, but we could imagine the outline or form of the bubble as still remaining, and this outline or form would be the surface.

It is evident that a surface may have any shape whatever; that is, it may be conical, spherical, bell-shaped, etc., and, consequently, may be flat, like the top of a surface plate. A flat surface is called a **plane surface,** and, when considered by itself, without reference to any particular body, it is regarded as indefinite in extent and is called a **plane.** A plane, like a surface, has no thickness.

When a body has several **sides,** as a cube, a nut, a house, etc., the whole outline or form of the body is called the **entire surface,** and it is customary to consider the entire surface as composed of partial surfaces having the shape of the sides. These partial surfaces may be plane (flat), curved, or irregular. Thus, a cube is composed of six plane surfaces; a cylinder having flat ends has one curved and two flat surfaces; a hexagonal nut has seven flat surfaces and one curved surface—the top.

When drawing an object on paper, the drawing is always made on a flat surface, and the surface on which the object is drawn is called the **picture plane.**

METHODS OF PROJECTION.

4. There are a number of methods in use for representing an object on a plane; of these methods, only the two most generally used will be mentioned here. Those drawings that represent the object as it appears to the eye are called **scenographic projection,** or **perspective,** drawings; the drawings of the other class are called **orthographic projection** drawings, or, more simply, **projection** drawings. The difference between the two classes of drawings may be illustrated as follows:

In Fig. 1, *A B C D* represents a rectangular hole in the block *H*; *S* is the sheet of paper on which the drawing is to be made; and *p* is the point where the eye is situated. The point *p* is called the **point of sight;** the lines *A a*, *B b*, etc. are called **rays** or **projectors;** the points *a*, *b*, *c*, etc. on the picture plane are said to be **projections** of the points *A*, *B*, *C*, etc.; and the lines *a b*, *b c*, etc. are said to be **projections** of the lines *A B*, *B C*, etc. The picture plane is supposed to be transparent, and the lines *A p*, *B p*, *C p*, etc. represent rays of light extending from the object, through the picture plane, to the eye *p*.

5. Several striking peculiarities in the representation of the object on the picture plane *S* will be noticed. It will be observed that all the lines *a b*, *b c*, etc. are shorter than the corresponding lines *A B*, *B C*, etc. on the object. This is caused by the fact that all the projectors or rays of light converge toward (meet at) the point of sight *p*. Another point to be considered is, that if the point of sight is moved to some position other than *p*, the outline on the picture

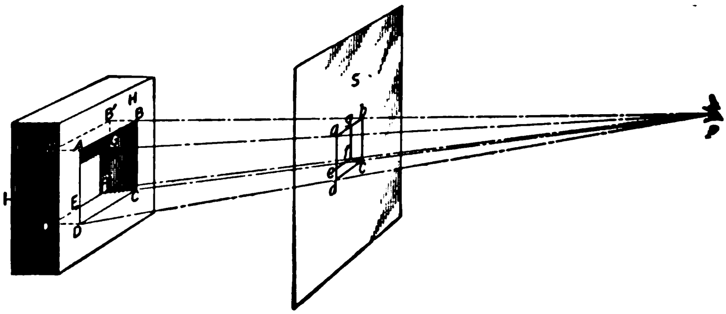


FIG. 1.

plane *S* will have an entirely different shape from that shown in Fig. 1, for we shall then be viewing the hole in *H* from a different position. A third fact will also be noticed—that one interior edge and two rear edges of the hole are seen from the point *p*, when *p* is in the position shown.

A drawing made according to the principles just explained is called a *scenographic projection*, or *perspective drawing*. The point of sight *p* may be at any suitable distance from the picture plane, which is always supposed to be transparent.

A perspective drawing is useless for a working or shop drawing for a number of reasons, one of which is that it would be practically impossible to measure the different lines and get their true lengths, and another is that it does not show the appearance of the inside of a hollow body.

6. Referring to Fig. 1, suppose the point of sight *p* to be moved farther back from the picture plane; it is evident that the lines *a b*, *b c*, etc. will then be longer than shown in the figure, and that the rays or projectors *A p*, *B p*, *C p*, etc. will be more nearly perpendicular, i. e., at right angles to, or square with, the picture plane *S*. If the point *p* could be conceived as having been moved an immense distance, a distance too great to be measured (i. e., an infinite distance), from the picture plane, the lines *a b*, *b c*, etc. would then be equal in length to *A B*, *B C*, etc., and the projectors *A a*, *B b*, *C c*, etc. would all be perpendicular to the picture plane *S*. The projection of the hole on the picture plane would then be as shown in Fig. 2, and the view would be the same size and shape in all respects as the front edges of the hole in the object. If the hole is straight, and the point of sight *p* is in line with the center of the hole, neither the rear edges nor the interior edges can be shown in Fig. 2. A view of this kind is called an *orthographic projection*, or, more simply, the projection, of *A B C D* on the plane *S*.

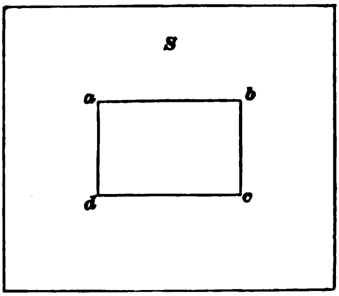


FIG. 2.

7. Now, in order to show the depth (length) of the hole, we turn the object (see Fig. 1) around so that the edge *I* of the block occupies the same position relative to the picture plane that the side *H* does. Although we cannot see through the block, we may imagine that we can, and, after projecting the outline of the face *I* on the picture plane *S* to the left of the projection of the hole in the face *H*, we project the outline *A A′ D′ D* of the hole into *a a′ d′d*, Fig. 3, in the same manner in which the outline *A B C D* was projected into *a b c d* in Fig. 1. We may then project the outline of the face *H* on *S*

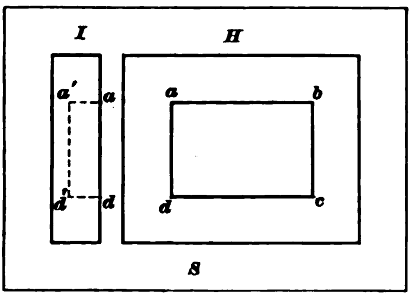


FIG. 3.

to complete this view, turning the object for this purpose back to the position shown in Fig. 1; the result is then as shown in Fig. 3. The outline *a a' d' d* has been drawn in dotted lines, with the exception of the line *a d*, to indicate that the lines *a a'*, *a' d'*, and *d' d* are hidden, i. e., they cannot be seen in the view shown. This view also shows that the hole does not extend through the block.

8. We have now described the essential features that distinguish the two leading methods of representing an object by means of a drawing. A drawing in scenographic projection, or perspective, has its point of sight located near the picture plane, while a drawing in orthographic projection has its point of sight located at an immense (infinite) distance from the picture plane. There is another way, however, in which to regard a drawing in orthographic projection, and this is to regard each point on the object as having its own point of sight *in* the picture plane. Thus, in Fig. 4, *a* may be regarded as the point of sight of *A*; *b* as the point of sight of *B*, and so on, the eye being supposed to be located at *a*, *b*, *c*, etc., in the picture plane, in such a manner that a line (projector) drawn from *any* point on the object to the eye will be perpendicular to the picture plane *S*; in other words, the lines *A a*, *B b*, etc. are all perpendicular to (square with) the plane *S*.

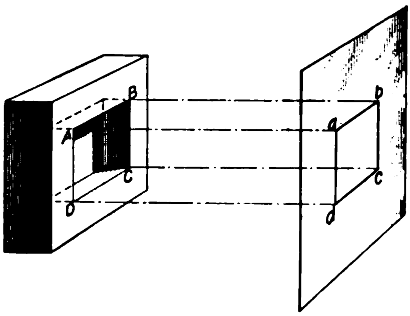


FIG. 4.

9. All mechanical and working drawings are constructed by using the principles of orthographic projection. Since, in order to read a drawing, it is necessary to understand the principles underlying the representation of objects on paper, together with all the conventionalities, short cuts, etc. employed by draftsmen, we shall now explain the various steps, proceeding by easy stages, so as not to confuse the student.

10. In Fig. 5, *a b c d* represents a solid having a flat bottom, a curved top, and flat ends square with the bottom.

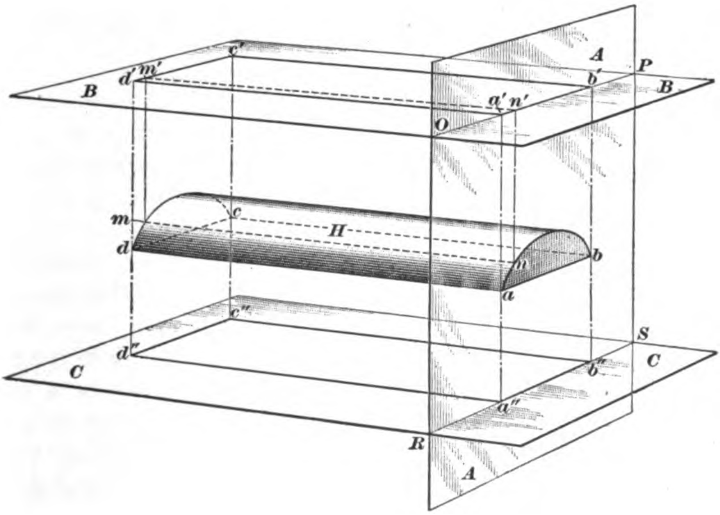


FIG. 5.

To make the drawing of this in orthographic projection, we place the picture plane in front of the end *a n b*, and, as it makes no difference when making a drawing of this kind where the picture plane is with respect to its distance from the object, we have shown it as touching the end *a n b*. The outline *a n b* then represents the projection of the solid *H* upon the plane *A*. In this case we could imagine the plane *A* to be a sheet of celluloid placed so as to touch the end of the object *H*, and then the outline *a n b* to be traced with a pencil. Now we imagine another plane *B* to be situated above the object *H*, and to be perpendicular to the plane *A*, and at the same time parallel to the bottom of the object. The eye is then supposed to be above this plane *B*, and the projectors *a a'*, *b b'*, etc. locate the projections *a' b' c' d'* of the corresponding points *a b c d* of the object upon the picture plane *B*.

The rectangle $a' b' c' d'$ is the projection of the entire curved surface of the object upon the plane B. Fig. 5 also shows another plane C, drawn beneath the object H, parallel to the plane B, and perpendicular to the plane A. The rectangle $a'' b'' c'' d''$ is the projection of the flat bottom of the object upon the picture plane C, the eye being supposed to be located below the plane C.

11. The reader will notice several striking facts in connection with this figure. He will notice, first, that when two planes intersect (cut each other), the line of intersection is a straight line. For instance, the line of intersection of the plane B and the plane A is the straight line $O P$, and the line of intersection of the plane C with the plane A is the straight line $R S$. In fact, the line of intersection of two planes is always a straight line, and can never be a curved line. Another feature that is brought out by the figure is the fact that the shape of the projection of a surface is determined by the bounding line of the surface projected, and not by its shape within the bounding line. This is shown by the fact that the projection on the plane B is exactly the same in all respects as the projection on the plane C. It is further shown by the fact that the projection of the curved line $a n b$ is the straight line $a' b'$ in the plane B.

12. While, theoretically, every point of the object should be projected on the picture plane, it is very seldom necessary to project but a very small number of these points for the following reasons: All straight lines, and all lines whose projections are straight lines, are determined, in so far as their projections are concerned, as soon as the projection of two of their points is known. To make this statement clear, refer to Fig. 5, and suppose that it is required to project a line such as $m n$, situated in the curved surface of the object, upon the picture plane B. This line is projected by simply projecting the point m in the point m' and the point n in the point n', and drawing a line through these two points. The dotted line $m' n'$ is then the projection of the line $m n$.

Consequently, in order to project the curved surface *a n b c m d* upon the picture plane *B*, all that was necessary in this case was to project the four points *a*, *b*, *c*, and *d*, and connect them by the straight lines *a' b'*, *b' c'*, etc.

13. It would, of course, be entirely impracticable to make drawings in the manner shown in Fig. 5. We could not go to the trouble of drawing the planes *A*, *B*, and *C*, as shown in this figure, both because it would result in too great a loss of time, and also because it would be impossible to do this in the case of a complicated drawing. For this reason, imagine the plane *B* to be revolved upwards, turning on the line *O P* until the planes *A* and *B* coincide. In the same way, we imagine the plane *C* to be revolved downwards, turning on the line *R S*, until it coincides with the plane *A*. Then, instead of three planes, as shown in Fig. 5, we have one plane, as shown in Fig. 6. Here *O P* and *R S* represent the lines *O P* and *R S* in Fig. 5. Also, *a n b* represents the end view of the object *H* in Fig. 5, or in other words, the projection of *H* upon the plane *A*; *a' b' c' d'* represents the projection of the object *H* upon the plane *B*, Fig. 5; and *a" b" c" d"* represents the projection of the object *H* upon the plane *C* in Fig. 5.

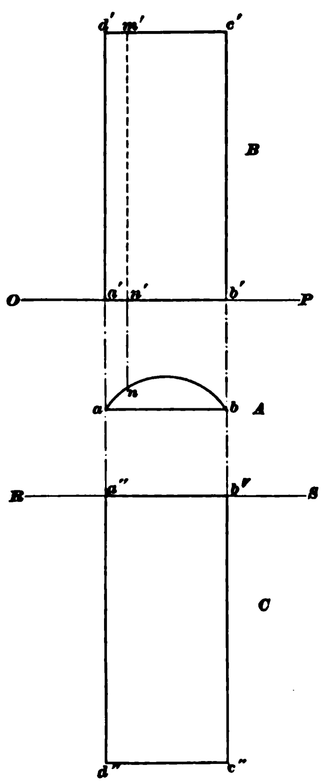


FIG. 6.

14. In Fig. 6, the rectangle *B* is called the **top view**, the rectangle *C* is called the **bottom view**, and *A* is called the **end view** or **side view**

of the object *H*. In this particular case, the bottom view *C* is not required in order to determine the shape of the object. In fact, the bottom view is very seldom necessary, being drawn only in special cases where it is essential, in order to obtain a view of certain details of the object that cannot very well be shown or indicated in some other view. So far as the simple object illustrated in Fig. 5 is concerned, all that was required to determine its shape and size were the two views *B* and *A*, the top view and end view, respectively. By means of view *B*, we determine the length and breadth of the object, and from view *A* we determine its height or depth. In fact, all that was necessary in order to draw this object was to draw a rectangle whose length and breadth should be the same as that of the flat bottom of the object (as shown in view *B*, Fig. 6), and the shape *a n b* of the end (as shown in view *A*, Fig. 6).

REPRESENTATION OF OBJECTS.

15. Suppose we desire to make a drawing of a block having a flat top and bottom, and flat sides square with the bottom. Suppose, further, that there is a semicircular groove in the top of this block, located exactly half way between the edges. The top view of this block may be supposed to be as shown at *B* in Fig. 7 (*a*). Now, suppose the line *P P* to represent the edge of the picture plane, which is parallel with the face *a b* of the block, and corresponds in every respect with the plane *A* in Fig. 5. The lines *a a'*, *c c'*, etc. represent the projectors that extend from the points *a*, *c*, etc. to the picture plane; in other words, they are projectors. Imagining the eye to be situated to the right of the line *PP* and looking in the direction of the arrow *X*, project those points on the right-hand side of the block *B* upon the plane *P* that are necessary in order to obtain the projection of the surface *a b*. Now, revolving the picture plane upwards, as described in connection with Figs. 5 and 6, we should obtain the end view *A*. An examination of

Fig. 7 (*a*) shows that the groove in the top of the block has straight edges. It will be impossible to determine from the top view *B* whether the rectangle *e c d f* indicates a projection extending above the face of the block, or whether it was a groove extending below the face of the block. It would likewise be impossible to tell, in case it was a groove, whether its shape was circular, rectangular, or any other shape that it might have. By examining the end view *A*, however, it is at once seen that the rectangle *e c d f* indicates that there is a groove in the block, and that this groove is semicircular in shape.

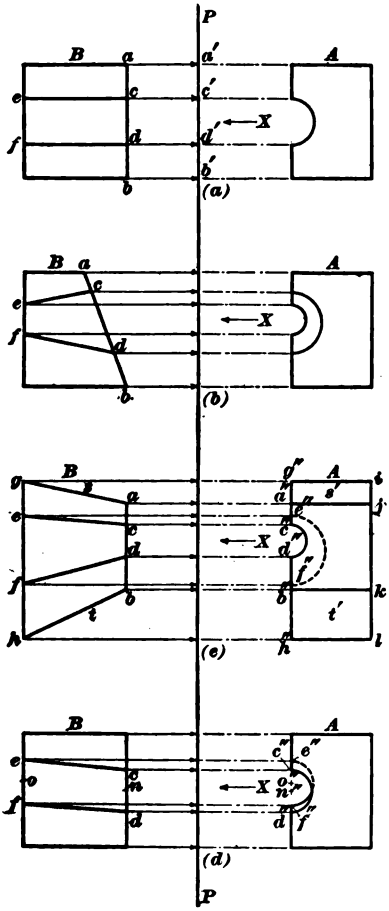


FIG. 7.

16. Referring to Fig. 7 (*b*), we see that the object shown here is somewhat similar to that shown in Fig. 7 (*a*), the principal difference being that the end *a c d b*, instead of being square with the sides, as at Fig. 7 (*a*), makes an angle with the sides; also the groove, instead of being straight as in Fig. 7 (*a*), is tapered in this figure. We may read this drawing in the following manner: Looking at *B*, we see a projection of the object, indicating that the object has one edge making a slant with its sides, and that it has a projecting part or a groove that is tapered. To determine whether it is a projecting part or a groove, we look at *A*, and there we see the two semicircles that extend from the top toward the bottom. This shows that *e c d f*, as represented in *B*, is a tapering groove. Both of the semicircles shown in the end view *A* are full lines, for the reason that when looking at the object from the right-hand side of the picture plane *P P*, both edges *e f* and *c d* of the groove will be seen.

17. In Fig. 7 (*c*), the top view *B* shows that the sides *s* and *t* are not square with the end *g h*. The lines *c c* and *f d* show that the block has a groove in its top, or a projecting part extending above it. In order to ascertain whether these lines indicate a groove or a projecting part, we refer to the end view *A*, and we see at once by the semicircles that *e c d f* indicates a groove. The lines $g'' i$, $a'' j$, etc. show how high the block is, and they indicate that the block is of uniform height, since all these lines are of the same length; $g'' i$ is the projection on the picture plane of the edge extending from the point *g* in the top view *B* to the bottom of the block; $a'' j$ is the projection of the edge extending from the top of the block at the point *a* to the bottom; $b'' k$ and $h'' l$ are the projections of similar edges at the points *b* and *h* in the top view *B*. The semicircle $e'' f''$ is drawn in dotted lines for the reason that it represents the projection of the rear edge of the groove in the top view *B*, which cannot be seen when looking through the picture plane in the direction of the arrow *X*.

18. Fig. 7 (*d*) shows a block similar in all respects to that shown in Fig. 7 (*a*), with the exception that instead of the straight groove *e c d f* being square with the ends of the block, it makes an angle with these ends. The full-line semicircle $c'' d''$ in the end view *A* represents the projection of the edge *c d* of the groove in the top view *B*. The line $e'' f''$ in the end view *A* is drawn partly dotted and partly full. The reason for this is that part of the back edge *e f* in view *B* is hidden by the front edge *c d*. That this is so will readily be perceived by imagining the eye to be situated to the right of the picture plane *PP*, and looking in the direction of the arrow *X*. It will then be apparent that no point of the line *ec* in the top view *B* will be in sight, except the extreme point *c*. In drawing the two semicircles shown in the end view *A*, we should determine how much of the semicircle $e'' f''$ should be dotted and how much should be full, in the following manner:

Project the center *n* of the line *c d* (this point *n* is the projection in the top view of the center from which the semicircle is described) into the point n''—the point of intersection of the two lines forming the lower cross—in the end view *A*. With this point as a center, describe the semicircle $c'' d''$. In the same way, we should project the center *o* of the line *e f* into the point o'', and, with this as a center, describe the semicircle $e'' f''$. That point in which these semicircles intersect (cut) each other is the point from which the full line and the dotted line start.

INSTRUMENTS.

19. In actual practice, certain instruments and appliances are employed by the draftsman in order to insure accuracy. The paper on which the drawing is to be made is fastened to what is termed a **drawing board,** by means of thumbtacks, or by gluing the edges to the board. **Thumbtacks** are made of German silver, brass, or steel, and have large flat heads, so as to afford the thumb a large bearing surface when pressing them through the paper into the board. Straight, horizontal, parallel lines are drawn by using the edge of the blade of a **T** square as a guide for the pencil or pen. **T squares** are usually made of pear wood, mahogany, or celluloid, but sometimes of hard rubber or steel; such a square is shown at *T*, Fig. 8. Straight, parallel, vertical lines are drawn by placing a **triangle** (sometimes called a **set square**) against the blade of the **T** square, so that one of its edges will be vertical, as shown at *S*,

Fig. 8; the vertical edge is then used as a guide for the pencil or pen. Triangles are made of pear wood, mahogany, hard rubber, or celluloid, and always have one right angle

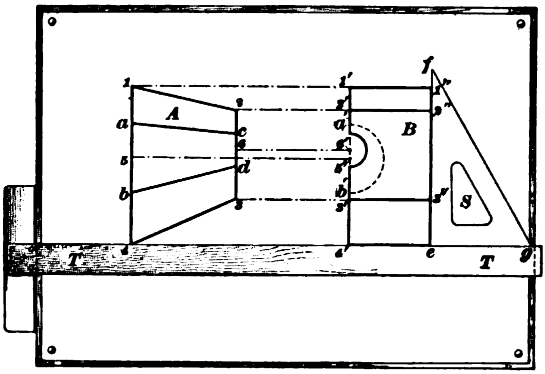


FIG. 8.

(see *e*, Fig. 8); the other two angles are either 45°, or one is 30° and the other is 60°. The triangle *S*, Fig. 8, has an angle *f* of 30° and an angle *g* of 60°.

20. Circles and circular arcs are described by means of **compasses**, one leg of which is fitted to receive a special pen or pencil. Curves that are not circles or circular arcs are drawn by finding as many points on the curve as are considered necessary, and then tracing a line through them. The only instruments of essential importance to the draftsman that have not yet been described are the **scales**, and these will be explained later. In a general sense, all drawings made with the aid of instruments, irrespective of what method of projection is used, are **mechanical drawings**. Common consent and universal practice, however, have limited the application of the term to drawings made in orthographic projection, whether made freehand in the form of sketches, or by the aid of instruments. Hence, whenever the term "mechanical drawing" is employed hereafter, it will be distinctly understood to be applied in the restricted sense just given.

OMISSION OF PROJECTORS AND PICTURE PLANE INTERSECTIONS.

21. In actual practice, the line *PP*, Fig. 7, which represents the intersection of two picture planes, is dispensed with, and the projectors are drawn straight across from one view to the other, as shown in Fig. 8, in which is a duplicate of the drawing shown at (*c*), Fig. 7.

Furthermore, the projectors themselves are also dispensed with, owing to the fact that in a drawing requiring a large number of lines to indicate the shape of the object, the projectors would add greatly to the number of lines on the drawing, and

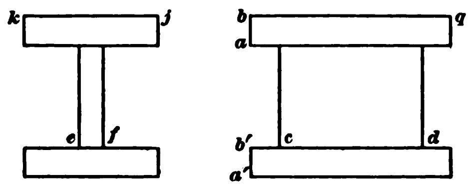


FIG. 9.

would create confusion when an attempt was made to read it. Fig. 9 shows a drawing in which the line *P P* and the projectors have been omitted.

22. The omission of the line of intersection of the picture planes and of the projectors will cause no confusion to the person attempting to read a drawing, for the reason that he mentally supplies these lines. For instance, referring to Fig. 8, suppose that the projectors *1 1'*, *2 2'*, etc. were omitted and that we are trying to form a mental image of what the object represented in this figure looks like. It is wholly immaterial which of the two views *A* or *B* we assume to be the top view. Suppose that we assume *A* to be the top view; then *B* will be an end view taken at a right angle to the view in *A*. Now, imagining the object to be stationary, and that its top appears as shown at *A*, we imagine a line to be drawn from the point *1* straight across the drawing to view *B*; we can then readily see, without the necessity of drawing the projector *1 1'*, that the point *1'* in view *B* corresponds with the point *1* in view *A*. Similarly, we note that the point *2'* in view *B* corresponds with the point *2* in view *A*, and so on.

To determine what the dotted semicircle in view *B* represents, we should mentally project its extremities *a'* and *b'* to the left to view *A*, and see what points in view *A* correspond with the points *a'* and *b'*. We can readily see that these points are *a* and *b* in view *A*. Note further, that the lines drawn through the points *1'*, *2'*, *3'*, and *4'* are parallel straight lines and that they are all of the same length. Imagining the drawing to be bent downwards, the line where the bending occurs being somewhere between views *A* and *B* and parallel to the lines *2 3* and *1' 4'*, until that part of the paper containing view *B* becomes perpendicular to the plane of the drawing board, we note that the object represented on this drawing is of uniform depth, this being indicated by the fact that the lines *1' 1"*, *2' 2"*, etc. are all equal in length. Further, it will be noted that the groove *a c d b* is a tapering groove and that it extends below the surface of the block. It is a good plan, whenever there is any doubt about the shape of an object, to imagine one view to be revolved in the manner just described, and then try to imagine some object that, if projected on the two planes, would give outlines similar to those shown on the drawing.

23. It would be well for the student to pay particular attention to the last article, and to compare the statement made in it with the perspective view of Fig. 7 (*c*) shown in Fig. 10. In all cases where it is somewhat doubtful which point on one view corresponds with a certain point on another view, it would be well to lay a straightedge on the drawing in such a manner that it will have the direction of a projector through the point, and then see what point on the other view corresponds to the point through which the projector would pass.

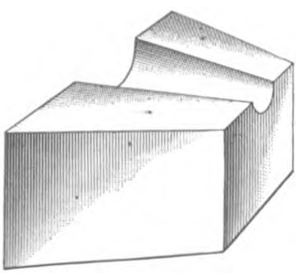


FIG. 10.

NUMBER OF VIEWS.

24. The question "How many views are necessary to represent an object so that it can be clearly understood by the workmen?" cannot be readily answered. In cases of very simple objects, one view is sometimes sufficient, particularly when an explanation regarding it is lettered on the drawing. As a general rule, two views are sufficient for objects that are comparatively simple in their outlines and whose interiors are not too complicated. In cases where the object can be represented only with great difficulty by means of a drawing, it is sometimes necessary to show three views, and even four, besides a number of sections.

SECTIONAL VIEWS.

25. A section or sectional view is obtained by imagining the object to be cut in two by passing a plane through the object along some line perpendicular to the picture plane, and imagining all that portion of the object on one side of

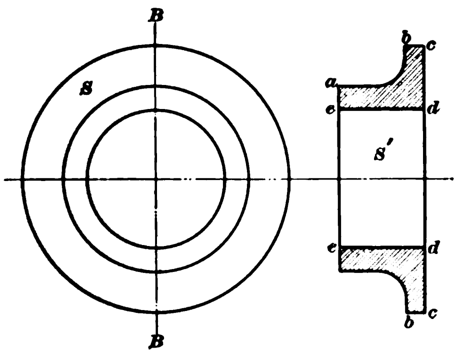


FIG. 11.

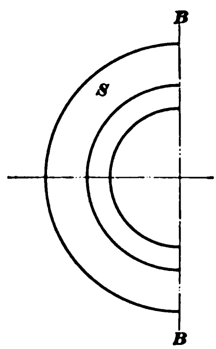


FIG. 12.

the cutting plane to be removed. The projection of the remaining part of the object is then drawn, and the view thus obtained is called a **section** or **sectional view** to distinguish it from the projection of the parts not cut, which is usually spoken of as a **view in full.** A sectional view of an object is shown in Fig. 11. Here S represents the top view and S' the sectional view. The view S' is obtained by imagining the plane to be passed through S along the line $B\,B$, and perpendicular to the plane of the paper, and that all that portion of the object to the right of the line BB is removed in the same manner as would be the case if the view S were drawn as shown in Fig. 12. The portions *a b c d e* of the view S', Fig. 11, have a series of straight lines drawn across them to indicate that each portion was touched by the plane cutting the object along the line $B\,B$ in view S. The drawing of sectional views will be explained in detail later.

DETERMINING THE SHAPE OF OBJECTS.

26. Referring now to Fig. 9, we can see from the two views shown that the object there represented has a flat top and a flat bottom of a rectangular shape, and of a thickness represented by *a b* and *a' b'*. The top and bottom are connected by another flat piece of a rectangular shape having a width *c d* and a thickness *e f*. A better way to have drawn this object is shown in Fig. 13. Here *h i j k* is the top view, the other being the side or end view. The reason why Fig. 13 is a better way for drawing the object than Fig. 9 is that it is impossible to tell by looking at Fig. 9 the exact shape of the top and bottom. We know that the top and bottom are not circular, because lines *k j* and *b q*, Fig. 9, are not of equal length, but we do not know whether the top surface has the shape of a rectangle, an oval, or ellipse, or some other curve. In Fig. 13, however, we see at once that the top surface is rectangular. The dotted outlines *m n f e* show that the connection *o p f e* between the top and bottom is rectangular in shape, and that it has a uniform height

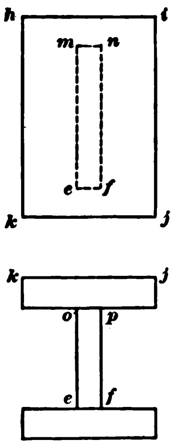


FIG. 13.

equal to *oe* or *pf*. In Fig. 9, neither of the two views shown could be called a top view; they would both be considered as side views. In Fig. 13, however, *hijk* is a top view and would be so considered by any one looking at the drawing. As a general rule, two views such as are shown in Fig. 13 are sufficient to indicate the shape of nearly any object, and are all that are usually given.

27. In Fig. 14 we show how the views are usually arranged when three views of an object are given. These views are labeled *top view*, *front view*, and *end view*. If it were necessary to give another view, showing the object as it would appear when looking upwards at the bottom, this view would be called the *bottom view*, and would be located beneath the front view *A* in the manner similar to that in which the top view *B* has been located. If still another view were needed, similar to end view *C*, showing the object as though we were looking at its left-hand side, this view would be located to the left of view *A* in a manner similar to that in which view *C* has been located on the right with respect to view *A*. View *C* would then be called the **right-end view** and the new view on the opposite side of *A* would be called the **left-end view.**

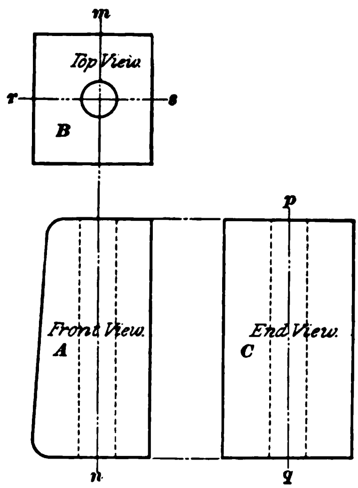


FIG. 14.

In many cases, especially in architectural drawings, and in complete drawings of a machine, draftsmen prefer to call view *A* the **front elevation,** view *B* the **plan,** and a bottom view the **inverted plan.** They would call view *C* a **right-side elevation,** and a view to the left of *A* the **left-side elevation.** It is very seldom necessary to show all the views just mentioned. In the case of a complete drawing of a steam engine, it might be necessary to show all five views on account of the confusion that would arise, owing to certain parts being projected over other parts. In what are termed **detail drawings,** by which are meant drawings of the details of a machine or mechanism, it is seldom necessary to show more than two views, or, at the most, three. In the object shown in Fig. 14, only two views were necessary—the top view and the front view. In this case, the front view and the end view would have been given by some draftsmen. It is the most common practice, however, to give a top view and front view in any case in which an object can be definitely pictured either by a top and a front view, or a front and a side view. In any case, as a general rule, those views should be, and usually are, selected that will show the object in the best manner with the fewest lines.

CENTER LINES.

28. Fig. 14 represents a thick wedge having a cylindrical hole running through its entire length. The lines *m n*, *p q*, and *r s* are called **center lines.** Center lines are usually drawn through the center of anything that is round, such as a cylinder or a cylindrical hole. In the case of a circle, there are usually two center lines, one being at right angles to the other, as shown in view *B*, Fig. 14. By drawing two center lines through a circle in the manner just mentioned, the center of the circle is located by their intersection. The mere presence of these lines shows in most cases that part of the object through which they are drawn is *round*. It is very seldom that center lines appear on drawings unless they are the center lines of cylindrical surfaces. They may sometimes be drawn to indicate that the surface is a regularly curved surface such as would be formed by circular arcs, or one having the shape of an ellipse. In very rare cases, for some special reason, a line that corresponds to a center line may be drawn for some particular purpose, but such a line is not, in the strict sense of the word, a center line.

29. Center lines are an extremely important feature of a drawing, since the workman is guided by them in doing the work called for by the drawing. For instance, suppose that it was required to make a wedge like that shown in Fig. 14, and that the workman was given a piece of cast iron having approximately the shape indicated by the drawing. Suppose, further, that it was necessary to have the hole located exactly as shown in the drawing with reference to the sides of the wedge, and that the sides and ends of the wedge were all to be "finished." The first thing that the workman would probably do would be to drill the hole, and, if the job had to be very accurate, he would drill the hole a little smaller than the drawing calls for and then ream it out to size. He would then face the ends square with the center line of the hole, and make the length of the wedge the same as shown on the drawing. The sides of the wedge would then be planed, and finally finished with a file, the workman working all the time from the center line *m n*. If the drawing shown in Fig. 14 is intended to be worked to, it would, in most shops, be supplied with proper dimensions.

LINES USED ON DRAWINGS.

30. In general, there are but six kinds of **lines** used on drawings. The various kinds of lines thus used are shown in Fig. 15. The **light full line** (*a*) is used more than any of the others and is used for drawing the outlines of all parts that can be seen by the eye. The **dotted line** (*b*) consists of a series of very short

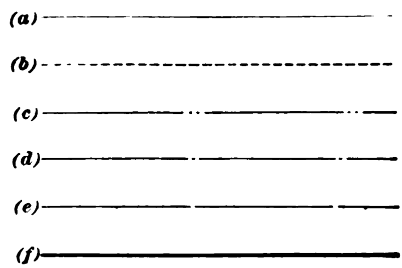


FIG. 15.

dashes. It is used for showing the position and shape of a part of the object that is concealed from the eye in the view shown. For example, in Fig. 14, the hole through the wedge cannot be seen in views *A* and *C*, and, consequently, it is shown by dotted lines. In view *B*, however, the edge of the hole can be seen by the eye, hence a full line is used for drawing the circle that represents the hole.

The **broken-and-dotted lines** (*c*) and (*d*), Fig. 15, consist of a long dash followed by either one or two dots, repeated regularly. It is very seldom that both of these lines appear in the same drawing, either one being used to represent center lines, or to indicate where a section has been taken, when a sectional view is shown. Line (*c*) is used, perhaps, more frequently than line (*d*). It would be a good plan, however, and one that is followed in a few drafting offices, to use line (*d*) for center lines only and line (*c*) to indicate where a section has been taken. In many drafting offices, all center lines are drawn full, and in red ink. This is especially the case when making pattern drawings, and it is nearly always done when the drawing is not traced. When drawings are traced and blueprints are made from the tracing, it is also customary to draw all center lines in red ink, making them about twice as thick as the regular full lines. When the workman is working to a blueprint, he will perceive by the extra thickness of the line what the latter is intended for. Then, again, on account of it being drawn in red ink, it will appear gray on the print, while those lines that are drawn in black ink will appear white.

The **broken line** (*e*), Fig. 15, is used chiefly for dimension lines. It consists of a series of long dashes. This line appears in Fig. 34. It is also used as an extension line when it is undesirable to draw the dimension line across the face of the view, and when it is desired to indicate the extension of a line that, in reality, does not appear on the object.

The **heavy full line** (*f*) is made not less than twice as thick as the ordinary full lines on the drawing, and is used only for shade lines. The system according to which shade lines are placed on a drawing will be explained in detail farther on.

SCALES.

31. In all offices where a large number of drawings are made, the size of a drawing is restricted to one of three, or, at the most, four sizes. The necessity for this is readily apparent when it is considered that in one office there may be several thousand drawings, and that these drawings are exceedingly valuable; hence, in order to file them, it is necessary to have them all of approximately the same size, so that they can readily be referred to. In some offices, the largest size would be 24 × 30, the next smaller size 15 × 20, and the smallest size 12 × 15. In consequence of this, it is, of course, impossible to represent all objects on the drawing in full size. Consequently, the drawing is made one-half size, one-quarter size, and so on, according to the length of the object. If the object is very large, as in the case of a plan of a shop, smaller scales are used. When making the drawing, the draftsman uses a special scale, instead of the regular scale of feet and inches in which the inches are subdivided into eighths, sixteenths, or thirty-seconds. The special scales used are always marked on the drawings.

32. Suppose that it were required to make the drawing one-quarter size, so that 3 inches on the drawing will represent 1 foot on the object. Then, if 3 inches be laid off and divided into 12 equal parts, each of these parts, which is actually $\frac{1}{4}$ inch in length, will represent 1 inch on the object. If these parts be subdivided into 2, 4, 8, etc. parts, each part will represent $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, etc. of 1 inch on the object. A scale of this kind is called a *quarter scale*, or a scale of *3 inches to the foot*. An *eighth scale*, or a scale of *1½ inches to the foot*, would be constructed in the manner just described, except the 1½ inches would be laid off and subdivided, instead of 3 inches. These various scales would be marked on the drawing: scale 3″ = 1 ft., $1\frac{1}{2}$″ = 1 ft., etc. In the case of a drawing showing complete views of a large object, such scales as the following might be written on the drawing: 1″ = 1 ft., $\frac{3}{4}$″ = 1 ft., 1″ = 4 ft., etc.

33. Although the workman, as a general rule, should always work to the written dimension and not attempt to scale the drawing, it may occasionally happen that he desires to measure some line on it. In that case, an ordinary scale or rule can be used, as follows: Suppose the scale on the drawing reads 3″ = 1 ft., then every inch on the drawing represents 4 inches on the object, and every $\frac{1}{4}$ inch on the drawing represents 1 inch on the object. Hence, supposing that the actual length of the line measured by the workman with his rule was $5\frac{5}{16}$ inches, the length of this line on the object would be found by reasoning as follows: Since 3 inches on the drawing represents 1 foot on the object, it is evident that this line is more than 1 foot long and less than 2 feet. Since every $\frac{1}{4}$ inch represents 1 inch, count the number of $\frac{1}{4}$ inches between the 3-inch mark and the $5\frac{5}{16}$-inch mark; the number so obtained is 9, that is, there are 9 $\frac{1}{4}$ inches between the 3-inch mark and the $5\frac{5}{16}$-inch mark. In other words, if the line had been $5\frac{1}{4}$ inches long instead of $5\frac{5}{16}$ inches long, the length of this line on the object would have been $12 + 9 = 21$ inches. Since $\frac{1}{16}$ inch is $\frac{1}{4}$ of $\frac{1}{4}$ inch, every $\frac{1}{16}$ inch on the drawing represents $\frac{1}{4}$ inch on the object, and as $\frac{5}{16}$ is $\frac{1}{16}$ more than $\frac{1}{4}$ inch, the length of the line measured is $21\frac{1}{4}$ inches. This same method can be followed in the case of any scale.

SHADE LINES.

34. On some mechanical drawings it will be observed that a number of the lines are made very heavy. These heavy lines are put on in accordance with a certain almost universally adopted system; they show by their location whether the part looked at is a hole in the object, or is raised beyond the surface. They are called **shade lines.** Thus, in Fig. 16, by means of the shade lines a person can determine, without looking at any other view of the object, that the rectangles *1* and *4* represent square holes, and *2* and *3* square bosses. Likewise, the heavy lines *C D* and *D B* show that the object has a material thickness.

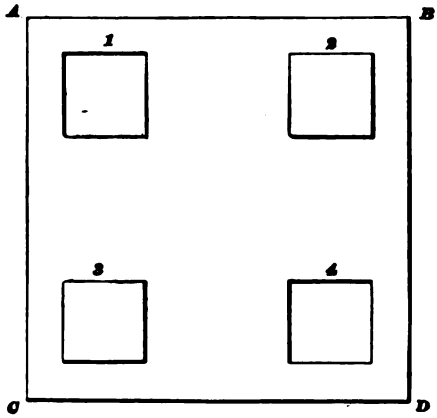


FIG. 16.

35. The benefit to be derived from shade lines is well illustrated by Fig. 17. Let the view at (*a*) be a front view, and that shown at (*b*) be a side view of an object. Now, looking only at the front view, it is impossible to determine whether the part *A* is a hole, as shown by the side view given in Fig. 17 (*b*), or a boss, as shown by the side view given in Fig. 17 (*c*). It may be mentioned that the majority of shop drawings are made with all the lines of uniform thickness, as on the drawings given in Fig. 17 (*a*), (*b*), and (*c*).

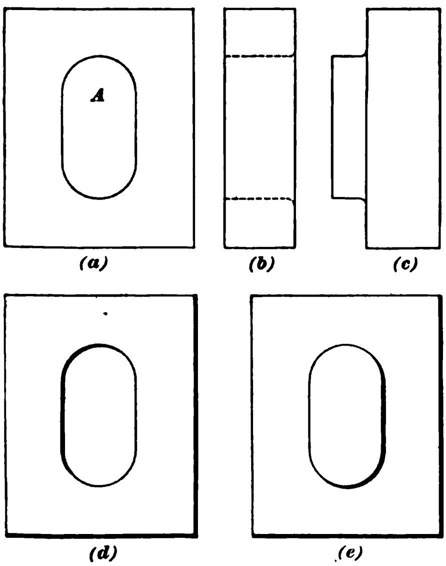


FIG. 17.

Now, if the front view of the object be drawn with heavy shade lines placed as in Fig. 17 (*d*), the shade lines by their position immediately show that the part *A* is a hole, without having first to refer to the side view shown at (*b*). If the shade lines are placed as in Fig. 17 (*c*), they would show that the part *A* is a boss, without any reference to the side view.

36. In the almost universally adopted system of shade lining, the light is assumed to come in one invariable direction, in such a manner as to be parallel with the plane of the paper; to make an angle of 45° with all horizontal and vertical lines of the drawing, and to come from the upper left-hand corner of the drawing. Each view of the object represented is shaded independently of any of the others; and, when shading, the object is always supposed to stand so that the view that is being shaded will be a top view.

37. Any surface that can be touched by drawing a series of parallel straight lines, making an angle of 45° with the horizontal and vertical lines of the drawing, is called a **light surface**; a surface that cannot be touched by lines having this angle is called a **dark surface.** All the edges caused by the intersection of a light and dark surface are usually shade-lined.

38. An application of these rules is shown in Fig. 18, where a top view of a series of triangular wedges radiating from the common center *O* is given. The top is, of course, a light surface; some of the perpendicular surfaces are light and some are dark. In the wedge *R O A*, a line drawn at an angle of 45°, the direction of the arrows, would strike the side of which *O A* is the edge; hence this side is a light surface, and as the top surface is also a light surface, the line *O A* is drawn as a light line. *O R*, on the contrary, is a heavy line, since the light cannot strike the side of which *O R* is the edge, without passing through the wedge. Hence, this is a dark surface, and its intersection *O R* with the light surface *O A R* requires a shade line. For the same reason, *A R* is also shaded. The same reasoning as the above applies to the lines *O B*, *O D*, *O G*, *O I*, *O K*, and *O M*; also, to *Q N*, *M L*, and *K J*. *C B* is not shaded, because the light strikes the surface of which *C B* is the edge. *O N* makes an angle of exactly 45° with a horizontal line, and is treated as if it were the edge of a light surface; this is done in every case in which the line considered makes an angle of 45° with a horizontal line.

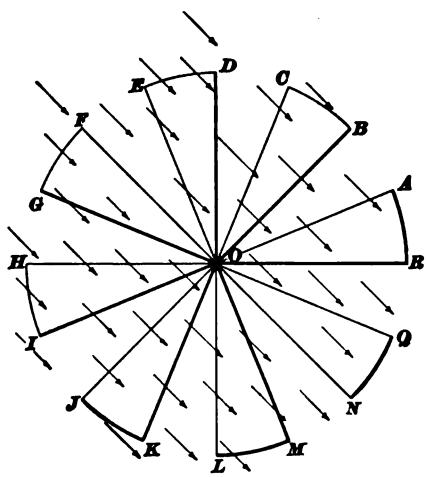


FIG. 18.

39. In shading holes, or any parts of the drawing denoting depressions below the surface under consideration, a slightly different assumption is made. Fig. 19 shows the top view of a square block with a hexagonal depression in the center. If the light passed over the surface *A B C D*, parallel to the plane of the paper, as previously assumed, all the inside surfaces would be dark, and the entire outline of the hexagon *E F G H I K* would be shaded. In order to prevent this, and to make the work similar to that which has preceded, the rays of light are assumed to make an angle of 45° with the plane of the paper when shading holes and depressions. Hence, the light will strike the surfaces whose edges are *G H*, *H I*, and *I K*, as shown by the arrows, leaving the surfaces whose edges are *K E*, *E F*, and *F G* dark, as before. Therefore, these latter edges will be shaded, and the edges *G H*, *H I*, and *I K* will be light.

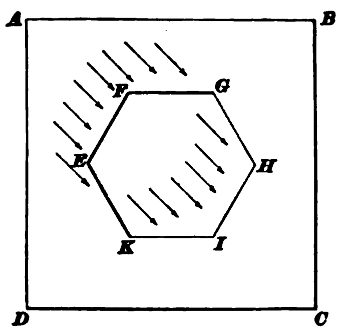


FIG. 19.

40. Drawings are occasionally found in which the foregoing rules of shading have been disregarded. In most cases, this departure is unintentional as far as the draftsman is concerned; in some rare instances it is caused by ignorance, and once in a while by good judgment. Cases may arise where a strict adherence to the rules will result in a drawing that is not clear; in that case, a draftsman of good judgment may break the rules rather than shade-line an object in such a manner that its shape is doubtful.

41. In **working drawings,** i. e., in drawings from which work is to be built, shade lines are rarely used, since the shape of a piece can be determined from the several views. A person with considerable experience in reading drawings can work about as readily from one in which all lines are of uniform thickness as from one that is shade-lined, particularly if he is familiar with the line of work represented on the drawing. However, shade lines are a great help to a person of limited experience, since they render each view more complete in itself and save, to some extent, a continual comparison of the several views to form an idea of the shape of the object.

SECTIONS AND SECTION LINING.

42. In order to show the interior of hollow objects, they are often drawn in section, and the kind of material is then usually indicated by certain combinations of lines. Unfortunately, there is no universally adopted standard; thus, a certain combination of lines may indicate that the material is cast iron, if drawn in one office; in another office, this same combination may have been adopted to represent brass, and so on. As far as working drawings are concerned, there is usually no difficulty experienced on account of this diversity of practice, since as a general rule the material is, and should always be, distinctly specified on the drawing in order to prevent any mistake on the part of the workman.

43. The most commonly used combination of lines for different materials is shown in Fig. 20. Steel of all kinds is indicated as shown in view *A*; view *B* shows the style of sectioning employed for wrought iron. Cast iron is usually sectioned as shown at *C*; brass and other similar copper alloys are sectioned in the manner shown at *D*. For lead, Babbitt, and similar soft metal, the sectioning shown at *E* is extensively used. Wood, when cut across the grain, is

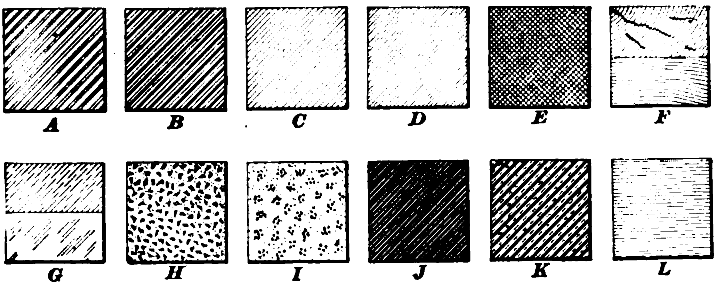


FIG. 20.

usually sectioned as shown in the upper half of view *F*, and when cut along the grain, as shown in the lower half. Wood is also frequently indicated on a drawing by section lines, even when it is not a section. Glass and stone, when in section, are often indicated in the manner shown by the upper half of view *G*; when not in section, they are frequently drawn as shown in the lower half of that view. Concrete may be indicated as in view *H*; view *I* gives a common representation of leather. Rubber and wood fiber are sectioned as in view *J*, firebrick as in *K*, and water as in *L*.

44. Instead of representing sections by lines, they are occasionally colored, the colors used indicating the different materials. While this practice is very common in Europe, it is very rarely found in the United States.

45. Sections of material that appear too thin on a drawing to be conveniently sectioned, or when it is desired to make the section very prominent, are often blackened in, as shown in Fig. 21. In order to separate different pieces, a white line is then usually left between them. Black sections are most frequently employed for sectional views of

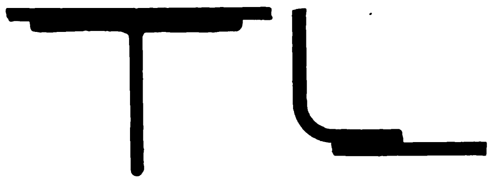


FIG. 21.

structures composed of plates and rolled sections, such as **I** beams, angle irons, bulb angles, rails, **Z** bars.

46. In most cases, sections are taken on a plane parallel to the picture plane; in some instances, the cutting plane is at an angle to the picture plane, and sometimes a section is taken in several directions. The cutting plane need not necessarily extend clear through the object; in many cases, the draftsman can save himself considerable work by making a view only partially in section. Thus, in Fig. 22, the top view of an object is shown; the left-hand part of the top view is a section showing what would be seen in case the object were cut by a plane perpendicular to the paper, as *A O* in the front view. In other words, the part of the object included between the two planes *A O* and *O C* is removed. In the half section shown, it will be noticed that a recess, which is indicated by dotted lines in the front view as being below the plane *A O*, is shown as though it were located in that plane. This is a conventionalism occasionally employed to do away with the necessity of taking a separate section through the recess. The part to the right of the center line of the top view shows half of the end of the object in full. The side view is also shown half in section and half in full; the sectional view shows what would be seen if the part included between the planes *B O* and *O D* (see front view) were removed. When a section is taken on a plane represented by a center line, as along *A O* or *B O*, the sectional view is rarely marked to that effect, it being generally understood that a sectional view not especially marked is taken along some center line. When a sectional view is taken on a plane not represented by a center line, it is customary to indicate in a suitable manner where the section has been taken; and the sectional view is

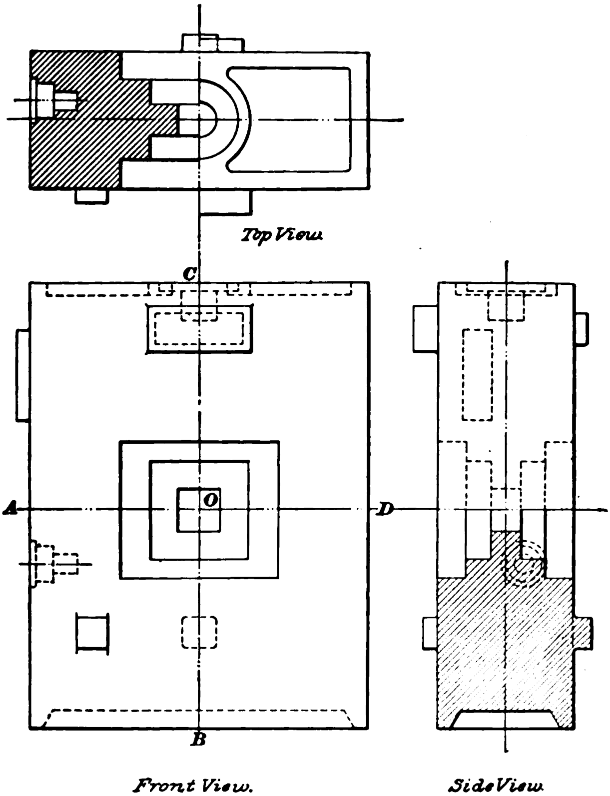


FIG. 22.

then marked "*Section along line A B*" or in some similar manner. Sectional views taken as in Fig. 22 are usually called **half sections**, or **partial sections**; if the cutting plane extends clear through the object, as in Fig. 11, it is called a **full section.** In general, the word *section* is used as an abbreviation of *sectional view.*

47. In some cases, it is considered advisable by the draftsman to pass the cutting plane only a little into the object, or perhaps beyond the center line, for the purpose of disclosing some special feature. In such a case, the extent of the cutting plane is usually indicated on the sectional view by a freehand wavy line drawn around the partial section, as, for instance, is done at *a* in Fig. 23, where one of the jaws of the rod has been partially broken away in order to show clearly that a dowel pin is to be inserted for the purpose of keeping the bolt from turning.

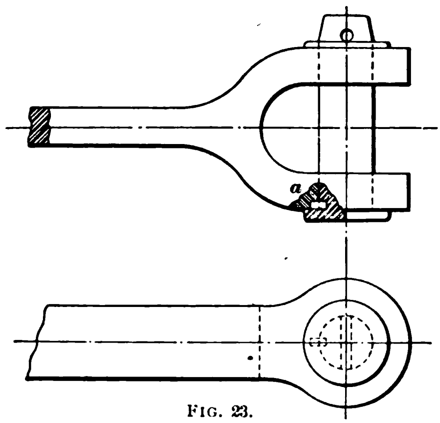


FIG. 23.

48. On many sectional views, it will be noticed that the section lines do not run in the same direction. This invariably means that there is more than one piece in the section given. Thus, referring to Fig. 24, it will be seen that the section lining shown at *b*, *b* is at a right angle to the other section lining. It is the general rule among draftsmen that all parts of the same piece shown in section must be section-lined in the same direction, irrespective of the continuity of the section. Thus, referring again to Fig. 24, the fact that all section lining marked *A* is in the same direction immediately establishes the fact that this part of the view is a section of the same piece. Likewise, since the sectioning shown at *b*, *b* runs in the same direction, it follows that *b*, *b* are sectional views of one piece, which is separate from *A*.

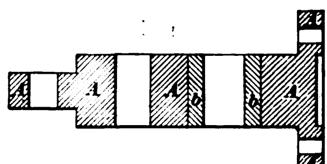


FIG. 24.

49. The above rule governing the direction of section lines is always adhered to when possible; when any departure is necessary, care is taken to prevent ambiguity.

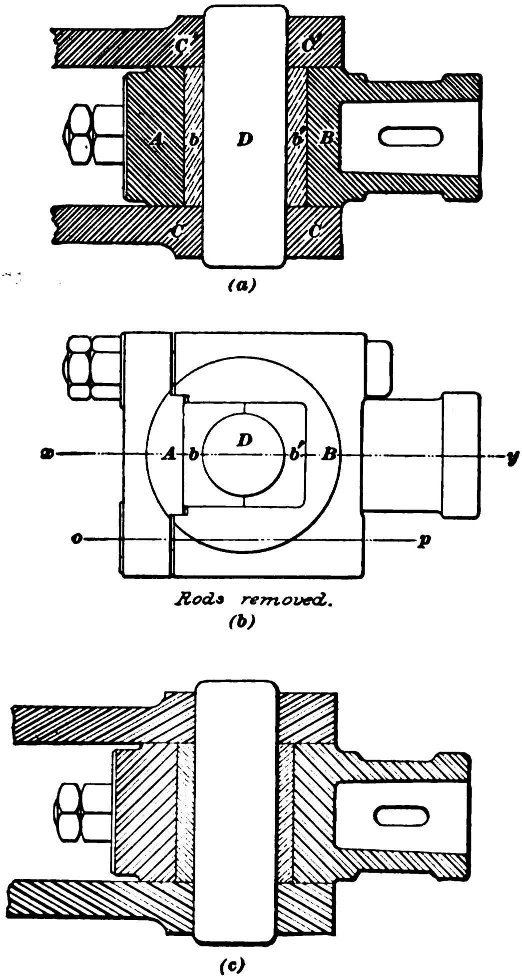


FIG. 25.

Where only the sectional view is given, it is often very difficult to understand the drawing, and sometimes a violation of the above rule will cause an erroneous conclusion to be drawn. Referring to Fig. 25 (*a*), cover up the front view shown at (*b*). Then, since the sectioning of *A* and *B*, and also that shown at *b* and *b'*, are respectively in the same direction, any one would be perfectly justified in assuming that *A* and *B* was a sectional view of a rod fitted with a solid bushing *b*. Furthermore, since *C*, *C* and *C'*, *C'* are sectioned the same way, the conclusion that they were the jaws of a forked rod would be justifiable. Referring now to view (*b*), it is seen that *b* and *b'* are separate brass boxes; the part *B* is seen to be separate from the cap *A*, and the note "*Rods removed*" indicates that *C* is separate from *C'*. The way the sectional view should have been section-lined to correspond to the front view shown at (*b*) is given in Fig. 25 (*c*).

50. When a cutting plane passes through the axis of a shaft, bolt, rod, or any other solid piece having a curved surface and located in the plane on which the section is taken, it is the general practice not to show such solid pieces in section, but in full. Thus, in Fig. 25 the sectional view is taken on the plane represented by the line *xy*, which passes through the axis of the pin *D*. This pin is shown in full, however. The practice here shown is rarely departed from by experienced draftsmen, since it makes a drawing easier to read, and also saves considerable time in making the drawing.

51. Fig. 25 also shows another feature that is frequently met with in shop drawings. Referring to the illustration, it is seen that no bolt is shown in the lower half of the object, as far as the front view (*b*) is concerned. A center line *op* is drawn in, however; this center line indicates to the workman, who reasons from the symmetry of the object in respect to the center line *xy*, that the lower half of the object is to be supplied with a bolt placed in the plane given by the center line *op*. In case of symmetrical work, draftsmen will frequently complete only one half of the view and merely indicate the other half by a few lines, or not at all, trusting to the judgment of the workman for a correct reading of the drawing. In the best practice, a note is made on the drawing calling attention to the fact that the indicated portion of the view is a duplicate of the complete portion.

52. Draftsmen occasionally make use of a conventional method of taking a section for the purpose of better conveying the meaning of the section to the mind. While there is no universal rule followed, a few examples will be suggestive of others, and the points brought out will allow other instances of conventional sectioning to be recognized.

Fig. 26 shows a front and a sectional view of a pulley. The sectional view is taken along the line *A B*, which

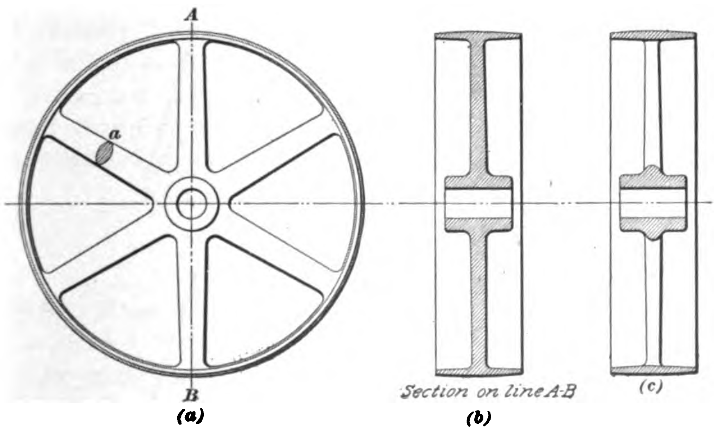


FIG. 26.

passes through two of the arms. If the sectional view is drawn strictly according to the rule of projection, it will appear as in Fig. 26 (*b*); that is, the arms will be sectioned, since they are cut by the cutting plane. Now, if the sectional view (*b*) be considered by itself, it will convey the idea to most persons that there is a solid web between the rim and the hub of the pulley. While reference to the front view will immediately dispel this impression, the fact remains that, without a second view, the conclusion that a solid web exists would be justifiable. Therefore, in a case like the one shown, in order to convey the idea better, the draftsman will often take the section on the assumption that

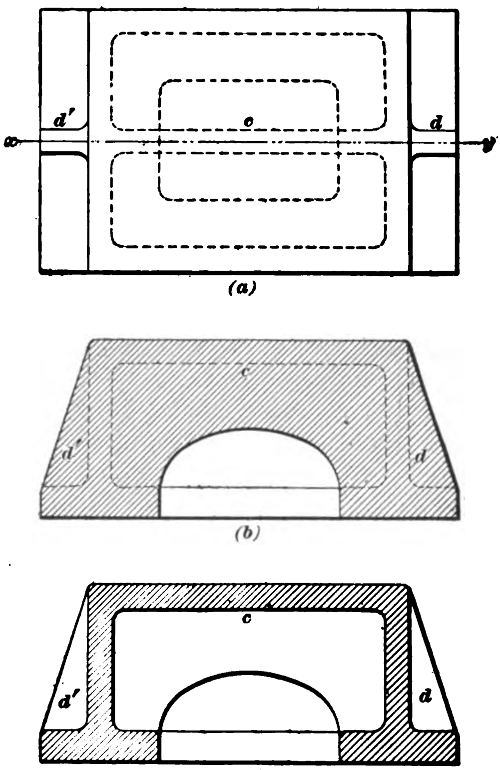


FIG. 27.

the arms are just back of the cutting plane, so that they will appear in full in the sectional view, or as shown in view (*c*).

53. Referring now to Fig. 26 (*a*), a section is shown at *a*. This is a conventionalism frequently employed to indicate the shape of the cross-section of the part on which it is placed. In this case, it shows that the arms are elliptical in cross-section. A **longitudinal section** is a section taken lengthwise through the object or parallel to the axis, if the object has an axis. A **cross-section** is one that is taken at an angle, usually at right angles, to the direction in which a longitudinal section would be taken, or to the axis, if the object has one.

54. Another case of a conventional section is shown in Fig. 27. Here the top view is shown at (*a*), and a strictly correct sectional front view at (*b*), the section being taken along the line *xy*. Now, since the cutting plane passes through the ribs *c*, *d*, and *d'*, they would be shown in section by some draftsmen, as illustrated in Fig. 27 (*b*); the outline of the main part of the object is then dotted in. Many draftsmen, however, prefer to assume that the ribs are directly back of the cutting plane, so that they will show in full in the sectional view, or as shown in Fig. 27 (*c*). It is claimed that a sectional view drawn in this conventional manner will convey the idea more readily than one drawn in strict accordance with the rules.

BREAKS.

55. When a long and comparatively slender object is to be drawn, it often happens that, when drawn to a sufficiently large scale to make it intelligible, it will extend beyond the space available. In such a case, part of the

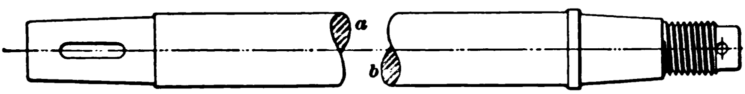
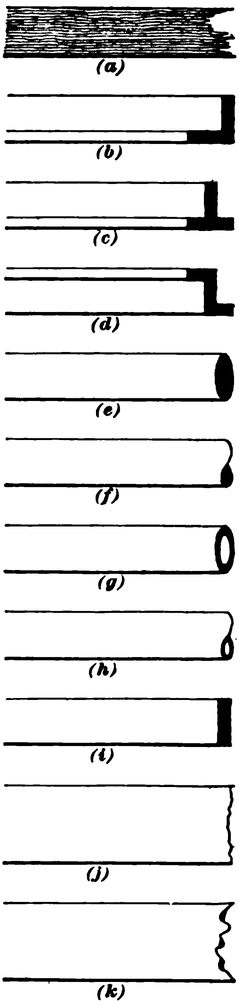


FIG. 28.

object is broken out and the remaining ends are pushed together. The fact that part of the object is broken away for the sake of convenience is indicated by a so-called **break.** It is always understood that the part broken away and not shown is of the same size and shape as the parts contiguous to the break. In some cases, one end of the object is broken away.

56. Fig. 28 shows a common method of drawing a piston rod or any similar object too long for the space available. It being essential in the particular case shown to know the shape and size of the ends, the rod is therefore shown with its central part broken away, as indicated by the breaks at *a* and *b*. It is customary to always section the break to suit the material of which the object is made.



(a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k)

FIG. 29.

57. Breaks may be indicated in various ways; most commonly, the break is given an outline that will reveal the shape of the object. Conventional methods of indicating breaks are shown in Fig. 29. Wood is usually shown broken in the manner illustrated at (*a*), angle irons as at (*b*), **T** irons as at (*c*), **Z** bars as at (*d*). Cylindrical objects are occasionally broken as shown at (*e*), but most frequently in the manner shown at (*f*). Pipes and similar hollow cylindrical objects may be broken as shown at (*g*); but, more frequently, the break is made as shown at (*h*). Rectangular objects may be broken in the manner shown at (*i*); plates and objects other than those included between views (*a*) and (*i*), are often shown broken off by drawing a wavy freehand line as in (*j*) and (*k*).

SCREW THREADS.

58. Owing to the labor required to draw a screw thread exactly as it appears in projection, this is very rarely done, and certain conventional methods of representing a screw thread are employed instead. The methods most commonly used for drawing screw threads on objects shown in full, and in tapped holes shown in section, are given in Fig. 30. Referring to the figure, probably the clearest, but at the same time the most expensive, representation of a screw

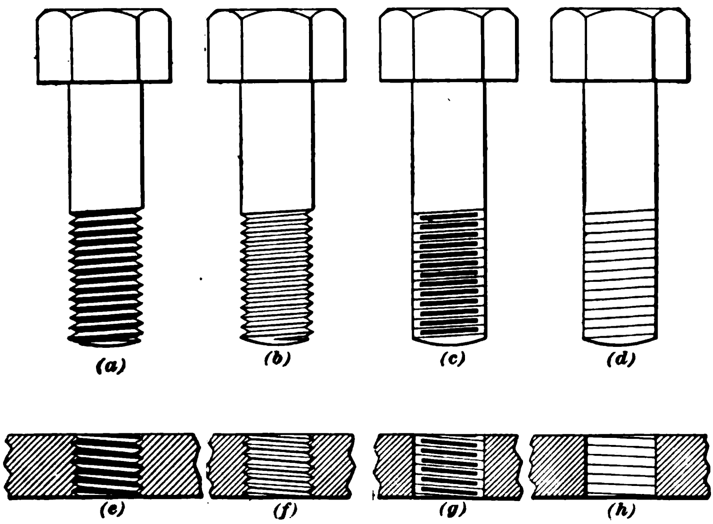


FIG. 30.

thread is shown in Fig. 30 (*a*) and (*e*). Fig. 30 (*a*) is a view in full of a screw (a bolt in this instance); Fig. 30 (*e*) is a sectional view of a tapped hole. It will be noticed that in each case the slant of the thread in the hole is in an opposite direction from that on the screw. Fig. 30 (*b*) and (*f*) show a cheaper representation; Fig. 30 (*c*) and (*g*) represent the most common way. Where appearance must be sacrificed to cheapness, draftsmen will often use the method shown in Fig. 30 (*d*) and (*h*).

59. When the screw thread is hidden by part of the object, and it is deemed necessary to show it in dotted lines, it is usually drawn in one of the four ways illustrated in

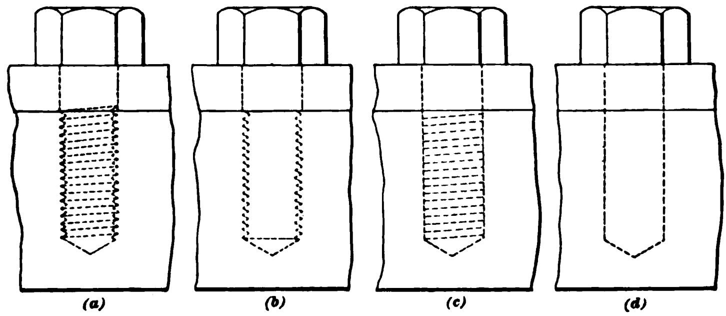


FIG. 31.

Fig. 31. Of these, the method shown in Fig. 31 (*a*) is probably the clearest; that shown in Fig. 31 (*b*) is fairly good; and the one shown in Fig. 31 (*c*) is cheap. The method illustrated in Fig. 31 (*d*) is practically no representation of a screw thread at all; if used, it usually must be supplemented by a note such as "¾" *stud*," or "1⅛" *bolt*," and so on.

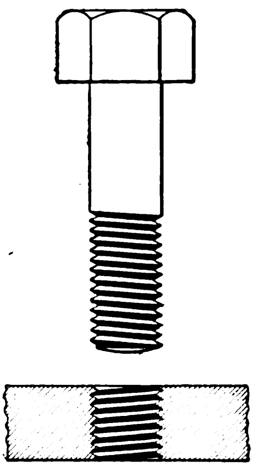


FIG. 32.

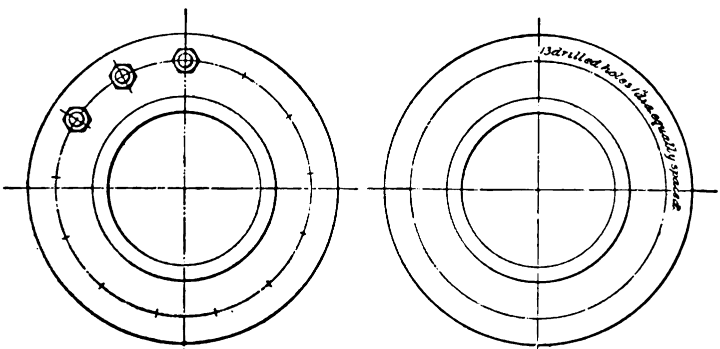
60. All the threads shown in Figs. 30 and 31 are **right-handed;** that is, when looking along the axis of the screw, the thread advances in the direction in which the hands of a watch move. When the thread advances in an opposite direction, the thread is **left-handed;** it is then drawn with the thread slanting the other way from that shown in Figs. 30 and 31. Thus, in Fig. 32, a left-handed screw thread is shown in full, and a left-handed tapped hole in section beneath it. It will be noticed that the thread in the hole slants the opposite way to that on the screw.

61. In case of doubt, a right-handed thread can always be told from a left-handed thread by holding the screw, or the drawing of it, so that the axis is vertical. Then, if the thread slants *upwards* to the *right* in case of a screw shown in full, or *upwards* to the *left* in case of a tapped hole in section, the thread is right-handed; if otherwise, it is left-handed.

REPEATED PARTS OF OBJECTS.

62. When an object has a relatively large number of similar component parts, they are rarely all shown on a working drawing. Usually, a few of them are shown in full, and the rest are merely indicated by showing the position of the center of each part. Sometimes even this is not done, but a note is placed on the drawing calling attention to the fact that some certain part of the object is to be repeated.

63. Fig. 33 is an example of how repeated parts of an object may be treated. Referring to the illustration, which is a top view of a pipe flange, Fig. 33 (*a*) shows three



(a) (b)

FIG. 33.

bolts drawn in. The position of the rest of the bolts is indicated by the short radial lines drawn across the bolt circle. In Fig. 33 (*b*), the bolt circle is drawn in, and a note is written along it that is sufficiently definite to convey the idea to the mind of the workman. This latter method is most commonly used on working drawings.

64. When making a drawing of a gear-wheel, especially when it is a working drawing, it is customary to draw in only two or three teeth and specify how many teeth the wheel is to have. This answers the purpose as well as if all the teeth were drawn, and has the advantage that an enormous amount of time is saved in making the drawing. Likewise, in drawings of objects built up of plates or rolled sections, as in boiler and bridge drawings and similar work, only a few rivets, or staybolts, or similar repeated parts are usually shown, and the location of the rest is indicated by showing the position of their centers, or by a suitable note placed on the drawing.

ABBREVIATIONS USED ON DRAWINGS.

65. The most commonly used abbreviations are *D.*, *Dia.*, *Diam.*, *d.*, *dia.*, and *diam.* for "diameter," and *R.*, *Rad.*, *r.*, and *rad.* for "radius." "Wrought iron" is usually abbreviated to *Wr't Iron.* The abbreviation *Thds.* or *thds.*, with a number prefixed, stands for "threads per inch"; thus, *14 thds.* means "make 14 threads per inch." The word *tap*, with a number prefixed, always means that a hole is to be finished by tapping it with a tap of standard proportions, having the diameter given by the prefixed number. When a tap other than a standard tap is to be used, it is distinctly specified. *Drill* is always taken to mean that a hole is to be put through the object by drilling. *Bored* or *Bore* means "finish a hole by boring it." *Planed* is always understood to mean "this surface is to be finished by planing." *Cored* implies that the hole to which it is applied is to be cored out and left that way; that is, it is not to be finished by machining. *Faced* almost invariably implies that the surface to which it is applied is to be machined square with a hole in the object. *Turned* is an abbreviation for "finish by turning." *Scraped* implies that a surface is to be finished by scraping. *Tool finish* means that the surface, after machining, is not to be finished any further. *Black*, on objects formed by forging, implies that the part to which it is applied is to be left as it comes from the smith. The term *Ream* or *Reamed* means that a hole is to be finished by reaming; when applied to a bolt, it is understood that the bolt is to be fitted to a hole that has been previously reamed. The terms *Shrinking Fit*, *Forcing Fit*, and *Driving Fit* written behind a dimension always imply that, in machining the part, the workman is to make the allowance necessary for the kind of fit called for. The fact that part of an object is to be finished by machining, filing, or grinding is often indicated by marking the outlines with an *f* written across or near it, or writing *fin.* along it. In some cases, draftsmen will draw a dotted line or a full red line at a little distance from the outline and write *f* across it; it is usually understood, in that case, that the lengths of the supplementary lines denote the distances that are to be finished.

66. While the abbreviations here given do not cover the whole range possible, they will serve to suggest the probable meaning of others that may be met with. In case a workman finds an unintelligible abbreviation, probably the best thing to do is to consult somebody in authority, rather than to make a mistake.

TAPERS.

67. The term **taper** denotes that the piece to which it is applied gradually diminishes toward one end. This definition is universally accepted. When it comes to expressing the *rate* at which the diminishing in size takes place, practice varies, however. In consequence of this, mistakes constantly occur; these cannot be justly charged to the workman, although they usually are.

68. Referring to Fig. 34 (*a*), some persons express the taper as the difference in diameter per foot of length measured along the axis. Other persons will measure the difference in radii, and, when reduced to inches per foot, call it the taper. This is shown in Fig. 34 (*b*). In case of keys, wedges, etc., probably the most common method is to take the difference in height in inches per foot of length as the taper, or as shown in Fig. 34 (*c*); occasionally, a person will measure the taper in the way shown in Fig. 34 (*d*), which is the same as that given in Fig. 34 (*a*).

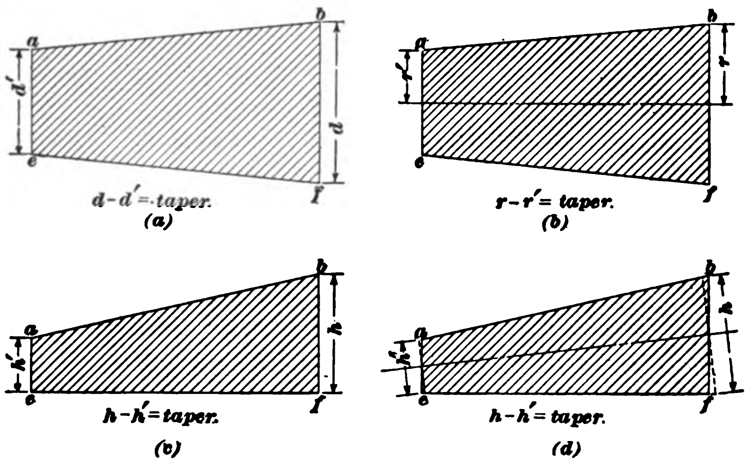


FIG. 34.

69. Now suppose that a piece of work when measured in accordance with Fig. 34 (*a*) has a taper of 1 inch per foot. Then, if the same piece be measured in accordance with Fig. 34 (*b*), the taper would be called ½ inch per foot. Furthermore, a piece measured in accordance with Fig. 34 (*c*) will not have the same angle between its edges *a b* and *e f* as a piece made according to Fig. 34 (*a*) or (*d*). Again, a piece thus measured will include only one-half of the angle between *a b* and *e f* of Fig. 34 (*b*).

From these considerations it can be seen that the only safe way is to find out from the person for whom the work is being done what his conception of taper is, and then do the work accordingly.

70. A taper may be expressed on a drawing in several ways. Most commonly it is specified in inches per foot, thus, "*taper 1" per foot*," "*taper $\frac{3}{16}$" per foot*," etc. Occasionally, it is specified as the difference in the diameters, radii, or heights for the given length; thus, a note "*taper $\frac{1}{4}$" in 5*" may be given. Once in a while a taper is given thus, "*taper 1" in 20.*" This means that the difference in diameters, radii, or heights is in the proportion of 1 inch for 20 inches of length. In some rare instances the taper is expressed as the angle included between the edges *a b* and *e f* of Fig. 34; thus, "*taper 9°*," "*taper 6° 28'*," etc.

Any of the foregoing methods of expressing a taper are definite only in case the method in which the measurement is to be made is known. For this reason, in the best modern practice, the term *taper* is not used at all, but a tapering piece is dimensioned at both ends and its length given. When dimensioned in this manner, no mistake is possible.

DIMENSIONS.

71. Dimension lines not only indicate the direction in which an object is to be measured, but also show, by the position of their ends, either by themselves or in conjunction with extension lines, just where the measurement is to be made. A dimension line may be placed directly on the object, as, for instance, that marked "*8" cored*" in Fig. 35, or it may be placed outside of the object, as the one indicating the width of the pulley. In the latter case, **extension lines,** as *a* and *b*, are drawn; the dimension line is then placed between them and arrowheads are placed on its ends in contact with the extension lines, as shown. This indicates that the measurement is to be made between the points from which the extension lines have been drawn.

72. In case of symmetrical objects, where a part of them has been omitted to save space, as, for instance, in the sectional view of a pulley given in Fig. 35, the dimension line denoting the diameter is usually drawn as far as the break; two arrowheads, as shown at c, are often placed on the end at the break in order to call attention to the fact that the dimension line has not been drawn its full length. Some draftsmen prefer to omit the double arrowhead; leaving the end of the dimension line plain also denotes that its full length is not shown. An instance of this is given in the dimension line indicating the radius of curvature of the pulley.

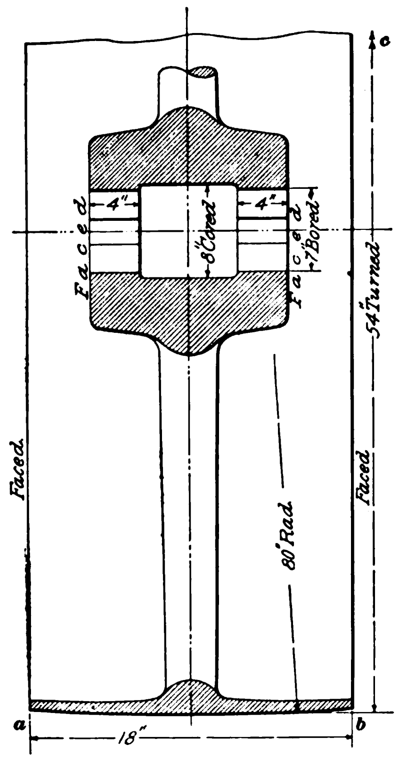


FIG. 35.

73. On drawings made in accordance with the British system of measurement, it is customary to give all dimensions up to and including 24 inches in inches. Larger dimensions are usually given in feet and inches, except in case of round work, where it is customary to give the dimensions up to 144 inches in inches.

On drawings made in accordance with the metric system, where the unit of measurement is the meter, which is subdivided into 1,000 millimeters, dimensions are usually given entirely in millimeters, except in cases where the dimensions are very large. The letters *mm.* are usually written after the dimensions to signify that they are millimeters; if they are omitted, it is always understood that the dimension, in the absence of any note to the contrary, means millimeters. The letter *m* written after the dimension always denotes meters; it should never be omitted when a dimension is given entirely in meters, or in meters and millimeters.

74. When a drawing is dimensioned, it is usually expected of the workman that he will go by the dimensions, and in no case attempt to scale the drawing. It must not be inferred from this, however, that the workman, upon discovering an error in a dimension, is to go ahead and spoil the job he is engaged on for the sake of obeying the rule. It is rather his duty to call the attention of somebody in authority to the fact that, in his judgment, an error has been made, and thus start an investigation, and hence cause the error to be rectified before any damage is done. When this cannot be done, the workman will usually have to shoulder the responsibility of making the change; in connection with this, it should be remembered that, before a person goes ahead, he ought to be perfectly sure that he himself is not in error.

In some cases only the leading dimensions are given, and the workman is expected to supply all others by scaling the drawing. In such a case, either a note to that effect appears on the drawing, or verbal instructions are given to that effect.

KINDS OF WORKING DRAWINGS.

75. Working drawings are divided into two general classes, which are: *assembly*, or *general*, *drawings*, and *detail drawings*.

Assembly, or general, drawings show the workman the relation between, and the places or positions occupied by, the different component parts of a structure, machine, device, fixture, implement, etc. If any dimensions are given, they are usually only leading dimensions.

Detail drawings show the exact shape and size of each integral part. For this purpose they are supplied with all the dimensions required by the workman and any additional explanatory notes that the draftsman may consider necessary.

Detail drawings may be made so complete that they will answer for the patternmaker, blacksmith, and machinist, and they are usually so made in the smaller shops. In the large shops, however, separate drawings are made for the patternmaker, blacksmith, and machinist; the detail drawing for the use of the patternmaker, then, contains only the dimensions and notes needed by him to make the pattern; that for the blacksmith contains the dimensions needed for making the forging; and, finally, that for the machinist contains all dimensions needed by him.

76. Attention is called to the fact that practice varies somewhat in different places in regard to the dimensions given on detail drawings, at least as far as drawings for the patternmaker and blacksmith are concerned. In some places, the dimensions given represent the size the object is to be when *finished;* hence, the blacksmith or patternmaker must make necessary finishing allowances himself. In other places, again, the finishing allowance has been, and usually is, made by the draftsman; the dimensions given are then those of the pattern or forging. If in doubt about the practice followed in a particular shop, it is a good plan to find out by inquiry what system is used in the particular shop under consideration. In the best modern practice, a note, calling attention to the fact that the sizes given are those when finished, is placed on the drawing, thus, "*All finished sizes,*" or some similar note.

DIFFERENT SYSTEMS OF PROJECTION.

77. There are two methods of projection in extensive use, which are known technically as the **first-angle method** and the **third-angle method.** The third-angle method is, probably, the one more generally used in the United States of America; in Europe, the first-angle method appears to be preferred.

In Fig. 36 (*a*), let *A B C D* and *E F G H* be two planes that intersect in *O P* and are at right angles to each other. Then, of the four right angles included between the planes, the angle $B P G$ is called the *first* angle; the angle $G P C$ is

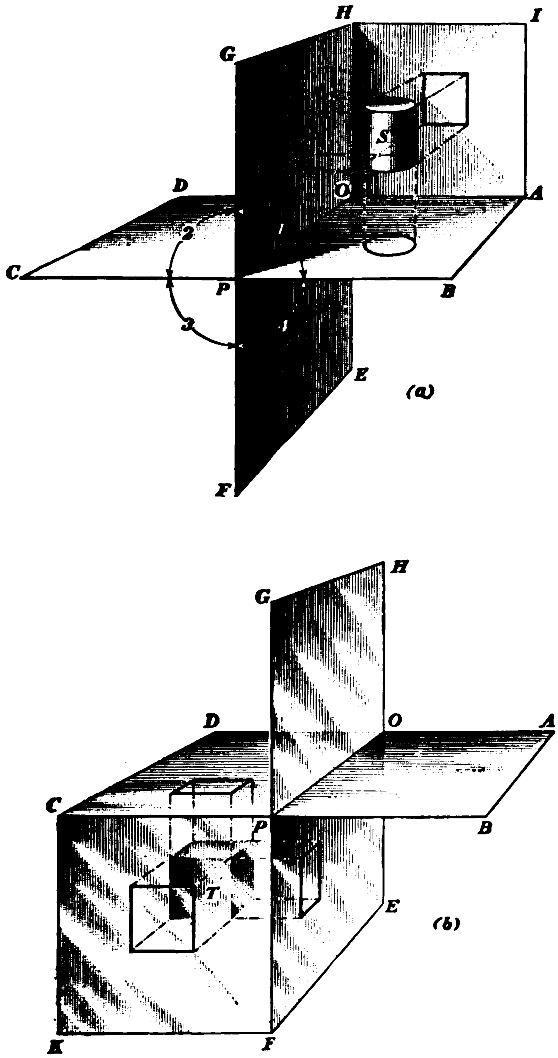


FIG. 36.

known as the *second* angle; the angle $C P F$ is the *third* angle; and the angle $F P B$ is the *fourth* angle.

Now, if an object, as the cylinder S, be placed in the first angle, the front view of the object is given by projecting its outline on the plane *E F G H*; the top view, or plan, is obtained by projecting the outline down on *A B C D*, it being understood that the planes are *opaque*, and that the object is *between* the point of sight and the planes. Imagine another plane *A O H I* to be placed at right angles to the other planes, and behind the object; the left-hand side view is then projected on this plane. In order to bring all views into the same plane, the plane *E F G H* is revolved around *O P* until its edge *E F* coincides with *A B*; the plane *A O H I* is revolved around *A O* until it coincides with *A B C D*. It will then be observed that the top view of the cylinder will be *beneath* the front view, and the left-hand side view will be to the *right* of the front view.

Now, let an object, as, for instance, the cube *T*, be placed in the third angle, as shown in Fig. 36 (*b*). All planes are now assumed as being *transparent* and are situated in *front* of the object. Then, the top view is projected on the plane *A B C D*; the left-hand side view is projected on the plane *P C K F*; and the front view on the plane *E F G H*. Revolve *E F G H* around *O P* until *A B* and *E F* coincide; also revolve *P C K F* around *P C* until it coincides with *A B C D*, in order to bring all views into the same plane. Then, the top view will appear *above* the front view, and the left-hand side view will appear on the *left* of the front view.

78. The difference between the two methods of projection is, in its results, simply a question of the relative arrangements of the views; it may be summarized as follows: In the third-angle method of projection, the top view is on top, the right-hand side view is on the right, the left-hand side view is on the left, and the bottom view is on the bottom. In the first-angle method of projection, the top view is at the bottom of the front view, the right-hand side view is on the left, the left-hand side view is on the right, and the bottom view is on top.

79. When the first-angle method is used, the top view is usually called the *plan;* the front view is then known as the *front elevation;* the side views are spoken of as the *right-side* and the *left-side elevations;* and the bottom view is called the *inverted plan.* (See Art. **27.**) By observing the relative arrangements of the views, it can be determined at a glance what method of projection has been used.

READING DRAWINGS.

80. The following general method of procedure has, by experience, been shown to be conducive to the accurate and rapid reading of a drawing made in orthographic projection. *First*, if the drawing is dimensioned, ignore the existence of the dimension lines and dimensions entirely until after the general shape of the object is fixed on the mind. *Second*, by referring to the several views, form an idea of the shape of the main body of the object; that is, observe if its outline shows it to be a cube, a sphere, a cylinder, a cone, a pyramid, etc., or a combination of several of these elementary forms. The shape of the main body having been impressed on the mind, observe how it is modified by details, determining, by reference to the several views, whether they project from the main body or are recesses, or holes. *Finally*, by referring to the dimensions, form an idea of the relative sizes of the component parts. Pay due regard to all conventional representations that may have been used; for instance, do not become confused if the arm of a pulley, or a rib, which, truly speaking, should have been in section, is shown in full. If two half-sections are placed on either side of a common center line, remember that each half must usually be viewed independently of the other and must be mentally completed.

81. A few examples of reading drawings are now given. Fig. 37 is a drawing of a flange coupling. The drawing can be read very readily when the purpose of the coupling is known. The object to be attained is to rigidly connect the ends of two separate shafts having the same center line, so that the motion of one shaft will be transmitted to

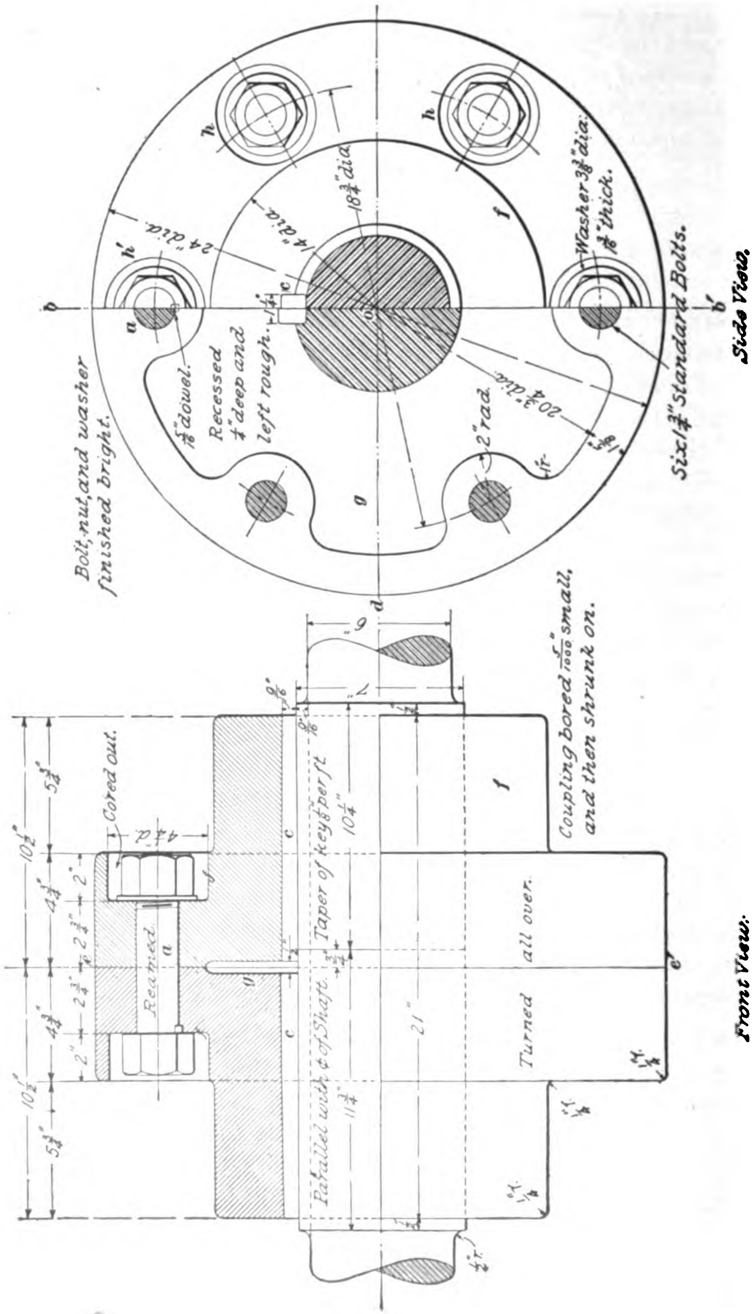

Bolt, nut, and washer finished bright.
24" dia.
14" dia.
18¾" dia.
Recessed ¼" deep and left rough.
5/16" dowel.
2" rad.
20¾" dia.
Washer 3⅜" dia. 3/16" thick.
Six 1¾" Standard Bolts.
Side View.
Cored out.
Reamed.
Parallel with ℄ of Shaft.
Taper of key ⅛" per ft.
Turned all over.
Coupling bored 5/1000" small, and then shrunk on.
Front View.

FIG. 87.

the other. The ends of the shaft butt together, as indicated by the vertical line, partly full and partly dotted, just to the right of the line *e e'*, in the front view. Referring to the front view, it is seen that the upper part is shown in section; as the bolt *a* and the keys *c*, *c* are shown, the proper inference is that the section has been taken along the center line *b b'* of the side view, and that the part included between *d o* and *o b* is supposed to have been removed. As is customary, neither the shafts, the keys, nor the bolt *a* are shown in section. The section lining on the coupling to the right and left of the line *e e'* runs in opposite directions; hence, the conclusion is reached that there are two parts to the coupling, and that the line *e e'* shows the joint.

Referring now to the side view, a glance shows that two half-views are given. Taking the one to the right of the center line *b b'*, the semicircle *f* shows a projection, which, by referring to the front view, is seen to be the hub *f*. Furthermore, as the nut on the end of the bolt *a* is shown, the conclusion to be arrived at is that the right-hand half-view is a side view drawn in full. Referring to the left half-view, it is noticed that nothing except the bolts and the shaft is shown in section. Consequently, the only place where this view could have been taken is along the line *e e'*, for, if taken in front of or behind the plane represented by this line, part of the coupling itself would have been touched by the cutting plane and would, consequently, have been sectioned. This is further indicated by the fact that the recess *g* shows in the left-hand half of the side view. The side view, by its outline, shows that the coupling is circular; this would also be inferred from the note "*Turned all over*" placed on the front view, since it is well understood by mechanics that only work of a circular cross-section can be finished by *turning*.

The front view shows a recess *g* to be placed in each half of the coupling; the shape of the recess, in a plane at a right angle to the axis of the coupling, is given by the left-hand half of the side view; in the absence of any note or other indication to the contrary, it is to be assumed that it is the same in the other half-view that would complete a view in full taken along the plane represented by *e e'*. The depth of the recess is indicated in the front view, and is specified by the note "*Recessed* $\frac{1}{4}$*" deep and left rough*" placed on the side view.

The fact that there are six bolts is clearly specified by the note, which also gives the size and specifies that they are to be proportioned in accordance with the United States standard system of screw threads and bolts. The circles *h*, *h* indicate that the nuts on the ends of the bolts are placed in recesses that have a circular cross-section; if these circles had not been shade-lined, a reference to the front view would have been necessary to discover if the circles indicated a projection or a recess. Neither of these two circles can be seen in the front view, but reference to the side view shows a semicircle *h'* occupying the same position in respect to the center, and, when projected over to the front view, it is seen to be the edge of a recess marked "*Cored out.*" It will be noticed that an *f*, which, as previously explained, means "finish," is placed on the surfaces of the cored recess for the bolthead and nut. This indicates to the machinist that the recess is to be finished by *counterboring;* this latter conclusion is due to judgment telling him that it is the most practicable way of finishing the recess.

As far as the bolts are concerned, no bolt circle has been drawn to definitely locate all of them at the same distance from the center. A short arc has, however, been drawn through the center of each bolt, and since there is a dimension "*18*$\frac{3}{4}$*" dia.*" placed between two opposite arcs, the workman infers from this that all bolts are located on the same circle, there being no note or other indication to the contrary. The position of the key *c* is fixed by the center line *b b'*, which is seen to pass through two of the coupling bolts. On the front view appears a note "*Parallel with* ℄ *of Shaft*"; in this note, the character ℄ is an abbreviation that is occasionally used for center line.

82. Fig. 38 is a sectional front view and a side view of some machine part. Looking at the side view, it is noticed

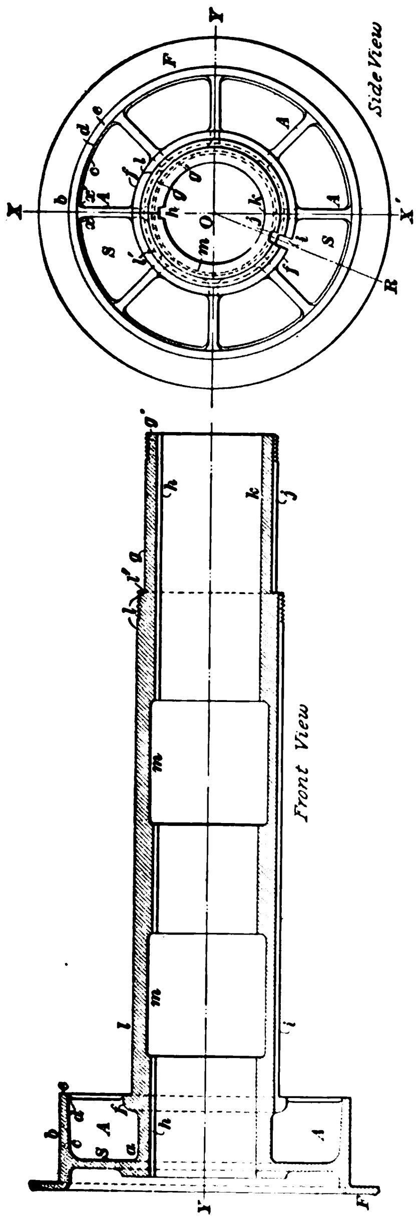
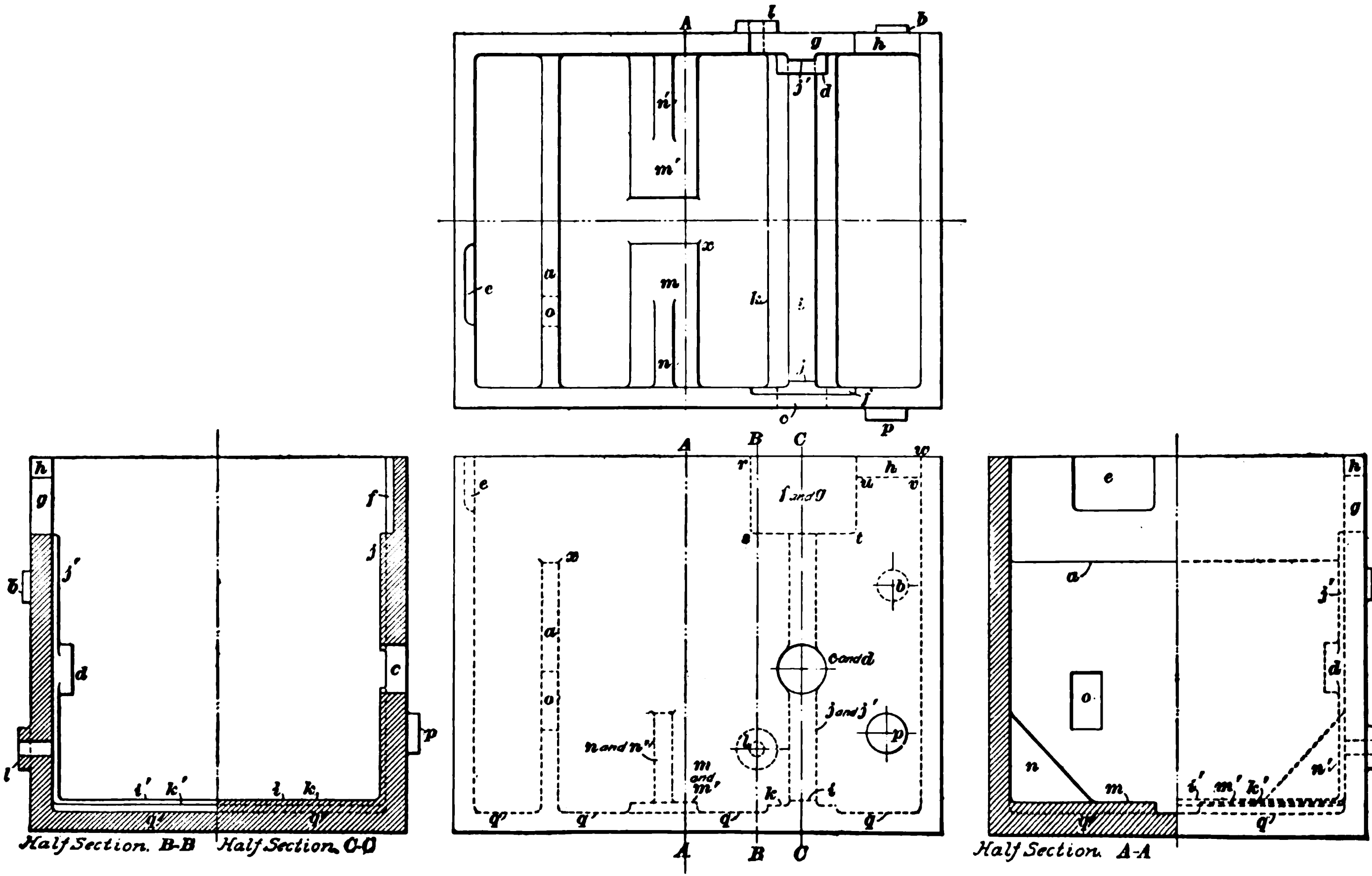


FIG. 38.

that the center line $X X'$ passes through the keyway h, which is seen in the sectional front view. Recesses or slots of some kind are indicated at i and j in the front view; looking at the side view, no indication of such recesses is found on the center line $X X'$, however. It is seen that two rectangular slots i and j are located close to that center line, being in fact on the auxiliary center line $O R$. Now, a section taken along $O R$ would have a rather peculiar and confusing appearance, as far as the section through the slots is concerned; for this reason, the draftsman has made use of a permissible conventionalism, and has shown the slots in the front view as if they were located on the center line $X X'$. At F, in the front view, a flange is shown, which, by the dotted line, is indicated to extend all



Half Section. B-B Half Section. C-C

Half Section. A-A

around the piece. Reference to the side view shows this flange to be circular.

To find the shape of the part having the bounding lines *b e d c S a f*, the side view shows the circle *b* to correspond to *b* in the front view; the surface *e* corresponds to the line *e* in the front view; the circle *d* corresponds to the edge *d* of the front view, etc. From this, the conclusion is drawn that this part is hollow and circular. The dotted lines of the front view also show that the part having the cross-section *b e d c S a f* extends around the central tubular part, but do not, in themselves, indicate that it is circular. Reference to the side view is needed to establish this fact, in the absence of any notes to this effect on the front view.

The side view shows the part just considered to be strengthened by eight ribs *A*, *A*, etc. Two of these are cut by the cutting plane, but are shown in the sectional front view as if they were just behind this plane; this conventionalism is frequently employed. The ribs join the part previously mentioned by fillets of ample size, as shown at *x* and *x'* in the side view. Projecting the line *g* over to the side view, the full circle *g* is found to correspond to it. Right inside of this circle a dotted circle *g'* is found; looking at the front view, a thread is found shown in section at *g'*, and hence the conclusion is reached that this dotted circle represents the bottom of the thread. Likewise, the circles *l* and *l'* represent, respectively, the outside diameter and diameter at the bottom of the thread shown at *l* and *l'* in the front view. Referring now to the dotted circle *m*, project its diameter on *X X'* over to the front view, and it is seen to be the projection of the circular recesses *m*, *m*. Finally, the circle *k* represents the cylindrical bore.

83. Fig. 39 is a drawing giving a top view, front view, and several half-sectional views of a part of a machine. By referring to the several views, it is seen that the general outline is that of a box open on the top; this general shape is modified by various ribs, bosses, recesses, and holes.

To find the shape of the part *a* shown in the top view as extending clear across the inside of the casting, we refer to the front view first, where the dotted lines, which extend clear down to the bottom, show that its cross-section is rectangular, and that it joins the bottom *q* by fillets, as shown by the small arcs. Referring to the right-hand side view, the top *a* of this part is shown straight, and, from the several views, the conclusion is reached that it is a partition having the thickness, height, and position shown in the drawing. At *o* in the top view there are two dotted lines drawn across the partition; in the front view there are also two dotted lines. This tends to show that an opening of some kind extends through the partition; reference to the half-section taken on the line *A A* shows the opening to be rectangular. At the top of the partition in the front view there are two short diagonal lines shown at *x*; these signify that the partition is joined by fillets to the sides of the box.

In the top view, at the right of the partition *a*, two parts *m* and *m'* of the casting are shown, which are rectangular in shape. Projecting these down on the front view, dotted lines are found at the bottom of the box showing *m* and *m'* to be flat strips raised above the bottom, which conclusion is shown to be correct by referring to the right-hand side view, where *m* is found shown in section and *m'* in dotted lines. The top view shows that something is placed on top of *m* and *m'* and against the sides of the box; from the dotted lines shown in the corresponding position in the front view, we derive the idea that this piece has a rectangular cross-section. To find the shape of these parts, when viewed from the ends of the box, we refer to the right-hand side view, where *n* and *n'* show them to be ribs that strengthen the sides of the box. At the right of the top view, *k* and *i* indicate something that may be ribs, or raised parallel strips, or a bar having a T shape, extending from side to side. To find what these lines represent, the front view is examined, where dotted lines at *k* and *i* are found.

Now, for the third view we refer either to the half side view shown in full, where dotted lines *k'* and *i'* show the height of *k* and *i*, or to the left-hand sectional view, where the right-hand half-section, taken on the line *C C*, which passes through *i*, shows the height of *i*. In this view, the height of *k* is shown by the dotted line *k*. In the half-section taken on the line *B B*, *k'* and *i'* show in full; from their several views it is seen that *k* is a raised rectangular strip extending from side to side, with another strip *i* placed on top of it. Referring now to *j* and *j'* in the front view, dotted lines *j* and *j'* in the front view and right-hand side view and the full lines of the left-hand side view show both to be strips extending from *i* upwards along the sides to the height indicated. The strip *j'* is seen to have some kind of a projection *d* on it (see top view).

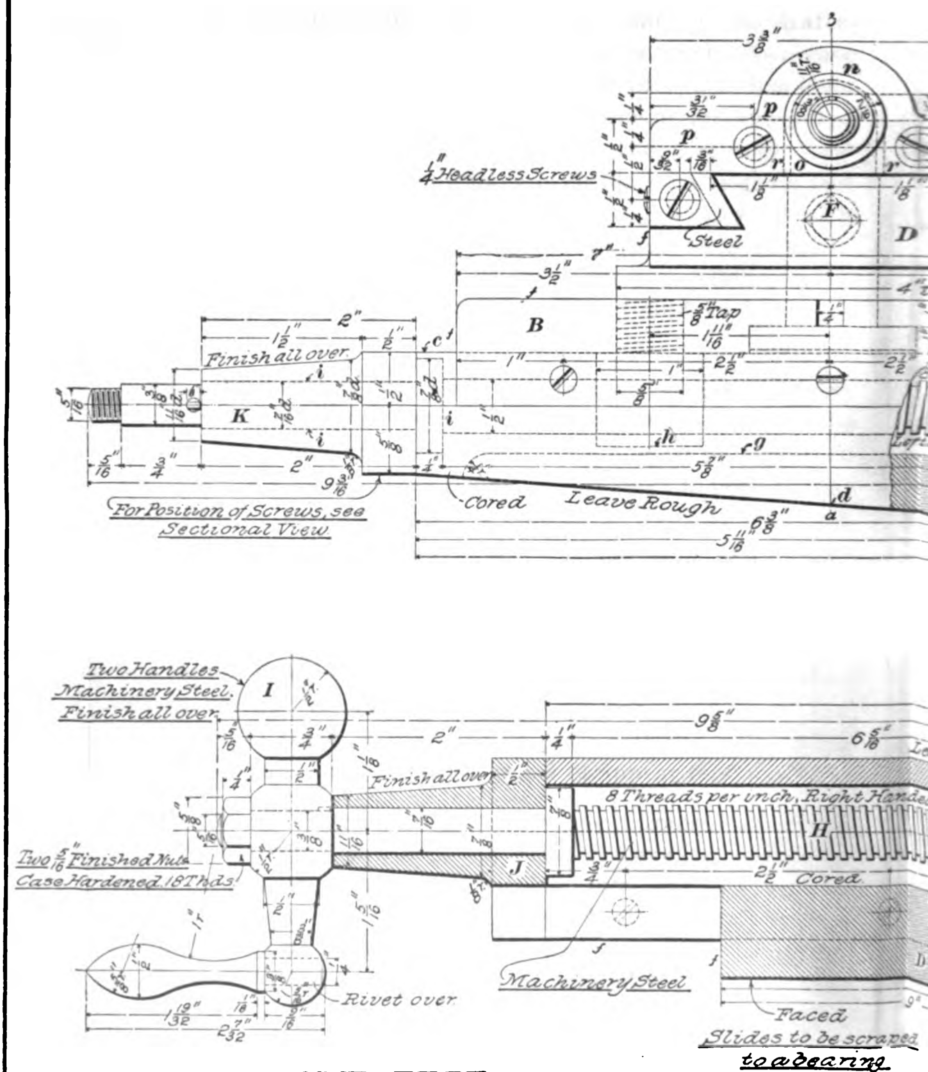
Now, in the front view, there are no dotted lines to show what *d* is; a hole is there shown instead. There are two conclusions now possible: either the draftsman has omitted the part marked *d* through an error, or *d* is a cylindrical boss directly opposite the circular hole *c*, and of the same diameter, so that the full line denoting the hole *c* in the front view covers up the dotted circle, which would show *d* to be a circular boss. Referring to the right-hand and left-hand side views, the latter conclusion is shown to be correct. At *f* in the top view, there is evidently a recess cut in the inside of the front wall; to find its depth, we refer to the front view, and to get its shape, to the sectional view taken on the line *C C*. The top view shows that at *g* and *h* the top of the rear wall is not straight; reference to the front view shows that a piece having the profile *r s t u v w* has been cut out of the wall. This is further shown in the half-section taken on the line *B B*.

In a manner similar to the foregoing, the shape of the recess *e*, and of the bosses *p*, *b*, and *l*, is traced out and fixed in the mind.

84. Fig. 40 is a working drawing of a compound rest for a speed lathe. This drawing is at one and the same time a detail and an assembly drawing, as it not only gives all dimensions required for each and every part, but also shows how they are assembled. Drawings are frequently made in this manner in order to save some of the draftsman's time. The particular drawing shown exhibits a case where the draftsman, on account of lack of space, has been compelled to break the rules governing the arrangements of the views. Referring to the figure, the sectional view taken on the line *a b* should have been placed alongside and on the right of the front view. In reading a drawing with the view thus placed, the reader is supposed to constantly imagine that the views are in their correct relative positions; with a little practice this will be found to be quite easy.

85. In a case of this kind, it is manifestly impossible to project points or lines from one view to the other by means of a straightedge, and a different method must be followed. Select some surface whose projection appears in both views, or a center line; now place a pair of dividers so that one point rests on the projection of the surface or center line selected, and open them until the other point reaches the point or line whose projection it is desired to find in the other view. Then place one point of the dividers on the line representing the selected surface in the second view, and move the dividers along this line until a line, or the projection of a line, is found to coincide with the other point of the dividers. Examples of this will appear later on.

86. In order to find the shape of the different parts, and also to discover, if possible, the relation between them, we must commence our investigation somewhere. Let us choose the bottom of the front view. Looking at this, it is noticed that a partial section is shown, from which, by reason of the section lining running in opposite directions, we conclude that *A* and *B* are separate parts. At the right and left of the front view, the full lines *c*, *c* show that some part of *A* is higher than the bottom of *B*, but we do not know whether these lines denote the top surfaces of projecting parts between which *B* is fitted, or if *c* is the top surface of a raised strip of some kind that extends clear through the inside of *B*. In order to settle this question, we note whether



COMPOUND REST

FOR 10"X 36" SPEED LATHE.

CAST IRON, UNLESS OTHERWISE SPECIFIED.

ONE OF THIS. SCALE FULL SIZE.

THE SCRANTON TOOL WORKS,

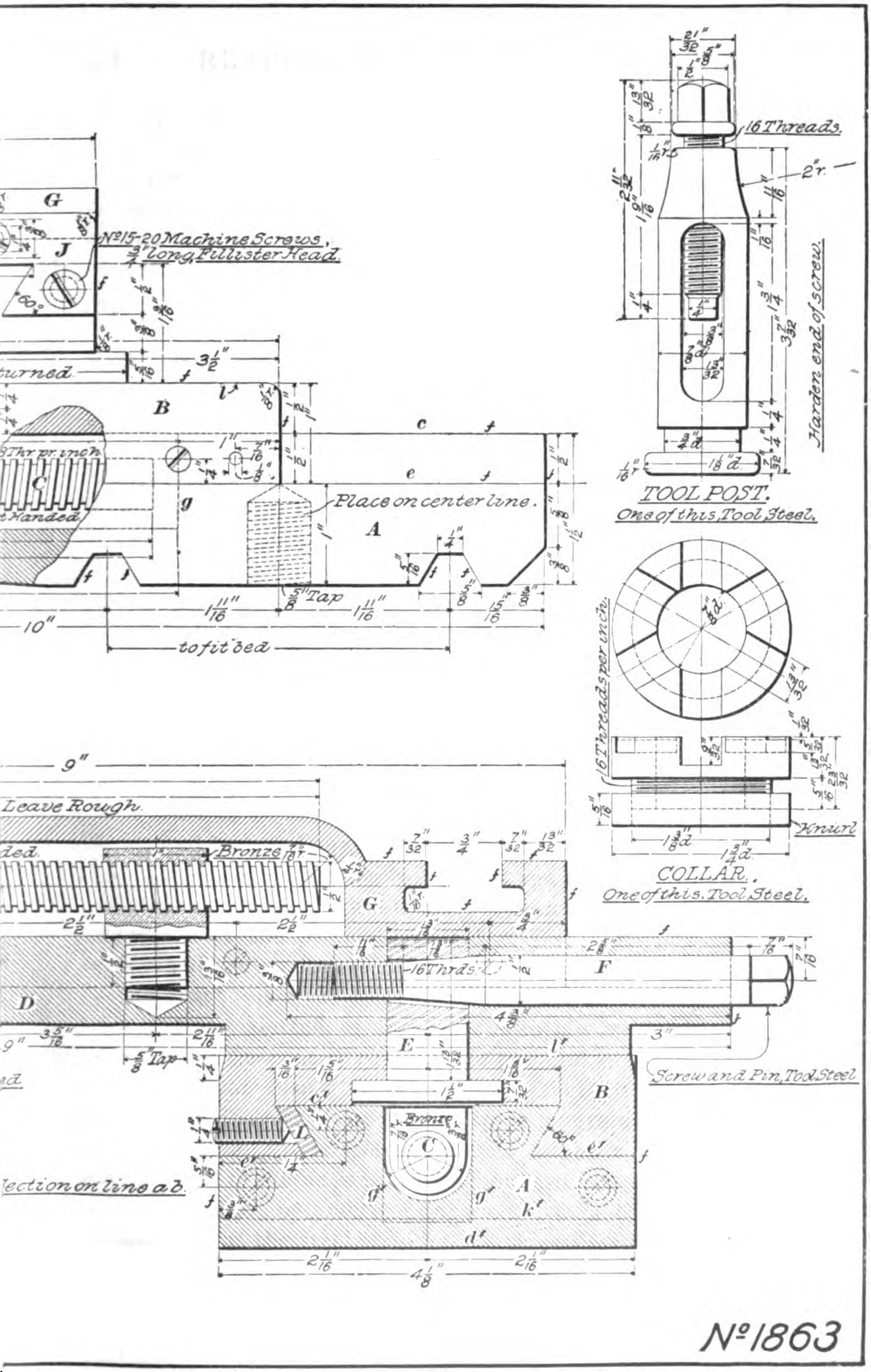
SCRANTON, PA.

Drawn By J.A.G Drawer 182

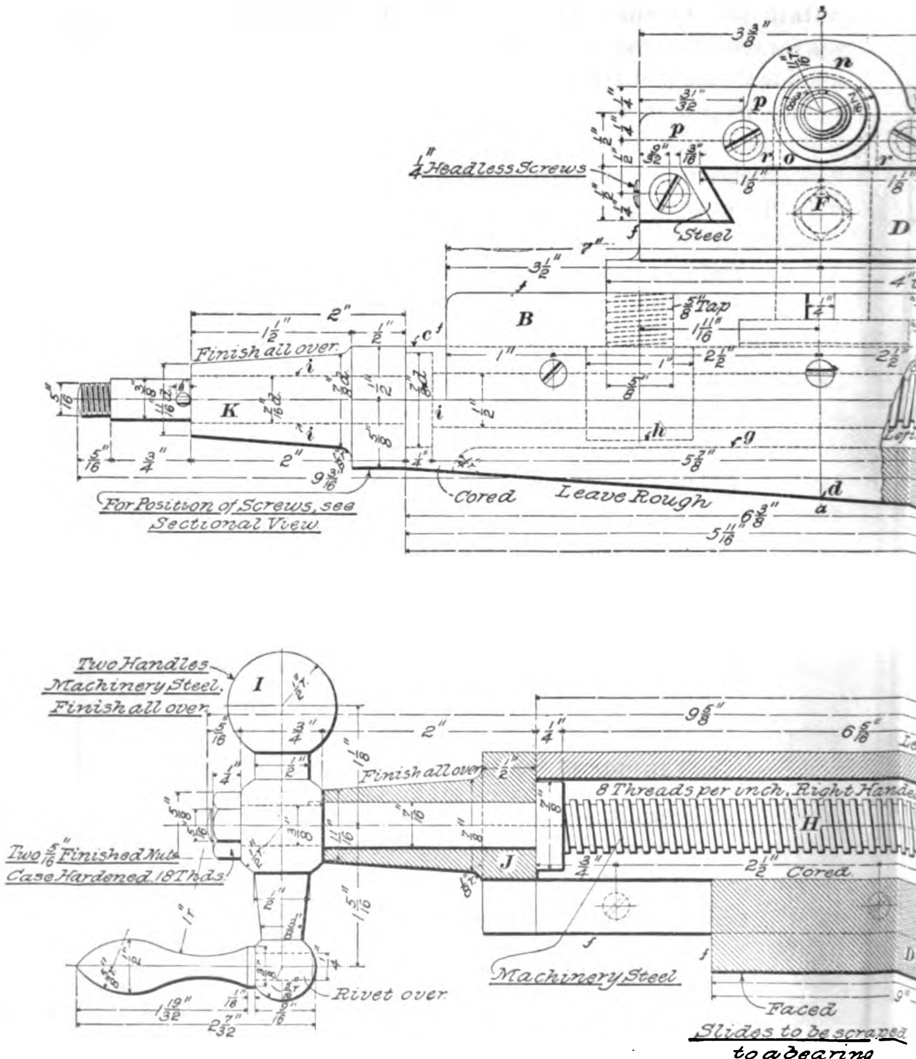
Checked By C.P.T Order No 97

DATE OCT 1-1900

FIG. 40.


No 15-20 Machine Screws,
¾" long Fillister Head.
Place on center line.
5/8" Tap
to fit bed
Leave Rough.
Bronze
16 Thrds.
Screw and Pin, Tool Steel
Section on line a b.
16 Threads.
Harden end of screw.
TOOL POST.
One of this, Tool Steel.
16 Threads per inch.
Knurl
COLLAR.
One of this, Tool Steel.
No 1863

. 40.



COMPOUND REST

FOR 10"X 36" SPEED LATHE.

CAST IRON, UNLESS OTHERWISE SPECIFIED,

ONE OF THIS. SCALE FULL SIZE.

THE SCRANTON TOOL WORKS,

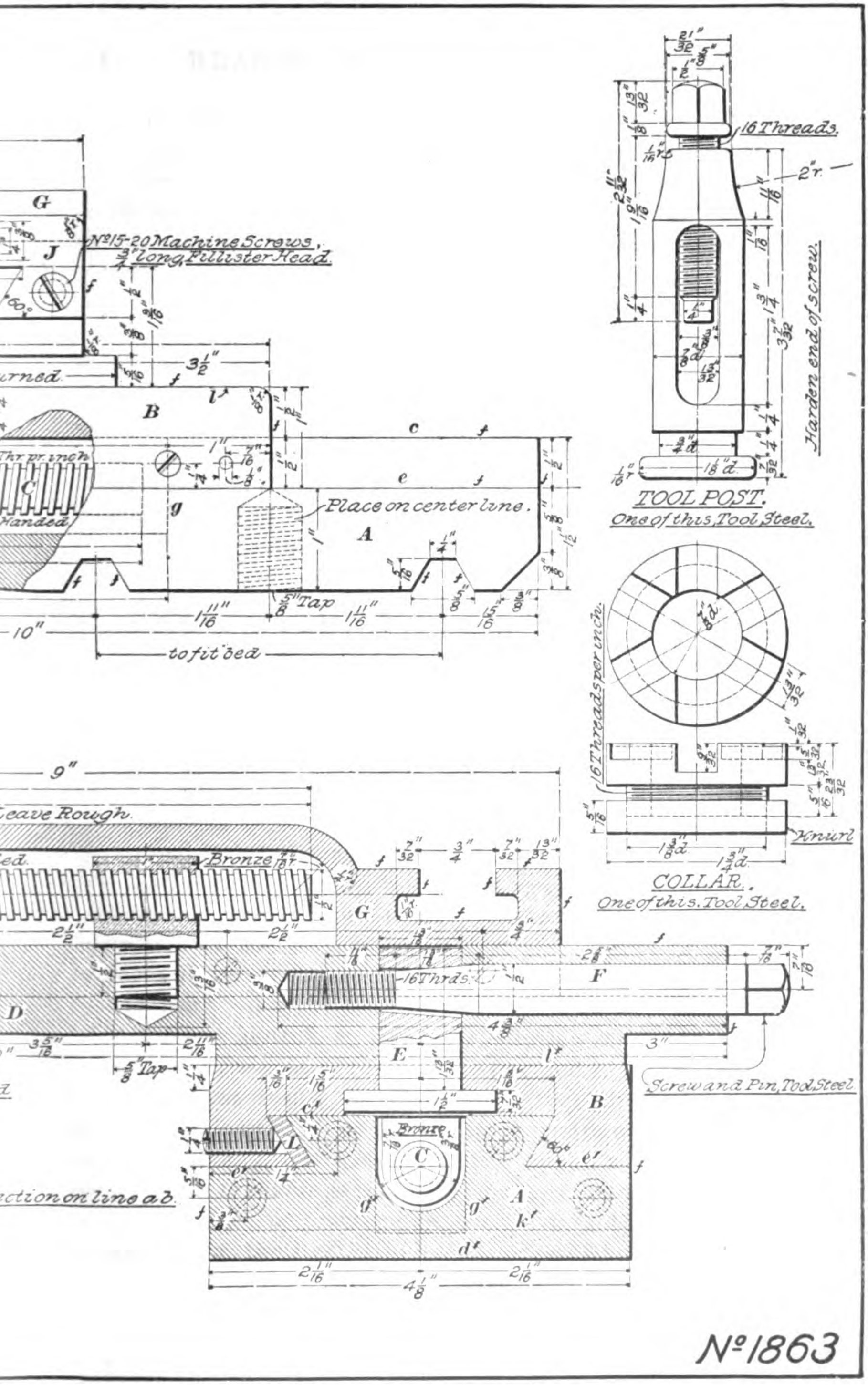
SCRANTON, PA.

Drawn By J.A.G Drawer 182

Checked By C.P.T Order No 97

DATE OCT 1-1900

FIG. 40.


No15-20 Machine Screws, 3/4" Long Fillister Head.
Place on center line.
to fit bed
Leave Rough.
Bronze
16 Thrds.
Screw and Pin, Tool Steel
Section on line a b.
16 Threads.
Harden end of screw.
TOOL POST.
One of this, Tool Steel.
16 Threads per inch.
Knurl
COLLAR.
One of this. Tool Steel.
No1863

the top surface is continued somewhere. Looking at the front view, it is seen that the line *c* is dotted clear through *B*, which settles conclusively that the part whose top surface is shown by the line *c* is a raised strip extending clear through *B*; this fact immediately implies that *B* has a groove of some kind running through it longitudinally in order to admit the raised strip.

Referring now to the sectional view, which, as previously stated, is a view taken on the line *a b* of the front view, and everything to the right of this line being removed, we may choose the bottom line *d'* of the sectional view as a base from which to make measurements. From the fact that the section is taken on the line *a b*, we know that the line just chosen is the projection of the intersection *d* of the plane represented by *a b* with the bottom of *A*. Measuring from *d'* upwards to the highest line *c'* of *A* in the sectional view, and placing one point of the dividers on *d* in the front view, it will be seen that the other point coincides with the dotted line forming a continuation of *c*, *c*; this shows that *c'* is the projection of *c*. In a similar manner, we determine that *e'* is the projection of *e*, and tracing the outlines of *A* in the sectional view, we notice that the raised strip on *A* has inclined sides. We also notice that *B* is cut out to suit the profile of *A*, except that on one side a steel part *L* is interposed between the inclined sides of *A* and *B*; it is also seen that a screw rests with its point against *L*.

Referring now to the front view, and knowing from inspection of the sectional view that the upper and lower surfaces of the steel part *L* are flush with *c'* and *e'*, or *c* and *e* in the front view, to determine the length of this part, notice if any dotted or full lines showing its length are shown anywhere at a right angle to *c* and *e*. None being found, the conclusion to be drawn is that either the steel part *L* is as long as *A*, or has the same length as *B*. A person without any practical experience might conclude that the length is the same as that of *A*; but any one having engineering instinct, or practical knowledge, would immediately notice that, as the steel strip has setscrews which evidently serve to push it against the inclined side of *A*, it would be unnecessary to make the strip the length of *A*, and, hence, we should immediately conclude that its length is the same as that of *B*. This latter conclusion is the one the draftsman desired the mechanic to arrive at.

87. Looking at the sectional view of *A* again, we notice that a groove, open on top, is cut into *A*. To find its length, we must find lines corresponding to it in the front view. Measuring from *d'* upwards to the bottom of the groove, and transferring the measurement to the front view, we find that the dotted line *g g* represents the bottom and end of the groove, which, at the left, is also shown to be open at the bottom, since the dotted line *g* curves around and continues to the bottom of *A*. This is also indicated by the dotted lines *g'* that form an extension of the sides of the groove in the sectional view; measuring from *c'* downwards to the horizontal dotted line joining the ends of *g' g'*, and then passing along *c* in the front view, the point of the dividers will be found to coincide with the point where the dotted line *g* meets the bottom of *A*. From this, the conclusion is drawn that the dotted horizontal line joining *g' g'* in the sectional view is the bottom edge of the opening.

88. Looking at the front view, we notice a left-handed screw *C* that is placed within the slot just investigated. Knowing that, in a view in line with its axis, the outline of a screw will be a circle, and knowing that this circle will be found inside of the slot, the screw is readily found in the sectional view. Now, experience teaches us that when a screw is shown in place in a machine drawing, there must also be somewhere along its axis a threaded hole (or a nut) to receive it. Looking at the sectional view, we see the outline of something (marked "*Bronze*") that surrounds the screw. Now, this part, at first glance, appears to be a continuation of the pin *E* directly above it; there are two reasons, however, why this is not the case. In the first place, the part *E* is sectioned for steel; this immediately shows that *E* and the part under investigation are separate parts. Furthermore, when tracing out the shape and positions of the objects in the front view, they will be seen neither to be in line nor to have any connection with each other. To find the part under investigation in the front view, we may take, in the sectional view, a measurement from the center of the screw downwards to the lowest point of the part we are investigating, and then, referring to the front view, proceed along the center line of the screw *C* until we strike the dotted line *h*. Since the sectional view shows only things to the left of the line *a b*, we know that as the part being investigated shows in the sectional view, we must look for it to the left of *a b* in the front view. At the ends of the horizontal dotted line *h* we notice two vertical dotted lines that show the length of the part under investigation; since these lines terminate against the line *c*, we know that the part butts against the surface of *B*.

This latter conclusion is further confirmed by examining, in the sectional view, the full outline of the part. Referring again to the front view, we see a screw thread indicated in *B* right above the part we are discussing, and in the absence of any indication to the contrary may justly assume that it is a threaded shank by means of which the part is attached to *B*. By this time we are probably convinced that the part we have been investigating is the nut we are looking for, but are not sure of it. To find out, let us try to investigate the whole of the screw. In the front view, the dotted lines *i*, *i* show that the screw has a bearing, and also has a collar butting against part of *A*; beyond the bearing, the screw shows in full, and, apparently, has a seat for some kind of an attachment, which must cause the screw to turn, since a dowel pin is shown in the seat. Inspecting the sectional view, we find a screw, similar to the one under discussion, with a ball handle and retaining nut on the end of it. As we find a note "*Two Handles Machinery Steel, Finish all over*," and as we cannot find any other place for the second handle, we naturally conclude that such a handle is to be placed on the end of the screw *C*. Now, from the fact that the screw is confined longitudinally by the collar and the ball handle, and that there is no thread on the part of the screw between them, we know that the nut must be to the right of the collar; since the part previously investigated is the only part we can find that directly surrounds the screw, we will now be justified in assuming that it is the nut we are looking for.

89. The fact that *A* and *B* are connected together by a screw provided with a handle for turning it will immediately suggest the idea that it is to be used for moving the part *B* along *A*, whence we conclude that *B* is a slide moving on *A*. Knowing this, the logical conclusion is that the piece *L* is a gib used for taking up the wear of the sliding surfaces, which view is proved to be correct when it is noticed, by reference to the sectional view, that a tightening of the setscrew will tend to draw the wearing surfaces together.

90. Looking now at the part *K*, at the left of *A*, in the front view, considering the part by itself, we cannot tell whether it is an integral part of *A*, or a separate piece fastened to it. But as soon as we consider it in connection with the screw *C*, we see that the latter cannot be placed in position unless either the part *K* is removable, or the collar on the screw is separate from the screw and pinned on. Since there is no indication that the collar is separate, we conclude that the part *K* is separate from *A*. The next question that suggests itself is: How is it fastened on? The note on the front view, and the dotted screw heads in the sectional view, show that screws with slotted heads are used.

91. As far as the shape of *K* is concerned, the front view shows that it is a cone joining some presumably flat part. Referring now to the sectional view, we discover by measuring successively from the center line and center of the screw *C*, that the dotted horizontal line k' represents the lower surface of *K*, and the absence of any other dotted lines in this part of the sectional view indicates that the profile of the flat part of *K* is the same as that of *A*.

92. On examining the sectional view, it is seen that some part of *D*, which from the section lining we know to be separate from *B*, projects downwards from the main body of *D* and is in contact with the upper surface *l'* of the part *B*. Referring now to the front view and looking along *l*, we find that the part under discussion is cylindrical; this is inferred from the dimension "*¼" turned.*" The main body of *D*, and also the parts *G*, *H*, and *J*, may now be investigated in a manner similar to that in which the relation of *A*, *B*, *C*, and *K* was traced; it will then be found that *D* is a part similar to *A*. Furthermore, the investigation will show that *G* is a slide; this slide is movable by means of the screw *H*, which turns in the bearing *J*.

93. Referring again to the sectional view, we see that *B* and *D* are connected together by a pin *E*, whose purpose is unknown as yet. Examining this pin, we notice that a hole is cut through its upper end, and that a screw *F*, with a tapered shoulder to the right of its screw thread, passes through this hole. On close examination, we see that the hole in *E* is so placed that the tapered part of the screw *F* bears against the upper side of the hole. We further notice that the screw *F* is not used as a fastening device to hold any parts of *D* together; this conclusion is forced upon us by the fact that the sectional view shows *D* to be one piece. Now, we know from experience that a screw is used either as a fastening device, or to transmit motion; as it obviously is not used for the purpose first mentioned, we conclude that it probably serves for the latter purpose. To make sure of this we trace out what will happen if the screw is rotated. We then noticed that if the screw is screwed inwards, it will raise the part *E*; but as *E* cannot move upwards by reason of being confined by the collar on it, it shows to us that screwing *F* inwards will force *D* down on *B*. The logical inference is that *E* and *F* form a clamping device intended to clamp *B* and *D* together.

Examining the pin *E* again, we do not find anything that would definitely tell whether it is round or square. Here judgment must be used. An experienced person would know upon the first glance that the clamping arrangement shown is an expensive one to make, and one not likely to be adopted when it is only required to fasten two pieces rigidly together, in which case *E* might be either round or square. The next inference would be that it is used in order to allow *D* to be rotated around *E*, and to be clamped in any position. This supposition requires the pin *E* to be round, and is correct in this case.

94. Referring now to the ball handle *I*, of which only one view is shown, the question of whether it is circular or square is immediately settled by experience teaching us that a handle having the shape shown is not likely to be anything else but round, and in the absence of any note or indication to the contrary, we would be justified in assuming it to be round.

95. As far as the part *G* is concerned, the sectional view shows it to be cored out in order to pass over the nut in which the screw *H* works. The width and profile of the coring must be obtained from the front view, which it will be remembered is a view at a right angle to the sectional view. The natural assumption to make is that the lines giving the width and profile of the coring will be found directly in the vicinity of the screw *H* in the front view. Measuring from the center line of this screw in the sectional view, upwards to the line showing the height of the coring, and then transferring this measurement to the front view, we find the full circle *n*. Now, as the coring is beyond the bearing *J*, we know that its profile would show in dotted lines and conclude that the circle *n* represents some part of the bearing *J*. As this bearing has a conical projection, the inference is that the full circle represents the largest diameter of the cone, which is the case. Now, the absence of a dotted line showing the coring forces us to conclude that the dotted line would be directly behind the full circle *n* and is thus hidden. This conclusion is further strengthened by finding two vertical dotted lines *r*, *r* tangent to the circle *n*, and we finally decide that the groove has straight sides with a semicircular top, as given by the dotted lines *r*, *r* and the upper semicircle of *n*. By measuring again in the manner previously explained, we decide that the dotted line *o* is a front view of the nut in which *H* works.

96. At the right-hand end of the sectional view of *G* we notice a T-shaped opening. Referring to the front view we can easily discover, by transferring measurements, that the dotted horizontal lines *p*, *p* show the length of the slot, which is seen to extend clear across *G*.

97. Referring now to the drawing of the tool post, it will be observed that only one view is given. While this does not definitively settle that the post is circular in cross-section, common practice would justify a person in assuming, in the absence of any note, or any other indication to the contrary, that such was the case. This view is strengthened by the fact that some dimensions are marked *d*, signifying diameter, which term is rarely applied to any but a round object.

98. The two views of the collar give its shape. Referring to the front view, while there is no definite note to that effect, it would be inferred from the fact that a thread is shown, that the lower part is separate, being, in fact, a circular nurled nut threaded to receive the upper part.

99. While, generally speaking, any one can learn to determine the shape of objects from a drawing, there are cases that arise in practice where this is very difficult without further verbal or written instructions. The cases in which this usually happens are where coring has various odd-shaped curved surfaces that curve in different directions, as occurs, for instance, with the steam ports and other passages of steam-engine cylinders and other similar work. Practical experience with a certain line of work, and, frequently, a knowledge of the object of the doubtful part, will often allow the reader to form a correct idea of what the draftsman is trying to convey; when this experience or knowledge is lacking, *consult somebody who is likely to know.*

Furthermore, the shape of an object does not necessarily, in itself, always reveal its purpose. Ability to determine at sight what an object is to be used for involves either a thorough knowledge of a particular line of work—in which case, the purpose of objects coming within its range can usually be determined at sight—or a very wide general knowledge of engineering construction.

100. Drawings made in orthographic projection are not always made so explicit that a person without any practical experience whatsoever can trace out the relation and shape of the various parts. Several examples of how practical experience is brought into play have been given in the description of Fig. 40. When such drawings serve as illustrations in textbooks and other technical literature, they are usually quite fully explained in the text; even then, however, some knowledge and judgment on the part of the reader is assumed. Thus, if the journal of a shaft is shown resting in a bearing, the reader is supposed to have judgment enough to know that the journal is round without being distinctly told so. Again, if only a side view of a pulley (a view taken parallel to its axis) is shown, the text may call attention to the fact that it is a pulley; the reader's judgment must supply the added information that it is round.

ARITHMETIC.

(PART 1.)

DEFINITIONS.

1. **Arithmetic** is the art of reckoning, or the study of numbers.

2. A **unit** is *one*, or a single thing, as *one*, *one* boy, *one* horse, *one* dozen.

3. A **number** is a unit or a collection of units, as *one*, *three* apples, *five* boys.

4. The **unit of a number** is one of the collection of units which constitutes the number. Thus, the unit of *twelve* is *one*, of *twenty* dollars is *one* dollar.

5. A **concrete number** is a number applied to some particular kind of object or quantity, as three *horses*, five *dollars*, ten *pounds*.

6. An **abstract number** is a number that is not applied to any object or quantity, as *three*, *five*, *ten*.

7. **Like numbers** are numbers which express units of the *same kind*, as 6 *days* and 10 *days*, 2 *feet* and 5 *feet*.

8. **Unlike numbers** are numbers which express units of *different kinds*, as ten *months* and eight *miles*, seven *dollars* and five *feet*.

NOTATION AND NUMERATION.

9. Numbers are expressed in three ways: (1) by words; (2) by figures; (3) by letters.

10. **Notation** is the art of expressing numbers by figures or letters.

11. **Numeration** is the art of reading the numbers which have been expressed by figures or letters.

12. The **Arabic notation** is the method of expressing numbers by figures. This method employs ten different **figures** to represent numbers, viz.:

Figures	0	1	2	3	4	5	6	7	8	9
Names	*naught, cipher, or zero.*	*one*	*two*	*three*	*four*	*five*	*six*	*seven*	*eight*	*nine*

The first character (0) is called **naught, cipher,** or **zero,** and, when standing alone, has no value.

The other nine figures are called **digits,** and each one has a value of its own.

Any whole number is called an **integer.**

13. As there are only ten *figures* used in expressing numbers, each *figure* must express a different *value* at different times.

14. The value of a figure depends upon its *position* in relation to others.

15. Figures have **simple** values and **local** or **relative** values.

16. The **simple** value of a figure is the value it expresses when standing alone.

17. The **local** or **relative** value is the *increased* value it expresses by having other figures placed on its right.

For instance, if we see the figure 6 standing alone, thus. 6

we consider it as *six units,* or simply **six.**

Place another 6 to the *left* of it; thus. 66

The original figure is still *six units,* but the second one is *ten times* 6, or 6 **tens.**

If a third 6 be now placed still one place further to the *left,* it is increased in value *ten times* more, thus making it 6 **hundreds** 666

A fourth 6 would be 6 **thousands** 6666

A fifth 6 would be 6 **tens of thousands,** or **sixty thousand** 66666

A sixth 6 would be 6 **hundreds of thousands** . 666666

A seventh 6 would be 6 **millions** 6666666

The entire line of seven figures is read *six millions, six hundred sixty-six thousands, six hundred sixty-six.*

18. The **increased value** of each of these figures is its *local* or *relative* value. Each figure is *ten times* greater in value than the one immediately on its *right*.

19. The **cipher** (0) has no value itself, but it is useful in determining the place of other figures. To represent the number *four hundred five*, two digits only are necessary, one to represent *four hundred*, and the other to represent *five units;* but if these two digits are placed together, as 45, the 4 (being in the second place) will mean 4 *tens*. To mean 4 *hundreds*, the 4 should have two figures on its right, and a *cipher* is therefore inserted in the place usually given to *tens*, to show that the number is composed of *hundreds* and *units* only, and that there are no *tens*. *Four hundred five* is therefore expressed as 405. If the number were *four thousand and five*, two ciphers would be inserted; thus, 4005. If it were *four hundred fifty*, it would have the *cipher* at the right-hand side to show that there were no *units*, and only *hundreds and tens;* thus, 450. *Four thousand and fifty* would be expressed 4050, the first cipher indicating that there are no hundreds and the second that there are no units.

NOTE.—When speaking of the figures of a number by referring to them as first figure, second figure, etc., always begin to count at the *left*. Thus, in the number 41,625, 4 is the first figure, 6 the third figure, 5 the fifth or last figure, etc.

20. In *reading* figures, it is usual to point off the number into groups of three figures each, beginning with the right-hand or **units** column, a comma (,) being used to point off these groups.

Billions.			*Millions.*			*Thousands.*			*Units.*		
Hundreds of Billions.	Tens of Billions.	Billions.	Hundreds of Millions.	Tens of Millions.	Millions.	Hundreds of Thousands.	Tens of Thousands.	Thousands.	Hundreds of Units.	Tens of Units.	Units.
4	3	2,	1	9	8,	7	6	5,	4	3	2

In *pointing off* these figures, begin at the right-hand figure and count—*units*, *tens*, *hundreds;* the next group of three figures is *thousands*, therefore, we insert a comma (,) before beginning with them. Beginning at the figure 5, we say *thousands*, *tens of thousands*, *hundreds of thousands*, and insert another comma; we next read *millions*, *tens of millions*, *hundreds of millions*, and insert another comma; we then read *billions*, *tens of billions*, *hundreds of billions.*

The entire line of figures would be read: *Four hundred thirty-two billions*, *one hundred ninety-eight millions*, *seven hundred sixty-five thousands*, *four hundred thirty-two.* When we thus *read* a line of figures it is called **numeration,** and if the **numeration** be changed back to *figures*, it is called **notation.**

For instance, the writing of the figures,

72,584,623,

would be the **notation,** and the **numeration** would be *seventy-two millions*, *five hundred eighty-four thousands*, *six hundred twenty-three.*

21. NOTE.—It is customary to leave the *s* off the words millions, thousands, etc., in cases like the above, both in speaking and writing; hence, the above would usually be expressed, seventy-two million, five hundred eighty-four thousand, six hundred twenty-three.

22. The four fundamental processes of Arithmetic are **addition, subtraction, multiplication,** and **division.** They are called fundamental processes, because all operations in Arithmetic are based upon them.

ADDITION.

23. Addition is the *process* of *finding* the *sum* of *two* or *more* numbers. The sign of addition is +. It is read *plus*, and means *more.* Thus, 5 + 6 is read 5 *plus* 6, and means that 5 and 6 are to be added.

24. The sign of equality is =. It is read *equals* or *is equal to.* Thus, 5 + 6 = 11 may be read 5 plus 6 *equals* 11.

25. *Like numbers* can be added, but *unlike numbers* cannot. Thus, 6 dollars *can* be added to 7 dollars, and the *sum* will be 13 dollars, but 6 dollars *cannot* be added to 7 *feet.*

26. The following table gives the sum of any two numbers from 1 to 12:

TABLE 1.

1 and 1 are 2	2 and 1 are 3	3 and 1 are 4	4 and 1 are 5
1 and 2 are 3	2 and 2 are 4	3 and 2 are 5	4 and 2 are 6
1 and 3 are 4	2 and 3 are 5	3 and 3 are 6	4 and 3 are 7
1 and 4 are 5	2 and 4 are 6	3 and 4 are 7	4 and 4 are 8
1 and 5 are 6	2 and 5 are 7	3 and 5 are 8	4 and 5 are 9
1 and 6 are 7	2 and 6 are 8	3 and 6 are 9	4 and 6 are 10
1 and 7 are 8	2 and 7 are 9	3 and 7 are 10	4 and 7 are 11
1 and 8 are 9	2 and 8 are 10	3 and 8 are 11	4 and 8 are 12
1 and 9 are 10	2 and 9 are 11	3 and 9 are 12	4 and 9 are 13
1 and 10 are 11	2 and 10 are 12	3 and 10 are 13	4 and 10 are 14
1 and 11 are 12	2 and 11 are 13	3 and 11 are 14	4 and 11 are 15
1 and 12 are 13	2 and 12 are 14	3 and 12 are 15	4 and 12 are 16
5 and 1 are 6	6 and 1 are 7	7 and 1 are 8	8 and 1 are 9
5 and 2 are 7	6 and 2 are 8	7 and 2 are 9	8 and 2 are 10
5 and 3 are 8	6 and 3 are 9	7 and 3 are 10	8 and 3 are 11
5 and 4 are 9	6 and 4 are 10	7 and 4 are 11	8 and 4 are 12
5 and 5 are 10	6 and 5 are 11	7 and 5 are 12	8 and 5 are 13
5 and 6 are 11	6 and 6 are 12	7 and 6 are 13	8 and 6 are 14
5 and 7 are 12	6 and 7 are 13	7 and 7 are 14	8 and 7 are 15
5 and 8 are 13	6 and 8 are 14	7 and 8 are 15	8 and 8 are 16
5 and 9 are 14	6 and 9 are 15	7 and 9 are 16	8 and 9 are 17
5 and 10 are 15	6 and 10 are 16	7 and 10 are 17	8 and 10 are 18
5 and 11 are 16	6 and 11 are 17	7 and 11 are 18	8 and 11 are 19
5 and 12 are 17	6 and 12 are 18	7 and 12 are 19	8 and 12 are 20
9 and 1 are 10	10 and 1 are 11	11 and 1 are 12	12 and 1 are 13
9 and 2 are 11	10 and 2 are 12	11 and 2 are 13	12 and 2 are 14
9 and 3 are 12	10 and 3 are 13	11 and 3 are 14	12 and 3 are 15
9 and 4 are 13	10 and 4 are 14	11 and 4 are 15	12 and 4 are 16
9 and 5 are 14	10 and 5 are 15	11 and 5 are 16	12 and 5 are 17
9 and 6 are 15	10 and 6 are 16	11 and 6 are 17	12 and 6 are 18
9 and 7 are 16	10 and 7 are 17	11 and 7 are 18	12 and 7 are 19
9 and 8 are 17	10 and 8 are 18	11 and 8 are 19	12 and 8 are 20
9 and 9 are 18	10 and 9 are 19	11 and 9 are 20	12 and 9 are 21
9 and 10 are 19	10 and 10 are 20	11 and 10 are 21	12 and 10 are 22
9 and 11 are 20	10 and 11 are 21	11 and 11 are 22	12 and 11 are 23
9 and 12 are 21	10 and 12 are 22	11 and 12 are 23	12 and 12 are 24

This table should be carefully committed to memory. Since 0 has no value, the sum of any number and 0 is the number itself; thus, 17 and 0 are 17.

27. For *addition*, place the numbers to be added directly under each other, taking care to place *units* under *units*, *tens* under *tens*, *hundreds* under *hundreds*, and so on.

When the numbers are thus written, the *right-hand figure* of *one number* is placed *directly under the right-hand figure* of the *number above it*, thus bringing the unit figures of all the numbers to be added in the same vertical line. Proceed as in the following examples:

28. EXAMPLE.—What is the sum of 131, 222, 21, 2, and 413?

SOLUTION.—

```
     131
     222
      21
       2
     413
     ---
sum  789  Ans.
```

EXPLANATION.—After placing the numbers in proper order, begin at the bottom of the right-hand or *units* column, and add, mentally repeating the different sums. Thus, three and two are five and one are six and two are eight and one are nine, the sum of the numbers in *units* column. Place the 9 directly beneath as the first or *units* figure in the sum.

The sum of the numbers in the next or *tens* column equals 8 *tens*, which is the second or *tens* figure in the sum.

The sum of the numbers in the next or *hundreds* column equals 7 *hundreds*, which is the third or *hundreds* figure in the sum.

The sum or answer is 789.

29. EXAMPLE.—What is the sum of 425, 36, 9,215, 4, and 907?

SOLUTION.—

```
      425
       36
     9215
        4
      907
    -----
       27
       60
     1500
     9000
    -----
sum 10587  Ans.
```

EXPLANATION.—The sum of the numbers in the first or units column is seven and four are eleven and five are sixteen and six are twenty-two and five are twenty-seven, or 27 units; i. e., two tens and seven units. Write 27 as shown.

The sum of the numbers in the second or tens column is six tens, or 60. Write 60 underneath 27 as shown. The sum of the numbers in the third or hundreds column is 15 hundreds, or 1,500. Write 1,500 under the two preceding results as shown. There is only one number in the fourth or thousands column, nine, which represents 9,000. Write 9,000 under the three preceding results. Adding these four results, the sum is 10,587, which is the sum of 425, 36, 9,215, 4, and 907.

NOTE.—It frequently happens, when adding a long column of figures, that the sum of two numbers, one of which does not occur in the addition table, is required. Thus, in the first column above, the sum of 16 and 6 was required. We know from the table that $6 + 6 = 12$; hence, the first figure of the sum is 2. Now, the sum of any number less than 20 and of any number less than 10 must be less than thirty, since $20 + 10 = 30$; therefore, the sum is 22. Consequently, in cases of this kind, add the first figure of the larger number to the smaller number and, if the result is greater than 9, increase the second figure of the larger number by 1. Thus, $44 + 7 = ?$ $4 + 7 = 11$; hence, $44 + 7 = 51$.

30. The addition may also be performed as follows:

```
       425
        36
      9215
         4
       907
     -----
sum  10587 Ans.
```

EXPLANATION.—The sum of the numbers in *units* column $= 27$ *units*, or 2 *tens* and 7 *units*. Write the 7 *units* as the first or right-hand figure in the sum. Reserve the two *tens* and add them to the figures in *tens* column. The sum of the figures in the *tens* column, plus the 2 *tens* reserved and carried from the *units* column $= 8$, which is written down as the second figure in the sum. There is nothing to carry to the next column, because 8 is less than 10. The sum of the numbers in the next column is 15 *hundreds*, or 1 *thousand* and 5 *hundreds*. Write down the 5 as the third or *hundreds* figure in the sum and carry the 1 to the next column. $1 + 9 = 10$, which is written down at the left of the other figures.

The second method saves space and figures, but the first is to be preferred when adding a long column.

31. EXAMPLE.—Add the numbers in the column below:

SOLUTION.—

```
      890
       82
       90
      393
      281
       80
      770
       83
      492
       80
      383
       84
      191
     ----
sum  3899 Ans.
```

EXPLANATION.—The sum of the digits in the first column equals 19 *units*, or 1 *ten* and 9 *units*. Write down the 9 and carry 1 to the next column. The sum of the digits in the second column + 1 = 109 *tens*, or 10 *hundreds* and 9 *tens*. Write down the 9 and carry the 10 to the next column. The sum of the digits in this column plus the 10 reserved = 38. The entire sum is 3,899.

32. Rule.—**I.** *Begin at the right, add each column separately, and write the sum, if it be only one figure, under the column added.*

II. *If the sum of any column consists of two or more figures, put the right-hand figure of the sum under that column, and add the remaining figure or figures to the next column.*

33. Proof.—*To prove addition, add each column from top to bottom. If you obtain the same result as by adding from bottom to top, the work is probably correct.*

EXAMPLES FOR PRACTICE.

34. Find the sum of

(*a*) 104 + 203 + 613 + 214.	Ans.	(*a*) 1,134.
(*b*) 1,875 + 3,143 + 5,826 + 10,832.		(*b*) 21,676.
(*c*) 4,865 + 2,145 + 8,173 + 40,084.		(*c*) 55,267.
(*d*) 14,204 + 8,173 + 1,065 + 10,042.		(*d*) 33,484.

(*e*) 10,832 + 4,145 + 3,133 + 5,872.		Ans.	(*e*) 23,982.
(*f*) 214 + 1,231 + 141 + 5,000.			(*f*) 6,586.
(*g*) 123 + 104 + 425 + 126 + 327.			(*g*) 1,105.
(*h*) 6,354 + 2,145 + 2,042 + 1,111 + 3,333.			(*h*) 14,985.

SUBTRACTION.

35. In Arithmetic, **subtraction** is the process of finding how much greater one number is than another.

The greater of the two numbers is called the **minuend.**

The smaller of the two numbers is called the **subtrahend.**

The number left after subtracting the *subtrahend* from the *minuend* is called the **difference,** or **remainder.**

36. The sign of subtraction is $-$. It is read **minus,** and means *less.* Thus, 12 − 7 is read 12 *minus* 7, and means that 7 is to be taken from 12.

37. Example.—From 7,568 take 3,425.

Solution.—

minuend	7 5 6 8
subtrahend	3 4 2 5
remainder	4 1 4 3 Ans.

Explanation.—Begin at the right-hand or *units* column and subtract in succession each figure in the subtrahend from the one directly above it in the minuend, and write the remainders below the line. The result is the entire remainder.

38. When there are more figures in the *minuend* than in the *subtrahend*, and when some figures in the *minuend* are *less* than the figures directly under them in the *subtrahend*, proceed as in the following example:

Example.—From 8,453 take 844.

Solution.—

minuend	8 4 5 3
subtrahend	8 4 4
remainder	7 6 0 9 Ans.

Explanation.—Begin to subtract at the right-hand or *units* column. We cannot take 4 from 3, and must, therefore, borrow 1 from 5 in *tens* column and annex it to the 3 in *units* column. The 1 *ten* = 10 *units*, which added to the 3 in *units* column = 13 *units*. 4 from 13 = 9, the first or *units* figure in the remainder.

Since we borrowed 1 from the 5, only 4 remains; 4 from 4 = 0, the second or *tens* figure. We cannot take 8 from 4, and must, therefore, borrow 1 from 8 in *thousands* column. Since 1 *thousand* = 10 *hundreds*, 10 *hundreds* + 4 *hundreds* = 14 *hundreds*, and 8 from 14 = 6, the third or *hundreds* figure in the remainder.

Since we borrowed 1 from 8, only 7 remains, from which there is nothing to subtract; therefore, 7 is the next figure in the remainder or answer.

The operation of borrowing is placing 1 before the figure following the one from which it is borrowed. In the above example the 1 borrowed from 5 is placed before 3, making it 13, from which we subtract 4. The 1 borrowed from 8 is placed before 4, making 14, from which 8 is taken.

39. EXAMPLE.—Find the difference between 10,000 and 8,763.

SOLUTION.—

minuend	10000
subtrahend	8763
remainder	1237 Ans.

EXPLANATION.—In the above example we borrow 1 from the second column and place it before 0, making 10; 3 from 10 = 7. In the same way we borrow 1 and place it before the next cipher, making 10; but as we have borrowed 1 from this column and taken it to the *units* column, only 9 remains, from which to subtract 6; 6 from 9 = 3. For the same reason we subtract 7 from 9 and 8 from 9 for the next two figures, and obtain a total remainder of 1,237.

40. Rule.—*Place the subtrahend or smaller number under the minuend or larger number, in the same manner as for addition, and proceed as in Arts.* ***37, 38,*** *and* ***39.***

41. Proof.—*To prove an example in subtraction, add the remainder to the subtrahend. The sum should equal the minuend. If it does not, a mistake has been made, and the work should be done over.*

Proof of the above example:

subtrahend	8763
remainder	1237
minuend	10000

EXAMPLES FOR PRACTICE.

42. From

	Ans.
(*a*) 94,278 take 62,574.	(*a*) 31,704.
(*b*) 53,714 take 25,824.	(*b*) 27,890.
(*c*) 71,832 take 58,109.	(*c*) 13,723.
(*d*) 20,804 take 10,408.	(*d*) 10,396.
(*e*) 310,465 take 102,141.	(*e*) 208,324.
(*f*) (81,043 + 1,041) take 14,831.	(*f*) 67,253.
(*g*) (20,482 + 18,216) take 21,214.	(*g*) 17,484.
(*h*) (2,040 + 1,213 + 542) take 3,791.	(*h*) 4.

MULTIPLICATION.

43. To **multiply** a number is to *add* it to itself a certain number of times.

44. **Multiplication** is the process of multiplying one number by another.

The *number* thus added to itself, or the number to be multiplied, is called the **multiplicand.**

The *number* which shows how many times the *multiplicand* is to be taken, or the *number* by which we *multiply*, is called the **multiplier.**

The result obtained by multiplying is called the **product.**

45. The sign of multiplication is $\times$. It is read *times* or *multiplied by*. Thus, 9×6 is read 9 *times* 6, or 9 *multiplied by* 6.

46. It matters not in what order the numbers to be multiplied together are placed. Thus, 6×9 is the same as 9×6.

47. In the following table, the product of any two numbers (neither of which exceeds twelve) may be found:

TABLE 2.

1 times 1 is 1	2 times 1 are 2	3 times 1 are 3
1 times 2 are 2	2 times 2 are 4	3 times 2 are 6
1 times 3 are 3	2 times 3 are 6	3 times 3 are 9
1 times 4 are 4	2 times 4 are 8	3 times 4 are 12
1 times 5 are 5	2 times 5 are 10	3 times 5 are 15
1 times 6 are 6	2 times 6 are 12	3 times 6 are 18
1 times 7 are 7	2 times 7 are 14	3 times 7 are 21
1 times 8 are 8	2 times 8 are 16	3 times 8 are 24
1 times 9 are 9	2 times 9 are 18	3 times 9 are 27
1 times 10 are 10	2 times 10 are 20	3 times 10 are 30
1 times 11 are 11	2 times 11 are 22	3 times 11 are 33
1 times 12 are 12	2 times 12 are 24	3 times 12 are 36
4 times 1 are 4	5 times 1 are 5	6 times 1 are 6
4 times 2 are 8	5 times 2 are 10	6 times 2 are 12
4 times 3 are 12	5 times 3 are 15	6 times 3 are 18
4 times 4 are 16	5 times 4 are 20	6 times 4 are 24
4 times 5 are 20	5 times 5 are 25	6 times 5 are 30
4 times 6 are 24	5 times 6 are 30	6 times 6 are 36
4 times 7 are 28	5 times 7 are 35	6 times 7 are 42
4 times 8 are 32	5 times 8 are 40	6 times 8 are 48
4 times 9 are 36	5 times 9 are 45	6 times 9 are 54
4 times 10 are 40	5 times 10 are 50	6 times 10 are 60
4 times 11 are 44	5 times 11 are 55	6 times 11 are 66
4 times 12 are 48	5 times 12 are 60	6 times 12 are 72
7 times 1 are 7	8 times 1 are 8	9 times 1 are 9
7 times 2 are 14	8 times 2 are 16	9 times 2 are 18
7 times 3 are 21	8 times 3 are 24	9 times 3 are 27
7 times 4 are 28	8 times 4 are 32	9 times 4 are 36
7 times 5 are 35	8 times 5 are 40	9 times 5 are 45
7 times 6 are 42	8 times 6 are 48	9 times 6 are 54
7 times 7 are 49	8 times 7 are 56	9 times 7 are 63
7 times 8 are 56	8 times 8 are 64	9 times 8 are 72
7 times 9 are 63	8 times 9 are 72	9 times 9 are 81
7 times 10 are 70	8 times 10 are 80	9 times 10 are 90
7 times 11 are 77	8 times 11 are 88	9 times 11 are 99
7 times 12 are 84	8 times 12 are 96	9 times 12 are 108
10 times 1 are 10	11 times 1 are 11	12 times 1 are 12
10 times 2 are 20	11 times 2 are 22	12 times 2 are 24
10 times 3 are 30	11 times 3 are 33	12 times 3 are 36
10 times 4 are 40	11 times 4 are 44	12 times 4 are 48
10 times 5 are 50	11 times 5 are 55	12 times 5 are 60
10 times 6 are 60	11 times 6 are 66	12 times 6 are 72
10 times 7 are 70	11 times 7 are 77	12 times 7 are 84
10 times 8 are 80	11 times 8 are 88	12 times 8 are 96
10 times 9 are 90	11 times 9 are 99	12 times 9 are 108
10 times 10 are 100	11 times 10 are 110	12 times 10 are 120
10 times 11 are 110	11 times 11 are 121	12 times 11 are 132
10 times 12 are 120	11 times 12 are 132	12 times 12 are 144

This table should be carefully committed to memory.

Since 0 has no value, the product of 0 and any number is 0.

48. To multiply a number by one figure only:

EXAMPLE.—Multiply 425 by 5.

SOLUTION.—	*multiplicand*	425	
	multiplier	5	
	product	2125	Ans.

EXPLANATION.—For convenience, the *multiplier* is generally written *under* the *right-hand figure* of the *multiplicand.* On looking in the multiplication table, we see that 5 × 5 are 25. *Multiplying* the *first figure* at the *right* of the *multiplicand*, or 5, by the *multiplier* 5, it is seen that 5 times 5 units are 25 units, or 2 tens and 5 units. Write the *5 units* in *units place* in the *product*, and *reserve* the 2 tens to *add* to the *product* of *tens.* Looking in the multiplication table again, we see that 5 × 2 are 10. *Multiplying* the *second figure* of the *multiplicand* by the *multiplier* 5, we see *that* 5 *times* 2 tens are 10 tens, *plus* the 2 tens *reserved*, are 12 tens, or 1 hundred plus 2 tens. Write the *2 tens* in tens place, and *reserve* the 1 hundred to *add* to the product of *hundreds.* Again, we see by the multiplication table that 5 × 4 are 20. *Multiplying* the *third* or *last figure* of the *multiplicand* by the *multiplier* 5, we see that 5 times 4 hundreds are 20 hundreds, *plus* the 1 hundred *reserved*, are 21 hundreds, or 2 thousands *plus* 1 hundred, which we write in *thousands* and *hundreds places*, respectively.

Hence, the *product* is 2,125.

This *result* is the same as adding 425 five times. Thus,

	425	
	425	
	425	
	425	
	425	
sum	2125	Ans.

EXAMPLES FOR PRACTICE.

49. Find the product of

(*a*)	61,483 × 6.	Ans.	(*a*)	368,898.
(*b*)	12,375 × 5.		(*b*)	61,875.
(*c*)	10,426 × 7.		(*c*)	72,982.
(*d*)	10,835 × 3.		(*d*)	32,505.

(*e*) 98,376 × 4.		(*e*) 393,504.
(*f*) 10,873 × 8.	Ans.	(*f*) 86,984.
(*g*) 71,543 × 9.		(*g*) 643,887.
(*h*) 218,734 × 2.		(*h*) 437,468.

50. To multiply a number by two or more figures:

EXAMPLE.—Multiply 475 by 234.

```
SOLUTION.—   multiplicand     475
             multiplier       234
                             ----
                             1900
                            1425
                            950
                           ------
             product       111150  Ans.
```

EXPLANATION.—For convenience, the *multiplier* is generally written *under* the *multiplicand*, placing units under units, tens under tens, etc.

We *cannot* multiply by 234 at one operation; we must, therefore, *multiply* by the *parts* and then *add* the **partial products.**

The parts by which we are to multiply are 4 units, 3 tens, and 2 hundreds. 4 times 475 = 1,900, the *first partial product;* 3 times 475 = 1,425, the *second partial product*, the *right-hand figure* of which is *written directly under* the *figure multiplied by*, or 3; 2 times 475 = 950, the *third partial product*, the *right-hand figure* of which is *written directly under* the *figure multiplied by*, or 2.

The sum of these *three partial products* is 111,150, which is the *entire product.*

51. Rule.—I. *Write the multiplier under the multiplicand, so that units are under units, tens under tens, etc.*

II. *Begin at the right and multiply each figure of the multiplicand by each successive figure of the multiplier, placing the right-hand figure of each partial product directly under the figure used as a multiplier.*

III. *The sum of the partial products will equal the required product.*

52. Proof.—*Review the work carefully, or multiply the multiplier by the multiplicand; if the results agree, the work is correct.*

53. When there is a *cipher* in the *multiplier*, multiply the entire multiplicand by it; since the result will be zero, place a cipher under the cipher in the multiplier. Thus,

(*a*)	(*b*)	(*c*)	(*d*)
0	2	15	708
× 0	× 0	× 0	× 0
0 Ans.	0 Ans.	0 Ans.	0 Ans.

(*e*)	(*f*)	(*g*)
3114	4008	31264
203	305	1002
9342	20040	62528
62280	120240	3126400
632142 Ans.	1222440 Ans.	31326528 Ans.

In examples (*e*), (*f*), and (*g*), we multiply by 0 as directed above; then multiply by the next figure of the multiplier and place the first figure of the product alongside the 0, as shown.

EXAMPLES FOR PRACTICE.

54. Find the product of

			Ans.
(*a*)	3,842 × 26.	(*a*)	99,892.
(*b*)	3,716 × 45.	(*b*)	167,220.
(*c*)	1,817 × 124.	(*c*)	225,308.
(*d*)	675 × 38.	(*d*)	25,650.
(*e*)	1,875 × 33.	(*e*)	61,875.
(*f*)	4,836 × 47.	(*f*)	227,292.
(*g*)	5,682 × 543.	(*g*)	3,085,326.
(*h*)	3,257 × 246.	(*h*)	801,222.
(*i*)	2,875 × 302.	(*i*)	868,250.
(*j*)	17,819 × 1,004.	(*j*)	17,890,276.
(*k*)	38,674 × 205.	(*k*)	7,928,170.
(*l*)	18,304 × 100.	(*l*)	1,830,400.
(*m*)	7,834 × 10.	(*m*)	78,340.
(*n*)	87,543 × 1,000.	(*n*)	87,543,000.
(*o*)	48,763 × 100.	(*o*)	4,876,300.

DIVISION.

55. Division is the process of finding how many times one number is contained in another of the same kind.

The number to be *divided* is called the **dividend.**

The number by which we *divide* is called the **divisor.**

The number which *shows* how many times the *divisor* is *contained* in the *dividend* is called the **quotient.**

56. The sign of division is $\div$. It is read *divided by*. $54 \div 9$ is read 54 *divided by* 9. Another way to write 54 *divided by* 9 is $\frac{54}{9}$. Thus, $54 \div 9 = 6$, or $\frac{54}{9} = 6$.

In both of these cases 54 is the *dividend* and 9 is the *divisor.*

Division is the *reverse* of **multiplication.**

57. To divide when the divisor consists of but one figure, proceed as in the following example:

EXAMPLE.—What is the quotient of 875 ÷ 7?

SOLUTION.—

```
          divisor dividend quotient
                7)875(125  Ans.
                  7
                  --
                  17
                  14
                  --
                   35
                   35
                   --
        remainder   0
```

EXPLANATION.—7 is contained in 8 *hundreds* 1 *hundred* times. Place the one as the first or left-hand figure of the quotient. Multiply the divisor 7 by the 1 *hundred* of the quotient, and place the product 7 *hundreds* under the 8 *hundreds* in the dividend, and subtract. Beside the remainder 1, bring down the next or *tens* figure of the quotient, in this case 7, making 17 *tens*; 7 is contained in 17, 2 times. Write the 2 as the second figure of the quotient. Multiply the divisor 7 by the 2 in the quotient, and subtract the product from 17. Beside the remainder 3, bring down the next or *units* figure of the dividend, in this case 5, making

35 *units*. 7 is contained in 35, 5 times, which is placed in the quotient. Multiplying the divisor by the last figure of the quotient, 5 times 7 = 35, which subtracted from 35, under which it is placed, leaves 0. Therefore, the quotient is 125. This method is called **long division.**

58. In **short division,** only the divisor, dividend, and quotient are written, the operations being performed mentally.

$$\begin{array}{rl} & \textit{dividend} \\ \textit{divisor} & 7\ )\ 8^{1}7^{3}5 \\ \hline \textit{quotient} & \ \ \ 1\ \ 2\ \ 5 \quad \text{Ans.} \end{array}$$

The mental operation is as follows: 7 is contained in 8, once and one remainder; 1 placed before 7 makes 17; 7 is contained in 17, 2 times and 3 over; the 3 placed before 5 makes 35; 7 is contained in 35, 5 times. These partial quotients placed in order as they are found, make the entire quotient 125.

The small figures are placed in the example given to better illustrate the explanation; they are never written when actually performing division in this way.

59. If the *divisor* consists of *2 or more* figures, proceed as in the following example:

EXAMPLE.—Divide 2,702,826 by 63.

```
            divisor  dividend   quotient
SOLUTION.—     63 ) 2702826 ( 42902  Ans.
                    252
                    ---
                     182
                     126
                     ---
                      568
                      567
                      ---
                        126
                        126
                        ---
                          0
```

EXPLANATION.—As 63 is not contained in the first two figures, 27, we must use the first three figures, 270. Now, by trial, we must find how many times 63 is contained in 270;

6 is contained in the first two figures of 270, 4 times. Place the 4 as the first or left-hand figure in the quotient. Multiply the divisor 63 by 4, and subtract the product 252 from 270. The remainder is 18, beside which we write the next figure of the dividend, 2, making 182. Now, 6 is contained in the first two figures of 182, 3 times, but on multiplying 63 by 3, we see that the product 189 is too great, so we try 2 as the second figure of the quotient. Multiplying the divisor 63 by 2, and subtracting the product 126 from 182, the remainder is 56, beside which we bring down the next figure of the dividend, making 568; 6 is contained in 56 about 9 times. Multiply the divisor 63 by 9 and subtract the product 567 from 568. The remainder is 1, and bringing down the next figure of the dividend, 2, gives 12. As 12 is smaller than 63, we write 0 in the quotient and bring down the next figure, 6, making 126. 63 is contained in 126, 2 times, without a remainder. Therefore, 42,902 is the quotient.

60. Rule.—I. *Write the divisor at the left of the dividend, with a line between them.*

II. *Find how many times the divisor is contained in the lowest number of the left-hand figures of the dividend that will contain it, and write the result at the right of the dividend, with a line between, for the first figure of the quotient.*

III. *Multiply the divisor by this quotient; write the product under the partial dividend used, and subtract, annexing to the remainder the next figure of the dividend. Divide as before, and thus continue until all the figures of the dividend have been used.*

IV. *If any partial dividend will not contain the divisor, write a cipher in the quotient, annex the next figure of the dividend and proceed as before.*

V. *If there be a remainder at last, write it after the quotient, with the divisor underneath.*

61. Proof.—*Multiply the quotient by the divisor, and add the remainder, if there be any, to the product. The result will be the dividend.*

		divisor dividend quotient
Thus,		63) 4235 ($67\frac{14}{63}$ Ans.
		378
		455
		441
	remainder	14
Proof,	*quotient*	67
	divisor	63
		201
		402
		4221
	remainder	14
	dividend	4235

EXAMPLES FOR PRACTICE.

62. Divide the following:

(*a*) 126,498 by 58.	Ans.	(*a*) 2,181.
(*b*) 3,207,594 by 767.		(*b*) 4,182.
(*c*) 11,408,202 by 234.		(*c*) 48,753.
(*d*) 2,100,315 by 581.		(*d*) 3,615.
(*e*) 969,936 by 4,008.		(*e*) 242.
(*f*) 7,481,888 by 1,021.		(*f*) 7,328.
(*g*) 1,525,915 by 5,003.		(*g*) 305.
(*h*) 1,646,301 by 381.		(*h*) 4,321.

CANCELATION.

63. Cancelation is the process of shortening operations in division by casting out equal factors from both dividend and divisor.

64. The **factors** of a number are *those numbers* which, when *multiplied* together, will *equal that number*. Thus, 5 and 3 are factors of 15, since $5 \times 3 = 15$. Likewise, 8 and 7 are the factors of 56, since $8 \times 7 = 56$.

65. A **prime number** is one which cannot be divided by any number except itself and 1. Thus, 2, 3, 11, 29, etc. are prime numbers.

66. A **prime factor** is any factor that is a prime number.

Any number that is not a prime is called a **composite** number, and may be produced by multiplying together its prime factors. Thus, 60 is a composite number, and is equal to the product of its prime factors, $2 \times 2 \times 3 \times 5$.

Numbers are said to be **prime to each other** when no two of them can be divided by any number except 1; the numbers themselves *may* be either prime or composite. Thus, the numbers 3, 5, and 11 are prime to each other, so also are 22, 25, and 21—all composite numbers.

67. Canceling *equal factors* from *both dividend and divisor* does *not* change the *quotient*.

The *canceling* of a *factor* in *both dividend and divisor* is the *same* as *dividing them both* by the *same number*, which, by the principle of division, does not *change the quotient*.

Write the *numbers* which make the *dividend* above the *line*, and those which make the *divisor* below it.

68. EXAMPLE.—Divide $4 \times 45 \times 60$ by 9×24.

SOLUTION.—Placing the dividend over the divisor, and canceling

$$\frac{\not{4} \times \overset{5}{\not{45}} \times \overset{10}{\not{60}}}{\not{9} \times \underset{\underset{1}{\not{6}}}{\not{24}}} = \frac{50}{1} = 50. \quad \text{Ans.}$$

EXPLANATION.—The 4 in the dividend and 24 in the divisor are both divisible by 4, since 4 divided by 4 equals 1, and 24 divided by 4 equals 6. Cross off the four and write the 1 over it; also, cross off the 24 and write the 6 under it. Thus,

$$\frac{\overset{1}{\not{4}} \times 45 \times 60}{9 \times \underset{6}{\not{24}}}.$$

60 in the dividend and 6 in the divisor are divisible by 6, since 60 divided by 6 equals 10, and 6 divided by 6 equals 1. Cross off the 60 and write 10 over it; also, cross off the 6 and write 1 under it. Thus,

$$\frac{\overset{1}{\not{4}} \times 45 \times \overset{10}{\not{60}}}{9 \times \underset{\underset{1}{\not{6}}}{\not{24}}}.$$

Again, 45 in the dividend and 9 in the divisor are divisible by 9, since 45 divided by 9 equals 5, and 9 divided by 9 equals 1. Cross off the 45 and write the 5 over it; also, cross off the 9 and write the 1 under it. Thus,

$$\frac{\overset{1}{\cancel{4}} \times \overset{5}{\cancel{45}} \times \overset{10}{\cancel{60}}}{\underset{1}{\cancel{9}} \times \underset{\underset{1}{\cancel{6}}}{\cancel{24}}}.$$

Since there are no two remaining numbers (one in the dividend and one in the divisor) divisible by any number except 1, without a remainder, it is impossible to cancel further.

Multiply all the uncanceled numbers in the dividend together, and divide their product by the product of all the uncanceled numbers in the divisor. The result will be the quotient. The product of all the uncanceled numbers in the dividend equals $5 \times 1 \times 10 = 50$; the product of all the uncanceled numbers in the divisor equals $1 \times 1 = 1$.

$$\text{Hence, } \frac{\overset{1}{\cancel{4}} \times \overset{5}{\cancel{45}} \times \overset{10}{\cancel{60}}}{\underset{1}{\cancel{9}} \times \underset{\underset{1}{\cancel{6}}}{\cancel{24}}} = \frac{1 \times 5 \times 10}{1 \times 1} = 50. \quad \text{Ans.}$$

It is usual to omit the 1's when canceling them, instead of writing them as above.

69. Rule.—I. *Cancel the common factors from both the dividend and divisor.*

II. *Then divide the product of the remaining factors of the dividend by the product of the remaining factors of the divisor, and the result will be the quotient.*

EXAMPLES FOR PRACTICE.

70. Divide

	Ans.
(*a*) $14 \times 18 \times 16 \times 40$ by $7 \times 8 \times 6 \times 5 \times 3$.	(*a*) 32.
(*b*) $3 \times 65 \times 50 \times 100 \times 60$ by $30 \times 60 \times 13 \times 10$.	(*b*) 250.
(*c*) $8 \times 4 \times 3 \times 9 \times 11$ by $11 \times 9 \times 4 \times 3 \times 8$.	(*c*) 1.
(*d*) $164 \times 321 \times 6 \times 7 \times 4$ by $82 \times 321 \times 7$.	(*d*) 48.
(*e*) $50 \times 100 \times 200 \times 72$ by $1{,}000 \times 144 \times 100$.	(*e*) 5.
(*f*) $48 \times 63 \times 55 \times 49$ by $7 \times 21 \times 11 \times 48$.	(*f*) 105.
(*g*) $110 \times 150 \times 84 \times 32$ by $11 \times 15 \times 100 \times 64$.	(*g*) 42.
(*h*) $115 \times 120 \times 400 \times 1{,}000$ by $23 \times 1{,}000 \times 60 \times 800$.	(*h*) 5.

ARITHMETIC.

(PART 2.)

FRACTIONS.

REMARK.—If a stick of wood is divided into, say, 12 equal parts, one of these parts is called a twelfth. If we take away 5 of these equal parts, we shall have left 7 parts or 7-twelfths. Since it would be very inconvenient to spell out the names of the number of parts into which an object has been (or is supposed to have been) divided, mathematicians invented, long ago, a kind of a shorthand method of expressing 7-twelfths, 25-forty-fifths, etc., viz.: they wrote the number of the equal parts taken or considered above a horizontal line, and called this number the *numerator;* then they wrote below the horizontal line the number which denoted the number of equal parts into which the object was supposed to be divided, and called it the *denominator.* Hence, instead of writing 7-twelfths, 25-forty-fifths, etc., they wrote $\frac{7}{12}$, $\frac{25}{45}$, etc.; but they read these expressions in the same manner as though they had been written the other way.

The subject of fractions is very important; it is not difficult, and the rules and processes are simple and easily remembered. Particular attention should be given to the subject of "Reduction of Fractions," the principles of which are used more frequently than any others relating to fractions. In many cases more accurate results can be obtained with fractions than by using decimals; this is particularly true of calculations relating to bookkeeping and accounting.

71. A **fraction** is a *part* of a *whole number: One-half, one-third, two-fifths* are fractions.

72. *Two* numbers are required to express a fraction, one called the **numerator,** and the other the **denominator.**

73. The *numerator* is placed above the *denominator*, with a *line* between them; as, $\frac{2}{3}$. 3 is the *denominator*, and shows into how many *equal parts* the *unit* or *one* is divided. The *numerator* 2 shows how many of these *equal parts* are taken or considered. The *denominator* also indicates the *names* of the parts.

$\frac{1}{2}$ is read one-half.
$\frac{3}{4}$ is read three-fourths.
$\frac{3}{8}$ is read three-eighths.
$\frac{5}{16}$ is read five-sixteenths.
$\frac{29}{47}$ is read twenty-nine-forty-sevenths.

74. In the expression "$\frac{3}{4}$ of an apple," the *denominator* 4 shows that the apple is to be (or has been) cut into 4 *equal parts*, and the *numerator* 3 shows that *three of these parts*, or *fourths*, are taken or considered.

If each of the *parts*, or *fourths*, of the apple were cut in *two equal pieces*, there would then be twice as many pieces as before, or $4 \times 2 = 8$ pieces in all; one of these pieces would be called one-eighth, and would be expressed in figures as $\frac{1}{8}$. Three of these pieces would be called three-eighths, and written $\frac{3}{8}$. The words three-fourths, three-eighths, five-sixteenths, etc., are abbreviations of three one-fourths, three one-eighths, five one-sixteenths, etc. It is evident that the larger the *denominator*, the greater is the number of parts into which anything is divided; consequently, the parts themselves are smaller, and the value of the fraction is less for the same number of parts taken. In other words, $\frac{7}{9}$, for example, is smaller than $\frac{7}{8}$, because if an object be divided into 9 parts, the parts are smaller than if the same object had been divided into 8 parts; and, since $\frac{1}{9}$ is smaller than $\frac{1}{8}$, it is clear that 7 one-ninths is a smaller amount than 7 one-eighths. Hence, also, $\frac{3}{8}$ is less than $\frac{3}{4}$.

75. The **value** of a fraction is the *numerator* divided by the *denominator;* as, $\frac{4}{2} = 2$, $\frac{6}{2} = 3$.

76. The line between the *numerator* and *denominator* means *divided by*, or $\div$.

$\frac{3}{4}$ is equivalent to $3 \div 4$.

$\frac{5}{8}$ is equivalent to $5 \div 8$.

77. The *numerator* and *denominator* of a fraction, when considered together, are called the **terms** of a fraction.

78. The *value* of a fraction whose *numerator* and *denominator* are equal is 1.

$\frac{4}{4}$, or four-fourths, $= 1$.

$\frac{8}{8}$, or eight-eighths, $= 1$.

$\frac{64}{64}$, or sixty-four-sixty-fourths, $= 1$.

79. A **proper fraction** is a fraction whose *numerator* is *less* than its *denominator.* Its *value* is *less* than 1; as, $\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{16}$.

80. An **improper fraction** is a fraction whose *numerator equals* or is *greater than* the *denominator.* Its *value* is *one* or *more* than *one;* as, $\frac{4}{4}$, $\frac{9}{8}$, $\frac{42}{32}$.

81. A **mixed number** is a *whole* number and a *fraction* united. $4\frac{2}{3}$ is a mixed number, and is equivalent to $4 + \frac{2}{3}$. It is read *four and two-thirds.*

REDUCTION OF FRACTIONS.

82. **Reduction of fractions** is the process of changing their form without changing their *value.*

83. A *fraction* is reduced to *higher terms* by *multiplying both terms* of the *fraction* by the *same number.* Thus, $\frac{3}{4}$ is reduced to $\frac{6}{8}$ by multiplying both terms by 2.

$$\frac{3 \times 2}{4 \times 2} = \frac{6}{8}.$$

The *value* is not changed, since $\frac{3}{4} = \frac{6}{8}$. For, suppose that an object, say an apple, is divided into 8 equal parts. If these parts be arranged into 4 piles, each containing 2 parts, it is evident that each pile will be composed of the same amount of the entire apple as would have been the case had the apple been originally cut into 4 equal parts. Now, if one of these piles (containing 2 parts) be removed, there will be 3 piles left, each containing 2 equal parts, or 6 equal parts in all, i. e., six-eighths. But, since one pile, or one quarter, was removed, there are three-quarters left. Hence, $\frac{3}{4} = \frac{6}{8}$. The same course of reasoning may be applied to any similar case. Therefore, multiplying both terms of a fraction by the same number does not alter its value.

84. To reduce a fraction to an equal fraction having a given denominator:

EXAMPLE.—Reduce $\frac{7}{8}$ to an equal fraction having 96 for a denominator.

SOLUTION.—Both the numerator and the denominator must be multiplied by the same number in order not to change the value of the fraction. The denominator must be multiplied by some number which will, in this case, make the product 96; this number is evidently $96 \div 8 = 12$, since $8 \times 12 = 96$. Hence, $\frac{7 \times 12}{8 \times 12} = \frac{84}{96}$. Ans.

85. Rule.—*Divide the given denominator by the denominator of the given fraction, and multiply both terms of the fraction by the result.*

EXAMPLE.—Reduce $\frac{3}{4}$ to 100ths.

SOLUTION.— $100 \div 4 = 25$; hence, $\frac{3 \times 25}{4 \times 25} = \frac{75}{100}$. Ans.

86. A *fraction* is reduced to *lower terms* by *dividing both terms* by the *same number*. Thus, $\frac{8}{10}$ is reduced to $\frac{4}{5}$ by dividing both terms by 2.

$$\frac{8 \div 2}{10 \div 2} = \frac{4}{5}.$$

That $\frac{8}{10} = \frac{4}{5}$ is readily seen from the explanation given in Art. **83**; for, multiplying both terms of the fraction $\frac{4}{5}$ by 2, $\frac{4 \times 2}{5 \times 2} = \frac{8}{10}$, and, if $\frac{4}{5} = \frac{8}{10}$, $\frac{8}{10}$ must equal $\frac{4}{5}$. Hence, dividing both terms of a fraction by the same number does not alter its value.

87. A *fraction* is reduced to *lowest terms* when its *numerator and denominator* cannot both be *divided* by the *same* *number* without a remainder; as, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{11}{24}$, $\frac{8}{15}$. In other words, the numerator and denominator are prime to each other.

EXAMPLES FOR PRACTICE.

88. Reduce the following:

(*a*) $\frac{7}{16}$ to 128ths.		(*a*) $\frac{56}{128}$.
(*b*) $\frac{24}{132}$ to its lowest terms.		(*b*) $\frac{2}{11}$.
(*c*) $\frac{64}{1000}$ to its lowest terms.	Ans.	(*c*) $\frac{8}{125}$.
(*d*) $\frac{5}{7}$ to 49ths.		(*d*) $\frac{35}{49}$.
(*e*) $\frac{13}{16}$ to 10,000ths.		(*e*) $\frac{8125}{10000}$.

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89. To reduce a whole number or mixed number to an improper fraction:

EXAMPLE.—How many *fourths* in 5?

SOLUTION.—Since there are 4 *fourths* in 1 ($\frac{4}{4} = 1$), in 5 there will be 5×4 fourths, or 20 fourths; i. e., $5 \times \frac{4}{4} = \frac{20}{4}$. Ans.

EXAMPLE.—Reduce $8\frac{3}{4}$ to an improper fraction.

SOLUTION.—$8 \times \frac{4}{4} = \frac{32}{4}$. $\frac{32}{4} + \frac{3}{4} = \frac{35}{4}$. Ans.

90. Rule.—*Multiply the whole number by the denominator of the fraction, add the numerator to the product, and place the denominator under the result. If it is desired to reduce a whole number to a fraction, multiply the whole number by the denominator of the given fraction, and write the result over the denominator.*

EXAMPLES FOR PRACTICE.

91. Reduce to improper fractions:

(*a*) $4\frac{1}{8}$.		(*a*) $\frac{33}{8}$.
(*b*) $5\frac{1}{9}$.		(*b*) $\frac{46}{9}$.
(*c*) $10\frac{2}{10}$.	Ans.	(*c*) $\frac{102}{10}$.
(*d*) $37\frac{3}{4}$.		(*d*) $\frac{151}{4}$.
(*e*) $50\frac{4}{5}$.		(*e*) $\frac{254}{5}$.
(*f*) Reduce 7 to a fraction whose denominator is 16.		(*f*) $\frac{112}{16}$.

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92. To reduce an improper fraction to a whole or mixed number:

EXAMPLE.—Reduce $\frac{21}{4}$ to a mixed number.

SOLUTION.—4 is contained in 21, 5 times and 1 remaining (see Art. **75**); as this is also divided by 4, its value is $\frac{1}{4}$. Therefore, $5 + \frac{1}{4}$, or $5\frac{1}{4}$, is the number. Ans.

93. Rule.—*Divide the numerator by the denominator, the quotient will be the whole number; the remainder, if there be any, will be the numerator of the fractional part of which the denominator is the same as the denominator of the improper fraction.*

EXAMPLES FOR PRACTICE.

94. Reduce to whole or mixed numbers:

(*a*) $\frac{145}{6}$.	Ans.	(*a*) $24\frac{1}{6}$.
(*b*) $\frac{185}{3}$.		(*b*) $61\frac{2}{3}$.
(*c*) $\frac{701}{6}$.		(*c*) $116\frac{5}{6}$.
(*d*) $\frac{149}{3}$.		(*d*) $49\frac{2}{3}$.
(*e*) $\frac{76}{19}$.		(*e*) 4.
(*f*) $\frac{125}{25}$.		(*f*) 5.

95. A **common denominator** of *two* or *more fractions* is a number which will contain (i. e., which may be divided by) all of the *denominators* of the *fractions* without a remainder. The **least common denominator** is the least number that will contain all of the denominators of the fractions without a remainder.

96. To find the least common denominator:

EXAMPLE.—Find the least common denominator of $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{9}$, and $\frac{1}{16}$.

SOLUTION.—We first place the denominators in a row, separated by commas.

```
2 ) 4, 3, 9, 16
2 ) 2, 3, 9,  8
3 ) 1, 3, 9,  4
    1, 1, 3,  4
```

$2 \times 2 \times 3 \times 3 \times 4 = 144$, the least common denominator. Ans.

EXPLANATION.—Divide the numbers by some prime number that will divide at least two of them without a remainder (if possible), bringing down to the row below those denominators which will not contain the divisor without a remainder. Dividing each of the numbers by 2, the second row becomes 2, 3, 9, 8, since 2 will not divide 3 and 9 without a remainder. Dividing again by 2, the result is 1, 3, 9, 4.

Dividing the third row by 3, the result is 1, 1, 3, 4. Since the remaining numbers are prime to each other, we cease dividing further. The product of all the divisors and of the numbers prime to each other, is $2 \times 2 \times 3 \times 3 \times 4 = 144$, which is the required least common denominator.

97. EXAMPLE.—Find the least common denominator of $\frac{4}{9}$, $\frac{5}{12}$, $\frac{7}{18}$.

SOLUTION.—

$$\begin{array}{r|lll} 3 & 9, & 12, & 18 \\ \hline 3 & 3, & 4, & 6 \\ \hline 2 & 1, & 4, & 2 \\ \hline & 1, & 2, & 1 \end{array}$$

$3 \times 3 \times 2 \times 2 = 36$. Ans.

98. To reduce two or more fractions to fractions having a common denominator:

EXAMPLE.—Reduce $\frac{2}{3}$, $\frac{3}{4}$, and $\frac{1}{2}$ to fractions having a common denominator.

SOLUTION.—The common denominator is any number which will contain 3, 4, and 2. The *least* common denominator is 12, because it is the smallest number which can be divided by 3, 4, and 2 without a remainder. $\frac{2}{3} = \frac{8}{12}$, $\frac{3}{4} = \frac{9}{12}$, $\frac{1}{2} = \frac{6}{12}$.

Reducing $\frac{2}{3}$ (see Art. **84**), 3 is contained in 12, 4 times. By multiplying both numerator and denominator of $\frac{2}{3}$ by 4, we find $\frac{2 \times 4}{3 \times 4} = \frac{8}{12}$. In the same way we find $\frac{3}{4} = \frac{9}{12}$ and $\frac{1}{2} = \frac{6}{12}$.

99. Rule.—*Divide the common denominator by the denominator of the given fraction, and multiply both terms of the fraction by the quotient.*

EXAMPLES FOR PRACTICE.

100. Reduce to fractions having a common denominator:

(*a*)	$\frac{3}{4}$, $\frac{5}{8}$, $\frac{7}{8}$.	Ans. (*a*)	$\frac{6}{8}$, $\frac{5}{8}$, $\frac{7}{8}$.
(*b*)	$\frac{3}{16}$, $\frac{3}{4}$, $\frac{7}{32}$.	(*b*)	$\frac{6}{32}$, $\frac{24}{32}$, $\frac{7}{32}$.
(*c*)	$\frac{7}{8}$, $\frac{7}{88}$, $\frac{10}{11}$.	(*c*)	$\frac{77}{88}$, $\frac{7}{88}$, $\frac{80}{88}$.
(*d*)	$\frac{3}{5}$, $\frac{5}{8}$, $\frac{11}{40}$.	(*d*)	$\frac{24}{40}$, $\frac{25}{40}$, $\frac{11}{40}$.
(*e*)	$\frac{4}{10}$, $\frac{6}{40}$, $\frac{9}{20}$.	(*e*)	$\frac{16}{40}$, $\frac{6}{40}$, $\frac{18}{40}$.
(*f*)	$\frac{7}{15}$, $\frac{17}{30}$, $\frac{21}{30}$.	(*f*)	$\frac{14}{30}$, $\frac{17}{30}$, $\frac{21}{30}$.

ADDITION OF FRACTIONS.

101. *Fractions cannot be added unless they have a common denominator.* We cannot add $\frac{3}{4}$ to $\frac{7}{8}$ as they now stand, since the denominators represent parts of different sizes. Fourths cannot be added to eighths.

Suppose we divide an apple into 4 equal parts, and then divide 2 of these parts into two equal parts. It is evident that we shall have 2 one-fourths and 4 one-eighths. Now, if we add these parts, the result is $2 + 4 = 6$ something. But what is this something? It is not fourths, for six fourths are $1\frac{1}{2}$, and we had only 1 apple to begin with; neither is it eighths, for six eighths are $\frac{3}{4}$, which is less than 1 apple. By reducing the quarters to eighths, we have $\frac{2}{4} = \frac{4}{8}$, and adding the other 4 eighths, $4 + 4 = 8$ eighths. This result is correct, since $\frac{8}{8} = 1$. Or, we can, in this case, reduce the eighths to quarters. Thus, $\frac{4}{8} = \frac{2}{4}$; whence, adding $2 + 2 = 4$ quarters, a correct result since $\frac{4}{4} = 1$.

Before adding, fractions should be reduced to a common denominator, preferably the *least* common denominator.

102. EXAMPLE.—Find the sum of $\frac{1}{2}$, $\frac{3}{4}$, and $\frac{5}{8}$.

SOLUTION.—The *least common denominator*, or the *least number* which will contain all the *denominators*, is 8.

$$\frac{1}{2} = \frac{4}{8}, \quad \frac{3}{4} = \frac{6}{8}, \quad \frac{5}{8} = \frac{5}{8}.$$

EXPLANATION.—As the *denominator* tells or indicates the names of the *parts*, the *numerators* only are added in order to obtain the total number of *parts* indicated by the *denominator*. Thus, 4 one-eighths plus 6 one-eighths plus 5 one-eighths =

$$\frac{4}{8} + \frac{6}{8} + \frac{5}{8} = \frac{4+6+5}{8} = \frac{15}{8} = 1\tfrac{7}{8}. \quad \text{Ans.}$$

103. EXAMPLE.—What is the sum of $12\frac{3}{4}$, $14\frac{5}{8}$, and $7\frac{5}{16}$?

SOLUTION.—The least common denominator in this case is 16.

$$12\tfrac{3}{4} = 12\tfrac{12}{16}$$
$$14\tfrac{5}{8} = 14\tfrac{10}{16}$$
$$7\tfrac{5}{16} = 7\tfrac{5}{16}$$
$$\textit{sum} = 33 + \tfrac{27}{16} = 33 + 1\tfrac{11}{16} = 34\tfrac{11}{16}. \quad \text{Ans.}$$

The sum of the fractions $= \frac{27}{16}$ or $1\frac{11}{16}$, which added to the sum of the whole numbers $= 34\frac{11}{16}$.

EXAMPLE.—What is the sum of 17, $13\frac{3}{16}$, $\frac{9}{32}$, and $3\frac{1}{4}$?

SOLUTION.—The least common denominator is 32. $13\frac{3}{16} = 13\frac{6}{32}$, $3\frac{1}{4} = 3\frac{8}{32}$.

$$\begin{array}{rr} & 17 \\ & 13\frac{6}{32} \\ & \frac{9}{32} \\ & 3\frac{8}{32} \\ \hline \textit{sum} & 33\frac{23}{32} \end{array} \quad \text{Ans.}$$

104. Rule I.—*Reduce the given fractions to fractions having the least common denominator, and write the sum of the numerators over the common denominator.*

II. *When there are mixed numbers and whole numbers, add the fractions first, and if their sum is an improper fraction, reduce it to a mixed number, and add the whole number with the other whole numbers.*

EXAMPLES FOR PRACTICE.

105. Find the sum of

(a) $\frac{4}{9}, \frac{7}{18}, \frac{5}{9}$.	Ans.	(a) $1\frac{7}{18}$.
(b) $\frac{3}{8}, \frac{5}{16}, \frac{13}{16}$.		(b) $1\frac{8}{16}$.
(c) $\frac{1}{2}, \frac{3}{8}, \frac{5}{16}$.		(c) $1\frac{3}{16}$.
(d) $\frac{5}{6}, \frac{11}{72}, \frac{13}{18}$.		(d) $1\frac{51}{72}$.
(e) $\frac{10}{11}, \frac{8}{33}, \frac{23}{66}$.		(e) $1\frac{33}{66}$.
(f) $\frac{33}{48}, \frac{11}{16}, \frac{12}{48}$.		(f) $1\frac{5}{8}$.
(g) $\frac{4}{11}, \frac{7}{22}, \frac{14}{22}$.		(g) $1\frac{7}{22}$.
(h) $\frac{2}{7}, \frac{12}{28}, \frac{2}{7}$.		(h) 1.

SUBTRACTION OF FRACTIONS.

106. Fractions cannot be *subtracted* without first reducing them to a *common denominator*. This can be shown in the same manner as in the case of addition of fractions.

EXAMPLE.—Subtract $\frac{3}{8}$ from $\frac{13}{16}$.

SOLUTION.—The common denominator is 16.

$$\frac{3}{8} = \frac{6}{16}. \quad \frac{13}{16} - \frac{6}{16} = \frac{13-6}{16} = \frac{7}{16}. \quad \text{Ans.}$$

107. EXAMPLE.—From 7 take $\frac{5}{8}$.

SOLUTION.— $1 = \frac{8}{8}$; therefore, since $7 = 6 + 1$, $7 = 6 + \frac{8}{8} = 6\frac{8}{8}$, or $6\frac{8}{8} - \frac{5}{8} = 6\frac{3}{8}$. Ans.

108. EXAMPLE.—What is the difference between $17\frac{9}{16}$ and $9\frac{15}{32}$?

SOLUTION.—The common denominator of the fractions is 32. $17\frac{9}{16} = 17\frac{18}{32}$.

$$\begin{array}{rr} \textit{minuend} & 17\frac{18}{32} \\ \textit{subtrahend} & 9\frac{15}{32} \\ \hline \textit{difference} & 8\frac{3}{32} \text{ Ans.} \end{array}$$

109. EXAMPLE.—From $9\frac{1}{4}$ take $4\frac{7}{16}$.

SOLUTION.—The common denominator of the fractions is 16. $9\frac{1}{4} = 9\frac{4}{16}$.

$$\begin{array}{rrr} \textit{minuend} & 9\frac{4}{16} \text{ or} & 8\frac{20}{16} \\ \textit{subtrahend} & 4\frac{7}{16} & 4\frac{7}{16} \\ \hline \textit{difference} & 4\frac{13}{16} & 4\frac{13}{16} \text{ Ans.} \end{array}$$

EXPLANATION.—As the *fraction* in the *subtrahend* is greater than the fraction in the *minuend*, it *cannot* be subtracted; therefore, *borrow* 1, or $\frac{16}{16}$, from the 9 in the *minuend* and *add* it to the $\frac{4}{16}$; $\frac{4}{16} + \frac{16}{16} = \frac{20}{16}$. $\frac{7}{16}$ from $\frac{20}{16} = \frac{13}{16}$. Since 1 was *borrowed* from 9, 8 *remains*; 4 from 8 = 4; $4 + \frac{13}{16} = 4\frac{13}{16}$.

110. EXAMPLE.—From 9 take $8\frac{3}{16}$.

SOLUTION.—

$$\begin{array}{rrr} \textit{minuend} & 9 \text{ or} & 8\frac{16}{16} \\ \textit{subtrahend} & 8\frac{3}{16} & 8\frac{3}{16} \\ \hline \textit{difference} & \frac{13}{16} & \frac{13}{16} \text{ Ans.} \end{array}$$

EXPLANATION.—As there is no *fraction* in the *minuend* from which to take the *fraction* in the *subtrahend*, *borrow* 1, or $\frac{16}{16}$, from 9. $\frac{3}{16}$ from $\frac{16}{16} = \frac{13}{16}$. Since 1 was *borrowed* from 9, only 8 is left. 8 from 8 = 0.

111. Rule I.—*Reduce the fractions to fractions having a common denominator. Subtract one numerator from the other and place the remainder over the common denominator.*

II. *When there are mixed numbers, subtract the fractions and whole numbers separately, and place the remainders side by side.*

III. *When the fraction in the subtrahend is greater than the fraction in the minuend, borrow 1 from the whole number in the minuend and add it to the fraction in the minuend, from which subtract the fraction in the subtrahend.*

IV. *When the minuend is a whole number, borrow 1; reduce it to a fraction whose denominator is the same as the denominator of the fraction in the subtrahend, and place it over that fraction for subtraction.*

EXAMPLES FOR PRACTICE.

112. Subtract

(*a*) $\frac{10}{24}$ from $\frac{11}{12}$.	Ans.	(*a*) $\frac{1}{2}$.
(*b*) $\frac{7}{14}$ from $\frac{17}{28}$.		(*b*) $\frac{3}{28}$.
(*c*) $\frac{4}{30}$ from $\frac{5}{10}$.		(*c*) $\frac{11}{30}$.
(*d*) $\frac{15}{35}$ from $\frac{45}{70}$.		(*d*) $\frac{3}{14}$.
(*e*) $\frac{15}{16}$ from $\frac{57}{48}$.		(*e*) $\frac{1}{4}$.
(*f*) $13\frac{1}{4}$ from $30\frac{1}{2}$.		(*f*) $17\frac{1}{4}$.
(*g*) $12\frac{1}{8}$ from 27.		(*g*) $14\frac{7}{8}$.
(*h*) $5\frac{1}{4}$ from 30.		(*h*) $24\frac{3}{4}$.

MULTIPLICATION OF FRACTIONS.

113. In *multiplication* of fractions it is not necessary to *reduce* the *fractions* to fractions having a *common denominator.*

114. Multiplying the *numerator* or *dividing* the *denominator multiplies* the fraction.

EXAMPLE.—Multiply $\frac{3}{4}$ by 4.

SOLUTION.— $\frac{3}{4} \times 4 = \frac{3 \times 4}{4} = \frac{12}{4} = 3.$ Ans.

Or $\frac{3}{4} \times 4 = \frac{3}{4 \div 4} = \frac{3}{1} = 3.$ Ans.

The word "of" in multiplication of fractions means the same as ×, or times. Thus,

$$\tfrac{3}{4} \text{ of } 4 = \tfrac{3}{4} \times 4 = 3.$$

$$\tfrac{1}{8} \text{ of } \tfrac{5}{16} = \tfrac{1}{8} \times \tfrac{5}{16} = \tfrac{5}{128}.$$

EXAMPLE.—Multiply $\frac{3}{8}$ by 2.

SOLUTION.— $2 \times \frac{3}{8} = \frac{3 \times 2}{8} = \frac{6}{8} = \frac{3}{4}.$ Ans.

Or $2 \times \frac{3}{8} = \frac{3}{8 \div 2} = \frac{3}{4}.$ Ans.

115. EXAMPLE.—What is the product of $\frac{4}{16}$ and $\frac{7}{8}$?

SOLUTION.— $\frac{4}{16} \times \frac{7}{8} = \frac{4 \times 7}{16 \times 8} = \frac{28}{128} = \frac{7}{32}.$ Ans.

or, by cancelation $\frac{\cancel{4} \times 7}{\underset{4}{\cancel{16}} \times 8} = \frac{7}{4 \times 8} = \frac{7}{32}.$ Ans.

116. EXAMPLE.—What is $\frac{4}{8}$ of $\frac{3}{4}$ of $\frac{16}{32}$?

SOLUTION.— $\frac{\cancel{4} \times 3 \times \cancel{16}}{8 \times \cancel{4} \times \underset{2}{\cancel{32}}} = \frac{3}{8 \times 2} = \frac{3}{16}.$ Ans.

117. Example.—What is the product of $9\frac{3}{4}$ and $5\frac{5}{8}$?

Solution.—$9\frac{3}{4} = \frac{39}{4}$; $5\frac{5}{8} = \frac{45}{8}$.

$$\frac{39}{4} \times \frac{45}{8} = \frac{39 \times 45}{4 \times 8} = \frac{1755}{32} = 54\frac{27}{32}. \quad \text{Ans.}$$

118. Example.—Multiply $15\frac{7}{8}$ by 3.

Solution.—

$$\begin{array}{r} 15\frac{7}{8} \\ 3 \\ \hline 47\frac{5}{8} \end{array} \quad \text{or} \quad \begin{array}{l} 15\frac{7}{8} \\ \;\;\; 3 \\ \hline 45 + \frac{21}{8} = 45 + 2\frac{5}{8} = 47\frac{5}{8}. \quad \text{Ans.} \end{array}$$

119. Rule.—I. *Divide the product of the numerators by the product of the denominators. All factors common to the numerators and denominators should first be cast out by cancelation.*

II. *To multiply one mixed number by another, reduce them both to improper fractions.*

III. *To multiply a mixed number by a whole number, first multiply the fractional part by the multiplier, and if the product is an improper fraction, reduce it to a mixed number, and add the whole number part to the product of the multiplier and whole number.*

EXAMPLES FOR PRACTICE.

120. Find the product of

(*a*) $7 \times \frac{3}{19}$.	Ans.	(*a*) $1\frac{2}{19}$.
(*b*) $14 \times \frac{5}{16}$.		(*b*) $4\frac{3}{8}$.
(*c*) $\frac{21}{32} \times \frac{5}{14}$.		(*c*) $\frac{15}{64}$.
(*d*) $\frac{16}{27} \times 4$.		(*d*) $2\frac{10}{27}$.
(*e*) $\frac{19}{18} \times 7$.		(*e*) $7\frac{7}{18}$.
(*f*) $17\frac{18}{21} \times 7$.		(*f*) 125.
(*g*) $\frac{105}{224} \times 32$.		(*g*) 15.
(*h*) $\frac{15}{28} \times 14$.		(*h*) $7\frac{1}{2}$.

DIVISION OF FRACTIONS.

121. In *division* of fractions it is not necessary to ***reduce*** the *fractions* to fractions having a *common* ***denominator***.

122. Dividing the *numerator* or *multiplying* the ***denominator***, *divides* the fraction.

Example.—Divide $\frac{6}{8}$ by 3.

Solution.—When *dividing* the *numerator*, we have

$$\frac{6}{8} \div 3 = \frac{6 \div 3}{8} = \frac{2}{8} = \frac{1}{4}. \quad \text{Ans.}$$

When *multiplying* the *denominator*, we have

$$\tfrac{6}{8} \div 3 = \frac{6}{8 \times 3} = \tfrac{6}{24} = \tfrac{1}{4}. \quad \text{Ans.}$$

EXAMPLE.—Divide $\frac{3}{16}$ by 2.

SOLUTION.— $$\tfrac{3}{16} \div 2 = \frac{3}{16 \times 2} = \tfrac{3}{32}. \quad \text{Ans.}$$

EXAMPLE.—Divide $\frac{14}{32}$ by 7.

SOLUTION.— $$\tfrac{14}{32} \div 7 = \frac{14 \div 7}{32} = \tfrac{2}{32} = \tfrac{1}{16}. \quad \text{Ans.}$$

123. To **invert** a fraction is to *turn* it *upside down*; that is, make the *numerator* and *denominator change places*.

Invert $\frac{3}{4}$ and it becomes $\frac{4}{3}$.

124. EXAMPLE.—Divide $\frac{9}{16}$ by $\frac{3}{16}$.

SOLUTION.—1. The fraction $\frac{3}{16}$ is contained in $\frac{9}{16}$, 3 times, for the *denominators* are the same, and one *numerator* is *contained* in the other 3 times. 2. If we now *invert* the *divisor* $\frac{3}{16}$, and *multiply*, the solution is

$$\frac{9}{16} \times \frac{16}{3} = \frac{\overset{3}{\cancel{9}} \times \cancel{16}}{\cancel{16} \times \cancel{3}} = 3. \quad \text{Ans.}$$

This brings the *same quotient* as in the first case.

125. EXAMPLE.—Divide $\frac{3}{8}$ by $\frac{1}{4}$.

SOLUTION.—We cannot divide $\frac{3}{8}$ by $\frac{1}{4}$, as in the first case above, for the *denominators* are *not* the same, therefore, we must solve as in the second case.

$$\tfrac{3}{8} \div \tfrac{1}{4} = \tfrac{3}{8} \times \tfrac{4}{1} = \frac{3 \times \cancel{4}}{\underset{2}{\cancel{8}} \times 1} = \frac{3}{2} \text{ or } 1\tfrac{1}{2}. \quad \text{Ans.}$$

126. EXAMPLE.—Divide 5 by $\frac{10}{16}$.

SOLUTION.— $\frac{10}{16}$ inverted becomes $\frac{16}{10}$.

$$5 \times \frac{16}{10} = \frac{\cancel{5} \times \overset{8}{\cancel{16}}}{\underset{\cancel{2}}{\cancel{10}}} = 8. \quad \text{Ans.}$$

127. EXAMPLE.—How many times is $3\frac{3}{4}$ contained in $7\frac{7}{16}$?

SOLUTION.— $3\frac{3}{4} = \frac{15}{4}$; $7\frac{7}{16} = \frac{119}{16}$.

$\frac{15}{4}$ inverted equals $\frac{4}{15}$.

$$\frac{119}{16} \times \frac{4}{15} = \frac{119 \times \cancel{4}}{\underset{4}{\cancel{16}} \times 15} = \frac{119}{60} = 1\tfrac{59}{60}. \quad \text{Ans.}$$

128. **Rule.**—*Invert the divisor, and proceed as in multiplication.*

129. We have learned that a line placed between two numbers indicates that the number above the line is to be divided by the number below it. Thus, $\frac{18}{3}$ shows that 18 is to be divided by 3. This is also true if a fraction or a fractional expression be placed above or below a line.

$\dfrac{9}{\frac{3}{8}}$ means that 9 is to be divided by $\frac{3}{8}$; $\dfrac{3 \times 7}{\frac{8+4}{16}}$ means that 3×7 is to be divided by the value of $\dfrac{8+4}{16}$.

$\dfrac{\frac{1}{4}}{\frac{3}{8}}$ is the same as $\frac{1}{4} \div \frac{3}{8}$.

It will be noticed that there is a heavy line between the 9 and the $\frac{3}{8}$. This is necessary, since otherwise there would be nothing to show as to whether 9 was to be divided by $\frac{3}{8}$, or $\frac{9}{3}$ was to be divided by 8. Whenever a heavy line is used, as shown here, it indicates that *all above the line* is to be divided by *all below it*.

EXAMPLES FOR PRACTICE.

130. Divide

(*a*)	15 by $6\frac{3}{7}$.	Ans.	(*a*)	$2\frac{1}{3}$.
(*b*)	30 by $\frac{6}{8}$.		(*b*)	40.
(*c*)	172 by $\frac{4}{5}$.		(*c*)	215.
(*d*)	$\frac{14}{18}$ by $1\frac{7}{16}$.		(*d*)	$\frac{112}{207}$.
(*e*)	$\frac{103}{6}$ by $14\frac{2}{3}$.		(*e*)	$1\frac{15}{88}$.
(*f*)	$\frac{142}{27}$ by $17\frac{1}{9}$.		(*f*)	$\frac{71}{231}$.
(*g*)	$\frac{14}{18}$ by $\frac{145}{72}$.		(*g*)	$\frac{56}{145}$.
(*h*)	$\frac{128}{18}$ by $72\frac{1}{3}$.		(*h*)	$\frac{64}{651}$.

---

131. Whenever an expression like one of the three following is obtained, it may always be simplified by transposing the denominator from *above* to *below* the line, or from *below* to *above*, as the case may be, taking care, however, to indicate that the denominator when so transferred is a multiplier.

1. $\dfrac{\frac{3}{4}}{9} = \dfrac{3}{9 \times 4} = \frac{3}{36} = \frac{1}{12}$; for, regarding the fraction above the heavy line as the numerator of a fraction whose denominator is 9, $\dfrac{\frac{3}{4} \times 4}{9 \times 4} = \dfrac{3}{9 \times 4}$, as before.

2. $\frac{9}{\frac{3}{4}} = \frac{9 \times 4}{3} = 12.$ The proof is the same as in the first case.

3. $\frac{\frac{5}{9}}{\frac{3}{4}} = \frac{5 \times 4}{3 \times 9} = \frac{20}{27}$; for, regarding $\frac{5}{9}$ as the numerator of a fraction whose denominator is $\frac{3}{4}$, $\frac{\frac{5}{9} \times 9}{\frac{3}{4} \times 9} = \frac{5}{\frac{3 \times 9}{4}}$; and $\frac{\frac{5}{\frac{3 \times 9}{4}} \times 4}{\frac{3 \times 9}{4} \times 4} = \frac{5 \times 4}{3 \times 9} = \frac{20}{27}$, as above.

This principle may be used to great advantage in cases like $\frac{\frac{1}{4} \times 310 \times \frac{27}{12} \times 72}{40 \times 4\frac{1}{2} \times 5\frac{1}{6}}$. Reducing the mixed numbers to fractions, the expression becomes $\frac{\frac{1}{4} \times 310 \times \frac{27}{12} \times 72}{40 \times \frac{9}{2} \times \frac{31}{6}}$. Now transferring the denominators of the fractions and canceling,

$$\frac{1 \times 310 \times 27 \times 72 \times 2 \times 6}{40 \times 9 \times 31 \times 4 \times 12} = \frac{1 \times \overset{10}{\cancel{310}} \times \overset{3}{\cancel{27}} \times \overset{\overset{3}{\cancel{6}}}{\cancel{72}} \times \cancel{2} \times \overset{3}{\cancel{6}}}{\underset{\underset{\cancel{2}}{\cancel{4}}}{\cancel{40}} \times \cancel{9} \times \cancel{31} \times \underset{2}{\cancel{4}} \times \cancel{12}} = \frac{27}{2} = 13\tfrac{1}{2}.$$

Greater exactness in results can usually be obtained by using this principle than can be obtained by reducing the fractions to decimals. The principle, however, should not be employed *if a sign of addition or subtraction occurs either above or below the dividing line.*

ARITHMETIC.

(PART 3.)

DECIMALS.

REMARK.—Decimals are to be preferred in most cases to fractions, as the operations of addition, subtraction, multiplication, and division are generally performed far more readily with decimals than with fractions. The subject of decimals is a very easy one, and the only operation that is likely to cause trouble is division, the locating of the decimal point in the quotient; hence, particular attention should be given to the rule governing this. The student should note particularly Art. **162** and Arts. **164** to **176**, inclusive. As was stated in the "Remark" at the beginning of the subject of fractions, the results obtained by the use of decimals are not, in general, as exact as those obtained by using fractions; the reason for this will be apparent after reading Art. **162**.

132. **Decimals** are *tenth* fractions; that is, the parts of a unit are expressed on the scale of ten, as *tenths*, *hundredths*, *thousandths*, etc.

133. The *denominator*, which is always ten or a multiple of ten, as 10, 100, 1,000, etc., is *not* expressed as it would be in common fractions by writing it under the *numerator*, with a line between them; as, $\frac{3}{10}$, $\frac{3}{100}$, $\frac{3}{1000}$. The denominator is always understood, the numerator consisting of the figures on the right of the *unit* figure. In order to distinguish the unit figure, a period (.), called the **decimal point,** is placed between the unit figure and the next figure on the right. The decimal point may be regarded in two ways: first, as indicating that the number on the right is the numerator of a fraction whose denominator is 10, 100, 1,000, etc.; and, second, as a part of the Arabic system of notation, each figure on the right being 10 times as large as the next succeeding figure, and 10 times as small as the next preceding figure, serving merely to point out the unit figure.

134. The *reading* of a *decimal number* depends upon the *number* of *decimal places* in it, or the *number* of *figures* to the *right* of the unit figure.

The first figure to the right of the unit figure expresses *tenths.*

The second figure to the right of the unit figure expresses *hundredths.*

The third figure to the right of the unit figure expresses *thousandths.*

The fourth figure to the right of the unit figure expresses *ten-thousandths.*

The fifth figure to the right of the unit figure expresses *hundred-thousandths.*

The sixth figure to the right of the unit figure expresses *millionths.*

Thus:

$.3 = \frac{3}{10}$ = 3 tenths.

$.03 = \frac{3}{100}$ = 3 hundredths.

$.003 = \frac{3}{1000}$ = 3 thousandths.

$.0003 = \frac{3}{10000}$ = 3 ten-thousandths.

$.00003 = \frac{3}{100000}$ = 3 hundred-thousandths.

$.000003 = \frac{3}{1000000}$ = 3 millionths.

The first figure to the right of the unit figure is called the *first* **decimal place;** the second figure, the *second decimal place*, etc. We see in the above that the *number* of *decimal places* in a decimal equals the *number of ciphers* to the *right* of the figure 1 in the *denominator* of its *equivalent fraction.* This fact kept in mind will be of much assistance in reading and writing decimals.

Whatever may be written to the *left* of a *decimal point* is a whole number. The decimal point affects only the figures to its *right*.

When a *whole number* and *decimal* are written together, the expression is a *mixed number*. Thus, 8.12 and 17.25 are mixed numbers.

The relation of decimals and whole numbers to each other is clearly shown by the following table :

hundreds of millions.	tens of millions.	millions.	hundreds of thousands.	tens of thousands.	thousands.	hundreds.	tens.	units.	decimal point.	tenths.	hundredths.	thousandths.	ten-thousandths.	hundred-thousandths.	millionths.	ten-millionths.	hundred-millionths.
9	8	7	6	5	4	3	2	1	.	2	3	4	5	6	7	8	9

The figures to the *left* of the *decimal point* represent *whole numbers*; those to the *right* are *decimals*.

In *both* the decimals and whole numbers, the *units* place is made the *starting point* of notation and numeration. The *decimals decrease* on the scale of *ten* to the *right*, and the *whole* numbers *increase* on the scale of *ten* to the *left*. The *first* figure to the *left* of units is *tens*, and the *first* figure to the *right* of units is *tenths*. The *second* figure to the *left* of units is *hundreds*, and the *second* figure to the *right* is *hundredths*. The *third* figure to the *left* is *thousands*, and the *third* to the *right* is *thousandths*, and so on ; the *whole* numbers on the *left* and the *decimals* on the *right*. The figures equally distant from units place correspond in name. The *decimals* have the ending *ths*, which distinguishes them from *whole* numbers. The following is the numeration of the number in the above table: Nine hundred eighty-seven million, six hundred fifty-four thousand, three hundred twenty-one, and twenty-three million, four hundred fifty-six thousand, seven hundred eighty-nine hundred millionths.

The *decimals* increase to the *left*, on the scale of *ten*, the same as *whole* numbers; for, beginning at, say, 4-*thousandths*, in the table, the next figure to the left is *hundredths*, which is ten times as great, and the next *tenths*, or ten times the *hundredths*, and so on through both decimals and whole numbers.

135. *Annexing* or *taking away* a *cipher* at the *right* of a *decimal* does *not* affect its value.

$.5$ is $\frac{5}{10}$; $.50$ is $\frac{50}{100}$, but $\frac{5}{10} = \frac{50}{100}$; therefore, $.5 = .50$.

136. *Inserting* a *cipher* between a *decimal* and the *decimal point divides* the decimal by 10.

$$.5 = \frac{5}{10};\ \frac{5}{10} \div 10 = \frac{5}{100} = .05.$$

137. *Taking away* a *cipher* from the *left* of a *decimal multiplies* the *decimal* by 10.

$$.05 = \frac{5}{100};\ \frac{5}{100} \times 10 = \frac{5}{10} = .5.$$

138. In some cases it is convenient to express a mixed decimal fraction in the form of a common (improper) fraction. To do so it is only necessary to write the entire number, omitting the decimal point, as the numerator of the fraction, and the denominator of the decimal part as the denominator of the fraction. Thus, $127.483 = \frac{127483}{1000}$; for, $127.483 = 127\frac{483}{1000} = \frac{127000+483}{1000} = \frac{127483}{1000}$.

ADDITION OF DECIMALS.

139. The only respect in which *addition* of *decimals* differs from *addition* of *whole numbers*, is that while the unit figures are placed under each other in both cases, the right-hand figures are not necessarily in line when adding decimals.

Whole numbers begin at units and increase on the scale of 10, to the left. Decimals decrease on the scale of 10, to the right. Whole numbers are to the left of the decimal point and decimals are to the right of it. In whole numbers the *right-hand* side of a column of figures to be added, must be in line, and in decimals, the *left-hand* side must be in line, which brings the decimal points directly under each other.

whole numbers	*decimals*	*mixed numbers*
342	.342	342.032
4234	.4234	4234.5
26	.26	26.6782
3	.03	3.06
sum 4605 Ans.	*sum* 1.0554 Ans.	*sum* 4606.2702 Ans.

140. A decimal, as .342, ought really to be expressed as 0.342, but it is quite customary to omit the cipher on the left of the decimal point, though many authors use it.

EXAMPLE.—What is the sum of 242, .36, 118.725, 1.005, 6, and 100.1?

SOLUTION.—

```
      242.
         .36
      118.725
        1.005
        6.
      100.1
      -------
sum   468.190  Ans.
```

141. Rule.—*Place the numbers to be added so that the decimal points will be directly under each other. Add as in whole numbers, and place the decimal point in the sum directly under the decimal points above.*

EXAMPLES FOR PRACTICE.

142. Find the sum of

	Ans.
(*a*) .2143, .105, 2.3042, and 1.1417.	(*a*) 3.7652.
(*b*) 783.5, 21.473, .2101, and .7816.	(*b*) 805.9647.
(*c*) 21.781, 138.72, 41.8738, .72, and 1.413.	(*c*) 204.5078.
(*d*) .3724, 104.15, 21.417, and 100.042.	(*d*) 225.9814.
(*e*) 200.172, 14.105, 12.1465, .705, and 7.2.	(*e*) 234.3285.
(*f*) 1,427.16, .244, .32, .032, and 10.0041.	(*f*) 1,437.7601.
(*g*) 2,473.1, 41.65, .7243, 104.067, and 21.073.	(*g*) 2,640.6143.
(*h*) 4,107.2, .00375, 21.716, 410.072, and .0345.	(*h*) 4,539.02625.

SUBTRACTION OF DECIMALS.

143. For the same reason as in addition of decimals, the *left-hand* figures of *decimal numbers* are placed in line and the *decimal points* under each other.

EXAMPLE.—Subtract .132 from .3063.

SOLUTION.— *minuend*	.3063	
subtrahend	.132	
difference	.1743	Ans.

144. EXAMPLE.—What is the difference between 7.895 and .725?

SOLUTION.— *minuend*	7.895	
subtrahend	.725	
difference	7.170 or 7.17	Ans.

145. EXAMPLE.—Subtract .625 from 11.

SOLUTION.— *minuend*	11.000	
subtrahend	.625	
difference	10.375	Ans.

146. Rule.—*Place the subtrahend under the minuend, so that the decimal points will be directly under each other. Subtract, as in whole numbers, and place the decimal point in the remainder, directly under the decimal points above.*

When the figures in the decimal part of the subtrahend extend beyond those in the minuend, place ciphers in the minuend above them, and subtract as before.

EXAMPLES FOR PRACTICE.

147. From

(*a*) 407.385 take 235.0004.		Ans. (*a*)	172.3846.
(*b*) 22.718 take 1.7042.		(*b*)	21.0138.
(*c*) 1,368.17 take 13.6817.		(*c*)	1,354.4883.
(*d*) 70.00017 take 7.000017.		(*d*)	63.000153.
(*e*) 630.630 take .6304.		(*e*)	629.9996.
(*f*) 421.73 take 217.162.		(*f*)	204.568.
(*g*) 1.000014 take .00001.		(*g*)	1.000004.
(*h*) .783652 take .542314.		(*h*)	.241338.

MULTIPLICATION OF DECIMALS.

148. In multiplication of decimals, we do not place the decimal points directly under each other as in addition and subtraction. We pay no attention for the time being to the decimal points. Place the multiplier under the multiplicand, so that the *right-hand* figure of the one is under the *right-hand* figure of the other, and proceed exactly as in multiplication of whole numbers. After multiplying, *count the number of decimal places in both multiplicand and multiplier, and point off the same number in the product.*

EXAMPLE.—Multiply .825 by 13.

SOLUTION.— *multiplicand*	.825	
multiplier	13	
	2475	
	825	
product	10.725	Ans.

In this example there are three decimal places in the multiplicand and none in the multiplier; therefore, 3 decimal places are pointed off in the product.

149. EXAMPLE.—What is the product of 426 and the decimal .005 ?

SOLUTION.— *multiplicand*	426	
multiplier	.005	
product	2.130	or 2.13 Ans.

In this example there are 3 decimal places in the multiplier and none in the multiplicand; therefore, 3 decimal places are pointed off in the product.

150. It is *not* necessary to multiply by the ciphers on the *left* of a *decimal;* they merely determine the number of decimal places. Ciphers to the *right* of a decimal should be removed, as they only make more figures to deal with, and do not change the value.

151. EXAMPLE.—Multiply 1.205 by 1.15.

SOLUTION.— *multiplicand*	1.205	
multiplier	1.15	
	6025	
	1205	
	1205	
product	1.38575	Ans.

In this example there are 3 decimal places in the multiplicand, and 2 in the multiplier; therefore, 3 + 2, or 5, decimal places must be pointed off in the product.

152. EXAMPLE.—Multiply .232 by .001.

SOLUTION.— *multiplicand*	.2 3 2	
multiplier	.0 0 1	
product	.0 0 0 2 3 2	Ans.

In this example we multiply the multiplicand by the digit in the multiplier, which makes 232 in the product, but since there are 3 decimal places in each, the multiplier and the multiplicand, we must prefix 3 ciphers to the 232, to make 3 + 3, or 6, decimal places in the product.

153. Rule.—*Place the multiplier under the multiplicand, disregarding the position of the decimal points. Multiply as in whole numbers, and in the product point off as many decimal places as there are decimal places in both multiplier and multiplicand, prefixing ciphers if necessary.*

EXAMPLES FOR PRACTICE.

154. Find the product of

	Ans.
(*a*) .000492 × 4.1418.	(*a*) .0020377656.
(*b*) 4,003.2 × 1.2.	(*b*) 4,803.84.
(*c*) 78.6531 × 1.03.	(*c*) 81.012693.
(*d*) .3685 × .042.	(*d*) .015477.
(*e*) 178,352 × .01.	(*e*) 1,783.52.
(*f*) .00045 × .0045.	(*f*) .000002025.
(*g*) .714 × .00002.	(*g*) .00001428.
(*h*) .00004 × .008.	(*h*) .00000032.

DIVISION OF DECIMALS.

155. In division of decimals we pay *no* attention to the decimal point until *after* the division is performed. The *number of decimal places* in the *dividend must equal* (*be made to equal by annexing ciphers*) *the number of decimal places in the divisor.* Divide exactly as in whole numbers. *Subtract the number of decimal places in the divisor from the number of decimal places in the dividend, and point off as many decimal* *places in the quotient as there are units in the remainder thus found.*

EXAMPLE.—Divide .625 by 25.

SOLUTION.—

```
          divisor dividend quotient
           2 5 ) .6 2 5 ( .0 2 5   Ans.
                  5 0
                  ---
                  1 2 5
                  1 2 5
                  -----
        remainder     0
```

In this example there are no decimal places in the divisor, and 3 decimal places in the dividend; therefore, there are 3 minus 0, or 3, decimal places in the quotient. One cipher has to be prefixed to the 25, to make the 3 decimal places.

156. EXAMPLE.—Divide 6.035 by .05.

SOLUTION.—

```
          divisor dividend quotient
           .0 5 ) 6.0 3 5 ( 1 2 0.7   Ans.
                  5
                  ---
                  1 0
                  1 0
                  -----
                    3 5
                    3 5
                    ---
        remainder     0
```

In this example we divide by 5, as if the cipher were not before it. There is one more decimal place in the dividend than in the divisor; therefore, one decimal place is pointed off in the quotient.

157. EXAMPLE.—Divide .125 by .005.

SOLUTION.—

```
          divisor dividend quotient
          .0 0 5 ) .1 2 5 ( 2 5   Ans.
                   1 0
                   -----
                     2 5
                     2 5
                     ---
        remainder      0
```

In this example there are the same number of decimal places in the dividend as in the divisor; therefore, the quotient has no decimal places, and is a whole number.

158. EXAMPLE.—Divide 326 by .25.

```
                    divisor  dividend  quotient
SOLUTION.—            .25)326.00(1304   Ans.
                          25
                          --
                           76
                           75
                           ---
                            100
                            100
                            ---
                  remainder   0
```

In this problem two ciphers were annexed to the dividend, to make the number of decimal places equal to the number in the divisor. The quotient is a whole number.

159. EXAMPLE.—Divide .0025 by 1.25.

```
SOLUTION.—         1.25).00250(.002   Ans.
                         250
                         ---
                 remainder 0
```

EXPLANATION.—In this example we are to divide .0025 by 1.25. Consider the dividend as a whole number, or 25 (disregarding the two ciphers at its left, for the present); also, consider the divisor as a whole number, or 125. It is clearly evident that the dividend 25 will not contain the divisor 125; we must, therefore, annex one cipher to the 25, thus making the dividend 250. 125 is contained twice in 250, so we place the figure 2 in the quotient. In pointing off the decimal places in the quotient, it must be remembered that there were only four decimal places in the dividend; but one cipher was annexed, thereby making $4+1$, or 5, decimal places. Since there are 5 decimal places in the dividend and 2 decimal places in the divisor, we must point off $5-2$, or 3, decimal places in the quotient. In order to point off 3 decimal places, two ciphers must be prefixed to the figure 2, thereby making .002 the quotient. It is not necessary to consider the ciphers at the left of a decimal when dividing, except when determining the position of the decimal point in the quotient.

160. Rule.—I. *Place the divisor to the left of the dividend, and proceed as in division of whole numbers;* ***in the***

quotient, point off as many decimal places as the number of decimal places in the dividend exceed those in the divisor, prefixing ciphers to the quotient, if necessary.

II. *If in dividing one number by another there be a remainder, the remainder can be placed over the divisor, as a fractional part of the quotient, but it is generally better to annex ciphers to the remainder, and continue dividing until there are 3 or 4 decimal places in the quotient, and then if there still be a remainder, terminate the quotient by the plus sign (+), which shows that it can be carried further.*

161. EXAMPLE.—What is the quotient of 199 divided by 15?

SOLUTION.—

```
            15)199(13 + 4/15  Ans.
               15
               --
                49
                45
                --
   remainder     4

Or,  15)199.000(13.266+  Ans.
        15
        --
         49
         45
         --
          40
          30
          --
          100
           90
          ---
           100
            90
           ---
   remainder 10
```

$13\tfrac{4}{15} = 13.266+$

$\tfrac{4}{15} = .266+$

162. It frequently happens, as in the above example, that the division will never terminate. In such cases, decide to how many decimal places the division is to be carried, and carry the work one place further. If the last figure of the quotient thus obtained is 5 or a greater number, increase the preceding figure by 1, and write after it the minus sign (−), thus indicating that the quotient is not quite as large as indicated; if the figure thus obtained is less than 5, write the plus sign (+) after the quotient, thus indicating that the number is slightly greater than as indicated. In the last example, had it been desired to obtain the answer correct to four decimal places, the work would have been carried to five places, obtaining 13.26666, and the answer would have been given as 13.2667 −. This remark applies to any other calculation involving decimals, when it is desired to omit some of the figures in the decimal. Thus, if it is desired to retain three decimal places in the number .2471253, it would be expressed as .247 +; if it was desired to retain five decimal places, it would be expressed as .24713 −. Both the + and − signs are frequently omitted; they are seldom used outside of Arithmetic, except in exact calculations, when it is desired to call particular attention to the fact that the result obtained is not *quite* exact.

EXAMPLES FOR PRACTICE.

163. Divide

		Ans.
(*a*)	101.6688 by 2.36.	(*a*) 43.08.
(*b*)	187.12264 by 123.107.	(*b*) 1.52.
(*c*)	.08 by .008.	(*c*) 10.
(*d*)	.0003 by 3.75.	(*d*) .00008.
(*e*)	.0144 by .024.	(*e*) .6.
(*f*)	.00375 by 1.25.	(*f*) .003.
(*g*)	.004 by 400.	(*g*) .00001.
(*h*)	.4 by .008.	(*h*) 50.

TO REDUCE A FRACTION TO A DECIMAL.

164. EXAMPLE.—$\frac{3}{4}$ equals what decimal?

SOLUTION.—
$$\begin{array}{r} 4\,)\,3.00 \\ \hline .75 \end{array}, \text{ or } \tfrac{3}{4} = .75. \quad \text{Ans.}$$

EXAMPLE.—What decimal is equivalent to $\frac{7}{8}$?

SOLUTION.—
$$\begin{array}{l} 8\,)\,7.000\,(\,.875 \\ \quad\;\; 64 \\ \quad\;\; \overline{60} \\ \quad\;\; 56 \qquad \text{or } \tfrac{7}{8} = .875. \quad \text{Ans.} \\ \quad\;\;\; \overline{40} \\ \quad\;\;\; 40 \\ \quad\;\;\; \overline{\;\;0} \end{array}$$

165. Rule.—*Annex ciphers to the numerator and divide by the denominator. Point off as many decimal places in the quotient as there are ciphers annexed.*

EXAMPLES FOR PRACTICE.

166. Reduce the following common fractions to decimals:

(*a*) $\frac{15}{32}$.	Ans.	(*a*) .46875.
(*b*) $\frac{7}{8}$.		(*b*) .875.
(*c*) $\frac{21}{32}$.		(*c*) .65625.
(*d*) $\frac{51}{64}$.		(*d*) .796875.
(*e*) $\frac{4}{25}$.		(*e*) .16.
(*f*) $\frac{5}{8}$.		(*f*) .625.
(*g*) $\frac{10}{200}$.		(*g*) .05.
(*h*) $\frac{4}{1000}$.		(*h*) .004.

---

167. To reduce inches to decimal parts of a foot:

EXAMPLE.—What decimal part of a foot is 9 inches?

SOLUTION.—Since there are 12 inches in one foot, 1 inch is $\frac{1}{12}$ of a foot, and 9 inches is $9 \times \frac{1}{12}$ or $\frac{9}{12}$ of a foot. This, reduced to a decimal by the above rule, shows what decimal part of a foot 9 inches is.

```
1 2 ) 9.0 0 ( .7 5 of a foot.   Ans.
      8 4
      ---
        6 0
        6 0
        ---
          0
```

168. Rule I.—*To reduce inches to decimal parts of a foot, divide the number of inches by 12.*

II. *Should the resulting decimal be an unending one and it is desired to terminate the division at some point, say, the fourth decimal place, carry the division one place further, and if the fifth figure is 5 or greater, increase the fourth figure by 1. Omit the signs + and −.*

EXAMPLES FOR PRACTICE.

169. Reduce to the decimal part of a foot:

(*a*) 3 in.	Ans.	(*a*) .25.
(*b*) $4\frac{1}{2}$ in.		(*b*) .375.
(*c*) 5 in.		(*c*) .4167.
(*d*) $6\frac{5}{8}$ in.		(*d*) .5521.
(*e*) 11 in.		(*e*) .9167.

TO REDUCE A DECIMAL TO A FRACTION.

170. EXAMPLE.—Reduce .125 to a fraction.

SOLUTION.— $.125 = \frac{125}{1000} = \frac{5}{40} = \frac{1}{8}$. Ans.

EXAMPLE.—Reduce .875 to a fraction.

SOLUTION.— $.875 = \frac{875}{1000} = \frac{35}{40} = \frac{7}{8}$. Ans.

171. Rule.—*Under the figures of the decimal, place 1 with as many ciphers at its right as there are decimal places in the decimal, and reduce the resulting fraction to its lowest terms by dividing both numerator and denominator by the same number.*

EXAMPLES FOR PRACTICE.

172. Reduce the following to common fractions:

		Ans.
(*a*)	.125.	(*a*) $\frac{1}{8}$.
(*b*)	.625.	(*b*) $\frac{5}{8}$.
(*c*)	.3125.	(*c*) $\frac{5}{16}$.
(*d*)	.04.	(*d*) $\frac{1}{25}$.
(*e*)	.06.	(*e*) $\frac{3}{50}$.
(*f*)	.75.	(*f*) $\frac{3}{4}$.
(*g*)	.15625.	(*g*) $\frac{5}{32}$.
(*h*)	.875.	(*h*) $\frac{7}{8}$.

---

173. To express a decimal approximately as a fraction having a given denominator:

174. EXAMPLE.—Express .5827 in 64ths.

SOLUTION.— $.5827 \times \frac{64}{64} = \frac{37.2928}{64}$, say $\frac{37}{64}$.

Hence, $.5827 = \frac{37}{64}$, nearly. Ans.

EXAMPLE.—Express .3917 in 12ths.

SOLUTION.— $.3917 \times \frac{12}{12} = \frac{4.7004}{12}$, say $\frac{5}{12}$.

Hence, $.3917 = \frac{5}{12}$, nearly. Ans.

175. Rule.—*Reduce 1 to a fraction having the given denominator. Multiply the given decimal by the fraction so obtained, and the result will be the fraction required.*

EXAMPLES FOR PRACTICE.

176. Express

		Ans.
(*a*)	.625 in 8ths.	(*a*) $\frac{5}{8}$.
(*b*)	.3125 in 16ths.	(*b*) $\frac{5}{16}$.
(*c*)	.15625 in 32ds.	(*c*) $\frac{5}{32}$.
(*d*)	.77 in 64ths.	(*d*) $\frac{49}{64}$.
(*e*)	.81 in 48ths.	(*e*) $\frac{39}{48}$.
(*f*)	.923 in 96ths.	(*f*) $\frac{89}{96}$.

177. The sign for dollars is \$. It is read dollars. \$25 is read 25 dollars.

Since there are 100 cents in a dollar, one cent is 1-one-hundredth of a dollar; the first two figures of a decimal part of a dollar represent *cents*. Since a mill is $\frac{1}{10}$ of a cent, or $\frac{1}{1000}$ of a dollar, the third figure represents mills.

Thus, \$25.16 is read twenty-five dollars and sixteen cents; \$25.168 is read twenty-five dollars, sixteen cents and eight mills.

178. The **vinculum** ——, **parenthesis** ( ), **bracket** [ ], and **brace** { } are called **symbols of aggregation,** and are used to include numbers which are to be considered together; thus, $13 \times \overline{8 - 3}$, or $13 \times (8 - 3)$, shows that 3 is to be taken from 8 before multiplying by 13.

$$13 \times (8 - 3) = 13 \times 5 = 65. \quad \text{Ans.}$$

$$13 \times \overline{8 - 3} = 13 \times 5 = 65. \quad \text{Ans.}$$

When the vinculum or parenthesis is not used, we have

$$13 \times 8 - 3 = 104 - 3 = 101. \quad \text{Ans.}$$

179. In any series of numbers connected by the signs +, −, ×, and ÷, the operations indicated by the signs must be performed in order from left to right, *except* that no addition or subtraction may be performed if a sign of multiplication or division *follows* the number on the *right* of a sign of addition or subtraction, until the indicated multiplication or division has been performed. In all cases the sign of multiplication takes the precedence, the reason being that when two or more numbers or expressions are connected by the sign of multiplication, the numbers thus connected are regarded as factors of the product indicated, and not as separate numbers.

EXAMPLE.—What is the value of $4 \times 24 - 8 + 17$?

SOLUTION.—Performing the operations in order from left to right, $4 \times 24 = 96$; $96 - 8 = 88$; $88 + 17 = 105$. Ans.

180. EXAMPLE.—What is the value of the following expression: $1{,}296 \div 12 + 160 - 22 \times 3\frac{1}{2} = ?$

SOLUTION.—$1{,}296 \div 12 = 108$; $108 + 160 = 268$; here we cannot subtract 22 from 268 because the sign of multiplication *follows* 22; hence, multiplying 22 by $3\frac{1}{2}$, we get 77, and $268 - 77 = 191$. Ans.

Had the above expression been written $1{,}296 \div 12 + 160 - 22 \times 3\frac{1}{2} \div 7 + 25$, it would have been necessary to have divided $22 \times 3\frac{1}{2}$ by 7 before subtracting, and the final result would have been $22 \times 3\frac{1}{2} = 77$; $77 \div 7 = 11$; $268 - 11 = 257$; $257 + 25 = 282$. Ans. In other words, it is necessary to perform *all* of the multiplication or division included between the signs + and −, or − and +, before adding or subtracting. Also, had the expression been written $1{,}296 \div 12 + 160 - 24\frac{1}{2} \div 7 \times 3\frac{1}{2} + 25$, it would have been necessary to have multiplied $3\frac{1}{2}$ by 7 before dividing $24\frac{1}{2}$, since the sign of multiplication takes the precedence, and the final result would have been $3\frac{1}{2} \times 7 = 24\frac{1}{2}$; $24\frac{1}{2} \div 24\frac{1}{2} = 1$; $268 - 1 = 267$; $267 + 25 = 292$. Ans.

It likewise follows that if a succession of multiplication and division signs occurs, the indicated operations must not be performed in order, from left to right—the multiplication must be performed first. Thus, $24 \times 3 \div 4 \times 2 \div 9 \times 5 = \frac{1}{5}$. Ans. In order to obtain the same result that would be obtained by performing the indicated operations in order, from left to right, symbols of aggregation must be used. Thus, by using two vinculums, the last expression becomes $24 \times \overline{3 \div 4} \times \overline{2 \div 9} \times 5 = 20$, the same result that would be obtained by performing the indicated operations in order, from left to right.

EXAMPLES FOR PRACTICE.

181. Find the values of the following expressions:

(*a*)	$(8 + 5 - 1) \div 4$.	(*a*)	3.
(*b*)	$5 \times 24 - 32$.	(*b*)	88.
(*c*)	$5 \times 24 \div 15$.	(*c*)	8.
(*d*)	$144 - 5 \times 24$.	(*d*)	24.
(*e*)	$(1{,}691 - 540 + 559) \div 3 \times 57$.	(*e*)	10.
(*f*)	$2{,}080 + 120 - 80 \times 4 - 1{,}670$.	(*f*)	210.
(*g*)	$(\overline{90 + 60} \div 25) \times 5 - 29$.	(*g*)	1.
(*h*)	$\overline{90 + 60} \div 25 \times 5$.	(*h*)	1.2.

Ans. (answers above)

MEASURING INSTRUMENTS.

STANDARDS OF ULTIMATE REFERENCE.

THE ENGLISH STANDARD.

1. The Imperial Yard. — In the United States of America, in England, and in most of the English colonies, the principal unit of length is the **imperial yard,** which was originally represented by the distance in a straight line between the centers of two points marked on gold studs inserted in a brass bar made in 1760, and in the custody of the British Government. By an Act of Parliament of June 17, 1824, this was declared to be the **standard imperial yard** at a temperature of 62° F.

2. Section III of the Act mentioned wisely provided that the standard imperial yard, if lost, destroyed, defaced, or otherwise injured, should be restored to the same length by reference to an *invariable natural standard.* The standard chosen was the length of a pendulum vibrating seconds of mean time in a vacuum at sea level in the latitude of London, England. The Act declared that such a pendulum, when compared with the standard imperial yard, had a length of thirty-nine inches and one thousand three hundred and ninety-three ten-thousandth parts of an inch (39.1393″).

§ 2

3. On October 16, 1834, both Houses of Parliament were destroyed by fire and the standard imperial yard hopelessly damaged. Since the passage of the Act of June 17, 1824, investigations had conclusively proved that the determination of the ratio of the effective length of the bar to the seconds pendulum was inaccurate—so much so that finally all attempts at reproducing the lost standard by referring to the seconds pendulum were abandoned. It was then decided to construct a new standard yard by reference to copies that had been previously made, and that had been compared with the original standard yard. This work was entrusted to Sir Francis Baily, who, unfortunately, died before its completion. As the result of a great many experiments, Sir Baily had decided on an alloy composed of 16 parts of copper, 2½ parts of tin, and 1 part of zinc as the most suitable material for a standard bar. This alloy is still known by the name of **Baily's metal.** The work of restoration was finally completed by Rev. R. Sheepshanks, and the new standard imperial yard bar that he produced is now known as *Bronze No. 1.* It is made of Baily's metal; its length is 38 inches, its width 1 inch, and its depth 1 inch.

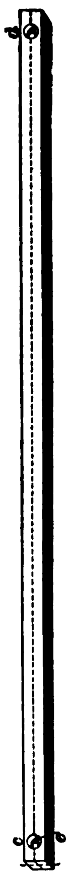


FIG. 1.

4. This bar is shown in Fig. 1. At a distance of 1 inch from each end of the bar, holes *c* are drilled in which gold plugs are inserted. The upper surface of the plugs is made coincident with the axis of the bar, to obviate the influence of flexure. Defining lines *c* and *d* are ruled on the plugs 36 inches apart; these lines are parallel and at a right angle to the axis. They represent the yard at a temperature of 62° F. Four copies, known as **parliamentary copies,** were then made and distributed to the Royal Mint, the Royal Observatory, the Royal Society, and the Westminster Palace. The original bar is kept within the walls of the Houses of

Parliament, while the copy known as *Bronze No. 6*, which is the accessible standard used for comparisons, is preserved in the Strong Room of the Old Treasury. The use of these standard bars was legalized in 1854 by an Act of Parliament. Additional copies were eventually made, two of which were delivered in 1856 to the United States Government. These are technically known as *Bronze No. 11* and *Low Moor Iron No. 57*.

THE AMERICAN STANDARD.

5. It is a curious fact that no standard of length of the English system of measurement has ever been formally legalized in the United States. The bar used from 1832 to 1856 was merely *adopted* by the Treasury Department in 1832, but it was never formally declared to be the legal standard.

6. This bar is known technically as *The Troughton Scale*. It is a brass bar $2\frac{1}{8}$ inches wide and $\frac{1}{8}$ inch thick and 82 inches in length, which is subdivided by fine lines, and the distance between the defining lines of the twenty-seventh and the sixty-third inch is the standard yard. After 1856, the British bars presented to the United States were used, and are now used, as standard bars, whenever great precision is required. The use of the Troughton scale was abandoned because its graduations are too coarse for accurate comparisons, and also because it is considered somewhat unreliable owing to its form. The standard bars now in use have never been formally declared as the legal standard.

7. In 1866, Congress passed a law declaring a metric bar in the possession of the government to be a legal standard; so that the only standard of length recognized by law in the United States is the **meter**—the unit of length of the French system of measurement.

8. Working copies of the standard bars in the possession of the United States Government have been constructed by private firms engaged in the manufacture of measuring instruments and gauges; these copies have been carefully compared with the standard bars and form the working standard of reference of the manufacturers. The standard bars in the possession of the government form the **ultimate standard of reference.**

9. As far as measurements of angular dimensions are concerned, no ultimate standard of reference is required, since the principal unit of angular measurement (the degree) can always be originated by the subdivision of the circle.

KINDS OF MEASUREMENTS.

10. Line Measurements and End Measurements.—Measurements, in accordance with the manner in which they are performed, are divided into *line measurements* and *end measurements.*

Line measurements are made by comparing the coincidence of lines either with the naked eye, with the aid of a simple magnifying glass, or, finally, with the aid of a powerful microscope.

End measurements are made by comparing lengths with instruments that are brought in contact with the pieces to be compared.

11. In many cases, the measurements made by the mechanic are a combination of line and end measurements; thus, the setting of a pair of calipers by the graduations of a steel scale to a given dimension is purely a line measurement, while the measuring of the work with the calipers so set is an end measurement. This is an instance of linear measurement.

12. Angular Measurements. — Angular measurements may be made by comparison of the coincidence of lines, by end measurements, or by a combination of both. The draftsman, when using the ordinary draftsman's protractor, measures angles entirely by line measurements;

the mechanic, in using his bevel protractor, sets it to the given angle by line measurement, and compares the angle with that of the work by bringing the bevel protractor into proper contact with the work; that is, he then uses an end measurement.

MEASURING INSTRUMENTS.

INTRODUCTION.

13. Definitions.—A **measuring instrument** may be defined as any tool, device, appliance, or instrument that serves to *measure* or *compare* a linear, angular, superficial, or cubical dimension, or some manifestation of force, with some established unit of measurement.

14. A **gauge** in its broadest sense is any kind of a measuring instrument. As far as mechanics are concerned, the term "gauge" is commonly restricted in its sense to any reasonably unchangeable device or appliance that establishes or *defines* some particular linear or angular dimension, but in itself is incapable of being used for measuring in principal or secondary units any deviation from that dimension. Secondary units are integral parts or multiples of the principal units. Thus, the principal unit of length being the yard, the foot and the inch, which are integral parts, and the mile, which is a multiple of the yard, are secondary units of length. Likewise, the minute and the second are secondary units of angular measurement, as they are integral parts of the degree, which is the principal unit. To sum up, the difference between a measuring instrument and a gauge, under the restricted definition here given, is that the first *measures* by comparison with a unit, while the second *defines* a particular unit or part thereof.

15. Since the measurements made by the mechanic are confined almost entirely to the comparison of linear or angular dimensions, measuring instruments and gauges intended for superficial and cubical measurements, or measurements of some manifestation of force, will not be treated here.

INSTRUMENTS FOR LINEAR MEASUREMENTS.

THE RULE.

16. The Two-Foot Rule.—The best known measuring instrument for the comparison of linear dimensions is the **two-foot rule,** which is usually made up of four leaves hinged together to allow it to be folded for convenience in carrying. For the sake of convenience, the edges on both sides are usually graduated with different kinds of subdivisions; frequently, two or more different kinds of subdivision appear on the same edge. Thus, the rule being 24 inches long, one edge may be divided into 24 inches, and each inch subdivided into halves, quarters, and eighths. The opposite edge may have 12 inches subdivided into halves and tenths, and the other 12 inches subdivided into halves, quarters, and twelfths. Turning the rule over it will often be found to have its one edge divided into 24 inches, subdivided into halves, quarters, eighths, and sixteenths. The fourth edge often carries graduations marked $\frac{1}{2}''$, $\frac{1}{4}''$, $1''$, $\frac{3}{4}''$, etc. These graduations represent **reduced scales;** that is, an actual length of 1 foot is represented by $\frac{1}{2}$ inch, $\frac{1}{4}$ inch, 1 inch, $\frac{3}{4}$ inch, etc. Reduced scales are occasionally convenient for taking a measurement from a drawing made to a reduced scale. While, in general, the practice of taking dimensions from a drawing or blueprint by scaling is not to be encouraged, there are occasions when for various reasons it must be done.

17. Two-foot rules are usually made of boxwood; the most expensive are made of ivory. Divisions smaller than $\frac{1}{16}$ inch are rarely marked on them, since the soiling they receive in use would soon render fine divisions illegible.

When divided into sixteenths, the smallest fraction of an inch that can be directly measured is $\frac{1}{16}$, but with a little practice it is possible to locate the middle point between the sixteenth-inch marks with a fair degree of accuracy, thus making it possible to measure distances as small as $\frac{1}{32}$ inch. It is customary to mark each inch graduation by a number that represents its distance in inches from the *right-hand end;* that is, the numbers increase from right to left. The numbers increase from right to left because the two-foot rule is mostly used in such a manner that its right-hand end forms a stop from which the required dimension is transferred by a lead-pencil mark or by scribing to the work. The two-foot rule is well adapted to comparatively rough work, where accuracy of measurement is not particularly essential.

18. The Standard Steel Rule.—For the use of machinists, and for more accurate measurements in general, so-called **standard steel rules** are used. In the better class of these instruments, all graduations are cut in a dividing machine; the accuracy of such standard steel rules when obtained from reputable makers is truly wonderful when the low price at which they are sold is considered. Standard steel rules bought in the open market are always graduated on both sides and both edges, and a large choice of different kinds of graduations is offered by the makers.

19. Fig. 2 shows the graduations of one side of a six-inch standard steel rule having several kinds of graduations along each edge. For convenience, and also for the purpose of an extensive range, the different kinds of graduation on each edge are usually made multiples of one another. Thus, on one edge are given divisions of the inch into 12, 24, and 48 parts, and on the other edge into 16, 32, and 64 parts. The figures denoting inches almost invariably increase from left to right, or in a direction opposite to that in which they are given on a two-foot rule.

There are several cases that may arise in practice, each of which requires a different method of procedure in using

the rule. Suppose that the measurement to be taken from the rule is smaller than the number of inches having the smallest number of divisions. Then, given a distance of, say, $3\frac{7}{12}$ inches, to set a pair of calipers to this dimension, place one leg against the left-hand end of the rule shown in Fig. 2 and in line with the graduation of the upper edge. Open the calipers until the other leg coincides with the seventh line past the 3-inch mark, counting from left to right. In case it is considered more convenient to make the measurement from the right, place one leg of the calipers against the right-hand end of the scale in line with the upper graduations. Count off a number of inch spaces equal to the whole number of inches called for by the given dimension, which is 3 in this case. Then count off to the left a number of twelfth graduations equal to the numerator of the fraction of the given dimension, which is 7 in this case. Open the calipers until the other leg coincides with the line denoting a distance of $3\frac{7}{12}$ inches from the right-hand end.

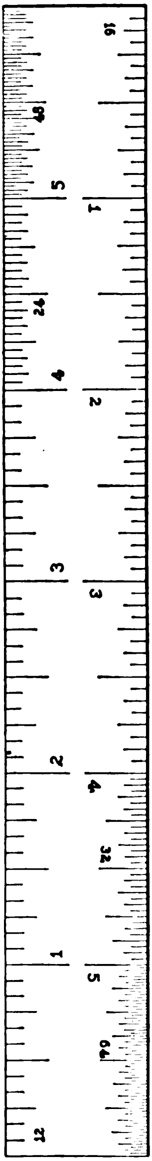


FIG. 2.

20. It will be observed that no attention has been paid to the figures denoting the inch divisions in this case. As these figures become smaller in value toward the left, the operation that has been performed is distinctly a case of mechanical subtraction; that is, $3\frac{7}{12}$ inches has been subtracted from the total length of the scale, which is 6 inches in this case. Then, the line denoting a distance of $3\frac{7}{12}$ inches from the right-hand end will be $6 - 3\frac{7}{12} = 2\frac{5}{12}$ inches from the left-hand end. It is thus seen that we could either actually perform the subtraction arithmetically in order to find the position of a line denoting a given distance from the right-hand end, or perform it mechanically. In the latter case, the actual subtraction is saved; there is also less liability of making an error.

21. When setting dividers to a rule, the greatest accuracy can be obtained by setting them until their points coincide with division lines that are the required distance apart. Thus, suppose that dividers are to be set to $3\frac{7}{12}$ inches by the rule shown in Fig. 2. Then, we may place one point into the division mark of the fourth inch, count to the left 3 whole inches, and 7 twelfth divisions, and adjust the other point until it just drops fairly into the division mark.

22. Sometimes it is more convenient to work both to right and left of a whole inch mark. Thus, taking the same dimension, we may start at the 1-inch mark and count 7 twelfth divisions to the left of it and 3 whole inches to the right of it, in order to get the positions of the division marks denoting a distance of $3\frac{7}{12}$ inches.

23. Now, suppose that the given dimension is larger than the number of inches on the rule divided into parts equal to the denominator of the fractional part of the given dimensions. We must then encroach upon the parts of the scale divided into multiples of this denominator. Assume that calipers are to be set to $5\frac{9}{12}$ inches. Then, inspection shows that by working from the right-hand end we can most easily obtain this distance by counting off 5 whole inches and 9 twelfth divisions. But we may also work from the left-hand end. Inspection of the last inch on the right-hand end and upper edge of the rule shows it to have twelfth divisions which are subdivided again into forty-eighths. Then, to obtain $5\frac{9}{12}$ inches, place one leg of the calipers against the left-hand end of the scale and in line with the upper graduation. Count 5 whole inches to the right and then count off 9 of the twelfth divisions on the inch subdivided into forty-eighths.

24. We will now assume that a pair of dividers is to be set to $5\frac{7}{12}$ inches. Evidently, with the given scale, we cannot put one point of the dividers in one of the full-inch marks, since the greatest measurement that can then be obtained is only 5 inches, or less than the required distance. Neither can we use the first half-inch mark, either on the right-hand end or the left-hand end, since the largest measurement that may be obtained is only $6 - \frac{1}{2} = 5\frac{1}{2}$ inches, or less than the required distance. But we may readily find the location of a graduation mark from which to start the measurement by choosing a graduation that is nearer the end of the rule than the difference between the length of the rule and the given dimension. The difference is $6 - 5\frac{7}{12} = \frac{5}{12}$ inch. Choosing the graduation mark representing the first quarter inch from the right-hand end, we place one point of the dividers into it. Now, *considering this line as the starting point of the graduations* and disregarding the full-inch marks entirely, count off 5 whole inches and then 7 of the twelfth divisions. Adjust the other point of the dividers to drop fairly into the division line.

25. When measurements are to be made that have a fraction expressed in multiples of the smallest number of divisions given on the rule, it is usually most convenient to work to the right and left of the mark, defining the beginning of the graduation equal to the denominator of the given fraction. For instance, referring again to Fig. 2, let it be required to find the division lines that define $4\frac{27}{48}$ inches. Then, since the forty-eighth division commences at the fifth inch mark, count off 4 full inches to the left of this mark, and next count off 27 forty-eighth divisions to the right of it.

26. The Gear Rule.—For special purposes, rules are occasionally made with inches subdivided into an uncommon number of divisions. Thus, in sizing the blanks for spur gears, it is very convenient to have a rule in which successive inches are divided to suit the various diametral pitches. For this purpose, special rules can be obtained.

For example, The Brown & Sharpe Manufacturing Co., Providence, Rhode Island, makes a 12-inch rule having the following subdivisions of the inch:

First edge: 11, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25.

Second edge: 16, 32, 64.

Third edge: 26, 27, 28, 29, 30, 31, 33, 34, 35, 36, 37, 38.

Fourth edge: 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 100.

The method of obtaining measurements from such a rule does not differ in any essential particular from that described in connection with Fig. 2.

27. The Differential Rule.—In order that dividers may be set to thousandths of an inch, The Brown & Sharpe

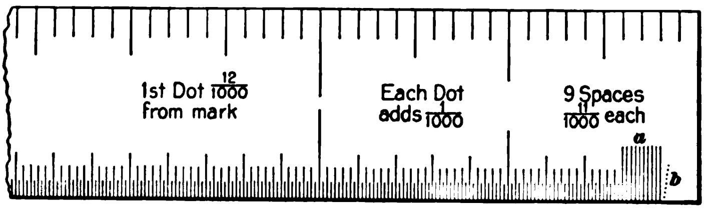


FIG. 3.

Manufacturing Co. furnishes a special rule having a peculiar system of graduation at one end, as shown at *a* in Fig. 3. This rule may be described as a **differential rule.** The one edge of the scale, the lower one in this instance, is divided into inches and hundredths of an inch. At the end of the hundredth graduations there are 10 lines more, the distance between which is made $\frac{11}{1000}$ inch. Beyond the last line there is a row of 8 dots, shown at *b*, so placed in reference to the last graduation line that the first dot, which is the one nearest the edge, is $\frac{12}{1000}$ inch from it; the second dot is $\frac{13}{1000}$ inch from it; the third $\frac{14}{1000}$; the fourth $\frac{15}{1000}$; the fifth $\frac{16}{1000}$; the sixth $\frac{17}{1000}$; the seventh $\frac{18}{1000}$; and the eighth $\frac{19}{1000}$. In order to show the divisions clearly, the illustration is made twice the real size. By the aid of the 9 supplementary lines shown at *a*, dividers can be set to any dimension within the range of the rule and greater than .1 inch. By the aid of the row of 8 dots, any dimension greater than .01 inch inclusive can be laid off in thousandths of an inch.

28. In order to be able to use the rule with facility, it is necessary to express the decimal part of the dimension in thousandths of an inch. In case it is expressed in tenths or hundredths, annex enough ciphers to reduce it to thousandths. Thus, read 1.5″ as 1.500″, and 4.47″ as 4.470″.

29. To set dividers to a dimension that is between .012 and .019 inch, inclusive of both, place one leg of the dividers in the last line of the graduation shown at *a* and adjust the other leg to the dot representing the given distance from the last graduation line. Thus, if dividers are to be set to .017 inch, measure from the sixth dot to the last graduation line.

30. To set dividers to any dimension that ends in a zero, use the regular hundredth graduation, remembering that every space on this graduation represents .010 inch. For instance, to set dividers to .450 inch, set off 45 of the hundredth spaces. If the dimension is, say, .070 inch, set off 7 of the hundredth spaces.

31. Any dimension that is between .021 and .118 inch, and is equal to the sum of any multiple of .011 inch, up to and including .099 inch, and any number from .012 to .019 inch, inclusive, can be obtained by measuring from one of the dots shown at *b* to one of the graduation lines shown at *a*. To find out which dot and line is to be used, subtract successively .011, .022, .033, .044, .055, .066, .077, .088, and .099 inch until the remainder is a number that lies between .012 and .019 inch, inclusive of both. Always subtract from the given dimension. For instance, let it be required to set dividers to .049 inch. Subtracting .011 inch from .049 inch, we get .038 inch as a remainder. Subtracting .022 inch, we get .027 inch. Subtracting .033 inch, we get .016 inch, which remainder lies between .012 and .019 inch. Now, we know from the construction of the rule that the fifth dot is .016 inch from the last graduation line. Place one leg of the dividers in this dot. Now, the number of spaces that must be taken on the graduation shown at *a* is always equal to the first significant figure of the last subtrahend. The last subtrahend equals .033; the first significant figure is 3; hence, set off three spaces in addition to the dimension denoting the distance from the last graduation line of the dot in which one leg of the dividers is placed. That is, open the dividers until the other leg coincides with the line between the third and fourth space, counting from right to left.

32. Any dimension that is directly a multiple of .011 inch up to and including .099 inch, as .011 inch, .022 inch, .033 inch, etc., can be obtained directly from the graduation shown at *a*, taking a number of spaces equal to the first significant figure of the given dimension. For instance, to set dividers to .088 inch, take 8 spaces, since the first significant figure is 8.

33. All dimensions that are not covered by any of the foregoing directions may be obtained by using the graduations shown at *a* in conjunction with the regular graduation. The number of spaces that are to be taken on the graduation shown at *a* is always equal to the last figure of the given dimension. The number of hundredth spaces that are to be taken is readily found by multiplying the last figure of the given dimension by .011 and subtracting this product from the given dimension. Thus, let it be required to set dividers to 1.576 inches. The last figure is 6, hence take 6 spaces of the graduation shown at *a*; that is, place one leg of the dividers on the line between the sixth and seventh space, *counting from left to right.* To find how many hundredth spaces to take, we subtract $6 \times .011 =$ .066 inch from 1.576 inches, getting 1.51 inches, or 151 hundredth spaces. Then, from the end of the regular graduation, count off 151 spaces; that is, place the other leg of the dividers on the line between the one hundred fifty-first and the one hundred fifty-second.

34. Facility in the use of this kind of a rule can only be obtained by actual practice with it. Practice will soon enable the user to perform the necessary calculations mentally, and measurements can then be made almost as quickly as with an ordinary rule. The rule here explained is not very well adapted for any purpose other than the setting of dividers.

35. The Shrink Rule.—For the use of patternmakers and molders, a special rule is made that is known as a **shrink rule.** Cast iron and brass shrink somewhat in cooling; for this reason, allowance has to be made in making the pattern or mold, in order that the casting may be of the correct dimensions. The average amount of shrinkage is $\frac{1}{8}$ inch per foot for cast iron; that is, if the mold for a rectangular bar is $12\frac{1}{8}$ inches long, the casting will be about 12 inches long. Now, to make a pattern with the aid of an ordinary rule would require a calculation for each separate dimension in order to obtain the proper shrink allowance. But if a rule is constructed where the foot is $12\frac{1}{8}$ inches long, and if this lengthened foot is subdivided into proportional inches and fractions thereof, by the use of this rule the proper shrink allowance is then made.

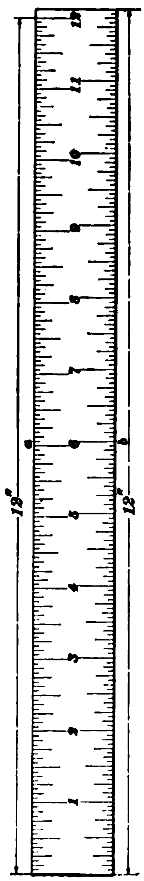


FIG. 4.

Shrink rules are made of steel or of boxwood; they can be obtained for cast iron and for brass. If intended for cast iron, $12\frac{1}{8}$ inches represent a length of 1 foot; those intended for brass castings have a shrink allowance of $\frac{3}{16}$ inch per foot, that is, $12\frac{3}{16}$ inches represent 1 foot. Many shrink rules for the sake of convenience have a standard graduation on one edge and a shrink graduation on the other edge. Such a rule is shown in Fig. 4. The rule illustrated has the standard graduation on the edge *a*; the opposite edge *b* has a length of 12⅛ inches, divided into 12 parts subdivided into 16 parts each, to form the shrink rule.

THE CALIPER SQUARE.

36. The **caliper square** shown in Fig. 5 is a measuring instrument in which line and end measurements are made at the same time, in order to obtain the size of work.

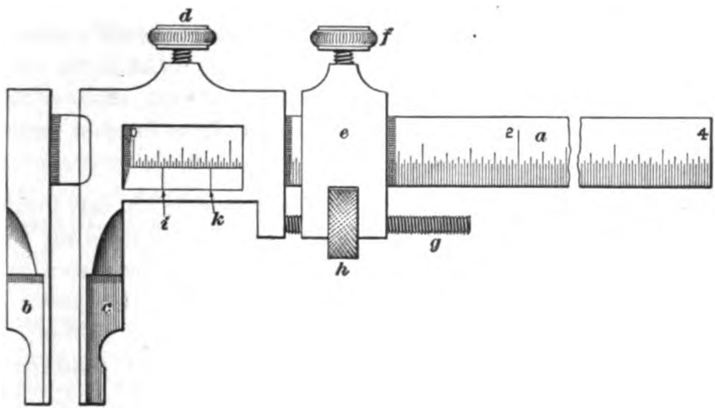


FIG. 5.

Referring to the figure, the caliper square consists of a graduated beam *a* fitted with a stationary head, or **jaw,** *b*, whose inner surface is straight and at a right angle to the beam. A sliding head *c* is carefully fitted to the beam, to which it can be clamped by means of the small thumbscrew *d*. The sliding head carries a jaw whose inside surface is exactly parallel to that of the fixed jaw. On the better grade of instruments, a supplementary sliding head *e* is fitted which can be clamped to the beam by means of the screw *f*. The two sliding heads are connected together by a fine-threaded screw *g*, which is fixed to *c* and passes through a clearance hole in *e*. A nurled nut *h* is set into a slot cut in *e*, and is screwed over *g*. By means of this supplementary sliding head, a very sensitive adjustment is possible, since, by first clamping *e* and slightly turning the nut *h*, the sliding head *c* can be moved a very small amount with the greatest ease. It will be understood that the sliding head *c* must always be unclamped when it is desired to move it.

37. The distance that the jaws are apart is indicated by the coincidence of a **zero line,** as *i*, with the graduation on the beam. The zero line on the sliding head coincides with the zero mark of the graduation on the beam when the jaws are against each other. In some designs of caliper squares, the zero line on the sliding head is omitted; the zero is then indicated by the edge of the sliding head. That is, to read the opening of the jaws in such a caliper square, observe the position of the edge of the jaw on the sliding head in reference to the graduation on the beam.

38. Most caliper squares are adapted both for inside and outside measurements. This is done by forming the lower parts of the jaws so that their outside surfaces are parallel and some definite distance apart when the jaws are closed. In most calipers, this distance is $\frac{1}{4}$ inch. Then, to take inside measurements, *add* the distance to that read from the graduation.

In the caliper square shown in Fig. 5, the necessity of adding has been overcome by adding a supplementary zero line *k* for inside measurements. When the jaws are brought together, the line *k* shows by its coincidence with a graduation line the distance from outside to outside of the measuring surfaces at the lower end of the jaws. Hence, for outside measurements, read the dimension by means of the line *i*; for inside measurements, use the line *k*.

THE MICROMETER CALIPER.

39. Let a screw of known pitch be carefully fitted in a fixed nut so that the screw can be turned while the nut remains stationary. Then, if the screw is turned one complete revolution, it will have advanced in the direction of its axis a distance exactly equal to the pitch of the thread. But, if it is turned exactly one-half of a complete revolution, it will advance a distance equal to one-half the pitch of the thread. Following this line of reasoning, it is seen that the amount advanced is always equal to the product of the pitch and the fraction expressing the part of the revolution through which the screw has been turned. Thus, if the pitch of the thread is $\frac{1}{40}$ inch, and if the screw is turned $\frac{1}{25}$ part of a complete revolution, the amount advanced will be $\frac{1}{40} \times \frac{1}{25} = \frac{1}{1000}$ inch.

40. The micrometer caliper is based on this principle. In order that it may be determined easily through what part of a revolution the screw has been turned, the **micrometer screw** *c*, Fig. 6, is supplied with a **thimble** *d*, which is graduated on the front. An axial line engraved on the **barrel** *a* serves as a zero line from which to read off

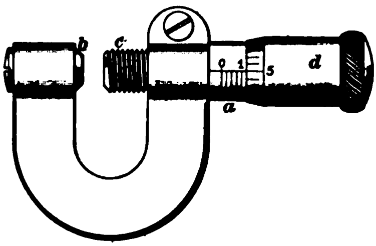


FIG. 6.

through what part of a revolution the micrometer screw has been turned. In order to adapt the micrometer screw for end measurements, an **anvil** *b* is provided, the surface of which is a plane surface parallel to that on the end of the screw. The anvil is so adjusted that when the end of the micrometer screw is in contact with it, the zero line of the graduation on the thimble will coincide with the axial zero line on the barrel. Now, assuming that the micrometer screw and the anvil are in contact, let the micrometer screw be turned until the graduations on the thimble show, by reference to the zero line on the barrel, that it has made $\frac{7}{25}$ of a revolution. Then, the opening between the end of the micrometer screw and the anvil will, if the pitch of the thread is $\frac{1}{40}$ inch, be $\frac{1}{40} \times \frac{7}{25} = \frac{7}{1000}$ inch. Almost all micrometer calipers made today use a screw having 40 threads per inch, or a pitch of thread of $\frac{1}{40}$ inch, and have the thimble graduated so that each space is equal to $\frac{1}{25}$ of a revolution. Hence, they read directly to thousandths of an inch.

41. Now, in order to measure sizes in excess of $\frac{1}{40}$ inch, the screw must make more than 1 turn. To obviate the labor of counting how many complete turns have been made, the zero line on the barrel is subdivided by lines at a right angle to it, and the distance between these graduation lines is made equal to the pitch of the screw, or $\frac{1}{40}$ inch. The first one of these graduation lines is placed so that it comes even with the end of the thimble when the micrometer screw and anvil are in contact. Then, if the micrometer screw is turned one complete revolution, the second graduation line will be even with the end of the thimble, so that the thimble is 1 space from the beginning of the graduation on the barrel. If the micrometer screw is turned through another revolution, there will be 2 spaces visible; hence, the number of spaces shows how many complete turns the micrometer screw has made. As each space represents $\frac{1}{40}$ inch, or $\frac{25}{1000}$ inch, to find the distance represented by an unknown number of whole turns, count the number of spaces and multiply by 25. Read off the fractional part of a turn and add it to the first value. Expressed as a rule, we have:

Rule.—*To read a micrometer caliper, multiply the number of* **whole** *spaces visible on the barrel by 25. Add the number of spaces between the zero line of the thimble and the zero line on the barrel, expressed as thousandths of an inch.*

42. The graduations on the barrel are invariably marked at the end of each 4 spaces with the figures 1, 2, 3, etc. By the aid of these figures and with a little practice, the multiplication called for in the rule may be saved. The figures given stand for an opening of .1, .2, .3 inch, and so on. Now, as each space represents a distance of $\frac{25}{1000}$ or .025 inch, the line at the end of the first space denotes .025 inch opening; the line at the end of the second space .050 inch;

the line at the end of the third space .075 inch. Then, in order to save multiplication, we have the following:

Rule.—*Look for the last figure that is exposed on the barrel. This is the first decimal figure of the dimension. Count the number of* **whole** *spaces beyond the last figure and between it and the end of the thimble. For one space, annex 25; for two spaces, annex 50; and for three spaces, annex 75 to the first figure. Mentally add the number of spaces between the zero line of the thimble and the zero line on the barrel, counting from the zero line of the thimble forwards, and expressed as thousandths of an inch.*

EXAMPLE.—What is the reading of the micrometer shown in Fig. 6?

SOLUTION.—The last figure that is exposed is 1. Since there is one whole space between this figure and the end of the thimble, annex 25, giving .125. The line at the end of the fifth space of the thimble coincides with the zero line on the barrel, hence add .005 inch, making the reading .125 + .005 = .130 inch. Ans.

43. Since the micrometer screw is made only long enough to give dimensions from 0 to 1,000 thousandths, any whole number of inches included in the measurement must be prefixed to the reading of the micrometer. Thus, in a 2-inch micrometer caliper, the micrometer screw will only give readings between 1 and 2 inches when the anvil and screw are arranged in such a manner that they are 1 inch apart when the micrometer is closed. In that case, 1 inch must always be prefixed to the reading. For instance, if the reading is .376 inch, the opening between screw and anvil is 1 + .376 = 1.376 inches. If the number of spaces between the zero line of the thimble and the zero line of the barrel is a whole number plus a fraction, estimate from the position of the zero line on the barrel what part of the space the fraction is, when expressed as tenths of a space. The numerator of the fraction will be the *fourth* figure to the right of the decimal point.

EXAMPLE.—If the first reading of the micrometer is .300 inch, and it is estimated that $\frac{4}{10}$ of a space more is included in the measurement, what is the reading?

SOLUTION.—Annexing the numerator of the fraction, we get .3004 inch as the reading. Ans.

44. When a measurement is to be made with a micrometer caliper, the operator places the work between its measuring points, i. e., between the anvil and the end of the micrometer screw. The micrometer screw is then slowly revolved until the sense of touch tells the operator that the micrometer screw is in contact with the work. The reading of the micrometer caliper is then taken.

Before making measurements with a new or strange micrometer caliper, it is considered a good idea to screw anvil and micrometer screw together, and note how much force is required to bring the zero line of the thimble in line with the zero line of the barrel. Then the operator should screw the micrometer screw against the work with the same force, in order to get a fairly correct measurement.

45. While the micrometer caliper obtained from a reliable maker will indicate sizes correctly within an extremely small limit of variation, this does not by any means imply that sizes can be measured within that limit of variation. The accuracy with which a size can be measured with an accurate micrometer caliper depends almost entirely on the sense of touch of the operator and the amount of training received.

46. The micrometer caliper shown in Fig. 6 is the oldest form of this instrument. It has been selected for illustration because it clearly exhibits the salient features of the micrometer caliper. In the more recent designs, the micrometer screw is encased within the barrel, as shown in Fig. 7, and is thus protected from injury and dust. A locking device is frequently supplied, by means of which the micrometer screw may be prevented from rotating; the micrometer caliper is thus transformed into a fixed gauge adjustable for size. Micrometer calipers are made in a great variety of forms, to suit different purposes and individual preferences; they are also made for measuring the inside of work. However, they all embody the same principle of operation. All the different forms of micrometer calipers are illustrated and fully described in the catalogues of the various makers of these instruments, from which the student can make his selection.

47. Nearly all the modern micrometer calipers that measure in accordance with the English system of measurements are stamped on the frame with a table of the decimal equivalents of the binary divisions of the inch. Thus, in the micrometer caliper shown in Fig. 7, on one side are stamped

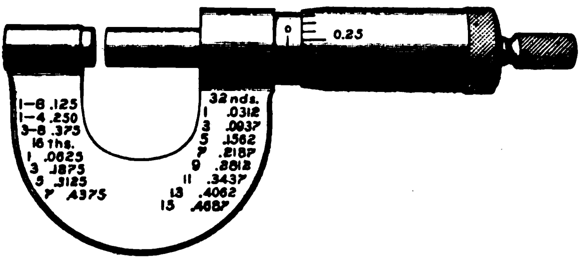


FIG. 7.

the decimal equivalents of eighths, sixteenths, and thirty-seconds; the other side contains the decimal equivalents of sixty-fourths within its range. This is very convenient, since, in many cases, the micrometer is used for measuring work to be finished to a given binary dimension. When micrometer calipers are made to measure in accordance with the metric system, no decimal equivalents are needed, since all divisions of the meter are decimal.

For special purposes, other tables are occasionally stamped on the frame, and sometimes certain useful formulas. Thus, a special micrometer caliper intended for measuring the thickness of tubing has stamped on it the gauge numbers and the decimal equivalents thereof of the gauge used by tube makers.

MEASURING MACHINES.

48. A measuring machine is used for measuring sizes beyond the range of the portable micrometer caliper, and a special design of it is used for measuring within a degree of accuracy not obtainable with an instrument constructed entirely on the principle of the micrometer caliper. There are a number of measuring machines in the market that differ only in the design of the details.

49. A representative design of a measuring machine that embodies all the features found in machines intended

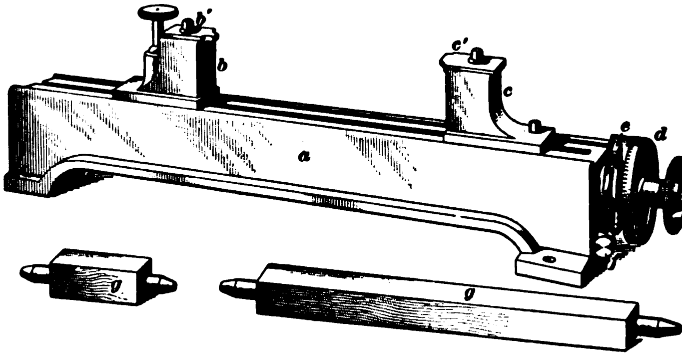


FIG. 8.

for shop use is that shown in Fig. 8. This machine is built by The John M. Rogers Boat, Gauge, and Drill Works, Gloucester City, New Jersey. In this machine, which embodies the principle of the micrometer caliper, the accuracy within which measurements can be made is dependent on the sense of touch of the operator. The limit is placed by the makers at .0001 inch, which is a conservative estimate.

Referring now to Fig. 8, the machine is seen to consist of a very rigid bed *a* to which two heads *b* and *c* are carefully fitted. These heads carry the hardened measuring points *b'* and *c'*. The head *b* can be slid along the bed and clamped rigidly to it. The head *c* is attached to a micrometer screw that carries a graduated index wheel *d*. This index wheel takes the place of the graduated thimble of the micrometer caliper, and serves the same purpose. The zero line, by means of which the rotation of the micrometer screw is observed, is drawn on an arm *e* mounted on a journal in such a manner that it can be slightly rotated around the axis of the micrometer screw. A screw *f* serves for this purpose.

50. When about to measure some size within range of the machine, the sliding head *c* is first placed at its farthest practicable position from the index wheel. The index wheel is then turned until its zero line coincides with the zero line on the arm *e*. The head *b* is now adjusted in reference to *c* by means of a test bar *g*, two of which are shown in Fig. 8. This distance is roughly adjusted by placing the test bar between *b'* and *c'* and pushing *b* by hand against the end of the test bar. The head *b* is now clamped, and the final adjustment made by slightly turning *d* until the operator is told by his sense of touch that the ends of the test bar are just in contact with the measuring points *b'* and *c'*. Now, by means of the screw *f*, the arm *e* is rotated until its zero line coincides with the zero line of the index wheel. The setting of the machine is now complete.

To measure with the machine, the work is placed between the points *b'* and *c'*, which are adjusted by turning the index wheel until his sense of touch tells the operator that the degree of contact is the same as that of the test bar with the measuring points. The fractional part of the revolution is read off the index wheel, which, by means of a special device called a **vernier,** is read to twenty-thousandths of an inch.

51. The test bars used for setting the machine are simply hardened steel bars ground and lapped on the ends until their length represents accurately a certain number of inches.

52. For end measurements that require to be made within the commercially possible limit of variation, machines are employed that depend but very little on the sense of touch of the operator for the correctness of the measure. The Pratt & Whitney measuring machine shown in Fig. 9 is a representative design of a machine intended for very fine measurements. With it, measurements within a limit of variation of .00001 inch can be made quite readily. This machine may be considered as a very refined combination of a caliper square and a micrometer, to which a special

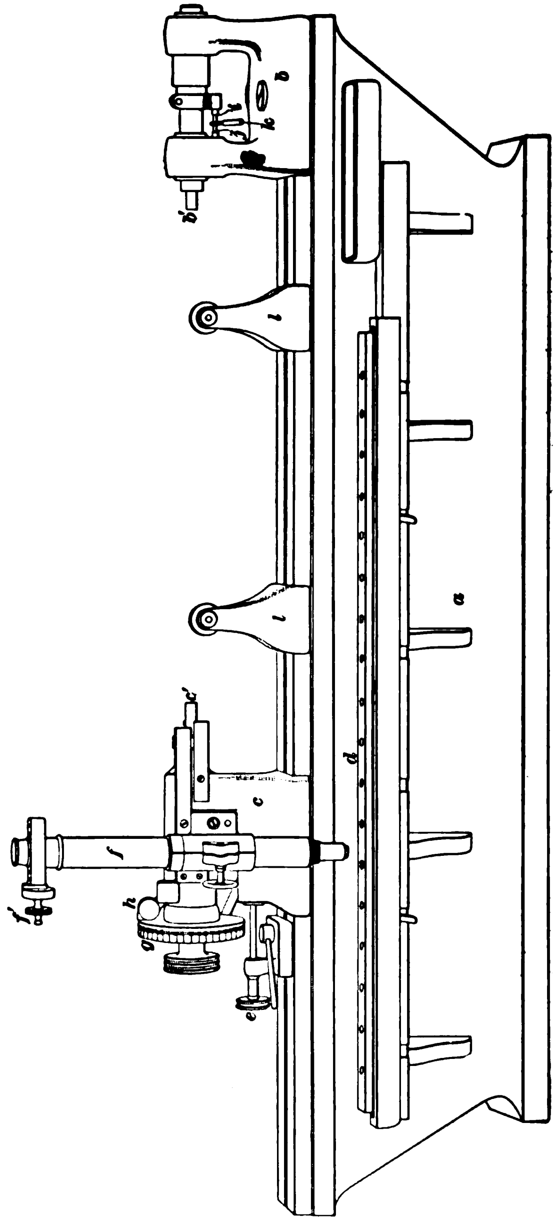


FIG. 9.

device for noting the degree of contact of the measuring points with the work has been added.

53. The machine consists of a rigid bed *a* supported on three points to obviate flexure; a stationary head *b* which carries the stationary measuring point *b'*; a sliding head *c* which carries the movable measuring point *c'* and the micrometer mechanism for moving the point and reading its movement; and, finally, a graduated test bar *d*, which is graduated to submultiples of the standard yard, or meter, usually to whole inches or to 25 mm. The sliding head *c* is set to coincide with the graduations on the test bar *d* by means of a fine-threaded screw *e*; a powerful microscope *f* shows when the sliding head is set correctly in reference to the graduations on the bar. In the machine shown, the micrometer screw has 50 threads per inch, or a pitch of thread of $\frac{1}{50}$ inch. The index wheel is divided into 400 spaces, so that each space represents a forward movement of the micrometer screw amounting to $\frac{1}{20000}$ inch. The fifth part of the space can readily be estimated by the eye. The zero line from which readings are obtained is engraved on an arm *h*, which can be slightly rotated about the axis of the micrometer screw by means of a suitable screw.

The measuring point *b'* of the stationary head is free to slide in its bearing; it is pushed outwards by a light helical spring. An auxiliary measuring point *i* is rigidly fastened to the measuring point *b'* and moves with it. A second, but stationary, auxiliary measuring point *j* is fastened to the frame of the stationary head in line with *i*. A small, light **feeling piece** *k* is placed between the auxiliary measuring points, and determines by its behavior the degree of contact of the primary measuring points at zero and with the work. When no pressure is exerted against *b'*, tending to push it inwards, the feeling piece is subjected to the whole pressure due to the tension of the helical spring. Let the piece be inserted so that one end is between the auxiliary measuring points, and the piece itself is in a horizontal position. Then, the friction due to the pressure exerted by the helical spring will hold the feeling piece in its horizontal position. Now, let a pressure that tends to push *b'* inwards be exerted against *b'*. This has the effect of lessening the pressure on the feeling piece until finally the friction has become small enough for the feeling piece to rotate under the influence of its own weight about the end by which it is held. Then, if the work is always measured just when the feeling piece rotates under its own weight, it follows that the degree of contact is the same, within extremely small variations, for each measurement made.

54. To adjust the machine for use, the micrometer screw in the sliding head is run all the way out and the zero line on its index wheel *g* placed opposite the zero line on *h*. The sliding head *c* is brought forwards and pushed against *b'* until the feeling piece just rotates. For getting this adjustment roughly, the screw *e* may be used, but for final adjustment the index wheel is turned slightly. The arm *h* is rotated until its zero line coincides exactly with the zero of the index wheel. The microscope is next adjusted so that the spider web in it coincides with the zero line of the test bar *d*. This is done by moving the spider web by means of the micrometer screw *f'* supplied with a graduated index wheel. The adjustment is now complete, giving the zero for the entire capacity of the machine.

55. To make a measurement, the sliding head is run back and adjusted by means of the screw *e* until the spider web of the microscope coincides with a graduation on the bar corresponding to the whole number of inches of the measurement to be made. The micrometer screw is now unscrewed sufficiently to admit the work between *c'* and *b'*; with the work resting on the supports *l*, *l*, the micrometer screw is then moved until the behavior of the feeling piece shows the correct degree of contact to have been obtained; the reading of the micrometer is then taken and added to that given by the test bar.

56. In order to obtain accurate results, it is very necessary to take the effect of changes in temperature into account. As is well known, all metals expand if their temperature is raised, hence it follows that a piece measured at a temperature beyond the normal one will measure less when cooled. While the change in length or size is not appreciable when using an ordinary micrometer caliper, except in skilled hands, its magnitude is very sensible when refined measuring machines are employed. The average temperature at which measurements of length are usually supposed to be correct is about 62°; all gauge manufacturers adjust their gauges to be correct at that temperature.

INSTRUMENTS FOR ANGULAR MEASUREMENTS.

THE PROTRACTOR.

57. The unit of angular measurement is $\frac{1}{360}$ part of a circle, which is called a **degree.** The degree is subdivided into 60 parts, called **minutes.** A minute is subdivided into 60 parts, called **seconds.** Smaller divisions of the degree are expressed as decimal parts of the second.

For the measurement of angles, an instrument called a **protractor** is used. The simplest form of protractor is that used by draftsmen for laying off angles on a drawing and for measuring the angle included between two lines drawn on a plane surface.

58. A common form of protractor is that shown in Fig. 10. The outer edge is a semicircle, with its center at *O*, and is divided into 360 parts. Each division is one-half of 1°, and, for convenience, the degrees are numbered from 0° to 180° from both *A* and *B*. Protractors are often made of metal, in which case the central part is cut away, to make the drawing under it visible. When using the protractor, it must be placed so that the line *O B*, Fig. 10, will coincide with the line forming one side of the angle to be laid off or measured, and the center *O* must be at the vertex of the angle.

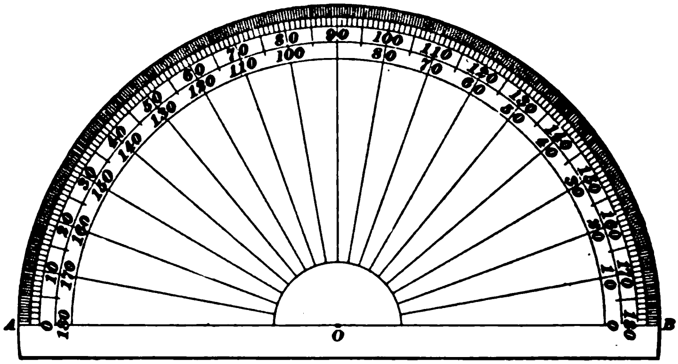


FIG. 10.

For example, let it be required to measure the angle between the line *C D* and *E F*, Fig. 11. Then, first of all, produce *E F* until it intersects *C D* in *C*. Now, place the

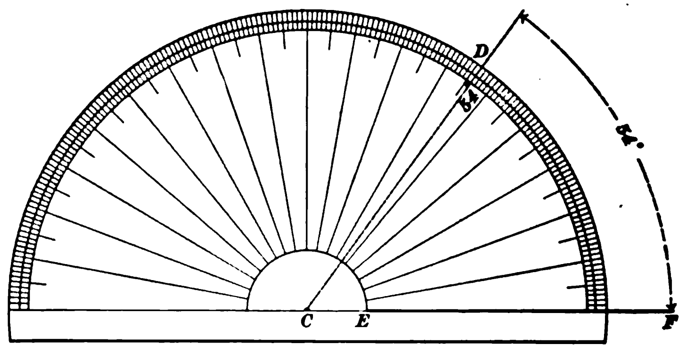


FIG. 11.

protractor upon the line *E F*, so that its center *O* (Fig. 10) coincides with *C* (Fig. 11) and its zero mark is in line with *E F*. Following up the graduations, it is seen that the 54° mark coincides with *C D*; hence, the angle included between *C D* and *E F* is 54°.

The measurements that can be made with the protractor shown belong to the class known as *line measurements*, since they depend entirely on the coincidence of lines.

THE BEVEL PROTRACTOR.

59. The angular measurements the mechanic is called upon to make can rarely be done with a protractor of the kind shown in Fig. 10. For mechanics' use, the protractor is modified to make measurements by a combination of line

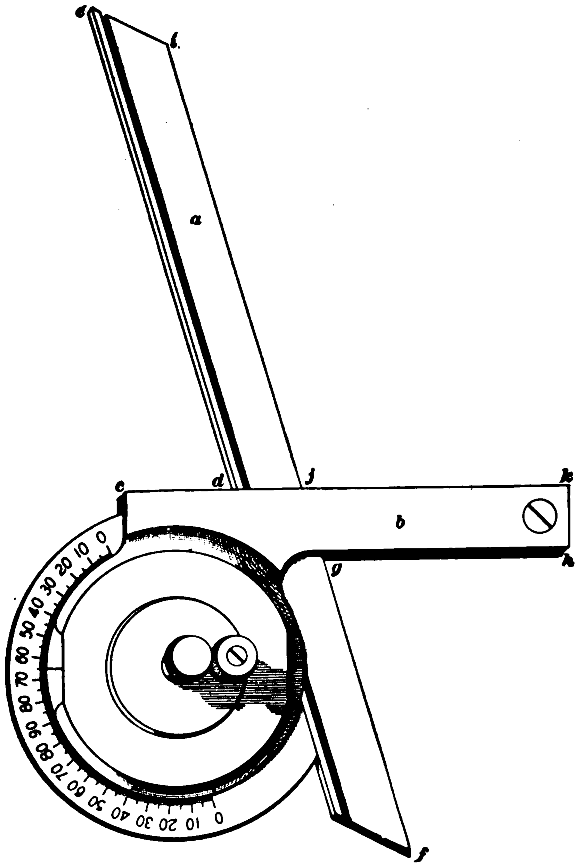


FIG. 12.

and end measurements. In this modified form, it is commonly known by the name of **bevel protractor.**

To suit different purposes and individual preferences, the bevel protractor is made in a number of different forms by the various manufacturers. All these forms embody the same principle of construction, which is the combination of two straightedges with a graduated circle or part of a circle.

60. All the salient features of the bevel protractor are well exhibited by the one illustrated in Fig. 12. The graduated semicircle is attached to the straightedge *a*, while two lines opposite each other and used as zero marks are on the straightedge *b*. The two straightedges are pivoted at the center of the graduated semicircle, and the zero lines on *b* are so placed that they exactly coincide with the zeros of the graduated semicircle when *a* and *b* are in the same plane; i. e., when the angle between them is 180°. For convenience, the straightedge *b* is slotted, to allow the straightedge *a* to pass through it; in consequence of this, either straightedge can be rotated through 360°. The straightedge *a* may be slipped back and forth its full length, and can be clamped at any point to the part on which the graduations are engraved.

61. To make a measurement, the two straightedges are brought in contact with the work; the angle is then read off by observing the position of the zero line on *b* in regard to the graduation. Some judgment is required to read the angle correctly; that is, if the angle measured is smaller than 90°, it can be read off directly, but if it is larger than 90°, the reading must be subtracted from 180°. Thus, the angles *c d e* and *f g h* are smaller than 90°. Since the zero line of *b* coincides with the mark denoting 65°, both of these angles are 65°. The angle *i j k*, however, is larger than 90°, hence its magnitude is $180 - 65 = 115°$.

THE VERNIER.

PRINCIPLE OF THE VERNIER.

62. There is a special system of graduations that serves to obtain very fine subdivisions of linear and angular dimensions without a confusing multiplicity of graduation lines. This system of graduations is employed in what is known as the **vernier,** so called from the name of its inventor. It is largely used on measuring instruments intended for measurements that depend primarily on the coincidence of lines.

63. In Fig. 13 (*a*) let *A* represent a scale that is divided into 10 equal parts, and let *A'* be another scale on which 9 of the equal parts of scale *A* have been divided into 10 equal parts. The scale *A* is called the **true scale,** and the scale *A'* the **vernier scale.** Now, evidently 1 division on *A'* is equal to $\frac{9}{10}$ of a division on the true scale *A*. Then, 5 divisions on the vernier scale will be equal to $5 \times \frac{9}{10} = \frac{45}{10} = 4\frac{1}{2}$ divisions on the true scale. If the zero points, or graduations, of the two scales be set opposite each other, the point *5'* on the vernier scale will be exactly at *4½*, or midway between *4* and *5* on the true scale. Therefore, if the zero point of the vernier scale be set exactly midway between *0* and *1* of the true scale, the point *5'* on the vernier scale will be exactly opposite the point *5* on the true scale, as shown in Fig. 13 (*b*). We thus

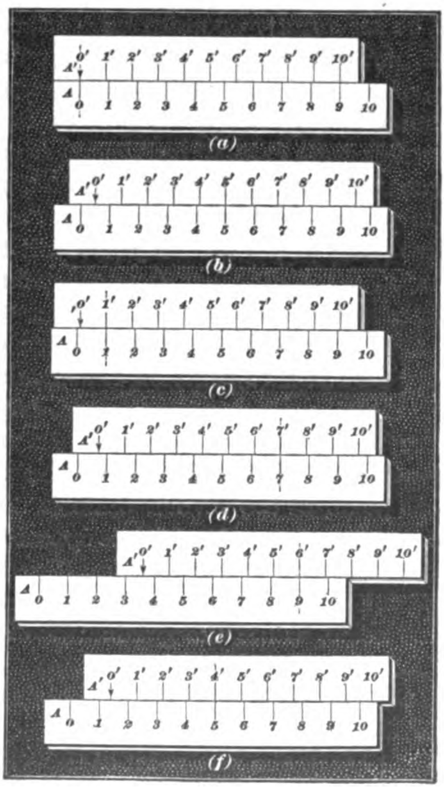


FIG. 13.

know that in order to place the zero point of the vernier scale exactly half way between the points *0* and *1* of the true scale, we have only to set the point *5'* of the vernier scale opposite the point *5* of the true scale.

Similarly, if we wish to set the zero point of the vernier scale at $\frac{1}{10}$ of a division from the zero point of the true scale, we have only to set the point *1'* on the vernier scale opposite the point *1* on the true scale. For, if the points *1* and *1'* be set exactly opposite each other, the zero point of the vernier will be at a distance of $\frac{9}{10}$ of a division from them, or $\frac{1}{10}$ of a division from the zero point of the true scale, as shown in Fig. 13 (*c*). If we wish to set the zero point of the vernier scale at $\frac{7}{10}$ of a division from the zero point of the true scale, we set the point *7'* on the vernier scale opposite the point *7* on the true scale, as shown in Fig. 13 (*d*). The zero point of the vernier scale will then be at a distance of $7 \times \frac{9}{10} = 6\frac{3}{10}$ divisions from the point 7, or $7 - 6\frac{3}{10} = \frac{7}{10}$ of a division from the zero point of the true scale.

But, in order that this principle shall hold, it is not necessary for the zero point on the vernier scale to be opposite the division adjacent to the zero point on the true scale; it may be opposite any division. In such a case, for the fractional part of the division of the true scale at which the zero point of the vernier scale is situated, that graduation of the vernier scale which is opposite *any* graduation of the true scale is read. Thus, in Fig. 13 (*e*), the zero point of the vernier scale is between the graduations *3* and *4* of the true scale, while the graduation *6'* of the vernier scale is directly opposite a graduation of the true scale. The zero of the vernier scale is thus known to be at a distance of $3\frac{6}{10}$ divisions from the zero point of the true scale. Similarly, in Fig. 13 (*f*), the zero point of the vernier scale reads $1\frac{4}{10}$ on the true scale. It will be found that for *any* position of the vernier scale, the position of its zero point, with reference to the graduations of the true scale between which it is situated, will be correctly indicated by that graduation on the vernier scale which is directly opposite a graduation on the true scale. The number of the graduation of the vernier scale which coincides with a graduation of the true scale will be the distance, in tenths of a division of the true scale, of the zero point of the vernier scale beyond its adjacent and next lower graduation of the true scale.

The foregoing illustrates the principles of the vernier, which is simply a device for reading smaller divisions of a scale than those into which the scale is divided.

64. There are two kinds of verniers, which are known as the **direct** and the **retrograde** vernier. Both of these accomplish the same purpose; they differ from each other in the manner in which the vernier scale is divided, which affects the reading of the vernier. Hence it is important to be able to distinguish quickly between a direct and a retrograde vernier. This can readily be done by a mental calculation made in accordance with the rule below; the rule given is perfectly general, in that it may be applied to *any* kind of a vernier.

Rule.—*Place the vernier scale so that its end graduation lines are in line with any two graduation lines of the true scale. Count the number of spaces on the true scale that are included between the end graduation lines of the vernier scale; divide this number by the number of spaces on the vernier scale. If the quotient is a mixed number, the fractional part of which has 1 for its numerator, the vernier is* **retrograde**; *in any other case it is* **direct.**

EXAMPLE 1.—Determine the kind of vernier shown in Fig. 13.

SOLUTION.—Placing the vernier scale as directed by the rule (see Fig. 13 (*a*)), it is seen that 9 spaces on the true scale are included between the end graduation lines of the vernier scale, which has 10 spaces. Dividing 9 by 10, we get $\frac{9}{10}$ as the quotient. Since the numerator of this fraction is not 1, the vernier is direct. Ans.

EXAMPLE 2.—What kind of a vernier is shown in Fig. 14?

SOLUTION.—There are 62 spaces included between the end graduations of the vernier scale, which itself has 60 graduations. Now, $62 \div 60 = 1\frac{2}{60} = 1\frac{1}{30}$. Since the numerator of the fraction is 1, the vernier is retrograde. Ans.

The direct vernier is almost exclusively used for instruments intended for linear measurements, and very largely for those that serve for angular measurements.

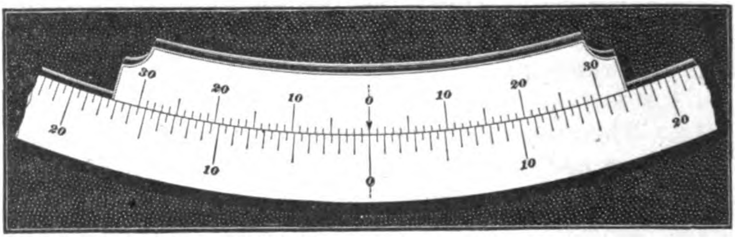


FIG. 14.

65. Referring again to Fig. 13, it has been seen that in this case the number of subdivisions of each division on the true scale that could be obtained were equal to the number of spaces on the vernier scale. If a number of different vernier scales be constructed, it will be observed that in all cases the subdivisions of each part of the true scale that can be obtained is *equal to the number of spaces into which the vernier scale is divided.*

Suppose that in Fig. 13 (*a*), the distance between the zero and tenth graduation mark is 1 inch, so that each space of the true scale is $\frac{1}{10}$ inch. Then, since the vernier scale subdivides each $\frac{1}{10}$ inch into 10 parts, it follows that by the aid of the vernier the scale can be read to $\frac{1}{100} = .01$ inch. From this fact we obtain the following rule:

Rule.—*To find the number of subdivisions of a unit of measurement obtained by the aid of a vernier, multiply the number of divisions of the true scale for one unit of measurement by the number of divisions of the vernier scale.*

EXAMPLE 1.—In a vernier, each inch of the true scale is divided into 16 parts. The vernier scale contains 8 divisions. What subdivision of the inch can be obtained?

SOLUTION.—Applying the rule just given, we get $16 \times 8 = 128$ as the number of parts into which the inch is divided. Ans.

EXAMPLE 2.—The unit of measurement on a true scale is not subdivided, while the vernier scale has 12 divisions or spaces. What subdivisions of the unit can be obtained?

SOLUTION.—Since the unit of measurement is not subdivided, the number of parts into which it may be conceived to be divided is 1. Then, by the rule just given, we get $1 \times 12 = 12$ subdivisions. Ans.

READING THE VERNIER.

66. From the principle of its construction, we obtain the following general rule for reading any direct or retrograde vernier:

Rule.—*Observe the location of the zero point of the vernier scale, to obtain the integral number of divisions it is from the beginning of the graduation of the true scale. From the* **zero point** *of the vernier scale,* **advance** *until a line is found that coincides with a line of the true scale. The number of spaces included between this line on the vernier scale and the zero point of the vernier scale is the number of the subdivisions obtained by the vernier that is to be added to the integral number of divisions.*

It is to be observed that when a direct vernier is used, the vernier scale must be read from its zero point onwards in the *same* general direction in which the numbers of the true scale increase. In a retrograde vernier, however, the vernier scale must be read from its zero point onwards in the *opposite* direction from that in which the numbers of the true scale increase. This fact must be carefully borne in mind.

EXAMPLE 1.—Read the indication of the vernier shown in Fig. 15.

SOLUTION.—By counting, each inch is shown to be divided into

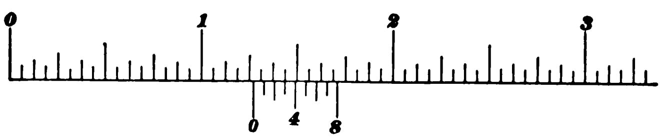


FIG. 15.

16 parts. As there are 8 divisions in the vernier scale, by the rule

given in Art. **65,** the vernier divides the inch into $16 \times 8 = 128$ parts. By the rule of Art. **66,** the zero point of the vernier scale is observed to be between the fourth and fifth graduations of the second inch, which shows that the measurement lies between $1\frac{4}{16}$ and $1\frac{5}{16}$ inches, and that the number of divisions of the true scale will read $1\frac{4}{16}$ inches. Starting at the zero point of the vernier scale and advancing, it is found that the line at the end of the third space coincides with a line of the true scale. This shows that $\frac{3}{128}$ inch is to be added to the first reading. Hence, $1\frac{4}{16} + \frac{3}{128} = 1\frac{35}{128}$ inches is the reading of the vernier. Ans.

EXAMPLE 2.—What is the reading of the vernier shown in Fig. 16?

SOLUTION.—Since there are 16 divisions to the inch, and 8 spaces in the vernier scale, the vernier subdivides the inch into $16 \times 8 = 128$ parts. Looking for the position of the zero point of the vernier scale, it is seen to be between $2\frac{5}{8}$ and $2\frac{11}{16}$ inches, which gives $2\frac{5}{8}$ inches

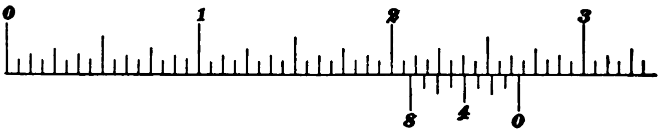


FIG. 16.

as the first reading. On observing the vernier scale, it is noticed that the numbering increases from right to left, hence advance from the zero point to the left until a line is found to coincide with one on the true scale. Examination shows that the line at the end of the fifth space coincides, hence $\frac{5}{128}$ inch is to be added to the first reading, giving $2\frac{5}{8} + \frac{5}{128} = 2\frac{85}{128}$ inches as the reading. Ans.

APPLICATIONS OF THE VERNIER.

67. Vernier Caliper Square.—The vernier is most frequently applied to caliper squares in order to obtain precise measurements. It is constructed to read to thousandths of an inch, although one caliper square in the market has the vernier read to one hundred and twenty-eighths of an inch.

68. A vernier caliper square intended to read to thousandths of an inch is shown in Fig. 17. The true scale *a* is engraved on the beam, while the vernier scale *b* is attached to the sliding head. For convenience in manufacturing, the vernier scale is in this case engraved on a separate plate, which is then fastened by small screws, as shown. The vernier is a direct vernier, as can be seen by applying the rule given in Art. **64.** Since each inch is divided into 50 parts, and since there are 20 divisions on the vernier

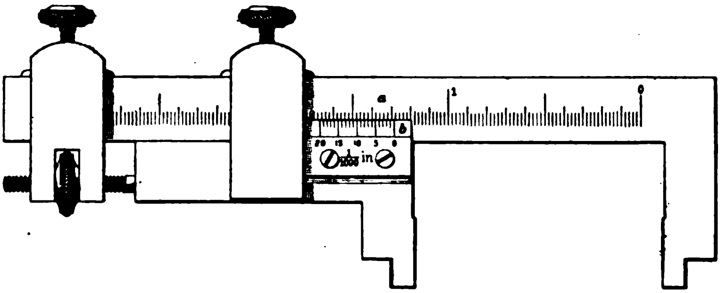


FIG. 17.

scale, by the rule of Art. **65,** we find that the vernier in this case subdivides the inch into 1,000 parts. Vernier caliper squares often have the true scale divided into 40 parts per inch; the vernier scale then contains 25 divisions. This vernier also divides the inch into 1,000 parts, since $40 \times 25 = 1,000$.

69. A vernier caliper square reading to thousandths of an inch may be most conveniently read by the following rule, *which is only applicable to one reading to thousandths.*

Rule.—*Count the number of whole inches between the zero of the true scale and the zero of the vernier scale. Count the number of tenths of an inch spaces between the last whole inch mark and the zero line of the vernier scale. This is the first decimal figure of the reading. Observe how many subdivisions of the tenth part of the inch are between the last tenth of an inch mark on the true scale and the zero of the vernier scale. Express the value of these subdivisions in thousandths of an inch and add it to the first decimal figure. Next, advance from the zero line of the vernier scale until a line is found to coincide with one of the true scale. Count the number of* *spaces between this line and the zero line of the vernier scale and on the latter; reduce the number to thousandths of an inch by prefixing ciphers, and add to the previous reading.*

At first thought, the rule will appear cumbersome; however, with a little practice the reading can be taken very rapidly by this rule, since the calculations are so simple that they can be performed mentally. It is to be observed that the reading is from inside to inside of the caliper square; that is, for an outside measurement.

EXAMPLE.—What is the reading of the vernier caliper square shown in Fig. 17?

SOLUTION.—The number of whole inches is 1. Hence, write 1 as the integral part of the reading. There are two $\frac{1}{10}$-inch spaces between the graduation mark denoting 1 inch and the zero line of the vernier scale. Hence, write 2 as the first decimal figure of the reading, giving 1.2 inches. By inspection of the caliper square, it is seen that there are 4 subdivisions of the tenth part of an inch between the last $\frac{1}{10}$-inch mark and the zero line of the vernier scale. Now, in this case, each space represents $\frac{1}{50}$ inch, or, expressed in thousandths, .020 inch. Hence, 4 spaces represent $.020 \times 4 = .080$ inch. Adding this to the previous reading, we get $1.2 + .080 = 1.280$ inches. Inspection shows that the line at the end of the seventh space of the vernier scale coincides with a line on the true scale. Reducing to thousandths by prefixing ciphers, we get .007 as the value to be added to the previous reading, which gives $1.280 + .007 = 1.287$ inches as the reading of the vernier. Ans.

70. Vernier Micrometer Caliper.—A vernier is occasionally applied to an ordinary micrometer caliper, in order to be able to read it to the tenth part of a thousandth of an inch. The vernier employed is almost invariably a direct vernier; the true scale is represented by the graduations on the thimble, while the vernier scale is engraved on the barrel in some convenient position. Usually, 9 of the graduations on the thimble are divided into 10 parts. The graduation lines of the vernier scale are parallel to the zero line of the barrel and extend its whole length; the zero line of the vernier scale may be a line separate from the zero line of the barrel, or the latter may at the same time form the zero line of the vernier scale. The reading of the vernier is the same in any case.

Rule.—*To read a vernier micrometer caliper, read it to three decimal places without paying any attention to the vernier. To obtain the fourth decimal place, find out which line of the vernier scale coincides with a line on the thimble. Count the number of spaces from the zero line of the vernier scale to this line, counting on the vernier scale. This number is the fourth decimal figure of the reading.*

EXAMPLE.—The reading of a micrometer caliper is .300 inch, to three decimal places. The seventh line of the vernier scale coincides with a line of the thimble. What is the reading?

SOLUTION.—Since the seventh line coincides, there are six spaces between the zero line of the vernier scale and its seventh line. Hence, annex 6 to the first reading, which gives .3006 inch as the final reading. Ans.

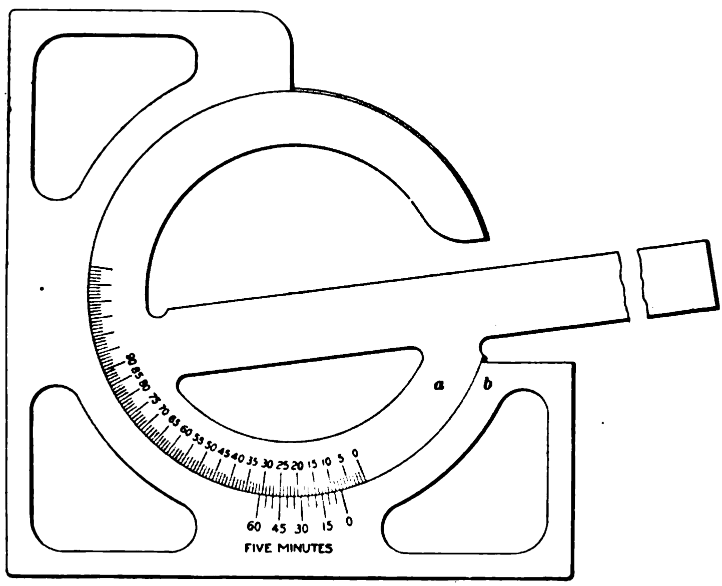


FIG. 18.

71. Vernier Protractor.—The vernier is applied to the protractor for the purpose of reading it to parts of a degree. Fig. 18 shows a form of protractor especially adapted for line measurements. As shown in the illustration, the graduations extend only around part of the circumference; in this case, 120° are divided into whole degrees only. In order to read to parts of a degree, 23° of the true scale on *a* have been divided into 12 parts on the vernier scale on *b*. By the statement made in Art. **65,** this divides the degree into 12 parts, and as there are 60 minutes in a degree, each one of these parts represents 60 ÷ 12 = 5 minutes. By applying the rule given in Art. **64,** it is shown that the vernier is direct.

Rule.—*To read the protractor, read off directly the number of whole degrees between the zero of the true scale and the zero of the vernier scale. From the zero of the vernier scale, count the number of spaces to a line coinciding with one on the true scale. Multiply this number by 5; the product will be the number of minutes to be added to the first reading.*

EXAMPLE.—Read the vernier shown in Fig. 18 to degrees and minutes.

SOLUTION.—There are 7 whole degrees between the zeros of the true scale and the vernier scale. On the vernier scale, the ninth line coincides with a line of the true scale, which gives 8 spaces. Then, 8 × 5 = 40; hence, the reading is 7° 40′. Ans.

GAUGES.

GAUGES OF LINEAR DIMENSIONS.

DIMENSIONAL GAUGES.

72. Gauges for linear dimensions are made in a variety of forms, to suit different purposes. They may be divided into two general classes, which are **dimensional gauges** and **numbered gauges.** Gauges of the first class are made to any required subdivision of the unit of length; their size is indicated by giving their dimension. Gauges of the second class express a size by an arbitrary number, or sometimes by arbitrarily selected letters.

73. Test Gauges.—Gauges intended primarily for reference purposes, which may be the testing of measuring instruments or other gauges, should always be made with the greatest degree of accuracy. In the form in which they are used by the mechanic, they can only be used for end measurements.

74. Fig. 19 shows an **end-measure standard** of the form adopted by The Pratt & Whitney Co. The ends of the

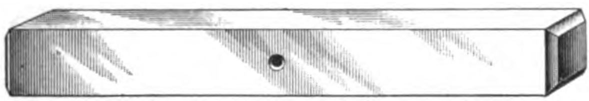


FIG. 19.

square, hardened bar are ground and lapped until they are plane surfaces parallel to each other. They are claimed by the makers to represent the nominal size within .00002 inch.

75. A somewhat different form of an end-measure standard has been shown at *g* in Fig. 8. These test bars are surrounded by a wooden jacket that leaves only the ends of the bar exposed; since wood is a poor conductor of heat, the jacket prevents a change in length due to contact of the hand.

76. The Brown & Sharpe Manufacturing Co. make their end-measure standards in the form of a circular disk, as shown in Fig. 20, which is provided with a circular hole for ease of manufacture and also to permit it to be used with a handle inserted therein. The circular form makes these disks very convenient for setting calipers. When used for testing purposes, a very delicate contact can be obtained, since they are only in line contact with the measuring instrument.

FIG. 20.

77. Working Gauges.—Gauges intended exclusively for testing work are known as **working gauges.** For testing the size of cylindrical holes and cylindrical work of relatively small diameter, the **plug-and-ring** gauge shown in Fig. 21 has a wide range of application. The **plug gauge** *a*, often called the **male gauge,** is a hardened steel cylinder that is ground and accurately lapped to size

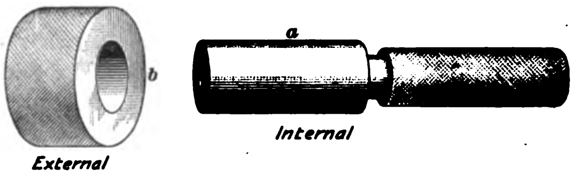


FIG. 21.

and provided with a suitable handle. The **ring gauge** *b*, often called the **female gauge,** is a hardened steel ring ground and lapped inside to accurately fit the plug gauge. The plug gauge is used for testing the size of cylindrical holes; the ring gauge serves for cylindrical work.

78. For testing the size of holes beyond the range to which a plug gauge is limited, because of its weight and cost, end-measuring rods of the form shown in Fig. 22 may be used. The ends of these rods are made part of a sphere equal in diameter to the length of the rod; consequently, they can be used for any kind of internal measurement without danger of cramping. They are also useful for setting calipers, comparing other working gauges, measuring between parallel surfaces, either plain or curved, and similar work.

FIG. 22.

79. For many classes of work, the standard **caliper gauge,** two forms of which are shown in Fig. 23, is preferable to any other form. In the smaller sizes they are usually made with one end for inside and the other for outside measurements, as shown in Fig. 23 (*a*); in the larger sizes, in order to keep the weight of the gauge within a reasonable limit, the gauge for internal measurement is made separate from that intended for outside measurement, as shown in Fig. 23 (*b*). The gauge intended for outside measurement has its measuring surfaces ground and lapped to be plane surfaces parallel to each other; the gauge intended

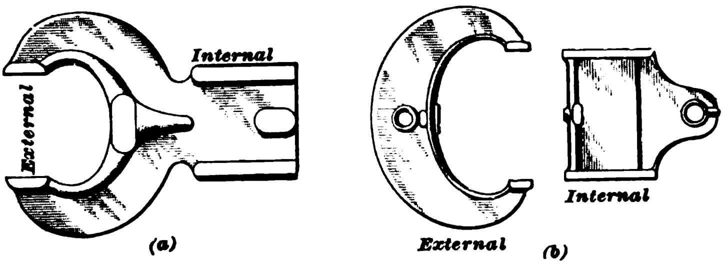


FIG. 23.

for internal measurement has its measuring surfaces formed as arcs of a circle when it is to be used for circular holes. For measuring between parallel plane surfaces, its measuring surfaces can be parallel plane surfaces.

80. Limit Gauges.—The working gauges so far shown simply determine whether the work is the true size or not; they do not show the amount of the variation from the true size, nor do they tell if the variation is sufficient to condemn the work. But suppose that we have two working gauges of which the one is made to the greatest size the work can be, without detrimental consequences, while the other one is made to correspond to the smallest size. Then, if the larger gauge goes over the work while the smaller one does not, it follows that its amount of variation from the true size must lay somewhere between the limit set by the two gauges.

81. Gauges used for this purpose are known as **limit gauges**; from their purpose it follows that a *pair* of gauges is required to form *one* limit gauge. Fig. 24 (*a*) shows a limit gauge for external measurement, while Fig. 24 (*b*) shows one intended for internal measurements. It must not be inferred that the two forms shown are the only forms limit gauges can have; they may be made in a number of ways, to suit the character of the work for which they are to be used.

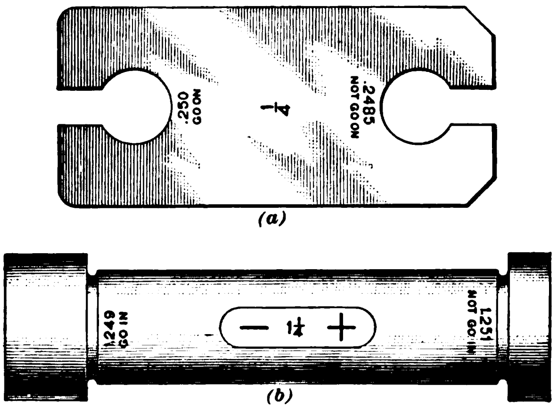


FIG. 24.

82. Screw Thread Gauges.—A special gauge is made by The Pratt & Whitney Co. for gauging the size of screws. The internal or male gauge shown in Fig. 25 (*a*) consists of a threaded cylinder made to standard size at one end, and a true cylinder of a diameter equal to that over the bottom of the thread on the other end. The threaded part is used for testing nuts; the plain part will tell if the hole in the nut has been drilled or bored large enough. The external or female gauge shown in Fig. 25 (*b*) is threaded to

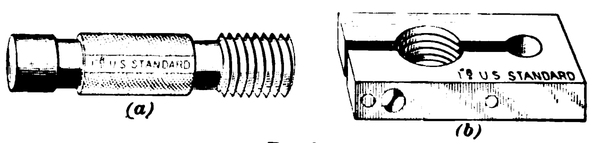


FIG. 25.

fit the male gauge; it is adjustable for wear within reasonable limits. The female gauge is used for testing the size of screws, bolts, taps, etc. For shop use, these gauges are made of hardened steel; for reference purposes they are left soft.

NUMBERED GAUGES.

83. The subject of gauging metal plates and wire is one that has proved very perplexing to manufacturers. It may be stated that there is a general tendency among intelligent mechanics and engineers to do away entirely with gauge numbers and specify all metals by their actual thicknesses in decimal parts of an inch. Such measurements are far more satisfactory, both to the trade worker and to the manufacturer, and greatly lessen the liability to error that arises from imperfect gauges and from the use of gauges made by different firms.

On this subject, Trautwine says: "No trade stupidity is more thoroughly senseless than the adherence to the various Birmingham, Lancashire, etc. gauges, instead of at once denoting the thickness and diameter of sheets, wire, etc. by the parts of an inch, as has long been suggested. * * * * To avoid mistakes that are very apt to occur from the number of gauges in use, and from the absurd practice of applying the same gauge number to different thicknesses of different metals in different towns, it is best to ignore them all, and, in giving orders, to define the diameter of wire and the thickness of sheet metal by parts of an inch."

84. The dangers that lurk in the use of arbitrary gauges are clearly indicated in the following extract, taken from a circular issued by Messrs. Miller, Metcalf & Parkin, steel manufacturers, Pittsburg, Pennsylvania:

"In regard to ordinary wire gauges, they are notoriously inaccurate, because they cannot be made accurate and be at all salable.

"We have two new gauges in our possession that were kept in our offices for purposes of comparison, and to prevent their wearing they were not allowed to go into the mills.

"In a recent case, a sample under discussion measured on one gauge tight 23, and on the other light 24, and our customer said it was neither by his gauge, and did not suit him, anyhow.

"One of our new gauges has its No. 23 so much larger than its No. 22 that the difference can be easily detected by the naked eye; yet No. 23 ought to be two to four thousandths smaller than No. 22.

"If we were to roll No. 23 by that gauge, how would our customer get what he wanted unless his gauge accidentally contained the same blunder? Yet our gauge is a new one, stamped with the maker's name, and cost about six dollars.

"Another trouble is with the wearing of the gauges, for which there is no remedy; and we imagine that no man ever throws away a gauge because it is worn out. On the contrary, it represents an outlay of six dollars; he is used to it; he measures everything by it; and he is mad when anything does not measure to suit it. A still more serious difficulty arises from a very common mode of ordering. We frequently have orders for such a gauge, 'light' or 'tight,' 'full' or 'scant,' 'heavy' or 'easy'; or such a number and one-half, for instance, 15½.

"This latter is terribly confusing to a roller; he almost always takes it to mean that it is to be thicker than the whole number, and is pretty certain to make 14½ for 15½, if he is not warned beforehand.

"* * * * There is a very simple way out of this whole

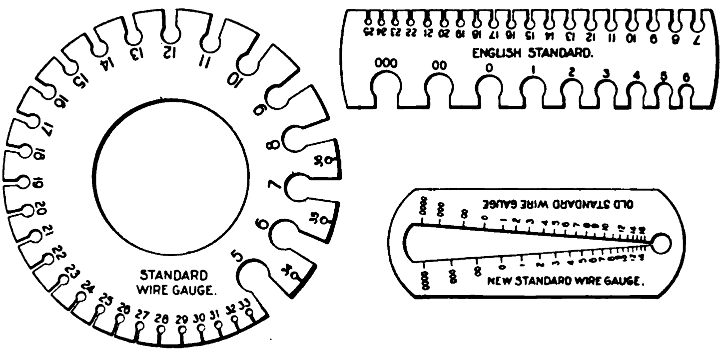


FIG. 26.

snarl, and that is to abandon fixed gauges and numbers altogether. Micrometer sheet-metal gauges cost less than a common gauge, or no more. They measure thousandths of an inch very accurately, and even a quarter of a thousandth may be very neatly measured. * * * * Our works are fully supplied with these instruments, and we urge all parties in ordering to give us dimensions and not numbers."

85. Common forms of sheet metal and wire gauges are shown in Fig. 26; the notched gauges are pushed over the material to be measured. The gauge with the triangular opening is adapted only for stock of circular cross-section, as wire and the shanks of screws. It is passed over the wire until it touches on both sides; the division at the point of contact indicates the gauge number.

86. The arbitrary gauges in most common use are given in Tables I to VII, together with the decimal equivalent, in inches, of each gauge number. Referring to Table I, the **United States standard gauge,** given in the second column, was established in 1893 by Act of Congress approved March 3d, as the gauge to be used in determining duties and taxes levied by the United States of America on sheet iron, plate iron, and steel. It is used to a limited extent by American rolling mills for sheet iron, plate iron, and steel, and also for galvanized sheet iron and American planished iron.

The **American,** or **Brown & Sharpe, gauge,** given in the third column of Table I, is almost exclusively used for sheet brass, sheet aluminum, sheet German silver, brazed brass tubing, brass wire, copper wire, and German silver wire of American manufacture. The **Birmingham,** or **Stubs', iron gauge,** given in the fourth column of Table I, is used by the trade for sheet iron, sheet steel, sheet copper, iron wire, Bessemer steel wire, and seamless tubing of all kinds, practically to the exclusion of all other gauges.

The **Washburn & Moen Manufacturing Co. gauge,** given in the fifth column of Table I, is used almost exclusively by the firm the name of which it bears for gauging their products.

TABLE I.

SHEET METAL AND WIRE GAUGES.

Number of Gauge.	Dimensions in Decimal Parts of an Inch.				Number of Gauge.
	U.S. Standard	American, or Brown & Sharpe.	Birmingham, or Stubs'.	Washburn & Moen Mfg. Co.	
0000000	.500000000			.49000	0000000
000000	.468750000			.46000	000000
00000	.437500000			.43000	00000
0000	.406250000	.460000	.454	.39380	0000
000	.375000000	.409640	.425	.36250	000
00	.343750000	.364800	.380	.33100	00
0	.312500000	.324860	.340	.30650	0
1	.281250000	.289300	.300	.28300	1
2	.265625000	.257630	.284	.26250	2
3	.250000000	.229420	.259	.24370	3
4	.234375000	.204310	.238	.22530	4
5	.218750000	.181940	.220	.20700	5
6	.203125000	.162020	.203	.19200	6
7	.187500000	.144280	.180	.17700	7
8	.171875000	.128490	.165	.16200	8
9	.156250000	.114430	.148	.14830	9
10	.140625000	.101890	.134	.13500	10
11	.125000000	.090742	.120	.12050	11
12	.109375000	.080808	.109	.10550	12
13	.093750000	.071961	.095	.09150	13
14	.078125000	.064084	.083	.08000	14
15	.070312500	.057068	.072	.07200	15
16	.062500000	.050820	.065	.06250	16
17	.056250000	.045257	.058	.05400	17
18	.050000000	.040303	.049	.04750	18
19	.043750000	.035890	.042	.04100	19
20	.037500000	.031961	.035	.03480	20
21	.034375000	.028462	.032	.03175	21
22	.031250000	.025347	.028	.02860	22
23	.028125000	.022571	.025	.02580	23
24	.025000000	.020100	.022	.02300	24
25	.021875000	.017900	.020	.02040	25
26	.018750000	.015940	.018	.01810	26
27	.017187500	.014195	.016	.01730	27
28	.015625000	.012641	.014	.01620	28
29	.014062500	.011257	.013	.01500	29
30	.012500000	.010025	.012	.01400	30
31	.010937500	.008928	.010	.01320	31
32	.010156250	.007950	.009	.01280	32
33	.009375000	.007080	.008	.01180	33
34	.008593750	.006304	.007	.01040	34
35	.007812500	.005614	.005	.00950	35
36	.007031250	.005000	.004	.00900	36
37	.006640625	.004453		.00850	37
38	.006250000	.003965		.00800	38
39		.003531		.00750	39
40		.003144		.00700	40

The **Illinois Zinc Company standard gauge,** given in Table II, is an arbitrary gauge adopted by the firms controlling the manufacture of sheet zinc and nickeloid. Little need be said concerning it, except that its existence affords still another argument in favor of the adoption of the decimal system of designating all sheet metals. Nickeloid is an alloy of zinc and nickel, the zinc predominating; the addition of nickel produces a metal of greater tensile strength, and one that is susceptible of a high polish. The manufacturers of nickeloid state that it can be drawn to nearly the extent of brass, and is somewhat lower in cost.

TABLE II.

ILLINOIS ZINC CO.'S STANDARD GAUGE.

Gauge Number.	Thickness. Inch.	Gauge Number.	Thickness. Inch.
1	.00186	14	.036
2	.00400	15	.040
3	.00587	16	.045
4	.00800	17	.050
5	.01100	18	.055
6	.01200	19	.060
7	.01400	20	.070
8	.01600	21	.080
9	.01800	22	.090
10	.02000	23	.100
11	.02400	24	.125
12	.02800	25	.250
13	.03200	26	.375

The **Russia sheet-iron gauge,** given in Table III, applies only to imported Russia iron. This material was formerly exclusively used for locomotive jackets, stove bodies,

TABLE III.

RUSSIA IRON GAUGE.

Russian Gauge Number.	U. S. Gauge Number (approx.).
16	21
13	23
12	24
11	25
10	26
9	27
8	28

etc., and as it was imported from Russia, it was natural that the foreign gauge numbers by which it was rolled should be used here to designate the various thicknesses. Planished iron and steel is now made by American manufacturers; it is superior in tensile strength and fully as finely finished as the imported sheet, although for certain purposes there is a sufficient demand for Russia iron to warrant jobbers in handling this product.

Since planished iron of American manufacture is gauged by the United States standard gauge, the corresponding approximate gauge numbers of that gauge are placed opposite those of the Russian gauge, to allow of ready comparison.

The **steel music wire gauge** given in Table IV is largely used for gauging the diameter of hard-drawn steel wire, commonly called **piano** wire.

This wire is usually sold coiled on spools; it is largely used by mechanics for helical and similar coiled springs. Since it is hard drawn, it possesses considerable elasticity; springs made from it do not need to be hardened.

TABLE IV.

SIZES OF THE NUMBERS OF STEEL MUSIC WIRE GAUGE.

No. of Gauge.	Size of Each No. in Decimal Parts of an Inch.	No. of Gauge.	Size of Each No. in Decimal Parts of an Inch.
00000000	.0083	12	.0296
0000000	.0087	13	.0314
000000	.0095	14	.0326
00000	.0100	15	.0345
0000	.0110	16	.0360
000	.0120	17	.0377
00	.0133	18	.0395
0	.0144	19	.0414
1	.0156	20	.0434
2	.0166	21	.0460
3	.0178	22	.0483
4	.0188	23	.0510
5	.0202	24	.0550
6	.0215	25	.0586
7	.0230	26	.0626
8	.0243	27	.0658
9	.0256	28	.0720
10	.0270	29	.0760
11	.0284	30	.0800

The **Stubs' special steel-wire gauge** given in Table V is used almost exclusively for tool-steel wire in the form of straight rods, commonly called **drill rods.** It is also used by some makers for tool-steel wire sold in coils and on spools.

Drill rod and wire gauged by this gauge are usually sold annealed. Hence, if such drill rod and wire are used for helical or other coiled springs, they must be hardened and tempered in order to retain their elasticity.

TABLE V.

TABLE OF DECIMAL EQUIVALENTS OF STUBS' STEEL-WIRE GAUGE.

Letter.	Size of Letter in Decimals.	No. of Wire Gauge.	Size of Number in Decimals.	No. of Wire Gauge.	Size of Number in Decimals.	No. of Wire Gauge.	Size of Number in Decimals.
Z	.413	1	.227	28	.139	55	.050
Y	.404	2	.219	29	.134	56	.045
X	.397	3	.212	30	.127	57	.042
W	.386	4	.207	31	.120	58	.041
V	.377	5	.204	32	.115	59	.040
U	.368	6	.201	33	.112	60	.039
T	.358	7	.199	34	.110	61	.038
S	.348	8	.197	35	.108	62	.037
R	.339	9	.194	36	.106	63	.036
Q	.332	10	.191	37	.103	64	.035
P	.323	11	.188	38	.101	65	.033
O	.316	12	.185	39	.099	66	.032
N	.302	13	.182	40	.097	67	.031
M	.295	14	.180	41	.095	68	.030
L	.290	15	.178	42	.092	69	.029
K	.281	16	.175	43	.088	70	.027
J	.277	17	.172	44	.085	71	.026
I	.272	18	.168	45	.081	72	.024
H	.266	19	.164	46	.079	73	.023
G	.261	20	.161	47	.077	74	.022
F	.257	21	.157	48	.075	75	.020
E	.250	22	.155	49	.072	76	.018
D	.246	23	.153	50	.069	77	.016
C	.242	24	.151	51	.066	78	.015
B	.238	25	.148	52	.063	79	.014
A	.234	26	.146	53	.058	80	.013
		27	.143	54	.055		

The **twist-drill gauge** given in Table VI is used entirely by American manufacturers for designating the smaller sizes of twist drills, excepting twist drills known as jobbers' drills, which are sold directly by their actual size. It is used to some extent for steel wire, and also for drill rods.

TABLE VI.

DECIMAL EQUIVALENTS OF THE NUMBERS OF TWIST-DRILL AND STEEL-WIRE GAUGE.

No.	Size of No. in Decimals.	No.	Size of No. in Decimals.	No.	Size of No. in Decimals.	No.	Size of No. in Decimals.
1	.2280	21	.1590	41	.0960	61	.0390
2	.2210	22	.1570	42	.0935	62	.0380
3	.2130	23	.1540	43	.0890	63	.0370
4	.2090	24	.1520	44	.0860	64	.0360
5	.2055	25	.1495	45	.0820	65	.0350
6	.2040	26	.1470	46	.0810	66	.0330
7	.2010	27	.1440	47	.0785	67	.0320
8	.1990	28	.1405	48	.0760	68	.0310
9	.1960	29	.1360	49	.0730	69	.0292
10	.1935	30	.1285	50	.0700	70	.0280
11	.1910	31	.1200	51	.0670	71	.0260
12	.1890	32	.1160	52	.0635	72	.0250
13	.1850	33	.1130	53	.0595	73	.0240
14	.1820	34	.1110	54	.0550	74	.0225
15	.1800	35	.1100	55	.0520	75	.0210
16	.1770	36	.1065	56	.0465	76	.0200
17	.1730	37	.1040	57	.0430	77	.0180
18	.1695	38	.1015	58	.0420	78	.0160
19	.1660	39	.0995	59	.0410	79	.0145
20	.1610	40	.0980	60	.0400	80	.0135

The **American screw gauge** given in Table VII is used exclusively for American machine screws and wood screws made of iron, steel, or brass. It gives the diameter of the unthreaded cylindrical part or shank of the screw, and is applicable to round-headed, flat-headed, and fillister-headed screws.

TABLE VII.

TABLE OF DECIMAL EQUIVALENTS OF SCREW GAUGE FOR MACHINE AND WOOD SCREWS.

(The difference between consecutive sizes is .01316 inch.)

No. of Screw Gauge.	Size of Number in Decimals.	No. of Screw Gauge.	Size of Number in Decimals.	No. of Screw Gauge.	Size of Number in Decimals.
000	.03152	16	.26840	34	.50528
00	.04468	17	.28156	35	.51844
0	.05784	18	.29472	36	.53160
1	.07100	19	.30788	37	.54476
2	.08416	20	.32104	38	.55792
3	.09732	21	.33420	39	.57108
4	.11048	22	.34736	40	.58424
5	.12364	23	.36052	41	.59740
6	.13680	24	.37368	42	.61056
7	.14996	25	.38684	43	.62372
8	.16312	26	.40000	44	.63688
9	.17628	27	.41316	45	.65004
10	.18944	28	.42632	46	.66320
11	.20260	29	.43948	47	.67636
12	.21576	30	.45264	48	.68952
13	.22892	31	.46580	49	.70268
14	.24208	32	.47896	50	.71584
15	.25524	33	.49212		

DIMENSIONED GAUGES.

87. Master Mechanics' Decimal Gauge. — The American Society of Mechanical Engineers appointed a committee to devise a gauge to take the place of the arbitrary numbered gauges in use for measuring sheet metal and wire, and they, together with a committee from the American Railway Master Mechanics' Association, adopted resolutions recommending that all sheet metal and wire be designated by thousandths of an inch and that for general use a notched gauge of the form shown in Fig. 27 should be

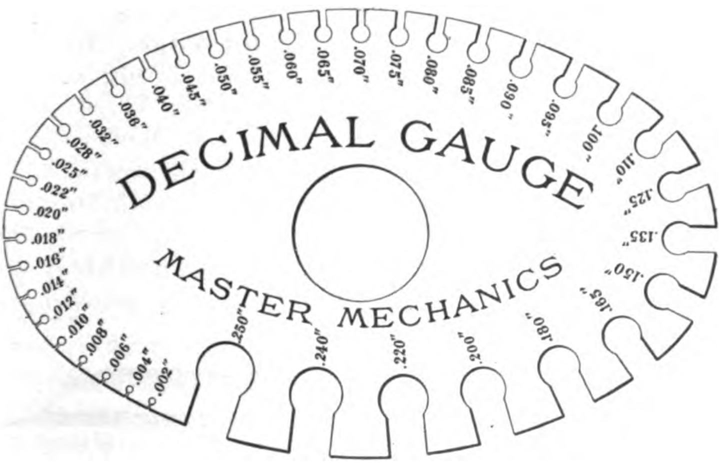


FIG. 27.

adopted, the notches to be marked with the dimensions which they represent, as shown in the illustration. This gauge has been adopted as the standard by the Railway Master Mechanics' Association and recommended by the American Society of Mechanical Engineers. It is made by The Pratt & Whitney Co.

The committees above referred to also communicated with various foreign societies and governments for the adoption of some system other than arbitrary numbered gauges, and the French government abolished the arbitrary gauges and established a legal measurement, the basis of which was one one-hundredth of a millimeter, so that it is probable that in the near future the arbitrary numbered gauges will pass out of existence and be replaced by decimal gauges both in this country and abroad.

GAUGES OF ANGULAR DIMENSIONS.

88. The Straightedge.—Gauges for angular measurements are usually known by special names given in accordance with their most common application. Thus, as a straight line is the measure of a 180° angle, the gauge for this angle is known as a **straightedge.** Straightedges are made in several forms, to suit individual preferences. They either have a rectangular cross-section, as shown in Fig. 28 (*a*), or are beveled on one edge, as shown in Fig. 28 (*b*). For the very finest work, straightedges are made as shown in Fig. 29 by The Pratt & Whitney Co.; if thus made, they are extremely sensitive, owing to the fact that they touch the work along a line only; a very small deviation will show daylight between the work and the straightedge in contact with it.

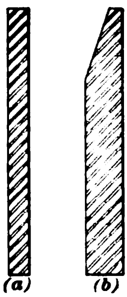


FIG. 28.

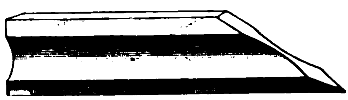


FIG. 29.

89. The Try Square.—The gauge for a 90° angle, when made in the form shown in Fig. 30, is called **a try square,** or a **steel square.** By custom, the first name is limited to a square that is hardened and ground and has no

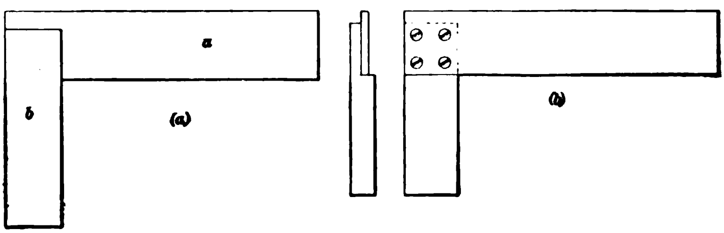


FIG. 30.

graduations on it. The smaller sizes are usually made with a non-detachable **blade** *a* fastened by soldering and rivets to the **stock** *b*, as shown in Fig. 30 (*a*). In the larger sizes, the stock and blade are usually united by screws, as shown in Fig. 30 (*b*). This allows them to be repaired more readily.

90. Squares are intended for use on the edges and not on the corners or sides of the blades. The makers of squares carefully true them on their edges. If the manufacturers were compelled to make the square true on the sides and corners as well as upon the edges, they would be compelled to charge such a high price for them that very few could afford an accurately made instrument. If the squares were made accurate upon the edges, corners, and sides, it would be practically impossible to keep them so, as the constant handling would soon throw them out of true on the edges. The square should always be placed against the work in such a manner that the beam of the square is at right angles to the face being measured.

91. To use squares larger than can be conveniently held in the hand, strips of thin paper may be placed at different points between the top and bottom of the blade, and when the edge of the blade is held square against the piece to be tested, the pieces of paper may be drawn out. If the blade holds all the strips equally well, the piece to be tested is true, but if one draws easier than another, the point from which the paper is drawn is open and the piece is not true.

92. The Center Square. — The **center square** shown in Fig. 31 derives its name from the fact that it can be conveniently used for finding the centers on the ends of cylindrical work. The stock is so placed that its two legs *a* and *a′* each make an angle of 45° with the blade *c*, and, consequently, make

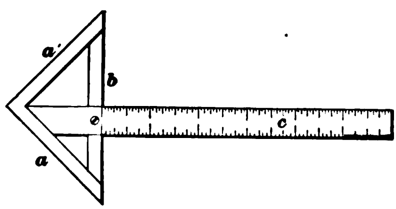


FIG. 31.

an angle of 90° with each other; the cross-bar *b* is placed at a right angle to the blade.

93. The Center Gauge.—The gauge defining a 60° angle is most commonly called a **center gauge,** as it defines the standard angle for lathe centers almost universally used in America. Such a gauge is shown in Fig. 32. Since 60° is also the standard angle for the sharp **V** screw thread and the Sellers, or United States standard, thread, notches *a* and *b* having that angle are convenient for grinding thread-cutting tools. These notches are cut so that their sides make the same angle with the edge in which they are cut; they can therefore be used for setting thread-cutting tools square with the work.

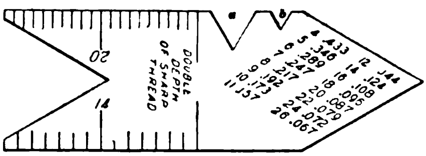


FIG. 32.

Gauges of this form can also be obtained for a 55° angle, which is the angle included between the sides of the thread in the British, or Whitworth, system of screw threads.

94. Most center gauges have a table of the double depth of thread for different numbers of threads per inch stamped on them. The figures in the first column usually give the number of threads per inch, and opposite this number the double depth of a sharp **V** thread, in thousandths of an inch. For finding the size of tapping drill for a given pitch of thread and diameter of the thread, subtract the number opposite the pitch from the diameter. Allowance is then to be made, as dictated by judgment, as to the extent to which the threads should be left flat on top.

95. Center gauges are usually graduated on both sides, along both edges, with divisions of the inch that are convenient for measuring the number of threads per inch on screws. Thus, the side shown in Fig. 32 has 20 divisions to the inch on one edge and 14 divisions on the other edge. The different number of threads per inch that each graduation is most suitable for are those by which the graduation is divisible without a remainder. Thus, the twentieth graduation is suitable for measuring 1, 2, 4, 5, 10, and 20 threads per inch, and also for any multiple of 20, as 40, 60, 80, etc.

96. The gauges so far described are those in most common use. There are quite a number of special gauges made for special purposes; these are described at length in the catalogues of the manufacturers of measuring instruments, to which the student is referred.

CARE OF MEASURING INSTRUMENTS.

MICROMETERS.

97. Opening and Closing.—The micrometer screw should always be revolved between the thumb and finger and not by holding the thimble firmly in the hand and swinging the frame. While this latter method is an easy one, it causes the hole in the frame around the smooth portion of the screw to wear out of shape, making a loose fit for the screw that impairs the accuracy of the micrometer. Whenever a micrometer is used in a dusty place, care should be taken to wipe the dust from the smooth portion of the screw.

LUBRICATION OF MEASURING INSTRUMENTS.

98. Lubricants Used.—As the accuracy of a micrometer, or any other measuring instrument using a screw, depends upon the accuracy of the screw, care should be taken to keep it in as good condition as possible. If thin oil is used upon a micrometer screw, it is liable to work down upon the smooth portion of the screw where it will collect dust, and this dust will be easily carried back into the threads, thus causing undue wear, which will soon destroy the accuracy of the instrument. The screws of measuring instruments should be oiled with only a heavy, high-grade lubricating oil, or better still, with vaseline. Care should be taken to see that as little lubricant is used as will insure easy working of the parts, as any excess of the lubricant is sure to work out and collect dust.

LATHE WORK.

(PART 1.)

THE LATHE.

HISTORICAL.

1. Early Forms of Lathes.—The art of turning, or the production of circular or cylindrical pieces by the aid of a machine and special tools, has long been known. One of the earliest forms of machines of which there is record is one used for this purpose. It consisted of a crude wooden frame in which the piece to be turned was held by pointed wooden or metal pegs passing through the frame and into the ends of the piece. The piece was made to rotate upon these pegs by wrapping a cord or band about one end of the piece. One end of the cord was fastened to a weight or a spring pole, while the other was held by the operator or an assistant. By pulling the cord, the work was made to rotate in one direction, the weight or spring pole pulling it back as soon as the forward pressure was released. The tools for cutting were held in the hand and presented to the work in such a way as to cause them to cut the various shapes desired. These early machines were called **lathes,** and the simple principle that they involved, i. e., of revolving the work upon its axis while being operated upon by the cutting tool, is still the fundamental principle in the most modern lathes.

2. Slide Rest.—It was not, however, until the invention of the **slide rest** and its application to the lathe, and, subsequently, to other forms of machine tools, that the rapid growth and improvement in machine-tool construction began. The credit for this invention is universally bestowed upon Mr. Henry Maudslay, an Englishman, who was born in the year 1771 and died in 1831. His slide rest was first applied to lathes in 1794.

His method was to fix the cutting tool rigidly in a block that was fitted into a groove or slide in such a manner that it could be moved only in one direction, it being held rigidly against all forces tending to move it in any other direction. A uniform speed or feed along this line of free motion was given by the use of a screw. These few simple principles are the ones still employed, and their use has made possible the rapid improvements and developments in machine construction that have resulted in the wonderfully high type represented in the automatic machines of the present day.

3. Development of Lathes.—The early lathe was more rapidly developed than the other metal-working machines, and consequently was called on to perform many operations that could now be more easily performed on other types of machines. It not only had to perform its own characteristic functions of producing cylindrical, tapered, or conical and radial surfaces, but it had to act in the capacity of drill press, boring mill, milling machine, and grinding machine as well.

These special forms of machines, which are for the most part branches from the original lathe, have now become so fully developed and adapted to their special work that the lathe has been greatly relieved of abnormal duties and can now be used almost exclusively in performing its normal functions. While the lathe is now assuming its particular line of work, it does not follow that its work is less complicated or of less importance; it simply admits of a greater development and a greater amount of skill.

CLASSES OF LATHES.

4. Lathe work probably embraces a greater variety of operations than the work of any other machine, and because of this fact lathes are divided into different sizes and classes specially designed to operate upon some particular class of work. Chief among these classes is the *engine lathe*, which might be considered as the typical metal-workers' lathe. This same type of lathe, when made with particular care and supplied with some extra attachments, is sometimes classed as a *toolmakers' lathe.* Other types of lathes that possess some peculiar characteristic are the *gap lathe*, *axle lathe*, *wheel lathe*, *turret lathe*, *bench* or *precision lathe*, and some other types specially designed for a particular duty, all of which will be described.

In operating any of the above-named lathes, it will be found that the underlying principles necessary for successfully completing a piece of work on any machine are similar, and that if the engine lathe be thoroughly mastered, the others may be successfully handled with a little practice. The principal differences will be found to arise from the size and peculiar shapes of the work.

THE ENGINE LATHE.

GENERAL DESCRIPTION.

5. In discussing the work of the lathe, the standard engine lathe of medium size, from 16-inch to 24-inch swing, will be considered first.

The term **engine lathe** generally indicates that the lathe is driven by some power other than foot power, that the tool motion is controlled by power feeds, and that the lathe is equipped with a leadscrew used for cutting screw threads.

6. Names of Parts.—Fig. 1 represents a standard type of screw-cutting engine lathe with the various parts numbered, and their respective names and duties are as follows:

A A is the bed or shears; *B*, the headstock complete; *C*, the tailstock complete; *D*, the carriage; *F*, the apron; *E*, *E*, the legs; *1*, the live center; *2*, the dead center; *3*, the driving cone; *4*, the driving gear keyed to spindle; *5*, the back gear;

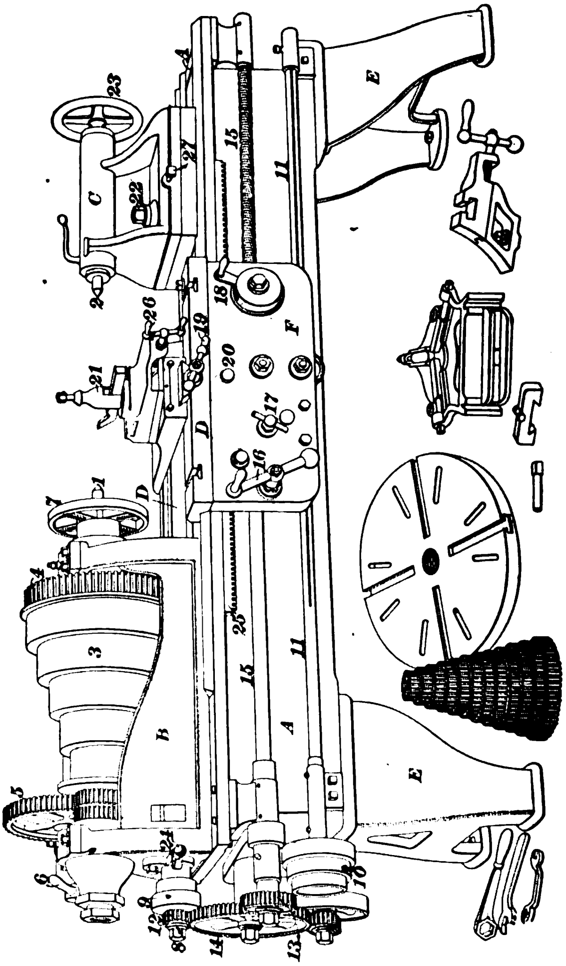


FIG. 1.

6, the handle for throwing the back gears "in" or "out"; *7*, the face plate; *8*, the stud, or spindle; *9*, a feed-cone on stud; *10*, the large feed-cone on feed-rod; *11*, the feed-rod;

12, a change gear on stud used in screw cutting; *13*, a change gear on leadscrew used in screw cutting; *14*, an intermediate gear for connecting gears *12* and *13*; *15*, the leadscrew used in screw cutting; *16*, a hand crank for traversing carriage by hand; *17*, a knob for throwing in automatic feed from feed-rod; *18*, a lever for throwing in automatic feed from leadscrew; *19*, a hand crank for operating cross-slide; *20*, a knob for throwing in automatic cross-feed; *21*, the tool post for holding the cutting tool; *22*, a nut for clamping tailstock to the bed *A*; *23*, a hand wheel for adjusting tailstock spindle and dead center; *24*, a lever in headstock for reversing direction of feed-motion; *25*, a feed-rack securely fastened to the lathe bed; *26*, a handle for operating compound rest cross-feed; and *27*, an adjusting screw for setting over tailstock spindle.

7. The Carriage.—The carriage is divided into two parts. The upper part *D* is called the **saddle.** It is carefully fitted and gibbed to the top of the lathe bed, carries the cross-slide and the tool, and receives all the strain and thrust exerted in cutting the work. The second part *F* is called the **apron.** This is secured to the saddle by screws. It hangs in front of the bed and contains the gearing through which the feed-motion is transmitted from the feed-rod *11* to the feed-rack *25* and the split nut which engages the leadscrew when cutting threads.

8. The Feed.—To operate the **feed** or cause the carriage to move automatically along the lathe bed, the knob *17* is turned, thus operating a friction clutch inside the apron. This operation throws in the feed and power is then transmitted from the stud cone *9* to the feed-rod cone *10* by means of a belt, and so along the rod to the carriage. The direction of the feed-motion may be changed by introducing another gear into the train of gearing either in the apron or in the headstock.

If we have a train of gears, as shown in Fig. 2, in which power is applied to rotate No. *1* in the direction indicated by the arrow, it will be observed that gears Nos. *3* and *5* rotate in the same direction, while gears Nos. *2* and *4* rotate in the opposite direction. From this we may see that if the number of gears in a train are even, the first and last gears revolve in opposite directions, while if the number of gears are odd, the first and last gears revolve in the same direction.

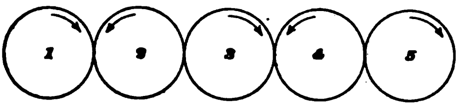


FIG. 2.

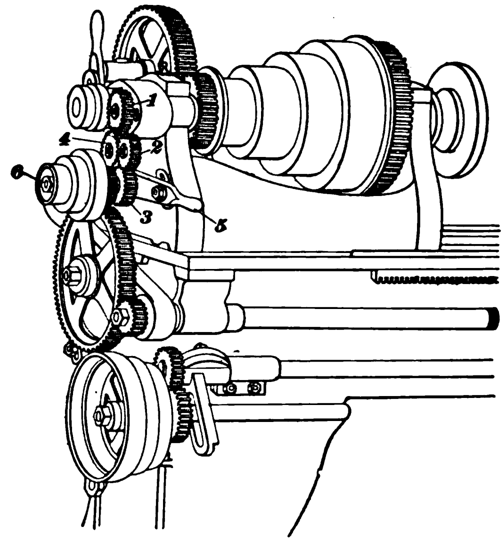


FIG. 3.

Fig. 3 shows an end view of a headstock and the gears by which the direction of the feed-motion is controlled.

Fig. 4 is a detailed end view of the same headstock. Gear No. *1* is keyed to the spindle, while gear No. *3* is keyed to the stud or change-gear spindle *6*. An arm pivoted on the stud spindle *6* carries the gears *2* and *4*. When the handle *5* is up, motion is transmitted from the gear on the headstock spindle, through gear *2* to gear *3*. Then, having three gears in the train, the first and last gear have the same direction. When the handle *5* is pushed down, as in Fig. 5, gear *2* is moved away from gear *1*, and gear *4*, which was before revolving idly, is brought against gear *1*. Motion is then transmitted from gear *1* to *4*, from *4* to *2*, and from *2* to *3*, so that while in this position there are four gears in

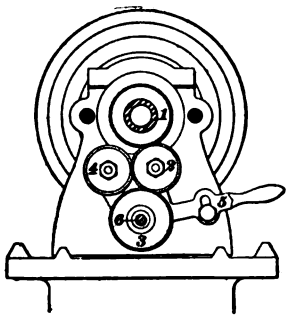


FIG. 4.

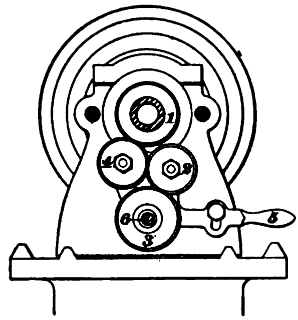


FIG. 5.

the train and the motions of the first and last gears are in opposite directions. In Fig. 1 this same reversing mechanism is used, but the gearing is placed inside the frame of the headstock.

9. The Speed.—The various speeds of the lathe are controlled by the belt running on different steps of the cone *3*, Fig. 1, and by the use of the back gears.

10. The Back Gears.—Fig. 6 is a horizontal section through the headstock, illustrating the operation of the **back gears.** The back gears *b* and *c* are rigidly fixed to the ends of a hollow quill, this quill being supported on an eccentric shaft on brackets at the back of the headstock. By partly rotating this eccentric shaft by means of the hand lever *e*, the back gears *b* and *c* can be brought forwards to engage with the gears *a* and *d*. The cone is fitted to revolve freely on the spindle, and carries with it gear *a*. Gear *d* is keyed to the spindle and revolves with it. When the back gears are out, the cone may be attached to the driving gear *d* by means of a block *f*, which may be moved into a radial slot cut in the end of the cone. When thus connected, the cone and spindle revolve together. When the back gears are to be used, this block is dropped out of the slot and the cone is again free to revolve on the spindle. The back gears are next brought forwards to engage with the cone and spindle gears. Power is then transmitted from the cone and gear *a* to gears *b* and *c*, and from gear *c* to the driving gear *d*, and so to the spindle. Because of the different sizes of the back gears, the speed is much reduced; the ratio of speed with the

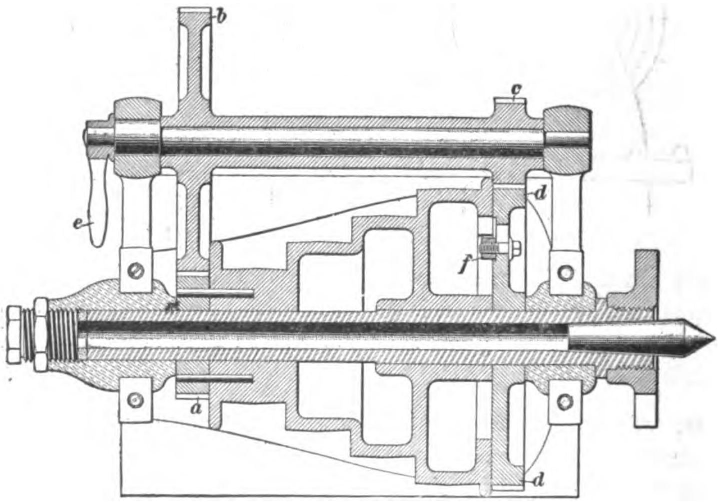


FIG. 6.

back gears out to the speed with the back gears in, the belt remaining on the same step of the cone, is about 10 to 1 on lathes of about 16-inch swing. This change by the introduction of the back gears not only reduces the speed but at the same time increases the power, making it possible to take much deeper cuts on the work.

11. Double and Triple Gearing.—When a greater change of speed is desired than can be obtained with the ordinary set of back gears, a second combination of gears of different ratios is introduced whereby the speed may be reduced still more. When this combination is used, the lathe is said to be double back-geared.

Fig. 7 shows a double back-geared headstock. The gears *b* and *c* are free to slide on a feather on the back-gear shaft, so that when moved to one position, *b* meshes with *a* on the cone spindle, giving one rate of speed. When *b* and *c* are moved to the other end of their seat, *c* meshes with *d*. Gears

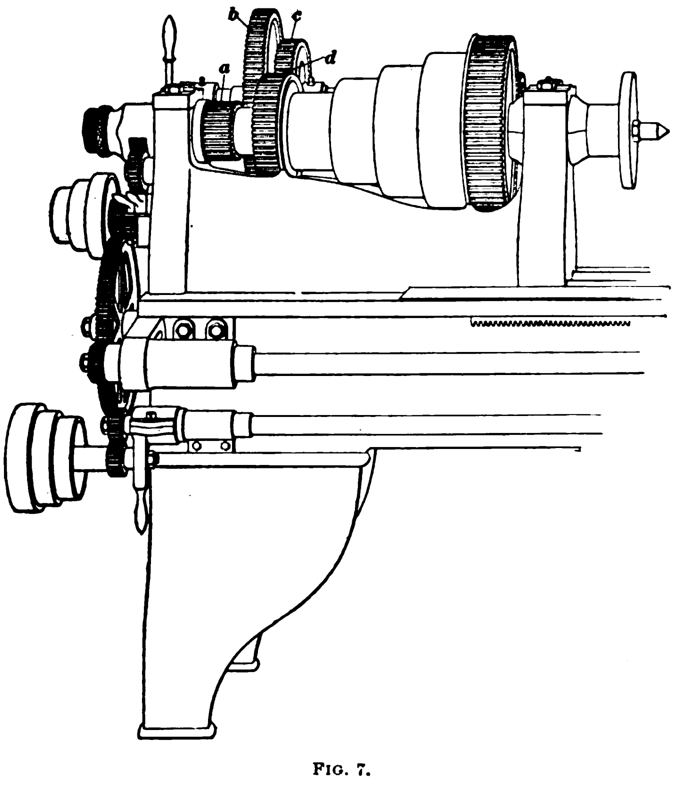


FIG. 7.

c and *d*, being of a different proportion in diameter from *b* and *a*, give a different rate of speed.

On the larger and more powerful lathes, a third combination is used and it is said to be triple geared. Fig. 8 illustrates a gear of this type. The first portion of the gearing is similar to that already described, but the triple gearing is obtained by means of an internal gear *a* attached to the

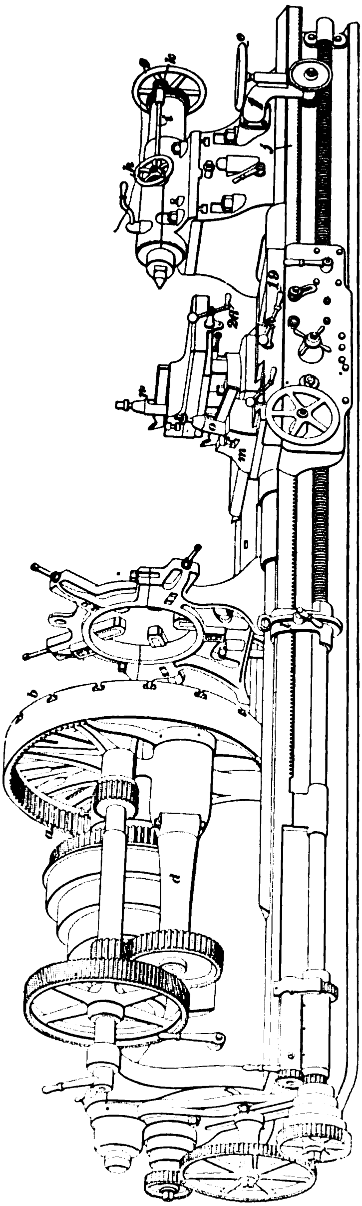


Fig. 8.

face plate *b*, which is operated by a pinion on the shaft *d*, thus producing a slow speed.

12. Tailstock. — In the simple engine lathe, as shown in Fig. 1, the tailstock is secured to the bedplate by a clamp bolt *22* and can be moved by loosening this and sliding the tailstock to the desired position by hand. In the case of large lathes, this would be difficult or impossible, and some special method is necessary. In the form shown in Fig. 8, an arm *f* is attached to the tailstock and provided with a hand wheel *e*, which operates the gearing arranged to engage with the rack *j*. By this device the tailstock can easily be moved by hand. In some cases, arrangement is made for connecting the traverse mechanism with the leadscrew so that the tailstock may be moved by power. In the form shown in Fig. 1, the tail spindle is moved in or out by means of the hand wheel *23*; but in the form shown in Fig. 8, the tailstock becomes of such extreme length that it is not always convenient to operate the spindle by the hand wheel *g*, and the auxiliary hand wheel *h* with the shaft *i* and gearing at *k* is provided, thus enabling the operator to control the spindle while he is close to the center.

13. Feed-Screw Supports.—In the case of a small lathe, as shown in Fig. 1, the feed-screw and feed-rod *15* and *11* are simply supported at the ends and in the apron. In the case of long or heavy lathes, additional supports, as shown at *l*, Fig. 8, become necessary. Sometimes several of these supports are arranged along the lathe.

14. Tool Posts.—In most lathes, the tool is secured in the ordinary tool post of the form shown at *21*, Fig. 1, and at *n*, Fig. 8, but in large lathes it is sometimes desirable to turn work that cannot be swung over the carriage. In such a case, the device illustrated in Fig. 8 is used. It consists of an auxiliary slide *m* placed at the front end of the carriage, and the tool post *o*. Such a tool post is located considerably below the line of the lathe centers, and, in order to obtain the proper cutting angles for the ordinary tools, the surface upon which the bottom of the tool rests is inclined at such an angle that a plane passing through the bottom of the tool would pass approximately through a line joining the centers.

PLAIN CYLINDRICAL TURNING.

15. Example of Turning.—In discussing this first exercise in lathe work, it may be well to have in mind some particular piece that is to be finished. A plain cast-iron cylinder 12 inches long, 2 inches in diameter, finished round, true, and parallel, according to the drawing, Fig. 9, has been selected. The stock may be $2\frac{1}{4}$ inches in diameter and long enough to "square up" or to have the ends finished smooth when it is the correct

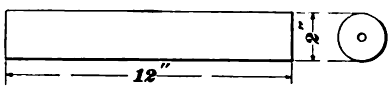


FIG. 9.

size. Work of this character, such as bolts, studs, spindles, shafts, etc., that has been forged, cut from the bar, or cast very near the finished length, is held in the machine between the lathe centers, holes having been previously drilled and reamed in the ends of the work for the reception of the lathe centers.

CENTERING.

LOCATING CENTERS.

16. Centering by Dividers.—The operation of locating, drilling, and reaming the center holes is one of importance and requires careful attention. Various methods are used for locating center holes, depending on the shape of the piece and the number of pieces to be centered. If the stock is round and true, the center may be roughly located by placing the work on a flat surface and using a pair of dividers, set to about half the diameter of the work, for scribing lines on the end, as shown in Fig. 10. To do this, the dividers are drawn across the chalked end of the work, scribing one line; the work is given a quarter revolution and another line is scribed, and so on until there are four lines intersecting, as shown. The center of the inscribed square is approximately the center of the work, provided the dividers were held at the same angle with the work each time a line was scribed. A prick-punch mark made in the center of the square locates the trial center.

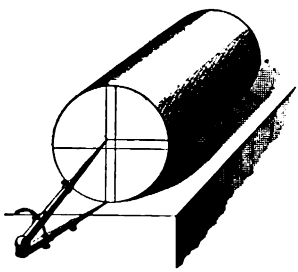


FIG. 10.

17. Centering by Surface Gauge.—Instead of the dividers, a **surface gauge** or scriber block may be used for scribing the lines. Fig. 11 shows how a surface gauge *a* may be used for centering a bolt *b*. In this piece, it is desirable to make the center true with the stem or shank of the bolt. The head cannot always be depended on to be forged true with the shank. The bolt is placed in the V's of two blocks *c*, *c*, as shown in Fig. 11. These blocks should

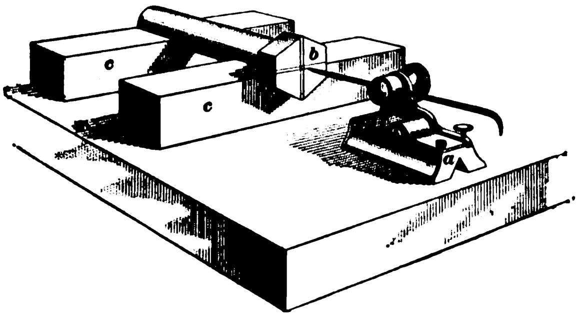


FIG. 11.

hold the bolt high enough from the bench or table so that the head will not touch when the bolt is revolved in the V's. The scriber point of the surface gauge is then set to about the center of the work and the four lines are scribed, intersecting as shown.

18. Centering by Hermaphrodites. — Another method of locating the center is by the use of hermaphrodites, as shown in Fig. 12. The hermaphrodites are set so that the pointed leg comes near the center of the work. With the other leg at the respective points *a*, *b*, *c*, and *d*, four arcs are scribed, intersecting as shown. The center *e* of this inscribed polygon is the approximate center.

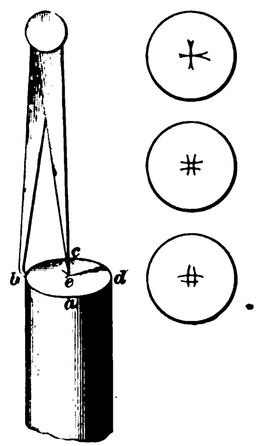


FIG. 12.

19. Centering by Cup Centers. When there are many pieces to be centered, time can be saved in locating the centers by the use of a **cup center**, shown in Fig. 13. The conical opening in the end is placed over the end of the work, as shown, and a light blow on the prick punch *p* with a hammer is sufficient to mark the point. If the end of the work to be centered is untrue, as in Fig. 14, or if the device is not held true on the end, as in Fig. 15, it will not locate the center accurately. The line *a b* shows the center line of the work, and *c d* the center

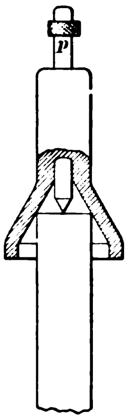


FIG. 13.

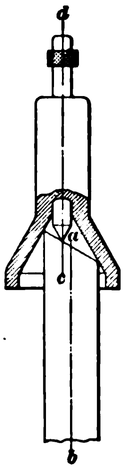


FIG. 14.

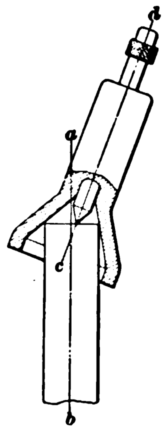


FIG. 15.

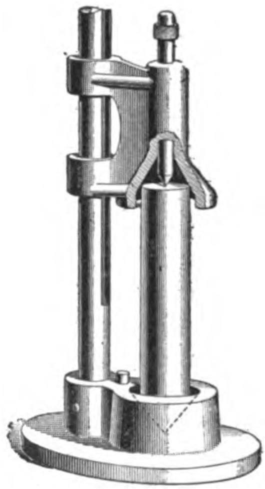


FIG. 16.

line of the punch. Fig. 16 shows a centering device that insures that the punch and the work will be held in line, but does not overcome errors due to untrue ends, as shown in Fig. 14.

20. Testing Location of Centers. — When the "stock," or the rough piece to be finished, is very close to the finished size, it is best to test the accuracy of the location of the centers before they are actually drilled and reamed. This may be done in the case of light work by supporting it between the centers of the lathe, allowing the points of the lathe centers to enter the prick-punch marks made in the ends of the work. While thus supported, the work should be revolved rapidly by drawing the hand quickly across it. While the work is thus spinning on the center points, chalk is held against it so that the chalk will just touch. If there is an untrue end or a high side, the chalk will mark the high place. Thus, the work is tested and the center mark moved, if necessary, until the work will run with sufficient accuracy to insure the correct location of the centers.

21. Changing Center Marks.—The center marks in the ends may be changed slightly in location by using a prick punch and slanting it in the direction in which it is desired to move the mark, as shown in Fig. 17 (*a*), or the prick punch may be held at one side of the center, as shown at (*b*). In the latter case, the point of the punch will move toward the old center when struck, but will draw the center to one side as desired. When the centers are satisfactorily located, they should be made quite large with the punch for the purpose of making a starting point for the drill. If only a very small mark is made in locating the center, the drill may not start in the desired place but begin drilling at some other point.

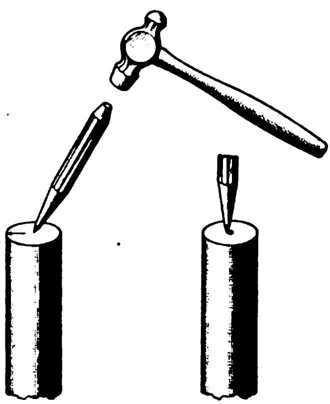


FIG. 17.

FORMING CENTERS.

22. Centering Machines.—When there are large quantities of work to be centered, much time and expense can be saved by the use of special centering machines. A type of one of these machines is shown in Fig. 18. These machines render the methods of locating centers just described unnecessary. The one illustrated is fitted with a universal chuck *a*, which holds the work to be centered accurately in line with one spindle of the machine. If the work is long, the end is supported in the V-shaped rest *b*. When in this position, the work is drilled and reamed, there being two spindles, *c* carrying a drill and *d* a reamer, which can be alternately brought in line with the center of the work. After the machine is once adjusted, it will drill and ream all pieces to the same depth and size.

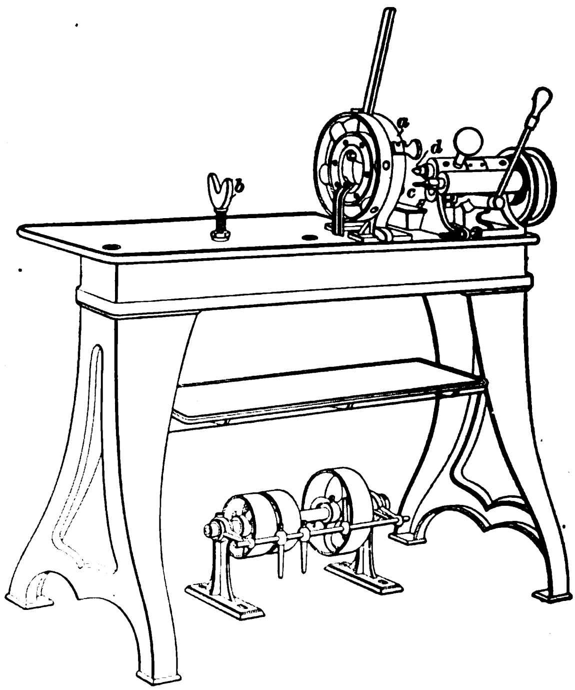


FIG. 18.

23. Drilling and Reaming on the Lathe or Drill Press.—If a centering machine is not at hand, the drilling and reaming may be done on a small sensitive drill press or on a speed lathe. Ordinarily, this operation consists of first drilling a hole from $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter about $\frac{1}{2}$ inch deep and then reaming the end of the hole with a reamer of the form shown in Fig. 19 (*a*) or Fig. 19 (*b*). This practice has been almost entirely abandoned in the case of small work by the introduction of the combination drill and reamer shown in Fig. 19 (*c*). This method saves time and insures that the reamed position of the hole will be axially true with the drilled position. This is a very important point when accurate lathe work is to be done.

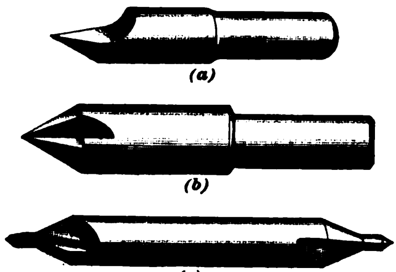


FIG. 19.

24. Correctly Formed Center Holes.—Fig. 20 (*a*) shows a section through a properly formed center hole and shows how it should fit the lathe center. It will be noticed that it is reamed to an angle of 60° to fit perfectly the angle of the lathe center; also that the drill hole extends into the work sufficiently deep to prevent the extreme point of the lathe center from bearing against the work.

The practice employed by some workmen of forming the center hole by simply making a very large prick-punch mark into the end of the work is a practice that should not be

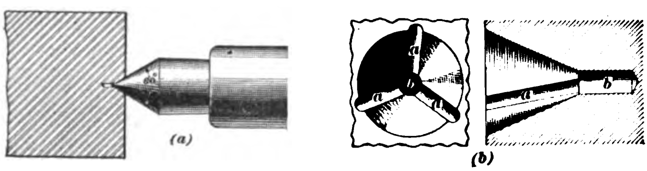


FIG. 20.

allowed, since it is impossible to produce accurate work with such center holes; besides, the work will soon wear or break off the points of the lathe centers.

When very large center holes are required for supporting extra heavy pieces, particularly in cast iron, it is an excellent plan to cut several oil channels, as *a*, Fig. 20 (*b*). It is also well to fill the end of the center hole *b* with wool, felt, or picked up waste saturated with oil.

HOLDING WORK BETWEEN CENTERS.

25. Precautions.—After centering, the work is ready for the lathe. A lathe dog, Fig. 21, is slipped on one end of the work, a drop of oil put in the center hole of the other end, and the tailstock adjusted to the proper position for holding the work between the centers. Care must be taken in adjusting the dead center. The proper adjustment is such that the work is free to turn, and at the same time is held so tight that there is no lost motion. The operator must also see that the tail of the dog fits loosely in the notch

FIG. 21.

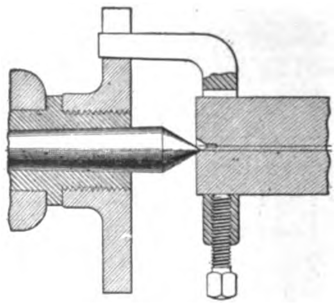


FIG. 22.

of the face plate. Sometimes the tail of the dog pinches in the face plate in such a manner as to hold the work off from the live center, ~~as shown in Fig. 22.~~ This prevents the work from running true. In adjusting the tailstock on the bed, it should be clamped in such a position that it will not be necessary to run the tailstock spindle out very far to reach the work, as greater rigidity is secured by keeping the spindle well in the tailstock.

SQUARING THE ENDS.

26. All work turned between the centers of a lathe should have its ends "squared up" or made flat and true before attempting to turn the cylindrical surfaces.

THE TOOL.

27. Side Tool.—The tool used for this kind of work is shown in Fig. 23 and is known as a right-hand **side tool** or **knife tool.**

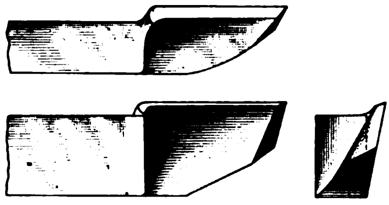


FIG. 23.

28. Grinding the Tool. — Lathe tools are ground for two purposes: *first*, to secure the desired form and shape; and, *second*, to make the tool sharp. After a tool is once correctly shaped, there should be as little grinding as possible, in order that the original shape may be preserved. Much grinding needlessly wears away the tool. Fig. 24 shows an end view of a side tool correctly shaped and illustrates how it is presented to the work as seen from the back of the lathe. The cutting edge of the tool is at the center of the work. It will be noticed that the face of the tool *A B* is ground flat and at an angle to the line *C D*, which is parallel to the side of the shank. This angle, formed by the

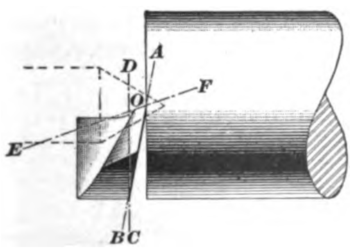


FIG. 24.

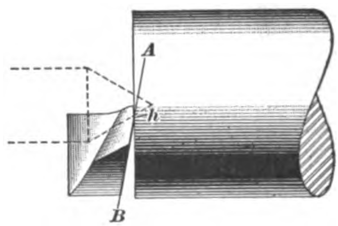


FIG. 25.

lines *A B* and *C D*, is the angle of side rake. The top face denoted by the line *E F* is usually ground to make an angle with the face *A B* of about 60° for cast iron and 55° for wrought iron or soft steel. When sharpening the tool, the most grinding should be done on the top face *E F*, care being taken to preserve the original shape of the tool. Fig. 25 shows how a careless workman may round the face *A B* of the tool in attempting to make the cutting edge sharp, with the result that the tool cannot cut because of the high place *h*, which touches the face of the work first. After a tool is ground on an emery wheel or grindstone, it should be sharpened by the use of an oilstone, to give it a keen edge.

SETTING THE TOOL.

29. General Considerations.—For roughing cuts, the tool should be clamped in the tool post so that the cutting edge *A B*, Fig. 26, makes an angle of from 10° to 15° with the end of the work. The tool should be clamped as close to the cutting edge as possible, in order to give rigidity to the tool. The tool should be adjusted for height, so that the cutting edge is level with the center of the work.

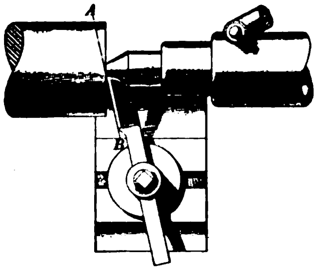


FIG. 26.

30. Rise-and-Fall Rest.—Various means are adopted for adjusting the height of the tool, depending on the style of lathe and carriage. Fig. 27 shows a very common form used on small sizes of lathes. This is known as the **rise-and-fall rest.** The rest is composed of two parts, one *a* resting on the bed of the lathe, while the upper part *b* is hinged at the points *p*, *p*, and carries the tool block. By means of the adjusting screw *s*, this upper part may be raised or lowered and the tool set at any desired height. This is one of the most convenient forms of tool rest used for small work. A weight is frequently attached to the under side of *b* by a link passing through *a*. The

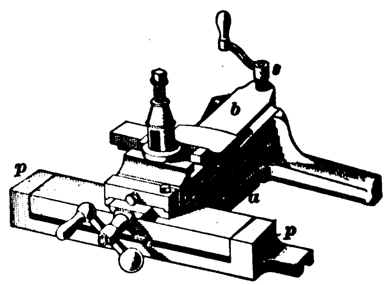


FIG. 27.

weight should be heavy enough to hold the top part down. Lathes fitted up in this manner are called **weighted-rest lathes.**

31. Plain Rest.—Fig. 28 represents another type of tool rest, known as the **plain rest.** This style is used principally on the larger lathes. In this type, the height of the tool point is adjusted before clamping in the tool post, by means of wedges, washers, or rings under the tool, as described in the following articles.

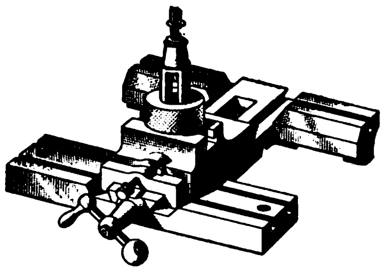


FIG. 28.

32. Adjustments for Height of Tool.—Fig. 29 (*a*) shows one style of adjustment commonly used. The tool rests on a chip *a*, which is convex on its under side. This chip fits the top of a concave ring *b*, which rests on the tool block. The tool point *o* can be set at any height within given limits, and the chip *a* under the tool will rock to a position that will give a flat bearing for the tool.

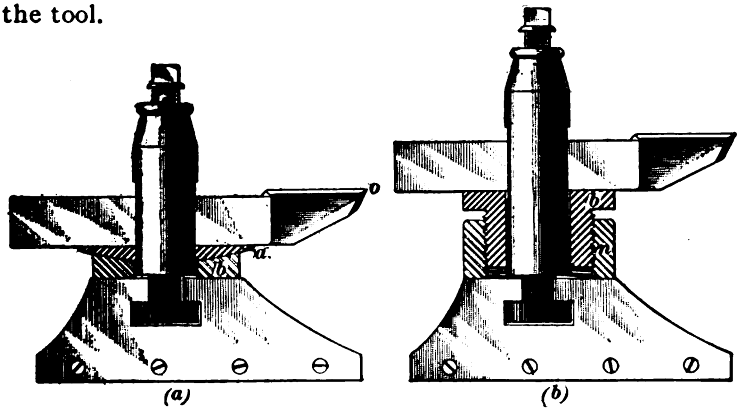


FIG. 29.

Fig. 29 (*b*) shows another method of adjusting the height of the tool. The nut *n* is threaded and fitted to the thimble *b*, which fits over the tool post. By rotating the nut *n*, the thimble *b* may be raised or lowered to any desired position. This form has an advantage over the style previously described in that it gives a level or flat bearing for the tool and keeps it in a horizontal position at all times. There are numerous other styles of tool-post adjustment that vary little in principle and accomplish the same purpose.

TAKING THE CUT.

33. Classification of Cuts.—On all machine work there are two classes of cuts used, namely, the *roughing cut* and the *finishing cut.* The roughing cut is, as its name implies, the first heavy cut taken over the work for the purpose of blocking out or roughing the work very close to size, the object being to remove the excessive metal in the shortest possible time. Roughing cuts are therefore made as heavy and as deep as the machine will drive. The finishing cut is the last cut taken on the piece and is intended for finishing the work to exact size and at the same time making it smooth and true. In order to obtain these results, the tool must be very sharp and keen.

34. Roughing Cuts.—When using the side tool, the cut is started at the center of the work. The tool is moved sidewise by moving the carriage by hand until the tool has a deep cut—deep enough to cut well under the skin and scale if the stock is cast iron. The tool is held in this position by holding the carriage still, while being drawn from the center by means of the cross-slide. These operations are repeated until the desired amount of metal is cut from the end. If much is cut from one end, a burr will be left around the center hole, as shown at *b*, Fig. 30. This burr may easily be removed by using the point of the tool, after having first loosened the

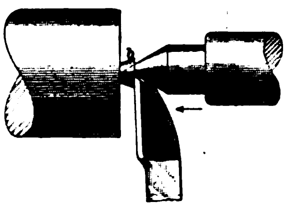


FIG. 30.

dead center to admit the tool, as shown. The tool is fed sidewise, in the direction of the arrow, by hand, and, at the same time, the dead center is fed in, to keep the work from dropping off. This will cause chips and shavings to get into the center hole, which should be carefully removed before any turning is done along the cylindrical surface of the work. After each end is roughed off and the piece is very close to length, the center holes should again be drilled and reamed, if necessary, to make them of the proper size to stand the strain when taking the heavy cuts on the outside.

35. Finishing Cuts.—Before taking a finishing cut, the tool should be reground if necessary and then made keen and sharp with an oilstone. In order to make the cuts smooth, it is better, in grinding, to slightly curve the edge

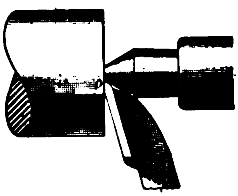


FIG. 31.

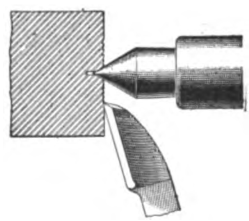


FIG. 32.

of the tool near the point, as shown in Fig. 31. The tool is set the same as for roughing cuts, with the exception that the cutting edge makes such an angle that the end of the work is flat or tangent to this curve at the point of the tool *o*. If the point of the tool is not rounded or curved, it will leave deep marks on the work, as shown in a somewhat exaggerated form in Fig. 32, the distance between the marks representing the movement of the tool for each revolution of the work. In some cases, when the work is small in diameter or when true square faces are not required, the edge of the tool is ground straight and set flat

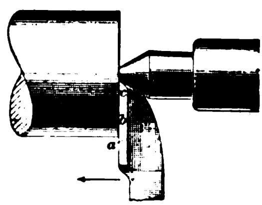


FIG. 33.

with the end of the work, as shown in Fig. 33. When the tool is thus set, it is fed in the direction of the arrow, that is, sidewise to the work and not drawn out from the center. The "squareness" of the end will then depend on the way in which the tool was set.

36. By setting the tool as in Fig. 31, so that only a small portion of the point cuts, and then drawing the tool out from the center, the squareness of the end is insured, because of the accuracy of the cross-feed. If, however, in making the cut, the tool and carriage are jarred or moved away from the work, or if the tool dulls, or springs in the tool post, the work will not be true. The work may be tested with sufficient accuracy for ordinary work by putting a scale or straightedge across the end, when, by holding it to the light, it will be easy to detect any slight error. If the lathe continues to make the work concave or convex after the spring of the carriage and tool have been cared for, the lathe centers will probably be found out of line. After the centers are lined up, the difficulty will probably disappear.

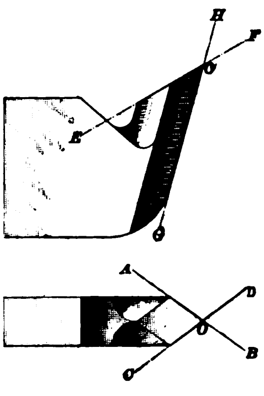


FIG. 34.

TURNING TO A DIAMETER.

THE TOOL.

37. Shape of Tool.—The tool selected for the outside cylindrical turning in this case is called a **diamond point** or **front tool.** Very much depends on its exact shape and the way it is held in the tool post and presented to the work. These tools will be discussed in full later. For the present, the typical form represented by the diamond point will be considered. Fig. 34 shows this tool as ordinarily formed. The cutting is done by the edge *A B* and the point *O* shown in plan.

38. Grinding.—The tool is sharpened by grinding the top face *E F* and the faces shown by the lines *A B* and *C D*. Care should be taken in grinding the front faces that the same amount be ground off the heel of the tool as at the point, so that the slope of the front of the tool, shown by the line *G H*, be kept the same. When the tool becomes dull, there is a tendency to hurry the grinding operation and make the cutting edges sharp by rounding the front faces, so that the tool soon appears as shown in Fig. 35. While this may make the cutting edge sharp, it entirely changes the cutting conditions of the tool.

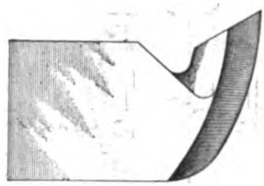


FIG. 35.

After grinding the three faces *E F*, *A B*, and *C D*, Fig. 34, they will form a sharp point at *O* and a sharp edge along the line *G H*. This edge should be rounded along its entire length, so that the point of the tool will be rounded as shown in plan in Fig. 34.

In grinding lathe tools when the tool is held in the hand, the point should be finished by holding it, when applied to the grindstone or emery wheel, as shown in Fig. 36. This allows the water to strike the cutting edge first, keeping it

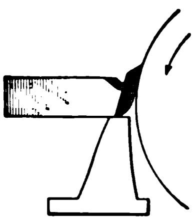


FIG. 36.

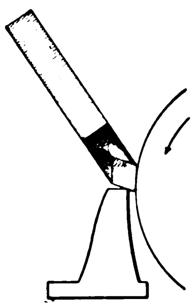


FIG. 37.

cool; it also sets in the correct direction the grain of the tool caused by the cutting particles of the emery wheel. The tool should never be held as shown in Fig. 37 when grinding by hand, as there is danger that it will catch between the wheel and the rest and cause much damage.

SETTING THE TOOL.

39. Position of Tool.—The tool should be clamped in the tool post as close to the cutting edge as possible, to

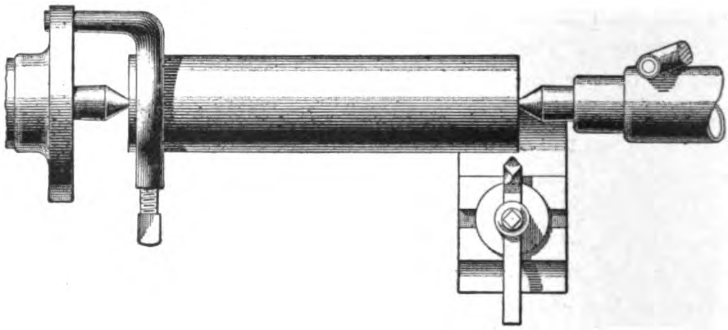


FIG. 38.

give it rigidity. The shank is generally set about square with the work, as shown in Fig. 38.

40. Height of Tool.—Very much depends on the height of the tool. The correct height is governed by the angle of front rake or the slope of front edge of the tool *G H*, Fig. 34. Fig. 39 shows a tool at the correct height for turning a piece to the diameter shown by the inner circle.

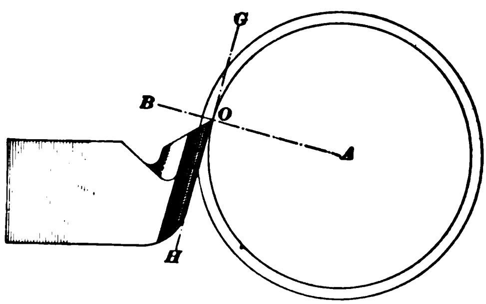


FIG. 39.

In this case, if a line *A B* be drawn from the center of the work *A*, through the point of the tool *O*, it will be found that the front of the tool *G H* is tangent at this point *O*.

If the tool should be raised, keeping the front of the tool *G H* at the same angle to the work, it would bring the

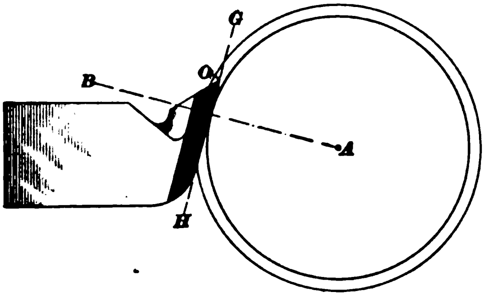


FIG. 40.

cutting point above the work, as shown in Fig. 40. It is obvious that in this position it would be impossible for the tool to cut.

Fig. 39 shows the exact position for a perfect tool, provided it would remain sharp. In practice, the tool dulls and the point rounds off slightly, so that it is customary to set the tool slightly below this theoretical point. This theoretical height varies with every diameter of work. Fig. 41

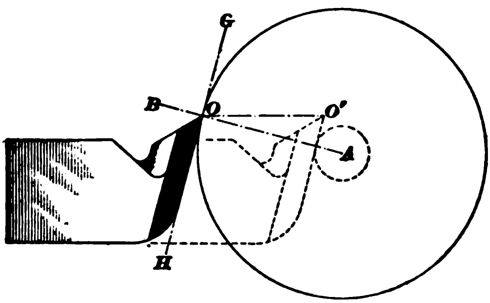


FIG. 41.

shows a tool correctly set for a piece of large diameter. The dotted lines show the same tool at the same height moved in to cut on a smaller piece shown by the dotted lines. It will readily be seen that the tool cannot cut the small diameter of work when its point O' is so far above the work. It will also be seen that the point of the tool should be lowered as the diameter decreases, the point O following along the line $A B$ until it finally reaches the axis of the work. In clamping the tool in the tool post, care should be taken that the point of the tool does not touch the work. When it does touch and the tool is clamped down, the edge is liable to be cracked off, as shown in Fig. 42.

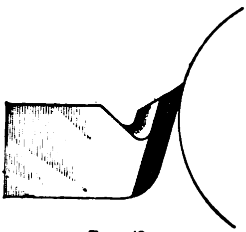


FIG. 42.

TAKING THE CUT.

41. Roughing Cuts.—Roughing cuts are taken to reduce the work very close to size in the shortest time, after which the work is finished to the exact diameter and at the same time made smooth.

When it is possible to remove the excessive amount of material at one cut, it should be done. Whether this can be done or not depends on the power of the machine and the strength of the tool, and on the strength of the piece to withstand a heavy cut without springing or breaking. Some pieces are so frail that a number of light cuts are required to remove an amount of material that under more favorable conditions could easily be taken off at one cut. Whatever the amount removed may be, there should be left from $\frac{1}{64}$ to $\frac{1}{32}$ inch in diameter over the finished size for the finishing cut. Only in special cases or on rough work is it allowable to rough and finish work with the same cut.

42. In making the first cut, the tool is started at the end of the work and fed by hand until it begins to cut. The feed is then thrown in and the tool moves along until a short piece is turned on the end. This part is calipered, and if correct, the lathe runs on until the tool has fed about half the length of the work. The work will then be as shown in Fig. 43, the part a being rough, and the part b turned. It will be seen that the tool cannot continue over the entire piece because of the lathe dog on the end *a*. The work should therefore be removed from the lathe and the tool

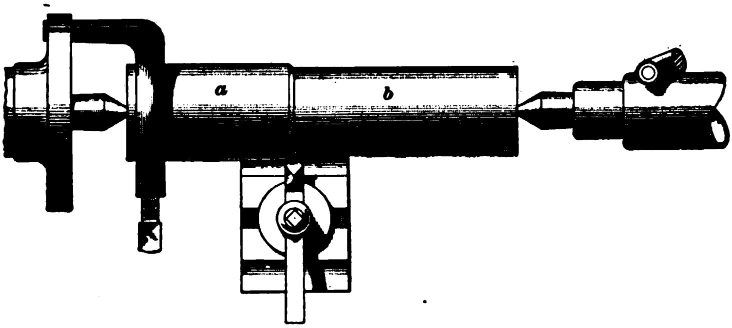


FIG. 43.

and carriage moved back to the starting point, care being taken not to move the cross-slide that moves the tool in or out from the work.

The dog is changed to the end *b* and the work reversed and again put in the lathe. This will bring the work as shown in Fig. 44. The end *a* is then turned the same as

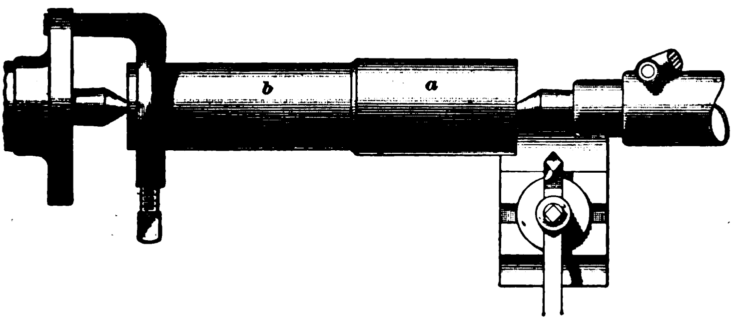


FIG. 44.

end *b*, and if the cross-feed has not been moved, the work will be the same diameter at each end, the two cuts meeting in the middle.

When it is necessary to take a number of cuts and accurate work is desired, it is better to reverse the work after each cut, as just described, than to take a number of cuts on one end before reversing. The speed of the work depends on certain conditions that will be treated of later. For this particular piece, Fig. 9, which is 2 inches in diameter, it should make about 50 revolutions per minute, provided the casting is soft. The feed should be comparatively coarse, making a thick shaving.

43. Finishing Cuts.—In taking the finishing cut, considerable skill must be exercised, since if the piece is once made too small, there is no remedy, and if cut rough and untrue, it requires much extra labor to complete it.

The tool should always be resharpened for the finishing cut. Its shape remains much the same as for roughing, except that the top face may be given a little more slant or top rake.

The shape for tools for roughing and finishing cuts will be described more fully when considering the theory of cutting tools. The shapes of tools and also the feed vary considerably, so that what may be considered good practice for this piece would not be the best for heavier work.

FINISHING TO AN EXACT SIZE.

44. Use of Calipers for Measuring.—The diameter of the work is measured by the use of special gauges or by calipers. When calipers are used, they are adjusted to correct size by trying them over a standard cylindrical gauge of the desired size, or they may be set to size by the use of a scale. When setting calipers by the use of a scale, they should be held as shown in Fig. 45. It will be noticed that the point of one leg of the caliper comes against the end of the scale. By means of the thumb nut, the calipers are adjusted so that the other point of the caliper comes even with the desired line on the scale,

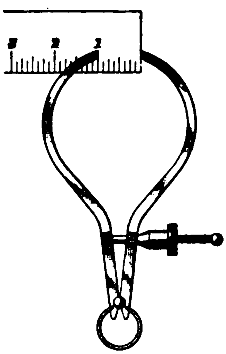


FIG. 45.

Care must be taken to hold the caliper true and to make the adjustment such that by looking squarely by the point of the caliper, it will appear to split the mark on the scale. The thickness of a line on a steel scale is equal to .002 or .003 inch, and in many instances this amount would be sufficient to cause considerable trouble.

45. Adjusting the Tool.—The lathe tool is set to turn the correct diameter by a series of careful trials. A light cut is first taken on the end, running along far enough to give sufficient length of turned part to caliper. The lathe is stopped and this part carefully calipered. If found to be too large, the lathe is again started, the feed thrown out, and the carriage and tool moved back to the starting point. The tool is moved forwards an amount determined by the judgment of the operator and another cut taken. The work is again calipered, and if found to be correct, the lathe is started and the cut proceeds; if the work is still too large, the previous operation is repeated until the correct diameter is obtained. It should be noticed that if, after measuring the work, it is found necessary to take another cut, the cross-feed screw must not be used except to advance the tool. If the tool is moved away from the cut, the operator has no means of estimating how much to turn the cross-feed screw to move the tool in a little deeper than it was for the last cut.

46. After the roughing cut, the work should be calipered along its entire length to see if it is all of the same diameter. If one end is larger than the other, it may result from either of two causes. The lathe centers may be out of line, or the tool point may have worn away enough to cause a noticeable difference of diameter. If the centers are out of line, the dead center must be moved until the two sides of the work are parallel. Care must be taken, however, to locate the cause correctly, in order that the center may not be moved when the tool is at fault. The adjustment of the dead center will be considered later.

CALIPERING.

47. Great skill and delicacy of touch may be acquired by careful calipering, and differences in diameter of .001 inch may be detected with ordinary spring calipers. There are two chances for error in calipering: *first*, by incorrectly setting the calipers, and, *second*, by not properly handling them.

Assuming that the calipers are correctly adjusted, they are held lightly between the thumb and fingers and passed gently over the work a number of times. It is obvious that the diameter of a cylinder must be measured at right angles to its axis, and if measured at any other angle, as along the line *CD*, Fig. 46, it would be incorrect. The calipers are therefore turned slightly from side to side until the position is found where the calipers pass over the easiest. This position, which appears to be the smallest diameter, is the correct one. When the work is of the correct size and the correct position is found, the calipers will just pass over with a very gentle pressure. If the pressure is sufficient to hold the weight of the calipers or if force is required to push them over the work, it is too large. Calipers may very easily be sprung, and it is an easy matter to force them over work $\frac{1}{16}$ or $\frac{1}{8}$ inch too large. When the calipers have been set from a gauge, the work should be turned so that they fit the work with the same pressure and feeling that they fit the gauge.

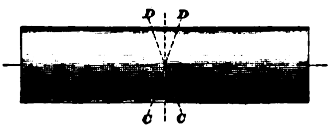


FIG. 46.

TAPER TURNING.

48. Expressing the Taper.—Taper is expressed by the difference in diameter per unit of length, as $\frac{1}{8}$ inch to 1 inch, or 2 inches to 1 foot, meaning, in the first case, that if measurements be taken on a taper 1 inch apart, the difference in diameters will be $\frac{1}{8}$ inch, or, in the second case, if measured 1 foot apart, the difference in diameters will be 2 inches. It matters not how large a piece may be, provided this ratio of diameter is maintained. Fig. 47 shows a number of pieces of different diameters but all of the same taper. Their lengths are the same, and the difference of diameters at the two ends is constant.

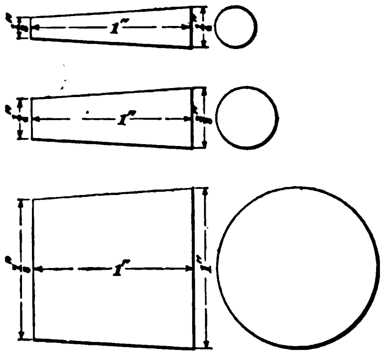


FIG. 47.

Fig. 48 shows pieces of different lengths but still of the same taper. The first piece, 1 inch long, has a difference of $\frac{1}{8}$ inch in diameter at the ends. The next piece, 2 inches long, has $\frac{2}{8}$ inch difference of diameter at the ends; the third piece, 4 inches long, has $\frac{4}{8}$ inch difference in diameter. If the piece were 12 inches long, the difference of diameter at the ends would be $\frac{12}{8}$ or $1\frac{1}{2}$ inches taper to the foot. It may thus be seen how taper expressed in one denomination may be reduced to another denomination. Thus, *to reduce taper per foot to taper per inch divide by 12. To reduce taper per inch to taper per foot multiply by 12.*

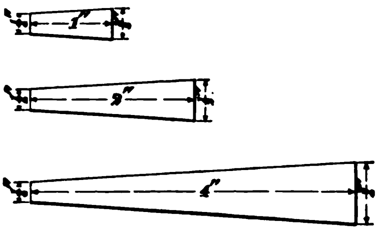


FIG. 48.

49. Standard Tapers.—Tapers are often spoken of by numbers or by the names of particular makers. For example, the Brown & Sharpe taper of a given number, or the Morse taper of a given number. The Brown & Sharpe taper is supposed to be a taper of $\frac{1}{2}$ inch to 1 foot and the number of the taper indicates a particular diameter. The Morse taper was intended to be $\frac{5}{8}$ inch to 1 foot and the numbers indicate different sizes. Unfortunately, the first standards were inaccurate and, consequently, the different numbers of Morse tapers are not the same and no one of them is exactly ⅝ inch to 1 foot, as originally intended.

METHODS OF TURNING TAPERS.

50. Classification of Methods. — There are four methods for turning tapers in common use, which are as follows: *first*, the dead center may be set out of line with the live center; *second*, a lathe provided with a special taper attachment may be employed; *third*, a special turning lathe in which the headstock and tailstock may be set at an angle to the line of tool feed-motion may be employed; *fourth*, the taper may be turned with the aid of a compound rest.

The first method is applicable only for outside turning, while the other three may be used for turning and boring.

SETTING OVER THE TAILSTOCK.

51. Construction of the Tailstock.—The tailstock of a lathe is so constructed that the spindle and dead center may be moved to bring it either exactly in line with the live center, for parallel turning, or out of line with the live center for taper turning.

Fig. 49 shows an end view of a tailstock. The part *a* is fitted to the lathe bed. The part *b* is fitted accurately to part *a* and may be moved toward either the front or the back of the lathe. The part *b* is moved by turning the adjusting screw *c* at the front. When it is desired to turn a taper, the tailstock is unclamped by loosening the nut *d*, which clamps it to the bed, and the dead center is moved out of line an amount that has been previously calculated or found by trial to be correct.

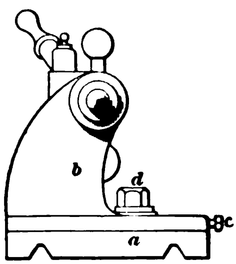


FIG. 49.

52. Estimating the Amount of Set-Over.—The amount that a center should be moved to turn a given taper

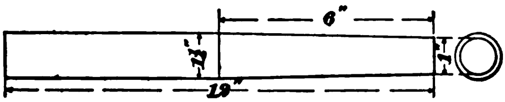


FIG. 50.

can be easily calculated. Suppose it is desired to turn a taper ½ inch to the foot on the piece shown in Fig. 50. This means that in 1 foot length the difference of diameter is ½ inch, and since the piece is 1 foot long, it will be necessary to move the dead center out of line and toward the front of the machine one-half of this half inch, or ¼ inch. It must be understood in turning that if we take a cut ¼ inch deep, we reduce the diameter ½ inch. Moving the dead center toward the tool ¼ inch is equivalent to taking a shaving or cut ¼ inch deep. The amount that a center is set out of line may easily be measured by moving the two centers close to each other and measuring from point to point with a scale, as in Fig. 51, or by means of a scale on the tailstock, as shown in Fig. 52.

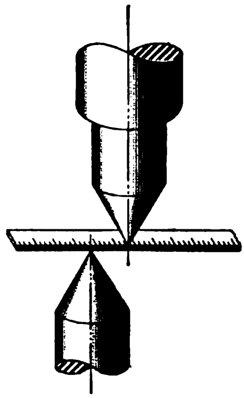


FIG. 51.

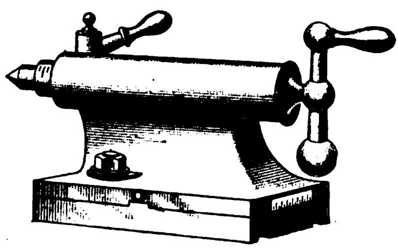


FIG. 52.

53. Suppose the piece to be as shown in Fig. 53. Here the taper is ¾ inch to 1 foot and the piece is 10 inches long. If the piece were 12 inches long, it could at once be estimated that the center should be set out of line ⅜ inch, but since the piece is less than 12 inches long, ⅜ inch would not be correct, as it would turn the taper too blunt. We must here reduce the taper per foot to taper per inch by dividing by 12. Dividing $\frac{3}{4}$ by 12 equals $\frac{3}{4} \times \frac{1}{12} = \frac{3}{48} = \frac{1}{16}$ inch; $\frac{1}{16}$ inch to the inch is therefore equal to $\frac{3}{4}$ inch to the foot. Multiplying the total length of the piece between centers by 10, $\frac{1}{16} \times 10 = \frac{10}{16} = \frac{5}{8}$ inch, the taper in a piece 10 inches long. Since the center is set over half the amount of the taper, divide $\frac{5}{8}$ by 2, which gives $\frac{5}{16}$ inch, the amount that the center should be moved out of line.

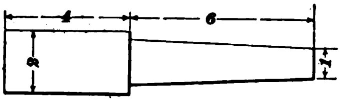


FIG. 53.

54. Setting by Notches.—When the taper per foot is not given but when we have the diameters, with the distance between them, another method may be used. Suppose a piece as shown in Fig. 54 is to be finished. Notches are first cut in the stock, as shown at *a* and *b*, Fig. 55. The dotted lines indicate the shape of the finished piece. One notch is cut $\frac{7}{8}$ inch from the end, until the diameter at the bottom is $1\frac{1}{8}$ inches, and the second notch is cut $3\frac{1}{4}$ inches from the first until it measures $1\frac{7}{16}$ inches at the bottom. These notches define the taper, and from these diameters, measurements are taken for setting the lathe, as will be shown later.

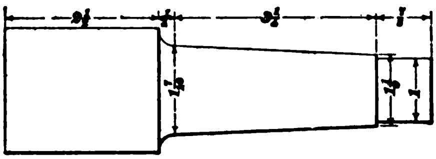


FIG. 54.

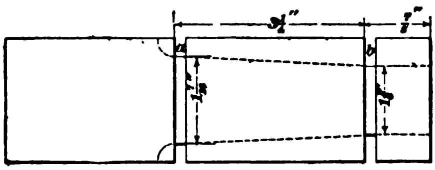


FIG. 55.

When the work is prepared, it is put between the center and a tool held in the tool post, the same as for turning. The dead center is moved an amount estimated by judgment. The tool is then moved opposite one notch of the work, as at *a*, Fig. 56, and the distance from the point of the tool to the bottom of the notch is measured. The tool and carriage are then moved opposite the second notch *b*, and the same measurement taken. If the measurements are alike, the work is correctly set; if not, the dead center must be adjusted until they are the same. After each adjustment of the tailstock, the work must be measured from

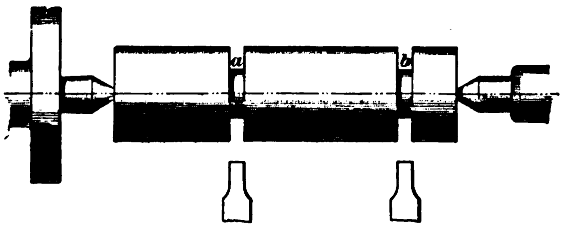


FIG. 56.

each notch. It is not right to measure with the tool in position *a*, and then adjust the tailstock until the measurement at *b* is the same, for it will be seen that in changing the measurement at *b* the measurement at *a* will also change, although not so rapidly.

Various methods are employed for taking the measurements from the work to the point of the tool. An ordinary scale or a pair of inside calipers may be used. When calipers are used, it is better to use the butt end of the tool, or some flat surface, as it is easier to measure between surfaces than between points.

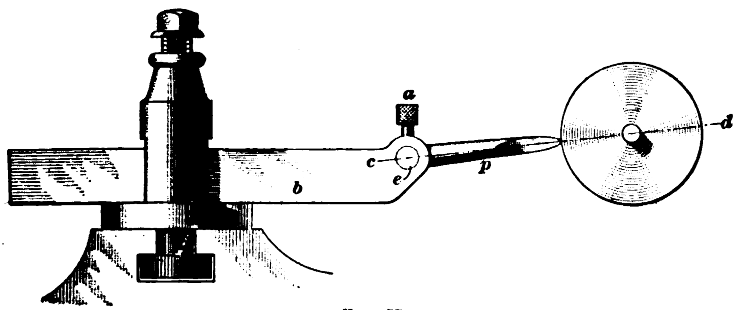


FIG. 57.

55. Caliper Tool.—A still better way is to have a special caliper tool, as shown in Fig. 57. It consists of a shank *b* like an ordinary lathe tool, to the end of which is pivoted a pointer *p*, which can be moved like the leg of a caliper. The tool is clamped to the tool post and adjusted so that the rivet *e* on which the pointer swings is at the same height as the axis of the work. When it is desired to test the work, the pointer is brought opposite one of the notches and the tool is adjusted by means of the cross-feed screw until the end of the pointer just touches the work, as shown. The nurled knob *a* is connected with the pointer and is used for moving it in calipering. After the tool is adjusted for one position, the pointer is dropped so that it can be moved to the other position, where it will at once indicate whether the work is correctly set or not.

56. Setting by Turning Parallel to Two Diameters.—Sometimes tapered work is set by turning to two diameters, as shown in Fig. 58, the work being turned to the smallest diameter of the taper up to its beginning, and then from this point to the head of the taper the work is turned to the largest diameter of the taper, as shown. After this, the tool may be set to the points *a* and *b*, as in the case of setting by notches. This method has the advantage that a large portion of the stock is removed while the work is between centers that are in line, and fits the centers of the work perfectly.

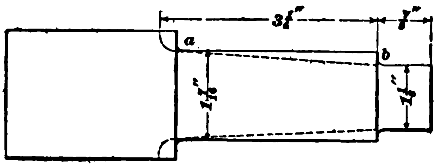


FIG. 58.

57. Setting With a Model Piece.—When a model taper has been furnished, the lathe may be set directly from it. The model is put between the lathe centers, and the dead center is adjusted so that the measurements from the point of a tool in the tool post to the taper model remains constant as the carriage and tool are moved along its length. When close measurements are desired, the tool, or, better, some article with a rounded end, is brought close to the model, so that it loosely pinches a piece of tissue paper. The tool and the paper are moved along the length of the taper and tested at various places by pulling the paper. If the paper slips between the tool and the taper model with about the same pull at all places, it is correct. While this method of turning tapers by setting over the tail-stock is a very common one, it is by no means the best, since there are some very objectionable features.

OBJECTION TO SETTING OVER LATHE CENTERS.

58. Wear of Centers.—Fig. 59 shows a section through work when the centers are set out considerably. It will be seen that the dead center touches the work in only two

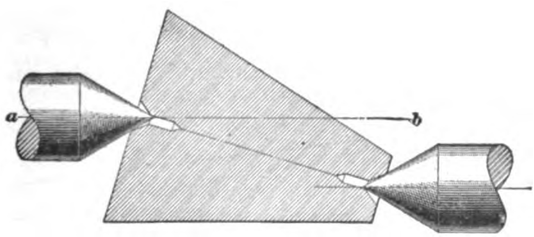


FIG. 59.

points. Since the work rotates about the dead center, there is a tendency to wear away the center hole and the lathe center. Much wear would result in a shape as shown in Fig. 60. The front side of the point of the center is worn away and a groove formed at the back, while the center hole is worn into a bell shape. The live center revolves with the work, so that the wearing action between it and the center is somewhat different. On the dead center the work has a rotating motion, while on the live center it has a reciprocating motion. The result is that the live center is worn evenly all around, and the center hole is worn into about the same shape as the dead-center hole.

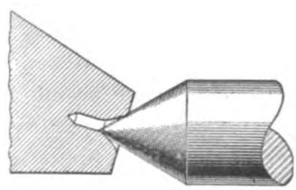


FIG. 60.

This wear on the center holes is very undesirable. It makes it difficult to turn a true taper, and if a part of the work has been turned true and parallel, it will be found to run untrue on the worn center holes. The result is that after a taper has been turned, the tapered part and the parallel part do not run true with each other. Besides this, if the lathe centers become much worn, it will be necessary to grind them before parallel or true work can again be turned.

59. Different Tapers for Different Lengths of Work.—When it is desired to turn the same taper on a number of pieces of different lengths, it will be found that the center must be adjusted or reset for each length of work. When the lathe is adjusted to turn a given taper or work of a particular length, it will be found that if the work is a little longer or shorter, it will change the taper. Suppose that in Fig. 61, *a b* represents the line of lathe centers for

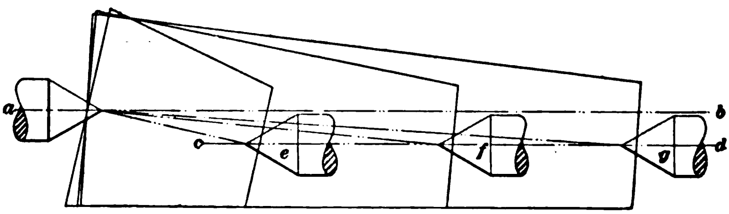


FIG. 61.

turning parallel work. Assume that the dead center is set out of line $\frac{1}{4}$ inch, as shown by the line *c d*.

Any piece that may be turned with the dead center thus set will have a difference of a diameter at its ends of $\frac{1}{2}$ inch. If the piece be 1 inch long, so that the dead center is in position *e*, the taper will be $\frac{1}{2}$ inch to the inch. If the piece be 2 inches long, so that the dead center is in position *f*, the taper will be $\frac{1}{2}$ inch to 2 inches, or $\frac{1}{4}$ inch to the inch. If the piece is 3 inches long, so that the dead center is in position *g*, the taper will be $\frac{1}{2}$ inch to 3 inches, or 2 inches to the foot. These three tapers may be compared by reference to the outlines. It is evident that any slight difference in the distances between centers in turning two pieces of work will make a difference of taper that can readily be detected when fitting work. If, in two pieces of the same length, one is centered and reamed with much deeper center holes than the other, it will allow the lathe centers to come closer together. This will cause a slight error. In estimating the amount that a dead center should be set over, as previously described, this error is often neglected, as the work is usually tested before the finishing cut is taken, and any slight error is corrected.

60. Amount of Taper Possible.—The amount of taper that can be turned between centers by setting over the center is limited by the total length of work and the amount of adjustment possible in the tailstock. Suppose the greatest amount of "set-over" in the tailstock is 2 inches. This will make a difference of diameter at the ends of the work of 4 inches. If we should wish to turn a taper of 1 inch to the foot, the greatest length of shaft on which we could turn it is 4 feet, and if the shaft or work should be longer than this, it would be necessary to use some other method of turning the taper.

TAPER ATTACHMENT.

61. Principle of Taper Attachment.—Very many of the objections that arise in taper turning due to the setting of the dead center are eliminated by the use of the **taper attachment.** The principle is simple. It consists primarily of a guide bar supported by brackets on the back of the lathe. This bar so controls the movement of the cutting tool that as it is fed along the bed it is made to advance or recede from the work.

Fig. 62 shows a taper attachment applied to a lathe as seen from the back. This particular carriage is fitted with a taper attachment and a compound rest *k*, a device also used for turning tapers. The peculiarity of this carriage for the taper attachment is that it requires an extra slide.

62. Description.—Fig. 63 shows a side elevation of a carriage with this form of taper attachment. The saddle *a*

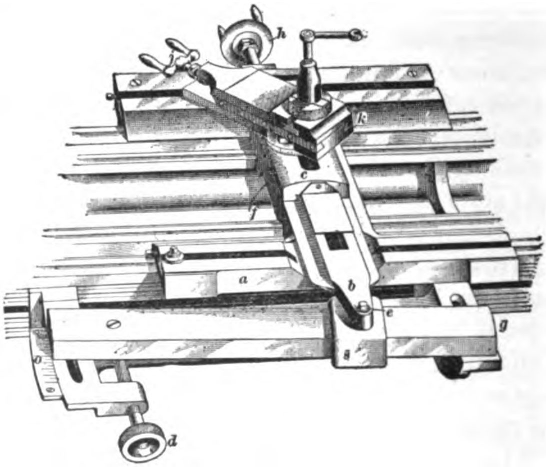


FIG. 62.

is fitted to the V's of the bed and to the apron, as on the

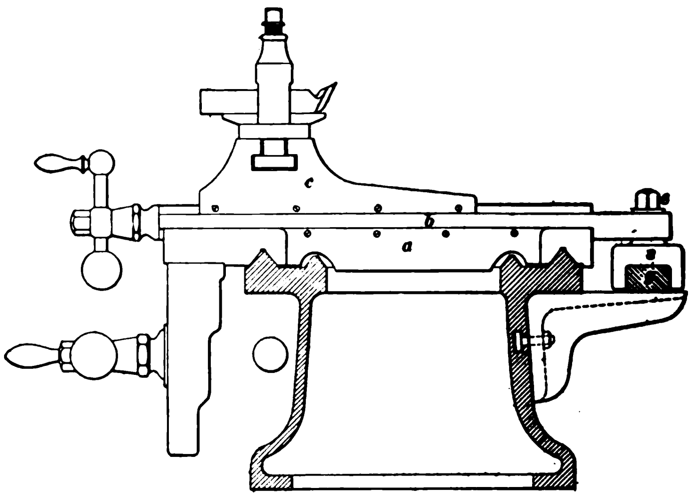


FIG. 63.

ordinary carriage. To this is fitted the extra cross-slide *b*, which projects at the back and is connected with a bolt *e* and shoe *s* to the guide bar *g*. The cross-feed screw is attached at the front end of the slide *b*, and operates the tool block *c*, which is fitted so as to slide upon part *b*. When the cross-feed screw is turned, the tool moves as in the ordinary carriage. When part *b* moves, it carries the tool with it. The movement of part *b* and, consequently, the movement of the tool, is controlled by the angularity of bar *g*. If this bar is set parallel to the V's of the lathe bed, there will be no motion of part *b* across the lathe and the tool will turn the work parallel. Suppose this guide bar to be 2 feet long and pivoted in the center. If the bar be turned at such an angle that the ends are out of line $\frac{1}{4}$ inch, and the carriage be moved along from the center of the bar to the end, then the part *b* and the tool will be moved across the lathe bed $\frac{1}{4}$ inch. This will be equivalent to setting over the center $\frac{1}{4}$ inch, which on a piece 1 foot long would turn a taper of $\frac{1}{2}$ inch to the foot. If the carriage moved the whole length of the bar, or 2 feet, the tool would move across the lathe bed $\frac{1}{2}$ inch, which would give a taper of 1 inch in 2 feet, which is the same as before. It will be seen from this that when the attachment is once set, it will turn the same taper on pieces of any length.

63. Adjusting to Turn a Given Taper.—In adjusting this style of taper attachment, the scale shown at the end of the bar *g*, Fig. 62, is used. A line at the center marked *o* indicates the mid-position, when the bar is parallel with the lathe bed V's. The scale indicates taper in eighths of an inch to the foot, so if a taper of $\frac{1}{2}$ inch to the foot is desired, the clamping bolts (not shown) that pass up through the slots in the end brackets are loosened and the adjusting screw *d* is turned until the pointer on the bar has moved over four marks. The bar is then clamped in place and all is ready to proceed with the cut. When the lathe is used for ordinary parallel work, the taper attachment is usually disconnected by removing the screw *e* from the block *s*, and the part *b* is clamped in its slide by tightening the setscrews *f* on the side.

64. Advantages.—The advantages of the taper attachment are apparent. By keeping the lathe centers in line while turning, the work centers do not wear untrue, the

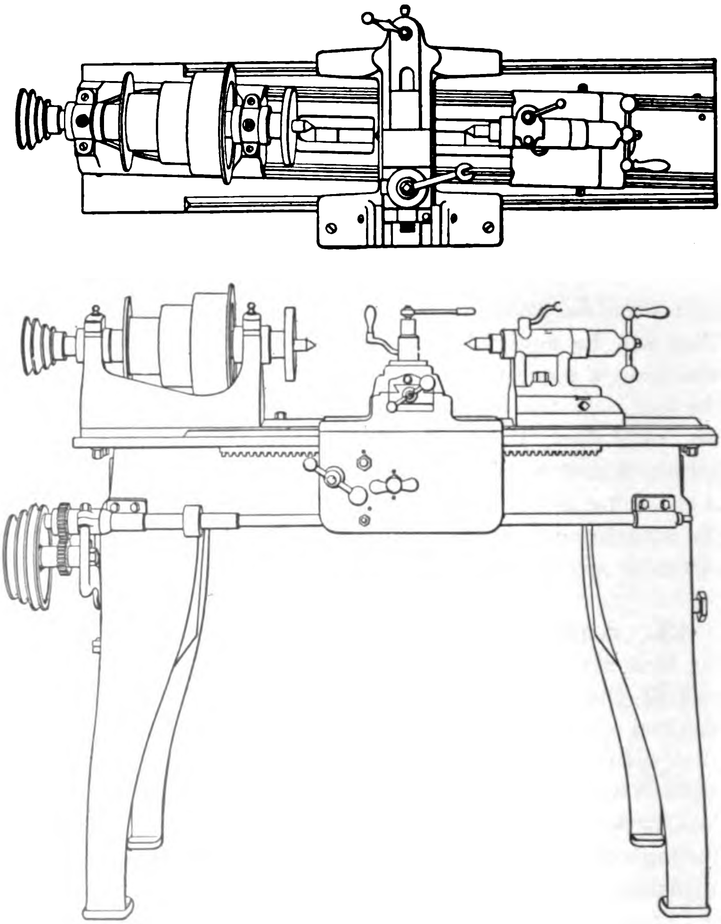


FIG. 64.

lathe centers are not subject to undue wear, and are constantly in line when a change is made from taper to straight work. When these attachments become much worn, there may be some lost motion in the parts. This will cause the lathe to turn parallel for a short distance on the end, until the lost motion is taken up. This trouble can easily be overcome by starting the cut far enough beyond the end of the work so that by the time the carriage and tool have fed up to the work, all the lost motion has been taken up. In practice this movement of the tool and carriage is made by hand to save time.

SPECIAL TAPER-TURNING LATHE.

65. A more perfect arrangement for taper turning is found in lathes specially designed for this purpose. Such a machine is represented in plan and elevation in Fig. 64. In this machine, the headstock and tailstock are fitted to the **V**'s of a plate or secondary bed. This plate is fitted to the main bed by being pivoted in the center in such a manner that it may be set at an angle with the **V**'s of the main bed on which the carriage runs. This secondary bed is set by means of a scale at the end, in much the same manner as the guide bar of the taper attachment.

While it may at first appear that the taper is produced by setting over both headstock and tailstock, it is quite different from the method first described. In this style of machine, the axes of the headstock and tailstock spindles are always in line, so that all the desirable features found in the taper attachment are found here, while the trouble due to lost motion in the parts is avoided.

TURNING TAPER WITH A COMPOUND REST.

66. Use of Compound Rest.—When the taper is very abrupt, such as 1 inch to the inch, it can best be turned by means of the **compound rest.** Such a rest is very clearly shown in Fig. 62. It consists of an extra slide for carrying the tool block, which is mounted in the place of the tool block on the ordinary saddle. This extra slide rests on a circular base and can be rotated and set so that the motion of the tool block may be in a line at any angle with the regular cross-feed.

In Fig. 62, the usual cross-slide is operated by means of the handle *h*, while the compound slide is operated by the handle *j*.

67. Setting the Compound Rest.—The base of the compound rest is usually graduated with degrees, so that it may easily be set at any desired angle. When the angle in degrees of a taper is not known, it may be found by making a drawing of the work.

68. Example of Turning With Compound Rest.—Suppose it is desired to turn the piece as shown in Fig. 65. If the drawing has been accurately made, the angle may be measured with a bevel protractor; if only a sketch with dimensions is given, the angle may be laid off as follows: Draw two lines *a b* and *c d*, Fig. 66, at right angles to each other, intersecting at *o*. On *a b* lay off from *o* a distance 8 inches, equal to the distance between the given diameters. On *c d* lay off 7 inches, equal to half the difference of diameters, or equal to the difference of radii. Draw a line through these two points. If a protractor is at hand, the angles may be measured; if not, a bevel may be set equal to angle *y*. With the bevel, the compound rest may be set at the proper angle by using it as shown in Fig. 67. The beam of the bevel is held against the face plate while the compound

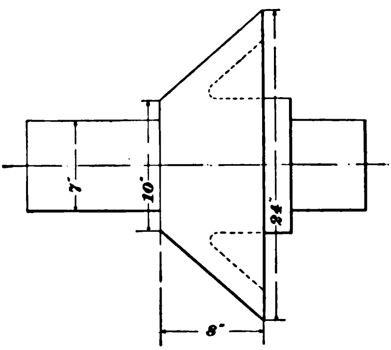


Fig. 65.

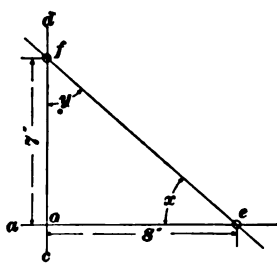


Fig. 66.

rest is swung to the angle indicated by the blade of the bevel. This method of setting the compound rest is also used when boring tapered holes.

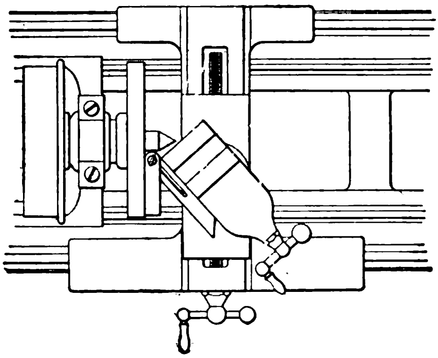


FIG. 67.

TURNING TAPER BY USE OF TWO FEED-MOTIONS.

69. Another method of turning tapers is to use the two feeds at once. The longitudinal feed is thrown in and the tool may be fed by hand. Sometimes the two feeds may be worked automatically, but the method is not generally used, as it is difficult to proportion the rates of feeds to turn a correct taper.

POSITION OF TOOL.

70. General Directions.—The operation of turning a taper after the machine has been set is similar to that of turning a plain cylinder. The difference will be found in the shape of the tool and in the manner of setting it. This latter exception is of sufficient importance to warrant the statement of the following rule:

71. Setting the Tool.—*In setting a tool for turning a taper, the point of the tool should be at the same height as the axis of the work.*

Since the position of the tool is fixed at a given height in taper turning, the tool should be forged with little front rake or clearance, keenness being given by increasing its top rake. If the tool is set above the center, it will make the large end of the work too small. It will also make the sides

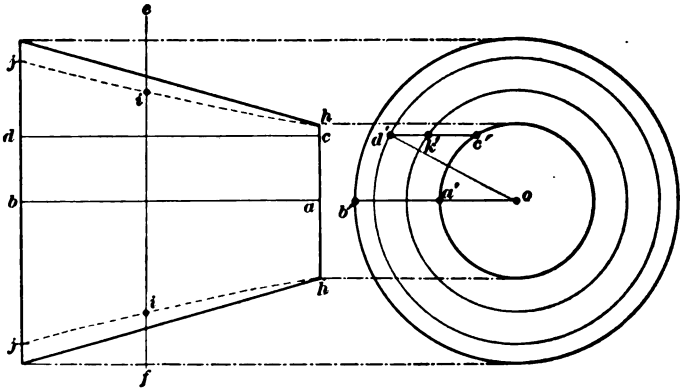


FIG. 68.

of the taper curved, as shown by the dotted lines *h i j* in Fig. 68. Suppose that we have turned a taper, as shown by the full lines, with the tool correctly set at the center. The line *a b* represents the path of the point of the tool, and is equal to the length of the piece. The line *a' b'* also shows the path of the point of the tool and represents exactly the amount that the tool recedes from the axis of the work in traveling along its length. With the machine once set, these conditions of tool travel will be repeated whether the tool is set high or low.

72. Suppose that the tool is set much above the center, as at *c*, and adjusted to cut the same diameter at the small end as before. The path of the tool will then be along the line *c d*, equal to *a b*. When the tool has reached the point *d*, it will also have moved along the line *c' d'* to the point *d'*, a distance equal to *a' b'*. A circle drawn through *d'* represents the diameter that the tool is turning when it leaves the work at *d*. This will be seen to be somewhat smaller than the correct diameter obtained when the tool is properly set. In the same manner we may find the exact diameter that the tool may be turning at any point along the taper.

Suppose we wish to find the diameter that the tool will turn in the middle of the piece when the tool is set above the center and follows the path *c d*. Divide the line *c' d'* in halves, which will give the point *k'*. Describe a circle about the center through this point, and it will indicate the diameter at this point. This diameter may be transferred to the side elevation by dividing the line *c d* in halves and erecting a perpendicular *e f* at the dividing point. With *o k'* as a radius, lay off points *i* on the line *e f*, each side of the center line *a b*. These points will be found to fall inside the true taper. In like manner, points may be found at any place along the length of the work, and they will all fall inside the true taper. If a line be drawn through these points, it will represent the curve to which the work will be turned.

FITTING THE TAPER.

73. Methods of Testing.—After the roughing cut has been taken on a tapered piece, and before it is near the finished size, it should be tested in the piece it is intended to fit. The taper is carefully placed in the tapered hole, and first tested by the sense of feeling. If one end is much too small, as at *c*, Fig. 69, it can be detected by rocking the work in the hole. The plug will just fill the hole at the end *a*, and while the imperfect fit cannot be seen, it can easily be felt. In this particular case, the indications are that the dead center was moved too far out of line. It should be moved back a very slight amount and another cut taken over the work. After this cut, the work should again be

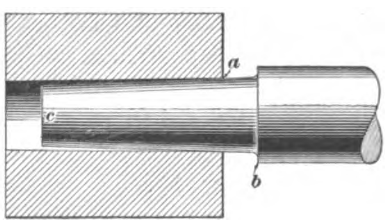


FIG. 69.

tested, and if there is no perceptible wabble, the fit may be tested still more closely by drawing three chalk lines along its length. The work is then placed in the hole and given a turn or two in a direction opposite the motion it had in the lathe. Upon removing the work, it will be seen that the chalk has rubbed off and is black at one end or the other, depending on which end was too large. In this way the work is tested and the lathe adjusted until the fit is satisfactory.

74. It should be observed that the work is tested and the machine accurately adjusted before the piece is turned to size. If the machine should be incorrectly set, and the piece at once turned to size at the small end, it might be found that the work was too small at the large end, and for this mistake there would be no remedy. In most cases it will be found that tapers must fit the hole exactly and go in a certain distance, up to a shoulder, as at *b*, or until the end *c* just comes through. If the taper is turned too small, even though it is a correct taper, it will allow the work to go in too far, which, in many cases, is as bad as an incorrect fit. In practice, the plug is left slightly large, so that it does not go in quite the desired amount. The final fitting is usually done by filing, or by grinding on a grinding machine, the filing or grinding being just enough to remove the tool marks. In fine fitting, the thickness of a chalk line is sufficient to make an error of some importance, so a substitute is used. One-half of the tapered piece along its length is coated with a very thin coat of Prussian-blue marking, it being applied with the finger and nearly all rubbed off, so that there is just enough left to give it color. The work is then tested in the hole or gauge and given a turn. If the marking is evenly distributed about the piece, it indicates a perfect bearing; but if it is rubbed off at one place only, it shows that it is too large at that point.

LATHE WORK.

(PART 2.)

BORING IN THE LATHE.

1. Definition.—The operation of turning or producing internally true cylindrical or conical surfaces is known as **boring**. This operation is performed by causing the work to turn upon its axis while held in a chuck or bolted to a face plate, the tool being fixed in the lathe carriage; or, by fixing the work securely to the carriage, while the tool revolves upon a bar placed between the lathe centers.

HOLDING THE WORK.

CHUCKS.

2. General Considerations. — Small regular work may best be held in the **lathe chuck.** The lathe chuck in principle consists of a heavy cast-iron disk which is screwed to the nose of the lathe spindle in place of the face plate. Radial slots are cut in its face, in which the jaws slide, these jaws being operated by means of

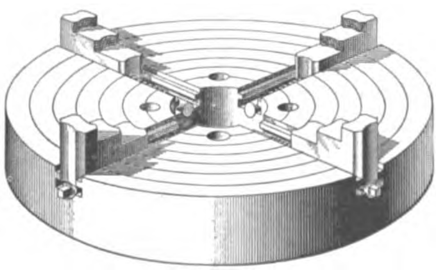


FIG. 1.

screws or by a scroll. Fig. 1 shows a common form of lathe chuck. Fig. 2 shows a section of the same chuck with one jaw and its screw removed and placed above the chuck. These lathe chucks are made as large as 3 feet in diameter. Work that would require the use of very large chucks may be better operated upon by fastening or bolting it to the face plate of the lathe.

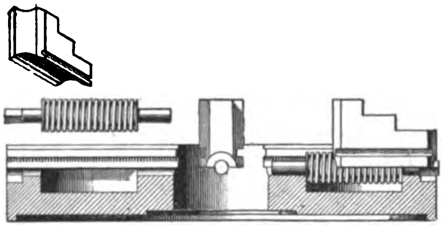


FIG. 2.

Chucks are made with two, three, or four jaws. Chucks similar to those shown in Fig. 2 may have the jaws reversed by unscrewing and putting them in in reversed position.

3. Classification of Chucks.—Chucks are classed as *independent*, *combination*, or *universal chucks*. Independent chucks are so arranged that each jaw is moved with an adjusting screw independent of the other jaws. Universal chucks are so constructed that when one jaw moves, the others move in the same direction a corresponding distance. Combination chucks are so constructed that they may be used either as independent or as universal chucks.

4. Universal and Combination Chucks.—Fig. 3 shows a **combination chuck** with a partial section moved from the back. A pinion *a* is cut on each adjusting screw, and these pinions engage with a circular rack *b* in the back of the chuck. When one adjusting screw is turned, the rack is rotated and each screw is turned an equal amount, thus moving each jaw a corresponding distance. To make this chuck independent, the rack must be lifted out of mesh with the pinions on the screws. The ring *c* rests against the back of the rack *b* and cams *d* project from the back of this ring. When the ring is partially rotated by means of the knob *e*, the cams *d* drop into pockets, thus allowing the ring and the rack to move away from the pinions sufficiently to disengage. When this is done, each screw is disengaged and the chuck is **independent.** When the ring is partly rotated in the opposite direction, the cams lift the ring and rack so that the latter again engages the pinions, and the chuck is again **univer-sal.** After using a combination chuck as an independent chuck for irregular work, the jaws will be out of true. To set the jaws true, adjust each to a circle that is drawn upon the face of the chuck, and then throw the rack into gear. Combination chucks can be used to good advantage for some classes of irregular work. The chuck is made independent, and after the work is once set true, the combination can be thrown in. When the work is removed, the jaws will all open together, occupying a relative position. If the next piece of work is set in the chuck in the same position in relation to the jaws as the first, the jaws can be tightened and the work will run true the same as the previous piece. A universal chuck may be constructed like the one shown in Fig. 3 with the ring *c* left out and the rack *b* in contact with the gears or the jaws may be moved by a scroll which is a flat disk with a spiral groove cut in it.

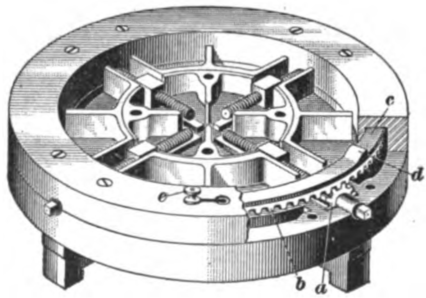


FIG. 3.

5. Independent Chucks.—In this style of chuck, the jaws can be set to accommodate any irregular shapes. When it is necessary to use an **independent chuck** on work of a regular shape, the difficulty of carefully centering each piece may be avoided by marking two jaws of the chuck (in the case of a four-jaw chuck) after the first piece has been placed in position. When the piece is finished, it can be removed by loosening the marked jaws, the succeeding piece placed in position, and the marked jaws tightened. This will insure the second piece being properly set. This operation may be repeated for any number of pieces that are alike. By this device, the one great objection to the use of the independent chuck is overcome, and work may be centered almost as quickly as in the universal chuck.

6. Advantages of the Different Classes.—Independent chucks are generally stronger and better adapted to irregular forms of work than either of the other types.

Universal chucks are best adapted to regular work; they save much time because of the ease and rapidity with which the work may be centered.

Combination chucks answer for both purposes, but require a little more care to keep them in proper condition.

USE OF CHUCKS.

7. Selection of Chuck for Work.—If the hole is to be bored concentric with the outside of the work, the universal chuck can be used. If the work does not run satisfactorily, it can be partly turned around in the chuck and tried in various positions. If this is not sufficient to make the part to be bored run sufficiently true, pieces of paper or brass can be placed between a jaw of the chuck and the work. When this amount of trouble is necessary, an independent chuck would be the better one to use.

8. Setting Work in an Independent Chuck.—To set a piece in an independent chuck, if the work is at all heavy, it can be held against the chuck by using a block of wood between the work and the dead center, as shown in Fig. 4. This will hold the work from falling out while the jaws are being adjusted. The jaws are tightened enough to hold the work. The lathe is started at a moderately fast speed and the work tested by holding chalk against the side of the work. If the work is untrue, the chalk will touch only on the high side. This indicates that the work should be moved. If the chalk touches the work as shown by the line *a b*, it would indicate that the jaw opposite jaw *1* should be loosened and jaw *1* tightened, thus moving the work across the face

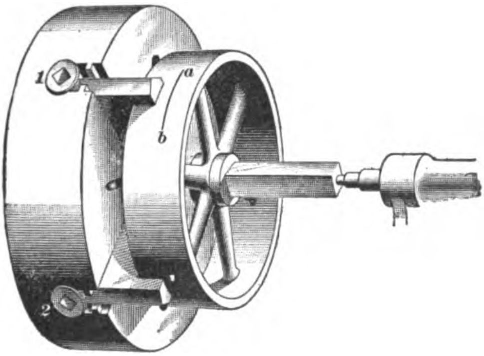


FIG. 4.

of the chuck. If the chalk touches between the two jaws, then the two opposite jaws must be loosened and the two front ones tightened a corresponding amount. The amount that each jaw is moved should be observed, as it will help to determine the amount of subsequent movements. When the work is to be turned or faced on a number of faces, each face should be considered in setting the work before beginning to turn any one face. For example, take the cone pulley, Fig. 5. Here the hole must be bored true, and the inside and outside of the cone bored and turned. If the casting is perfectly true, the work may be set by any one face and the others will naturally run true, but this is not apt to be the case. All parts should be tested to see if there is enough stock, and to see if the faces run true enough to turn to size.

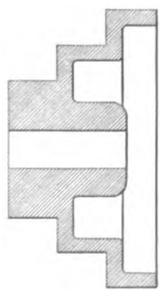
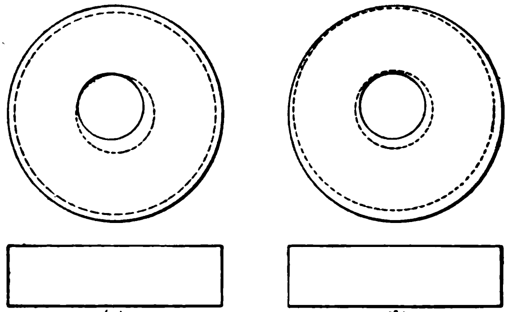


FIG. 5.

9. Example of Chucking.—Suppose a disk, as shown in Fig. 6 (*a*), with a hole cored very much to one side, is to be bored and turned to a given size. If set in the chuck so that the outside runs perfectly true, the cored hole would be so out of true that it could not be finished. If the cored hole is set to run true, then the outside could not be finished all over. In such a case, the work should be so set that both the outside and the cored hole run out of true. By thus dividing up the eccentricity, it will be found that the work



(a) (b)

Fig. 6.

can be finished all over to the desired size, as shown by the dotted lines, Fig. 6 (*b*).

10. Spring of Work From Pressure of Jaws.—When the work is light or frail, there is much danger of springing because of the pressure of the jaws necessary to hold the piece. In chucking a piece, advantage should be taken of the shape of the work in order to have the jaws of the chuck come against the more solid parts. For example, in chucking a pulley, it should be so set that the jaws come opposite the arms of the pulley. Suppose that a

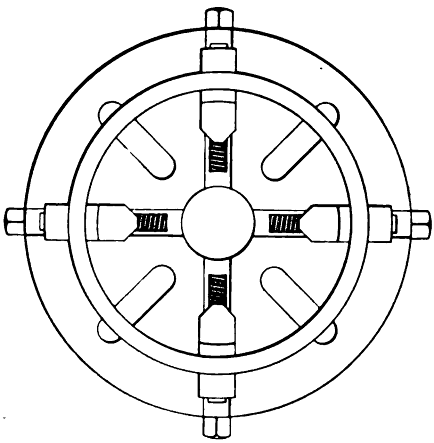


Fig. 7.

ring is held in the chuck, as shown in Fig. 7. When the jaws are tightened, the work is sprung opposite each jaw. If a cut is taken, the work will be bored true and round while under pressure of the jaws. When this pressure is removed, it will be found that the work will no longer be true but will spring back to its normal shape. This will cause the work to be untrue, as shown in Fig. 8, the dotted lines indicating the true circle. In such cases, the jaws of the chuck should be loosened before taking the finishing cut, so that the pressure will be just sufficient to hold the work.

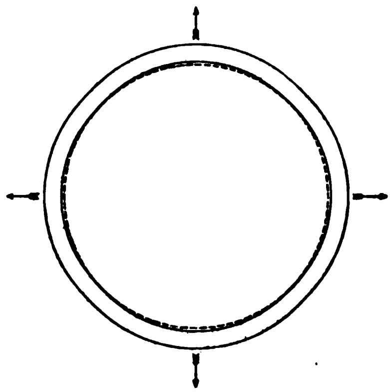


FIG. 8.

11. Care of Lathe Chucks.—Lathe chucks should be treated with care, especially universal chucks, since their value depends in many cases on their ability to hold the work true. When these chucks are abused by hammering or by unduly heavy strains, they become sprung and thus lose their characteristic value. In putting a chuck on the lathe, it should be held carefully against the nose of the spindle while the lathe is turned by hand. It is not good practice to start the lathe by power and hold the chuck against the spindle, expecting the thread in the chuck to catch squarely on the lathe: neither is it good practice to let the spindle screw into the chuck up to the thread with a bang. This often causes the chuck to stick so tightly to the spindle that it becomes quite difficult to remove it. When the chuck does stick on the spindle, it may be loosened by running the lathe backwards at the slowest speed and inserting a block of wood between the jaw of the chuck and the lathe bed.

SPECIAL CHUCKS.

12. Some work is of such shape that the ordinary lathe chuck will not hold it with sufficient rigidity to take heavy cuts. In this case, **special chucks** may be made, when there are enough pieces to be turned to warrant the cost. For example, the cone pulley shown in Fig. 5 may best be held in a special chuck. Such a chuck is shown in Fig. 9. This chuck consists of a bell-shaped casting *a*, which is fitted to the spindle *b* of the lathe. The outer end is bored to receive the work *c*, which is held in place by setscrews *d* at the sides. This form of chuck holds the work with great rigidity and makes possible the taking of heavy cuts that could not otherwise be accomplished. For special work, other forms of chucks may be devised that depend on the shape of the work.

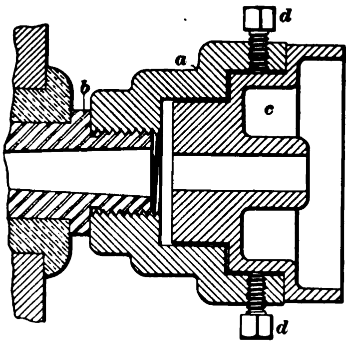


FIG. 9.

CHUCKING ON THE FACE PLATE.

13. Use of Face Plate.—When the work is large or heavy, or for other reasons cannot be held in the chuck, it may be fastened to the face plate by means of special blocks, bolts, or strips used for that purpose. It is essential in setting work on the face plate that it is secured firmly, so that it will not slip or change its position because of its weight or the pressure of the tool.

14. Adjustable Jaws for Face Plates. — For securing work upon the face plate, and in order to enable the operator to successively chuck similar pieces with the least amount of labor, adjustable jaws are frequently clamped on the face plate. These adjustable jaws usually consist of a block, as *a*, Fig. 10, in which jaws *b* work. The blocks are clamped to the face plate by means of **T** bolts *c*. This really makes a special form of chuck of the face plate. A face plate fitted with these adjustable jaws is shown in Fig. 11. The jaws have the advantage that they can be placed evenly, as shown, or they can be arranged unevenly to accommodate irregular work, either placing some of the jaws nearer the center than others or spacing them irregu-

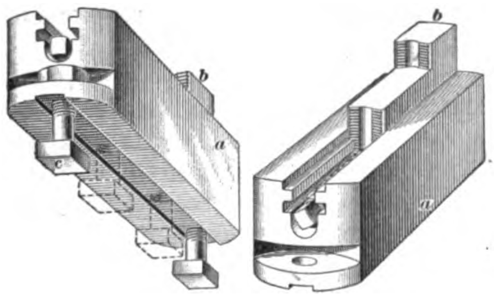


FIG. 10.

larly in the different slots in the face plate. The entire piece that is attached to the face plate is usually called a *jaw*, but in reality only the portion *b* is the jaw, and these

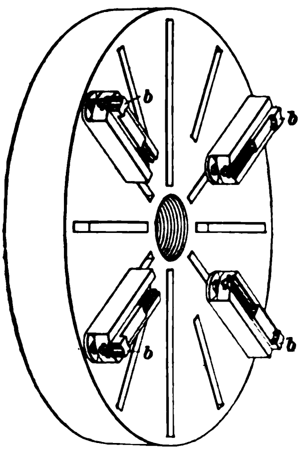


FIG. 11.

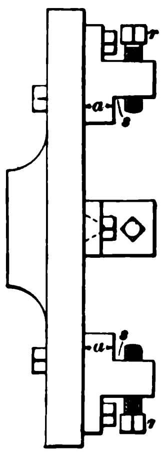


FIG. 12.

pieces *b* may be made reversible, thus giving a greater range of work that can be held by this device.

In some cases, a more simple form of jaw may be used, as shown in Fig. 12. These consist of castings *s* bolted to the face plate and provided with setscrews *r* for securing the work. The shoulder below the points of the setscrew should be turned off so that the dimension *a* is equal on all of them. This will enable the operator to place work against these shoulders during chucking.

15. Example of Clamping Regular Work.—Fig. 13 illustrates a very simple method of clamping a large flange to a face plate when it is only desired to bore the hole in the center of the flange and to face the hub *f*, the surface *r* being left rough. This method will do very well where the back face of the flange may be clamped directly to the face plate or on parallel blocks, and where but a single hub is to be operated upon. If it becomes necessary either to face the surface *r* or to operate upon a number of pieces, it is best to use jaws similar to those illustrated in Figs. 11 and 12.

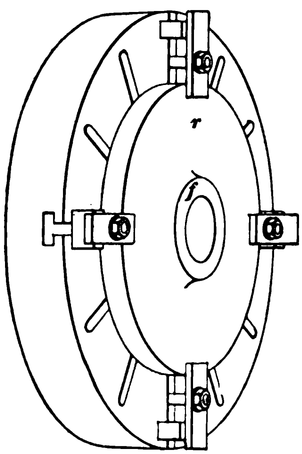


FIG. 13.

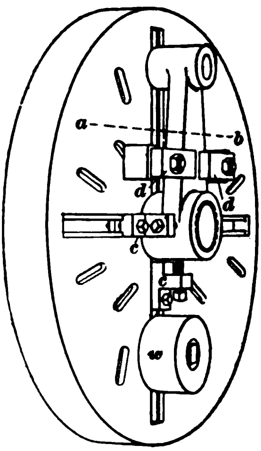


FIG. 14.

16. Clamping a Rocker-Arm.—When it is desired to clamp a rocker-arm similar to the one shown in Fig. 14, this may be accomplished by using three chucking-block jaws similar to those shown in Fig. 12. These are placed at *c*, *c* and bear against three sides of the large hub of the rocker-arm. The work is held securely against the face plate by means of the two clamps *d*, *d*, as shown in Fig. 14. Fig. 15 is a section on the line *a b*, Fig. 14, and shows the arrangement of the clamps and blocking; *e* is the arm, *d*, *d* are the clamps, *g*, *g* the blocks, and *f*, *f* the bolts. Care should be taken to see that the blocks *g* are of exactly the height of the work, so that the clamps *d* will set level or parallel to the face plate. The bolts *f* should be placed as close to the work as possible. If much strain is brought upon the work *e* by the clamps *d*, it is evident that there will be danger of springing the arm between its hubs or bosses. To overcome this, a block may be fitted under the arm, or a planer jack *j* may be adjusted under the arm, as shown in Fig. 15. In order to balance the portion of the rocker-arm extending to one side of the center and the clamps and bolts *d* and *f*, a counterweight *w* may be attached to the opposite side of the face plate, as shown, and adjusted in or out until it balances the whole exactly. Such work as this, which has a number of faces that must be finished in certain relations to one another, should be laid out before attempting to set it in the chuck or on the face plate. In Fig. 14, the work is to be bored to the circle indicated by the dotted lines, and may be set so that it will run true with this circle by testing with a scriber or point held in the tool post.

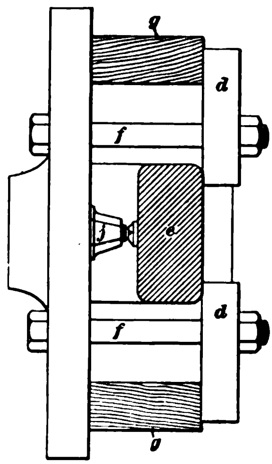


FIG. 15.

17. Use of Paper on a Face Plate.—When a finished surface is to be clamped against the face plate or any other metal surface, the danger of its slipping can be greatly reduced by putting a sheet of paper between the two surfaces. If this precaution is not taken, it will be found almost impossible to clamp the work so that it will resist the action of the boring tools.

18. Pulley Clamp.—Pulleys that have to be bored and turned can be clamped by means of the arms. Fig. 16 illustrates a clamp intended for this purpose. The block *a* is bolted to the face plate and supports an adjustable clamp *c* having a turned portion that fits into a socket in the block *a*, and is secured by the setscrew *d*. The pulley arm *b* is held in the clamp *c* by the setscrew *e*. Similar clamps can be devised for holding a great variety of irregularly shaped work.

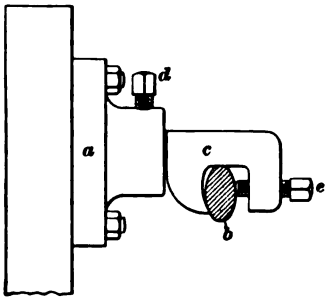


FIG. 16.

19. Angle Plate.—A very convenient attachment for face-plate work is the **angle plate,** as shown at *a*, Fig 17. This angle plate is made so that its two faces make an angle of 90° with each other. When it is desired to finish two faces of a piece square with each other, as, for instance, the flanges of a pipe elbow, one face is clamped to the angle plate as shown. This holds the other face of the elbow in such a position that it will be cut square with the first face. This angle plate may be used to great advantage for many operations in face-plate work.

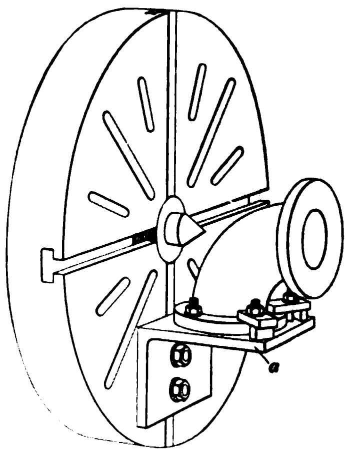


FIG. 17.

The methods of fastening work to the lathe face plate are similar to those for fastening work to the platen of the planer, or to the table of the boring mill.

TAKING THE CUT.

20. The Tool.—Suppose a shaft collar 2 inches long is to be bored 1$\frac{5}{16}$ inches in diameter. The tool used is a boring tool, as shown in Fig. 18. The tool is clamped rigidly in the tool post so that it lies parallel with the lathe V's and so that it will pass through the hole in the work. The tool should be set as low as possible in the hole.

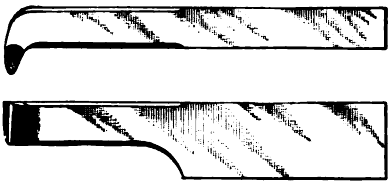


FIG. 18.

21. Roughing and Finishing.—The cut is started at the front end. Roughing cuts should be taken as heavy as possible. They can never be taken very heavy because of the spring of the tool. After the first cut, the hole should be calipered to see if it is boring parallel. If it is found to be tapered, lighter cuts should be taken. Sometimes the hole may be made parallel by reversing the direction of the feed, which will start the cuts at the back end of the hole.

MEASURING BORED HOLES.

22. Use of Calipers and Gauges.—Greater skill is required for measuring the diameters of holes than for measuring outside work. The holes may be measured by the use of plug gauges, limit gauges, or inside calipers. When inside calipers are used, they may be set from a standard ring gauge, from a scale, or from a pair of outside calipers that have previously been set from a scale. When setting inside

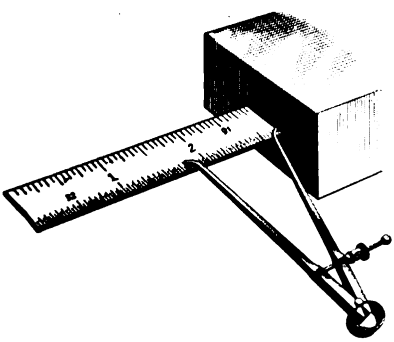


FIG. 19.

calipers from a scale, one end of the scale should be held squarely against a block, as shown in Fig. 19, and the caliper adjusted to the line on the scale. When work is measured with inside calipers that have been set from outside calipers, there are three chances for error: *first*, in adjusting the outside calipers; *second*, in transferring the size to the inside calipers; *third*, in the final measuring. It will be seen by reference to Fig. 20 that in order to measure accurately, the calipers must be held in line with the axis *A B* of the work. If the calipers are held in any other line, as, for example, *C D*, the hole would appear too large, since, with one point resting against the work at *b*, the other point *a* would be in the position *a'*. When the solid plug gauge is used for testing, extreme care is necessary. If the hole is the exact size, the gauge will enter only when its axis is held exactly in the line *A B*; because of this, the work is often bored too large, since sufficient care is not used in making the trial.

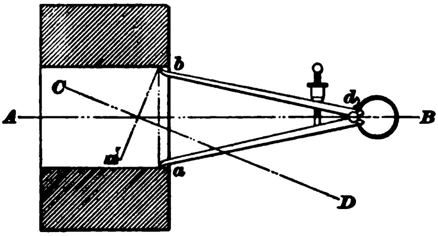


FIG. 20.

If, in calipering a hole, it appears to be very close to size, a second cut may be run through without adjusting the tool deeper. A sufficient amount may often be removed by this second cut, its depth depending on the spring of the tool during the previous cut. When the work is large enough to admit heavy tools, they should be used to avoid the spring as much as possible.

CHUCKING TOOLS.

23. Method of Holding Chucking Tools.—When the holes are small, 3 inches or less in diameter, they can be more rapidly and accurately bored by using special **boring, or chucking, tools.** These forms may be held in a special holder on the carriage, or in the tailstock in place of the dead center. The latter method is the more common. When a chucking tool is to be held in the tailstock, care should be taken that it is perfectly in line with the live spindle, otherwise trouble will be encountered.

FLAT DRILLS AND REAMERS.

24. Flat Drills and Holders.—For rough boring in cored holes, the flat drill shown in Fig. 21 is sometimes used. This drill may be made from flat bar steel with the point ground like the point of an ordinary flat drill. The other end has a large center hole for receiving the dead center. In using the drill, a specially made holder is employed, as shown in Fig. 22.

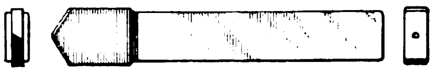


FIG. 21.

This holder consists of a flat piece of iron or steel with one end bent at an angle. A slot *a* is cut through this end sufficiently large to allow the drill to pass through.

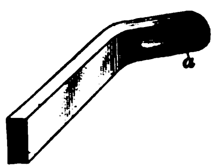


FIG. 22.

25. Operating a Flat Drill.—When used, the holder, Fig. 22, is clamped in the tool post so that the opening *a* comes opposite the center of the hole in the work. The drill is passed through the opening *a* and held against the work by pressure of the dead center. The holder keeps the drill from revolving. In starting the cut, there will be a tendency for the drill to wabble, owing to the irregularity of the cored hole. In order to start the drill true, a monkeywrench is used on the drill, as shown in Fig. 23. By pulling on the wrench in the direction of the arrow, the drill is

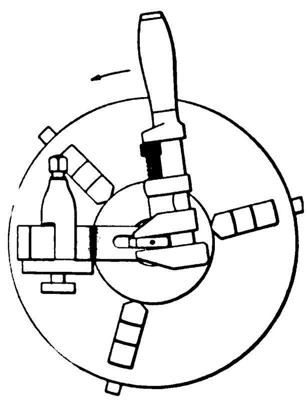


FIG. 23.

rotated sufficiently to make it pinch in the holder. While in this position, the drill is fed into the work a short distance, after which the pressure on the wrench is released and the drill fed in still farther. This operation of holding the drill by means of the wrench causes it to cut off the high sides, and in a short time it will be found that the point of the drill runs true. After once being started true, very little trouble will be experienced. The holes that are drilled with this form of tool can never be depended on to be either round or straight.

26. Flat Reamers or Turned Drills. — To finish the hole more perfectly, a **flat reamer,** or **turned drill,** shown in Fig. 24, may be used in the same manner as the flat drill. This reamer is made of flat bar steel and turned parallel on the sides *c* and *d* to a diameter equal to the diameter of the desired hole.

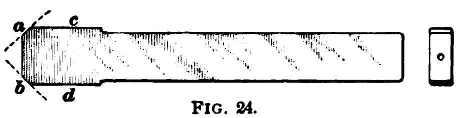


FIG. 24.

27. Wood Reamers.—The cutting edges are at *a* and *b*. These reamers are sometimes covered with wood, which is fastened to the sides and then turned so that it will just follow the hole being bored. These wooden faces are used to keep the reamer from chattering and to guide it so that the holes will be more nearly accurate. Such wood-covered reamers are sometimes called **wood reamers.**

ROSE AND FLUTED REAMERS.

28. Rose Reamers.—A better form of tool for cored holes, known as a **rose reamer,** is shown in Fig. 25. The

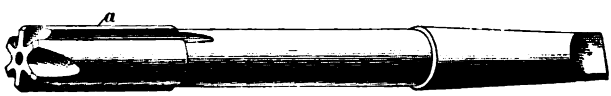


FIG. 25.

part marked *a* is ground round and parallel to the diameter of the desired hole. This form of reamer will generally produce holes slightly larger than the size, due to the wear of the reamer on the walls of the hole.

29. Three-Fluted Chucking Reamer.—For deep holes, the **three-fluted chucking reamer** shown in Fig. 26 is an excellent tool. Because of the spiral flutes,

FIG. 26.

there is less danger of the shavings clogging than there is in the style shown in Fig. 25. The cutting is done by the edges *a*, and the chips pass away through the larger flutes; the small flutes *b* are formed for clearance and to allow the oil or other lubricant to flow to the point of the reamer.

30. Fluted Chucking Reamer.—Fig. 27 represents a **fluted chucking reamer** for finishing holes smooth and true to standard size. In this form of reamer, the cutting edges are along the lines *a b*. When used in connection

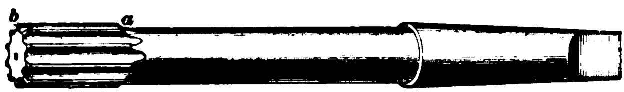
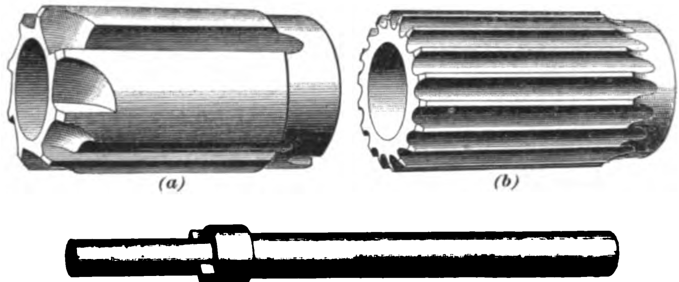


FIG. 27.

with the rose reamers, the latter should leave about .005 inch diameter for this reamer to remove in finishing. Since it is intended for finishing holes to exact diameter, it should be used with considerable care. The cutting speed and the feed are therefore reduced.

31. Shell Chucking Reamers.—Fig. 28 (*a*) shows a **shell chucking reamer** of the rose-reamer type, and in Fig. 28 (*b*) is shown a shell reamer of the fluted or finishing-reamer type. These reamers are cheaper and in many cases more convenient than the solid reamers just described.

They are used on an arbor as shown in Fig. 28 (*c*). One arbor can be used for quite a large range of sizes of reamers.



(*a*) (*b*)

(*c*)

FIG. 28.

32. Boring Bars for Chucking.—Fig. 29 shows a chucking tool that can easily be made for odd sizes. The blade or cutter *c* is held in the bar by a setscrew *s*. Different sizes of cutters may be made at little expense, which

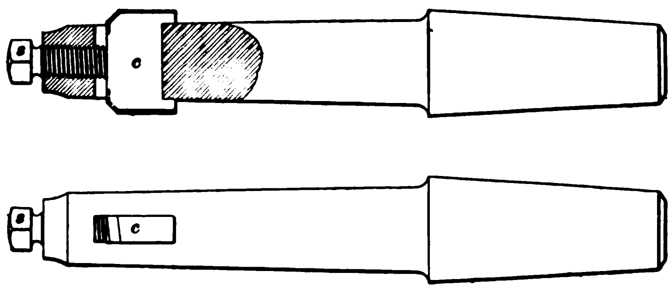


FIG. 29.

will take the place in many instances of the more expensive standard chucking tools. When the holes to be bored are long, a bar can sometimes be used, as shown in Fig. 30. The cutter *c* is held in the slot cut in the bar by a setscrew *s*. One end of the bar is fitted to the tailstock, while the other end fits a cylindrical bushing *b* in the headstock. This gives support for each end of the bar, which is very desirable on some kinds of work when it is necessary to have the hole run true.

33. Starting Chucking Reamers True.—If the cored hole does not run true, the chucking reamer will not

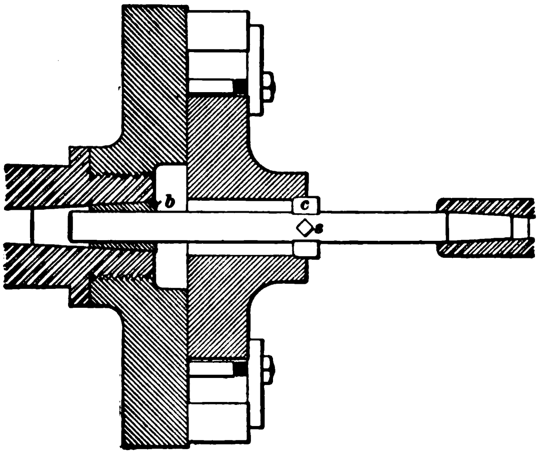


FIG. 30.

start true, the tendency being to follow the cored hole. When it is desired to start the reamer true, it may be done by using a common boring tool and boring out the mouth of the hole to nearly the correct size, so that the reamer will enter ⅛ inch or so. This will give a bearing all around and hold the reamer true.

34. Drilling Solid Material.—The tools thus far described, with the exception of the flat drill, are for enlarging holes that have been previously drilled or cored. The flat drill will pierce a hole in the solid metal as well as it will follow cored holes, but it will not cut as freely as the twist drill. Twist drills are often used in the lathe in a special holder or socket fitted in the tailstock, the drill being fed into the work the same as the chucking tools just described.

35. Starting a Twist Drill.—It is essential that the twist drill be started to run true and that its point be centered before the outer corner of the drill has begun to cut. After the outside corner of the drill has entered the work, its position cannot be changed. It is well to make the starting points true by using a tool in the tool post, as shown in Fig. 31. This tool is forged with a thin flat point and

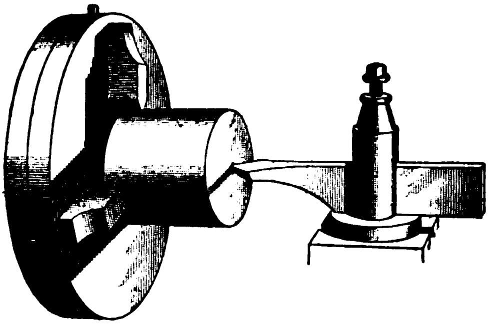


FIG. 31.

ground like the point of a flat drill. The hole is started true with the tool, after which the twist drill in the tailstock will follow in the hole previously started. When this starting tool is not at hand, the twist drill may be started true by placing the butt of an ordinary lathe tool in the tool post and adjusting it so that it just touches the twist drill. This will steady the point of the drill sufficiently, so that in most cases it will start true.

BORING WITH A BORING BAR BETWEEN CENTERS.

36. Use of Boring Bar.—When the work is heavy or the holes comparatively long, the work of boring can quite often be accomplished by reversing these operations, clamping the work to the carriage and revolving the tool in the work. When this is done, a bar is passed through the work and held between the centers. This bar is called a **boring bar.** It carries the blades or cutters that do the boring. The boring of an engine cylinder furnishes a good example of a typical operation performed in this manner.

TYPES OF BORING BARS.

37. Boring Bars With Fixed Cutters.—There are two types of boring bars; one has a fixed cutter in the center that may project sufficiently to cut only on one end, or it may project equally on each side of the bar and cut at each end. Such a bar is shown in Fig. 32. The cutter is

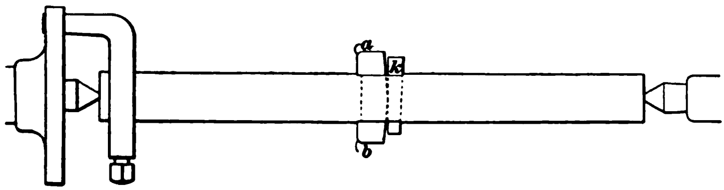


FIG. 32.

fitted into a rectangular slot and held in place by a key *k* driven in at the back. The cutter blade should previously be turned to the desired diameter before hardening. The cutting is done by the points or edges *a* and *b*. When this style of bar is used, it must be twice as long as the hole to

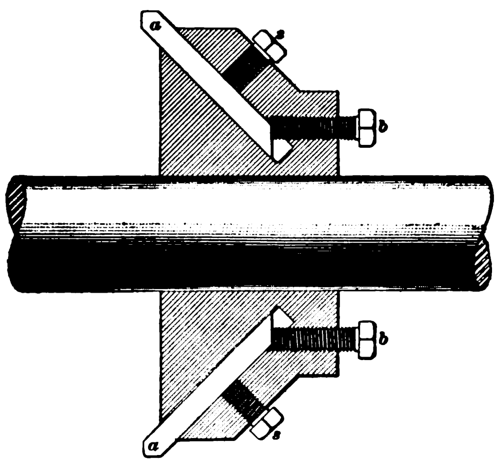


FIG. 33.

be bored, since there must be room for work at one side of the cutter before starting, and room for it to pass beyond the cutter after the cut is finished.

When the work is large so that the cutter would project a considerable distance beyond the bar, it is best to fix a cutter head to the bar. Such a head is shown in Fig. 33. It consists of a cast-iron collar carefully fitted to the bar and kept from turning by a key and setscrew. There are generally four blades or cutters *a* inserted in the head and held in place by the setscrews *s*, *s*; *b*, *b* are setscrews for adjusting the blades. It will be seen that by tightening these screws, which stand against the ends of the blades, the blades will be pushed out of their sockets. As the blade becomes short, pieces must be put between the screw and the blade to make the screws effective.

38. Boring Bars With Sliding Heads.—When much heavy boring is done, the second type of boring bar, shown in Fig. 34, is more desirable. This bar *a* is fitted with a head *h*, which slides upon the bar *a*. The head is

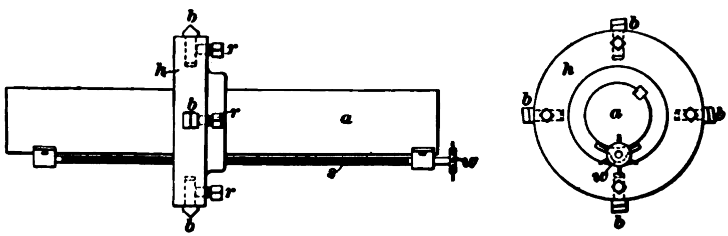


FIG. 34.

kept from rotating on the bar by means of a key that slides in a spline cut the entire length of the bar. Four cutting tools *b* are used and held in place by setscrews *r*. Clamps or wedges are often used for holding the tools in the head. A feed-screw *s*, supported in bearings at either end of the bar, passes through a nut in the sliding head. By revolving this feed-screw, the head is moved along the bar. This feed-screw is generally set in a slot cut in the side of the bar. By doing this, the screw is protected.

39. Boring an Engine Cylinder.—Fig. 35 shows the general scheme of using this type of bar when boring an engine cylinder. The cross-slide is removed from the lathe and the work set upon blocking and clamped with bolts in its correct position. Considerable care should be exercised in setting this class of work upon the machine, to see that it is so set that all faces can be finished in their correct relation to one another and to correct sizes. It will be seen that the bar passes through the work, is held between the lathe centers, and is driven with a dog. One of the various methods of operating the feed mechanism is by means of the star feed, as shown in Fig. 34. A star wheel *w* is fastened to the end of the feed-screw. This revolves with the bar. A pin *t*, Fig. 35, is fastened in some convenient place so

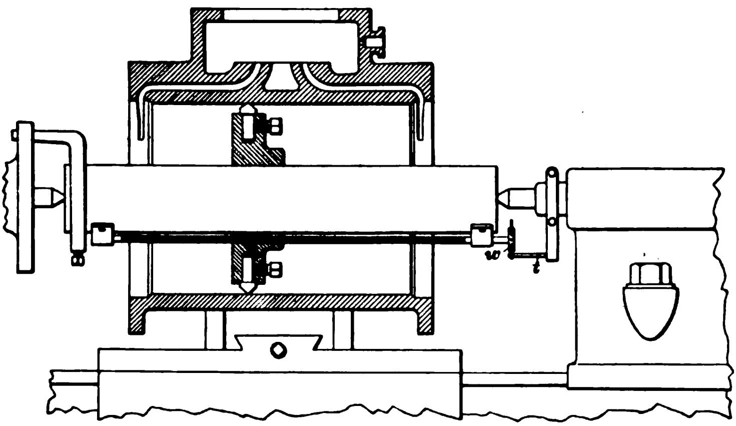


FIG. 35.

that for each revolution of the work it strikes one of the arms in the star wheel and gives it a partial revolution. When a coarser feed is desired, two or more pins may be arranged to act one after the other. This revolves the feed-screw and so gives feed-motion to the head. Another method of revolving the feed-screw is to put a gear-wheel in the place of the star wheel. A second gear is fixed to the lathe center so that it gears with the wheel on the feed-screw. As the bar revolves, the gear and the feed-screw rotate about the fixed gear, thus revolving the feed-screw upon its axis. If the gears are of the same size, the screw will make one revolution for each revolution of the bar. By varying the proportion of these gears, various rates of feed may be obtained.

This form of bar is more desirable for large work than the type of bar with the fixed head. Because of the sliding head, the bar need be but a little longer than the work to be bored. This shortening of the bar gives it greater rigidity. When the bar has a sliding head, the work does not need to be fastened to the carriage of the lathe, but may be more securely bolted to the lathe bed. This also adds to the rigidity of the work.

TAKING A CUT WITH THE BORING BAR.

40. Adjusting the Tools.—After the work has been carefully set, so that it is known to be correct, the cut is started at one end. One tool is used at first until a sufficient depth of cut is obtained and a short distance bored into the work. After this true place is turned, the other tools are carefully adjusted so that they each do their share of the work.

41. Shape of the Boring Tools.—The tools for the roughing cuts are ground round on the point similar to the diamond point. Very little clearance should be given. The first roughing cuts are generally made deep, with a moderately fine feed. The finishing cuts are made with a very coarse feed. The finishing tool, therefore, has a broad cutting edge with a minimum of clearance.

42. Spring of the Bar and Work.—It will be seen that the boring bar held between the lathe centers is limited in its power by the strength of the lathe center. When each of the four tools is doing its share of the work, the bar is well balanced in the cut and the strain on the lathe centers is small. If the cut is very heavy on one side and light on the other, the opposite cuts will be unbalanced, the heavier cut tending to spring the bar away and into the lighter cut on the opposite side. This action will bring a great strain upon the centers of the lathe. Special boring mills have been designed for this class of work and will do it better and more rapidly than the lathe. At the same time, the lathe is always at hand for special jobs when boring mills or boring lathes are not available.

BORING TAPERS.

43. Boring With Taper Attachment or Compound Rest.—Taper boring is often best done on the lathe. If the work is held in the chuck, the taper may be bored by using the taper attachment. For this, the attachment is set in the same way as for taper turning, and the operation of taking the cut is the same as in boring cylindrical holes. When the holes to be bored are short or an abrupt taper is desired, the compound rest may be used. For some kinds of work, taper chucking reamers are used. They are held in the tailstock the same as the ordinary chucking tools.

44. Reaming Tapers.—Tapers may be reamed by a tool or tools inserted in the cutter head of a boring bar. The tools must be in the form of blades as long as the hole, and set so that their cutting edge is at the desired angle.

45. Boring Tapers With a Boring Bar.—When the boring bar with the sliding head is used, a taper hole may be bored in work fastened to the carriage or bed by setting over the headstock end of the bar. This is accomplished by fastening a false center *c*, Fig. 36, to the face plate, which may be adjusted at any distance from the true center of the lathe. The amount that this center is to be set out of line may be estimated the same as the amount that the dead center is set out of line in plain taper turning. When the bar is thus set out of line, it will be noted that but one cutter point *p* can be used. This should be so set that when the false face-plate center *c* is at the front and at the same height as the dead center, the cutter point *p* is also at the same height.

The boring bar shown in Fig. 36 (*b*) may be used for either straight or tapered holes. The bar *a* is fastened to

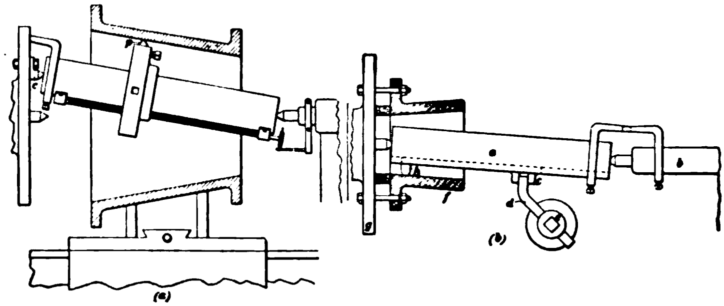


FIG. 36.

the dead spindle *b* so that it cannot rotate. It is provided with a **T** or dovetail slot its entire length, which carries a sliding cutter. This cutter has lugs *c* which engage the end of a feeding piece *d* held in the tool post *e*. The work *f* may be clamped to the face plate *g* as shown. As the feeding piece *d* is fed along the lathe, it will force the sliding cutter fitting the **T** or dovetail slot to feed along the bar *a*, so that the cutting point *h* will bore either a tapered or a cylindrical hole, depending upon the position of the dead center. The live center rotates in a stationary bar and hence it should be hardened and supplied with oil. It is also necessary to feed the tool post in by means of the cross-slide as the cut advances so as to prevent the lugs *c* from passing out of contact with the feeding piece *d*.

RADIAL FACING.

FACING OF REVOLVING WORK.

46. Definition of Radial Facing.—When a true flat surface is produced with a lathe, it is called a **radial face.** The end of a piece that is squared up between centers is a radial face, but the term **radial facing** is generally applied to larger pieces of work that have to be held in the chuck or on the face plate.

47. Precautions to be Taken in Radial Facing.—There are two important points in all facing. First, all end play of the lathe spindle must be taken up. Second, the carriage must be clamped upon the **V**'s, thus preventing the tool from moving away from the work.

48. Tools Used and Their Shape.—Tools for radial facing do not need as great a clearance angle on the front; i. e., they do not require as much front rake as when turning cylindrical shapes. In shape the tools for radial facing are similar to planer or shaper tools, especially when they are used for facing from the outside toward the center. This point is taken up more fully under "Forms of Cutting Tools." Quite a large variety of tools can be used for radial facing, and in most cases a bent tool is preferable, because it can be held in the tool post closer to the cutting edge, thus giving greater stiffness. In Fig. 37 a front elevation of a tool presented to the work for radial facing is given, the front rake being shown by the line *G H*. The tool point *a* is placed about level with the center of the work. Fig. 38 gives a plan of the same tool illustrating how it should be set. The tool should make an angle of 30° to 45° with the face

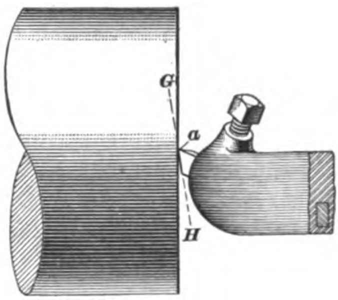


FIG. 37.

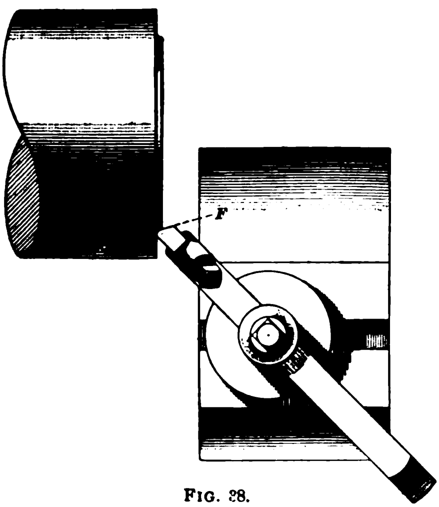


FIG. 38.

of the work, and the cutting edge should be presented to the work as indicated by the line *E F*. The type of tool shown should be fed from the outside toward the center, the tool being set the same height as the center of the work. The tool may be fed either by hand or by means of a power feed.

For finishing radial surfaces, the side tool may be employed, or a special square-nosed tool may be used. The square-nosed tool has the advantage that it can be fed in either direction. If the feed and the cut are heavy, care must be taken that the tool does not spring into the work.

49. Cutting Speeds for Radial Facing.—In radial facing, the cutting speed of the tool will vary according to the diameter of the work at the point where the tool is operating, the number of revolutions per minute remaining the same; hence it is evident that, as the tool advances toward the center, the cutting speed will decrease. For this reason, on large surfaces, it may be advantageous to speed up the lathe as the tool advances toward the center.

FACING OF STATIONARY WORK.

50. Holding Stationary Work for Facing.—When the work to be operated upon is so large that it cannot be swung upon the face plate, it may be bolted to the carriage or lathe bed and faced by means of a rotating tool or cutter. The work must be blocked up to the proper position and then bolted securely, so that there will be no chance of its moving during the facing.

51. Facing Arms.—For facing the ends of cylinders as shown in Fig. 35, a facing arm is used, as shown in Fig. 39. This arm is fastened to the boring bar and rotates with it. On one side of the arm is fitted a tool block *a*, which slides in a guide. This tool block carries the cutting tool *b*. Feed-motion is given by means of a screw operated by the star wheel *c*, which is made to rotate partly for each revolution of the bar. In this way, the tool is fed entirely across the face of the work. When a facing arm is not at hand, a cross-slide of some sort is fastened to the face plate of the lathe. Very often the compound rest is fastened to the face plate so that the slide may be used for feeding a tool across the face of the work.

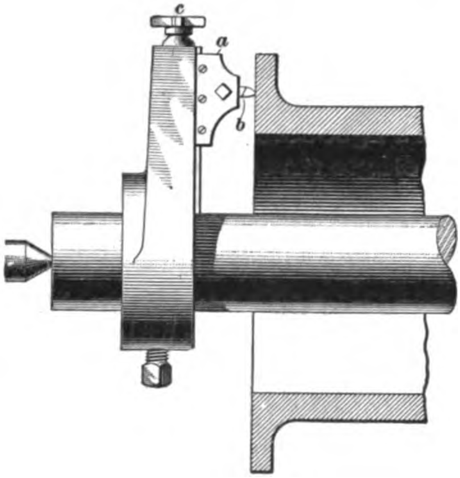


FIG. 39.

52. Reason for Facing Before Boring.—When a piece of work held in a chuck or on a face plate is to be bored and faced, it is best to do the facing first, or at least take a roughing cut before doing the boring. This gives a better chance to start chucking tools and also furnishes a better edge for calipering the hole. When facing, the tool has a greater leverage on the work and, hence, a greater tendency to displace it. For this reason, all facing and outside turning should be done before boring.

SCREW CUTTING.

53. Definitions.—The **point** of a thread is the projecting end *p*, Fig. 40.

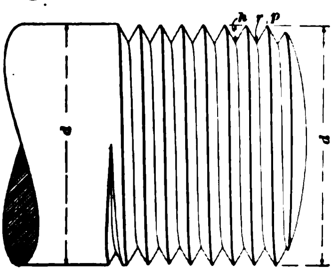


FIG. 40.

The **diameter** of a thread is the diameter measured over the points, or the diameter *d* of the bolt, Fig. 40, before the thread was cut.

The **root** of the thread is the bottom of the space *r* where the threads unite, Fig. 40.

The **height** of a thread is the vertical distance *h* from the root to the point, Fig. 40.

A **right-hand thread** is one that is turned in the direction of the hands of a clock when it is being screwed into a nut. It is the common thread.

A **left-hand thread** turns in the opposite direction from a right-hand thread.

A **single thread** has one spiral groove cut around the bolt. This leaves one spiral projection or thread, Fig. 40.

A **double thread** has two spiral grooves cut around the bolt. This leaves two spiral projections or threads. Fig. 41 shows a double thread. One thread is cut farther along the bolt than the other, to show how the first thread is cut.

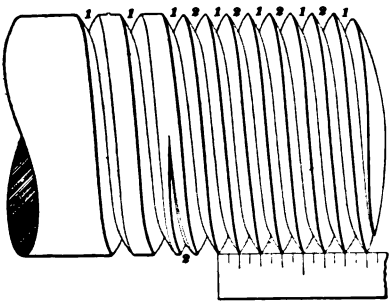


FIG. 41.

A **triple thread** has three spiral grooves and, consequently, three spiral projections or threads.

A single thread may be illustrated by winding a string around a lead pencil. The string will represent the thread of the screw. If two strings be wound at the same time about the pencil, keeping them flat and side by side, the strings will represent a double thread. If three or four strings be used, a triple or a quadruple thread will be illustrated.

The **pitch of a thread** is the number of turns it makes in advancing 1 inch along the work.

54. Measuring the Pitch.—In measuring the pitch of a thread, one must not be deceived in the count. Fig. 42 represents a 4-pitch thread with a scale held against it so that one thread comes opposite one of the inch marks. If we count from the first to the last, we will count 5 threads. This is because the first and last threads were counted. Never include both the first and last threads in the count.

Thus, in Fig. 42, the thread marked *5* should, if we continued to count the threads in the second inch, be *1*.

In counting the pitch of a double-threaded screw, it must be remembered that there are two sets of threads on the screw; therefore, alternate threads must be skipped. If we should count the pitch of the double-threaded screw shown in Fig. 41, it would appear to be 4. By skipping alternate threads or points, we count 2 threads, which is the correct pitch. If we divide the apparent pitch (four) by 2, the number of threads, it gives the correct pitch, which is 2. In triple threads, dividing the apparent pitch by 3 will give the real pitch.

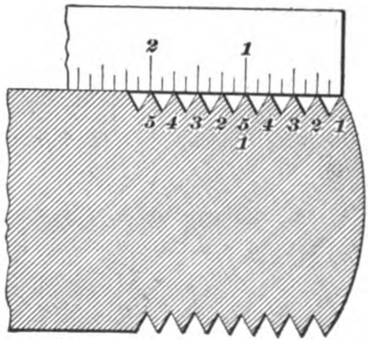


FIG. 42.

Double and triple threads are used when a very coarse pitch screw of small diameter is desired. By cutting a number of threads in the place of one large thread, we can keep the coarse pitch without cutting very deep into the piece. Fig. 43 shows a section of a screw with triple threads. The dotted lines show the depth that would be necessary to cut a single thread of the same pitch.

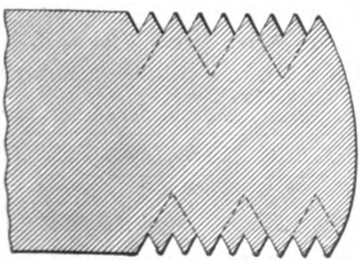


FIG. 43.

SHAPES OF SCREW THREADS.

55. Common Forms of Threads.—There are four forms of screw threads in common use. They are the *sharp* **V** *thread*, the *United States standard*, also known as the *Sellers*, or *Franklin Institute thread*, the *British* *standard*, known also as the *Whitworth thread*, and the *square thread*. Besides these forms there are some other forms, such as the *ratchet thread*, the *acme thread*, and some others. These last named, however, are used only for special purposes.

The two forms that are most commonly used in the United States are the **V** thread and the United States standard. These are used on commercial bolts and screws, and whenever fastening devices are required in machine construction.

56. Shape of V Thread.—Fig. 44 is a section through a part of a **V** thread, showing its exact shape. It will be seen that the sides of the thread are straight and make an angle of 60° with each other, and 60° with the center line of the screw. These side faces meet and form a sharp point p and a sharp corner r at the root; hence its name, **sharp thread.**

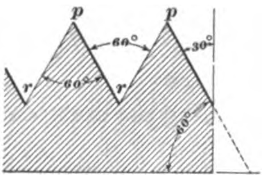


FIG. 44.

57. Shape of United States Standard Thread.—Fig. 45 shows a section through a United States standard thread. The shape is similar to the **V** thread, in that the sides are straight and form an angle of 60° with each other and with the center line. The point p and the root r are flat. The amount of flatness is determined by dividing the total height of a sharp **V** thread into eight parts. One-eighth of the total height is cut from the point and an equal amount filled in at the root, thus making the total height of the United States standard three-fourths that of a **V** thread of the same pitch.

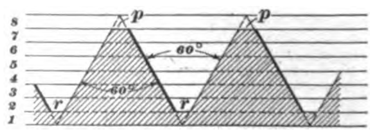


FIG. 45.

58. Shape of British Standard Thread. — The exact shape of the British standard is shown in Fig. 46. In this thread the sides are straight and form an angle of

55° with each other. The point and root are rounded. The total height of a sharp thread is divided into six equal parts. One part is taken from the point and one part filled in at the root. The thread is further shaped by rounding the bottom, or root, and top with curves that just come tangent to the sides.

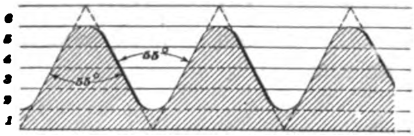


FIG. 46.

59. Shape of Square Thread.—The square thread, as its name implies, is square in section, as shown in Fig. 47. The space between the threads is also square, so that in theory the dimensions *a*, *b*, and *c* should all be equal. In practice, *a* is made slightly greater than *b*.

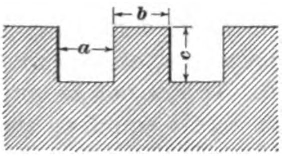


FIG. 47.

STANDARD THREADS.

UNITED STATES STANDARD THREAD.

60. Origin of a Standard Thread. — Originally, each manufacturer adopted his own standard as to the number of threads per inch and the form of thread. The result was that bolts and screws made by different parties were not interchangeable, and, in the case of a breakdown, it was often very inconvenient to obtain repairs for machines. As manufacturing interests became specialized and shops exchanged tools and commodities, interchangeability of the parts became very desirable, and a number of leading manufacturers brought out special types of threads which they tried to have adopted.

In the year 1864, The Franklin Institute, of Philadelphia, appointed a committee to investigate and report upon this subject of screw threads. They made a careful investigation, and finally recommended a system designed by Mr. William Sellers, which was later adopted by the Institute.

61. Reason for Selecting Present Standard.— In determining the exact shape and pitch for a screw, many things had to be considered. Among these were the best angle for the sides, and whether the angle of the sides should be equal or not. When a bolt has a thread cut on its end, the strength of that bolt is reduced because of the reduced diameter at the root of the thread. It will not be any stronger than a bolt equal to the diameter at the root of the threads. It would, therefore, seem desirable to make the threads shallow, so as not to reduce the strength of the bolt. The threads then might be of the shape shown in Fig. 48. Suppose we have this form of thread on a bolt that passes through the pieces shown, and it is intended to carry a load acting in the direction of the arrow. A nut shown in section holds the bolt in place. As the load is applied, the bolt will tend to draw through the nut, and, by so doing, will tend to stretch or burst it. The bursting strain on the nut will depend on the angle of the side of the threads, each thread acting like a wedge in the nut. It will be seen that the bursting strain in this case will be much greater for a given load than it would be if the threads were more acute, as shown in Fig. 49 (*a*). Besides, the great bursting strain

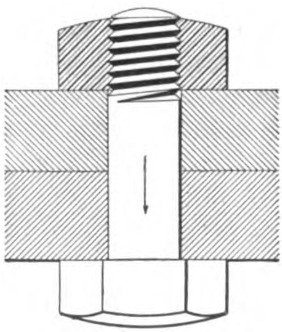


FIG. 48.

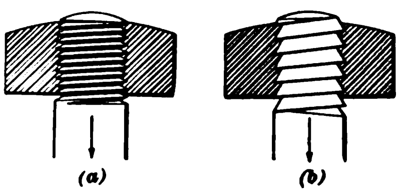


FIG. 49.

would cause great friction on the thread, and there would be danger, in tightening the nut, that the bolt would be twisted off. It is evident, therefore, that a thread having a flat angle is not desirable. The sharp acute thread would so weaken the bolt that it is not desirable. The friction and the bursting strain on the nut might be eliminated by using a ratchet thread, as shown in Fig. 49 (*b*). This would be flat on the under side, relieving the nut from the wedge-shaped thread tending to burst the nut. The thread would not be deep, so that the bolt would not be much reduced in strength after the thread was cut. This would at first seem to answer the conditions, but if the direction of the load should be changed, these ideal conditions would vanish. In every case, the workman would have to consider the direction of the load before he could determine which side of the thread should be flat and which side beveled. Furthermore, the nut used for this thread would only fit from one side; if the nut were turned over, it would not go on. This and many other considerations led to the adoption of a thread with equal angles on either side. The angle of 60° was chosen after much consideration, it being an angle easily obtained and one that seems best to answer the conditions. To give the thread durability, it was decided to take off the sharp point, since it did not add to the strength of the thread. By removing the point of the thread in the nut, it made it possible to fill in a corresponding amount in the root of the screw. This added to the strength of the bolt. The points were left flat because of the ease with which the screw could be constructed when compared with the curved points represented by the British standard.

62. Pitch of United States Standard Threads.—The pitch of the screw for different diameters was also considered, and a standard number of threads to the inch for various diameters was adopted.

The standard pitches of United States standard threads are given in the following table:

PITCH OF UNITED STATES STANDARD THREADS.

Diam. of Screw. Inches.	Diam. at Root of Thread. Inches.	No. of Threads Per Inch.	Diam. of Screw. Inches.	Diam. at Root of Thread. Inches.	No. of Threads Per Inch.
1/4	.185	20	2	1.712	4 1/2
5/16	.240	18	2 1/4	1.962	4 1/2
3/8	.294	16	2 1/2	2.175	4
7/16	.344	14	2 3/4	2.425	4
1/2	.400	13	3	2.629	3 1/2
9/16	.454	12	3 1/4	2.879	3 1/2
5/8	.507	11	3 1/2	3.100	3 1/4
3/4	.620	10	3 3/4	3.317	3
7/8	.731	9	4	3.567	3
1	.837	8	4 1/4	3.798	2 7/8
1 1/8	.940	7	4 1/2	4.028	2 3/4
1 1/4	1.065	7	4 3/4	4.255	2 5/8
1 3/8	1.160	6	5	4.480	2 1/2
1 1/2	1.284	6	5 1/4	4.730	2 1/2
1 5/8	1.389	5 1/2	5 1/2	5.053	2 3/8
1 3/4	1.490	5	5 3/4	5.203	2 3/8
1 7/8	1.615	5	6	5.423	2 1/4

63. Formal Adoption of United States Standard Threads.—This system was authorized for the naval service by the Government in the year 1868. In the year 1871, the Master Car Builders' Association recommended it for use in the construction of locomotives and cars. The system is now entirely used in the United States Navy, and very generally used in locomotive and car construction. It has been adopted by manufacturers generally. It has not entirely taken the place of the **V**-thread system, however, since for very small screws and fine pitches the **V** thread is in many instances more desirable.

64. Variations in Diameter of Standard Bolts.—It will be noticed that the United States standard diameters of bolts vary by sixteenths, eighths, and fourths of an inch. Until recently, many makers used the same number of threads per inch, but made the diameter of the bolt $\frac{1}{64}$ or $\frac{1}{32}$ inch under or over the standard diameter; thus, a $\frac{3}{4}$-inch bolt might be $\frac{1}{64}$ inch over or under $\frac{3}{4}$ inch in diameter. Taps and dies made according to this system are still in use in many blacksmith shops. Fortunately, the confusion arising from this cause is rapidly being done away with, and manufacturers generally are adopting the single standard system and making all their bolts of exactly the nominal diameter. The United States standard thread is used on commercial capscrews.

PITCH OF V THREADS.

65. This form of thread has been almost universally adopted for the making of case-hardened setscrews. The number of threads per inch adopted by universal consent is slightly different from that employed in the United States standard, and is given in the following table:

Diameter of Tap. Inches.	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2
Number of Threads Per Inch.	20	18	16	14	12	11	10	9	8	7	7	6	6	5	5	$4\frac{1}{2}$	$4\frac{1}{2}$

BRITISH STANDARD.

66. Origin of the System.—In the year 1861, Sir Joseph Whitworth, of England, proposed a system of standards for screw threads to overcome the evils that were arising in England by the use of a great number of individual systems, each individual builder or manufacturer having had his own standard up to that time. The system that he introduced is now the standard thread used by British manufacturers, and the same form has been adopted very largely throughout Europe. The rounding of the top and bottom of the thread has certain very desirable features, since it adds greatly to the strength and durability of the screw and does away with the sharp corners, which are more liable to be nicked or bruised.

Most American manufacturers that are accustomed to the United States standard consider the difficulty of keeping up to standard the necessary tools for producing these curved points and roots a sufficient argument against the adoption of the British standard screw thread in this country.

CUTTING SCREW THREADS.

67. Methods of Cutting Threads in Use.—Screw threads may be cut on bolts or screws by either one of two methods. *First*, a die may be used that cuts the thread to size at one passage over the work. *Second*, the work may be revolved between the centers of a lathe and a single-pointed tool held in the tool post passed along the course of the thread a number of times, so as to remove the metal a little at a time.

68. Definitions of Male and Female Threads.—When a screw is cut upon the outside of a piece of work, it is called a **male thread.** When a thread is cut on the inside of a nut or collar, it is called a **female thread.**

CUTTING THREADS BY HAND.

69. General Consideration. — When accuracy of pitch is desired, or the screws are long, the thread should be cut in a lathe between the centers, but if a limited number of short threads is required, these can be advantageously cut by hand with dies; while if a large number is required, they can be produced by means of a special bolt-cutting machine.

70. Hand Dies.—Fig. 50 shows a die for cutting threads, which is intended to be operated by hand. It is held in a die holder, as shown in Fig. 51. When these hand dies are used, the rod to be threaded is held in a vise. The die is then screwed down on the end of the rod until the desired length of screw has been cut. Some pressure will be necessary to start the die, but, after a few threads are cut, it will feed itself along as it is revolved. The die shown in

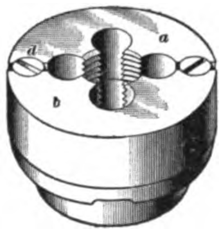


FIG. 50.

Fig. 50 is adjustable within certain limits. Fig. 52 shows it with one half removed. Parts *a* and *b* compose the die proper. Part *c* is a guide that slips on the end of the work

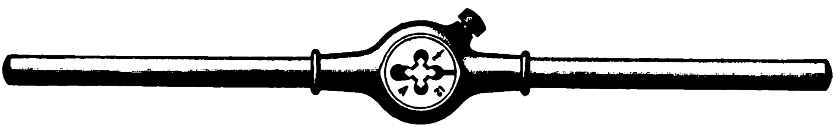


FIG. 51.

and holds the die true when starting the thread. Adjustment is made by the tapered-head screw *d*. When this is screwed into the lower guide, it forces the halves of the dies

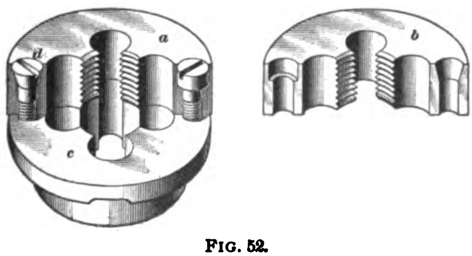


FIG. 52.

apart slightly, which will cause them to cut a larger thread. When in use, the two halves of the die are kept from springing apart by being held in the die holder.

71. Inaccuracy of Pitch of Thread.—This method is slow, as it requires nearly as much time to remove the dies from the work as it does to cut the thread. Hand-cut threads can never be depended on to be true with the axis of the work, as the guide does not fit with sufficient accuracy to start the dies perfectly true. Worst of all is the inaccuracy of pitch. It is not uncommon to find dies that would cut a thread, which, if continued for a foot in length, would be in error $\frac{1}{8}$ inch. With care, dies can be made that will cut short threads with sufficient accuracy of pitch for commercial purposes.

BOLT CUTTERS.

72. General Description of Bolt Cutter.—For rapid screw cutting, special machines are used. These machines, called **bolt cutters,** rotate the dies while the work is held in a chuck on the machine. Fig. 53 shows a type of

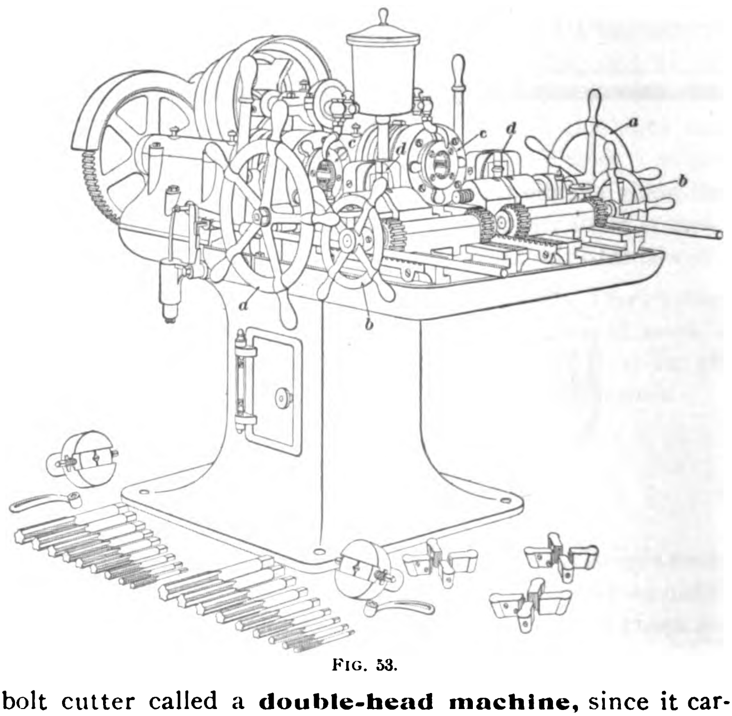


FIG. 53.

bolt cutter called a **double-head machine,** since it carries two heads or die holders. Work is clamped horizontally in the machine in the jaws or chucks *d*, *d* by means of the large hand pilot wheels *a*, *a*. The chuck and work are moved up to the dies *c*, *c* by means of hand wheels *b*, *b*, these wheels operating the gears, which engage with the racks shown.

73. Automatic Dies.—The dies used on bolt-cutting machines are quite different from the hand dies just described. They are automatic in action, so that when the die has cut a sufficient length of thread on the bolt, a lever

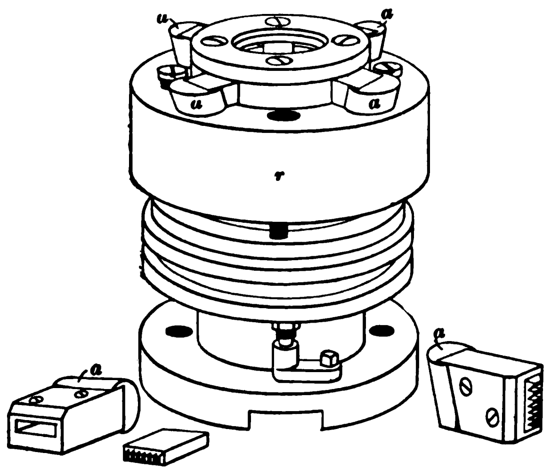


FIG. 54.

automatically opens the die, causing it to cease cutting and allowing the work to be freely withdrawn. This saves much time. Fig. 54 shows one style of special head for bolt cutters designed to hold detachable dies. Dies of various sizes may be used in this head for cutting different diameters of bolts. Fig. 55 shows the principle of this style of automatic head. The body of the head *b* has four radial grooves cut in the end, in which the four cutter dies *d* can slide. A cap *c*, fastened to the head *b* with screws, holds the dies in place. The outer ends of the dies are beveled, as shown. The ring *r* fits over the head *b* and partly over the ends of the dies. When in the position shown in the illustration, the dies are open. To close the dies, the ring *r* is pushed in the direction of the arrow, over the ends of the dies to the position of the dotted lines. This forces each of the dies toward the center. When in this position, the dies are ready to cut. Levers are so arranged that after a thread

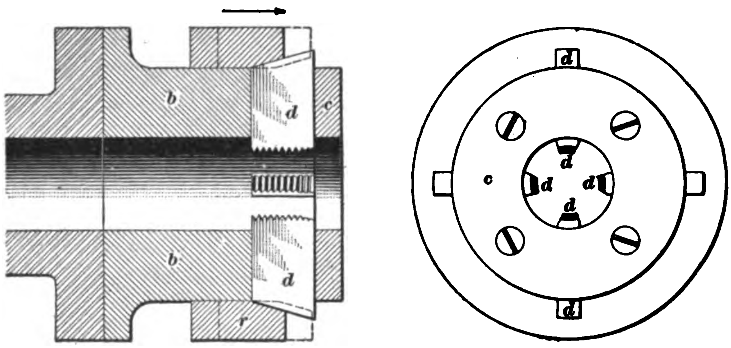


FIG. 55.

of the desired length is cut on a bolt, the ring *r* is suddenly released and moved back to its normal position, as shown. This releases the dies, which are as quickly opened by the cylindrical portions *a*, Fig. 54, sliding in the ring *r* and the dies cease to cut.

74. Lubrication.—When these machines are being used, a stream of lard oil is kept flowing on the dies and the work to keep them cool and to lubricate the cutting edges.

TAPPING.

75. Use of Taps.—The operation of cutting internal or female threads is in many respects similar to the cutting of male threads. It may be done on the engine lathe, as will be described later, or by the use of *taps*, which may be operated either by hand or machine power. The use of taps for cutting internal threads is the common practice, and only when large or special forms of threads are desired is the lathe employed.

76. Hand Taps.—Taps are generally made from the solid bar of steel. They are accurately threaded and fluted,

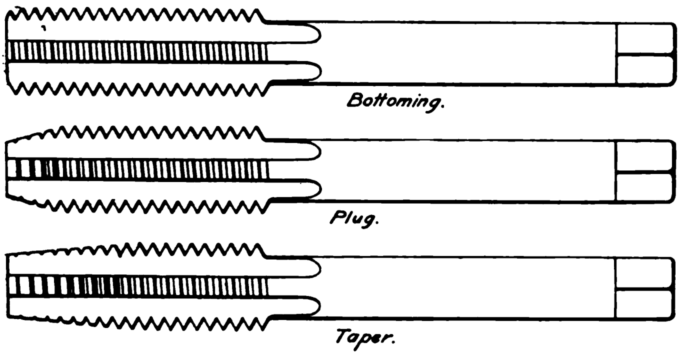


FIG. 56.

and then tempered. Fig. 56 shows a set of machinists' hand taps. A set consists of a taper, a plug, and a bottoming tap.

77. Tapping a Hole.—When a hole has been drilled entirely through a piece, it is only necessary to use the taper tap, which may be run entirely through the piece being tapped. When a hole that has been drilled partly through a piece is to be threaded to the bottom, as shown in Fig. 57, it is necessary to use all three taps. In order to start the thread, it is necessary to use the taper tap. This is screwed in until it touches the bottom of the hole. The plug tap is next used, which, when screwed to the bottom of the hole, will cut "full" threads somewhat deeper, and, for finishing, the bottoming tap is used.

FIG. 57.

78. Machine Tapping.—For machine tapping, the taper tap is used, the principal difference being that it has a longer shank than the hand taper tap. The machines used are similar to those used for bolt cutting. The die head is removed and the taps are held in suitable chucks in the place of the die heads.

CUTTING SCREWS ON THE LATHE.

79. Accuracy of Pitch.—When screws of accurate pitch or lead are desired, or when screws are desired that will be true with the axis of the work, they can be cut with more certainty on the lathe than with dies. The accuracy of the screw cut will depend on the accuracy of the leadscrew in the lathe used. For ordinary threads, the ordinary leadscrew is sufficiently accurate. When greater accuracy is required for such work as making taps or dies, the making of precision screws for measuring instruments, or similar work, a leadscrew that has been made with more than ordinary care and has been tested all along its length must be used.

GEARING FOR SCREW CUTTING.

80. Screw Feed-Motion.—To cut a screw in the lathe, of a given pitch, it is necessary that the feed-motion be so arranged that, for a given number of revolutions of the work, the tool and the carriage move sidewise 1 inch. The feed-motion is communicated to the carriage by means of the leadscrew *15*, Fig. 1, *Lathe Work*, Part 1. The feed is thrown in by pushing down the lever *18*, Fig. 1, Part 1. This lever operates a split nut in the apron. When the nut is open, half is on each side of the leadscrew, the opening being sufficient to allow the screw to run clear of the nut. By pushing down the lever, the two halves of the split nut are brought together about the leadscrew. The nut is secured to the apron in such a manner that, as the leadscrew revolves and draws the nut along, the carriage moves with it. Motion is given to the leadscrew by gears, which connect it directly with the lathe spindle.

Suppose it is desired to cut a screw of 5 pitch on a lathe with a leadscrew of 5 pitch. Then it would be necessary to use such gears in connecting the spindle with the leadscrew in order that the leadscrew would make 5 revolutions while the work is making 5 revolutions. If it were desired to cut

10 threads to the inch, then the work must make 10 revolutions while the carriage is moving 1 inch, or while the leadscrew makes 5 revolutions.

The proper gears to be used for any pitch of screw can readily be determined. First, it must be ascertained whether the lathe is simple or compound geared.

81. Simple-Geared Lathes. — In a simple-geared lathe, the stud or spindle on which the change gear is placed makes the same number of revolutions as the lathe spindle or work. The head of such a simple-geared lathe is shown in Fig. 58. Here, one change gear *a* is put directly on the small end of the lathe spindle and the other *b* is placed on the leadscrew. The lathe shown in Fig. 1, *Lathe Work*, Part 1, is also a simple-geared lathe, since the stud or spindle *S* is so geared by means of the reversing gears that it makes the same number of revolutions as the lathe spindle.

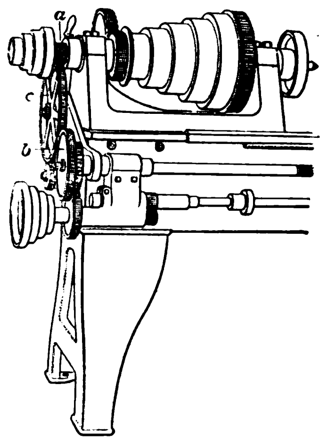


FIG. 58.

82. Compound-Geared Lathes.—Lathes of this class are so geared that the stud on which the change gear is placed does not make the same number of revolutions as the lathe spindle, or some other combination of gears is introduced that changes the ratio of simple gearing.

83. Pitch of Leadscrew.—The pitch of the leadscrew is the number of threads per inch of the leadscrew, but in figuring the gears necessary to cut a given thread, it is sometimes necessary to use the **apparent pitch** of the leadscrew. In the case of all simple-geared lathes, the pitch of the leadscrew is the same as the apparent pitch of the leadscrew; but in the case of compound-geared lathes, the number of revolutions of the leadscrew is not only affected by the change gears, but by compound gears in the head also. For instance, if the gear on the driving stud of the lathe is connected to the spindle by a train of gears, so that it makes two revolutions to one of the spindle, the leadscrew will make twice as many revolutions as it would with any given set of ordinary change gears, and hence the apparent pitch of the leadscrew will be just twice the actual pitch of the leadscrew. In some cases the compound gears are placed inside of the head of the lathe, where they cannot be seen, and hence it is impossible to determine the apparent pitch of the leadscrew by inspection. In such a case it may be found by selecting two gears of equal size, placing one on the stud and the other on the leadscrew, with any convenient gear as an intermediate. With this combination, cut a thread upon a piece of work between the centers. This thread will be the same as the apparent pitch of the leadscrew and may be used in all thread-cutting calculations for the lathe in question.

84. Rule for Simple Gearing.—When the lathe is simple geared, the following rule may be used for finding a combination of gears to cut any pitch of thread:

Rule.—*Write the pitch of the leadscrew over the pitch of the desired thread in the form of a fraction. The numerator will indicate the number of teeth in the gear to be put on the stud or spindle, and the denominator will represent the number of teeth required in the gear on the leadscrew.*

85. Application of Rule for Simple Gearing.—In practice it is impracticable to use gears having much less than 20 teeth for screw cutting, and hence it is usually necessary to multiply both numerator and denominator of the fraction obtained, by the rule given in Art. **84**, by some common number so as to obtain a pair of gears both of which shall have more than 20 teeth.

86. As a rule, the teeth of the change gears of any lathe increase in a regular manner, as for instance 20, 24, 28, 32, etc., or 18, 24, 30, 36, etc. In the first case each gear has four teeth more than the preceding one, and in the second case each gear has six teeth more than the preceding one. When the gears of a lathe increase by a common number in this manner, the common number may be used to multiply both terms of the fraction obtained by the rule given in Art. **84,** and this will give the gears to be used. If the lathe is intended for cutting some fractional pitches, there are generally some extra gears in the set, which do not correspond to the regular ratio, and in some cases the gears of a lathe do not follow in any regular order. In such cases it will be necessary to multiply the numerator and the denominator of the fraction obtained by the rule given in Art. **84** by common numbers successively, as for instance, $\frac{2}{2}$, $\frac{3}{3}$, $\frac{4}{4}$, $\frac{5}{5}$, etc., until a pair of numbers are found which correspond with the teeth of the gears in the set belonging to the lathe.

Example.—It is desired to cut a screw having 10 pitch on a lathe having a leadscrew of 6 pitch and in which the common number of the gears is 4.

Solution.—Applying the rule given in Art. **84,** we obtain $\frac{6}{10}$, or a gear of 6 teeth for the driving stud and 10 teeth for the screw, but both of these contain too small a number of teeth, hence both numerator and denominator must be multiplied by a common number, or $\frac{6}{10} \times \frac{4}{4} = \frac{24}{40}$, or a 24-tooth gear for the driving stud and a 40-tooth gear for the screw. Any gear may be used to connect the gear upon the driving stud and the gear upon the screw.

87. Fractional Threads.—In the case of fractional threads, the rule given in Art. **84** is applied and the resulting compound fraction reduced to a simple fraction. This may often be accomplished by multiplying both numerator and denominator by the same number.

Example.—It is desired to cut a standard 1-inch pipe thread of $11\frac{1}{2}$ threads per inch in a lathe having a leadscrew of 5 threads per inch.

Solution.—Applying the rule given in Art. **84,** we obtain $\frac{5}{11\frac{1}{2}}$; multiplying the fraction by $\frac{4}{4}$, $\frac{6}{6}$, etc., we obtain $\frac{20}{46}$, $\frac{30}{69}$, etc. Any one of these combinations may be used, provided the necessary gears are found in the set belonging to the lathe, the number in the numerator being placed upon the driving stud and the number in the denominator upon the screw.

88. Cutting Threads per Pitch.—When threads are designated as a fraction, as for instance $\frac{3}{8}$ pitch, it means that there is one thread for every $\frac{3}{8}$ inch, or 8 threads in 3 inches. For calculating the gears for threads so designated, the following rule may be used:

Rule.—*Multiply the numerator of the fraction by the pitch of the leadscrew and the numerator of the resulting fraction will correspond to the number of teeth in the gear upon the driving stud and the denominator to the number of teeth in the gear upon the spindle.*

EXAMPLE.—It is desired to cut a thread having $\frac{5}{8}$ pitch on a lathe having a leadscrew of 4 threads per inch.

SOLUTION.—Applying the above rule, we obtain $\frac{5}{8} \times \frac{4}{1} = \frac{20}{8}$. Multiplying both numerator and denominator by 3, we obtain $\frac{60}{24}$, that is, a gear having 60 teeth would be required upon the driving stud and a gear having 20 teeth upon the screw.

89. Cutting Threads on Compound-Geared Lathes.—In the case of lathes which contain a set of compound gears in the head, either one of two courses may be followed. The apparent pitch of the leadscrew may be found and used in all gear calculations. In this case the rule given in Art. **84** is used with the apparent pitch as though the lathe contained no compound gears. The other method is to apply the following rule:

Rule.—*Divide the pitch of the screw to be cut by the ratio of the revolutions of the work to the revolutions of the change-gear spindle or driving stud, and then proceed as in simple gearing.*

EXAMPLE.—It is required to cut a 10-pitch thread on a lathe having a 6-pitch leadscrew and in which the work makes two revolutions to one revolution of the change-gear spindle, the common number for the change gears of the lathe being 4.

SOLUTION.—Applying the rule given above, we obtain $\frac{10}{2} = 5$ as the apparent thread to be cut. Applying the rule given in Art. **84** and multiplying by the common number, we obtain $\frac{6}{5} \times \frac{4}{4} = \frac{24}{20}$, or a 24-tooth gear for the driving stud and a 20-tooth gear for the screw.

90. Cutting Threads by Compounding the Gears. When it is necessary to cut a thread very much coarser or

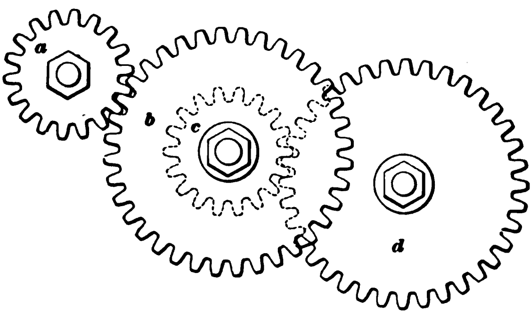


FIG. 59.

very much finer than the pitch on the leadscrew, the size of the gears differs so greatly that it is impossible to find gears having the required number of teeth in a set commonly belonging to a lathe; or if they could be found it would frequently be impossible to place them in position. To overcome these difficulties, some lathes are arranged in such a manner that an extra pair of gears may be introduced between the gear on the driving stud and that on the screw. This extra pair of gears are keyed to a loose sleeve which turns on a pin. This arrangement keeps the extra pair of gears in the same relation to each other so that they take the place of the intermediate gear usually employed in simple thread cutting. When compound gearing is resorted to, the gears are arranged as shown in Fig. 59, where *a* is the gear on the driving stud, *b* is the gear on the compound or intermediate stud, *c* the second gear on the compound stud, and *d* the gear on the screw.

Rule.—*Write the pitch of the leadscrew over the pitch of the desired screw in the form of a fraction. Factor both numerator and denominator into two numbers, so as to form two fractions which multiplied together will give the original fraction. Multiply both the numerator and the denominator* *of the resulting fractions by common numbers, which will give two sets of numbers corresponding to the teeth of the gears required, the numerator of the first fraction representing the number of teeth in the gear upon the driving stud and the denominator the number of teeth upon the first gear upon the compound stud, the numerator of the second fraction representing second gear upon the compound stud and the denominator the gear upon the screw.*

EXAMPLE.—It is required to cut a 50-pitch screw on a lathe having a 6-pitch leadscrew.

SOLUTION.—Applying the rule given above, we have $\frac{6}{50} = \frac{3}{10} \times \frac{2}{5}$; multiplying the numerator and denominator of both fractions by 8, we obtain $\frac{24}{80} \times \frac{16}{40}$. It does not make any difference which one of the fractions is considered first, but the numerators represent drivers and the denominators driven gears, so that the 24-tooth gear can be placed either on the driving stud or as the second gear upon the compound stud, and the 16-tooth gear will be placed in the other position, but care must be taken to see that each pair of gears are kept together. For instance, the 24-tooth gear on the driving stud, and the 80-tooth gear as the first gear on the compound stud, the 16-tooth gear as the second gear on the compound stud, and the 40-tooth gear as the gear on the leadscrew.

EXAMPLE.—It is required to cut a screw having a pitch of 4 inches to one revolution, or $\frac{1}{4}$ of one thread per inch, in a lathe having a 4-pitch leadscrew.

SOLUTION. —Applying the above rule, we have $\frac{4}{\frac{1}{4}} = \frac{16}{1} = \frac{4}{1} \times \frac{4}{1}$. Multiplying the numerator and denominator of each fraction by 20, we have $\frac{80}{20} \times \frac{80}{20}$, or an 80-tooth gear on the driving stud, and 20-tooth gear as the first gear on the compound stud, an 80-tooth gear as the second gear on the compound stud, and a 20-tooth gear on the screw.

91. Cutting Right- and Left-Hand Threads.—As lathes are commonly geared, they will cut a right-hand thread when one intermediate gear is used and a left-hand thread when two intermediate gears are used. The number of teeth in the intermediate gears has no effect upon the thread cut so long as they are all in one continuous train without compounding. In the case of simple compounding, the compound gears take the place of the intermediate for right-hand thread cutting, while for cutting a left-hand thread, it is necessary to introduce another intermediate gear into the train, either between the driving stud and compound stud or between the compound stud and the leadscrew. Most lathes have gearing in the head for reversing the feed, and in such a case this can be used to reverse the motion when cutting left-hand threads.

92. Cutting Threads on a Lathe Having Its Apparent Lead Expressed per Pitch.

Rule.—*Invert the fraction representing the pitch and multiply the denominator by the number representing the pitch of the required thread. Then multiply both the numerator and the denominator by the common number for the change gears of the lathe or by any pairs of common numbers until a pair of numbers is obtained which correspond to gears contained in the set of change gears in the lathe.*

EXAMPLE.—It is required to cut 4 threads on a lathe whose leadscrew has a $\frac{8}{3}$ pitch.

SOLUTION.—Applying the above rule, we have $\frac{8}{3} \times \frac{1}{4} = \frac{8}{12}$. Multiplying both numerator and denominator by 3, we have $\frac{8}{12} \times \frac{3}{3} = \frac{24}{36}$, or a 24-tooth gear for the driving stud and a 36-tooth gear for the screw.

93. Finding One Gear by Proportion.—When the pitch of the leadscrew, the pitch of the screw to be cut, and the number of teeth in one of the gears are known, the number of teeth necessary for the other gear may be found by the following rule:

Rule.—*The pitch of the leadscrew divided by the pitch of the screw to be cut equals the number of teeth in the gear on the spindle divided by the number of teeth in the gear on the leadscrew.*

EXAMPLE.—It is desired to cut a 10-pitch screw with a 6-pitch leadscrew by using a 24 gear on the driving stud. What gear should be used on the screw?

SOLUTION.—Applying the rule given above, we have $6 \div 10 = 24 \div$ the required gear, or $\frac{6}{10} = \frac{6 \times 4}{10 \times 4} = \frac{24}{40}$. Hence 40 equals the number of teeth in the gear on the leadscrew. Ans.

It should be remembered that when a lathe is geared to cut a screw, if the pitch of the leadscrew is multiplied by the number representing the teeth in the gear on it, and the pitch of the thread being cut by the number representing the number of teeth in the gear on the spindle, the two products will be equal. In the above case, this will be shown to be true, since 6 × 40 = 240 and 10 × 24 = 240.

THE THREADING TOOL.

94. Shape of Threading Tool.—When a screw thread is to be cut, the tool is ground and shaped as shown in Fig. 60. The tool is ground flat on top. The side faces *N S* and *G K* are ground to form an angle of 60°. This angle is tested by using a thread gauge, shown in Fig. 61. When the gauge is used to test the angle of the point of the tool, it should be held so that it lies flat with the top face in the line *A B*, Fig. 60. If it is desired to measure the exact angle that the two faces make with each other, the gauge would be held at right angles to the faces, or along the line *P Q*. It will be apparent that the way the tool fits the gauge will depend on the way the gauge is held to the tool. In order to make the angle at the point along the line *A B* equal 60°, it will be necessary to make the angle of the faces along the line *P Q* a little over 60°. Little attention, however, is paid to the exact angle, since the angle along the line *A B* is the important one. The angle of front rake and clearance of the tool is shown by the line *E F*. This should be about 15° with the perpendicular *C D*.

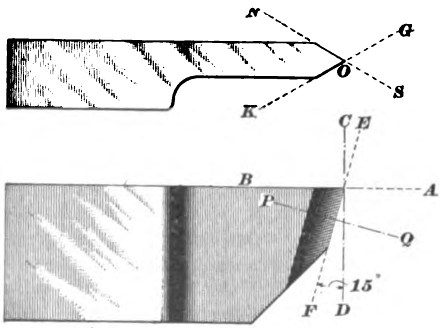


FIG. 60.

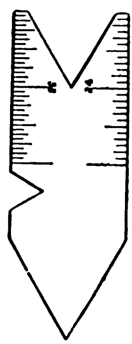


FIG. 61.

95. Grinding Threading Tool.—These tools may be ground by the same method used in grinding ordinary lathe tools, the gauge being used to test the angle of the point. Whenever it is possible, it is better to grind the tools in machines specially designed for grinding tools. With these machines, it is possible to grind more accurate angles and truer faces than it is by hand.

96. Setting Threading Tool.—The tools should be clamped in the tool post at such an angle to the work that the faces of the tool *N S* and *G K*, Fig. 60, will make equal angles with the work. This is accomplished by using a thread gauge, as shown in Fig. 62. The back of the gauge lies flat against the work while the point of the tool is moved so that it just fits the notch in the front of the gauge. It will be seen that since the point of the tool is ground to an angle of 60° and the sides of the threads to be cut make an angle of 60°, the angle between one of the faces of the tool and the work will be an angle of 60°. It will therefore be found more convenient on some kinds of work to hold the gauge as shown in Fig. 63. When one edge of the tool is properly set, the other edge will be at the correct angle, provided the tool is correctly ground.

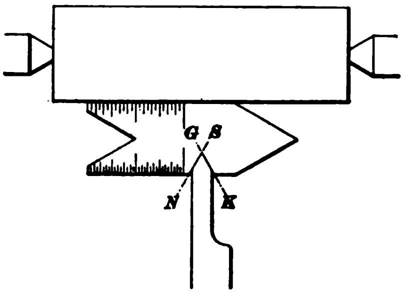


FIG. 62.

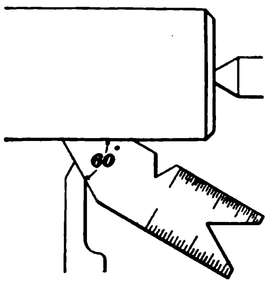


FIG. 63.

CUTTING THE THREAD.

97. Operation of Cutting the Thread.—Before starting the cut, care should be taken that the tool is firmly clamped in the tool post, that the dog is tight on the work, and that all gearing is properly adjusted so that nothing can slip when the cut is being made. The feed should be from right to left when the lathe is running forwards. This will cut a right-hand thread. The tool is moved forwards so that the point just touches the work. The lathe is started forwards and continues in this direction until the tool has fed along the work a distance equal to the desired length of thread. When the tool reaches that point, it is quickly drawn away from the work by a turn of the cross-feed screw with one hand, while the lathe is quickly reversed by swinging the shifter handle with the other hand. By reversing the lathe, the work moves backwards and the tool will feed back to the starting point.

98. Stop for the Threading Tool.—To keep the tool from cutting too deep, a stop is arranged on the cross-slide, as shown in Fig. 64. The stop *b* is rigidly fastened to the slide by tightening the screw *a*. A screw *s*, with a large shoulder and nurled head, passes loosely through the stop and screws into the tool block *t*. When the stop is adjusted as shown in the figure, the tool and tool block can be moved away from the work, since the screw *s* is not threaded to the block *b*. When the block is moved forwards, it can only move until the head of the screw *s* comes against the stop.

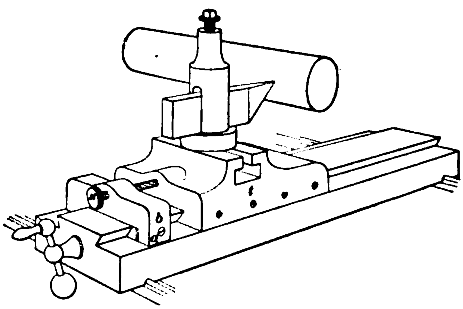


FIG. 64.

After the tool has passed over the work and it is desired to take a deeper cut, the stop-screw *s* is unscrewed a partial turn; this will allow the tool to be advanced slightly, depending on the amount the screw is turned. After the first cut or scratch is made on the work with the point of the tool, it is good practice to hold a scale against the threads and count the number to the inch to see if the lathe is cutting correctly. If a mistake is discovered, it can be rectified, but if the error of pitch is not discovered until the thread is cut, there is no remedy.

FITTING THE THREAD.

99. A Perfectly Fitted V Thread.—As was shown by Fig. 40, a V thread is sharp at its point and at its root. If a 1-inch thread were being cut, the thread would be complete when the groove cut by the tool just formed the sharp point of the thread. It is difficult to know just when this point is reached, therefore the work is taken from the lathe and tested with a gauge or in the piece it is to fit.

Fig. 65 represents a section through a bolt and nut, showing how accurately the faces of the threads should fit each other.

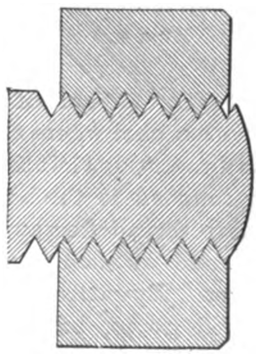


FIG. 65.

100. Calipering Threads.—Before the final testing in the gauge or work, the thread may be tested by the use of specially prepared calipers. These calipers are made very thin on their point, so that they fit into the V's of the thread and measure the diameter at the root, as shown in Fig. 66. The calipers may be set from a tap or a standard gauge.

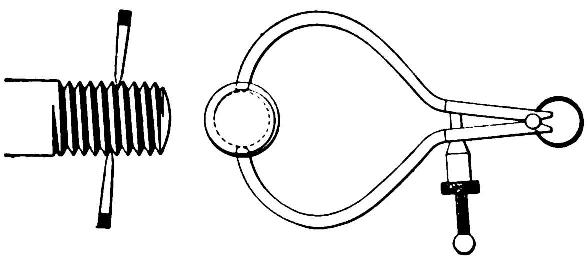


FIG. 66.

101. Effect of Using a Dull Threading Tool.—Fig. 67 shows a bolt that has been threaded with a dull-pointed tool. Because of the rounded point of the tool, the threads are rounded at the bottom. When this kind of a thread is tested in a perfectly threaded nut, as shown, it will be seen that it will not enter until the thread is cut sufficiently deep to allow the rounded root of the thread to pass in. While this may hold the work so that no lost motion can be detected at first, it is evident that the piece would soon wear loose, since there is no bearing on the sides of the threads.

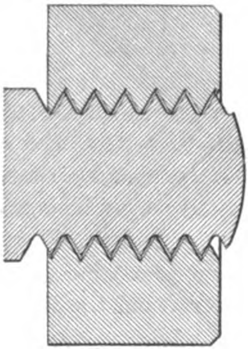


FIG. 67.

102. Effect of Using a Dull Tap.—Fig. 68 shows another case where the nut to be fitted has been cut with a dull tap, which left the threads slightly rounded in the bottom. When a sharp threaded screw of full diameter is tried in such a nut, it will not enter. By cutting the screw smaller, it will go in, but the fit will be as shown, the bearing being entirely on the points of the threads. In practice, when the thread has been cut to a sharp point and it will not enter, this trouble should be looked for, and if it is found that the threads in the nut are imperfect, the points of the screw being cut should be slightly rounded with a file. A screw thread should fit by bearing on the sides of the threads and not on the points.

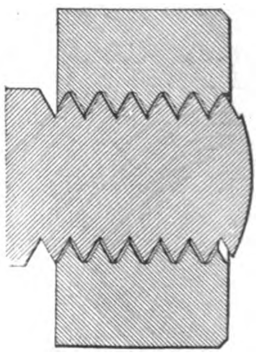


FIG. 68.

103. Advantage of Large Tap Holes.—In machine construction where holes are drilled and tapped for **V** threads in various parts of castings, it is customary to drill the holes slightly larger than would be necessary to cut such a full sharp thread as shown in Fig. 65. After the holes are tapped, they are more nearly the shape shown somewhat exaggerated in section in Fig. 69, where it may be seen that the threads are not full on the points. When a bolt is being fitted to this kind of a tapped hole, the necessity of keeping a very sharp point on the tool and cutting the thread sharp at the root is not so important.

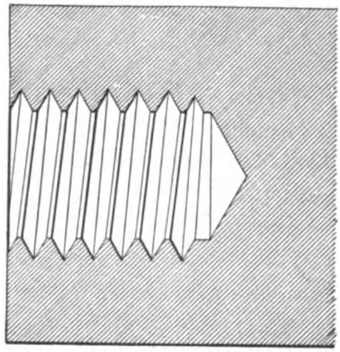


FIG. 69.

104. Effect of a Slight Difference in Pitch on the Fit.—Fig. 70 shows a section through a bolt and nut having slightly different pitches. In fitting such a bolt, it will be found upon trial that it enters the nut for a few turns easily, growing tighter as it is screwed in, with the appearance of being tapered. After more cutting, the bolt will pass through the nut, appearing to fit. When the end of the bolt is once passed through the work, it will not fit any more closely as it is screwed along the bolt. When a bolt and nut are of slightly different pitches, the effect is much more noticeable if the nut is long than it is if the nut is short. It may be seen from Fig. 70 just what the real contact is. In this case, the thread on the bolt is of a coarser pitch than the thread on the nut, and bears only on the first and last threads of the nut.

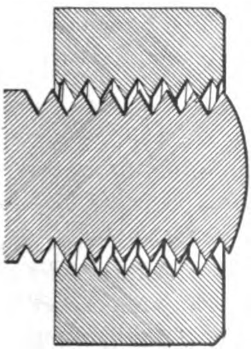


FIG. 70.

105. Fitting Threads on the Same Lathe.—When two threads are to be cut that are desired to fit each other perfectly, the female thread being long, it is desirable that they each be cut on the same lathe. By the use of the same lathe, they can be made to have the same pitch, and if there is any error in the pitch, it will be the same in each thread.

106. Putting Work Back Into Lathe After Testing.—If, after testing the work carefully, it is found to be too large, it should be put back into the lathe and a sufficient number of light cuts taken to reduce it to the desired size. Care must be taken to notice and mark the notch in the face plate used for the tail of the dog, and to put the dog back in the same position from which it was taken. A failure to do this will cause the point of the tool to start another thread that will destroy the one nearly completed.

107. Precautions to Observe in Thread Cutting.—When cutting screws in a lathe, lard oil should be freely applied to the tool and the work. The finishing cuts should be light shaving cuts. The tool should be made sharp and keen with an oilstone.

RESETTING THE TOOL.

108. When the tool has been removed for sharpening or other purpose, it may be reset as follows: Adjust the tool in the tool post to fit the gauge, Fig. 62, the same as before the thread was started. Turn the lathe forwards and note whether the tool point comes opposite the cut in the work or not. If not, drop the intermediate gear *c*, Fig. 58, away from the stud change gear *a*. Turn the lathe forwards until the tool comes exactly opposite the notch or thread in the work. Bring the two gears together again, which will throw in the feed, and proceed to cut the thread as before. It should be noted that the lathe must always be turned forwards. This is to take up the slack or back lash in the gears and the lead-screw. This back lash can be noted at the time the lathe is reversed, when it will be seen that the work may make a part of a turn before the tool will start to feed back. This will cause the tool to drag behind, and if the tool should be brought up to the work when it is running back, it would not fit in the notch as it did when the lathe was running forwards.

OPENING THE LEAD NUT.

109. When cutting threads on the ordinary lathe, after the thread is once started, the feed-nut is seldom opened from the leadscrew. In some cases, however, this is allowable. Suppose that a thread of 10 pitch is being cut with a leadscrew of 6 pitch. If the feed-nut is opened and the carriage moved along one notch or thread on the leadscrew, so that the nut will just close again in the second notch, the carriage will have moved $\frac{1}{6}$ inch. The point of the lathe tool will also have moved $\frac{1}{6}$ inch. The second notch or thread on the screw being cut is $\frac{1}{10}$ inch from the first, so it will be seen that the point of the tool has moved a little beyond the notch of the thread being cut. If the carriage should be moved 2 threads on the leadscrew, the tool point would move along $\frac{2}{6}$ inch. This position would not correspond with any thread on the screw being cut. If we should move it 3 threads and close the nut, the tool point would have moved $\frac{3}{6}$ or $\frac{1}{2}$ inch. At this point it would be found that the point of the tool would come opposite the fifth thread of the screw being cut, which would be $\frac{5}{10}$ or $\frac{1}{2}$ inch on the screw being cut. If we move along 6 threads or 1 inch on the leadscrew, we would move 10 threads or 1 inch on the screw being cut. From this it will be seen that in the case of a 6-thread leadscrew cutting 10 threads, the nut may be opened and the carriage moved along, and for every $\frac{1}{2}$ inch along the leadscrew the nut may again be closed on the thread and the cutting proceed without damage to the thread; it will be seen that for any other position the nut will not close, or, if it does, the tool point will not come opposite the thread being cut. If the thread to be cut were 11 pitch, it would be found that the nut could only be closed on the leadscrew at spaces 1 inch apart. If the pitch

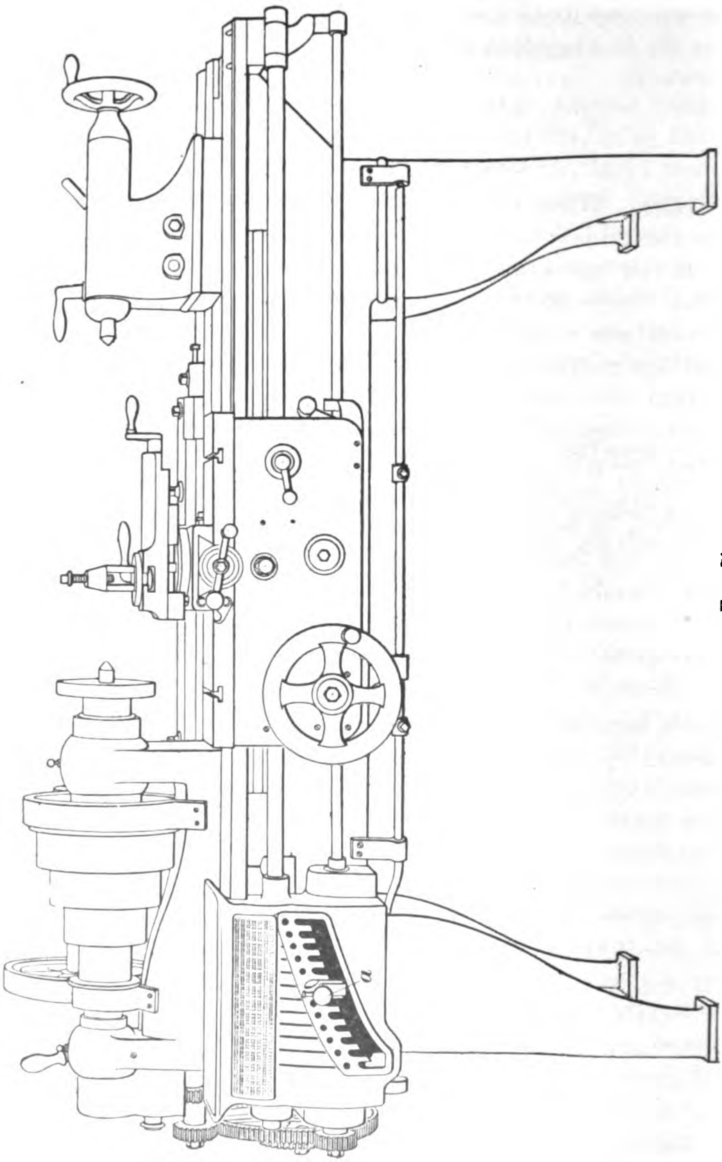


FIG. 71.

to be cut were 2¼ pitch, the spaces on the leadscrew would be 2 inches apart. If the threads to be cut were 6, 12, 18, 24, or any multiple of the pitch of the leadscrew, then the split nut might be opened and again closed in any place on the screw and the tool point would be found to come opposite the thread being cut; for if the tool moved ⅙ inch, it would be equal to 2 threads on the 12-pitch screw, 3 threads on the 18-pitch screw, 4 threads on the 24-pitch screw, and so on.

110. *When cutting a thread that is a multiple of the pitch of the leadscrew, the lathe need not be reversed, but may be allowed to run in one direction all the time.* When the tool has fed to the end of the cut, it is quickly drawn out, while the feed is stopped by opening the split nut. The carriage is then moved back by hand, the feed thrown in, and the operation repeated.

AN IMPROVED METHOD OF GEARING LATHE FOR SCREW CUTTING.

111. The operation of changing the gears for every desired pitch of screw consumes considerable time and offers a chance to make mistakes. A new system of gearing has been introduced which is applied to small lathes. A lathe with this system applied is shown in Fig. 71. In this system all the change gears are on a shaft in the gear-box seen at the front of the lathe, directly under the headstock. To change from one set of gearing to another, the knob *a*, which moves in the slot in the gear-box, is moved to a position indicated by the table. This is a very convenient arrangement when compared with the older methods. This particular lathe possesses another feature that makes it desirable for screw cutting, viz., the reversing of the feed-motion by a lever in the apron. This makes it possible to keep the work running in one direction all the time.

LATHE WORK.

(PART 3.)

SCREW CUTTING.

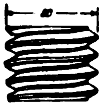
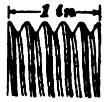
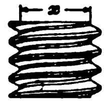
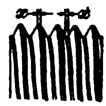
CUTTING UNITED STATES STANDARD THREADS.

1. Tool for Cutting United States Standard Threads.—The operation of cutting United States standard threads is similar to that of cutting V threads. The only difference is in the tool, and that consists of grinding a very small portion from the point of the tool. It will be seen by reference to Fig. 45, *Lathe Work*, Part 2, that the United States standard thread is flat in the root. The width across the flat in the root and also at the point of the thread varies for every pitch of thread, since one-eighth the space between the threads is removed from the points and filled in at the roots, and this amount would vary with each pitch. The tool should therefore be ground to an angle of 60° as for V threads, and the proper amount taken from the point. The best way to determine the amount to be removed from the point is to try the tool into a standard tap or to have a gauge to which the tool can be fitted.

2. United States Standard Thread Gauge.—Such a gauge is shown in Fig. 1. The figures opposite the different notches indicate the notch to be used in shaping the tool for that pitch. The following table gives the widths of

TABLE I.

UNITED STATES STANDARD SCREW THREADS.

Diameter of Screw. 	Threads Per Inch. 	Diameter at Root of Thread. 	Width of Flat. 
¼	20	.1850	.0063
5/16	18	.2403	.0069
⅜	16	.2936	.0078
7/16	14	.3447	.0089
½	13	.4001	.0096
9/16	12	.4542	.0104
⅝	11	.5069	.0114
¾	10	.6201	.0125
⅞	9	.7307	.0139
1	8	.8376	.0156
1⅛	7	.9394	.0179
1¼	7	1.0644	.0179
1⅜	6	1.1585	.0208
1½	6	1.2835	.0208
1⅝	5½	1.3888	.0227
1¾	5	1.4902	.0250
1⅞	5	1.6152	.0250
2	4½	1.7113	.0278
2¼	4½	1.9613	.0278
2½	4	2.1752	.0313
2¾	4	2.4252	.0313
3	3½	2.6288	.0357
3¼	3½	2.8788	.0357
3½	3¼	3.1003	.0385
3¾	3	3.3170	.0417
4	3	3.5670	.0417
4¼	2⅞	3.7982	.0435
4½	2¾	4.0276	.0455
4¾	2⅝	4.2551	.0476
5	2½	4.4804	.0500
5¼	2½	4.7304	.0500
5½	2⅜	4.9530	.0526
5¾	2⅜	5.2030	.0526
6	2¼	5.4226	.0556

flats for different pitches and also the diameter of the screw at the root of the threads.

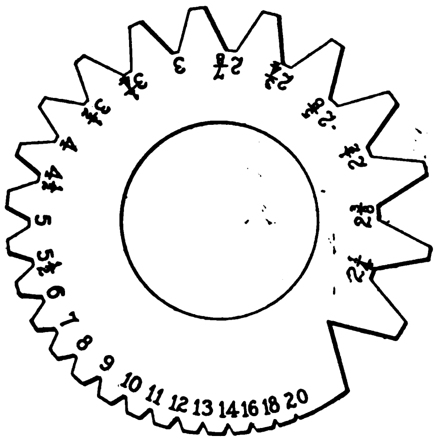


FIG. 1.

3. Cutting United States Standard Threads.—When cutting United States standard threads, the cutting is continued until the space between the grooves is equal to the width of the flat of the desired thread. The mistake is sometimes made of cutting until the thread comes sharp like a V thread and then cutting off the point. This method is incorrect.

CUTTING BRITISH STANDARD THREADS.

4. Tool for Cutting British Standard Threads.—The operation of cutting British standard threads is similar to that just described. The difference in thread is due to the shape of the tool. Every pitch of thread requires a tool of particular size and shape, the same as the United States standard, but because of the curved point and root of the thread (see Fig. 46, *Lathe Work*, Part 2), the tool is much more difficult to make. Fig. 2 shows the plan of a tool as it is applied to the work. It will be seen that the point is rounded and round corners are formed on the sides of the tool, to form the round points of the threads. After these tools are made, they are, in reality, *forming tools*. They are sharpened by grinding on the top face. These tools are formed by using a hob, which is shaped like a tap, except that it has eight or ten flutes, while a tap has but four. These hobs are accurately formed screws before the flutes are cut. After they are fluted and hardened, they are used like milling cutters for "hobbing" the threading tools. The hob is held between the lathe centers while the blank tool is held in the tool post. As the hob revolves, the tool blank is fed up to it; at the same time, it is fed along by the lead-screw. By repeating these operations, as in cutting a screw, the blank is soon formed into a threading tool. After hardening, it is ready to be used to cut the desired screw.

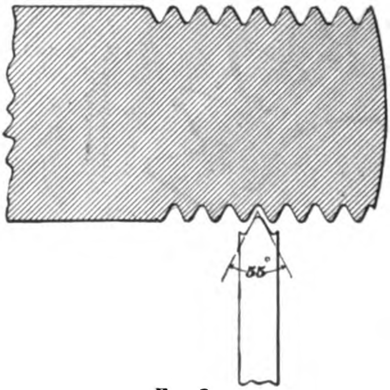


FIG. 2.

CUTTING SQUARE THREADS.

5. Tool for Cutting Square Threads.—The tool used for cutting square threads is similar to a parting tool except for its angle of side rake, which varies for every diameter and every pitch of thread. Suppose it is desired to cut a square thread of 2 pitch, as shown in Fig. 3. Since the thread is 2 pitch, the space and thread together would be equal to ½ inch, while the space or

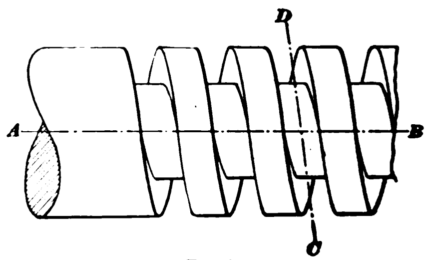


FIG. 3.

the thread would each be $\frac{1}{4}$ inch wide. The tool therefore would be $\frac{1}{4}$ inch thick. It will be seen from the figure that the space between the threads slopes to one side, as shown by the line *C D*. The tool, therefore, must have sufficient side rake to allow it to run freely in this space. The angle of side rake is found by laying off on the line *E F*, Fig. 4, a distance equal to the circumference of the work. At *F* erect a perpendicular *F R*, equal to the pitch for one revolution, and draw *E R*. Angle *R E F* is the angle of side rake

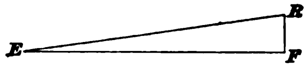


FIG. 4.

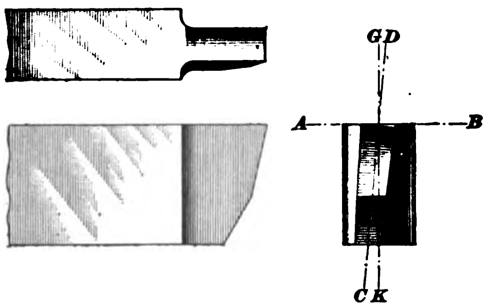


FIG. 5.

or the slope to one side that the tool blade *C D*, Fig. 5, should make with the line *G K*. The tool blade should be ground thinner at the bottom than at the top, so that the sides of the tool will not rub against the sides of the thread.

6. The thread should be cut as deep as it is wide, thus making the threads square. When the screws are large and it is desired to finish the sides of the threads very smooth, the threading tool, Fig. 5, is made a little thinner than the desired width of space. After the notch is cut the desired depth, a side tool may be used for cutting the side of the threads, the blade being set flat with the side. Care must be taken that the tool does not catch and spring into the work.

THE 29°, OR ACME, THREAD.

7. Use of Acme Thread.—In many instances, a coarse pitch screw is desired that has but little friction on the sides, but is neither a square thread nor a **V** thread. Without a standard, there are apt to be differences in shape used by different manufacturers. In order that there may be a standard, the 29° screw thread, called the **acme thread,** has been proposed, and is extensively used in many places to take the place of square threads.

8. Shape of Acme Thread.—The sides of the thread are inclined $14\frac{1}{2}°$, making the included angle 29°. This is the angle that is used for cutting worm-threads. The depth of the thread is the same as a square thread of the same pitch. Fig. 6 illustrates the form of the thread, and the accompanying formulas and table give the proportions for threads of various pitches. It will be observed that the top of the thread does not touch the bottom of the space. This opening represents the clearance, which is provided to insure a perfect fit upon the sides of the thread.

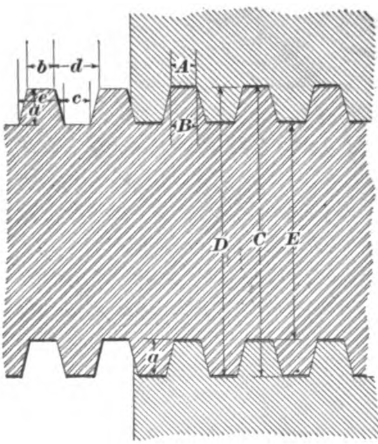


FIG. 6.

9. The various parts of 29° screw thread, acme standard, are obtained as follows:

A = width of point of tool for screw or tap thread;
B = width of point of screw or nut thread;
C = diameter of tap;
D = diameter of screw;
E = diameter of screw at root of thread;
T = number of threads per inch;
a = depth of thread.

$$A = \frac{.3707}{T} - .0052. \qquad E = D - \left(\frac{1}{T} + .02.\right)$$

$$B = \frac{.3707}{T}. \qquad a = \frac{1}{2T} + .01.$$

$$C = D + .02.$$

TABLE II.

TABLE OF THREAD PARTS.

Number of Threads Per Inch. Linear.	Depth of Thread. *a*	Width at Top of Thread. *b*	Width at Bottom of Thread. *c*	Space at Top of Thread. *d*	Thickness at Root of Thread. *e*
1	.5100	.3707	.3655	.6293	.6345
1⅓	.3850	.2780	.2728	.4720	.4772
2	.2600	.1853	.1801	.3147	.3199
3	.1767	.1235	.1183	.2098	.2150
4	.1350	.0927	.0875	.1573	.1625
5	.1100	.0741	.0689	.1259	.1311
6	.0933	.0618	.0566	.1049	.1101
7	.0814	.0529	.0478	.0899	.0951
8	.0725	.0463	.0411	.0787	.0839
9	.0655	.0413	.0361	.0699	.0751
10	.0600	.0371	.0319	.0629	.0681

SPRING OF THE TOOL WHEN CUTTING A THREAD.

10. Cause of Spring of the Tool.—When the tool is slender or slightly dull, there is a tendency for the tool to spring to one side, away from the work, just at the time it is entering the cut. It will be seen that, as the tool starts into the cut for the first half revolution, the cutting is done entirely along one edge. This will tend to spring the tool away from the cut. After the work has made a complete revolution, the cutting on the two sides of the point balance each other and the tendency to spring the tool is reduced. This spring of the tool will make the first thread on the work slightly thicker than the others, so that, in testing work, the nut may be found to be tight on the end, while, after it has passed over this thick thread, the fit will be loose. This trouble is very apt to occur when cutting square threads. The remedy is to run over that part of the cut with the tool a few more times, until the thread is cut down. This tendency to spring is greatly increased when the tool has insufficient side rake or clearance.

11. Cause of Tools Breaking.—Sometimes the tool will show a tendency to break. The point of the tool may be chipped off from the right side, as shown in plan, Fig. 7. When a tool shows this kind of a break, it is evidently caused by the dog slipping. It is evident that the breaking strain was in the direction of the arrow. When the tool takes a heavy cut and the dog slips, the work will stop revolving while the lathe and feed continue. When the feed continues and the point is in the thread, the tool must either slip or break. Sometimes a tool will break by chipping off the top face, as indicated in Fig. 8. This kind of a break indicates that the lathe was reversed and the work was running backwards before the tool was withdrawn from the work. In many instances, a careful observance of results will enable the operator to determine the cause of the trouble.

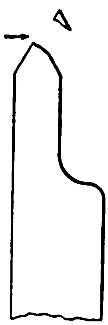


FIG. 7.

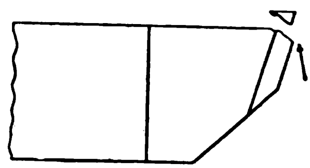


FIG. 8.

HEIGHT OF TOOL FOR CUTTING THREADS.

12. Correct Height of Thread-Cutting Tool.—When a thread is being cut, the tool should be at such a height that if a line is drawn from the center of the work through the point of the tool, it will just lie flat with the top face of the tool. If the tool is correctly ground, this position will cut the correct angle of thread. When a section of a thread is given, it is always supposed to be taken through the axis. Suppose we have a correctly shaped thread, Fig. 9, and a section is taken parallel to the axis but above it, as shown. By examining the shape of the threads at this section, it is seen that the sides are not straight, but convex; also that the height of the thread appears to be greater at this section than when a section is taken on the axis.

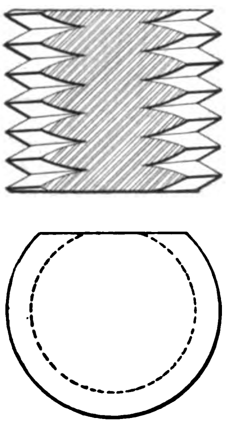


FIG. 9.

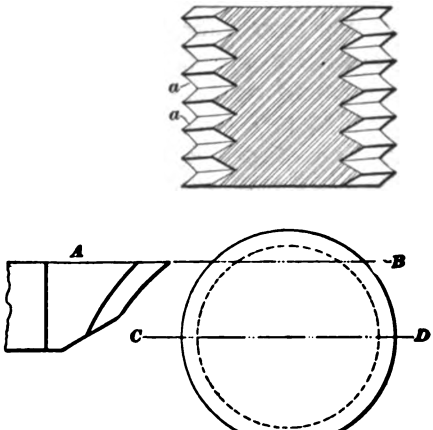


FIG. 10.

13. Incorrect Height of Thread-Cutting Tool.—If a tool is correctly ground, and set as much above the center as shown by the line *A B*, Fig. 10, and a thread is cut to a sharp point, it will be found that on this section the sides of the threads are straight and form the correct angle with each other. It will be noticed that on the line *C D* the sides of the thread are concave, as at *a*, and that they are not as deep as they should be. It will thus be seen that by setting the tool above the center, an imperfect thread is cut.

14. It is possible to cut a perfect thread with the tool above the center, provided the tool is correctly shaped for that position. A correct thread could be cut by making the sides of a tool curved as in Fig. 11, these curves being taken from the curves of the section of the threads in Fig. 9. The tool must be set as much above the center as the section was taken.

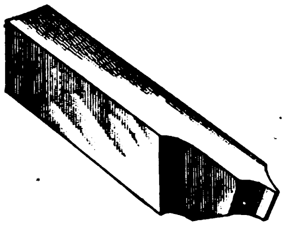


FIG. 11.

15. Top Rake to Threading Tools.—It will be seen that the ordinary threading tool that cuts with its two edges cannot be given any top rake or keenness. By means of the compound rest set at an angle of 60° with the center line of the work, as shown in Fig. 12 (*a*), and a tool shown in Fig. 12 (*b*), a thread may be cut with a tool having top rake. The tool is ground so that the broad cutting edge *C D* makes an angle of 60° with the side of the tool, while the top face is given slope or top side rake. When the cut is taken, the tool is fed into the work by the compound rest. Since the rest is set at an angle of 60°, it may be seen that the side of the tool *A B* will just slide by the side of one thread while all the cutting is done with the keen edge *C D* of the tool.

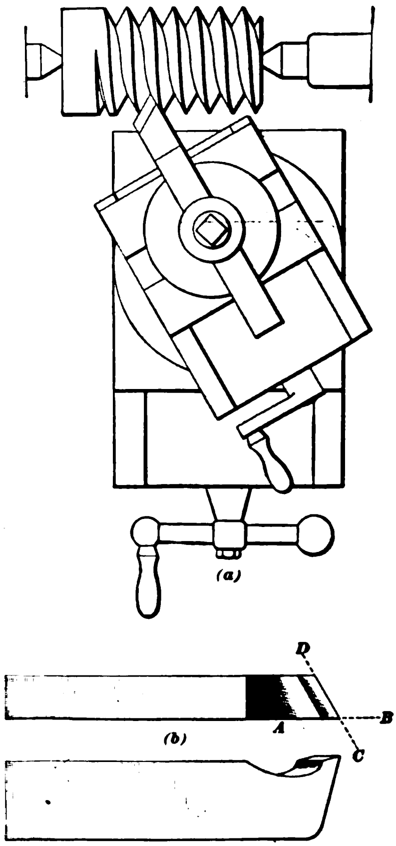


FIG. 12.

CUTTING DOUBLE OR TRIPLE THREADS.

16. Cutting Double Threads.—When a double thread is to be cut, it must be remembered that two threads are to be cut in the space that would be required for a single thread.

To cut a double V thread, proceed as in cutting a single thread until the space left between the grooves is equal to the width of the grooves, as shown in Fig. 13. The work is then given half a turn so that the point of the tool will be opposite the center of the uncut part, as shown. The work may be given this half turn by removing it and turning it so that the tail of the dog is in the notch of the face plate diametrically opposite the one used for the first thread. Another and better method is to disconnect the feed-gears and then turn the lathe and work half a turn. Suppose a change gear with 48 teeth is on the stud. One of the teeth that meets with the intermediate gear may be marked with chalk, after which the two gears may be disconnected. By turning the lathe so that this change gear passes over half its number of teeth, or 24 teeth, the work will also have made half a revolution. The gears are then brought together and the second thread cut the same as the first. If the lathe is compound-geared between the spindle and stud, instead of turning the stud gear half a turn, it is turned a proportional part, depending on the ratio of the compound.

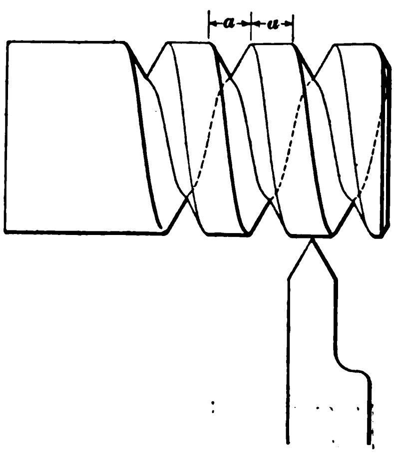


FIG. 13.

17. Cutting Triple Threads.—To cut triple threads, after the first thread is cut, the space between the grooves should be double the width of the groove. The work is given a third of a revolution and the second thread cut, after which another third of a revolution is given and the third thread is cut. A similar method is used for cutting quadruple threads.

INSIDE SCREW CUTTING.

18. Holding the Work for Inside Screw Cutting.—When an internal or female thread is to be cut in the lathe, the work is held in a chuck or on a flat plate, the same as for boring.

19. Tool for Inside Screw Cutting.—Inside threading tools are similar to boring tools except that the point

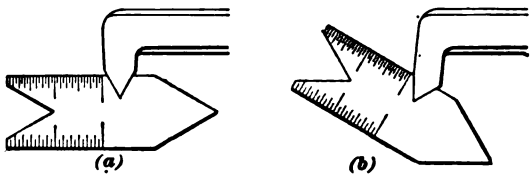


FIG. 14.

is ground to the shape necessary to cut the desired thread. In grinding an inside threading tool for a V or United

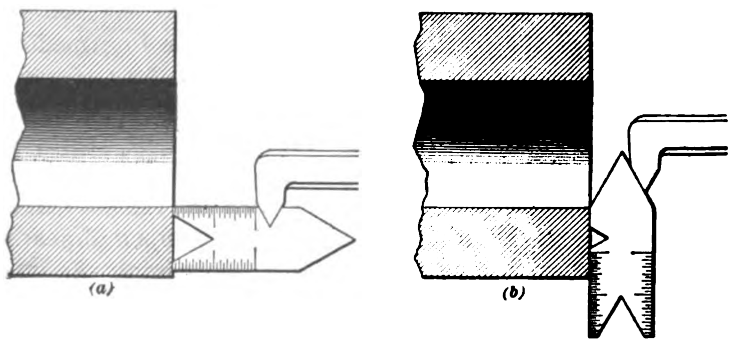


FIG. 15.

States standard thread, the point is ground to fit the gauge when the back of the gauge is nearly parallel to the shank of the tool, Fig. 14 (*a*). If the tool fitted the gauge when held in the position shown in Fig. 14 (*b*), it would not go far into the hole before the back of the tool would touch the work. Fig. 15 (*a*) and (*b*) show methods of holding the gauge against the work in order to set the tool true. Fig. 16 shows the result of untrue grinding, which necessitates setting the shank of the tool at an angle with the axis of the hole, and it also shows how the tool may be pushed so far away from its cut at the front, when running the lathe backwards, that the tool will drag in the hole and spoil the first threads.

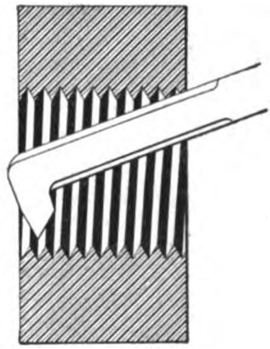


FIG. 16.

20. Stop for Inside Screw Cutting.—When cutting inside threads, the **stop** shown in Fig. 63, *Lathe Work*, Part 2, may be used by taking the screw out of the stop and putting it in the tool block so that it comes between the tool block and the stop. For inside screw cutting, it is necessary to move the tool in an opposite direction, to take the tool out of the cut, from that required in outside screw cutting. It is therefore necessary to adjust the stop-screw so that the head of the screw comes against the stop. Deeper cuts may be made by turning the screw into the tool block.

TESTING INSIDE THREADS.

21. Moving Tool Away From Work.—In most cases, the work cannot be taken from the lathe and must be tested in place. The tool can be moved out of the way by reversing the lathe and allowing the carriage to feed back far enough to allow the gauge to be used. This is a very slow way and need not be used. Sometimes it is possible to move the tool back, by means of the cross-slide, far enough to allow the gauge to be used. If the tool is brought back to the stop after the work has been tested, it will be in place to continue the work. Another method is to open the feed-nut in the apron, and move the carriage by hand out of the way. When this is done, some means must be provided whereby the carriage can be brought back to the same place and the feed-nut locked as before. This may be done by making a mark on the bed of the lathe, or, better, by measuring from the point of the tool to the work, as shown in Fig. 17. After testing, the tool can be moved back so that the measurement is the same as before and the feed thrown in. Care should be taken that the lathe is not turned while the feed-nut is opened, for it will cause trouble in getting the feed to start again in the correct place.

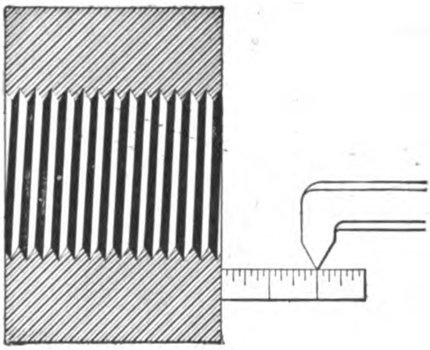


FIG. 17.

22. When the pitch of screw to be cut is a multiple of the pitch of the leadscrew, this care is not necessary, for the tool will come correctly into the cut whenever the feed-nut is closed on the leadscrew. When cutting these screws of multiple pitches of the leadscrew, it is possible to keep the lathe running forwards all the time by throwing out the feed and moving the tool and carriage by hand back to the starting point. This operation will save much time.

23. Testing Inside Threads With a Gauge.—After the cutting tool has been moved away from the work, the gauge should be screwed in, taking care to have it exactly in line with the hole. Care should also be taken to see that the first thread is not thicker than the others, owing to the spring of the tool at the beginning of the cut. Sometimes a tap is used in place of a gauge, and in this case the tap is sometimes allowed to take a very light cut from the hole, especially when square threads are being cut. When the tap is used for taking a light cut, in order to finish the thread, the tool is usually moved back by means of the cross-feed, and the tail-center is introduced into the center in the shank of the tap, so as to guide it while it is being passed through the work. Sometimes, when the piece is in a rather light chuck, the latter may be removed from the spindle and the work tried upon the piece that it is to fit. This is very often done when the thread being cut is inside of a new face plate or chuck back, the work being tried upon the spindle of the lathe that it is intended to fit while it is still held in the chuck.

THREADING TAPERED WORK.

24. Setting Tool for Threading Tapered Work.—In setting the tool for taper turning, the gauge is put against

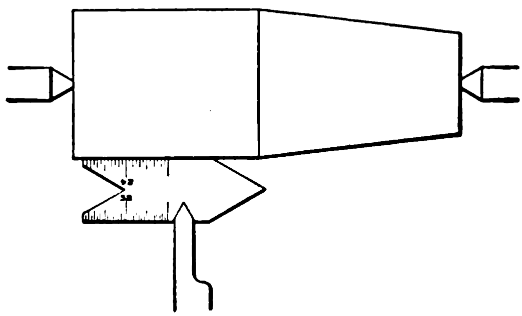


FIG. 18.

the work so that its back is parallel to its axis and the tool is set the same as for parallel thread cutting, as shown in Fig. 18.

25. Error in Pitch Due to Setting Over the Tail-Center.—If the center is set over, it will give an incorrect pitch, and also an incorrect thread. This point will be taken up later, under the head of "Errors in Lathe Work."

If a taper thread is cut by setting over the tailstock, the pitch of the thread will not agree with the pitch that would be cut by the use of the taper attachment. Suppose we have the tapered piece, Fig. 19, to be threaded. The piece is 2 inches long and should have a thread of 10 pitch. This means that for 10 revolutions of the piece, the tool would

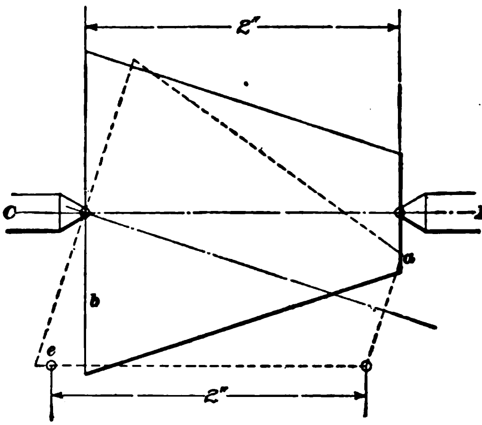


FIG. 19.

advance 1 inch, and, to advance 2 inches, it would require 20 revolutions; therefore there should be 20 threads on the piece. When the taper attachment is used and the lathe is properly geared, this result will be obtained. The tool will start at the end *a*, and, after 20 revolutions of the work, will have moved 2 inches sidewise, which will bring it to the end *b*, the carriage moving in a direction parallel to the line *CD*.

26. When the dead center is set over, the tapered piece will take the position shown by the dotted lines. The threading tool will move along parallel to the face of the work and also parallel to the center line *CD*. If the cut is started at the end *a* as before, 20 revolutions of the work will move the tool along the face of the work 2 inches, to the point *e*. It will be seen that there remains a part unthreaded, since the taper measured on the slope is greater than the true length of the piece measured parallel with its axis. It will therefore require more than 20 turns to carry the thread to the end of the piece; consequently, there will be more than 20 threads on the piece.

Thus, it may be seen that the pitch of the thread on a tapered piece depends on whether it was cut by setting over the center or by the use of a taper attachment. Tapered threads should be cut with a taper attachment whenever possible.

SPECIAL THREADING TOOL.

27. A threading tool, Fig. 20, by means of which many of the difficulties in screw cutting that have been mentioned may be overcome, has recently been placed upon the market.

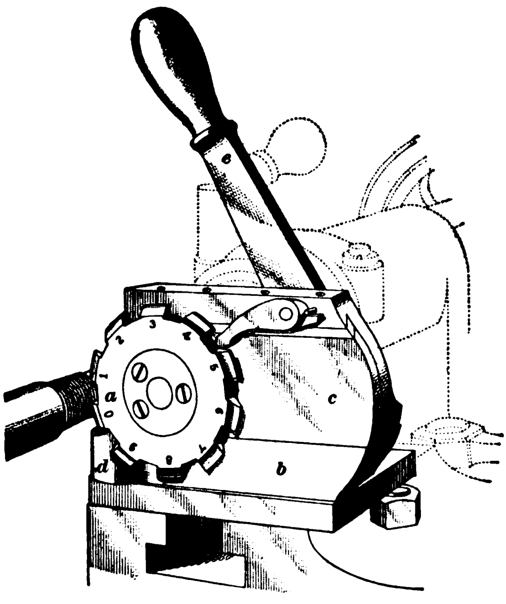


FIG. 20.

It consists of a cutter *a*, resembling a milling cutter, supported upon a bracket *b* by a slide *c*. The device is clamped upon the tool rest of a lathe from which the tool post has previously been removed.

The cutter *a* has 10 teeth on its circumference, each one of which is formed to cut deeper than the preceding one, and gives the thread its actual width to the full depth of the cut. For instance, in Fig. 21, the first tooth cuts the full width of the thread to the line *1*, the second cuts to the line *2*, and so on until the tenth tooth cuts to the bottom. In Fig. 22, (*a*), (*b*), (*c*), (*d*), (*e*), and (*f*) show the shape of the teeth and the corresponding forms of the thread for the first, second, third, fifth, eighth, and tenth cuts, two and one-half times the actual size of a 7-pitch **V** thread.

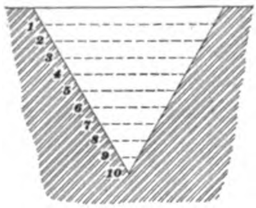


FIG. 21.

28. The tool is set up and adjusted for the first cut, as shown in Fig. 20, proper side rake for either right-hand or left-hand thread being given by means of an adjusting screw on the far side of the device, which is not shown. The tooth rests upon the support *d*, which holds the top face level with the center line of the screw. When all adjustments have been made, both the device and the rest are clamped, and the first cut is taken. The rest is then brought back to its starting point in the usual way. The second tooth is brought into position and locked by throwing over the lever *e* and bringing it back into place. The second cut is then taken, and the operation repeated until the tenth tooth has taken its cut. The last tooth may be advanced in 9 steps by means of an eccentric stud and micrometer stop. Each step advances the cutter a fraction of a thousandth of an inch, thus permitting very fine fits and exact duplicates to be made.

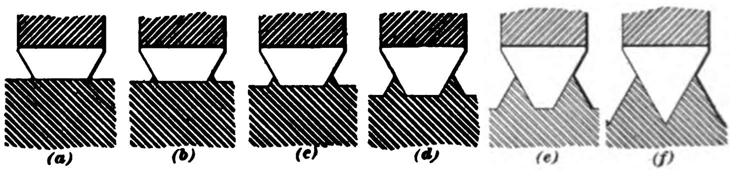


FIG. 22.

The special advantage claimed for this tool is that each tooth comes to the work in better condition than when a single tool is used, the work being distributed over 10 cutting edges instead of 1. The finishing tool comes into service with a sharp point, while its duty is comparatively light. Under these conditions, the lathe can be run at a higher speed, since the danger of injuring the tool point by its continuous use on every cut has been eliminated. A perfect thread can, therefore, be formed in less time without injury to the tool. For rough work many shops prefer the ordinary single tool, the thread being finished with six or seven cuts.

THEORY OF CUTTING TOOLS.

DISCUSSION OF CUTTING PROPERTIES OF TOOLS.

29. Theory of Cutting Tools Applied to Hand Tools.—In discussing a cutting tool from a theoretical standpoint, attention will first be given to that part known

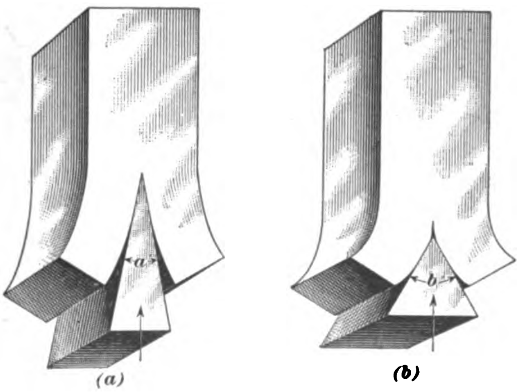


FIG. 23.

as the **cutting wedge,** which enters the work and severs or removes a part known as the **shaving.**

The cutting qualities of a tool are governed largely by the shape of the cutting point or cutting edge. We can best understand the first principles if we consider the action of a chisel when cutting a block of wood. If we place a chisel in the center of a block, as shown in Fig. 23, and apply pressure as indicated by the arrow, the chisel will be forced into the block, bending each side out equally until the block splits. The force required to press the tool into the work will depend on the strength of the block and the angle *a* of the cutting wedge. If we have two blocks (*a*) and (*b*), Fig. 23, of the same strength, it can easily be proved by the laws of physics that it requires more power to force the blunt wedge *b* into the work than the more acute one *a*.

30. Fig. 24 (*a*) represents a chisel cutting a block. The edge of the chisel is ground to an acute angle *a* the same as the wedge in Fig. 23 (*a*). Fig. 24 (*b*) represents a similar block, being similarly cut with a tool ground with a blunt cutting edge, the cutting angle *b* being equal to the angle of

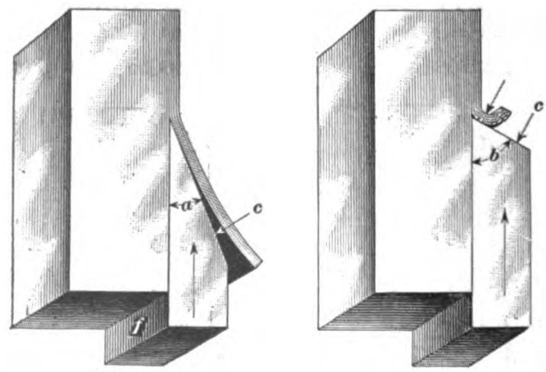
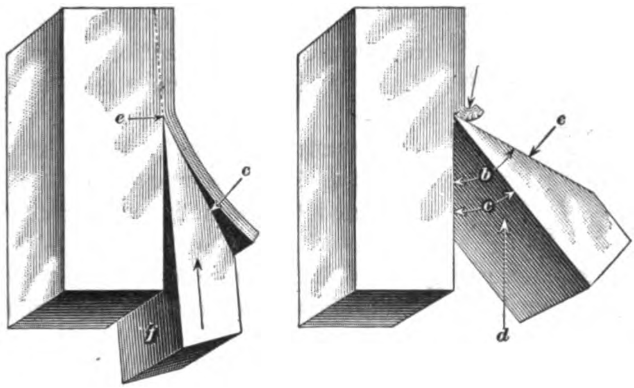


FIG. 24.

the wedge *b*, Fig. 23 (*b*). In estimating the force necessary to push each of the tools along its cut, it will be seen that the blunt tool will require the greater force, as the blunt wedge, Fig. 23 (*b*), required the greater force to push it into the block. In Fig. 24 (*a*) the shaving is forced from the block and slightly bent away, while in Fig. 24 (*b*) the shaving is very much bent and broken. This bending and breaking of the shaving at the time of severing it from the block absorbs an extra amount of power. The direction of the force required to turn the shaving is represented graphically by drawing a line at right angles to the cutting face of the tool. In Fig. 24 (*a*) the pressure on the face of the tool is



(*a*) (*b*)

FIG. 25.

in the direction of the arrow *c*. The intensity of the pressure varies with the thickness of the shaving. This force tends to hold the tool very close to the work, and, if it were not for the broad flat face of the tool, it would be pressed deeper into the work. If the angle of the tool be changed, as in Fig. 25 (*a*), so that the face of the tool *f* does not touch the work except along its cutting edge *e*, the pressure of the shaving would be sufficient to force the tool into the work so that as the tool moved along it would cut in the direction of the dotted line.

31. In Fig. 24 (*b*), in which the tool is very blunt, the result of this pressure against the tool is quite different. The direction of the pressure of the shaving is at right angles to the face of the tool, as shown by the arrow *c*. If we divide this force into two forces, one acting against the direction of tool motion and the other at right angles to it, tending to hold the tool into the cut, we will find the greater force exerted against the direction of tool motion and but little pressure tending to hold the tool against the work. If the tool were made square on the end, as shown in Fig. 26, the force tending to hold the tool against the cut would be entirely eliminated, and the cutting action would be changed from a shaving to a scraping action.

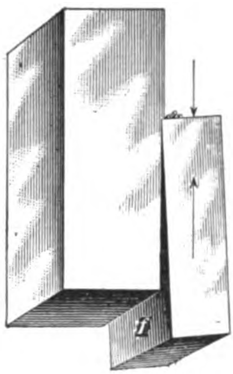


FIG. 26.

In these hand tools, which are free to move in their natural directions, governed by the angle of the faces, it will be noticed that the tool is guided by one of its cutting faces sliding upon the heavier part of the work, while the other cutting face bends the shaving out of its place.

32. Theory of Cutting Tools Applied to Machine Tools.—It has been shown that, of the two tools illustrated in Fig. 24, less power is required to force the tool with the acute angle *a* than is necessary to force the tool with the blunter cutting edge *b*. This was true when the tools were free to follow in their natural courses. When the tool is rigidly held in some position and forced to cut along some other line than its natural one, the condition becomes very much changed, and the power required varies accordingly. Suppose the tool with the acute cutting angle shown in Fig. 24 (*a*) be presented to the work as shown in Fig. 25 (*b*), so that its cutting face makes the same angle *b* as the cutting face of the tool shown in Fig. 24 (*b*). If this tool be rigidly held at this angle and forced along the work in the direction of the arrow *d*, it will be found that for equal depths of cuts the same amount of power will be required to move it as in the case of the tool shown in Fig. 24 (*b*). From this it may be seen that if a tool is clamped in any position and moved along a certain line of motion, the cutting action depends as much on the position it holds relative to the work as on its exact shape.

33. Angles of Clearance and Keenness.—If we consider the strength of the two tools shown in Figs. 24 (*b*) and 25 (*b*), it can readily be seen that the tool shown in Fig. 24 (*b*) is much the stronger because of the greater support given to the cutting edge. In Fig. 25 (*b*) the cutting edge has very little backing or support, and it would break at once. When this tool is held and moved as shown in Fig. 24 (*a*), it is in its strongest position. When it is moved so that its face makes an angle with the work, its strength begins to decrease as the angle *c*, Fig. 25 (*b*), increases. This angle *c*, which the back face of the tool makes with the work, is called the **angle of clearance.**

If the tool in Fig. 24 (*a*), which is held in its strongest position, is compared with the tool shown in Fig. 24 (*b*), it will be seen that the latter is the stronger. This strength is due to the support given to the cutting edge because of its bluntness. The angle between the cutting faces of a tool, *a*, Fig. 24 (*a*), and *b*, Fig. 24 (*b*), is called the **angle of keenness** of the tool. The strength of a cutting tool, therefore, depends on the angle of clearance and the angle of keenness. The angle of keenness of a tool should vary with the degree of hardness of the material to be cut. For turning soft woods, the turning tools are ground very keen, or so that the cutting faces make a very acute angle with each other. In turning metals, the cutting edges are made less keen, depending on the hardness of the metal. In some cases, such as turning chilled cast-iron rolls, the angle formed by the cutting edges is nearly 90°.

34. Angles of Rake and Keenness.—Fig. 27 shows a diamond point with lines drawn to indicate its angles of rake and keenness. *A B* is drawn through point *O*, parallel to the base of the tool. *C D* is perpendicular to *A B* at *O*. *E F* is parallel to the top face of the tool at *O*. *H K* is parallel to the front edge of the tool at *O*. Angle *A O E* represents the angle of top front rake of the tool. Angle *D O H* represents the angle of front rake. Angle *E O H* represents the angle of keenness.

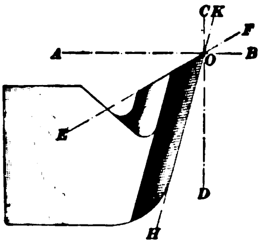


FIG. 27.

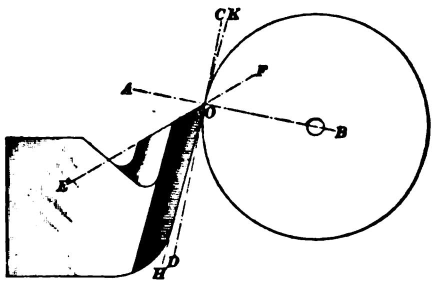


FIG. 28.

These angles as here described refer to the tool alone. When the tool is clamped in the tool post and presented to the work to take a cut, these angles assume a new relation to each other, and the cutting qualities of the tool depend on these new relations. Fig. 28 shows the tool properly set for cylindrical turning.

35. Angles of Rake and Keenness of Lathe Tools When Applied to Work.—To properly measure the angles of the tool thus set, draw the line *A B* from the center of the work through the point of the tool. Draw *C D* perpendicular to *A B* at *O*. Draw *E F* parallel to the top face of the tool through the point *O*. Draw *H K* parallel to the edge of the tool. Angle *A O E* equals the top rake of the tool. Angle *E O D* equals the effective keenness. Angle *D O H* equals the angle of clearance.

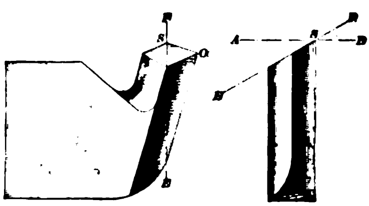


FIG. 29.

It will be noted that the difference in drawing the lines in Fig. 27 and Fig. 28 begins with drawing the line *A B*. After this line is properly drawn, the other lines follow in the same course. When the top face of the tool is ground sloping from one side, as shown in Fig. 29, the tool has top side rake. The angle of top side rake is measured by drawing $A B$ parallel to the base of the tool through the point S, and $E F$ parallel to the top face of tool through the point S. Angle $A S E$ is the angle of top side rake.

CONDITIONS THAT GOVERN THE SHAPE OF THE TOOL.

36. General Statement.—These effective angles of rake, clearance, and keenness depend on (1) *kind of metal being cut;* (2) *hardness of metal;* (3) *character of cut,* whether *roughing* or *finishing;* and (4) *particular manner in which the tool is presented to the work.*

37. Effect of Kind of Metal Being Cut Upon Shape of Tool.—This matter will be more thoroughly taken up later, but, in general, it may be stated that for soft material, such as mild steel, the angles are keener than for hard material, such as chilled cast iron, while for some materials that have a tendency to draw the tool in, as brass or copper, the angles may be made very blunt indeed—in fact, a negative rake is often given them.

38. Hardness of Metal.—As before stated, the angle of keenness varies with the hardness of the material. Tools for cutting soft steel should be ground with sufficient keenness to enable them to turn long, curly shavings. The character of the shaving indicates much regarding the cutting of the tool. When the shavings come off in large curls and are very strong, it indicates that the tool is properly ground and set in the machine. When the shavings come from the work broken in small pieces, it indicates that the tool is laboring because of incorrect setting in the machine or incorrect grinding. A word of caution should be given here to those who, for the first time, experience the delight of seeing a tool, properly ground and set, roll off a beautifully curled shaving. Never attempt to remove the shaving from the work by taking it in the hand and pulling or jerking it. A good steel shaving is very strong and its edges are as keen as any knife. The danger is that the shaving will slip through the hand, cutting away the flesh in a most painful way. To remove the shaving from the cut, throw out the feed and the tool will cut the shaving off.

39. Roughing or Finishing Cuts.—The angle of top rake depends on the nature of the cut, whether roughing or finishing. Fig. 30 shows a piece of work with the tool set to take a heavy **roughing cut.** Here the cutting is done

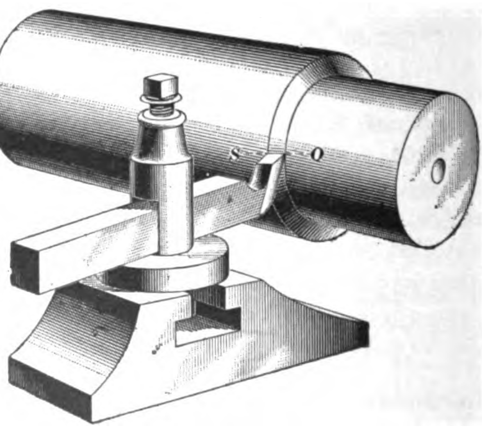


FIG. 30.

along the edge *O S* of the tool, the point *O* doing a very small part of the work. It is evident that this tool should be ground to give keenness all along the edge *O S*. This is done by giving the tool top side rake.

When the tool is used for a **finishing cut,** the cut is not deep, and most of the cutting is done with the point of the tool *O*. In this case, top front rake, as shown in Fig. 28, should be given. Top side rake and top front rake are governed also by the rate of feed used.

40. Fig. 31 illustrates a case in which the feed is coarse and the tool point broad, so that the rate of feed per revolution of the work is greater than the depth of cut. In such a case, the top front rake should exceed the top side rake. When the feed is fine compared with the depth of cut, the top side rake should be the greater.

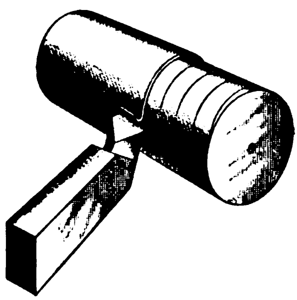
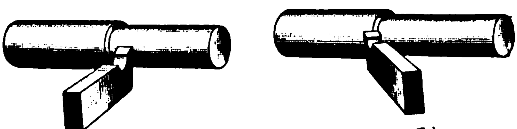


FIG. 31.

41. Manner in Which Tool Is Presented to Work. The **shape** or **width** of the point of a tool depends on the feed used, and this depends on the nature of the work. In finishing small rods, shafts, or spindles that should be very true, the roughing cut is made deep with as coarse feed as the work and the tool will stand, while the finishing cut is light and the feed comparatively fine. This fine feed is allowable because it cuts the work very true, and on small work the tool will quickly feed over it and remain sharp up to the end of the cut. On large work, the method is different. Deep, heavy roughing cuts are taken, as before, but the finishing cut is taken with a tool that has a broad, flat point and a very coarse feed. When the work is heavy, this form of tool can be used and will turn comparatively true, while on slender work, a broad-nosed tool could not be used at all. When it is possible to use a broad-nosed tool for finishing, it should be done. It saves much time because of the coarse feed that can be used, and the tool will usually remain sharp until the end of the cut, unless it is a long one.

42. Change of Front Top Rake to Front Side Rake.—The angle of top rake may be effectively changed



(a) FIG. 32. (b)

from front top rake to side top rake by changing the angle of the tool with the work. Fig. 32 (*a*) shows a broad-nosed finishing tool ground with top front rake. This may be changed to a very efficient roughing tool with top side rake, by swinging it in the tool post so that it has the position shown in Fig. 32 (*b*).

Special care should be taken when using a tool set in the manner shown in Fig. 32 (*b*), as if it becomes loose in the tool post it will swing into the work and may do great damage. It is always best to have the tool post in advance of the point at which the tool is cutting so that the tool will rotate away from the work if it becomes loose in the tool post. When working upon expensive material, the tool should never be set as shown in Fig. 32 (*b*), but a regular roughing tool, such as will be described later, should be employed.

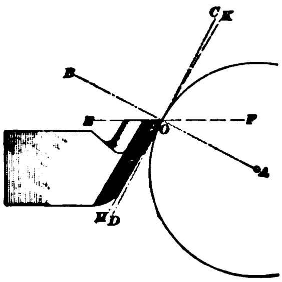


FIG. 33.

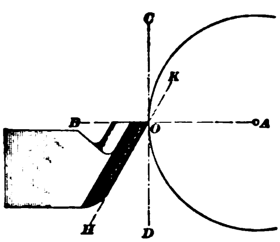


FIG. 34.

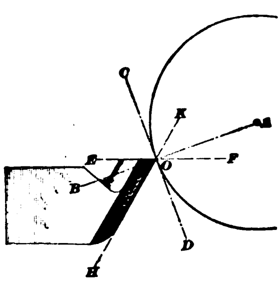


FIG. 35.

43. Effect of Height of Tool on Angles of Rake and Clearance.—It is well to study the effect of setting the tool at different heights, so that any difficulty from this cause may be recognized and remedied.

Fig. 33 shows a tool ground flat on its top face so that according to Fig. 27 it is without top rake. By applying this tool at its highest possible cutting position, and drawing the lines as in Fig. 27, we have an effective angle of top rake *E O B*, and an effective angle of keenness *E O D*. Suppose this same tool is next lowered to a position shown in Fig. 34, the point of the tool being level with the axis of the work. By drawing the lines as before, we find that the line *A B* coincides with the line *E F*, so that the tool has no effective top rake, and the effective angle of keenness BOD is equal to 90°. At this point, the cutting action changes from a shaving to a scraping action, which can never admit of a deep cut. Next, suppose the tool to be set below the center, as shown in Fig. 35. By drawing the lines as before we will find that AB passes into the tool below the line EF. In this position, the tool has a negative angle of top rake EOB and would do little more than scrape the work.

44. Effect of Height of Tool on Its Strength.—The effect of the position of a tool upon its strength can also be seen from Figs. 33, 34, and 35. In Fig. 33 the angle of clearance DOH is very small and the cutting edge is well supported; consequently, the tool is in its strongest position. In Fig. 35 the angle of clearance DOH is great, and it is easy to see that the cutting edge cannot endure much pressure. From this it will be seen that a tool is strongest when set as high as possible upon the work.

SIDE RAKE OF SIDE TOOLS.

45. Determining Clearance Angle for a Side Tool.—In the case of side tools, as shown in Fig. 24, *Lathe Work*, Part 1, the angle that the side face of the tool AB makes with the end of the work or with the line CD drawn parallel to the end of the work, is called **side rake.** In theory, this angle of side rake or clearance should vary to suit every diameter of work and every amount of feed. Having given a rate of feed per revolution of work and a given diameter, the exact angle of clearance can be estimated.

Suppose we have a side tool, with its edge ground straight, set to the work as shown in Fig. 33, Part 1, and we wish to find the necessary angle of clearance at points *a*, *b*, and *c* along its cutting edge, which will allow it to feed in the direction of the arrow at the rate of $\frac{1}{4}$ inch per revolution. It is assumed to be understood that if the side tool were flat or had no clearance, it could not cut, since it would simply lie flat against the work.

46. To estimate the angle of clearance for point *a*, draw a line *A B*, Fig. 36, equal to the circumference of the work at point *a*. At *B* erect a perpendicular and lay off *B F* ($\frac{1}{4}$ inch) from *B* equal to the desired feed per revolution. Draw a line through *A F*. The angle *B A F* indicates the required angle of clearance for this point of the tool. To find the correct angle of clearance for point *b*, lay off from *A* a distance *A C* equal the circumference of the work at *b*; at point *C* erect a perpendicular and lay off a distance *C F'* equal to the desired feed. Draw *A F'*. Angle *F'A C* represents the necessary angle for the tool at point *b*. To find the angle for point *c*, proceed as before, laying off *A D* equal to the circumference of the work at point *c*. Angle *F''A D* will represent the necessary angle at this point. It will be observed that the angle of clearance changes for each of these points, increasing as it approaches the point of the tool or the center of the work. The correct shape for this face of the tool would be a warped surface with little clearance at the heel of the tool *a*, but with considerable clearance at the point.

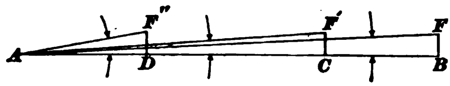


FIG. 36.

In practice, however, the tools are ground nearly flat, with sufficient clearance at the point of the tool to let it cut, and the rest of the cutting edge will have excessive clearance, but not enough to cause any serious objection.

TOOLS FOR BRASS WORK.

47. Shape and Setting of Tools for Brass Work.—The theory of the shapes of tools and the methods of applying them to the work, as just described, do not seem to be sustained in all cases when applied to tools for brass. This is due largely to the peculiar nature of brass found in its toughness and its flexibility. These qualities tend to cause a tool to spring into the work and the work to spring over the tool in such a way as to make very untrue cuts. If the work and the tool could be held with sufficient rigidity to avoid all danger of springing, the tool could be ground with more keenness than is allowable for iron or steel. In practice, it is found that the best results are obtained when the tool is ground and set as shown in Fig. 34. This is ground without top rake and set at the center of the work. Other shapes of tools are used for brass, which will be discussed later, but, in most cases, the cutting angles remain as here indicated.

BORING TOOLS.

48. Working Conditions of Boring Tools.—The conditions under which a boring tool must work are most unfavorable for carrying out the principles that naturally lead to good results. The boring tool, because of the long slim arm required to reach into the bottom of small holes, lacks that rigidity of cutting edge that is essential in rapid accurate work.

49. Cutting Angles of Boring Tools.—By reference to Fig. 37, it will be found that the angles of rake and keenness for a boring tool may be defined the same as in a diamond point. The line *A B* is drawn from the axis of the work through the point of the tool; *E F* is drawn along the top face of the tool through the point *O*. The angle *B O F* represents the angle of top rake. If the tool be raised or lowered in the hole, the angle of top rake will vary, as shown in Figs. 33, 34, and 35.

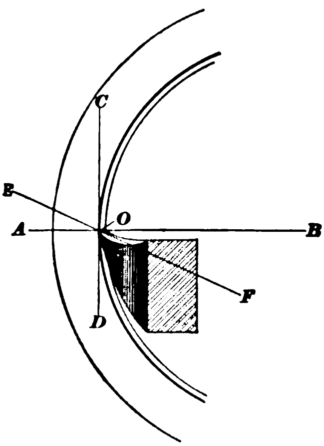


FIG. 37.

50. Spring of Boring Tools.—The force necessary to hold the point of the tool up to the cut depends largely on the shape of the point. Fig. 38 (*a*) shows a well-shaped tool for small work. The point is narrow and is shaped much the same as the point of a diamond-pointed tool. The force tending to spring the tool away from the work is in the direction of the arrow, at right angles to the line *A B*. Fig. 38 (*b*) shows a tool with the point more rounded, with the force tending to spring it away from the work more at right angles to the shank of the tool. Fig. 38 (*c*) shows a broad-nosed tool with the force acting squarely across the shank of the tool. This form of tool would chatter and spring away from the work so that it would be difficult to do much with it. Single-pointed boring tools as here shown should have narrow points, as shown by Fig. 38 (*a*), and should be used with moderately fine feeds. When broad-edged boring tools are used with very coarse feeds, they are held in boring bars or heads, or in some other way than here mentioned.

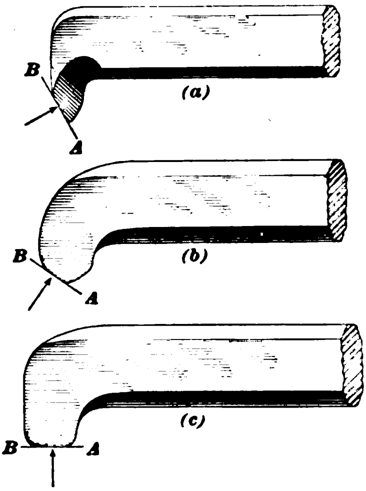


FIG. 38.

51. Height of Boring Tools.—The correct height of the boring tool in the work, to give it the strongest and the easiest cutting position, is as much *below* the center as it can be set and still have its cutting point cut. This is for the same reason that the diamond point is set *above* the center of the work. It is not always safe to set the tool in this low position, if the tool is long or springy; for, being below the center, if the tool should catch and spring down, it would spring into the work more deeply and cause trouble. Ordinarily, a boring tool is set at about the center of the work, it having been ground so that when thus set it will have but little clearance.

52. Boring Small Holes.—When the hole is small, the conditions are more unfavorable. Fig. 39 shows a section through work with the tool in place. The tool nearly fills the hole. When a line *A B* is drawn from the center through the point *O*, it passes into the tool, showing that in this position it has negative top rake. The best that can be done in this case is to grind the top face back from the edge *E*, giving the tool a great deal of *top side* rake.

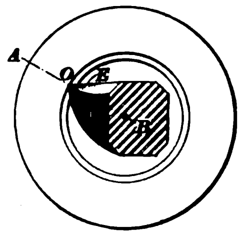


FIG. 39.

FORMS OF CUTTING TOOLS.

FORGED TURNING TOOLS.

53. Diamond-Pointed Tool.—Thus far, the **forged diamond-pointed tool** has been the principal tool considered for cylindrical turning. This has been done because the principles that have been shown to govern its cutting actions are applied in the same way to other forms of tools, and the similarity of cutting edges will be apparent.

54. Self-Hardening Steel. — During the last few years, specially prepared self-hardening or air-hardening steel has taken a leading place in the making of lathe and planer tools. This steel is so treated in manufacturing that it does not require heating and hardening, as does the ordinary tool steel. By heating it to a dull-red color and allowing it to cool in the open air or in a blast of air, it is made extra hard. If this kind of steel be plunged into water while it is hot, it cracks, which spoils the tool.

Among the advantages of self-hardening steel are: *First*, its hardness will enable it to hold a sharp edge when cutting very hard material, such as hard castings, castings with a heavy scale, steel castings, or similar work. *Second*, since its hardness is little affected by heat, it is possible to run the work much faster or at a higher rate of cutting speed than is possible with the ordinary tool-steel tool. On account of these facts, it is used almost universally in many shops.

The objections that are raised against self-hardening steel are that it is difficult to forge and that it is expensive, costing about four times as much per pound as ordinary tool steel.

55. Shapes of Forged Roughing Tools.—In forging self-hardening steel, it can only be worked at a low heat, and it is very difficult to draw or bend it into such a shaped tool as shown in Fig. 27. It is usually heated and cut with a hot chisel approximately to shape, with little forging or bending, and is finally shaped on the grinding wheel. Fig. 40 shows an elevation and plan of a front tool as forged from this kind of steel. The

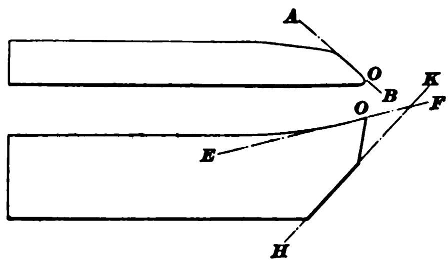


FIG. 40.

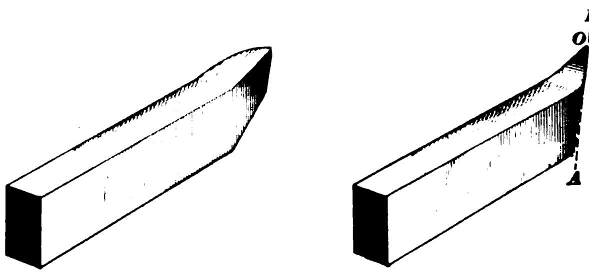


FIG. 41. FIG. 42.

side $A B$ has been trimmed off to make the cutting edge, the point O bent up to give top rake along the line $E F$, and the heel cut off along the line $H K$, so that little grinding will be required on the front end of the tool. When the tool is ground, it appears as shown in Fig. 41. This tool will be seen to possess the same cutting angles as shown in Fig. 27, although it is quite different in general appearance. Since the point *O* is at one side, its cutting edge is entirely along the edge *A B*. This designates it as a *right-hand tool* in contrast with one beveled, as shown in Fig. 42, which would be called a *left-hand tool.* The ordinary diamond point, with the point in the center and ground without top front rake, may be used to cut in either direction. If ground with top side rake, as shown in Fig. 29, to cut toward the live center, it is called a *right-hand diamond point;* if ground sloping the other way, it is called a *left-hand diamond point.*

56. When heavy cuts and great strength are required, the outline of the cutting edge is curved and the point considerably rounded. This applies particularly to heavy work.

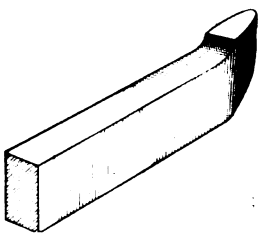


FIG. 43.

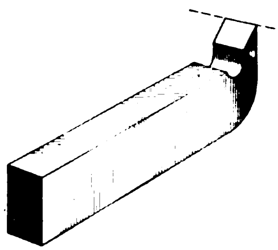


FIG. 44.

Fig. 43 shows a form of round nose used for some kinds of heavy work. Fig. 44 shows a broad-nosed tool used for finishing when coarse feeds are permissible.

57. Proper Form for Round-Nosed Tools. — For some kinds of work, a **round-nosed tool,** shown in Fig. 45, is used. This is ground round on its point, and top rake is sometimes given by grinding a notch *a* on the top face, as shown. Grinding the top face of a tool in this way is not good practice, as it soon spoils the shape. If a tool is to be given top rake, it should be so forged that the top rake can easily be ground without forming a notch *a* on the tool. Fig. 46 shows how such a tool should be forged. This

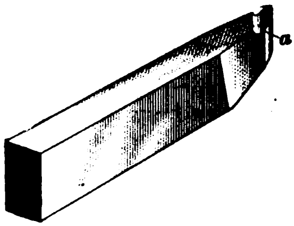


FIG. 45.

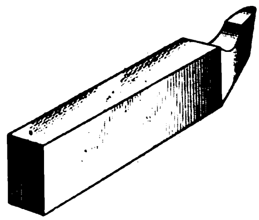


FIG. 46.

style of forging gives opportunity to grind the top face of the tool and keep the angles and shapes constant. Fig. 47

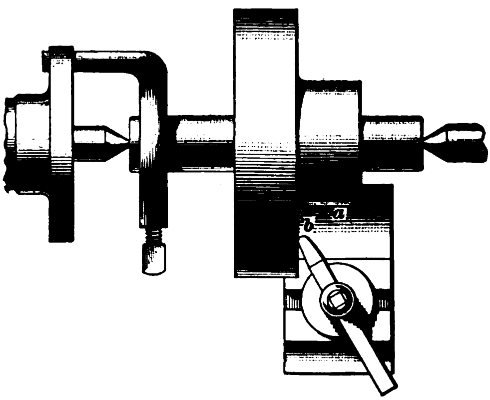


FIG. 47.

shows a piece of work of such shape that this form of tool is desirable, since it can be set to finish the faces *a* and *b* at the same setting. When top side rake is desired, it should be given by setting the tool at an angle to the work, as shown in Fig. 32 (*b*), or by grinding the tool as shown in Fig. 48, but never allowing a corner or notch to be formed as shown in Fig. 45.

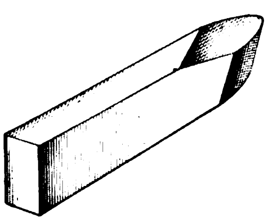


FIG. 48.

TOOL HOLDERS FOR TURNING TOOLS.

58. Advantages of Tool Holders.—The expense of keeping up a stock of tools forged from the bar, whether of ordinary tool steel or of special self-hardening steel, is great, and this fact has led to the devising of many forms of holders employing small blades of steel to do the cutting. The holder is made the same size as the shank of the ordinary forged tool. They make a very great saving in the cost of the steel used, as one holder will be sufficient for a great variety of shapes of cutting points, tools, or blades. The blades may be of the very finest and most expensive quality of steel and still cost far less than the forged tool.

59. Disadvantages of Tool Holders.—The objection to these inserted-blade tools or tool holders is that it is difficult to find a means of clamping the small blade in the holder so that it will have the same rigidity as the forged tool. The holders soon wear, allowing the blades to spring. This causes trouble. This is caused in many cases by using too small a holder to do the work. If heavy holders are used and comparatively large blades, the trouble will be partly avoided.

60. Diamond-Pointed Tool Holders.—Figs. 49 and 50 show two styles of diamond-pointed tool holders. The similarity of Fig. 50 to the regular forged diamond point is readily seen. In Fig. 49 the tool shown has the outline of a diamond point sketched over it in dotted lines. From this it will be seen that the shapes of the cutting edges are identical.

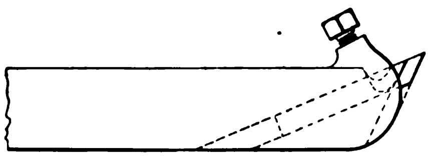


FIG. 49.

61. Grinding of Diamond-Pointed Inserted-Blade Tools.—The methods of grinding these two tools are quite different. In Fig. 50 the cutting tool is ground entirely on its top face, which corresponds to the face *E F*, Fig. 27. This determines the angle of keenness, and since the angle of front rake remains unchanged in the tool, it is always set at the same height for a given diameter.

In Fig. 49 the angle of top rake of the tool is determined by the angle at which the tool sets in the holder. Grinding should be done entirely along the end of the blade which corresponds to the face *H K*, Fig. 27. In this case, if we wish to increase the keenness of the tool, we grind it away at the heel. It must be remembered, however, that the keenness given the tool by changing its angle of front rake will not change the effective keenness when applied to the work, unless the position of the tool is changed. Grinding away the heel makes it possible to set the point higher on the work. This higher position gives an increased angle of top rake and therefore increases the effective keenness. Other forms of tool holders are made that are similar to these and accomplish the same purpose.

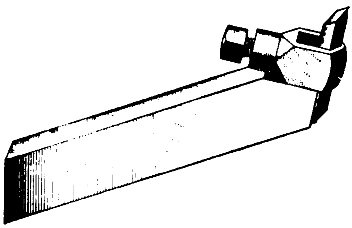


FIG. 50.

THE PARTING, OR CUTTING-OFF, TOOL.

62. Forged Parting Tool.—Fig. 51 represents a common form of parting tool. This tool is used for cutting grooves or notches in work, for cutting square corners, or for cutting off work held in a chuck. The cutting edge of the tool is along the line *A B*. The blade is forged and ground so that the cutting edge is the thickest part. The sides of the blade are each ground with a slight amount of clearance, as shown by section *C D* at (*b*). The tool is seldom ground with top rake, keenness being given by varying the angle of front rake and changing its height. When this tool is used as a cutting-off tool, its theoretical height is constantly changing as it approaches the center of the work, and so it should be set at the same height as the center of the work.

63. Use of Parting Tool.—Work held between the centers should not be cut in two with this tool. Work may be partly cut in two if care is used, after which it should be

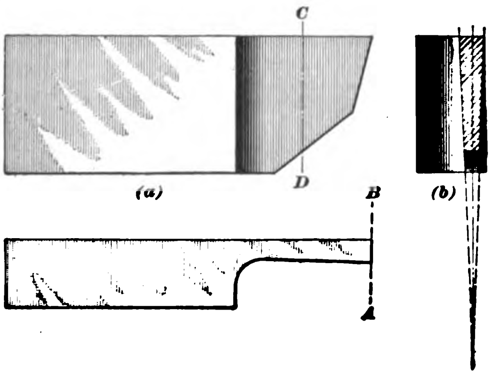


FIG. 51.

taken from the lathe and either broken or sawed apart. Fig. 52 shows the tool deep in a cut. Soon the piece will become so reduced in diameter that the force required to

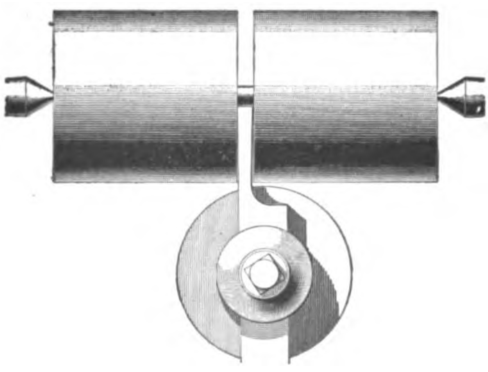


FIG. 52.

take the cut will bend the work. By bending the work at this small diameter, it will open the notch on one side and close it on the other, so that the tool cannot pass through, but will become jammed in the cut. This will result in either breaking the lathe tool, or the lathe center will be broken or torn out of the center hole.

64. Inserted-Blade Parting Tool.—Inserted-blade tool holders are very successfully used for parting tools. Fig. 53 shows one style of inserted-blade parting tool. The blade is held in the holder by the clamping screw *s* and is

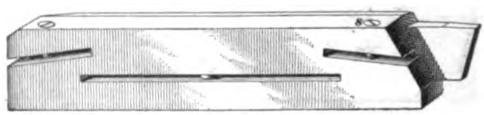


FIG. 53.

still further clamped when the tool holder is clamped in the tool post, because of the spring of the tool holder. Fig. 54 shows another form of bent parting tool with inserted blade. The blades for these tools are ground either concave on the

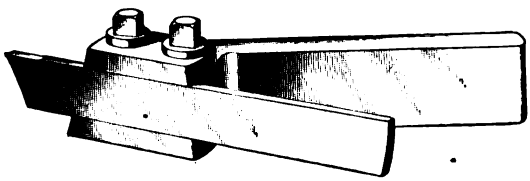


FIG. 54.

side or thinner on the bottom edge, to give clearance. They are made either from self-hardening steel or regular tool steel. When the blades are made from regular tool steel and hardened, it is customary to draw the temper along the lower edge, which gives the tool toughness—a quality much desired.

THREADING TOOLS.

65. Forged Threading Tools. — A good form of threading tool for **V** threads is shown in Fig. 59, *Lathe Work*, Part 2. This has an advantage over the common form shown in Fig. 55 in that it does not become thicker each time it is ground. This constant thickness is a desirable feature when threads are to be cut very close to a shoulder.

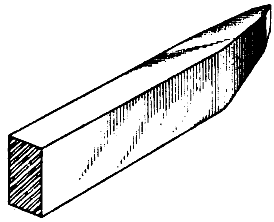


FIG. 55.

66. Inserted-Blade Threading Tools.—Various forms of tool holders have been designed for threading tools. Fig. 56 shows one of these forms for **V** threads. The tool is accurately made and ground so that the front faces form such an angle with each other when the top face is ground flat that the angle of the cutting edges will measure 60°. These inserted blades are sharpened by grinding the top face. Tool holders are made

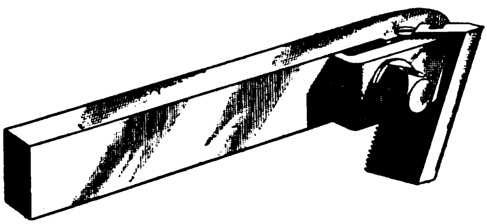


FIG. 56.

for cutting square threads, blades of various thickness being used to cut the various pitches of threads. When coarse pitches on small diameters are to be cut, these tools cannot be used because of the excessive side rake required on tools used for this purpose.

BENT TOOLS.

67. Right-Hand or Left-Hand Tools.—For some kinds of work, the straight tools that have been described cannot be used, and a class of tools known as *bent tools* becomes necessary. These are classed as right-hand or left-hand tools, depending on the direction they are intended to cut.

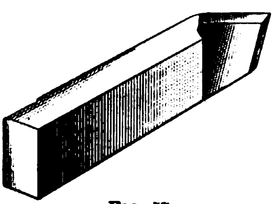


FIG. 57.

68. Bent Side Tool. — Fig. 57 shows a right-hand **bent side tool.** This form of tool is especially desirable when cutting a shoulder that is very close to the lathe dog, as shown in Fig. 58.

69. Bent Parting Tool.—When it is desired to cut work very close to a shoulder or the jaws of a chuck, a **bent**

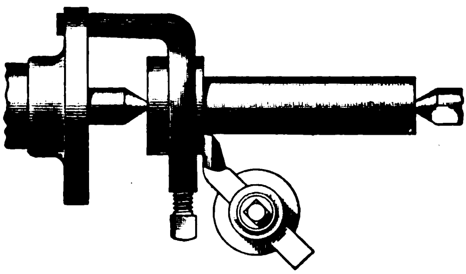


FIG. 58.

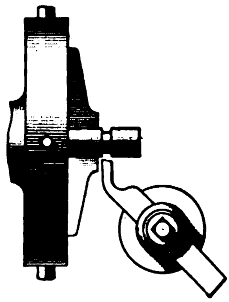


FIG. 59.

parting tool may be used, as shown in Fig. 59. The form of tool shown in Fig. 54 is particularly well adapted to this class of work.

70. Bent Round-Nosed Tool. — Round-nosed tools may be bent either right or left, to meet certain conditions of work. The right-hand **bent round-nosed tool** is often used for facing, and it makes a good inside turning or boring tool.

BORING TOOLS.

71. Special Holders for Boring Tools.—For boring tools **special holders** with inserted blades are superior to forged tools. Fig. 60 shows a special boring tool that can be held in the tool post of the lathe. The blade is held in the end of the bar *b* by a cap *c*, which screws over the end of the bar. The bar *b* can be adjusted in the holder so that it will just pass through the work.

Fig. 61 shows another form of boring tool with inserted blade. This form holds the bar *b* very rigidly in a special block bolted on the lathe tool block.

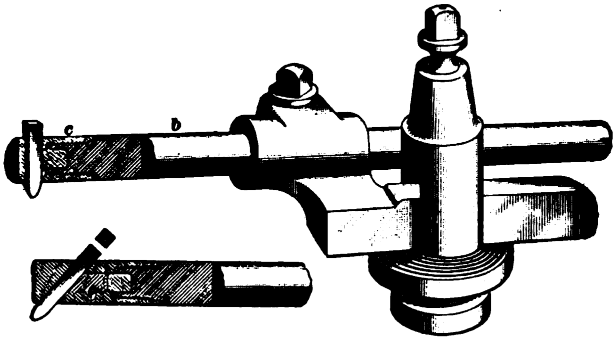


FIG. 60.

72. Advantages of Special Holders for Boring Tools.—Among the advantages of this type of tools, the following may be mentioned. When the holes to be bored are small, a bar that nearly fills the hole may be used. It

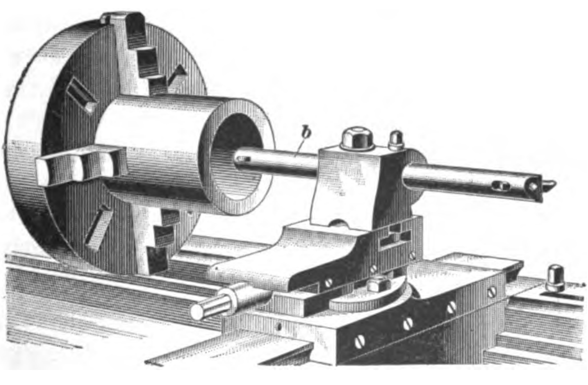


FIG. 61.

may be set to project beyond the holder just far enough to pass through the work. This gives the tool the greatest possible rigidity. Furthermore, because of the low position of the cutting tool, Fig. 62, the cutting action is much better than could be obtained with the forged tool as ordinarily ground.

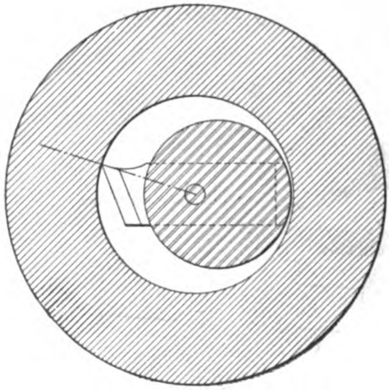


FIG. 62.

For heavy work, the style of bar shown in Fig. 60 has too much spring, hence the form shown in Fig. 61 should be employed. The lighter bar is very handy for small work. At times, the clamping block shown in Fig. 61 is split and secured to the tool block by two bolts. These bolts hold the block together as well as in place, and so secure the bar *b*.

FORMING TOOLS.

73. Under favorable conditions, it is possible to use a tool with a very broad cutting edge, 8 inches or more in width. These conditions are: rigidity of the work, rigidity of the tool, and power of the lathe.

When a piece is to be finished with a curved or irregular surface, as shown in Fig. 63, special tools can be made that save much time

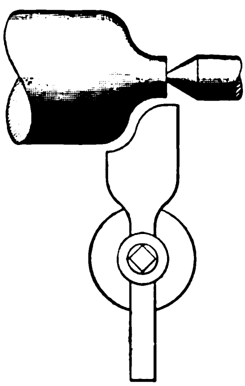


FIG. 63.

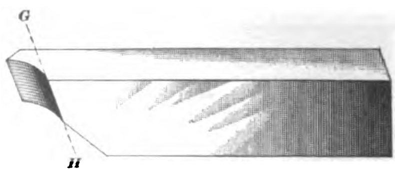


FIG. 64.

and do much better and more uniform work than can be done by hand. These tools are carefully made so that they have the proper clearance along the line *G H*, Fig. 64, and should be sharpened by grinding entirely on the top face. When used, they should be set at the same height as the center of the work. On wrought iron or steel, a bountiful supply of lard oil should be used. Very complicated forms may be produced by the use of forming tools.

SPRING TOOLS.

74. Use of Spring Tools.—In most cases, rigidity of work and tool is sought for the purpose of producing the most accurate and the smoothest surfaces. In a few instances, the **spring** or elasticity of a tool is made use of to overcome a roughness of cut that cannot otherwise be avoided.

75. Forms of Spring Tools.—Fig. 65 shows a **spring tool,** or **gooseneck** tool, as it is sometimes called, applied to the work. The tool is set level with the center of the work. Any tendency on the part of the tool or the work to vibrate or chatter is taken up by the narrow springy part of the tool. It will be seen that this form of tool can never dig into the work, since the pressure of the cut is constantly tending to press the edge away in the direction of the arrow, in a circle described about the center *c*.

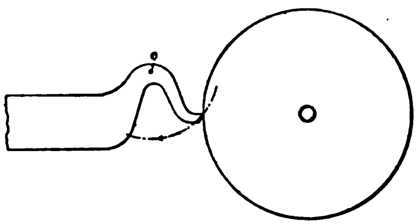


FIG. 65.

Fig. 66 shows another form of spring tool applied to the work. This form of tool is intended to avoid all danger of springing into the work. The tool is so set that as the force of the cut bends it down, the point follows the arc of the circle as indicated. This circle is described about the point of support of the tool. As the tool springs down, the point will naturally move away from the work, and so prevent its digging into the stock.

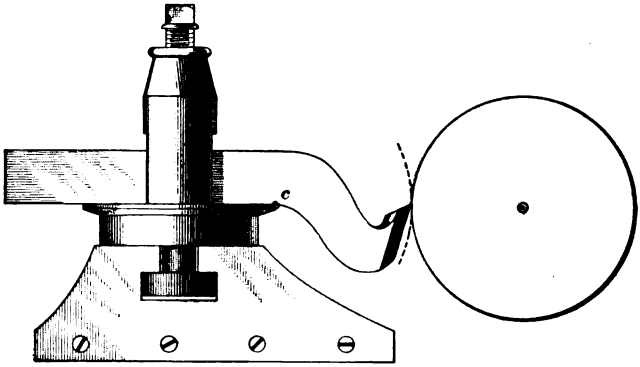


FIG. 66.

CHATTERING.

76. Cause of Chattering.—Chattering of the tool, which produces a rough corrugated surface on the work, may be traced to many sources. The action that occurs when chattering takes place is as follows: The tool is caught by the work and drawn in so as to cut deeply; when it has sprung in a certain depth, the tool and work are placed under a strain that causes them to spring apart. These performances take place in quick succession and in more or less of a rhythmical order, producing at times a musical sound, and, at other times, a most discordant noise. This springing action that takes place may be traced to different causes, as, to the frailty of the work, as in long slender shafts or long pieces being turned upon slender arbors; to the method of driving or rotating the work; to looseness of the spindle in the headstock bearings, or to looseness in the cross-slide of the tool rest; to looseness between the lathe centers or to the peculiar shape or manner of setting the tool. Broad-edged tools have a greater tendency to chatter than narrow ones.

77. Remedies for Chattering.—When a second cut is taken on a surface that shows slight chatter marks, they may be removed by grinding the tool so that its top face has a slight angle of top side rake just sufficient to keep the broad edge of the tool from falling into the old chatter marks. If in Fig. 67 the cutting edge of the tool was at first along the line *A B*, the chatter marks would be parallel to it. These chatter marks can generally be removed by giving the tool top side rake along the line *C D*.

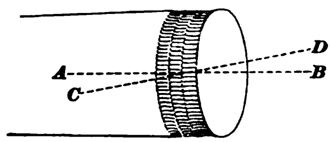


FIG. 67.

When remedies in the way of adjustment and methods of driving have been tried without avail, the spring tool often proves successful in removing the chatter marks.

HAND TOOLS OR GRAVERS.

78. Diamond-Pointed Graver.—**Hand tools,** as their name implies, are held in the hand while operating upon the work. Their cutting action depends on the laws of rake and clearance. Their cutting power, compared with tools held in a slide rest, is very small. Their principal use in metal working is turning very small pins and pivots on such lathes as watchmakers' or small bench lathes for working brass, and for finishing curves and pieces of irregular outline. Chief among these tools is the **diamond-pointed graver.** It is a piece of steel ground with a bevel on the point, as shown in Fig. 68. When this tool is used for rounding a corner such as the end of a bolt or screw, it rests upon one

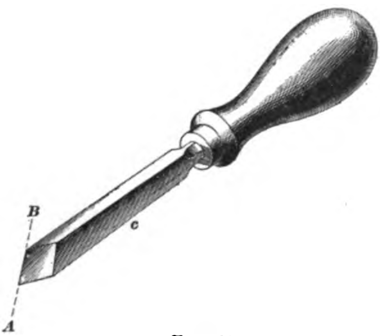


FIG. 68.

corner *c*, Fig. 69, while the edge *A B* does the cutting. The angles of rake and clearance are easily changed to give the best results by changing the position of the tool.

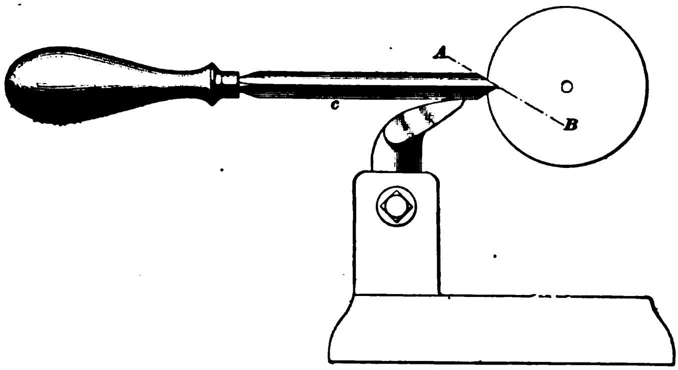


FIG. 69.

79. Round-Nosed Graver.—Fig. 70 shows a **round-nosed graver.** This tool is used for finishing concave curves. The under side lies flat on the rest when it is used.

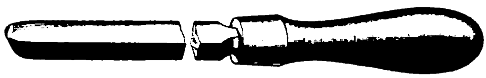


FIG. 70.

Gravers are commonly made from worn-out files of either square or rectangular section. Their points can be ground to any particular shape best suiting the work.

TOOLS FOR BRASS.

80. Tools for brass are usually drawn out nearly to a point similar to a round-nosed tool. The top face is made flat, as shown in Fig. 71, while the point is ground similar to a threading tool with the point rounded. Tools with broad edges are seldom used for brass unless they are some kind of forming tool. The characteristic features of

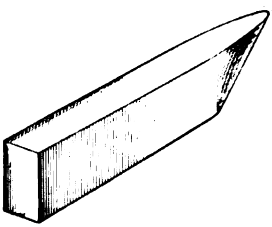


FIG. 71.

a brass tool are: it is flat on the top, is set at the center of the work so that it has no top rake, and is ground with more front rake than similar tools used on iron and steel.

TOOL GRINDERS.

81. Tool Grinding.—It is a common practice in most shops for each man to grind his tools to suit himself, the grinding being done on grindstones or special emery wheels for tool grinding. The result is a very great stock of steel, which is necessary to make up the sets of tools for the different machines, and an almost infinite number of shapes. The best managed shops are now adopting a system whereby the tools are systematically and scientifically ground by one man. All tools are kept in a tool room and are checked to the workmen as used. There are a number of automatic tool grinders on the market designed for this purpose, and some of them are described later.

82. Machine-Ground Tools.—Fig. 72 shows a few typical lathe tools as ground upon one of the standard tool grinders. Fig. 73 shows some typical planer tools as ground upon the same machine, and Fig. 74 some slotting machine tools, threading, and other special tools. Figs. 75 and 76 illustrate charts that are sent out with Sellers' grinding machine, giving the clearance angles for grinding the different tools. The numbers placed opposite the tools in Figs. 72, 73, and 74 correspond to similar numbers on the shanks of the tools in Figs. 75 and 76. In the case of the side-finishing planer tools illustrated in Fig. 76, it will be noticed that two angles are given for *d*. The upper angle is the top side rake, at right angles to the cutting face, and the lower angle is the top rake in the direction of the cutting face. These charts and figures are given simply to show what is considered good practice in regard to the shape of the tools.

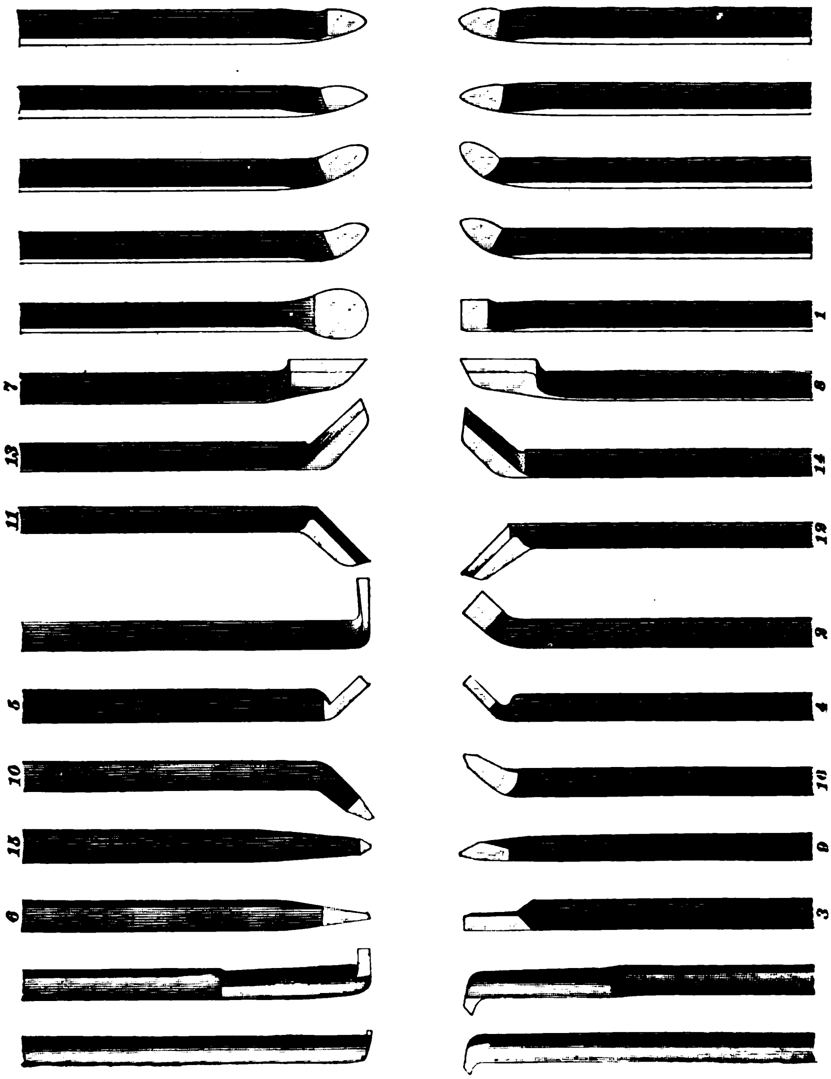


FIG. 72.

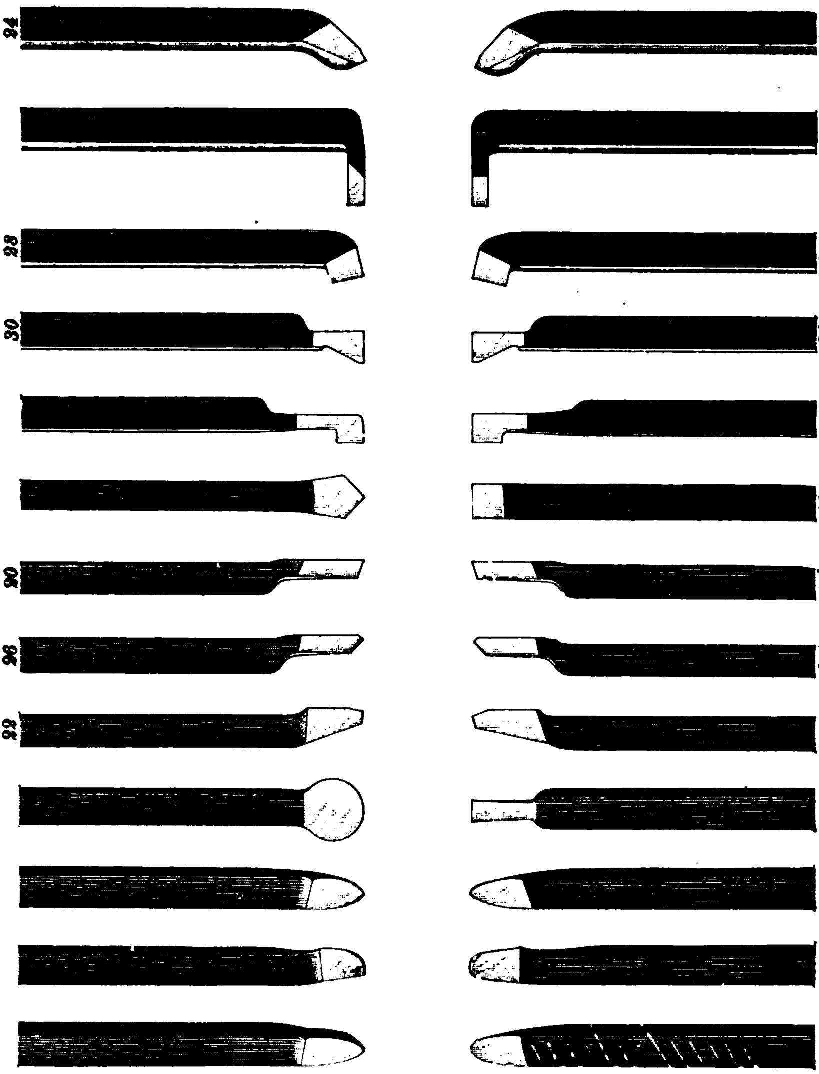


Fig. 73.

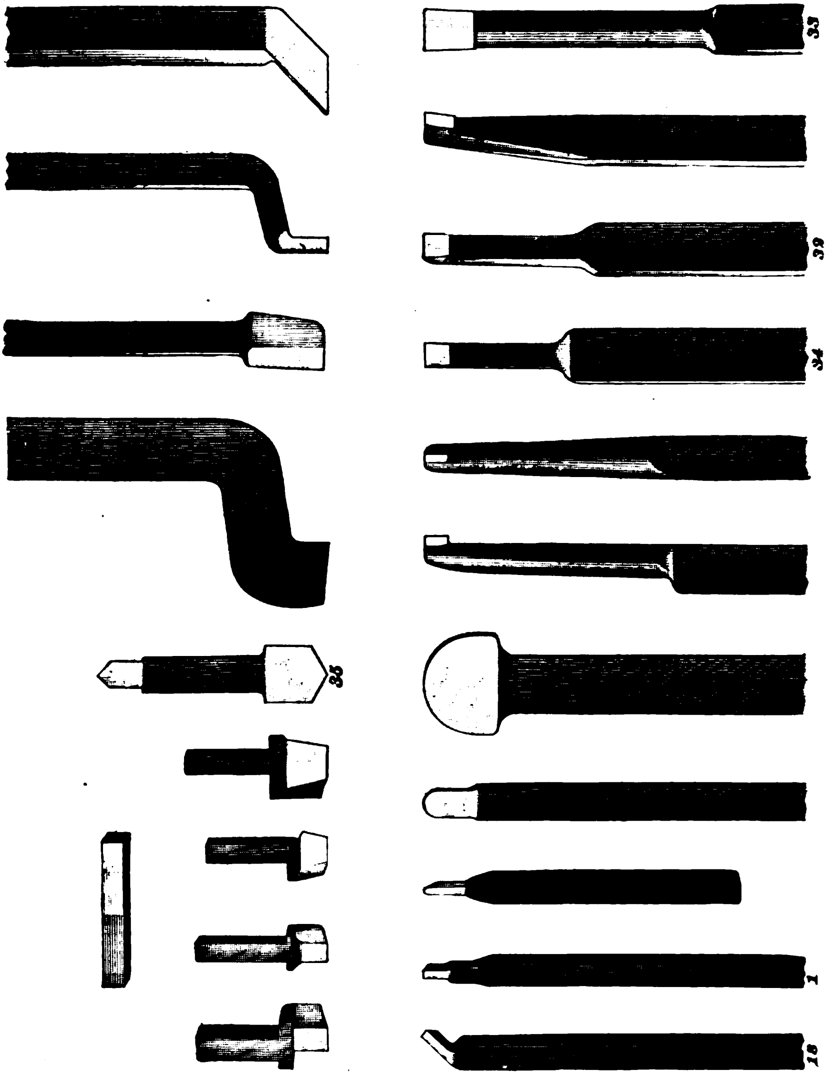


FIG. 74.

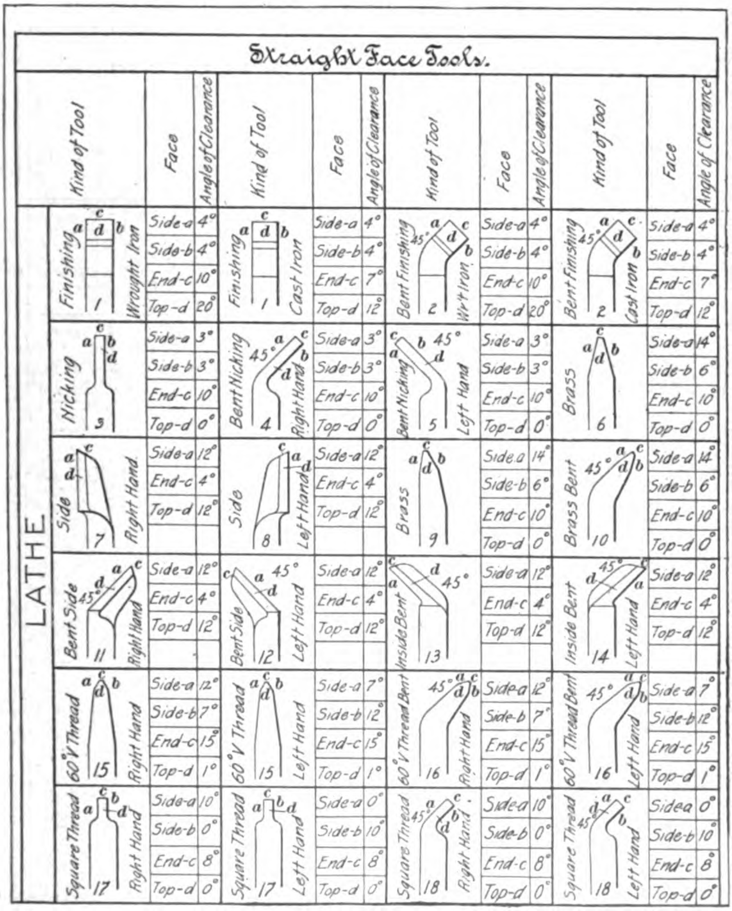

Straight Face Tools.
LATHE
Kind of Tool
Face
Angle of Clearance
Finishing 1 Wrought Iron: Side-a 4°, Side-b 4°, End-c 10°, Top-d 20°
Finishing 1 Cast Iron: Side-a 4°, Side-b 4°, End-c 7°, Top-d 12°
Bent Finishing 2 Wr't Iron: Side-a 4°, Side-b 4°, End-c 10°, Top-d 20°
Bent Finishing 2 Cast Iron: Side-a 4°, Side-b 4°, End-c 7°, Top-d 12°
Nicking 3: Side-a 3°, Side-b 3°, End-c 10°, Top-d 0°
Bent Nicking 4 Right Hand: Side-a 3°, Side-b 3°, End-c 10°, Top-d 0°
Bent Nicking 5 Left Hand: Side-a 3°, Side-b 3°, End-c 10°, Top-d 0°
Brass 6: Side-a 14°, Side-b 6°, End-c 10°, Top-d 0°
Side 7 Right Hand: Side-a 12°, End-c 4°, Top-d 12°
Side 8 Left Hand: Side-a 12°, End-c 4°, Top-d 12°
Brass 9: Side-a 14°, Side-b 6°, End-c 10°, Top-d 0°
Brass Bent 10: Side-a 14°, Side-b 6°, End-c 10°, Top-d 0°
Bent Side 11 Right Hand: Side-a 12°, End-c 4°, Top-d 12°
Bent Side 12 Left Hand: Side-a 12°, End-c 4°, Top-d 12°
Inside Bent 13: Side-a 12°, End-c 4°, Top-d 12°
Inside Bent 14 Left Hand: Side-a 12°, End-c 4°, Top-d 12°
60° V Thread 15 Right Hand: Side-a 12°, Side-b 7°, End-c 15°, Top-d 1°
60° V Thread 15 Left Hand: Side-a 7°, Side-b 12°, End-c 15°, Top-d 1°
60° V Thread Bent 16 Right Hand: Side-a 12°, Side-b 7°, End-c 15°, Top-d 1°
60° V Thread Bent 16 Left Hand: Side-a 7°, Side-b 12°, End-c 15°, Top-d 1°
Square Thread 17 Right Hand: Side-a 10°, Side-b 0°, End-c 8°, Top-d 0°
Square Thread 17 Left Hand: Side-a 0°, Side-b 10°, End-c 8°, Top-d 0°
Square Thread 18 Right Hand: Side-a 10°, Side-b 0°, End-c 8°, Top-d 0°
Square Thread 18 Left Hand: Side-a 0°, Side-b 10°, End-c 8°, Top-d 0°

FIG. 75.

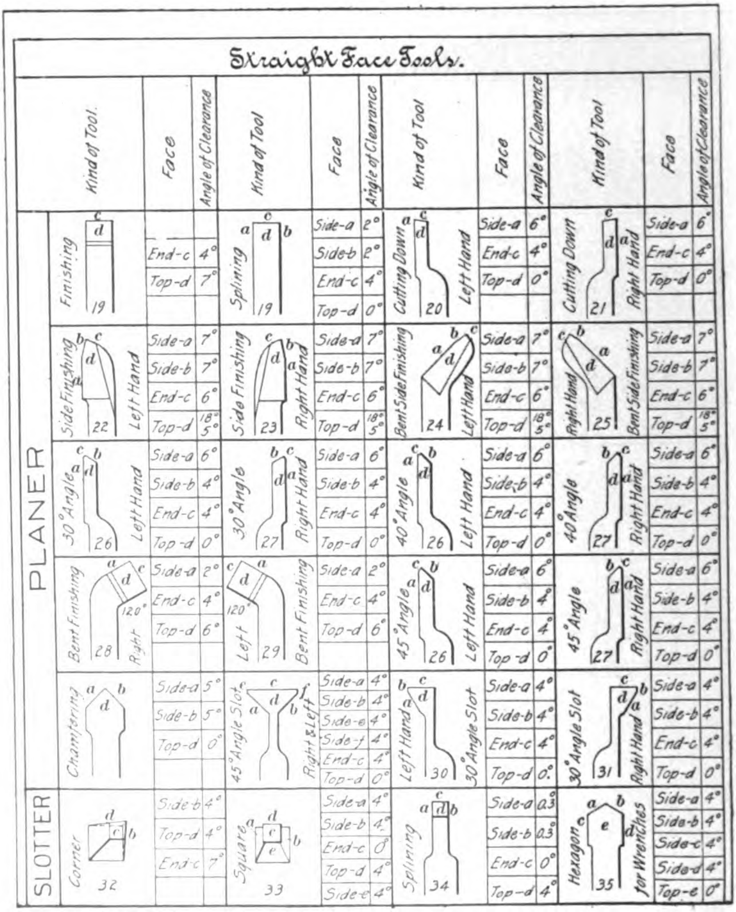

Straight Face Tools.
Kind of Tool
Face
Angle of Clearance
PLANER
Finishing 19: End-c 4°, Top-d 7°
Splining 19: Side-a 2°, Side-b 2°, End-c 4°, Top-d 0°
Cutting Down, Left Hand 20: Side-a 6°, End-c 4°, Top-d 0°
Cutting Down, Right Hand 21: Side-a 6°, End-c 4°, Top-d 0°
Side Finishing, Left Hand 22: Side-a 7°, Side-b 7°, End-c 6°, Top-d 18° 5°
Side Finishing, Right Hand 23: Side-a 7°, Side-b 7°, End-c 6°, Top-d 18° 5°
Bent Side Finishing, Left Hand 24: Side-a 7°, Side-b 7°, End-c 6°, Top-d 18° 5°
Right Hand, Bent Side Finishing 25: Side-a 7°, Side-b 7°, End-c 6°, Top-d 18° 5°
30° Angle, Left Hand 26: Side-a 6°, Side-b 4°, End-c 4°, Top-d 0°
30° Angle, Right Hand 27: Side-a 6°, Side-b 4°, End-c 4°, Top-d 0°
40° Angle, Left Hand 26: Side-a 6°, Side-b 4°, End-c 4°, Top-d 0°
40° Angle, Right Hand 27: Side-a 6°, Side-b 4°, End-c 4°, Top-d 0°
Bent Finishing, Right 28 (120°): Side-a 2°, End-c 4°, Top-d 6°
Left, Bent Finishing 29 (120°): Side-a 2°, End-c 4°, Top-d 6°
45° Angle, Left Hand 26: Side-a 6°, Side-b 4°, End-c 4°, Top-d 0°
45° Angle, Right Hand 27: Side-a 6°, Side-b 4°, End-c 4°, Top-d 0°
Chamfering: Side-a 5°, Side-b 5°, Top-d 0°
45° Angle Slot, Right & Left: Side-a 4°, Side-b 4°, Side-e 4°, Side-f 4°, End-c 4°, Top-d 0°
Left Hand, 30° Angle Slot 30: Side-a 4°, Side-b 4°, End-c 4°, Top-d 0°
30° Angle Slot, Right Hand 31: Side-a 4°, Side-b 4°, End-c 4°, Top-d 0°
SLOTTER
Corner 32: Side-b 4°, Top-d 4°, End-c 7°
Square 33: Side-a 4°, Side-b 4°, End-c 0°, Top-d 4°, Side-e 4°
Splining 34: Side-a 0.3°, Side-b 0.3°, End-c 0°, Top-d 4°
Hexagon, for Wrenches 35: Side-a 4°, Side-b 4°, Side-c 4°, Side-d 4°, Top-e 0°

FIG. 76.

LATHE WORK.

(PART 4.)

CUTTING SPEEDS AND FEEDS.

CUTTING SPEED.

1. Meaning of the Term Cutting Speed. — The *cutting speeds* and *feeds* of machine tools is a subject for much careful study. The output of work from a machine and the cost of production depend very largely on the cutting speed used.

The **cutting speed** of a machine tool is the speed at which it passes over the surface of the work. This speed is measured in feet per minute. Before discussing cutting speeds, a very clear understanding should be had of its exact meaning. Suppose the speed of a lathe is such that the tool can cut in 1 minute a shaving that, if it could be straightened, would measure 20 feet in length. The cutting speed would then be 20 feet per minute. If the speed of the lathe were such that the tool would cut a shaving 10 feet long in 1 minute, the cutting speed would be 10 feet per minute.

2. Relation Between Cutting Speed and Speed of Work.—Cutting speed and the speed of the work must not be confused. Two lathes are working and each making 50 revolutions per minute. One is turning a piece 1 inch in diameter and the other a piece 2 inches in diameter. The lathe turning the 1-inch piece would be giving a cutting speed of about 13 feet per minute, while the second lathe working on the 2-inch piece would be cutting at the rate of 26 feet per minute. It will thus be seen that *the cutting speed varies directly with the diameter of the work when the speed of the lathe remains constant.*

LIMIT OF CUTTING SPEED.

3. Factors Limiting the Cutting Speed.—The cutting speed should always be as great as the conditions will permit, whether these conditions arise from the shape or the nature of the work or the durability of the tool. There is a limit of cutting speed that cannot be exceeded. This limit depends on the durability of the tool. A tool that will cut well when the work is running at a low cutting speed will not cut well nor endure long when the cutting speed is much increased. This limit may be ascertained by a number of trial speeds. By testing at a moderately low speed, the tool retains its edge. If the speed be still further increased, a point will be reached at which the tool will heat so rapidly at the point that the temper will be started, and the point softened and quickly worn away. As soon as the cutting point or edge is dulled, the friction increases and greater heat is generated, so that in a very short time the entire point of the tool will be worn away.

4. The greatest speed at which the tool will retain its cutting edge a sufficiently long time to turn a fair amount of work is the **limit of cutting speed.** When iron or steel pieces are run at a very high speed in the lathe, the heat generated at the tool point removes the temper and the tool will not cut. Soft pieces of steel that could easily be turned at a low speed would, when running rapidly, wear away the point of the hardest tool nearly as fast as if the tool were brought against a rapidly revolving emery wheel.

This limit of cutting speed varies greatly. In attempting to determine this limit, it will be found that it depends largely on, *first*, the kind of metal being turned ; *second*, the hardness of that particular piece; *third*, the cut, whether it be a heavy roughing cut or finishing cut; and, *fourth*, the diameter and length of the work.

5. Effect of Kind of Metal on Cutting Speed.—The cutting speed is greater for soft metals than for hard. This is illustrated in the high speed used for wood-cutting tools. Copper, brass, babbitt, and similar metals will admit of a much higher cutting speed than cast iron or steel. One reason why copper will admit of a higher cutting speed than iron is because it is softer and less force is required to turn the shaving; consequently, less heat is generated at the cutting point of the tool. Moreover, copper is such an excellent conductor of heat that, as soon as heat is generated, it is at once conducted from the point of the tool so that the heat cannot accumulate as fast as in iron or steel. It will be found in turning iron or steel that the work and the shank of the tool keep quite cool, most of the heat being concentrated at the point of the tool and in the shaving. Whatever the metal being turned, the speed must be slow enough to give the heat time to pass into the work before it becomes sufficient to draw the temper on the tool. One reason why the tool becomes so much hotter than the work is that the tool is constantly under strain and the action of cutting, while the work, because of its motion, is constantly bringing new points in contact with the tool. This allows the heated part, caused by the severing of the shaving, to cool while it is completing the rest of the revolution. The shaving, which is light compared with the mass of the work, has no way of distributing its heat except by radiation, and, consequently, it comes away from the work at a temperature nearly equal to that at the point of the cutting tool. To a certain degree, the rotating of a large piece tends to keep the point of the tool cool, for it no sooner severs a part of a shaving at one point on the surface of the work than a second point is presented to it, and so on around the work, the tool constantly being forced into cool metal, which, for an instant, would tend to cool the point of the tool.

6. When the tool is exceedingly sharp, a greater amount of heat is generated by the force required to turn the shaving than by the act of severing it. The force required to press a sharp tool into the work depends on the angle of the side faces, and if a blade could be made infinitely thin, with its edge infinitely sharp, it would be found that the mere act of severing a shaving would require very little power. For illustration, the thin blade of a cheese knife will pass easily through a cheese, while a thick, wedge-shaped knife will require a heavy pressure. This is caused by the necessary bending aside of the parts before the blade can enter farther.

7. It may therefore be assumed that the heat generated in taking a cut is due to the bending and turning aside of the shaving, and to the friction of the shaving on the top face of the tool and of the work on the front face. This applies to a tool with a sharp edge. This fact in part accounts for the peculiar wear that is sometimes noticed on tools that are considered excellent.

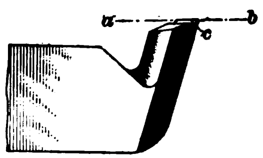


FIG. 1.

Fig. 1 shows a tool as it is sometimes worn after taking a cut on steel. It will be noticed that the cutting edge *a b* has retained its original sharpness, while immediately behind it a small groove *c* has been worn.

This peculiar wear may be explained by assuming that the cutting edge possessed an unusually fine temper, being of sufficient hardness to retain its keen cutting qualities and at the same time being tough enough not to break., This keen edge severed the shaving with ease and caused but little heat. As fast as it entered the work, it was constantly coming in contact with cool points. This tended to keep the edge cool. At the instant the shaving was severed or cut loose from the work, it was at once turned from its course by sliding on the top face of the tool. The heat thus generated slightly softens the top face of the tool, and the shaving tends to wear away this top face as it turns and slides from the tool. This is more apt to occur when light cuts are being taken at high speeds.

At high speeds, the edge of the tool is more rapidly cooled because of the rapid succession at which the cool points on the work are brought against it. At slower speeds, with heavy cuts, the heat from turning the shaving overbalances the cooling action of the work; consequently, the edge of the tool becomes hot and suffers from it. It must not be inferred from these statements that a tool will stand better at a high than at a low rate of speed. Such is not the case. If, in the case of the tool shown in Fig. 1, the speed had been slightly reduced, the tool would have done the work just as well and would not have been worn on the top face. This simply shows that in this case the limit or critical cutting speed had been reached, and increasing it even slightly would have ruined the tool.

8. The power required to force a tool into the cut depends on the angles made by the cutting faces, and the harder the material being cut, the less acute should the cutting angle be. This large angle of the cutting faces is necessary to support the cutting edge, since, for hard materials, the tool must be exceedingly hard, otherwise the sharp edge will be pressed down and rounded. This is what really does occur as a tool dulls. The keen cutting edge is worn off so that it becomes a rounded surface, as shown in much exaggerated form at *a*, Fig. 2. As soon as the keen edge becomes rounded, heat is generated at this edge as it is forced to sever the shaving, and the more it becomes rounded, the more heat is generated, until at last the tool will cease to cut. If the edge were sufficiently hard

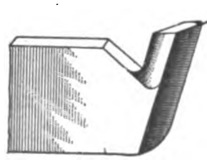


FIG. 2.

to resist the pressure of very hard material, it would be so brittle that, unless the cutting edge were well supported, the tool would break. Keen acute angles would cut more easily and be more desirable if they would not break.

9. It is thus seen that for hard, tough materials, hard tools with little top rake must be used, while, for softer materials, greater keenness or top rake may be given. Because of the greater power required to force tools having little keenness into the work, a greater amount of heat will be developed. *Since the limit of cutting speed is governed by the amount of heat generated, it will be seen that the tool having the greater angle of keenness must be used at a lower speed than the acute one, otherwise it will pass its heating limit.*

This applies in the same way to cuts taken upon the same kind of material that varies in degree of hardness. Cast iron, for instance, will be found to vary a great deal in its degree of hardness, some being very soft and some very hard.

10. If two pieces be of the same strength or hardness, the more acute the tool, the less the power required to force it into the work. With two tools of the same shape, and taking the same depth of cut in materials of different degrees of hardness, the softer material will require the less power. This is because of the ease with which the shaving is bent and turned from the tool. The softer material, therefore, develops less heat for the same shape of tool and depth of cut than the harder material; consequently, an increased speed may be used.

11. Roughing Cuts.—Roughing cuts are generally heavy and the duty of the tool severe. It therefore becomes necessary to use slower cutting speeds for roughing than for finishing cuts. This reduced cutting speed will give a slight increase in lathe power, thereby making it possible to take still heavier cuts when it is necessary.

12. Finishing Cuts.—Finishing cuts are best made at a high cutting speed, especially on cast iron, as it will give a smoother surface than can be obtained with a slower cut. When a slow cutting speed is used on cast iron, there is a tendency for the shavings to break out of the work slightly in advance of the cutting edge. This is due to the crystalline structure of the material. This is shown in somewhat exaggerated form in Fig. 3,

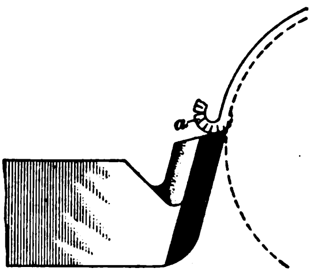


Fig. 3.

where a shaving *a* is shown just as it is breaking from the work. When the slow speed is used, the shaving breaks slowly from the work and in so doing breaks into the surface and carries away with it particles of metal that should be left. This will leave a surface that is more or less pitted, and, should it be desired to finish it by polishing, these little pits will be found to be of sufficient depth to make it very difficult to obtain a fine polish. When a higher speed is used, or the tool is ground with a keener cutting edge, this pitting will disappear.

INFLUENCE OF DIAMETERS ON RESISTANCE TO CUT.

13. Suppose that a diamond-pointed tool is cutting a cylinder of the diameter represented by the circle *e*, Fig. 4, to the size represented by the dotted lines. The force or pressure on the top face of the tool is measured in a direction at right angles to the face of the tool; therefore, the direction of the force on this tool is along the line *c o* perpendicular to *a o*. This line intersects the circumference of the outer circle at *b*. Suppose, in the

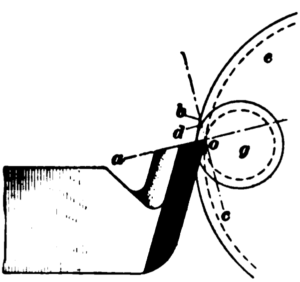


Fig. 4.

second case, that the tool is cutting the same depth of cut on a smaller cylinder represented by *g*. The force of the cut will be in the same direction as in the previous case along the line *c o*. The line *c o* intersects this smaller circle at *d*. These lines *d o* and *b o* graphically represent the relative forces required to turn the shaving. In the larger piece, the shaving has a backing and support extending from the point of the tool to the point *b*, while, in the smaller piece, the shaving is backed only by metal to the point *d*. It will readily be seen that less power will be required to turn the shaving on the smaller piece than on the larger one. Since this is true, it is theoretically possible to take a deeper cut on the small piece with the same power required for the original depth of cut on the larger piece.

14. Average Cutting Speeds.—The cutting speed depends on so many conditions that it is impossible to give any exact rule that will apply to all cases. Different cutting speeds have been given for the different metals, but these vary greatly. An average, however, has been taken, as given in the accompanying table, which gives fair speeds that may be used under favorable conditions for taking roughing cuts of medium depth.

It will be noticed in this table that the cutting speed of brass is considerably greater than that of iron or steel, also that the cutting speed is increased for the small diameters of work. The cutting speeds given for cast iron are for short cuts taken on very soft castings. Long, continuous cuts on hard castings would require a cutting speed somewhat below that given in the table.

15. Relation of the Steel to Cutting Speed.—In the case of special self-hardening steel, the cutting speeds of machine tools have been much increased. This is due largely to the amount of heat these tools will stand before their temper is impaired. With some of the best brands of self-hardening steel, the rate of cutting speed, compared with that used with ordinary forged and tempered tools, is nearly doubled. With these tools, shavings may often be cut from tool steel at such a high cutting speed that the heat

CUTTING SPEEDS.

	Diameter of Work.	Cutting Speed in Feet Per Minute.
Wrought Iron and Machine Steel.	½	38
	1	35
	1½	30
	2	28
	2½	25
Cast Iron.	1	45
	1½	45
	2	40
	2½	40
Tool Steel.	¾	24
	⅞	20
	1	20
	1½	18
Brass.	¾	110
	1	100
	1¼	90
	1½	80

generated will sometimes be sufficient to draw the temper color on the steel shaving to a dark blue. This is equivalent to a temperature of about 550°.

16. When Low Cutting Speeds Should Be Used. While in most cases it is desirable to work up to the limit in cutting speed, it is not in all cases the most advisable. With a single-pointed turning tool that may be quickly and easily sharpened, it is a desirable thing to do. In the case of special tools intended to perform certain finishing operations and when the accuracy of the piece depends to some extent on the action of the special tool, then that tool should be favored by using lower cutting speeds. For example, consider a reamer that is to finish holes smooth and true and to an exact diameter within a thousandth of an inch. The size of the hole will depend on the size of the reamer, and when the cutting edge is worn away one-half a thousandth of an inch, the reamer will make the holes too small. Such a tool should be handled with care and the cutting speed sacrificed for the sake of maintaining the cutting edge.

Taps and dies should not be run at such a high cutting speed as can be used for lathe tools. Chucking tools should also be favored, especially if they are intended to remain at a particular size. Due care and judgment must be exercised in each case to get the best results.

CUTTING FEED.

17. Definition of Feed.—The **feed** of a tool is the amount of its side movement along the length of the bed per revolution of the work, or the number of revolutions required to move the tool sidewise 1 inch. The feed, in turning, and the pitch of the screw, in screw cutting, are the same; thus, a feed of 10 means that 10 turns of the work feed the tool over the work a sufficient distance to finish 1 inch in length. Sometimes the coarser feeds are spoken of as a feed of $\frac{1}{2}$ inch or 1 inch, which means that 2 revolutions or 1 revolution are necessary to move the tool along 1 inch.

18. Relation Between Feed and Material Being Cut.—The best feed to use on a piece of work depends on many conditions. When cylindrical accuracy is desired on wrought-iron or steel shafts, it is best to use a fine feed for finishing, since, with a fine feed, it is possible to use a tool with a narrow point. The narrow-pointed tool will cut more freely and, consequently, with less spring to the tool and the work. Time, however, is of great importance in machine work, and sometimes coarser feeds will finish with sufficient accuracy. The feed and the width of the point of the lathe tool are interdependent, the point of the tool being slightly wider than the amount of feed per revolution.

19. Cast iron will generally admit of broader feeds than wrought iron or steel. This is due largely to the difference in the action of the shaving on the tool. With cast iron, there is a tendency for the shaving to break immediately when turned out of its course by the top face of the cutting tool. This constant breaking of the shaving tends to relieve the tool of undue pressure. In wrought iron or steel, the shaving does not break up so easily. When, in turning steel, the broad cutting edge of the tool is set parallel to the axis of the work, any slight pressure that may tend to spring the tool into the work causes the whole broad edge to spring in. This causes the tool to take instantly a very much deeper hold, and, because of the tenacity of the steel, the tool will be carried deeper and deeper until it reaches a point where the strain on the tool balances the pressure of the shaving, at which point the tool will continue to cut at this depth. If the work is not sufficiently rigid to hold its shape while the tool is thus sprung and taking a deep cut, the piece will bend slightly. As the hollow side of the bent piece comes around to the tool, the cut will grow less until the heavy side again comes around, whereupon the cut will be heavier than before, and, in most cases, the work will be ruined. Broad cutting-edged tools should never be put on a piece of wrought iron or steel, unless the operator is quite sure that there is sufficient rigidity to withstand the cut.

COMPUTATIONS RELATING TO CUTTING SPEEDS.

20. To Find the Cutting Speed.—Suppose a shaft 4 inches in diameter is being turned at the rate of 10 revolutions per minute. It is desired to find the cutting speed of the tool in this case. The circumference or distance around the shaft is $3.1416 \times 4 = 12.5664$ inches. This is the length of shaving that would be cut in 1 revolution of the work. Multiplying 12.5664 by 10, the number of revolutions of the work per minute, gives 125.664 inches. This is the length of shaving in inches turned in 1 minute. The cutting speed is measured in feet per minute, so, dividing 125.664 by 12, to reduce it to feet, gives as a result 10.472 feet, the cutting speed. In some cases, for a rough or approximate value, the fraction is neglected. Thus, in the above case, if a shaft is 4 inches in diameter, its circumference will be 3 times that, or 12 inches, equal 1 foot, and if it cuts 1 foot of shaving for 1 revolution, it will cut 10 times that, or 10 feet, for 10 revolutions.

21. The rule for finding the cutting speed when expressed as a formula is

$$S = \frac{\pi D R}{12}, \qquad (1.)$$

in which S = cutting speed in feet per minute;
π = 3.1416, ratio of a circumference to its diameter;
D = diameter of work in inches;
R = number of revolutions per minute.

Suppose we wish to find the cutting speed when a shaft 1 inch in diameter is making 150 revolutions per minute. Substituting in the formula, we have

$$S = \frac{3.1416 \times 1 \times 150}{12} = 39.27 \text{ feet.}$$

Therefore, the cutting speed in this case is 39.27 feet per minute.

22. To Find the Number of Revolutions Required to Give a Desired Cutting Speed.—Suppose we have a steel shaft 9 inches in diameter. It is desired to use a cutting speed of 20 feet per minute. We wish to find the number of revolutions necessary to obtain this cutting speed.

The distance around the shaft equals 3.1416 times its diameter, or 28.2744 inches; therefore, for 1 revolution of the shaft, 28.2744 inches of shaving will be cut. Twenty feet equals 240 inches. To cut off 240 inches of shaving per minute will require as many revolutions as 28.2744 is contained in 240, or 8.5 nearly. Therefore, the shaft should make $8\frac{1}{2}$ revolutions per minute to give a cutting speed of 20 feet per minute. As in the previous case, the fractions may be neglected.

23. In another case, suppose the work to be 1 inch in diameter and that the same cutting speed of 20 feet per minute is desired. The circumference of the work equals 3.1416 times the diameter, or 3.1416 inches. The length of the shaving equals 240 inches. It will take as many revolutions of the work to turn 240 inches as 3.1416 is contained in 240, or 76.4 revolutions per minute. This relation may be expressed by the formula

$$R = \frac{12\,S}{\pi\,D}, \qquad (2.)$$

when R = revolutions per minute;
S = cutting speed in feet per minute;
π = 3.1416;
D = diameter of the work in inches.

24. Suppose it is desired to use a cutting speed of 30 feet per minute on a shaft 2 inches in diameter. How many revolutions should it make?

Substituting the values in the formula given in Art. **23**, we have

$$R = \frac{12 \times 30}{3.1416 \times 2} = 57.3.$$

Therefore, the work should make 57.3 revolutions.

25. To Find the Time Required to Take a Cut.—The time required to turn a shaft can also be determined when its length, the feed, and the number of revolutions are given.

Suppose it is desired to find the time required to turn a shaft 10 feet long that is making 25 revolutions per minute with a feed of 20, that is, 20 revolutions of the work to move the tool along the shaft 1 inch.

If the tool moves over 1 inch of length of the shaft in 20 revolutions, to move over 120 inches (the length of the shaft in inches), it will take 20 times 120, or 2,400 revolutions of the work. If the shaft makes 25 revolutions in 1 minute, it will take as many minutes as 25 is contained in 2,400, or 96 minutes, equal 1 hour and 36 minutes.

26. A formula may be used for finding the time required for the above example. It is

$$T = \frac{LF}{R}, \qquad (3.)$$

when
T = time in minutes;
F = feed per inch;
R = revolutions per minute;
L = length in inches.

Substituting for the above example in the formula, we have

$$T = \frac{120 \times 20}{25} = 96 \text{ minutes},$$

which is the same as was found before.

In the above formula, R, the number of revolutions, has been computed to give the desired cutting speed. Suppose a shaft 6 feet long, 18 inches diameter, is to be turned, and it is desired to use a feed of 20 and a cutting speed of 18 feet per minute. We wish to find the time required.

We may first find the number of revolutions necessary to give the desired cutting speed by formula **2**, $R = \frac{12 \times 18}{3.1416 \times 18} = 3.82.$

Substituting the value of R in formula **3**, we have $T = \frac{72 \times 20}{3.82} = 377$ minutes = 6 hours and 17 minutes.

27. Instead of using the two formulas and substituting the value of R in the second, the following formula, which is a combination of the two, may be employed:

$$T = \frac{\pi D F L}{12 S}. \qquad (4.)$$

By substituting in this formula the values given in the last problem,

$$T = \frac{3.1416 \times 18 \times 20 \times 72}{12 \times 18} = 377 \text{ minutes.}$$

This same result was obtained by the other method. The number 12, which is used in the various formulas, is used to reduce the cutting speed from feet to inches, since the diameter of the work is given in inches. If the diameters in the various problems were given in feet, the number 12 would not be needed. For example, how long will it take to turn a flywheel 20 feet in diameter, 2 feet face, if a cutting speed of 15 feet and a feed of $\frac{1}{2}$ inch is used?

A feed of $\frac{1}{2}$ inch equals a feed of 2. Substituting these values in formula **4**, and omitting the number 12, since the diameter is given in feet,

$$T = \frac{3.1416 \times 20 \times 2 \times 24}{15} = 201 \text{ min.} = 3 \text{ hours } 21 \text{ min.}$$

28. Advantages of Coarse Feeds.—When the finishing cut is being taken on a large piece, it is desirable to have the tool retain its sharp edge until the operation is completed, so that the last part of the cut will be as smooth and true as the first. When the tool dulls so that it becomes necessary to resharpen it before the cut is completed, much time is lost, especially on heavy work. In setting a tool for heavy work, it takes some time for the work to make a revolution, and by the time the tool is adjusted to the same depth as before and the feeds are again working, much time is lost.

29. Suppose, in the flywheel just mentioned, a finishing cut should be attempted by using a feed of 10. By the time the piece was finished, the shaving would be $3.1416 \times 20 \times 10 \times 24 = 15{,}080$ feet, or nearly 3 miles long. At a cutting speed of 18 feet per minute, this would require 13 hours 58 minutes. It would be impossible to get a tool that would stand to cut nearly 3 miles of shaving without getting dull, and the time would be considerably more than necessary. On such a piece as this, the feed would be increased to nearly 1 inch per revolution and the speed reduced to about 15 feet per minute. This would reduce the length of the shaving to 1,508 feet, and at 15 feet per minute would require 100½ minutes, or 1 hour 40½ minutes. This reduces the time to one-tenth the original and makes it possible to use a tool that will last throughout the cut.

CHANCES FOR ERROR IN LATHE WORK.

30. General Consideration.—The chances for error in machine work are numerous. No sooner is one difficulty overcome than another appears. The workman must never take anything for granted regarding the accuracy of a machine or the work it is producing until he has made sure that all is right by a personal investigation. Even then he must be on the watch, or errors will creep in that are unexpected. These small errors that occur in lathe work become more numerous and troublesome as the degree of accuracy is increased. Many things that would not be noticeable in an ordinary line of work would become very important in the case of accurate work.

Many of the chances for error that occur may be found and illustrated in a simple piece of cylindrical turning. They may be due to: (1) *spring of the tool;* (2) *spring of the work;* or (3) *inaccurate adjustment of the machine used.*

SPRING OF LATHE TOOLS.

31. Factors Governing Spring of the Tool.—The amount that the tool will spring depends on the position it holds in relation to the work; on the rigidity of the tool; on the closeness of fit between the tool block and the slide; on the stiffness of the shank of the tool; and on the shape of the tool.

32. Position of the Tool.—It has been shown, Fig. 66, *Lathe Work*, Part 3, that when the point of a tool is set above the center of the work, as it bends in its shank the point tends to follow in an arc of a circle described about the bending point. If this arc cuts into the work, the tool, following in that path, will spring deeper into the work. If the tool is so located that when it bends or springs, the arc described about the bending point moves away from the work, then the tool will spring away from the work. It would seem from this that the best place to set the point of the tool would be level with the center, so that, if the tool springs, it will not spring into the work. A tool properly shaped for this position would have very little front rake, and its keenness would be given entirely by increasing the angle of top rake. Such a tool is absolutely required for taper turning, but, for ordinary turning, other conditions arise, making it objectionable. It may be seen that when this tool is used, the total force acting upon it is in a direction tangent to the diameter of the work at the point of the tool.

33. When a tool without front rake is used, the force will be directly down, or perpendicular to the top of the lathe bed, in the direction of arrow *D C*, Fig. 5. As increased front rake is given to the tool, and it is set higher on the work, the line of force changes its direction, so that if the front rake is 30°, the line of force acting against the point of the tool at *O′* will be in the direction of the arrow *B A*. When the force on the tool is in the

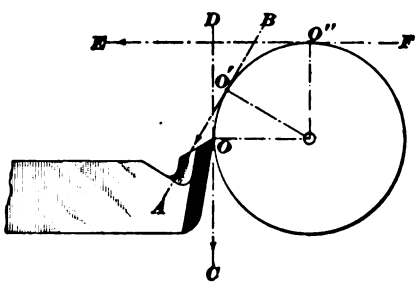


Fig. 5.

direction of the arrow BA, it tends to force the tool block back from the work; this causes some pressure on the cross-feed screw. If the tool had still more front rake and were set higher, the pressure on the cross-feed screw would increase, and if the tool could be set as high as the point O'', the force of the cut would be in the direction of the line FE, which would be entirely against the cross-feed screw. This pressure against the cross-feed screw is very desirable. It holds the tool block back and takes up the lost motion that may be in the screw, so that, when an adjustment is being made, any partial turn of the screw at once acts in moving the tool block. It also allows the tool to be held in such a position that there is little danger that the pressure of the shaving on the top face of the tool will pull the tool and tool block forwards, thus taking up the lost motion in the cross-feed screw.

34. It will be seen from Fig. 6 that when a tool is set at the center and ground with much top rake, the pressure of the shaving on the top face is in the direction of the arrow a. This is so nearly parallel to the line of the cross-slide that if the slide is loose or the screw has lost motion, the tool will tend to slide into the cut. If the tool is set higher, this force on the top face is in the direction shown in Fig. 7, and there is little tendency to drag the tool into the cut. Practice, therefore, has settled upon tools with a fair amount of front rake, which allows them to be set above the center of the work. This gives the desired pressure against the cross-feed screw.

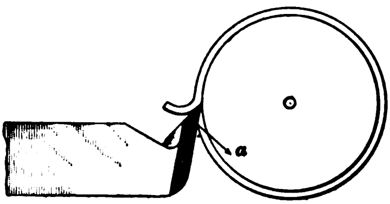


FIG. 6.

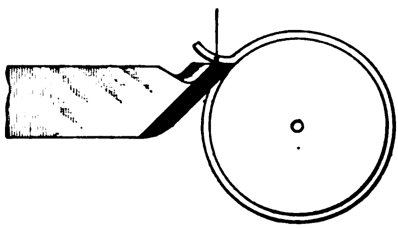


FIG. 7.

35. Spring of the Tool Caused by Variations in the Depth of Cut.— If, in turning a piece, an attempt is made to finish the work very close to size with the first cut, leaving a very light cut for the last, the following results may ensue: The tool is started and the cut taken for a short distance, and, by a series of fine cuts, the work is brought to the desired diameter shown at *a*, Fig. 8.

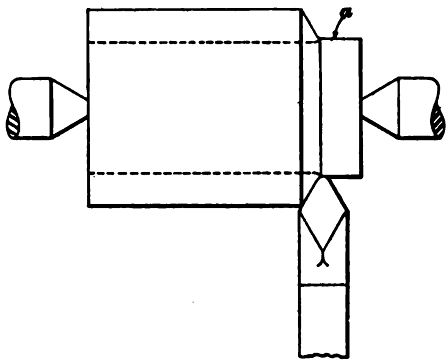


FIG. 8.

The feed is thrown in and soon the tool starts in the heavy cut. The result is that as soon as the heavy pressure comes upon the tool, it causes it to spring and take a still heavier cut. The piece will therefore be turned smaller in diameter, as shown by the dotted lines, and, in many cases, may make the piece below the desired size. This is one reason why at least $\frac{1}{64}$ inch should be left for finishing.

Suppose another case in which a casting or a forging has a large lump on one side, Fig. 9, which must be turned off. Because of the form of the work, the shaving will be of different thicknesses, and, consequently, there will be different pressures upon the tool. This will cause the tool to spring to various depths in the work, with the result that the piece will be neither round nor true. It will be evident that a second finishing cut will be necessary if any degree of accuracy is desired.

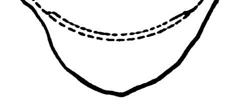


FIG. 9.

36. Methods for Reducing the Error Due to the Spring of the Tool.—The possibilities of error due to the springing of the tool are guarded against by using tools with heavy shanks, clamping the tool very close to the cutting edge, and in adjusting the tool block so that there is no lost motion in the slide. With these precautions, work may be performed, so far as the tool is concerned, with sufficient accuracy for all ordinary machine construction. In discussing the spring of the tool, it has been assumed that the work was very rigid, so that all the spring occurred in the tool. The tool, however, must not be held responsible for all error, since much is caused by the spring of the work.

SPRING OF THE WORK.

37. Effect of the Weight of the Work on Its Spring.—Any action that may cause the work to bend or deflect so that its axis is not a straight line will cause the work to be untrue. If the piece is short and its diameter great, the spring is less than when the work is long and slender.

In long pieces, the weight of the piece between the centers is sufficient to demand attention.

38. Effect of the Force of the Cut on the Spring. The force required to turn a shaving acts against the tool, tending to spring it down, and reacts in the opposite direction, tending to bend or spring the work up. When the tool is starting at the end of the work, there is less deflection than when it has reached the center. If a bar be supported at the two ends and a load applied at the center, it will deflect more than if the load is applied very near the ends. Because of this greater deflection at the center of the work, the tool cannot cut so deeply; consequently, the work, when turned, will be larger at the center than at the ends. This must be corrected by taking very light finishing cuts, or, in the case of long slender pieces, the work must be supported by the use of steady rests.

SPRING DUE TO METHOD OF DRIVING.

39. Action of Bent Tail-Dog in Springing the Work. — Probably as much spring in cylindrical work is produced by the imperfect methods of driving or rotating the work in the lathe as in any other way.

The ordinary bent tail-dog so commonly used produces a variety of strains in the work, some of which are constant and some variable. All, however, tend to distort the work.

These forces may be considered separately. First, there is a leverage from the point of the live center. The amount of this leverage depends on the length of the live center. This is shown in Fig. 10, which represents a side view of a

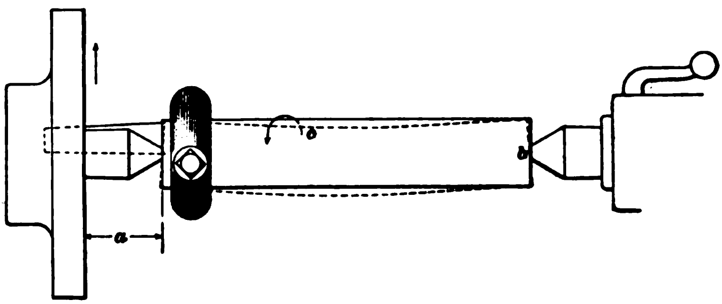


FIG. 10.

piece of work between the centers. The tail of the dog is at the back of the machine. Suppose the end *b* of the piece be clamped rigidly so that it cannot turn. If power be applied to the lathe, the work will tend to turn in the direction of the arrow *c*. Since it cannot, it puts the piece under such a strain that it springs it. The leverage is represented by the distance *a* that the lathe center projects beyond the face plate. The force of the face plate, which tends to lift the tail of the lathe dog, acts from the point of the center as a fulcrum and tends to bend the work down, as shown by the dotted lines. If the lathe center were longer, there would be a greater force tending to spring the work because of the increased length of leverage *a*.

40. When the tool begins to cut at the end *b*, the resistance of the cut at this point acts the same as if the work were clamped at this end as just described. This produces the same effect, though not so great, as clamping the end, for, with a tool, the strain can never be greater than that required to cut the shaving. As the tool feeds along, this resisting point approaches the point of the live center or the fulcrum from which the work bends. The result is that the amount of spring of the work will change. Here we have a changing force tending to spring the work; this force depends on the position of the tool along the work.

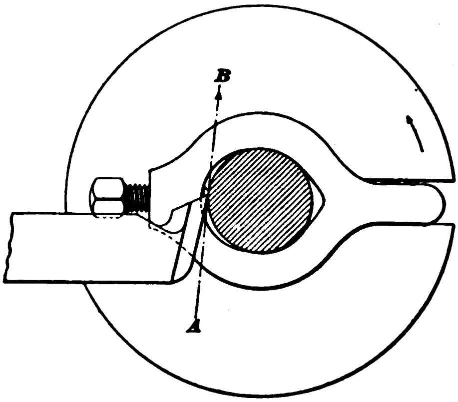


FIG. 11.

41. Suppose, in the next case, that the tool is cutting in a position midway along the length of the work. A section through the work is taken at this point, as shown in Fig. 11. This shows the tool at the front with the tail of the dog diametrically opposite. As the work revolves in the direction of the arrow, the force required to turn the shaving is made with an upward pressure of the tool. This force tends to

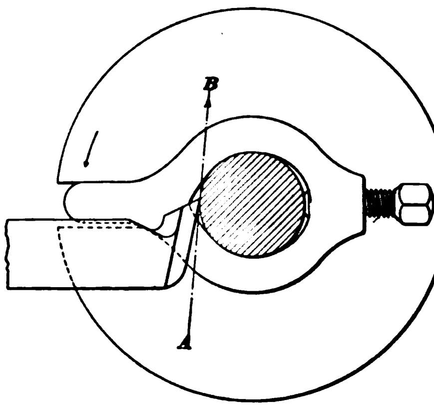


FIG. 12.

spring the work up in the direction of the arrow *A B*. The force required to revolve the work tends to spring the work down, since the dog is at the back of the lathe, and the forces act as shown in Fig. 10. In this case, we have two forces tending to spring the work in opposite directions and tending to balance each other—one, the force of the cut, the other, the pressure on the lathe dog.

Suppose the work makes half a revolution so that the tail of the dog is at the front, as in Fig. 12. While in this position we will have the force of the cut in an upward direction *A B* as before, but the pressure on the tail of the dog is now in the same direction. Hence, we have two forces, both tending to spring the work up. In the first case, it is the difference of the forces that tends to spring the work. In the second case, the sum of the forces acted to spring the work up. Here, again, because of the varying forces, various degrees of deflection occur.

42. When a straight-tailed dog and driving pin, as shown in Fig. 13, are used, the conditions are reversed, the effect of the leverage of the bent tail-dog being entirely eliminated, so that when the dog is at the back, both forces tend to spring the work up, and when the dog is at the front, the two forces are opposite and tend to balance each other.

CORRECT METHODS OF DRIVING THE WORK.

43. Straight Tail-Dogs.—Fortunately, these complicated strains arising from the ordinary methods of driving the work may be eliminated by changing the driving devices. The distortion shown by Fig. 10 may be remedied by using a straight-tailed dog and a driving pin in the face plate, as shown by Fig. 13. By this method, a joint is obtained between the pin and the dog. This breaks the leverage *a*, Fig. 10, and so eliminates that bending strain.

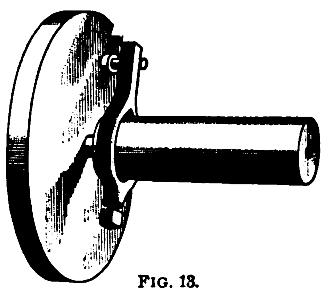


FIG. 13.

44. The variable forces represented in Figs. 11 and 12 may be balanced by using a two-tailed dog and two driving pins in the face plate, as shown by Fig. 14. When the work is thus driven, the two forces at the end of the dog balance each other, and the only force remaining that tends to spring the work is the upward force of the tool. If the pressures at the end of the dog do not balance, the same trouble that is found with the single-tailed dog will appear. Great care, therefore, is necessary in adjusting the driving pins in the face plate so that an equal pressure will be brought against each pin. This may be accomplished in some instances by moving one of the pins in the slot of the face plate in or out from the center. Since the tail of the dog and the slots in the face plate are not parallel, moving the pin toward the center will bring it against the dog, and moving it from the center will move it away from the dog. The pressure on the pins may be tested with pieces of paper put between the dog and the pins. The work is turned backwards by hand on the centers, to hold the dog against the pins, and the paper tested by pulling. Any inequality in pressure may thus be detected.

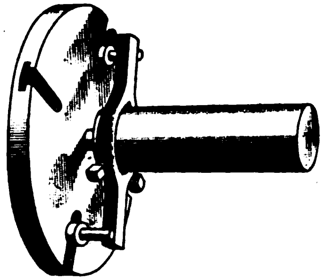


FIG. 14.

45. Equalizing Dogs.—Instead of adjusting the pins each time, an **equalizing dog,** Fig. 15, may be used. In this case, the dog is adjusted to the pins by tightening or loosening the screws *a*, *b*, as may be necessary. While it is very desirable to drive the work by the methods described, the difficulty in adjusting the dogs and the uncertainty that they will remain as adjusted do not warrant their general use. When some device can be used that will automatically balance or

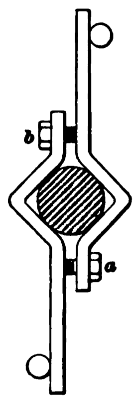


FIG. 15.

equalize the pressure on the pins, this method becomes more practicable. Many forms of equalizing dogs have been devised. They serve better for small than for large work. A very convenient and successful method of equalizing the pressure on the pins when the two-tailed dog is used, is by means of the equalizer or driver shown in Fig. 16. This consists of a plate carrying the driving pins *p*, *p*. This plate is fastened loosely to the front face of the face plate by means of bolts or studs screwed solidly into the face plate but fitting loosely in the long slots *s*, *s* in the driver. These studs keep the driver from slipping around on the face plate, but give it freedom to move a distance along the slots equal to their length. Suppose, in using, the greater pressure of the dog first comes against the top pin. The pressure would force the entire driver back, which would slide the lower pin up to the dog. As soon as the pressures balanced each other, the plate would stop sliding and continue to keep up the equilibrium.

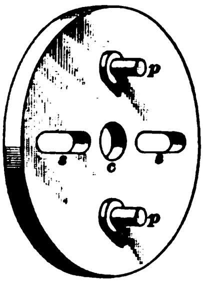


FIG 16.

ERRORS IN THE MACHINE.

46. Poor Adjustment.—Imperfect work may often be traced to the poor adjustment of the machine or to the fact that the machine is much worn. When the lathe is much worn, it will be noticed that the spindle is slightly out of line with the bed and that it will not bore holes properly or face surfaces true. A great deal of wear comes upon the lathe bed at a part quite near the headstock, since the greater part of the work turned upon the lathe is short, and the carriage moves over this part more than any other. If the gibs that hold the carriage to the bed be adjusted so that the carriage is in good adjustment at this worn place, it will be found that when longer work is to be turned, the carriage will not slide along the unworn part of the bed.

47. Accuracy of New Lathes.—In the manufacture of lathes, all parts are carefully tested to see if the line of the spindles is exactly parallel with the bed, the carriage square across the bed, and all parts correct. All these tests require that the lathe shall produce work within a limit of from .00025 to .001 inch, depending on the kind of work for which the lathe is to be used.

The accuracy of the machine is not so important as the skill of the operator, for a skilful and careful workman will overcome the inaccuracies of the machine, but the careless workman will have trouble even with the best machine.

LATHE CENTERS.

48. Shape of Lathe Centers.—Fig. 17 shows the most common form of lathe center. The sides *A B* and *C D* form an angle of 60° with each other and 30° with the center line. For very heavy work some prefer a blunter center, as shown in Fig. 18. This form is used because of its apparent strength, but while there is less danger of breaking the point of the center, it cannot hold work to run as truly as the 60° angle. The cause of the breaking of 60° angle centers is generally due to the imperfect fit in the center hole, which brings all the strain on the point of the center. When the centers are 90°, there will be a greater tendency to force the centers apart and out of the center hole, due to the weight of the work and the force of the cut, than if the centers are shaped as shown in Fig. 17. Suppose two pieces of work are being turned on lathes with these two forms of centers. If each center were backed out of its work the same

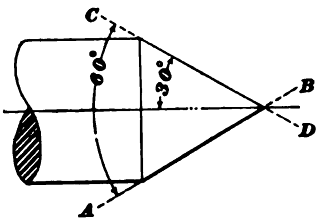


FIG. 17.

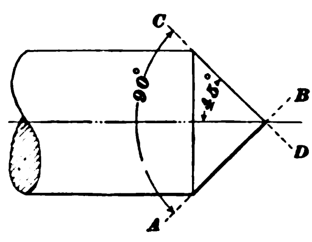


FIG. 18.

distance, the work on the 90° center would drop more out of line than the work on the 60° center; therefore, to keep the work up in line with the spindles, the adjustment of the 90° center must be closer than for the 60° center. Many builders of heavy machinery use a center having a 55° included angle in place of a 60° or a 45° angle. Such a center combines many of the good points of both of the other forms.

49. Necessity of True Centers.—The live center should run true in the headstock. The dead center should be sharp and smooth. If a live center were out of line so that its point wobbled slightly and a piece of work were turned on it, the work might be round and straight, but the turned part would not be true with the center hole. A piece may be turned to various diameters and shapes on untrue centers and the different cuts may all run true with each other, provided they were all taken at one setting. If, however, the dog had been loosened and the work given a half turn, the dog being again clamped, the piece just turned will run out of true an amount double the error of the live center. When, therefore, a piece is partly finished on one machine and then taken to another for final finishing, it is necessary that the centers be true on each machine.

50. Hard or Soft Centers.—The dead center is always hardened and tempered. The live center may or may not be hardened. Some leading manufacturers prefer a soft live center, since it may easily be put in place and a very fine cut taken from it as it revolves in the headstock. This makes it practically true and little time is expended in truing it, but because of its softness, it is easily made untrue by bending or bruising. If a center, after being trued, is hardened and tempered and then put back in its place, it will be found that it no longer runs true, owing to the warping or springing of the center in the operation of hardening and tempering. To use hardened live centers successfully, they must be made true, as they revolve in the spindle, by grinding. Sometimes the live center is hardened and the temper drawn to such a point that it can just be turned.

51. Grinding Lathe Centers.—To grind lathe centers, a properly constructed grinding machine should be used. There are very many forms of center grinders on the market that are sufficiently convenient to warrant their use in many shops. Fig. 19 shows a very convenient form and its application to the lathe. In setting this grinder in the lathe, the shank *a* is passed loosely through the tool post

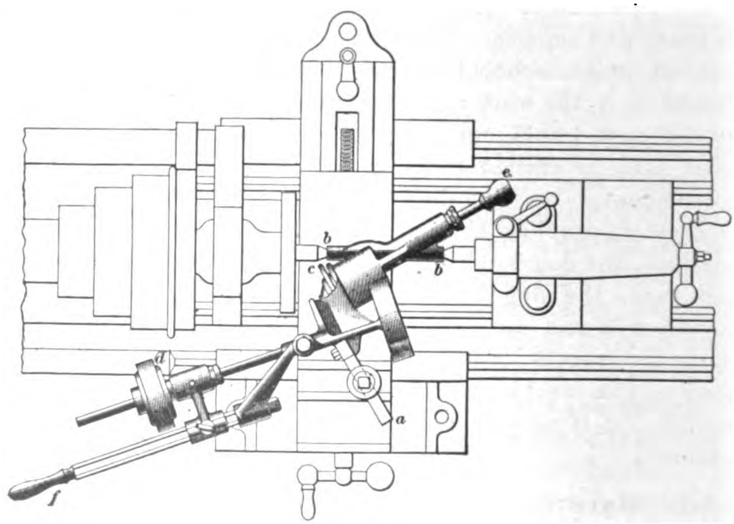


FIG. 19.

of the lathe, while the lathe centers come into the reamed center holes *b*, *b* in the grinder. These center holes have been so located that they hold the axis of the grinding wheel *c* at an angle of 30° with the axis of the lathe. After adjusting the rest to such a height that the shank *a* bears fairly on its bottom, it is clamped rigidly in the tool post. The dead center may be removed and the machine adjusted so that the emery wheel comes against the lathe center. A rubber wheel *d* is pressed against the cone pulley by the handle *f*. The lathe is run at its fastest speed backwards, while the emery wheel is moved along the face of the center by moving the shaft operated by the knob *e*.

52. When both centers are to be trued, the dead center should be trued first. It is put in the place of the live center, and, while there, ground smooth and true. It is well to polish the dead center with emery cloth and oil. The live center may next be ground and left in place after grinding, so that it will run true. Before grinding or truing a center, great care should be taken that the center hole in the spindle is very clean before the center is put in place. If any dirt or specks of shavings are between the center and the hole, it will hold the center away at that point and make an incorrect fit. The center might be trued while in this position and it would run true until the dirt was removed, whereupon it would at once be untrue.

53. Removing the Live Center.—Live centers should never be removed from the spindle of the lathe unless it is absolutely necessary. When chucks are used on lathes, and rods are passed through the spindle, it becomes necessary to remove the centers. If only for plain chuck work, the center hole should be plugged with waste, as it is very difficult to clean the dirt that accumulates from the spindle when the hole is left open.

It is often the case that the center hole in the spindle is not absolutely true and that if the center be true in one position in the hole, it would run untrue if given a part of a revolution to another position. In such cases it is best to mark a line along the length of the lathe center *b*, Fig. 20, and draw a radial line *a* on the nose of the lathe spindle. The center

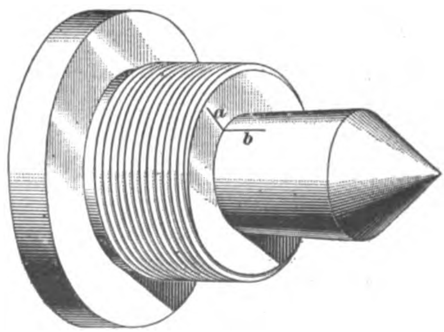


FIG. 20.

can always be put in the same relative position to the spindle by making the marks *a* and *b* coincide, as shown. After lathe centers are once made true, they should be cared for. Care should be taken to keep the dead center well oiled. When the live center appears to be true, but has not been recently ground, its truth may be tested by using an indicator. ~~These indicators will be described later.~~

54. Lining Lathe Centers.—In order to turn work properly between the lathe centers, it is necessary that they be "in line" with each other and with the line of tool motion. If the centers are much out of line, as they would be after turning a taper, they may be roughly set by placing the dead center very close to the point of the live center and adjusting until the points appear to be opposite, or the dead center may be set by the use of the scale or zero mark on the tailstock. To adjust the dead center still further, a test bar about 1 foot long may be used. It is carefully centered with its ends each finished to some one diameter, while the middle portion is slightly reduced. This bar is held between the lathe centers and the tool adjusted to touch the bar at the live-center end. After the tool is thus adjusted, the carriage is moved to the dead-center end and the tailstock adjusted so that the tool just touches the bar at this end. Instead of using a tool in the tool post, an indicator may be used. This will indicate how much the centers are out of line. After the centers are lined, the work being turned should be carefully calipered as the cut proceeds, to be sure that the "lining" was correctly done.

55. Wear of the Tool.—Sometimes when the centers are correctly lined, the work may be slightly tapered, growing larger at the headstock end, owing to the wearing away of the point of the tool, thus making the work larger.

ERRORS IN SCREW CUTTING.

56. Errors Due to Imperfect Leadscrews.—The chances for error in cut screws in the lathe are numerous. The chief error is the inaccuracy of pitch due to an imperfect leadscrew. The best remedy for this sort of error is to use a leadscrew that is known to be perfect within a given limit. All the lathes in a shop should be tested, and all particular screw cutting given to those that have the most perfect leadscrews. In cutting long screws, the work frequently becomes heated above the temperature of the leadscrew. The result is that the screw being cut will be short when cool. The remedy is to keep the work cool with plenty of oil or water.

57. Cutting Taper Threads.—In cutting taper threads, the taper attachment should be used. *A true*

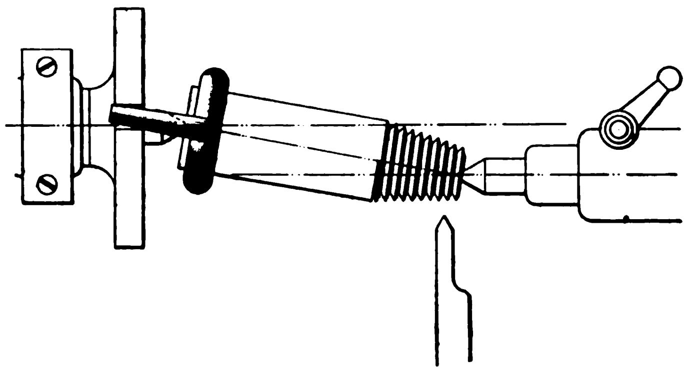


FIG. 21.

taper thread cannot be cut by setting over the center. If the point of a thread be followed around a screw, it will be found to follow in the line of a true curve. This curve, which is made by the sharp point of a **V** thread, is called a **helix.** If a thread should be so cut that, in following this curve, it would advance rapidly along the screw for a part of a turn, and slowly for another part of the turn, the rate of advance not being uniform, then the thread would not be a true thread, but would be known as a *drunken thread.*

58. Suppose that it is desired to cut a very blunt taper by setting over the center, as shown in Fig. 21. Let Fig. 22 represent an end view of the same piece, with the tailstock removed and the work still in position. Suppose the line *A B* be drawn through the axis of the work and through the lathe dog, as shown. It will be noticed that the notch in the face plate is slightly behind its perpendicular position. This is due to the angularity of the tail of the dog, caused by setting over the dead center. This angularity may be more clearly seen by reference to Fig. 21. Suppose we wish to give the work a quarter of a turn. As the work and the machine revolve, the tail of the dog slides into the notch of the face plate until it is directly at the front of the lathe in a horizontal position. At the end of the next quarter of a turn of the work, when the line *A B* is inverted, as shown in Fig. 23, it will be seen that the notch in the face plate has passed beyond the lower quarter point. After the next half turn, the work would be in the position shown in Fig. 22.

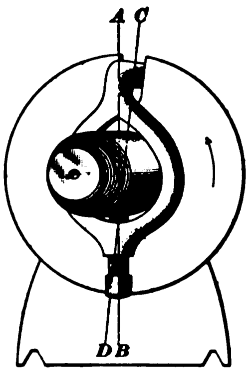


FIG. 22.

It will be seen that during the first half turn of the work, the lathe or face plate made considerably more than half a turn, passing through the angle *a b c*, Fig. 23. During the second half turn of the work, the face plate did not make a complete half turn, as it only passed through the angle *c d a*. This shows that the work did not revolve at a uniform rate of speed with the lathe. While the lathe revolved at a uniform speed, the work first dragged behind and then accelerated until at the end of the revolution they were again together. The feed, however, would be moving the tool along at a uniform rate of speed. When this sort of action takes place in screw cutting, the screw cannot be of uniform pitch, but will be a *drunken pitch*.

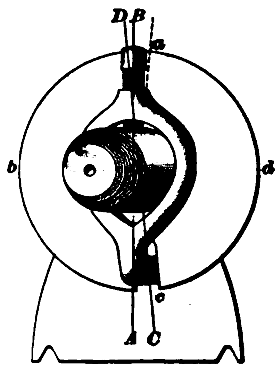


FIG. 23.

FITTING CYLINDRICAL WORK.

59. Meaning of the Term Fit.—The expression "making a fit" may convey a number of meanings to the workman. It may mean that when two pieces are put together they will be free to slide over each other, or that they will be locked together, so that that which would be called a good fit in one instance would be a bad fit in another. The closeness of a fit depends upon the purpose for which it is to be used.

60. Kinds of Fits.—In ordinary machine construction, there are four kinds of fits commonly used. They are: (1) *working* or *sliding fit*; (2) *driving fit*; (3) *force fit*; (4) *shrinking fit*. The first is used for parts that work or slide upon each other, such as shafts, spindles, etc. The last three are used when the parts are put together with the intention of their remaining in a fixed position.

SLIDING FITS.

61. Requirements for a Good Sliding Fit.—The most nearly perfect sliding or working cylindrical fits are those whose surfaces most nearly approach perfect cylinders. There must be sufficient difference in diameter to allow the shaft to revolve freely and to admit oil for lubricating. If the shaft and bearing were exactly the same diameter, the shaft might be turned in the bearing so long as it was kept slightly in motion, but, as soon as it stopped, it would be very difficult to start it again. With such perfect fits, the heat that would be generated by the revolving shaft would cause it to expand so that it would be larger than the bearing. This, of course, would change the sliding fit to a solid fit.

62. Allowances in Sliding Fits.—The closeness of the cylindrical fit depends on the diameter of the work, the length of hole, and the condition of the surfaces. Greater differences in diameter are allowed for large shafts than for small ones. In some small machines, spindles about ¼ inch in diameter will require not over .0005 inch difference in diameter, while a shaft 12 inches would require from .005 to .01 inch.

63. Making Sliding Fits.—To make a good fit, the surface should be smooth and true. If the hole or bearing is finished by boring, the tool should be made to take a very smooth cut. If there is any danger that the work is sprung from the chucking, the pressure should be relieved as much as possible before taking the finishing cut. The work should be tested to determine if it is round and the sides parallel. Whenever it is possible to finish holes by reaming, it is best to do so. Reaming tends to make the holes a standard size and to make the walls of the holes smooth and parallel. When a working fit is being made, it is best to finish the bearing first, as it is easier to fit the shaft to the hole than to bore the hole to fit the shaft. When gauges are at hand, the "cut-and-try" method is done away with, since the holes are all reamed to pass the limit gauge and the shaft also is turned within limits, so that the pieces will fit each other with sufficient accuracy.

64. Standard or limit gauges are not always used, especially when but a few pieces of a size are to be fitted. In this case, the hole that has been finished must act as the gauge for the shaft. The closeness of the fit depends greatly, as before stated, on the smoothness of the surfaces. Suppose the bearing has been reamed, but the shaft finished with an ordinary finishing cut, and the shaft just slides easily into the bearing. A section through the work showing the conditions of the fit is shown in Fig. 24. Here the bearing touches only upon the points of the tool marks, which are shown in somewhat exaggerated form in the figure. It

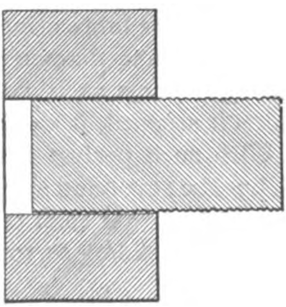


FIG. 24.

may be seen that if such a fit were allowed to pass, it could not wear long, since the pressure would come on the points of the tool marks, causing them to wear away rapidly. Furthermore, because of the spiral threads or tool marks around the work, it would be difficult to keep the bearing lubricated, the spiral thread tending to drive the oil out of one end or the other of the bearing, depending on the direction of the rotation of the shaft. Because of a lack of oil and the narrow bearing points, such a fit would soon wear loose.

This same wearing action would take place if the shaft were smooth and true, but the bore left with clearly defined tool marks.

65. To make the fit as it should be, the shaft should be turned with a smooth cut to such a diameter that it would not quite enter the hole because of the projecting tool marks. These tool marks should be carefully removed by filing or by grinding. The best class of work is now being finished on grinding machines, since this method finishes the work smooth and true and in less time than it can be done by filing. When, however, it is necessary to fit by filing, care should be taken that it is evenly done. If the turning is correctly done, it will need only a few strokes of the file to remove the desired amount. The less filing necessary after the tool marks are removed, the better the chances for a good fit.

DRIVING FITS.

66. Meaning of the Term Driving Fit.—In a **driving fit** the plug or shaft is made slightly larger than the enveloping piece, and they are put together by driving. This method is used when the two pieces are intended to keep a fixed position in relation to each other.

67. Allowances for Driving Fits.—The **allowance** for driving, which is the difference in diameter, depends on the diameter of the work, the lengths of the holes, the condition of the surfaces, and the strength of the enveloping piece. If the holes are long, less difference in diameter is required than when the holes are short. When the hole and the shaft are each finished smooth, a very slight difference in diameter makes a great difference in the closeness of fit. If the surfaces are rough, a much greater difference in diameter is allowable. When the surfaces are smooth, a difference of from .0005 to .001 inch will make a very tight fit on work about 1 inch in diameter, while for such a fit as shown in Fig. 24, where the surfaces are rough, a difference of .002 or .003 inch will be necessary. When these rough pieces are put together, the roughness of the faces is worn down as they are driven over each other, so that, if they should be driven apart, the surfaces would be found to be much smoother than before.

68. Making a Driving Fit.—When putting pieces together with a driving fit, the surfaces should be oiled. The piece into which the shaft is to be driven should be set upon a firm foundation and the shaft driven to place with a hammer or sledge. Care should be taken not to bruise the work when driving it; consequently, a block of wood or lead is used to strike upon. Sometimes the work is of such shape and in such a position that a *ram* can be rigged for driving the pieces together. This consists of a beam supported from above by ropes or chains so that it hangs in a horizontal position, level with the work. The beam is drawn back and then pushed forwards so that its end strikes against the work. This makes a very effective way of driving. If the work is large and the fit is very close, the driving may be helped by using clamps and bolts, which can be arranged to assist in drawing or forcing the pieces together. With the combined forces of the bolts and the ram, the shaft can be driven to place.

FORCED FITS.

69. Use of Forced Fits.—When the work is large, and there is a large amount to be done, the pieces are forced together by hydrostatic pressure. When fits are prepared to be put together in this way, they are called **forced fits.** This method of putting pieces together is used for putting engine cranks on shafts, or for putting crankpins in the cranks, and for a great variety of similar work. It is probably used more extensively for putting the wheels on car axles than for any other purpose.

70. Allowances for Forced Fits.—The allowance for forced fits is a little more than for driving fits. The amount, however, depends on the materials used, the size of the hole, its length, and the condition of the surfaces. It is the practice of some engine builders, who put the cranks and crankpins together with forced fits, to allow about .0025 inch difference for each inch in diameter. This requires a pressure of from 10 to 13 tons per inch in diameter, depending on the length of the hole, to force the pieces together. This pressure is estimated for diameters that range from 3 to 8 inches.

In fitting car wheels and axles, they are required to go together within the limits of certain pressures. One railroad company requires that, for certain classes of wheels, the pressure required to force the wheel on to the axle shall not be less than 25 tons nor over 35 tons. On an axle 7 inches long and 4¾ inches in diameter, an allowance of about .007 inch is made. This requires a pressure of about 30 tons to press the wheel on.

71. Making a Forced Fit.—Considerable skill is required by the workmen to make these fits, yet, after a little practice, they do it rapidly and can tell within a few tons the exact pressure that will be required to force the wheel into place. In calipering the axles, the exact difference is not always measured by the workman. He may use a snap gauge that has been made sufficiently large to allow for the fit; or, if calipers are used, he may set them the correct size and test the work so that a certain pressure is required to force them over the work, experience having taught him how great this pressure should be.

SHRINKING FITS.

72. Meaning of the Term Shrinking Fit.—A **shrinking fit** refers more particularly to the method of putting the parts together than to the fit itself. The pieces are prepared in much the same way as for the forced fit. When the pieces are put together, the outer piece is heated, which expands the hole sufficiently to let the plug drop in. When the outer piece again cools, it contracts sufficiently to grip the pin with great force.

73. Use of Shrinking Fits.—When the pieces are large and strong and of certain shapes, pressure may be used for putting them together without danger of bending or distorting them. On other classes of work there is no chance to drive or force the pieces together; for example, putting the tires on locomotive wheels. For such large diameters, the difference of diameter in the fit would be so great that it would be difficult to start the tire on the wheel and very powerful presses would be required. By heating the tire, it expands sufficiently to let it drop over the wheel center with perfect freedom. Shrinking fits are very often employed on small work in shops that have no press to put forced fits together.

74. Allowance for Shrinking Fits.—The amount of allowance for shrinking fits is generally a little more than for forced fits. A fair rule for small work in making shrinking fits is to allow about .003 inch for the first inch in diameter and to add .001 inch for each extra inch. The amount allowed for locomotive drivers varies, depending on the size of the wheel and the service. Most locomotive builders allow from $\frac{1}{100}$ to $\frac{1}{80}$ inch to the foot in diameter.

75. Assembling Shrinking Fits. — In making a shrinking fit, the piece that has been bored is heated slightly and evenly. Ordinarily, a heat just sufficient to show a dull red is more than is required. Care should be taken that the piece is never hot enough to scale. The diameters should previously be tested so that there will be no danger that the pieces will not go together when one is heated. If too much allowance has been made, the pieces sometimes catch before the shaft is quite through to the desired place. Unless it is instantly removed, it will bind so that it will be impossible to move it either way. This is because the shaft begins to expand as soon as it enters the bored piece, and if the difference in diameter is slight at first, it will be very quickly made up by the rapid expansion of the shaft. Thus, it may be seen that great speed is necessary in putting the pieces together when shrinking fits are used. This is especially true on small work. When the pieces are larger, such haste is not important.

In shrinking smaller pieces, as soon as the plug is in place, water should be applied to keep it cool. The enveloping piece must not be cooled too suddenly or it is liable to crack, especially if it be cast iron. If a gear-wheel is being shrunk on a shaft and too much water is applied to the shaft and the hub of the wheel, there is danger that some of the arms will crack. If a cast-iron disk is being shrunk on a shaft and the circumference of the disk be rapidly cooled, there is danger that a radial crack will appear at the edge.

76. Building Up Large Guns.—There is probably no finer example of making shrinking fits than that illustrated in the building of the large guns now constructed for the army and navy. These guns are built up, or made of a number of pieces. The first part is a long tubular piece the length of the gun. Over this tube is fitted and shrunk a number of bands or hoops called **jackets**, and over these is fitted another set of hoops. Great skill is required in turning the jackets and the tube so that when the jackets are shrunk on, they will exert a certain amount of compressive force. This compressive force varies along the length of the tube. A corresponding difference or allowance in the fit must be made to give the various pressures desired. The average allowance is from .0012 to .0015 inch per foot. It may be seen that great skill is required to bore and turn these pieces to the correct size, as a difference of from .001 to .002 inch may be sufficient to cause rejection.

When the jackets or hoops are put on a gun tube, they are first heated by wood or gas fires. When sufficiently hot, they are dropped over the tube standing on end in a pit. As soon as the jacket is in place, streams of water are turned on the tube to keep it cool and to cool the jacket.

LATHE ARBORS, OR MANDRELS.

SOLID ARBORS.

77. Meaning of the Terms Arbor and Mandrel. A **lathe arbor** is a shaft or spindle that may be used when turning the outside of bored pieces by driving the arbor into the bored hole and revolving it between the lathe centers.

The term **mandrel** is very commonly applied to the same article, but is also used for designating a piece or form about which the blacksmith forges a ring, tube, or collar, or for a center about which glass or any similar material is cast, the term *arbor* never being used in this latter sense. The term *mandrel* is also used to designate the support for a circular saw or milling cutter.

78. Shape or Form of Solid Arbors.—Arbors are commonly used on work having a bore of 3 inches in diameter or less. The best forms are the solid ones made from tool steel and hardened and tempered.

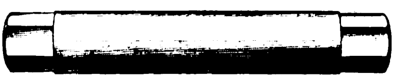


FIG. 25.

Such an arbor is shown in Fig. 25. These arbors are made slightly under size at the ends, for the dog to be put on. The center holes should be carefully made so that they will not be injured by driving. Fig. 26 shows a section through the end of a properly formed center hole in a lathe arbor. It will be noticed that the edges of the center hole are well rounded. This form is given to

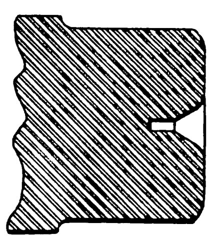


FIG. 26.

the center hole so that if the arbor is bruised on the end when driving, or from any other cause, there will not be so much danger of the center hole being destroyed. If the end of the arbor were flat and it should be bruised near the center hole, a slight bump would be raised on one side of the hole that would be sufficient to throw the arbor slightly out of line. To further preserve the center holes, the arbor is hardened. These center holes should be made with great care, the angle being 60°, so that they will exactly fit the lathe center. In the best made arbors, the center holes are ground true after hardening. The central portion of the arbor is carefully ground to size, being made slightly tapered.

79. The small end of the arbor is generally about the exact size, while the large end is from .002 to .003 inch larger, depending on the length of the arbor and the length of the work to be turned. The large end is distinguished by the size of arbor being stamped upon it. These arbors are ground to standard sizes and should fit holes reamed with standard reamers. The necessity of keeping them true may readily be seen when a pulley or similar piece is to be turned true with a part that has been bored and reamed. It is evident that if the arbor is untrue, the hole will run untrue as the work revolves. The rim or part of the work being turned will be cut true with the machine, but will not be true with the bore. When the finished pulley is placed on a shaft that runs true, the rim of the wheel will wobble. It may be seen that an untrue arbor will always produce untrue work and lead to a great deal of trouble.

Arbors may become untrue from the wear of the center holes and from their being sprung when driven into the work, or by taking too heavy a cut on the work for which they are used

80. Care of Centers of Arbors.—Care should be given to the dead center when the arbor is being used, to keep it well oiled and to see that the arbor does not expand because of heat sufficiently to make it grip on the dead center. When there is danger of spoiling both arbor center and lathe center, a bronze dead center may be used. The bronze is soft enough so that if the arbor becomes dry it will simply wear away the bronze without injury to itself. For certain classes of work, the accuracy of which would not be affected by having the dead center moved slightly during the cut, these bronze centers are very good, but, for the general run of work, it is better to employ steel centers and see that they are well lubricated and not set up too closely.

81. Putting Arbors in the Work.—When an arbor is put in a piece of work, it is usually driven in. The hole and the arbor are coated with oil, to keep the surfaces from cutting, and, while the work is well supported upon the driving block, the arbor is driven in with a soft-faced mallet or hammer. Hard-faced hammers should never be used for driving arbors. Babbitt or rawhide-faced hammers are the best. If the work is small, much driving is not necessary. Judgment should be used, as it will be found that, if the pieces fit well, it will take but little pressure to force the arbor into the work sufficiently to keep it from slipping. The practice of some workmen of driving an arbor as long as it can be moved is bad. When driving arbors, care should be taken to strike fair blows on the end, as untrue blows are liable to spring it.

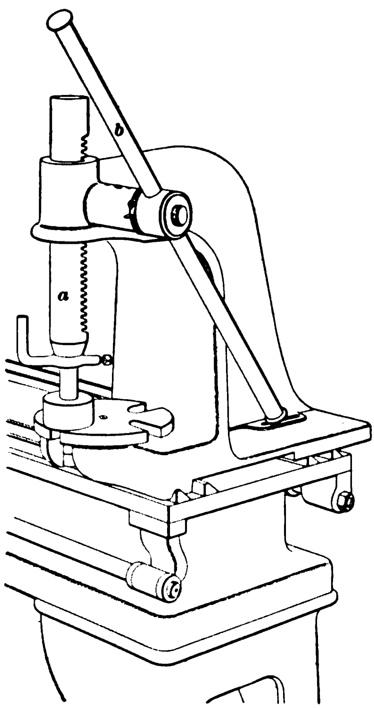


FIG. 27.

82. A far better way of putting arbors in the work is by the use of an arbor press. Fig. 27 shows a style of press used for this purpose. It consists of a heavy cast-iron frame, to which is fitted a plunger *a*, which is operated by means of the hand lever *b*. When an arbor is to be pressed into a piece of work, the work and the arbor are brought under the plunger so that the arbor may be pressed in with a direct, uniform load. These presses are much more convenient for putting in arbors than the method of driving, and they also lessen the danger of springing the work. Sometimes an arbor may be sprung by driving it into a crooked hole, if the hole is long and the arbor slender.

After an arbor is driven into the work with a soft-faced hammer, the center hole should be carefully cleaned before the work is put between the lathe centers. Dirt in the center holes of an arbor has the same result in making work untrue as untrue lathe centers.

83. Heavy Cuts on Light Arbors.—Very often an arbor is sprung by taking too heavy a cut. This is particularly true if the work is large. For small work, the arbor will have sufficient friction in the work to drive it so that a dog may be put on the arbor, but if the work is large and the bore is small, the arbor will not have sufficient friction to drive it. The arbor can then only be used to support the work, while the driving should be done by means of a pin or stud on the face plate. When the work is thus driven, it makes it possible to take heavy cuts, but if a deep, heavy cut be taken on the outside of a large piece supported on a small arbor, the side thrust of the tool will act with such a leverage on the work that it will spring the arbor. Light cuts, therefore, must be taken.

84. Cutting Close to Arbors With a Tool.—When cutting close to an arbor with a side tool, as is the case when facing hubs or similar work, care should be taken not to cut into the arbor with the tool. While the arbor may be hardened, it is not always harder than the tool point.

85. Cast-Iron Solid Arbors.—When solid arbors of large size are to be used, they are sometimes made from cast iron. The ends of such an arbor are drilled and steel plugs fitted for the center holes. These plugs are hardened after the center holes are correctly made and driven or screwed into the cast-iron arbor. When cast-iron boring bars are made, it is better to use hardened-steel center plugs.

EXPANDING MANDRELS.

86. Advantages of Expanding Mandrels.—While the hardened solid steel arbor is the best form, there are inconveniences that arise from its exclusive use. In order to be prepared for all sizes of work, a very large stock of arbors would be necessary. This leads to inconvenience in some shops, while in other shops it is beneficial. Shops doing a great variety of work where all sizes of holes are bored, demand an arbor or mandrel that can be adjusted to slight differences of diameter. Shops that are making a particular line of work where many pieces are turned to the same size are benefited by using the solid arbor; *first*, because it is more accurate in itself; and, *second*, it acts as a second check-gauge on the work. If a piece that has been bored too large gets into the lot, it cannot be finished, since the arbor will not hold the work. When the cost of keeping a lot of arbors up to a standard size is considered, the type of arbor that will expand within certain limits and fit all sizes of holes within these limits is much cheaper than a great stock of solid arbors.

87. Types of Expanding Mandrels.—A number of types of **expanding mandrels** are on the market. Fig. 28

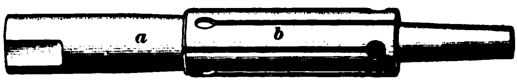


FIG. 28.

shows one type of expanding mandrel. It consists of a tapered arbor *a*, which fits into a tapered split bushing *b*. The bushings are ground round and parallel on the outside.

As the tapered mandrel is driven into the work and the bushing, the latter expands, thus filling the hole. The method of splitting the bushing as here shown allows it to spring and expand evenly within quite a wide range of limits.

88. Another form of expanding mandrel is shown in Fig. 29. This consists of a steel arbor that has been centered with the same care found necessary in solid arbors.

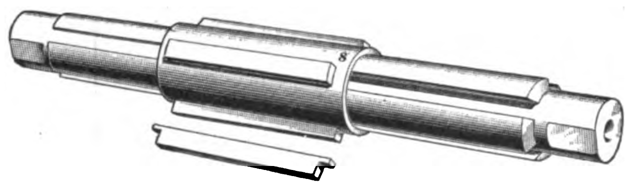


FIG. 29.

Four rectangular grooves are cut along its sides, these grooves being cut deeper at one end than at the other. A sleeve *s* fits nicely over the arbor. This sleeve has slots cut in its sides, which come opposite the grooves cut in the arbor. A hardened-steel jaw is fitted into each groove and slot. As the sleeve moves along the arbor, it carries the jaws with it, and, because of the varying depths of the slots, the jaws are moved in or out, depending on the direction the sleeve is moving upon the arbor. With this type of mandrel, different sets of jaws of different heights may be used, which will give it a range for different sizes of holes. When the work is thick enough to be stiff, so that it cannot be sprung, these mandrels are very convenient, but if the work on the mandrel is slender, there is danger of springing it, due to the outward pressure of the four jaws.

89. Cone Arbors.—For some classes of work, a cone mandrel, as shown in Fig. 30, is used. This consists of the arbor part *a*, to which are fitted two cone-shaped pieces *c*. One piece is held from sliding along the arbor by the shoulder *s*. The work is placed between the cones, and the second cone tightened against the work *w* by the nut *d*. The cones are kept from turning on the arbor by keys. This

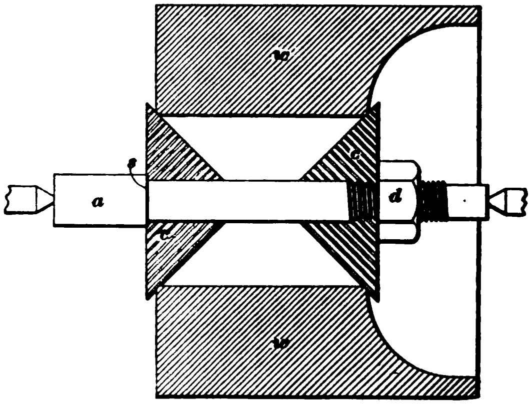


FIG. 30.

is a very convenient way of holding work to be turned that does not require great accuracy.

90. Special Expanding Arbor. — Fig. 31 shows another form of arbor for carrying bored or cored work that is being turned and faced. A heavy bar is drilled and tapped so that screws may be put in around the bar, as shown

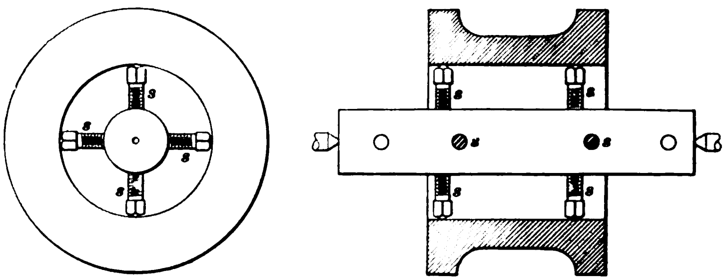


FIG. 31.

at *s*, *s*. The circles around the bar in which the screws are placed are at such a point that the screws come near each end of the work. The work is adjusted and held in place by unscrewing the screws from the bar, thus bringing the pressure on the heads of the screws.

91. Bridges in Castings.—When heavy cast work has a tapered cored hole that would make it difficult to use the arbors just described, it is very good practice to cast a bridge across the end in which the center hole may be placed. Such a bridge is shown at *b*, Fig. 32. A similar bridge should be cast at the other end of the work. After the turning is done, these bridges can easily be broken out if so desired.

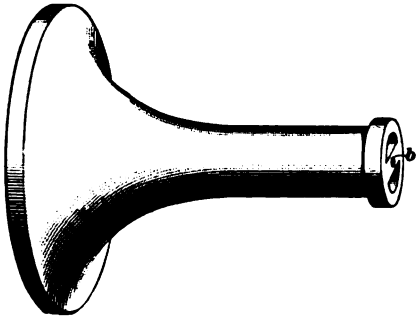


FIG. 32.

NUT ARBORS.

92. After a nut is tapped, it is still further finished by facing so that it will be true with the thread. This facing is usually done by screwing the nut on an arbor that has been threaded up to a shoulder. Such an arbor is shown in section in Fig. 33 with the nut in place. It will be seen that if the nut has not been tapped squarely and that if it fits loosely on the arbor, it will first come against the shoulder at the point *a*. As soon as this point touches, the nut will be rocked on the thread so that the axis of the nut thread will not be parallel to the axis of the arbor. If the nut should be faced while in this position, the face would not be true with the tapped thread.

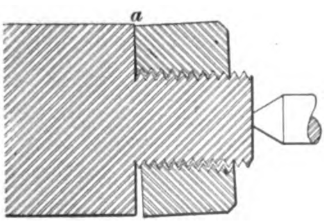


FIG. 33.

93. To overcome this difficulty, some sort of equalizing washer must be put between the shoulder of the arbor and the nut, so that the nut cannot be thrown out of line, but will be held back squarely against the threads. Such a device is shown in section by Fig. 34. The shoulder of the arbor is rounded to a spherical shape, while the equalizing washer is concaved to fit the round end of the arbor. This makes a joint similar to a ball-and-socket joint. When the

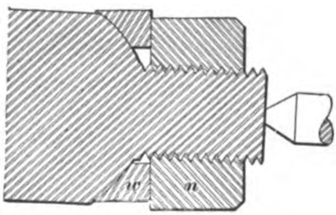


FIG. 34.

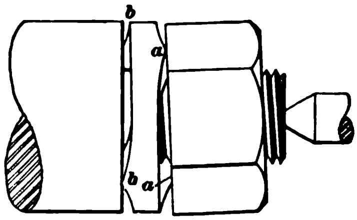


FIG. 35.

nut *n* is screwed against the washer *w*, and it bears heavier on one side than the other, the washer at once rocks on the rounded end of the arbor and adjusts itself to the face of the nut. Sometimes an equalizing washer, as shown in Fig. 35, is used. The shoulder of the arbor in this case is squared. On one face of the washer are two projecting points *a*, *a* diametrically opposite each other. On the other face of the washer are two other points *b*, *b* diametrically opposite, but quartering with those on the first side. When the nut is screwed against the washer thus supported, it is free to rock in any direction, with the result that it centers itself with its threads and not with the face of the arbor.

LATHE WORK.

(PART 5.)

THE TURRET LATHE.

1. Characteristic Feature of the Turret Lathe.—Probably no one machine deserves greater credit for helping along the movement toward rapid production, and, consequently, the reduction of cost of manufactured articles, than the **turret lathe.** Its characteristic feature is found in the turret, which is made to bring, in quick succession, a number and variety of cutting tools to act on a bar or rod passed through the hollow spindle in the headstock and held in a chuck.

2. Action of the Turret.—The turret is mounted on a slide, parallel to the line of the live spindle, and occupies a position relatively the same as the tailstock on the ordinary lathe. It is made to slide upon the base either automatically or by a hand lever or wheel. After the tool, which is held in one of the radial holes in the turret, has made a certain cut upon the work, the turret is moved back, and, by an automatic arrangement, it is unclamped and made to rotate a part of a turn upon a vertical axis. This partial rotation brings the second tool in the turret in line with the work. Each full backward movement of the turret causes it to revolve a part of a turn, sufficient to bring the second tool in perfect line for the second cut.

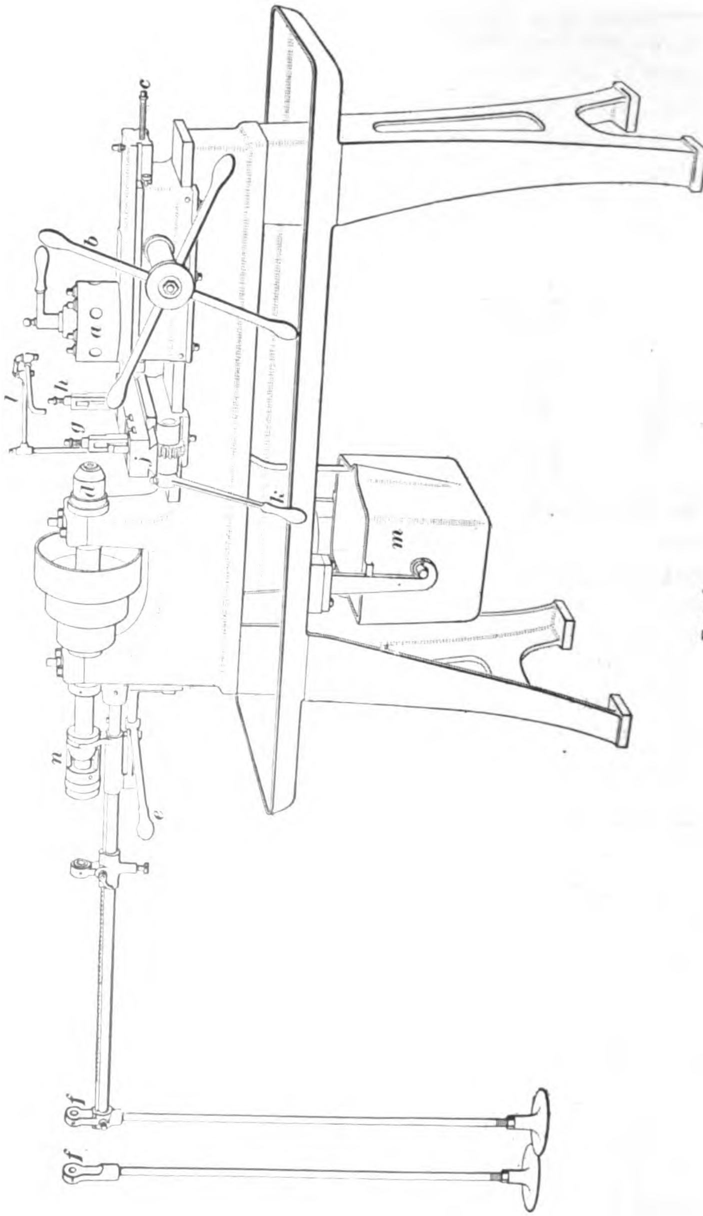


FIG. 1.

3. Various Types of Turret Lathes.—This style of turret has been applied to a variety of lathes for various kinds of work, so that we have, under the head of turret lathes, the *turret screw machine*, *plain turret lathe*, *brass-worker's lathe*, and *monitor lathe*. Besides these there are some other special forms of turret lathes that are adapted to certain classes of work. In the screw-machine class are the hand and automatic machines.

HAND SCREW MACHINE.

4. Characteristics of the Screw Machine.—The **hand screw machine** more nearly embodies all the characteristics of turret lathes than any other type. Fig. 1 represents a typical turret screw machine. Its characteristic features are, the turret moving on a slide that takes the place of tailstock, a special form of chuck for gripping rods, and the rod-feed mechanism. Characteristic of the screw machine is the rod feed and the arrangement for supplying oil to the cutting tools.

5. Names of Parts of Screw Machine.—In this lathe, Fig. 1, the parts are named as indicated by the following letters: *a*, the turret; *b*, the pilot wheel for moving the turret; *c*, the stop screw for adjusting the travel of the turret slide; *d*, a special chuck for holding the rod, or stock; *e*, the lever for opening and closing the chuck *d*, and for feeding the rod into the machine; *f*, supports for holding long rods; *g*, the front tool post; *h*, the back tool post; *j*, the cross-slide; *k*, the handle for operating the cross-slide; *l*, the distributing pipe for oil; *m*, the oil tank; *n*, the clutch for operating the chuck.

6. The Screw-Machine Chuck.—The success of the screw machine is due largely to the method employed in holding the work; this method gives great rigidity, and at the same time is so simple that the work can be quickly clamped or released.

Fig. 2 shows a section through the chuck screwed to the spindle of a lathe as it is used for holding rods. The grip

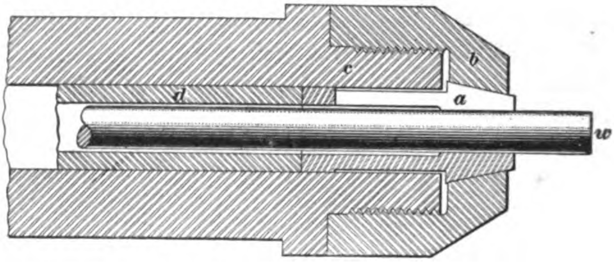


FIG. 2.

of the rod is accomplished by pushing the split collet *a* through the tapered hole in the end of the cap *b*, the cap being screwed to the nose of the lathe spindle. Fig. 3 shows the collet *a* removed. The collets are made of various sizes, depending on the size of the rod to be held, and are hardened, as is also the cap in which they slide.

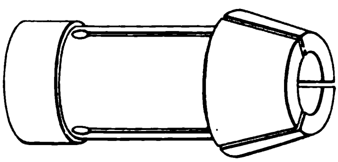


FIG. 3.

7. When gripping the work, the collet is pushed into the cap *b* by means of the hollow tube *d*, which passes

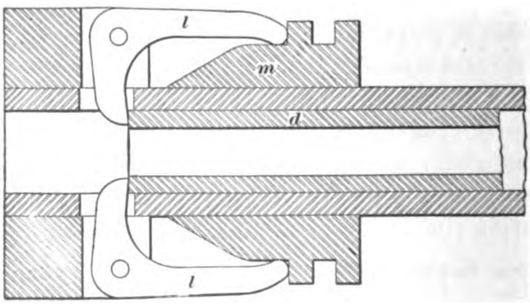


FIG. 4.

through the lathe spindle to the rear end. Fig. 4 shows a section through the rear end of the spindle and the gripping mechanism. The end of the tube *d* comes against the two levers *l*, *l*. These levers are operated by the cone-shaped piece *m*, which slides on the spindle. When *m* is moved to the position indicated, the ends of the levers are forced apart, which moves their other ends against the end of the tube *d*. This operation pushes the tube through the spindle and against the collet, thus causing it to grip the work. When the cone *m* is moved back, the long ends of the levers spring together and relieve the pressure on the end of the tube *d*. Springs are arranged to open the chuck as soon as the cone *m* is removed from under the levers *l*, *l*. In this description, only the essential points have been mentioned, all unnecessary details, such as springs, being left out.

WORK OF THE TURRET SCREW MACHINE.

TURRET TOOLS AND THEIR USES.

8. Class of Work Done on Turret Machines.—The work of the turret screw machine is confined to a class of work that can be made on the ends of rods held in the chuck. Turret lathes are, therefore, without centers for supporting the work. The work of the screw machine can be understood by following the operations necessary to complete some particular piece. The tools used for the turret are quite different from those used in the ordinary engine lathe.

9. A Typical Piece of Work for Turret Screw Machines.—Suppose it is desired to make a large number of screws with a round nurled head, as shown in Fig. 5. Having decided upon the screw to be made, the machine must be *set up*.

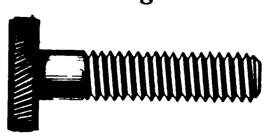


FIG. 5.

10. Setting Up the Turret Machine.—This means setting the various tools in a turret and in the cross-slide, adjusting the stops to determine the length of cuts, and adjusting the cutter blades to turn the correct diameters. A rod is put through the spindle, and the chuck is so arranged that the work can be gripped rigidly, and also so that when it is released, the feed will move the rod through the spindle.

11. The Stop.—The first tool in the turret to be used will be the adjustable **stop gauge** shown in Fig. 6. This stop is so adjusted that when the turret and slide are at the full length of their travel next the headstock, and the work is fed up to the stop and gripped in the chuck, the correct length to make the screw will project from the chuck. Having clamped the work, the turret is moved back and revolved a part of a turn, which brings the first turning tool to place. This turning tool is known as a *roughing box tool.*

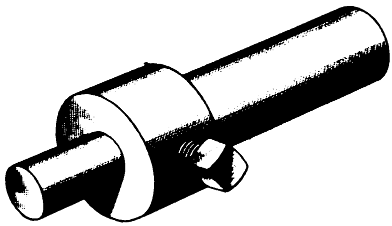


FIG. 6.

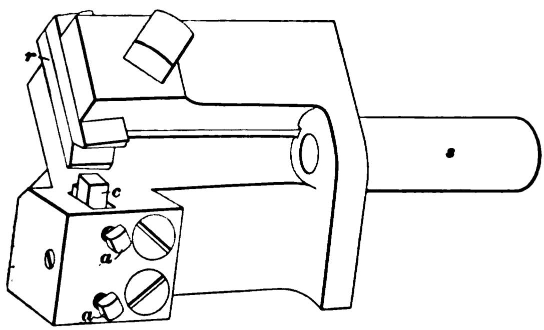


FIG. 7.

12. Roughing Box Tool.—The **roughing box tool** is shown in Fig. 7. The shank *s* is held in the turret, and the tool, or blade, *c* is clamped in place by the screws *a*, *a*. The tool is adjusted to turn the correct diameter by a series of careful trials. To support the work while the cut is being taken, the back rest *r*, opposite the tool *c*, must be adjusted so that it just supports the end of the work. Fig. 8 shows an end view of the box tool with a section of work *w* in place. This shows how the tool, or blade, *c* comes against the work, and how the back rest supports it, thus keeping it from springing when the cut is being taken. With this tool, a cut is taken over the stem of the screw up to the shoulder under the head. If the bar is iron or steel, a supply of lard oil is kept running on the work, to keep it and the tool blade from heating. When this roughing tool has cut a sufficient length, the turret slide comes against a stop. This stop is so adjusted that each cut taken by the succeeding tools will stop when the desired length has been turned. The turret is given another partial turn, which brings the second cutting tool in line for the cut. This tool is known as the *finishing box tool.*

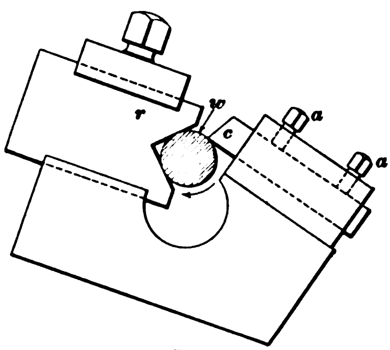


FIG. 8.

13. Finishing Box Tool.—The **finishing box tool** acts on the same principle as the roughing box tool, except that the blades are made and adjusted to cut similar to a broad-nosed lathe tool. The blade for the rough cut is ground on the same principle as the roughing tools for lathe work. Fig. 9 shows a finishing box tool. This will be seen to carry a number of cutters, each of which may be adjusted to cut a given depth by the setscrews *a* at the end of the blades. These blades are used when it is desired to finish parts to different diameters at the same time. Each blade is so adjusted along the length of the box tool that it will turn the desired length of work to that particular diameter. For the screw being made, only the first blade in the tool will be used. This will be adjusted to finish the stem of the screw to the correct diameter. Before cutting the thread, the end of the stem should be beveled or chamfered. This is done with a *pointing tool.*

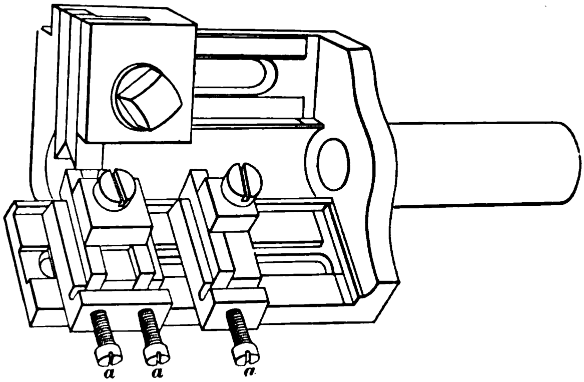


Fig. 9.

14. Pointing Tool.—The **pointing tool** is similar to the roughing box tool shown in Fig. 7. The blade, however, instead of being straight on the edge, is beveled to an angle, the same as the desired bevel on the end of the screw. The back rest is adjusted on a pointing tool the same as on other box tools. When brought to the end of the work, this tool will cut the desired bevel.

15. Dies and Die Holders.—The screw is now ready to be threaded. On all the screw machines the threads are cut with **dies.** In order that the threads will be cut an exact length on the stem of each screw, a special *die holder* must be used.

A **die holder** is shown in Fig. 10. The die holder *a* has a circular opening into which the dies are fastened by the screws *e*. The stem *d* passes through a sleeve, this sleeve having a flange on one end. The sleeve is held in one of the holes in the turret. When in the position shown in the illustration, the

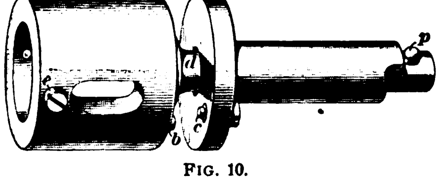


Fig. 10.

holder is free to revolve in the sleeve. When it is used and the die pressed against the work, the holder slips back in the sleeve until the pins *b* and *c* slip by the side of each other. Pin *c* will then keep the die holder from revolving. As soon as the holder ceases to revolve, the die will begin to cut, and, after cutting a few threads, it will continue to screw and feed itself along the work. If provision were not made to stop it as the lathe continued to revolve, the die would at once screw up to the shoulder on the work and destroy the thread. With the holder shown, the die will feed upon the work, the turret being made to follow it, until the turret slide reaches its stop. The work, however, continuing to revolve, will feed the die still farther, and bring the holder with it until the pins *b* and *c* disengage, whereupon the holder again revolves with the work, thus stopping the cut. In the meantime, the direction of the lathe is reversed and the turret moved back by hand until the pin *p* engages the notch cut in the end of the sleeve. This keeps the holder from turning backwards and so the die is backed off the screw. When considerable uniformity of size of threads is desired, a second sizing die is run over the thread. These operations complete the turret operations on the screw.

CROSS-SLIDE TOOLS.

16. Nurling Tool.—When the head of a screw is to be **nurled,** as in the present case, it is done by pressing hardened-steel rollers against the face of the work while it revolves. These hardened-steel rollers have teeth, or special forms, engraved around their outside, so that when pressed against the work they will form the soft metal into the desired shape. In the case in hand, the nurling tool shown in Fig. 11 is employed and will be described more fully later. Nurling tools are held in one of the tool posts on the cross-slide.

17. Parting Tool.—The **parting tools** used in the turret lathe are very similar to those used in a regular lathe, and are held in one of the tool posts on the cross-slide. Combination parting and forming tools are sometimes employed. They are intended to round the head and cut off the stock at the same time.

18. Combination of Parting and Nurling Tool.—Fig. 11 shows a special nurling tool held in the tool post,

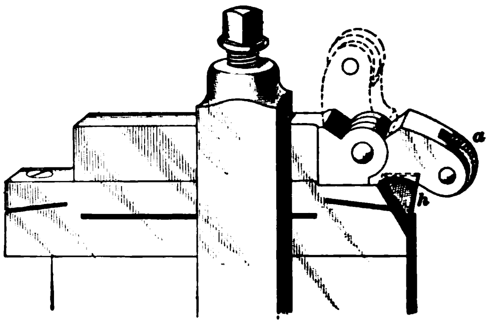


FIG. 11.

together with a parting tool. The parting tool is clamped under the nurling tool, with its blade shown at *h*. The nurling tool is jointed, so that when the parting tool is used, the nurl *a* may be lifted up to the position shown by the dotted lines. While the screw is being made, the nurl should be turned back and the parting tool used to cut a shallow notch in the work, which will define the thickness of the head. If the head must be made true, a light cut should be taken with a back tool held in the back tool post. This back tool should be shaped the same as a broad-nosed lathe tool and set in the tool post upside down, so that it will cut on the back of the work when the lathe is running forwards. The stop on the cross-slide should be so adjusted that the tool will just cut the head to the desired diameter. The nurling tool may then be brought against the work, and, by pressure of the hand lever, forced against the work until the teeth in the nurl roll press corresponding grooves in the head of the screw. When the work has been properly nurled, the parting tool is again brought to place and the screw cut from the bar.

When the parting tool is sharp and working well, it should leave the head of the screw bright and smooth, without any projection in the center. The parting tool, therefore, must be so set that its edge comes exactly in line with the axis of the work. If the parting tool is ground square across

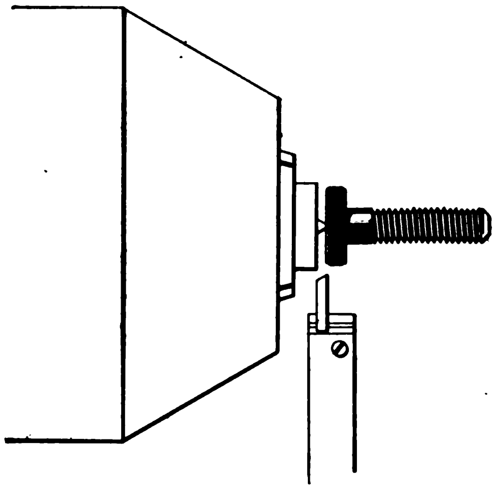


FIG. 12.

its cutting edge, the work will break off before the cut is quite finished. This may be avoided by grinding the cutting edge of the parting tool beveled, as shown in Fig. 12. Here it cuts a smaller diameter near the head, and, when the work breaks off, it will break at this small diameter.

19. The operation of making a screw just described is but one of a very great variety that may be performed on the screw machine. While certain tools were chosen to perform this operation, there are other forms of tools that could have been used with the same result.

OTHER FORMS OF TURRET TOOLS.

20. Solid Hollow Mills.—In place of the roughing box tool, a **hollow mill** could have been used. Fig. 13 shows a solid hollow mill, and Fig. 14 shows a holder used for it. These mills cut on the edges *a*, *a*, and are bored to the size that they are intended to turn. As soon as the mill

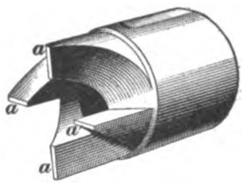


FIG. 13.

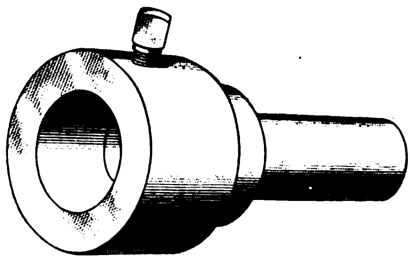


FIG. 14.

begins to cut, the end of the work at once enters it and is thereby steadied or supported while the cut is being taken. Because of the four cutters on opposite sides of the work, it is balanced so that there is less tendency for it to spring than when there is but one cutter acting.

21. Adjustable Hollow Mills.—Fig. 15 shows an **adjustable hollow mill.** By loosening the screws at the front and turning the nurled head, the blades *a*, *a* can be

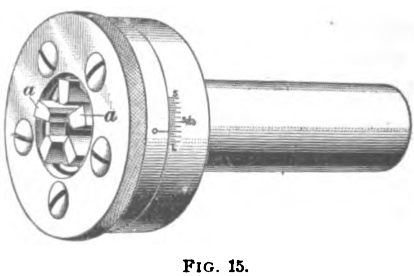


FIG. 15.

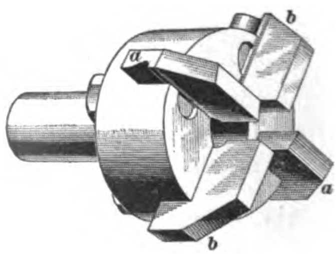


FIG. 16.

moved toward or from the center, thus making the cut larger or smaller. The cutting action of this tool is the same as that of the solid hollow mill. The cut is taken on the end face of the cutter blades, the inner faces acting as guides to support the work after it is turned. It is always advisable to run a finishing box tool over the cut made with a hollow mill, since it cannot be depended on to be perfectly true. Finishing tools are made in a variety of shapes. Fig. 16 shows a style of finishing hollow mill that has two inserted blades *a*, *a*, which do the cutting, while the other two blades *b*, *b* are simply back rests to steady the work.

22. Spring Dies.—Besides the solid dies mentioned, other forms are used. Fig. 17 shows a form of **hollow spring die** that is held in the holder shown in Fig. 10. When in use, this die would tend to spring, so that it is necessary to use a clamp, Fig. 18, that will pass around the die and hold it in shape. By means of this clamp, the die may be adjusted to make slight differences in cutting. When such a form of die is employed, considerable time is lost in reversing the machine and backing the die from the work.

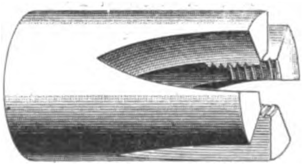


FIG. 17.

23. Automatic Dies.—To overcome the above difficulty, **automatic dies** are used, which act on a principle similar to that found in the automatic dies used on bolt cutters. The die passes over the work and cuts the thread, which, when completed, automatically opens the die and releases the work. Fig. 19 shows an excellent form of automatic die adapted particularly to turret screw machines. The die heads are made in a number of sizes, each head taking a variety of sizes of dies. In the figure, the dies *d*, *d* may be removed by taking out the screws *s*, *s* and different sizes put in their places. They may be set to cut any length of thread

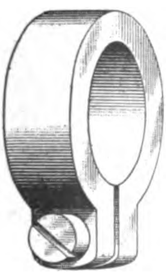


FIG. 18.

within limits. When the desired length is cut, the die automatically opens. To close the die, the handle *h* is given a partial turn. This die may be adjusted to cut threads slightly above or below standard size by loosening the nut *n* at the back of the die holder and moving the pointer to one side or the other of the zero mark. By means of this adjustment, it is possible to cut threads as much as $\frac{1}{64}$ inch over or under standard size.

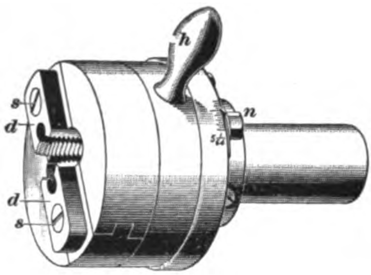


FIG. 19.

DRILLING AND TAPPING.

24. Holding the Tools.—When operations require that drilling or tapping be done, the drills or taps are held in the turret in the same manner as the other tools. The drills may be held in a chuck provided for that purpose. When the taps are used, a special tap holder that works on the same principle as the special die holder, Fig. 10, is employed. This is to keep the taps from running into the work too far and breaking.

25. Many other shapes and kinds of tools may be used in the turret. Those that have been mentioned are the standard tools, and embody a general principle, which is, that the work must be supported while the blades are cutting. By following this principle, a great variety of shapes of tools may be designed and adapted to particular classes of work with advantage.

OTHER FORMS OF CROSS-SLIDE TOOLS.

26. Forged Forming Tools.—The tools used in the cross-slide perform various operations, the more important of which are the forming of irregular surfaces with forming tools, and the cutting of the finished piece from the bar with the cutting-off tool. The forming tools may be forged from bar steel, and filed or machined to the desired form. When so made, they are similar to the forged forming tools used in the engine lathe. The main objection to the forged forming tool is that only a limited amount of grinding can be done before the tool will change its shape.

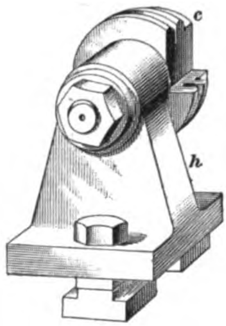


FIG. 20.

27. Circular Forming Tools.—This class of forming tools has been brought out both to overcome the objections to the forged forming tool and on account of the ease with which the cutters can be manufactured. Fig. 20 illustrates a typical tool of this class. Here a circular cutter *c* has been carefully turned and formed so that when a section is taken out at its cutting edge, it will conform to the desired shape of the work. A notch is cut on one side of the cutter so that the lower face *C D*, Fig. 21, is in a plane that would pass slightly below the center of the cutter *A B*. This amount *k* varies with the diameter of the cutter. On a 2-inch cutter, from $\frac{1}{8}$ to $\frac{1}{4}$ inch is sufficient. The holder *h*, Fig. 20, is made of such height that it holds the center of the cutter above the center of the work, thus bringing the face of the cutter *C D*, Fig. 21,

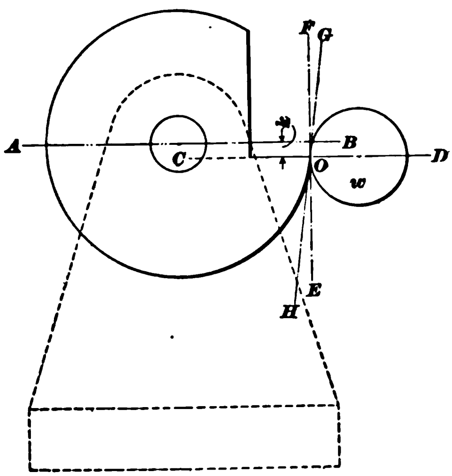


FIG. 21.

in line with the center of the work *w*. The object in cutting the notch in the cutter below its center and then raising it above the center of the work is to give the tool slight clearance. If the two circular pieces, the tool and the work, be set at the same height, Fig. 22, they will touch at the point *O*, which is in a line joining the centers. If we draw a tangent to the work through the point *O* and another line tangent to the tool through the same point, we will find that the two tangents coincide in the line *C D*. When the tool is thus set, it does not have any clearance, and can cut only so long as it remains absolutely sharp.

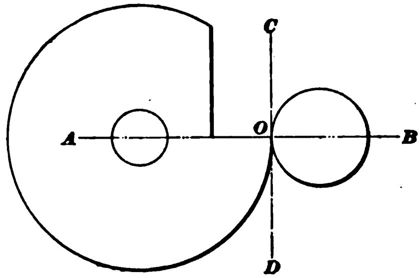


FIG. 22.

28. Referring to Fig. 21, if we draw a line *E F* tangent to the work through the point of the tool, and the line *G H* tangent to the circular cutter at the point, we will find that the lines do not coincide as in Fig. 22, but form an angle. The angle *H O E* is the angle of clearance when the tool is thus set.

Cutting the face of the notch on the tool slightly below the center will slightly change the outline of the cutting edge, since a section of the cutter on the line *A B* is different from the section on the line *C D*, Fig. 21. If the cutter is 2½ inches in diameter, the difference in section caused by cutting from ⅛ to ¼ inch below the center line will not be sufficient to cause trouble in ordinary work. If an exact outline is required, the cutter must be formed to give the desired outline on its cutting edge and not on the diametrical section. This form of tool is sharpened by grinding the top cutting face, after which the cutter is revolved sufficiently to bring the cutting edge to the desired height.

29. Straight-Faced Forming Tools.—Another style of forming tool is shown in Figs. 23 and 24. The heavy cast block, or holder, shown in Fig. 23, is bolted to the cross-slide. Into the front side of this tool block is cut a dovetailed slot *c*, into which is fitted the dovetailed part *d* of the forming cutter, Fig. 24. The cutter is clamped to the block by tightening the bolt *e*, which has a special clamp head *f*.

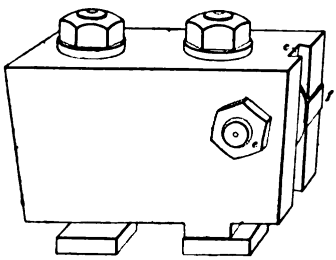


FIG. 23.

These forming cutters are shaped along the front edge the same as ordinary forming tools, so that the section across the top cutting face gives the desired outline. They are set in the holder so that the front face *b* has a slight angle of clearance. The top face *a* is ground flat and set at the same height as the center of the work. This is a very rigid form of tool.

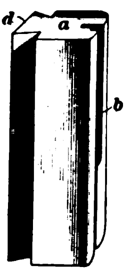


FIG. 24.

30. The forming tools just described are fed to the work in such a way that the cutting edge follows in a line that would pass through the axis of the work; thus, in Fig. 21, as the tool advances to take a deeper cut, it moves along the line *C D*.

VERTICAL-SLIDE FORMING TOOLS.

31. Vertical Slide for Holding Tools.—Another method of operating forming tools is by means of a vertical slide rest shown in Fig. 25. Here a vertical slide is clamped to the back of the ordinary cross-slide. When this slide is used with the forming tool, the cutting edge does not move in a line that would pass through the axis of the work, but in a line tangent to the work.

Fig. 26 shows a side elevation with the forming cutter *c* in place. The cutting edge follows the line *A B* as the tool moves down in the slide. This particular movement is very desirable at times. The cutter *c* is clamped to the block *b* by a bolt *d*. The slide *s* carrying the block *b* travels

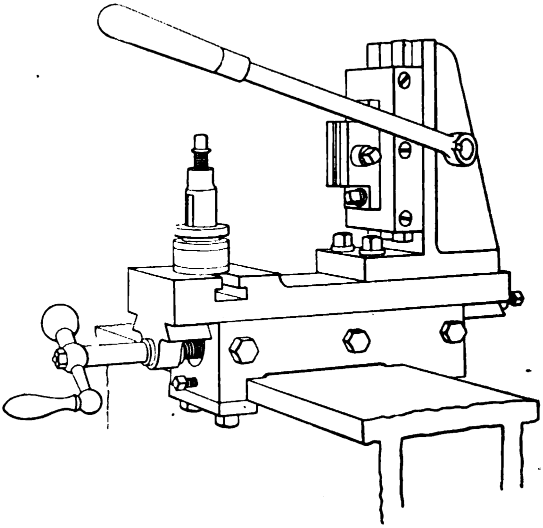


FIG. 25.

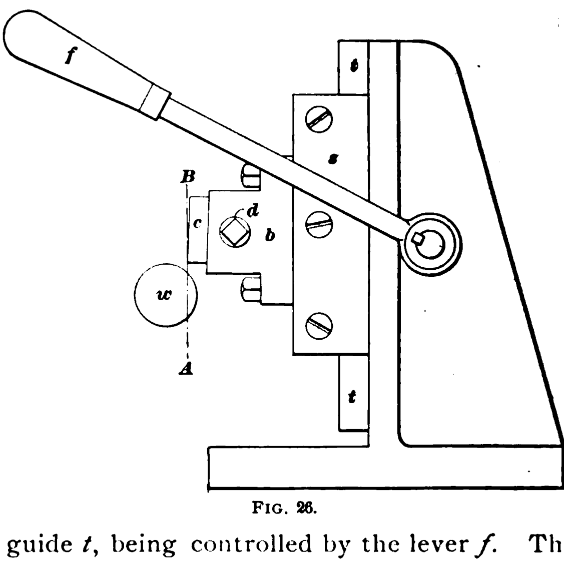


FIG. 26.

on the guide *t*, being controlled by the lever *f*. The work is shown at *w*.

32. Form of Tool to Prevent Chattering.—When tools are used as in Fig. 21, the entire cutting edge of the tool is acting at once. If the cut is complicated, or the edge broad, the work will spring and chatter because of the broad cutting edge. When the vertical slide is used, it is possible to grind the top face of the forming tool with considerable slope to one side, which corresponds to the top side rake in the diamond-pointed lathe tool. A tool thus ground is shown in plan and elevation in Fig. 27, and also the shape of the work *w* that this particular form of tool would produce. It will be seen that as the tool is fed downwards past the work, the edge or point *a* will be the first to cut. When the tool is still farther fed along, the point *a* soon cuts to its depth and passes by the work, while other points along the cutting edge are approaching the work. By the time that the point *b* of the cutting edge has reached the work, the point *a* and all the other points along the edge have passed by, having done their respective parts in the cutting. This method, therefore, permits the use of broad-edged forming tools, since the action is a shaving one, and whatever the total length of the edge of the forming blade may be, only a small part of it cuts at a time. This same principle is used on tools that work on a horizontal slide and cut on the under side of the work.

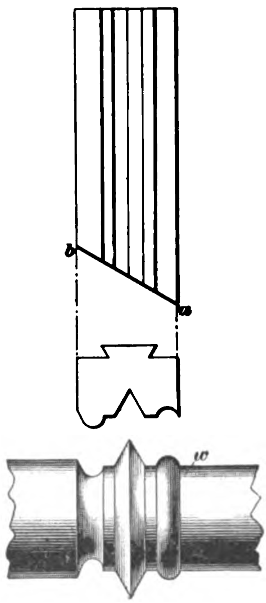


FIG. 27.

SPECIAL FORMING HEADS.

33. Arrangement of Forming Head.—When very much forming is to be done, and greater production is desired than can be obtained by the use of the forming tools just described, a **special forming head** is used that holds two forming cutters, one at the front and the other at the back of the work. Such a forming attachment is shown in Fig. 28. In this, the front and back forming blades *a* and *b* are held in place in tool blocks *c* and *d*. These blocks slide in the base *e*. They are operated by the same screw, which has a right-hand thread at one end and a left-hand thread at the other, each being of the same pitch. By turning the hand wheel *h*, the blocks *c* and *d* advance or recede from the work at a uniform speed. When in use, the blocks and blades are so adjusted that each forming blade is cutting the same depth. The hand wheel *h* is then turned until the blades have entered the work the desired depth.

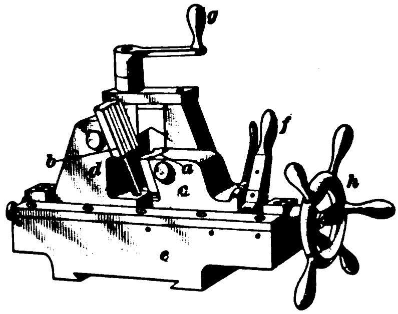


FIG. 28.

34. Form of Blades Employed.—In the forming attachments using two forming blades, the edges of the

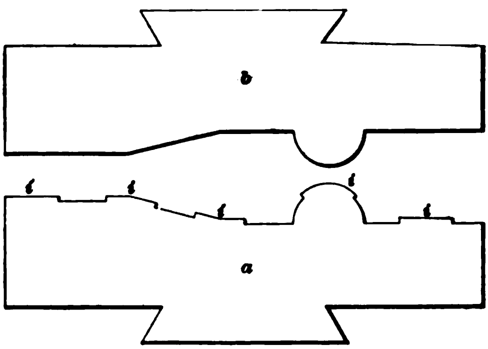


FIG 29.

blades are not exactly alike. In this case, the back tool *b* may be of the desired outline, while the front tool *a* is similar, but may have notches cut along its face. This is shown in Fig. 29, where the cutting edges of the forming tools are compared. The back tool *b* has a regular outline, while the edge of the front tool *a* is slightly broken. The result of this is that the shaving is broken, the high parts of the front tool doing the cutting at the points *i*, while the back blade takes all the remaining parts. This relieves the strain on the work and the cutters very much. When the work is nearly completed, the front blade is slightly backed away from the work by moving the lever *f*. This allows the tool at the back to finish the work smooth. When two cuts are thus taken, the work is quite well balanced, but to still further steady it, a steady rest with V jaws, operated by the hand crank *g*, is used. These types of forming attachments are extensively used in bicycle making on such pieces of work as hubs, cones, spindles, pedal pins, and similar pieces that are cut from the solid bar.

SPECIAL PARTING TOOLS.

35. Inverted Parting Tool.—Instead of the regular parting tool held in the tool post for cutting off the finished work, a special holder for blades may be used, as shown in Fig. 30. This tool is intended to be used at the back of the machine; consequently, the blade is inverted, with the cutting edge at *e*. By holding the cutting blade sloping, as here shown, the tool will have a top rake, which will add to its efficiency.

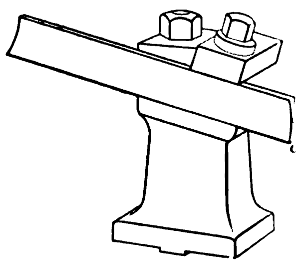


FIG. 30.

36. Combined Parting and Forming Tool.—When the head of the piece to be cut off is curved, as in the case of round-headed screws, **circular forming tools** may be used. Fig. 31 shows a section through a circular forming tool that could be used for a cutting-off tool, and at the same time be a forming tool for the head of the work.

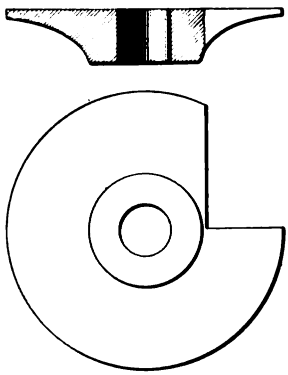


FIG. 31.

37. Steady Rest for Turret Work.—In some cases, a **steady rest** can be used in the turret for certain purposes. Suppose the piece shown in Fig. 32 were being made. The part *a* would first be turned to size. A hardened-steel sleeve *s*, shown in section, which has been bored to fit over the part *a*, is then slipped over it. This supports the work while the part *b* is being formed, and while the work is being cut off.

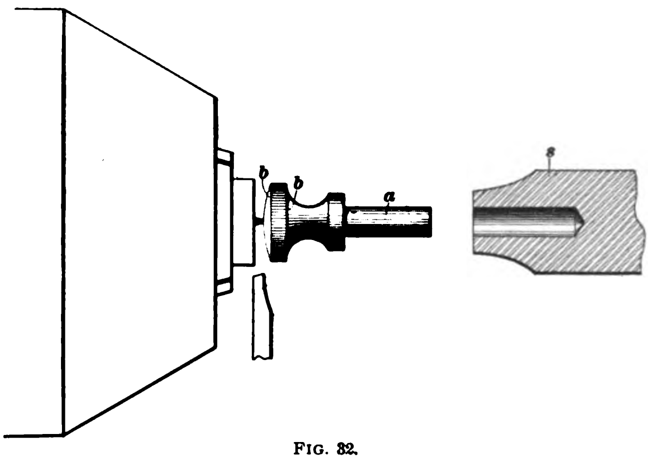


FIG. 32.

This method of supporting the end of the work may be applied to many styles and classes of work.

UNIVERSAL MONITOR LATHES.

38. Description of the Monitor Lathe.—Another class of turret lathe that is extensively used for brass work and for work that is not made on the ends of rods, is the

monitor lathe, shown in Fig. 33. This style of lathe lacks the ordinary rod feed and chuck, also the oil tank and pump found on the regular screw machines. The work performed by this class of lathe is usually held in a chuck of

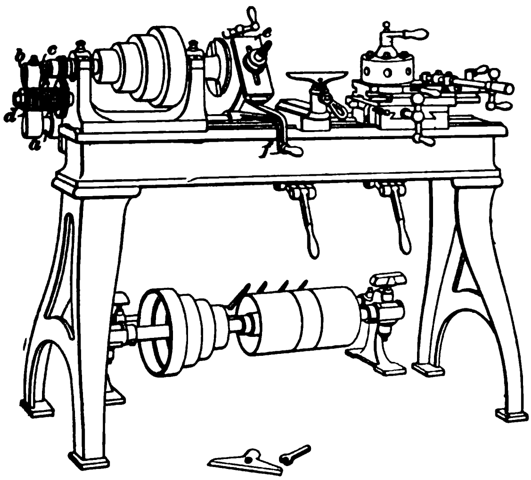


FIG. 33.

some special form designed for the particular work at hand. The turret is mounted on a double slide, so that it can move along the line of centers, or at right angles across the lathe. This gives a combination of movements for the turret that are not possible on the screw machines.

39. Chasing Threads.—Besides the method of cutting screws by holding dies in the turret, this lathe has a special attachment for **chasing threads.** At the back of the lathe, nicely fitted to bearings at either end of the lathe bed, is the large circular *chaser bar a*, Fig. 33, which is free to move in the direction of its length. To the headstock end of the chaser bar an arm *b* is rigidly attached. On the end of the arm *b* a piece *c* is attached, on which a few threads are cut similar to those in a half nut. These threads engage with the screw *d*, seen on the stud of the lathe. When thus engaged, as the lathe revolves, the threads on the piece *c* follow the threads in the screw *d*.

This tends to feed or draw the chaser bar *a* through its bearings. To stop the feed, it is only necessary to lift the arm and the threads *c* away from the screw *d*. The bar can then be moved back to its starting point. Near the center of the bar a slide rest is attached, as shown at *e*. Extending over the bed to the front is a lever *f* to be operated by hand.

40. Suppose a center were put in one of the turret holes and the work held between centers in order to have a thread cut or chased. The tool would be adjusted in the tool post of the slide *e* so that it just touched the work when the piece *c* was against the screw *d*. As the lathe revolved, the tool would be drawn along and would chase a thread on the work of the same pitch as the screw *d*. When the desired length of thread has been chased, the lever *f* at the front of the bed is lifted, thus raising the tool from the work and, at the same time, the piece *c* from the screw *d*. The bar may then be moved back to the starting point, the tool moved forwards a little on the slide *e*, and the lever *f* again dropped until the piece *c* engages with the screw *d*, when the second cut may be taken. This operation is repeated until the desired depth of thread has been chased. It will be seen that by this method only short threads can be cut and that the screw *d* must be changed for every desired pitch. These screws *d* are, in reality, shells that fit over the spindle or stud. They are made with various pitches of threads and are variously called *leaders*, *hobs*, or *master threads*. This method is extensively used in cutting the threads on brass pipe, valves, or similar work.

SPECIAL FORMS OF TURRET LATHES.

41. The Turret Applied to Engine Lathes.—For certain chucking operations, the turret may be applied very conveniently to an ordinary engine lathe. Suppose a great many pulleys are to be bored and the hubs faced. Instead of changing the tools in the tool post each time it is used for boring and reaming, if a turret is used, each tool can be kept in its place, thus saving much time. Fig. 34 shows a set of tools that may be used in the turret on an engine lathe for such work as boring and facing pulleys. Tool (*a*) can be used to ream the ends of the cored hole, and to make a starting place for the chucking reamer (*b*). A fluted shell reamer for finishing the holes to size is shown at (*c*),

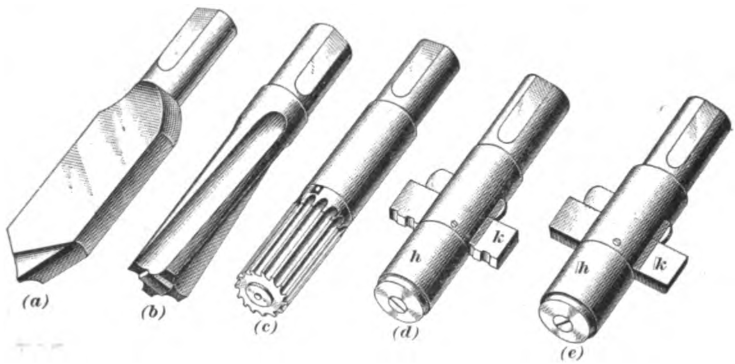


FIG. 34.

while (*d*) and (*e*) are facing tools, the ends *h* having been turned to just fit the bore of the pulley and to steady the tool while the blades *k* are cutting. In (*d*), which is the roughing facing tool, edges are nicked to break the shaving, while, in the finishing tool (*e*), the cutter blade has a straight edge.

42. Illustration of Turret Lathe Applied to Heavy Work.—Fig. 35 shows another application of the turret to the lathe. In this case an octagonal turret takes the place of the saddle on the lathe. Power feed moves the turret automatically along or across the bed, it having the same motion as an ordinary tool post in the lathe. In this figure an engine cylinder head, 22 inches in diameter, is being finished. Special chuck jaws hold the work to the face plate, while the blocks *a*, *a*, which have been faced off after being bolted to the face plate, aid in setting the work true with the face plate. The turret has flat faces on its sides, so that special tool holders can be clamped to it. By

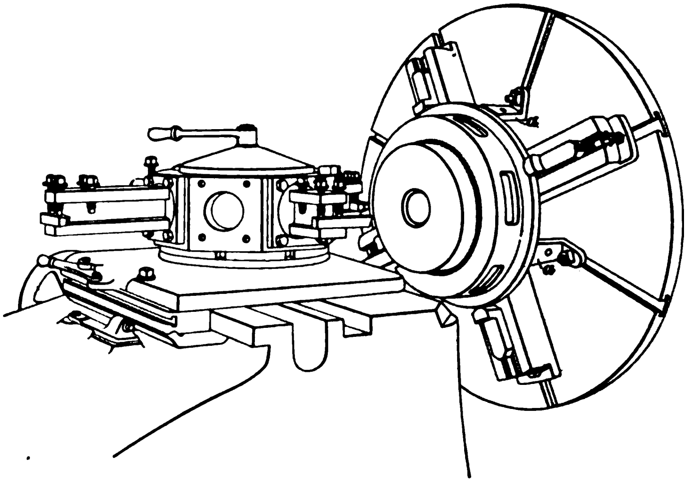


Fig. 35.

the use of these holders, facing, turning, and boring tools may be held in the turret and brought in quick succession to perform their respective duties.

43. Special Turret Lathe for Heavy Work.—Fig. 36 illustrates a chucking lathe designed for the heaviest class of work on castings or forgings. The machine is massive in design and its power is sufficient to take the heaviest cuts. Like all turret lathes, special forms of tools and cutters are required before work of any kind can be done; but, once the machine is equipped with a set of tools designed for a special purpose, its productive capacity is very great. Where the number of like pieces to be finished is relatively small, it will rarely pay to install one of these powerful machines and to equip it with its expensive special tools; but if a considerable number of pieces of any special design are to be made, such a machine will be a valuable acquisition to the shop equipment.

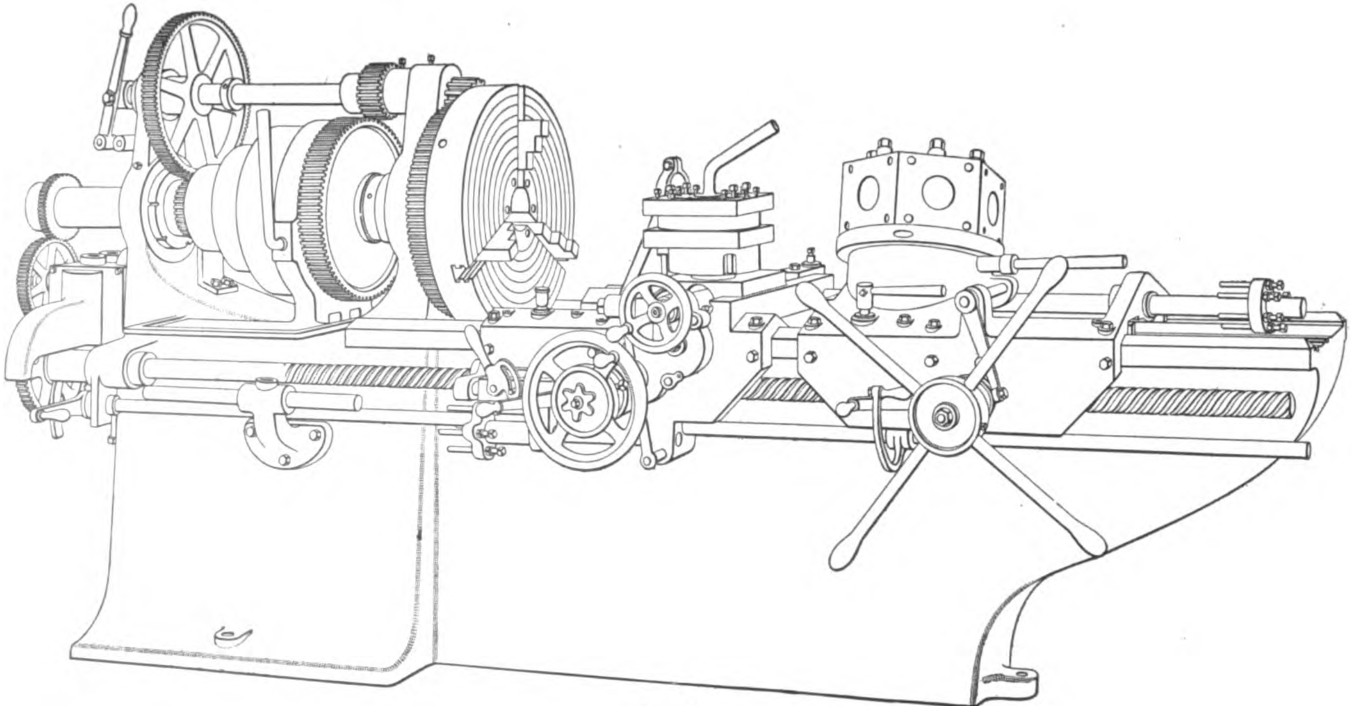


FIG. 86.

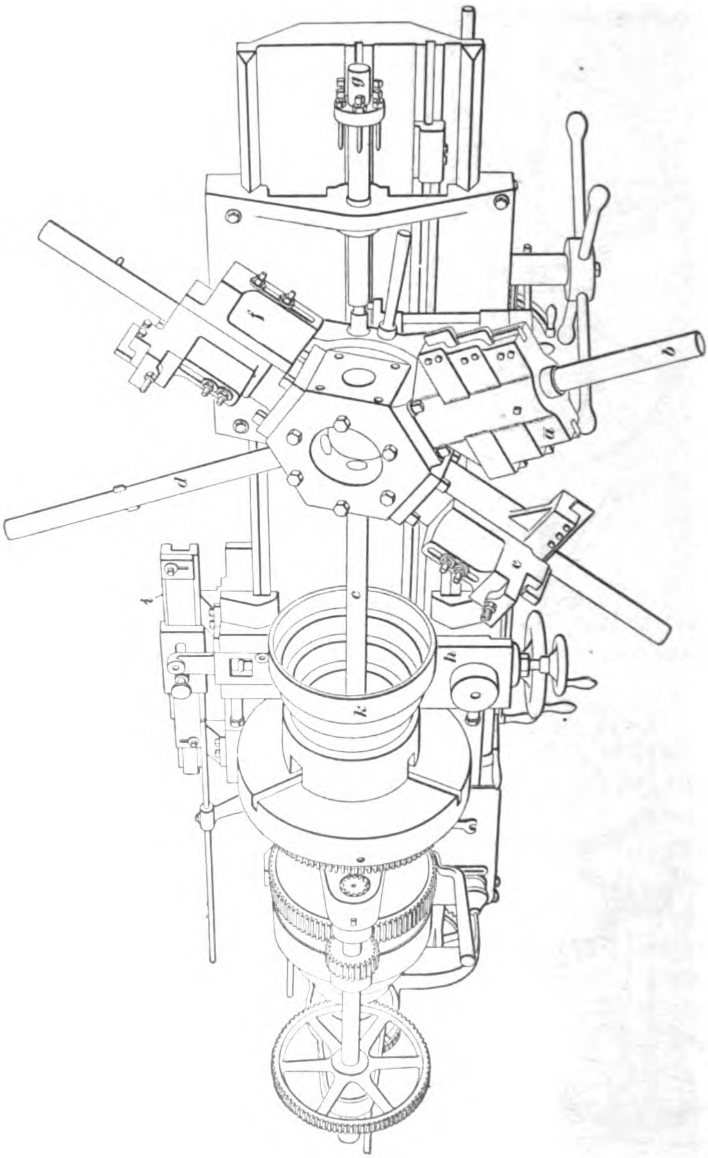


FIG. 37.

44. Boring Cone Pulleys in Turret Lathes.—Fig. 37 illustrates the lathe shown in Fig. 36 fitted up to bore a cone pulley *k*. The hub is roughed out by a cutter on the bar *c* and finished by the cutter on the bar *d*. The steps of the cones are bored and the faces finished by the special tools *a* on the bar *b*, while the outer edge of the pulley is faced and a finishing cut taken on the inside of the largest cone by the heads *e* and *f*. It will be noticed that all the tools are provided with extensions on the ends of the bars, which fit bushings in the spindle of the machine or the chuck and thus furnish a guide for the end of the bar. This adds greatly to the stiffness of the tool and to the effectiveness of the machine. At *g* a series of screws are arranged to act as stops for the various tools. Each one of these can be adjusted separately. In the illustration, the carriage *h* and the taper attachment *i* are not in use. These cone pulleys may be finished on the outside on the same machine by mounting them on suitable arbors and turning them with special tools placed on the carriage *h*. This example is given simply as an illustration of the class of work for which this style of machine is adapted.

45. Special Turret Lathe for Large Bar Work. Fig. 38 illustrates a turret lathe especially designed for work on large bars of steel or iron, either round, rectangular, or having any other cross-section. The parts of the machine are lettered; *a* is the automatic chuck for holding the bar; *b*, the lever for operating the chuck and controlling the forward feeding of the stock; *c*, the lever for throwing in the back-gear clutch; *d*, the roller-feed mechanism for feeding the bar forwards; *e*, the turret, which is of special construction, being flat on top and having the tools so attached to it that it is possible to operate on long bars by allowing them to pass through the tools and across the top of the turret; *f* shows one of the tool holders; *g*, the cross-slide lever for operating the cross-slide; *h*, the circular gib that holds the flat turret in place; *i*, the feed-lever for throwing the automatic feed; *j*, the stock stop, which can be thrown up, and against which the stock is fed in order to obtain the desired length; *k*, the back stop; *l*, the stops which can be arranged to control the various tools; *m*, the

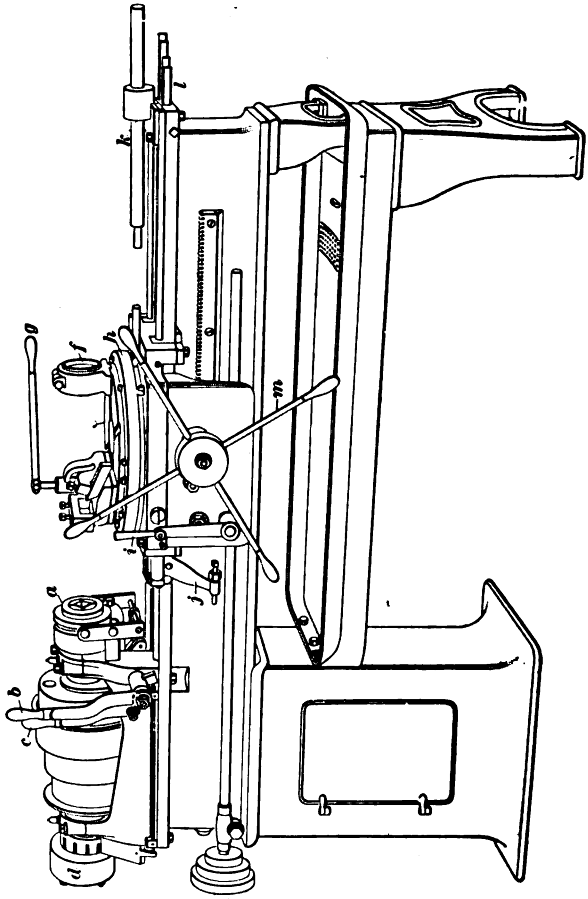


Fig. 38.

pilot wheel for feeding the carriage by hand. The roller feed is so arranged that when the chuck is loosened, the stock is fed forwards at once against the stock stop.

46. The turning tools used in this lathe are similar in principle to the box tools used on the ordinary screw machine, though they are somewhat different in appearance. Fig. 39

shows an end view of a turning tool for this lathe. The blade *a* is clamped in the tool block *b* by setscrews. The tool block *b* is pivoted so that it may be rotated by turning the screw *c*. This operation moves the point of the cutting

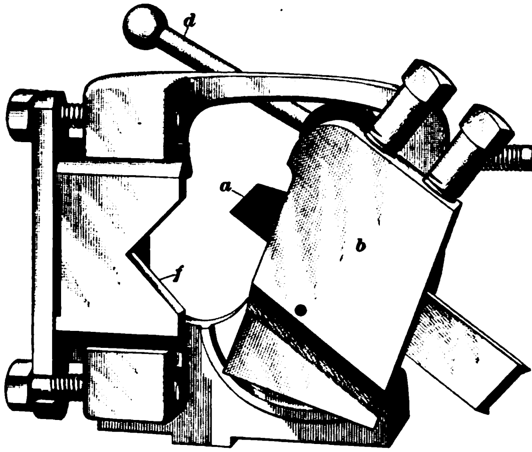


FIG. 39.

tool *a* toward or away from the work. The lever *d* may be used for quickly moving the tool to or from the work. The back rest *f* is adjusted to the work the same as in the ordinary box tools.

This flat style of turret gives great rigidity to the tools and their cutting edges, and this rigidity is not dependent on the length of the work. Ordinary box tools can only be used upon comparatively short work, while this style of tool will operate upon much longer stock.

AUTOMATIC SCREW MACHINES.

47. Characteristic Features of Automatic Screw Machines.—The characteristic feature in the **automatic machines** is that the movements made by hand when operating the hand screw machine are automatically made in the automatic machines. These movements are brought about by a series of cams and levers that control the working of each part of the machine. The introduction of the automatic controlling part makes the machine much more complicated than the simple hand machine.

48. Setting Up Automatic Machines.—Whenever a piece of a certain shape is to be made, a special cam must be designed that will give the proper movements to the parts. Every new shape of work requires a specially designed cam and a new arrangement of tools. These factors also vary for each make of machine.

The cutting tools are the same in principle for the automatic as for the hand machines; hence, no special description of this class of machines is necessary.

49. When to Use Turret Lathes.—Before a piece of work can be successfully performed with the turret machines, some special fixtures must be made and the machine adjusted for that particular piece of work. When turret machines have been adjusted, they produce the finished pieces much more rapidly than the engine lathe.

In determining whether to use the hand turret or automatic machines, the amount of finished work to be produced must be considered. If only a few pieces are to be made, it will not pay to make special tools, or even to take the time to set up an automatic machine. When the number of pieces to be finished has increased so that the saving in the cost of time overbalances the cost of making special tools and fixtures, then it pays to employ the automatic machine. Hand machines may be employed for a moderate number of pieces, but if there are only a very few the engine lathe or a chucking machine should be used.

SPECIAL FORMS OF LATHES.

TOOLMAKERS' LATHE.

50. General Description of Toolmakers' Lathe.—The term **toolmakers' lathe** is applied to lathes having from 10 to 16 inches swing, and, in appearance, are similar to the regular screw-cutting engine lathe. They are equipped with taper attachment, compound rest, and special chucks, and are made with a greater degree of perfection than is the ordinary engine lathe.

51. Special Chucks.—The **special chucks** found on toolmakers' lathes are used for holding rods or bars of different sizes. They are similar in principle to those used on turret screw machines. The collets shown in Figs. 2 and 3 are known as **push-in collets,** that is, they are pushed into a taper hole to close them. Another style of collet that works on the same principle is the **draw-in collet.** In the draw-in collet, the bevel on the large end slopes in an opposite direction from that shown in Fig. 3, so that, to close the chuck, it is drawn into a tapered hole in the headstock. This latter style is very commonly used on toolmakers' lathes.

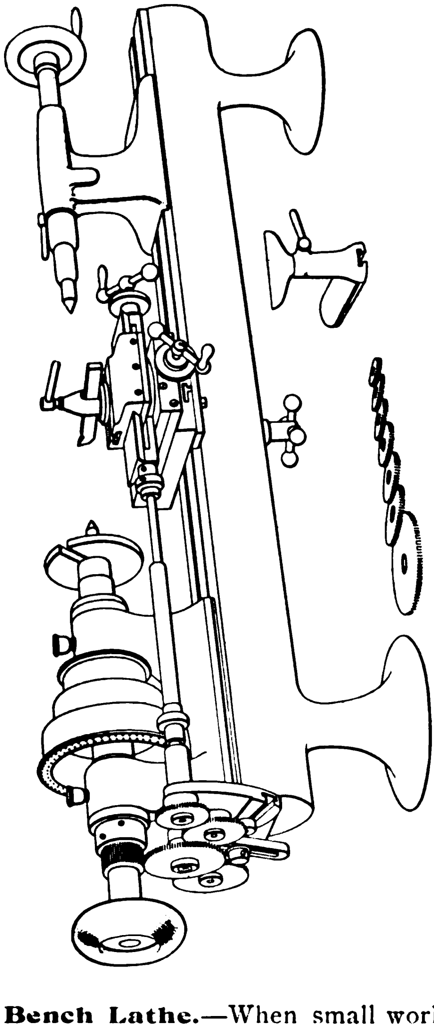


FIG. 40.

BENCH LATHES.

52. General Description of the Bench Lathe.—When small work must be finished with

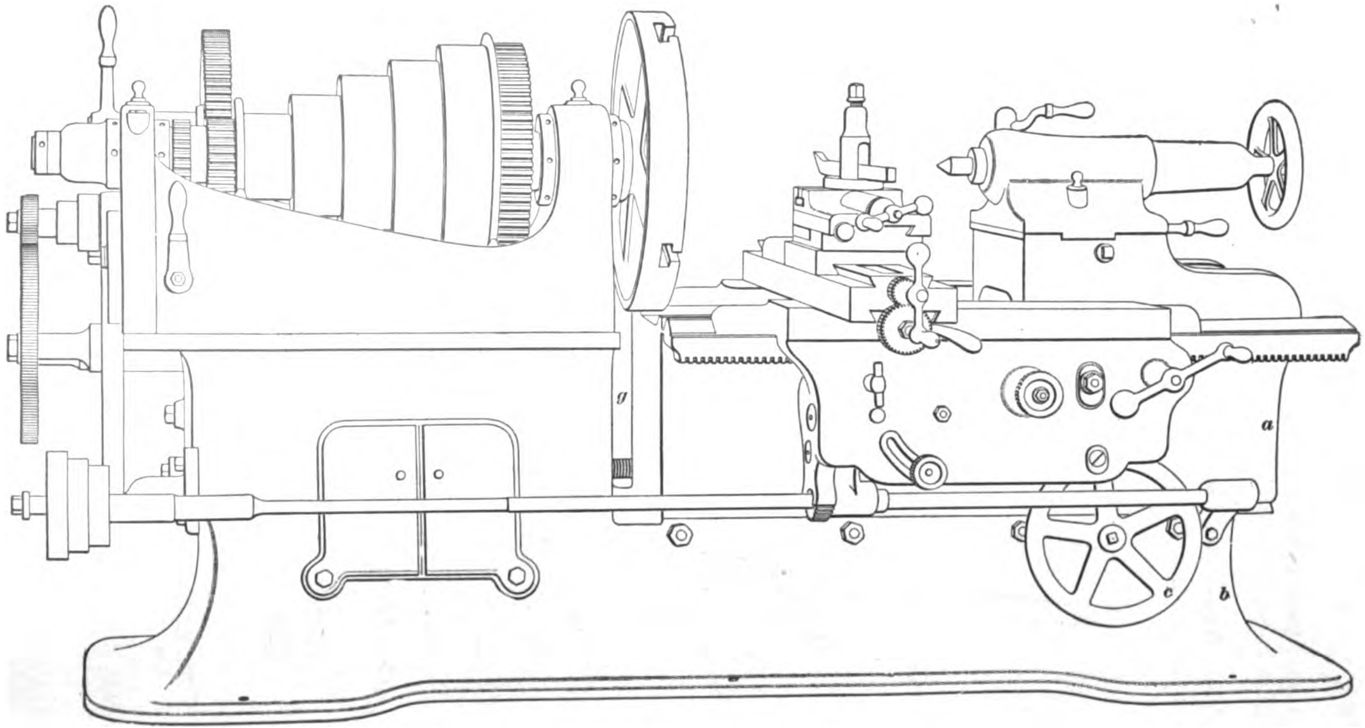


FIG. 41.

considerable accuracy, the ordinary engine lathe is too large and clumsy, and the hand lathe does not possess the accuracy or the attachments necessary to do the work. To finish this class of work, the **bench,** or **precision, lathe,** Fig. 40, may be used. This lathe is fitted with a double slide rest with automatic feed. The slide rest may be removed and another attachment supplied in its place for special milling operations. For cutting threads, a chaser bar is provided. This chaser bar is operated as the one described in connection with turret lathes, Fig. 33. Special draw-in collets are used for holding small rods. These lathes, while not in reality watchmakers' lathes, are similar to them. They are intended only for light work.

GAP LATHES.

53. Special Feature of the Gap Lathe.—A style of lathe that is often seen in shops where large lathes of considerable swing are seldom needed, is shown in Fig. 41. This is known as the **gap lathe.** Its principal feature is the second bed *a*, which slides upon the main bed *b*. When ordinary work is to be turned, the top bed is moved up very close to the face plate, nearly closing the gap *g*. It is then used as an ordinary lathe. When a particularly large piece is to be turned, the upper bed is moved away from the headstock by turning the hand wheel *c*, thus opening the gap *g* and giving the lathe its full swing over the main bed *b*.

TWO-SPINDLE LATHE.

54. Distinguishing Characteristics of the Two-Spindle Lathe.—A style of lathe that in many cases answers the same purpose is the **two-spindle lathe** shown in Fig. 42. For ordinary work, the lower set of spindles *a*, *b* are used, but when the piece is too large to be swung on the lower set of spindles, the high ones *c*, *d* are used and the tool post blocked up by using a special cross-slide.

55. Blocking Up of Lathes.—It is common practice in lathe work, when the piece to be operated upon is a little too large to be swung in the largest lathe, to **block up** the headstock and tailstock by putting under them

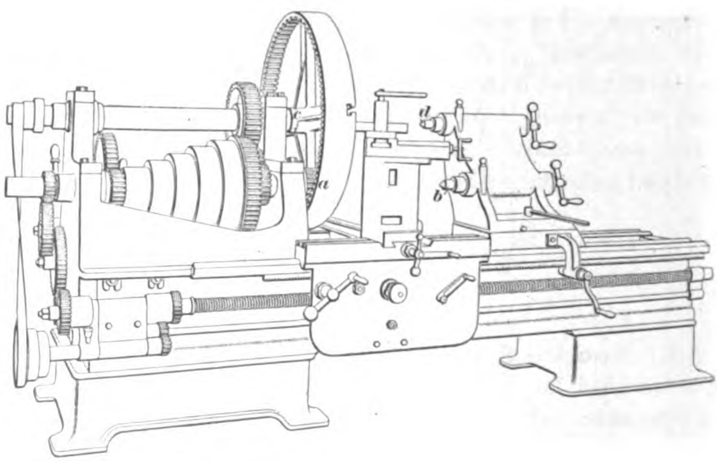


FIG. 42.

wooden or iron blocks until the centers are sufficiently high above the bed to allow the work to swing. The gap lathes and the two-spindle lathes are intended to take the place of the blocked-up lathe. Thus far, the lathes mentioned have been of the same type as the standard engine lathe, with only slight modifications.

AXLE LATHES.

56. General Description of the Axle Lathe.—Specially designed machines are often made when there is enough of a particular kind of work to warrant them. Car axles may be turned on an ordinary engine lathe, but it is possible to do the work much faster on one of a special design, such as is shown in Fig. 43. This **axle lathe** is

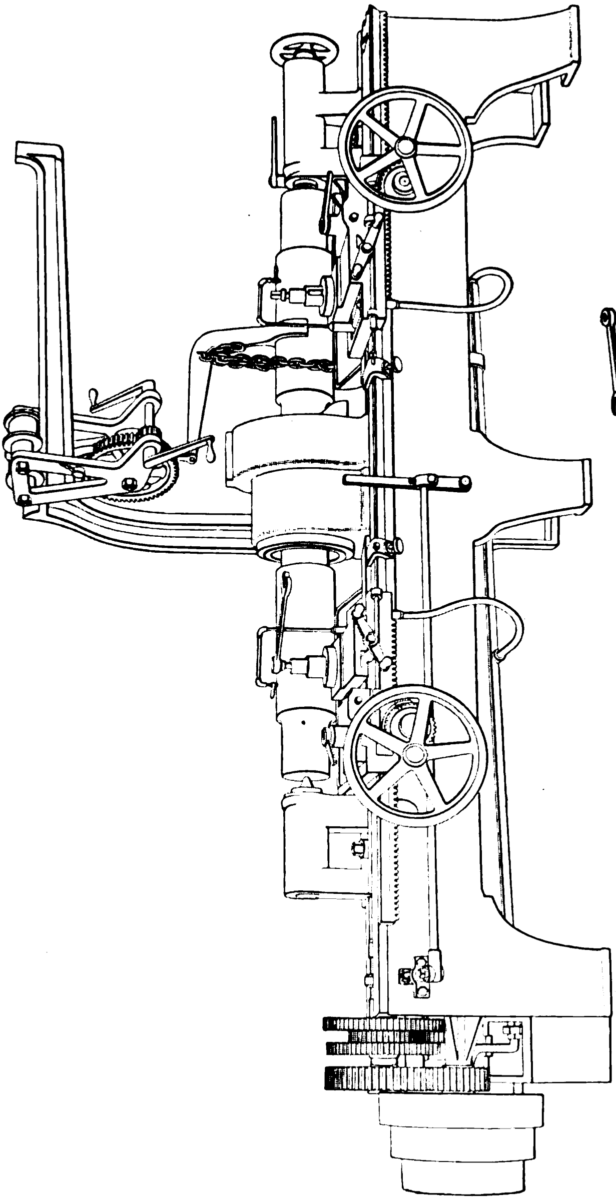


FIG. 43.

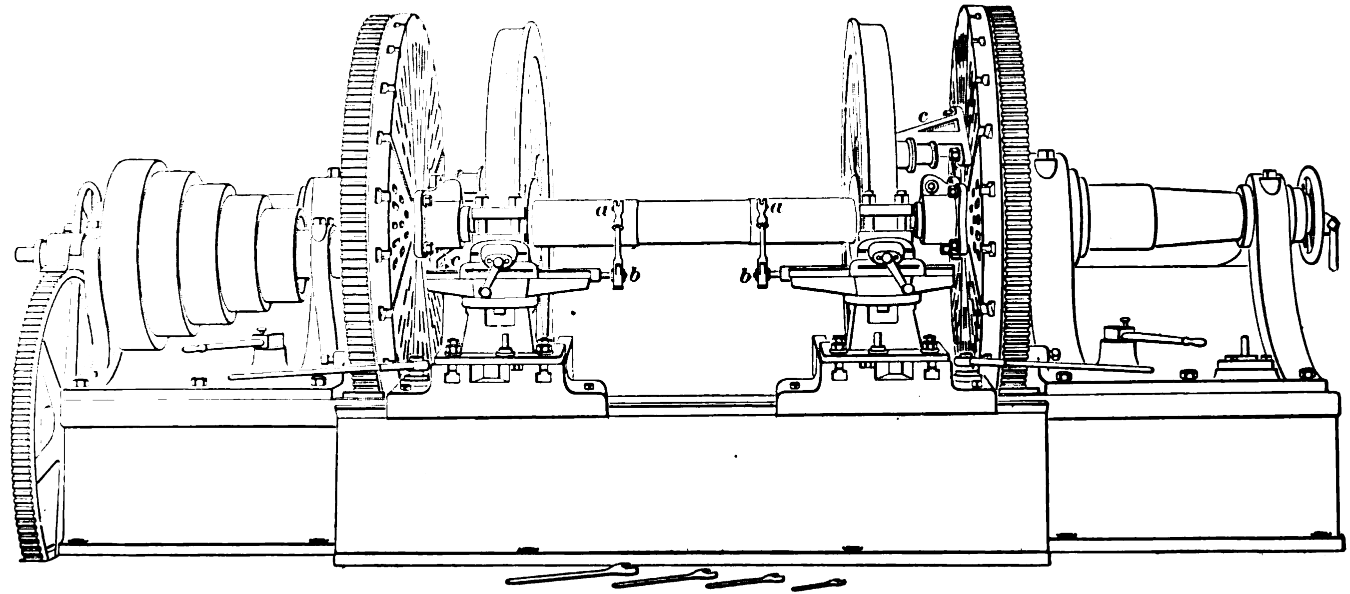


FIG. 44.

designed so that the two ends of the axle may be turned at the same time. To accomplish this, the driving head is placed in the center of the lathe bed. This allows the work to be turned on dead centers—a very desirable thing when accuracy is desired—and it also leaves the ends free, so that a cut may be taken on each end at the same time. The driving head is operated by gearing connected by a shaft with the cone pulley seen at the left. The axle shown in place in the lathe is handled by means of the overhanging crane.

57. Method of Driving the Work.—After the work is adjusted between the centers, the dog or driver is put in place. This should be an equalizing dog, or a two-tailed dog operated by an equalizing device, so that the force required to drive the work will not spring the axle. Chucks cannot be used, as they spring the work. Means are provided for keeping a large supply of soda water flowing on the tool during the cut.

WHEEL LATHES.

58. Fig. 44 shows a style of lathe especially designed for turning locomotive driving wheels after they have been pressed on to an axle. This lathe is designed with two driving heads and two tool rests, thus enabling the operator to turn both driving wheels at the same time. It will be noticed that there are no feed-rods along the bed to operate the tool carriages, as found in ordinary lathes. The tool carriage ordinarily used is similar to the compound rest, since it may be turned on its base and set at any desired angle. Two slides allow the tool to be moved in two directions, at right angles to each other. Screws for moving the slides are operated by a lever *a* connected to the feed-screws by ratchets *b*. These levers are moved automatically by levers and cams in a separate mechanism above the lathe to which they are connected by chains.

After the wheels on the axles are put between the centers, the drivers *c* shown on each face plate are so adjusted against each wheel that it is driven from its face plate. These lathes may also be used for boring the tires of locomotive driving wheels, the tires being bolted to the face plate and bored and faced, as in ordinary face-plate work. This method of boring tires is not often employed, as they can be bored much better on a boring mill.

PULLEY LATHES.

59. Fig. 45 shows a type of lathe specially designed for turning pulleys. The lathe has two tool rests so that

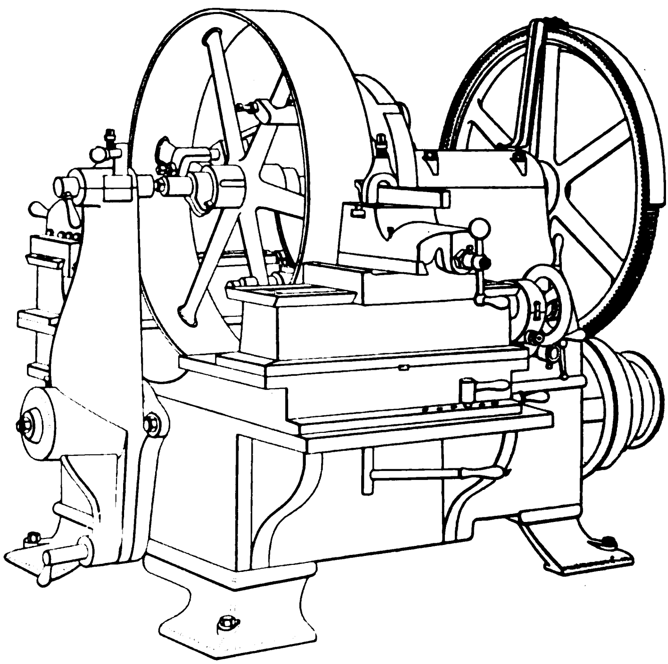


FIG. 45.

two tools may be used, one at the front and one at the back of the machine. Special driving dogs attached to the face plate drive the pulley by its arms.

HAND, OR SPEED, LATHES.

60. General Description of the Hand Lathe.—Hand lathes, or **speed lathes,** are the smaller sizes of lathes used for such operations as can be performed with tools held in the hand, or for such operations that require a higher speed of work than can be obtained by the ordinary turning lathe. These lathes are without back gears or slide rests. Fig. 46 shows a standard type of hand lathe. It is mounted on a table, which makes a convenient place for holding tools and work.

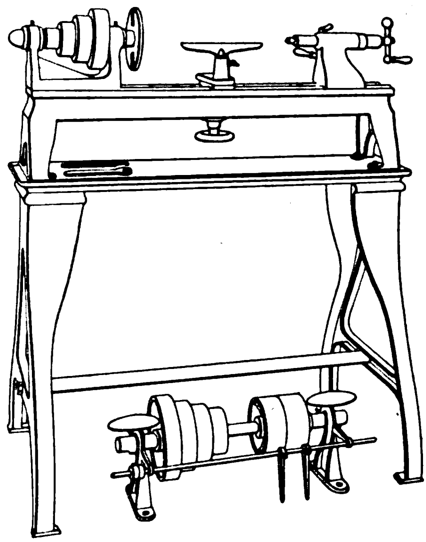


FIG. 46.

61. Use of the Hand Lathe.—Work that is of irregular outline, requiring the use of hand gravers, is often finished on this type of lathe. When a small chuck is fitted to the spindle of the lathe, it is very handy for turning or pointing small rods and pins, and a variety of similar work. Drilling may also be done very conveniently on certain classes of work. When much drilling is to be done, a tailstock with a lever attachment for feeding the spindle is more convenient than the screw attachment.

62. Special Centers.—When the lathe is used for drilling or reaming center holes, the drill is held in a chuck and the work pressed against the drill by the tailstock spindle.

FIG. 47.

When holes are to be

drilled in thin flat pieces, a **pad center,** Fig. 47, can be used in place of the **cone center.** When holes are to be drilled diametrically through rods or tubes, a forked center, Fig. 48, aids in holding the work true.

FIG. 48.

63. Hand Slide Rest.—Fig. 49 shows a **hand slide rest** that is often used on these hand lathes. The ordinary hand rest is removed and this is clamped in its place. A small tool

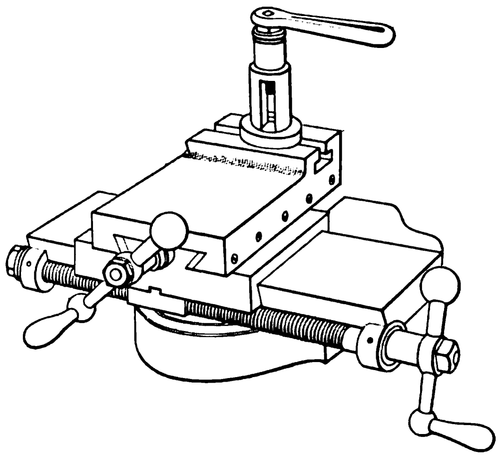


FIG. 49.

can be held in the tool post, and for light work it is very convenient.

POLISHING.

64. Object of Polishing.—One of the principal uses for which the speed lathe is adapted is **polishing** cylindrical work. The various parts of a machine are polished to add to its attractiveness and beauty, and not to add to the perfection of its movements or to increase its efficiency. Parts of the machine that are fitted to each other, or are in unseen places, should not be polished. When a piece is well polished, it is smooth and true, free from scratches, possesses brilliancy, is even in its appearance, and free from bright- and dull-colored streaks.

FILING.

65. General Consideration.—When a cylindrical piece is to be polished, it should be finished with a very smooth finishing cut on the lathe. It is next made smooth by **filing.** Just enough filing should be done to remove the tool marks, care being taken not to scratch the work. This scratching often occurs and is called *pinning*. Pinning is caused by the filings collecting in the teeth of the file and forming little balls of metal. When the file is passed over the work, these little balls of shavings will catch in the surface and produce deep scores or scratches. This will occur every time the file passes over the work until the file is cleaned. For cleaning the teeth of the file, a *file card* should be used. A file card is similar to a very stiff brush with very fine steel wires taking the place of the bristles. When the card is used, it is drawn across the file so that the wires follow in the spaces between the teeth. Ordinarily, this operation will clean the file, but if it does not, and the little bright spots of shavings are still seen, they must be picked out with a piece of soft-iron wire that has been flattened on the end. The flat end is laid on the file and moved across it in such a way that it will get under the ball of shaving and remove it.

66. Files for Lathe Work.—The best files to use for lathe work are the mill files. These are single-cut and there is less danger of their pinning than with the double-cut files. They also cut smoother.

67. Avoiding Pinning.—Pinning may be more or less avoided by properly holding the file on the work. When filing, the point of the file should be held to the right so that it is at an angle to the work, as shown in

Fig. 50. While held in this position, the file is moved across the work squarely in the direction of the arrow. This makes it appear as if the file were moving toward the left. Such, however, is not the case. Pinning may also be avoided at times by filling the teeth of the file with chalk.

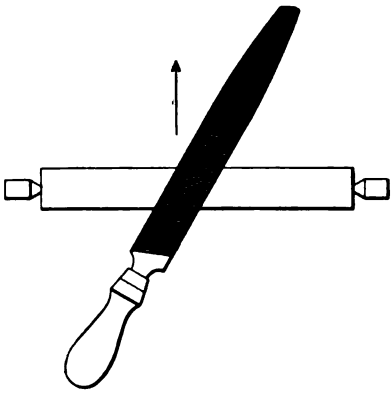


FIG. 50.

68. Speed of the Work for Filing.—The speed of the work for filing must be considered the same as the speed of the work for turning. If the file be brought against a rapidly revolving piece, like the face of a large pulley, or similar work, it will be found that the points of the teeth are instantly worn away, and that the file is as quickly destroyed as if it had been held against a rapidly revolving emery wheel. The cutting speed of a file should not be much over 40 or 50 feet per minute on iron or steel.

When the work is small in diameter, it may be run at quite a high number of revolutions, so that in making one stroke of the file over the work, the work will make a number of revolutions. This is desirable when an attempt is being made to keep the work true. It is difficult to file the same amount from every point along the work, since one part of the work will be filed more than another, with the result that the longer the filing operation is continued, the more untrue the work becomes.

69. Even Filing.—When the work is large in diameter, it will be necessary to run it at a lower number of revolutions per minute. Suppose the rate of file strokes were one a second, and the rate of revolutions of the work the same. Then, for one stroke of the file forwards, the work would make half a revolution, and it would be filed half around its circumference. While the file is being drawn back for the second stroke, the work begins its second revolution and the file again cuts half of the circumference of the work. It will also be on the same side of the work. In this case, the file has cut twice on one side of the work, and has entirely skipped the opposite side. This will be continued so long as the rate of file strokes and revolutions of the work are the same. It may be seen from this that *to keep the work nearly true, the file strokes should be slow enough to allow the work to make a number of revolutions for each stroke of the file.*

USE OF EMERY.

70. Use of a Polishing Stick.—After the tool marks have been removed by filing, the piece is treated with a coarse piece of emery cloth, which will remove the file marks. After the file marks have been removed, a finer grade of emery is used until the coarser emery marks have been removed, and so on, using finer grades of emery until the desired polish is obtained. Emery cloth should be pressed very hard against the work by using a polishing stick, which is passed over the tool rest of the lathe and under the work, the emery cloth being held between the stick and the work. By pressing down on the outer end of the stick, the emery cloth can be brought with great pressure against the work.

71. Speed for Polishing.—The speed for polishing is quite different from that used for filing. The higher the speed the better, provided the work and the machine are balanced so that the high speed does not shake the machine too badly. When polishing, the stick should be moved so that it will not remain in one position on the work, but will move back and forth, in order that the lines cut by the particles of emery will be constantly crossing and recrossing one another. Oil should be supplied to the work and the emery, in a quantity sufficient to keep the surface moistened, but not so that it will be thrown from the machine in great quantities.

72. Care of the Centers.—When a piece of work is being polished, so much heat may be generated as to cause it to expand along its entire length. If, in the first place, the dead center has been made fairly tight, it will become locked in the end of the work, the oil having been burned out, and will be twisted off. This should be carefully guarded against by keeping the centers free and well oiled.

73. Finishing a Polished Surface.—When the piece is nearly finished, the pressure of the emery is reduced and the movement along the length of the work is slower. For the finest grades of polish, fine crocus cloth is used and still finer polishes are produced by using rottenstone. Not much machine work is carried to that perfection of polish that requires crocus cloth or rottenstone for finishing. A very high polish may be obtained by using a much worn piece of No. 0 or 00 emery cloth.

Grain emery is often used in the place of emery cloth. Bare wood, or pieces of lead on the face of the wood, is used to hold the emery against the work. The particles of emery

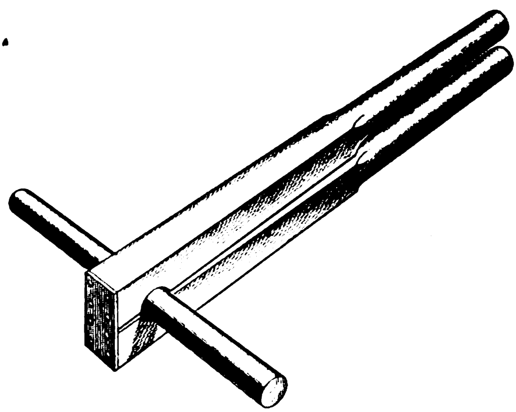


FIG. 51.

embed themselves in the soft wood or in the lead and so are held from being thrown from the work. Oil is used as before.

74. Polishing Clamp.—For plain cylindrical work, a very convenient and effective way of holding the emery against the work is brought about by fastening two pieces of wood together at the end with a leather hinge. The two inside faces of the pieces are cut out at a short distance from the hinged end, so that they will fit over the shaft, as shown in Fig. 51. By pressing the outer ends together, considerable pressure is brought against the shaft. Either emery cloth or grain emery may be used with this device.

SPECIAL LATHE WORK.

USE OF STEADY REST.

75. General Considerations.—When long shafts are to be turned, it is necessary to support them along their length. If there is no support, they will bend and vibrate so that it will be very difficult to take a cut from them. Fig. 52 shows a form of steady rest that is usually supplied with engine lathes. When in use, this steady rest is bolted to the top of the lathe bed at a place where it is desired to support the shaft. The rest is made in two parts, with a hinge *a* at the back and a latch or clamp *b* at the front. After the steady rest is clamped on the bed, the latch is unclamped and the top half turned back so that the shaft can be put in the lathe between the centers. The top half is then closed and clamped in place. If the shaft be perfectly true, the jaws *c* of the

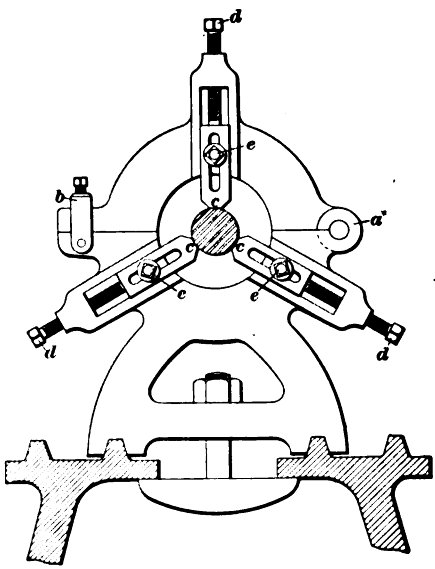


FIG. 52.

steady rest may be adjusted so that they just touch it. Screws *d* stand against the ends of the jaws and hold them against the work. After the jaws have been adjusted so that they all touch the shaft, but do not spring it, they are clamped by the bolts *e*, which pass through the jaws and the rest. The jaws should be oiled where the shaft turns on them.

76. Spotting the Shaft.—If the shaft does not run perfectly true, a **spot** must be turned on it that does run true and the jaws of the steady rest adjusted to the spot. If the steady rest were adjusted to a place that did not run true at first, it would be found that after it was adjusted, the shaft would appear to run true and would continue to do so until the jaws were again loosened, when the shaft would spring to its natural shape and wabble as before. When a shaft is to be spotted for the steady rest, a very fine light cut is made (of any diameter so long as it is true) to give the jaws a fair bearing.

If the shaft is quite long and it is desired to put the steady rest near the middle of the shaft, it may be found that a cut cannot be taken in the middle of the shaft to spot it because of its extreme flexibility. Cuts near the end of the shaft, where it is better supported by the lathe centers, may be taken. In such a case, a cut would be taken near the dead center and a spot made. Having the shaft thus spotted, the steady rest may be adjusted to this place and the second spot turned farther along. In this way, the spots may be moved along the shaft until the middle is reached.

77. The Cat Head.—On some classes of work, it is desirable to use the steady rest on a part that does not run true and it is not desirable to spot the place on the shaft. In such a case, a device called a **cat head** is adjusted on the shaft. A cat head is a collar that fits loosely over the shaft to the place where the steady rest is to be adjusted, and is here clamped upon the shaft by a number of setscrews, as shown in Fig. 53. By varying the adjustment of the setscrews at the ends, the cat head may be set to run true.

After it has been set, the jaws of the steady rest may be adjusted to it the same as to a larger shaft. In the case of the slim shaft just mentioned, the cat head may be used instead of making the series of spots from the end.

If the shaft is long, it may be necessary to use two or more steady rests. When the tool and carriage have fed up

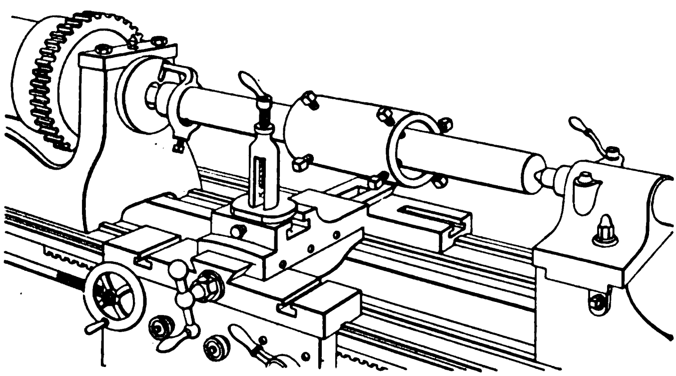


FIG. 53.

to the steady rest, it must be moved to another position to allow the cut to pass. It is difficult to turn long shafts and have them remain straight, even if the spots are turned with great care. When the shaft is rolled, its surface is more or less under tension, and, as it is turned, this tension is removed, thus allowing the shaft to spring so that the spot that was turned true when the shaft was rough is untrue after it is turned.

FOLLOWER RESTS.

78. Another method of supporting shafts while being turned is by the use of the **follower rest.** Such a style of rest is shown in Fig. 54. This rest is bolted securely to the carriage and travels with it. When it is used, a cut of the desired diameter is started at the end of the shaft. As soon as a spot is made true, the two jaws *c*, *c* are carefully adjusted to the work *w*. Since there is a tendency to spring the shaft away from the tool, it will be seen that the two jaws are sufficient to support the work.

79. Solid Bushings.—Another method of supporting the work is by means of the follower rest supplied with

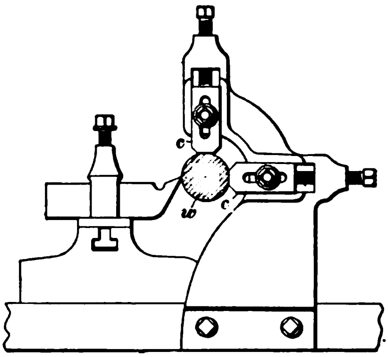


FIG. 54.

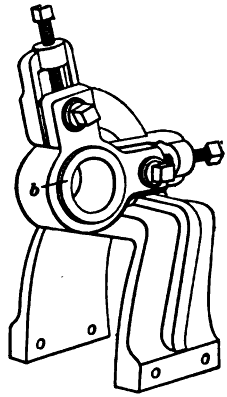


FIG. 55.

bushings, so that as soon as the end of the shaft is turned, it enters a rigid bearing. Such a follower rest is shown in Fig. 55. Bushings *b* bored to different diameters are used for different sizes of shafts. This style of follower rest gives a very perfect support for the shaft. When used, the tool is set slightly in advance of the follower. The closer the tool is set to the follower rest, the less danger there is of its chattering.

SHAFTING LATHES.

80. Special Shafting Turner.—When much shafting is to be turned, a regular **shafting lathe** is used. These lathes have very long beds and the carriage is fitted with a **shafting turner.** The shafting turner consists of a follower rest with bushings to fit around the shaft, similar to that shown in Fig. 55. It also has two, three, or four tool slides, so that an equal number of tools may be used to cut at once. When used, two or three roughing tools precede, and one finishing tool follows the rest. Thus, the shaft is roughed and finished at one cut.

81. Torsion in the Shaft.—Much power is required to take a cut with four tools cutting at the same time, and, in the case of a long shaft, the torsion in it, when the tools are at the beginning of the cut, is considerable. To overcome this, long shafts are driven from both ends.

STRAIGHTENING.

82. Straightening Machines.—After the shafts are turned, they are apt to be crooked for the reasons mentioned above. They are straightened on a regular **shafting straightener,** which consists of a number of conical rolls so arranged that, as the shaft is revolved and drawn between the rolls, it is bent and straightened.

83. Straightening Small Work.—A special straightener is not always necessary in order that a shaft may be made true. Small straightening presses may be used for bending the crooked shaft to make it straight. These straightening presses are so constructed that the shaft to be straightened may rest upon two supports from 1 to 3 feet apart, depending on the size of the straightener. An arm projects from behind the machine, midway between the points of support, and over the shaft in such a way that a vertical screw may be used for pressing the shaft down. When the shaft is to be straightened, it is supported between the centers of the lathe, and, while revolving slowly, it is marked with chalk on the high side. It is then removed from the lathe, taken to the straightener, and bent sufficiently to make it straight. A number of trials may be necessary to make the shaft run true. If the bend is a short kink, then all the straightening should be done at that place, but if the original crook is a long sweep, the work should be straightened by a series of applications of the press along the work. These presses are sometimes supported on wheels and set directly on the lathe bed. After the work is tested, the press is moved along the bed to the crooked place on the shaft, and, after loosening the lathe centers, the machine is used for straightening the work.

84. If such a press is not at hand, a shaft may be straightened after marking by taking it from the lathe and resting it upon two solid blocks of wood, with the marked part up between the blocks. A third block is rested on the shaft between the supporting blocks, and is struck a blow with a hammer or sledge. Care must be taken not to deliver too heavy a blow or the work will be more crooked than before.

85. Sometimes, when the proper straightening devices are not at hand, slender work may be straightened between the lathe centers, but such practice injures the lathe and should not be used except in special cases. The work is revolved between the lathe centers and the high side marked. A bar or lever is then put over a tool in the tool post and under the work in such a way that when the lever is pushed down by hand the work will be sprung up. By turning the work so that the marked part is down, it can be so sprung that, after a number of trials, it will run quite true. If the bend is a long uniform one, it can be straightened by simply bending or springing the bar as just indicated. If the shaft appears to have a short bend, while either side of the bend appears to be straight, this short bend can be taken out by springing up the shaft with the lever, as described, and striking a few blows with the hammer on the top of the shaft on the bent part. The hammering should be light at first or the bar will be found to be bent as badly as it was before, but to the opposite side. This hammering has a peening action that tends to slightly stretch the shaft on the side struck.

86. Straightening Leadscrews.—This method of peening is sometimes used for straightening large or long lathe leadscrews after they have been threaded. A special tool is used for peening the threads, as shown in Fig. 56. This tool is made thin at its edge, so that it will go between the threads down to the root. It is concave, so that it fits around the screw for a short distance. When the screw is tested and found to be untrue, it is sprung up with the lever at the bent place, and, while held in this sprung position, a few of the threads on the top side are peened with the peening tool and a hammer. With some skill, a screw that was badly bent may be quickly straightened. It may be seen that this method of straightening screws will not do when the pitch of the leadscrew must be accurate, since it will slightly stretch the screw. For ordinary purposes, however, the stretching of the screw caused by slight peening would be so little that it would scarcely be perceptible. The most accurate leadscrews are always straightened without peening.

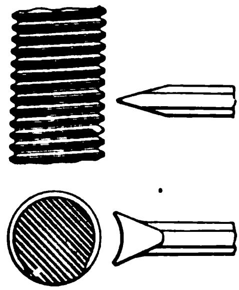


FIG. 56.

USE OF STEADY REST IN CHUCKING.

87. Application of Steady Rest to Bars.—Fig. 57 shows how a bar may be held when it is desired to operate on the end for boring or turning. In adjusting the steady rest, the bar is held by one end in the chuck, while the other end is supported on blocks of wood at a height equal to that of the dead center. The steady rest is moved very close to the chuck and the jaws adjusted to touch the bar. After the jaws are adjusted, the steady rest is opened by turning back the top, but without changing the adjustment of the jaws. It is then moved down the bar and clamped in the desired place. By this method of adjusting the jaws, the work is held in line with the headstock spindle. This method of supporting work is often used for very large

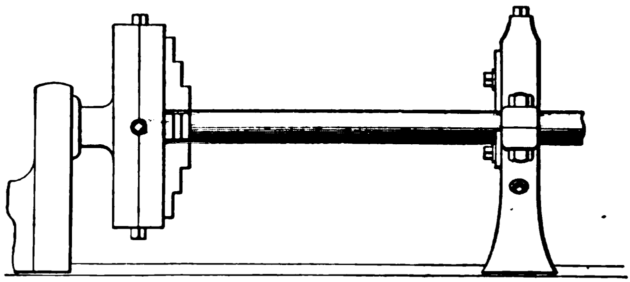


FIG. 57.

pieces, and, when necessary, very large and heavy steady rests are used.

88. Application of Steady Rest to the Turning and Boring of Large Guns.—The forgings for large guns are usually operated upon while one end is supported in and driven by a chuck, and the body of the piece rests on one or more steady rests. These steady rests are of a specially heavy design. Fig. 58 illustrates one of them supporting the inner tube for a 12-inch gun, *a* being the tube and *b* a large chucking drill used for boring the inside of the tube. In this gun work, the roughing and finishing tools are specially designed drills and reamers,

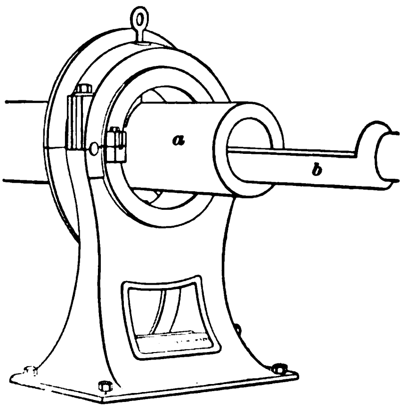


FIG. 58.

and the cutting speeds are very slow, it having been found that speeds exceeding 6 or 8 feet per minute are usually unprofitable, on account of the fact that they cause excessive wear and breakage of the costly tools.

TURNING BY MEANS OF A ROTATING TOOL.

89. Occasionally a job has to be done that requires the turning of a trunnion, or projection, upon a large and heavy

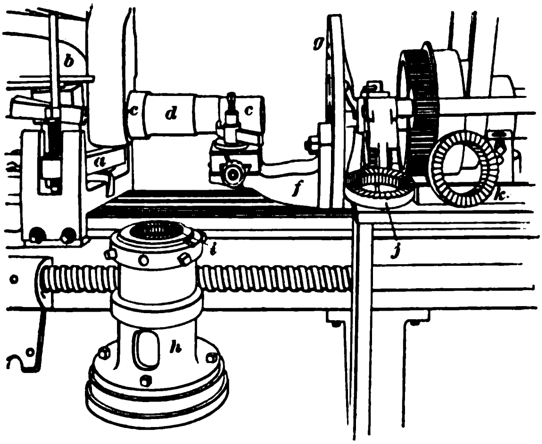


FIG. 59.

casting. If such a casting *b* were placed in the lathe and rotated upon centers, it would require a very large lathe to do the work. Fig. 59 illustrates a method by means of which this difficulty has been successfully overcome. The casting in question is long and heavy and is supported at one end upon a regular carriage *a*, and at the farther end upon a special carriage not shown in the illustration. The work requires that the portions *c*, *d*, and *e* be turned to three different diameters. They are roughed by means of a tool attached to the special arm *f* attached to the face plate *g*. After the three diameters have been roughed out, the face plate *g* is unscrewed from the spindle and the attachment *h*, shown in the foreground, substituted for it. This attachment carries hollow mills, as shown at *i*. The mill shown at *i* is intended for finishing the portion *c*, and, after this portion is finished, the mill shown at *j* is substituted to finish the portion *d*, and the mill shown at *k* to finish the portion *e*. The tool or mill always revolves at the same distance from the face plate or end of the spindle, the work being fed into or past the revolving tool by means of an ordinary feed upon the carriage *a*.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the various Question Papers that follow have been given the same section numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until the Instruction Paper having the same section number as the Question Paper in which the questions or examples occur has been carefully studied.

READING WORKING DRAWINGS.

(1) Define the following terms: Surface; inside surface; outside surface; plane surface; plane.

(2) What is the difference between a perspective drawing and one drawn in orthographic projection?

(3) What advantage has the orthographic projection for shop use?

(4) What is meant by the term "mechanical drawing" as commonly used?

(5) How many views are required to fully illustrate an object?

(6) What is a sectional view and how is a section designated?

(7) What is a scale drawing and how is the scale marked or designated on a drawing?

(8) What are shade lines and for what are they used on mechanical drawings?

(9) When it is desired to draw a long piece, such as a shaft, in a limited space, how can the drawing be made without reducing the scale to such an extent as to make the diameter appear so small that details cannot be shown plainly?

(10) How are screw threads shown on a drawing?

(11) When a small detail, such as a nut or rivet head, occurs a great many times on a drawing, how does the draftsman avoid the work of drawing the detail each time and still make it plain to the workman how the detail is to be formed ?

(12) How are dimensions usually placed on a drawing ?

(13) (*a*) What is a general drawing ? (*b*) What is a detail drawing ?

(14) Describe each of the following kinds of lines and state how they are usually employed on drawings: Light full line; dotted line; broken-and-dotted line; broken line; heavy full line.

ARITHMETIC.

(PART 1.)

(1) What is arithmetic?

(2) What is a number?

(3) What is the difference between a concrete number and an abstract number?

(4) Define notation and numeration.

(5) Write each of the following numbers in words: (*a*) 980; (*b*) 605; (*c*) 28,284; (*d*) 9,006,042; (*e*) 850,317,002; (*f*) 700,004.

(6) Represent in figures the following expressions: (*a*) Seven thousand, six hundred. (*b*) Eighty-one thousand, four hundred, two. (*c*) Five million, four thousand, seven. (*d*) One hundred eight million, ten thousand, one. (*e*) Eighteen million, six. (*f*) Thirty thousand, ten.

(7) What is the sum of $3,290 + 504 + 865,403 + 2,074 + 81 + 7$? Ans. 871,359.

(8) $709 + 8,304,725 + 391 + 100,302 + 300 + 909 =$ what? Ans. 8,407,336.

(9) Find the difference between the following: (*a*) 50,962 and 3,338; (*b*) 10,001 and 15,339. Ans. { (*a*) 47,624. (*b*) 5,338.

(10) (*a*) $70,968 - 32,975 =$? (*b*) $100,000 - 98,735 =$? Ans. { (*a*) 37,993. (*b*) 1,265.

(11) From 5,962 + 8,471 + 9,023 take 3,874 + 2,039.
Ans. 17,543.

(12) Find the products of the following: (*a*) 526,387 × 7; (*b*) 700,298 × 17; (*c*) 217 × 103 × 67.
Ans. (*a*) 3,684,709. (*b*) 11,905,066. (*c*) 1,497,517.

(13) Solve the following by cancelation:

(*a*) $\frac{72 \times 48 \times 28 \times 5}{96 \times 15 \times 7 \times 6} = ?$ (*b*) $\frac{80 \times 60 \times 50 \times 16 \times 14}{70 \times 50 \times 24 \times 20} = ?$

Ans. (*a*) 8. (*b*) 32.

(14) What is the quotient of: (*a*) 589,824 ÷ 576? (*b*) 369,730,620 ÷ 43,911? (*c*) 2,527,525 ÷ 505? (*d*) 4,961,794,302 ÷ 1,234?
Ans. (*a*) 1,024. (*b*) 8,420. (*c*) 5,005. (*d*) 4,020,903.

(15) What is the product of: (*a*) 1,024 × 576? (*b*) 5,005 × 505? (*c*) 43,911 × 8,420?
Ans. (*a*) 589,824. (*b*) 2,527,525. (*c*) 369,730,620.

ARITHMETIC.

(PART 2.)

---

(1) What is a fraction ?

(2) What are the terms of a fraction ?

(3) What does the denominator show ?

(4) What does the numerator show ?

(5) How do you find the value of a fraction ?

(6) Is $\frac{13}{8}$ a proper or an improper fraction, and why ?

(7) Write three mixed numbers.

(8) Reduce the following fractions to their lowest terms: $\frac{4}{8}$, $\frac{4}{16}$, $\frac{8}{32}$, $\frac{32}{64}$. Ans. $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{2}$.

(9) Reduce 6 to an improper fraction whose denominator is 4. Ans. $\frac{24}{4}$.

(10) Reduce $7\frac{7}{8}$, $13\frac{5}{16}$, and $10\frac{3}{4}$ to improper fractions. Ans. $\frac{63}{8}$, $\frac{213}{16}$, $\frac{43}{4}$.

(11) What is the value of each of the following: $\frac{13}{2}$, $\frac{17}{4}$, $\frac{69}{16}$, $\frac{16}{8}$, $\frac{67}{64}$? Ans. $6\frac{1}{2}$, $4\frac{1}{4}$, $4\frac{5}{16}$, 2, $1\frac{3}{64}$.

(12) Solve the following: (*a*) $35 \div \frac{5}{16}$; (*b*) $\frac{9}{16} \div 3$; (*c*) $\frac{17}{2} \div 9$; (*d*) $\frac{113}{64} \div \frac{7}{16}$; (*e*) $15\frac{3}{4} \div 4\frac{3}{8}$.

Ans. (*a*) 112. (*b*) $\frac{3}{16}$. (*c*) $\frac{17}{18}$. (*d*) $4\frac{1}{28}$. (*e*) $3\frac{3}{5}$.

(13) $\frac{1}{8} + \frac{2}{8} + \frac{5}{8} = ?$ Ans. 1.

§ 1

(14) $\frac{1}{4} + \frac{3}{8} + \frac{5}{16} = ?$ Ans. $\frac{15}{16}$.

(15) $42 + 31\frac{5}{8} + 9\frac{7}{16} = ?$ Ans. $83\frac{1}{16}$.

(16) An iron plate is divided into four sections; the first contains $29\frac{3}{4}$ square inches; the second, $50\frac{5}{8}$ square inches; the third, 41 square inches; and the fourth, $69\frac{3}{16}$ square inches. How many square inches are in the plate?

Ans. $190\frac{9}{16}$ sq. in.

(17) The numerator of a fraction is 28, and the value of the fraction $\frac{7}{8}$; what is the denominator? Ans. 32.

(18) What is the difference between (*a*) $\frac{7}{8}$ and $\frac{7}{16}$? (*b*) 13 and $7\frac{7}{16}$? (*c*) $312\frac{9}{16}$ and $229\frac{5}{32}$?

Ans. { (*a*) $\frac{7}{16}$. (*b*) $5\frac{9}{16}$. (*c*) $83\frac{13}{32}$.

ARITHMETIC.

(PART 3.)

---

(1) Write out in words the following numbers: .08, .131, .0001, .000027, .0108, and 93.0101.

(2) How do you place decimals for addition and subtraction?

(3) Give a rule for multiplication of decimals.

(4) Give a rule for division of decimals.

(5) State the difference between a fraction and a decimal.

(6) State how to reduce a fraction to a decimal.

(7) Reduce the following fractions to equivalent decimals: $\frac{1}{2}$, $\frac{7}{8}$, $\frac{5}{32}$, $\frac{65}{100}$, and $\frac{125}{1000}$.

Ans. { .5. / .875. / .15625. / .65. / .125.

(8) How many inches in .875 of a foot? Ans. $10\frac{1}{2}$ in.

(9) What decimal part of a foot is $\frac{3}{16}$ of an inch?

Ans. .015625.

(10) Express: (*a*) .7928 in 64ths; (*b*) .1416 in 32ds; (*c*) .47915 in 16ths.

Ans. { (*a*) $\frac{51}{64}$. / (*b*) $\frac{5}{32}$. / (*c*) $\frac{8}{16}$.

(11) Work out the following examples: (*a*) $709.63 - .8514$; (*b*) $81.963 - 1.7$; (*c*) $18 - .18$; (*d*) $1 - .001$.

Ans. (*a*) 708.7786. (*b*) 80.263. (*c*) 17.82. (*d*) .999.

(12) Work out the following: (*a*) $\frac{7}{8} - .807$; (*b*) $.875 - \frac{3}{8}$; (*c*) $(\frac{5}{32} + .435) - (\frac{21}{100} - .07)$.

Ans. (*a*) .068. (*b*) .5. (*c*) .45125.

(13) What is the sum of .125, .7, .089, .4005, .9, and .000027? Ans. 2.214527.

(14) Solve the following: (*a*) $.875 \div \frac{1}{2}$; (*b*) $\frac{7}{8} \div .5$; (*c*) $\frac{.375 \times \frac{1}{4}}{\frac{5}{16} - .125}$.

Ans. (*a*) 1.75. (*b*) 1.75. (*c*) .5.

(15) Reduce the following fractions to equivalent decimals and carry the result to four decimal places: (*a*) $\frac{113}{256}$; (*b*) $\frac{169}{196}$; (*c*) $\frac{1728}{2744}$; and (*d*) $\frac{3375}{4096}$.

Ans. (*a*) .4414. (*b*) .8622. (*c*) .6297. (*d*) .8240.

(16) Reduce the following decimals to common fractions: (*a*) .35; (*b*) .625; (*c*) 12.725; and (*d*) .00096.

Ans. (*a*) $\frac{7}{20}$. (*b*) $\frac{5}{8}$. (*c*) $12\frac{29}{40}$. (*d*) $\frac{3}{3125}$.

MEASURING INSTRUMENTS.

(1) What are the ultimate standards of reference in the United States?

(2) Define line measurements and end measurements.

(3) What is the difference between a *measuring instrument* and a *gauge* in the ordinary, restricted meaning of the word "gauge"?

(4) How would you set a pair of dividers to $5\frac{37}{64}$ inches by the standard steel rule shown in Fig. 2 of the Instruction Paper?

(5) What is a reduced scale?

(6) How would you set a pair of dividers to 1.623 inches by the differential rule shown in Fig. 3 of the Instruction Paper?

(7) Explain in detail the reading of a micrometer caliper when the barrel and thimble occupy the positions shown in Fig. 1. The micrometer screw has 40 threads per inch and the thimble 25 divisions.

Ans. .228 inch.

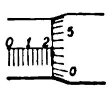


FIG. 1.

(8) What are the distinctive features of the measuring machine shown in Fig. 9 of the Instruction Paper?

(9) What is a protractor?

(10) How is an angle measured by a draftsman's protractor, such as is shown in Fig. 10 of the Instruction Paper?

(11) How is an angle measured by a bevel protractor, such as is shown in Fig. 12 of the Instruction Paper?

(12) Determine which of the verniers shown in Fig. 2 (*a*) and (*b*) is direct and which retrograde, showing work.

(13) What number of subdivisions of the unit of measurement is obtained by the aid of the verniers shown in Fig. 2 (*a*) and (*b*)?

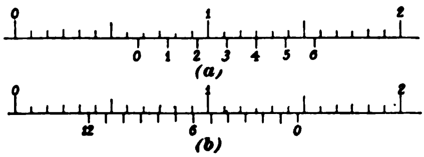


FIG. 2.

Ans. $\begin{cases} (a) & 72. \\ (b) & 144. \end{cases}$

(14) The true scale of a vernier shows inches subdivided into 8ths; how many divisions must the vernier scale have to allow of reading 64ths? Ans. 8

(15) What number of subdivisions of the inch can be obtained by a vernier in which the true scale shows 50ths of an inch and the vernier scale has 20 divisions?

Ans. 1,000.

(16) Read the verniers shown in Fig. 2 (*a*) and (*b*).

Ans. $\begin{cases} (a) & \frac{23}{36} \text{ unit.} \\ (b) & 1\frac{67}{144} \text{ units.} \end{cases}$

(17) Read the vernier shown in Fig. 3, in which the true scale shows inches divided into 10ths and 40ths and the vernier scale has 25 divisions.

Ans. 1.284 inches.

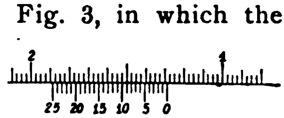


FIG. 3.

(18) Describe how to set a vernier micrometer caliper to .5555 inch. The divisions on the instrument are as described in Art. **70** of the Instruction Paper.

(19) Describe how to set a vernier protractor, such as is shown and described in Art. **71** and Fig. 18 of the Instruction Paper, to 20° 15′.

(20) What is a limit gauge?

(21) What is a try square?

(22) What is a center square conveniently used for?

(23) What is a center gauge?

(24) What do the numbers stamped on the center gauge shown in Fig. 31 of the Instruction Paper signify?

LATHE WORK.

(PART 1.)

---

(1) In speaking of an engine lathe, it is generally understood that the lathe in question possesses certain special features; what are they ?

(2) What are the two main parts of the lathe carriage called ?

(3) How is the feed-motion transmitted from the spindle to the feed-rod ?

(4) How is the feed-motion reversed ?

(5) Describe the arrangement and operation of the back gears.

(6) How may the centers be located on cylindrical work ?

(7) How should correctly formed center holes be made ?

(8) Why should the practice of using simply a large prick-punch mark for a center hole be discouraged ?

(9) What precautions should be taken in inserting a centered piece between the lathe centers ?

(10) How should a side tool be set ?

(11) Where would you look for the trouble if the ends of a piece of work do not square up rightly under a side tool ?

(12) How is a diamond-point tool set ?

(13) What determines the correct height of a front tool ?

(14) In inserting the tool in the tool post, what precaution should be taken?

(15) How is the tool started in taking a cut for turning to a diameter?

(16) If in calipering, after the first cut, one end of the turned cylinder is found to be larger than the other, where would you look for the cause of the trouble?

(17) A taper of 3 inches per foot is equal to what taper expressed in inches per inch? Ans. $\frac{1}{4}$ inch per inch.

(18) What methods do you know for turning tapers?

(19) What amount must the tailstock be set over to turn a taper of $1\frac{1}{8}$ inches per foot on a piece of work 6 inches between centers? Ans. $\frac{9}{32}$ in.

(20) How is the tailstock adjusted by notches in the work?

(21) What is the objection to turning tapers by setting over the dead center?

(22) What influence has the depth of the center holes on the taper?

(23) Describe the principle of a taper-turning attachment.

(24) In what way does the principle of a special taper-turning lathe differ from the method of setting over the lathe centers?

(25) How must the tool be set in turning a taper, and why?

(26) How is a taper fitted?

LATHE WORK.

(PART 2.)

---

(1) What is understood by the term *boring?*

(2) What are the advantages of the various kinds of lathe chucks?

(3) What kind of chuck would be best suited for boring a piece of work that has been previously turned true on the outside, as, for instance, a pulley?

(4) In setting a piece of work having several concentric surfaces that have to be turned and bored, what precautions must be observed?

(5) In chucking frail pieces of work, what is likely to occur and how should the effects of it be taken account of?

(6) By what means can a piece of work that is to be clamped with a finished surface to the face plate be prevented from slipping?

(7) In measuring bored holes by means of inside calipers, what should be observed in order to get the right measurement?

(8) Describe the process of boring out a cored hole by means of a flat drill.

(9) What is the purpose of a wood reamer?

(10) What kind of reamer is best suited for long holes?

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(11) How can a taper be bored with a boring bar having a sliding head?

(12) What is meant by the term *radial facing?*

(13) What precautions must be taken in radial facing?

(14) Facing and outside turning should be done before boring; give the reason why.

(15) Define the terms *point*, *diameter*, *root*, *height*, and *pitch* of a thread.

(16) In measuring the pitch of a screw, what error must be guarded against?

(17) What is the difference between a sharp or **V** thread and a U. S. standard thread?

(18) What are the drawbacks in cutting threads by hand?

(19) On what depends the accuracy of a screw-thread cut in the lathe?

(20) What gears can be used on a simple-geared lathe to cut a thread of 12 pitch, the pitch of the leadscrew being 4?

Ans. $\frac{20}{60}$.

(21) On a simple-geared lathe a thread of $9\frac{1}{2}$ pitch is to be cut. The leadscrew has 4 pitch. What change gears can be used?

Ans. $\frac{40}{95}$ or $\frac{32}{76}$.

(22) On the stud of a simple-geared lathe is a gear having 40 teeth. It is desired to cut a thread of 10 pitch. The leadscrew is 4 pitch. What must be the number of teeth of the gear on the leadscrew?

Ans. 100.

(23) The pitch of the leadscrew in a simple-geared lathe is 6. The gear on the spindle is 20. It is desired to cut a thread of 15 pitch. How many teeth must the gear on the leadscrew have?

Ans. 50.

(24) The ratio of compounding in a compound-geared lathe is such that the headstock spindle makes 3 revolutions to 1 revolution of the change-gear spindle. The leadscrew is 4 pitch. What change gears can be used to cut a thread of 27 pitch?

Ans. $\frac{40}{90}$.

(25) How is the threading tool for U. S. standard thread shaped?

(26) What instrument is used in setting the threading tool, and how?

(27) What is the effect of threading a bolt with a dull die, or a nut with a dull tap?

(28) What is the effect on the fit of a slight difference in pitch between the thread on the bolt and the thread in the nut?

(29) How do you proceed in resetting the threading tool after removing it from the tool post for sharpening?

(30) In what cases is it permissible in screw cutting to run the carriage back by opening the leadscrew nut?

LATHE WORK.

(PART 3.)

---

(1) How is the threading tool for cutting the British standard thread made?

(2) Lay out on a piece of paper the angle of side rake for a threading tool to cut a square thread of 3 pitch on a piece 3 inches in diameter.

(3) What are frequent causes of the threading tool breaking?

(4) At what height should a threading tool be set?

(5) What is the effect of setting a threading tool too high?

(6) By the use of what appliance can a thread be cut with a tool having top rake?

(7) How is a double thread cut?

(8) When an inside thread to be cut is not a multiple of the leadscrew thread, what care must be taken in removing the tool for testing?

(9) How should the threading tool be set for threading tapered work?

(10) What difference will there be between cutting a taper thread with a taper attachment and by setting over the tailstock center?

(11) Define the terms *angle of clearance* and *angle of keenness.*

(12) What are the general conditions that govern the shape of a cutting tool?

(13) By what means can you tell in working soft steel whether the tool is properly ground and set?

(14) On what does the angle of top rake depend?

(15) On what does the width of the cutting tool depend?

(16) Why should a broad-nosed tool be used for finishing whenever possible?

(17) What is, generally speaking, the best shape of tool for brass work, and how should it be set?

(18) What is, generally speaking, the best position with regard to height to give to a boring tool?

(19) What are the advantages and disadvantages of self-hardening steel?

(20) What is the objection to forming the top rake as done in the tool shown in Fig. 45 of the text?

(21) What are the advantages and disadvantages of tool holders?

(22) How is a cutting-off tool usually set with regard to the work?

(23) Why should work held between the centers not be cut into with a parting tool?

(24) Name a case in which a bent tool must be used.

(25) What are the advantages of special holders for boring tools?

(26) Name some of the causes that may produce chattering of tools.

(27) How may chattering be remedied?

LATHE WORK.

(PART 4.)

---

(1) What is understood by the term *cutting speed?*

(2) When the cutting speed of a tool turning a cylinder 5 inches in diameter is 20 feet per minute, what will the cutting speed be with the same number of revolutions on a cylinder $7\frac{1}{2}$ inches in diameter? Ans. 30 ft. per min.

(3) (*a*) What is to be considered the limit of cutting speed of a tool? (*b*) On what conditions does it depend?

(4) Of two turning tools having different angles of keenness, which should be given the greater cutting speed on the same material?

(5) What do you know of finishing cuts on cast iron?

(6) Name some cases where slow cutting speeds should be used.

(7) Define the term *cutting feed.*

(8) The diameter of a piece of cast iron to be turned is 8 inches, the number of revolutions of the lathe spindle is 20 per minute; what is the cutting speed?

Ans. 42 ft. per min., approximately.

(9) A piece of brass is 3 inches in diameter, and it is making 100 revolutions per minute; what is the cutting speed? Ans. $78\frac{1}{2}$ ft. per min., approximately.

§ 6

(10) The cutting speed in a certain case should not exceed 30 feet per minute; the piece to be turned is $1\frac{1}{2}$ inches in diameter; how many revolutions per minute should the spindle make? Ans. 76 rev. per min., approximately.

(11) A piece of tool steel is to be turned to a diameter of 1 inch, using the cutting speed given in the table, Art. **14**; how many revolutions should the work make?

Ans. 76 rev. per min., approximately.

(12) For finishing a piece of work of a certain kind, a cutting feed of 10 has been determined upon; the piece is a cylinder 18 inches long. What time is required to do the job when the spindle makes 8 revolutions per minute?

Ans. $22\frac{1}{2}$ min.

(13) A shaft 50 inches long is to be roughed out with a cutting feed of 16, the spindle making 15 revolutions per minute. What time will be required to do the job?

Ans. $53\frac{1}{3}$ min., approximately.

(14) A cast-iron roller of 10 inches diameter is to be roughed out with a cutting speed of 40 feet per minute, a cutting feed of 12. The length of the cylinder is 72 inches. What time will it take to do the work?

Ans. 57 min., approximately.

(15) What is the effect of a bent tail-dog on the work?

(16) What is the angle between the sides of lathe centers usually?

(17) Can a true taper thread be cut by setting over the tailstock center?

(18) In making a working fit for a shaft and bearing by the "cut-and-try" method, which would you finish first, the bearing or the shaft?

(19) What is meant by the allowance for a driving, forced, or shrinking fit?

(20) What is a lathe arbor?

(21) What sorts of hammers are the best for driving arbors?

(22) What is an arbor press?

(23) When a large piece of work is to be turned on a rather small size arbor, what precaution should be taken to avoid springing the arbor?

LATHE WORK.

(PART 5.)

---

(1) What is the characteristic feature of the turret lathe?

(2) What are the characteristic features of a screw machine?

(3) What class of work can be done on a turret machine?

(4) Name the various tools that may be employed in succession on a screw machine for producing a nurled-head screw, as shown in Fig. 5 of the text.

(5) What is the objection to forged forming tools?

(6) What is the object of cutting the notch in a circular forming tool below its center?

(7) What advantage can be gained by the use of a vertical slide forming tool?

(8) Point out, briefly, the difference between a screw machine and a universal monitor lathe.

(9) What are the characteristic features of automatic screw machines?

(10) When is it and when is it not profitable to use a turret lathe?

(11) What is a toolmaker's lathe?

(12) What is a gap lathe?

(13) What is the purpose of a two-spindle lathe?

§ 7

(14) When no gap lathe or two-spindle lathe is available, how can work, having a diameter greater than the swing of the largest lathe at hand, be turned?

(15) What is a speed lathe?

(16) What is the object of polishing?

(17) What kind of files are best suited for lathe work?

(18) When using a file, how can pinning be avoided?

(19) To produce as near a cylindrical surface as possible by filing, what rule should be observed?

(20) In polishing, what precaution should be taken with regard to the lathe centers?

(21) What is meant by *spotting* a shaft?

(22) What device is used to avoid spotting?

(23) How can a shaft be straightened without the aid of a straightening device between the centers of the lathe? Is this method to be recommended?

(24) How may leadscrews be straightened?

A KEY

TO THE

EXAMPLES

INCLUDED IN THE

Question Papers in this Volume.

It will be noticed that the Keys have been given the same section numbers as the Question Papers to which they refer. All article references refer to the Instruction Paper bearing the same section number as the Key in which it occurs, unless another "Part" or the title of some other Instruction Paper is given in connection with the article number. With the exception of the Question Papers on Arithmetic, answers have been given only to those questions which require an arithmetical calculation.

ARITHMETIC.

(PART 1.)

(1) See Art. **1.**

(2) See Art. **3.**

(3) See Arts. **5** and **6.**

(4) See Arts. **10** and **11.**

(5) (*a*) 980 = Nine hundred, eighty.

(*b*) 605 = Six hundred, five.

(*c*) 28,284 = Twenty-eight thousand, two hundred, eighty-four.

(*d*) 9,006,042 = Nine million, six thousand, and forty-two.

(*e*) 850,317,002 = Eight hundred fifty million, three hundred seventeen thousand, and two.

(*f*) 700,004 = Seven hundred thousand and four.

(6) (*a*) Seven thousand, six hundred = 7,600.

(*b*) Eighty-one thousand, four hundred, two = 81,402.

(*c*) Five million, four thousand, and seven = 5,004,007.

(*d*) One hundred and eight million, ten thousand, and one = 108,010,001.

(*e*) Eighteen million and six = 18,000,006.

(*f*) Thirty thousand and ten = 30,010.

(7) In adding whole numbers, place the numbers to be added directly under each other, so that the extreme right-hand figures will stand in the same column, regardless of the position of those at the left. Add the first column of figures at the extreme right, which equals 19 units, or 1 ten and 9 units. We place 9 units under

$$
\begin{array}{r}
3290 \\
504 \\
865403 \\
2074 \\
81 \\
7 \\
\hline
871359
\end{array}
\quad \text{Ans.}
$$

the units column and reserve 1 ten for the column of tens. $1 + 8 + 7 + 9 = 25$ tens, or 2 hundreds and 5 tens. Place 5 tens under the tens column and reserve 2 hundreds for the hundreds column. $2 + 4 + 5 + 2 = 13$ hundreds, or 1 thousand and 3 hundreds. Place 3 hundreds under the hundreds column and reserve the 1 thousand for the thousands column. $1 + 2 + 5 + 3 = 11$ thousands, or 1 ten-thousand and 1 thousand. Place the 1 thousand in the column of thousands and reserve the 1 ten-thousand for the column of ten-thousands. $1 + 6 = 7$ ten-thousands. Place this 7 ten-thousands in the ten-thousands column. There is but one figure, 8, in the hundreds of thousands place in the numbers to be added, so it is placed in the hundreds of thousands column of the sum.

A simpler (though less scientific) explanation of the same problem is the following: $7 + 1 + 4 + 3 + 4 + 0 = 19$; write the 9 and reserve the 1. $1 + 8 + 7 + 0 + 0 + 9 = 25$; write the 5 and reserve the 2. $2 + 0 + 4 + 5 + 2 = 13$; write the 3 and reserve the 1. $1 + 2 + 5 + 3 = 11$; write the 1 and reserve 1. $1 + 6 = 7$; write the 7. Bring down the 8 to its place in the sum.

(8)

$$\begin{array}{r} 709 \\ 8304725 \\ 391 \\ 100302 \\ 300 \\ 909 \\ \hline 8407336 \end{array} \text{ Ans.}$$

(9) (*a*) In subtracting whole numbers, place the subtrahend or smaller number under the minuend or larger number, so that the right-hand figures stand directly under each other. Begin *at the right* to subtract. We cannot subtract 8 units from 2 units, so we take 1 ten from the 6 tens and add it to the 2 units. As 1 *ten* = 10 *units*, we have 10 units + 2 units = 12 units. Then, 8 units from 12 units leaves 4 units. We took 1 ten from 6 tens, so only 5 tens remain.

3 tens from 5 tens leaves 2 tens. In the hundreds column we have 3 hundreds from 9 hundreds leaves 6 hundreds. We cannot subtract 3 thousands from 0 thousands, so we take 1 ten-thousand from 5 ten-thousands and add it to the 0 thousands. 1 *ten-thousand* = 10 *thousands*, and 10 thousands + 0 thousands = 10 thousands. Subtracting, we have 3 thousands from 10 thousands leaves 7 thousands. We took 1 ten-thousand from 5 ten-thousands and have 4 ten-thousands remaining. Since there are no ten-thousands in the subtrahend, the 4 in the ten-thousands column in the minuend is brought down into the same column in the remainder, because 0 from 4 leaves 4.

```
 50962
  3338
 -----
 47624  Ans.
```

```
(b) 15339
    10001
    -----
     5338  Ans.
```

(10)

```
(a) 70968          (b) 100000
    32975               98735
    -----              ------
    37993  Ans.          1265  Ans.
```

(11) The numbers connected by the plus (+) sign must first be added. Performing these operations we have

```
 5962
 8471          3874
 9023          2039
-----          ----
23456 sum.     5913 sum.
```

Subtracting the smaller number (5,913) from the greater (23,456) we have

```
23456
 5913
-----
17543 difference.  Ans.
```

(12) In the multiplication of whole numbers, place the multiplier under the multiplicand, and multiply each term of the multiplicand by each term of the multiplier, writing the right-hand figure of each product obtained under the term of the multiplier which produces it.

```
(a)  526387
          7
    -------
    3684709  Ans.
```

7 × 7 units = 49 units, or 4 tens and 9 units. We write the 9 units and reserve the 4 tens. 7 times 8 tens = 56 tens; 56 tens + 4 tens reserved = 60 tens, or 6 hundreds and 0 tens. Write the 0 tens and reserve the 6 hundreds. 7 × 3 hundreds = 21 hundreds; 21 + 6 hundreds reserved = 27 hundreds, or 2 thousands and 7 hundreds. Write the 7 hundreds and reserve the 2 thousands. 7 × 6 thousands = 42 thousands; 42 + 2 thousands reserved = 44 thousands, or 4 ten-thousands and 4 thousands. Write the 4 thousands and reserve the 4 ten-thousands. 7 × 2 ten-thousands = 14 ten-thousands; 14 + 4 ten-thousands reserved = 18 ten-thousands, or 1 hundred-thousand and 8 ten-thousands. Write the 8 ten-thousands and reserve the 1 hundred-thousand. 7 × 5 hundred-thousands = 35 hundred-thousands; 35 + 1 hundred-thousand reserved = 36 hundred-thousands. Since there are no more figures in the multiplicand to be multiplied, we write the 36 hundred-thousands in the product. This completes the multiplication.

A simpler (though less scientific) explanation of the same problem is the following:

7 times 7 = 49; write the 9 and reserve the 4. 7 times 8 = 56; 56 + 4 reserved = 60; write the 0 and reserve the 6. 7 times 3 = 21; 21 + 6 reserved = 27; write the 7 and reserve the 2. 7 × 6 = 42; 42 + 2 reserved = 44; write the 4 and reserve 4. 7 × 2 = 14; 14 + 4 reserved = 18; write the 8 and reserve the 1. 7 × 5 = 35; 35 + 1 reserved = 36; write the 36.

(*b*) In this case the multiplier is 17 *units*, or 1 *ten* and 7 *units*, so that the product is obtained by adding two partial products, namely, 7 × 700,298 and 10 × 700,298. The actual operation is performed as follows:

```
   700298
       17
 --------
  4902086
  700298
 --------
 11905066  Ans.
```

7 times 8 = 56; write the 6 and reserve the 5. 7 times 9 = 63; 63 + 5 reserved = 68; write the 8 and reserve the 6. 7 times 2 = 14; 14 + 6 reserved = 20; write the 0 and reserve the 2. 7 times 0 = 0; 0 + 2 reserved = 2; write the 2. 7 times 0 = 0; 0 + 0 reserved = 0; write the 0. 7 times 7 = 49; 49 + 0 reserved = 49; write the 49.

To multiply by the 1 ten we say 1 times 700298 = 700298, and write 700298 under the first partial product, as shown, with the right-hand figure 8 under the multiplier 1. Add the two partial products; their sum equals the entire product.

(*c*) Multiply any two of the numbers together and multiply their product by the third number.

$$\begin{array}{r} 217 \\ 103 \\ \hline 651 \\ 2170 \\ \hline 22351 \\ 67 \\ \hline 156457 \\ 134106 \\ \hline 1497517 \end{array} \text{ Ans.}$$

(**13**) (*a*) (72 × 48 × 28 × 5) ÷ (96 × 15 × 7 × 6).

Placing the numerator over the denominator, the problem becomes.

$$\frac{72 \times 48 \times 28 \times 5}{96 \times 15 \times 7 \times 6} = ?$$

The 5 in the *dividend* and 15 in the *divisor* are both divisible by 5, since 5 divided by 5 equals 1, and 15 divided by 5 equals 3. *Cross off* the 5 and write the 1 *over* it; also *cross off* the 15 and write the 3 *under* it. Thus,

$$\frac{72 \times 48 \times 28 \times \overset{1}{\cancel{5}}}{96 \times \underset{3}{\cancel{15}} \times 7 \times 6} =$$

The 5 and 15 are *not* to be considered any longer, and, in fact, may be erased entirely and the 1 and 3 placed in their stead, and treated as if the 5 and 15 never existed. Thus,

$$\frac{72 \times 48 \times 28 \times 1}{96 \times 3 \times 7 \times 6} =$$

72 in the dividend and 96 in the divisor are divisible by 12, since 72 divided by 12 equals 6, and 96 divided by 12 equals 8. Cross off the 72 and write the 6 over it; also, cross off the 96 and write the 8 under it. Thus,

$$\frac{\overset{6}{\cancel{72}} \times 48 \times 28 \times 1}{\underset{8}{\cancel{96}} \times 3 \times 7 \times 6} =$$

The 72 and 96 are not to be considered any longer, and, in fact, may be erased entirely and the 6 and 8 placed in their stead, and treated as if the 72 and 96 never existed. Thus,

$$\frac{6 \times 48 \times 28 \times 1}{8 \times 3 \times 7 \times 6} =$$

Again, 28 in the dividend and 7 in the divisor are divisible by 7, since 28 divided by 7 equals 4, and 7 divided by 7 equals 1. Cross off the 28 and write the 4 over it; also, cross off the 7 and write the 1 under it. Thus,

$$\frac{6 \times 48 \times \overset{4}{\cancel{28}} \times 1}{8 \times 3 \times \underset{1}{\cancel{7}} \times 6} =$$

The 28 and 7 are not to be considered any longer, and, in fact, may be erased entirely and the 4 and 1 placed in their stead, and treated as if the 28 and 7 never existed. Thus,

$$\frac{6 \times 48 \times 4 \times 1}{8 \times 3 \times 1 \times 6} =$$

Again, 48 in the dividend and 6 in the divisor are divisible by 6, since 48 divided by 6 equals 8, and 6 divided by 6 equals 1. Cross off the 48 and write the 8 over it; also, cross off the 6 and write the 1 under it. Thus,

$$\frac{6 \times \overset{8}{\cancel{48}} \times 4 \times 1}{8 \times 3 \times 1 \times \underset{1}{\cancel{6}}} =$$

The 48 and 6 are not to be considered any longer, and, in fact, may be erased entirely and the 8 and 1 placed in their stead, and treated as if the 48 and 6 never existed. Thus,

$$\frac{6 \times 8 \times 4 \times 1}{8 \times 3 \times 1 \times 1} =$$

Again, 6 in the dividend and 3 in the divisor are divisible by 3, since 6 divided by 3 equals 2, and 3 divided by 3 equals 1. Cross off the 6 and write the 2 over it; also, cross off the 3 and write the 1 under it. Thus,

$$\frac{\overset{2}{\cancel{6}} \times 8 \times 4 \times 1}{8 \times \underset{1}{\cancel{3}} \times 1 \times 1} =$$

The 6 and 3 are not to be considered any longer, and, in fact, may be erased entirely and the 2 and 1 placed in their stead, and treated as if the 6 and 3 never existed. Thus,

$$\frac{2 \times 8 \times 4 \times 1}{8 \times 1 \times 1 \times 1} =$$

Canceling the 8 in the dividend and the 8 in the divisor, the result is

$$\frac{2 \times \overset{1}{\cancel{8}} \times 4 \times 1}{\underset{1}{\cancel{8}} \times 1 \times 1 \times 1} = \frac{2 \times 1 \times 4 \times 1}{1 \times 1 \times 1 \times 1}.$$

Since there are no two remaining numbers (one in the dividend and one in the divisor) divisible by any number except 1, without a remainder, it is impossible to cancel further.

Multiply all the *uncanceled numbers* in the *dividend* together, and divide their *product* by the *product* of all the *uncanceled* numbers in the divisor. The *result* will be the *quotient*. The product of all the uncanceled numbers in the dividend equals $2 \times 1 \times 4 \times 1 = 8$; the product of all the uncanceled numbers in the divisor equals $1 \times 1 \times 1 \times 1 = 1$.

Hence, $$\frac{2 \times 1 \times 4 \times 1}{1 \times 1 \times 1 \times 1} = \frac{8}{1} = 8. \quad \text{Ans.}$$

Or, $$\frac{\overset{\overset{2}{\cancel{6}}}{\cancel{72}} \times \overset{\cancel{8}}{\cancel{48}} \times \overset{4}{\cancel{28}} \times \overset{1}{\cancel{5}}}{\underset{\underset{1}{\cancel{8}}}{\cancel{96}} \times \underset{\underset{1}{\cancel{3}}}{\cancel{15}} \times \underset{1}{\cancel{7}} \times \underset{1}{\cancel{6}}} = \frac{8}{1} = 8. \quad \text{Ans.}$$

(*b*) $(80 \times 60 \times 50 \times 16 \times 14) \div (70 \times 50 \times 24 \times 20)$.

Placing the numerator over the denominator, the problem becomes

$$\frac{80 \times 60 \times 50 \times 16 \times 14}{70 \times 50 \times 24 \times 20} = ?$$

The 50 in the dividend and 70 in the divisor are both divisible by 10, since 50 divided by 10 equals 5, and 70 divided by 10 equals 7. Cross off the 50 and write the 5 over it; also, cross off the 70 and write the 7 under it. Thus,

$$\frac{80 \times 60 \times \overset{5}{\cancel{50}} \times 16 \times 14}{\underset{7}{\cancel{70}} \times 50 \times 24 \times 20} =$$

The 50 and 70 are not to be considered any longer, and, in fact, may be erased entirely and the 5 and 7 placed in their stead, and treated as if the 50 and 70 never existed. Thus,

$$\frac{80 \times 60 \times 5 \times 16 \times 14}{7 \times 50 \times 24 \times 20} =$$

Also, 80 in the dividend and 20 in the divisor are divisible by 20, since 80 divided by 20 equals 4, and 20 divided by 20 equals 1. Cross off the 80 and write the 4 over it; also, cross off the 20 and write the 1 under it. Thus,

$$\frac{\overset{4}{\cancel{80}} \times 60 \times 5 \times 16 \times 14}{7 \times 50 \times 24 \times \underset{1}{\cancel{20}}} =$$

The 80 and 20 are not to be considered any longer, and, in fact, may be erased entirely and the 4 and 1 placed in their stead, and treated as if the 80 and 20 never existed. Thus,

$$\frac{4 \times 60 \times 5 \times 16 \times 14}{7 \times 50 \times 24 \times 1} =$$

Again, 16 in the dividend and 24 in the divisor are divisible by 8, since 16 divided by 8 equals 2, and 24 divided by 8 equals 3. Cross off the 16 and write the 2 over it; also, cross off the 24 and write the 3 under it. Thus,

$$\frac{4 \times 60 \times 5 \times \overset{2}{\cancel{16}} \times 14}{7 \times 50 \times \underset{3}{\cancel{24}} \times 1} =$$

The 16 and 24 are not to be considered any longer, and, in fact, may be erased entirely and the 2 and 3 placed in their stead, and treated as if the 16 and 24 never existed. Thus,

$$\frac{4 \times 60 \times 5 \times 2 \times 14}{7 \times 50 \times 3 \times 1} =$$

Again, 60 in the dividend and 50 in the divisor are divisible by 10, since 60 divided by 10 equals 6, and 50 divided by 10 equals 5. Cross off the 60 and write the 6 over it; also, cross off the 50 and write the 5 under it. Thus,

$$\frac{4 \times \overset{6}{\cancel{60}} \times 5 \times 2 \times 14}{7 \times \underset{5}{\cancel{50}} \times 3 \times 1} =$$

The 60 and 50 are not to be considered any longer, and, in fact, may be erased entirely and the 6 and 5 placed in their stead, and treated as if the 60 and 50 never existed. Thus,

$$\frac{4 \times 6 \times 5 \times 2 \times 14}{7 \times 5 \times 3 \times 1} =$$

The 14 in the dividend and 7 in the divisor are divisible by 7, since 14 divided by 7 equals 2, and 7 divided by 7 equals 1. Cross off the 14 and write the 2 over it; also, cross off the 7 and write the 1 under it. Thus,

$$\frac{4 \times 6 \times 5 \times 2 \times \overset{2}{\not{14}}}{\underset{1}{\not{7}} \times 5 \times 3 \times 1} =$$

The 14 and 7 are not to be considered any longer, and, in fact, may be erased entirely and the 2 and 1 placed in their stead, and treated as if the 14 and 7 never existed. Thus,

$$\frac{4 \times 6 \times 5 \times 2 \times 2}{1 \times 5 \times 3 \times 1} =$$

The 5 in the dividend and 5 in the divisor are divisible by 5, since 5 divided by 5 equals 1. Cross off the 5 of the dividend and write the 1 over it; also, cross off the 5 of the divisor and write the 1 under it. Thus,

$$\frac{4 \times 6 \times \overset{1}{\not{5}} \times 2 \times 2}{1 \times \underset{1}{\not{5}} \times 3 \times 1} =$$

The 5 in the dividend and 5 in the divisor are not to be considered any longer, and, in fact, may be erased entirely and 1 and 1 placed in their stead, and treated as if the 5 and 5 never existed. Thus,

$$\frac{4 \times 6 \times 1 \times 2 \times 2}{1 \times 1 \times 3 \times 1} =$$

The 6 in the dividend and 3 in the divisor are divisible by 3, since 6 divided by 3 equals 2, and 3 divided by 3 equals 1. Cross off the 6 and place 2 over it; also, cross off the 3 and place 1 under it. Thus,

$$\frac{4\times \overset{2}{\not 6}\times 1\times 2\times 2}{1\times 1\times \underset{1}{\not 3}\times 1}=$$

The 6 and 3 are not to be considered any longer, and, in fact, may be erased entirely and 2 and 1 placed in their stead, and treated as if the 6 and 3 never existed. Thus,

$$\frac{4\times 2\times 1\times 2\times 2}{1\times 1\times 1\times 1}=\tfrac{32}{1}=32.\quad \text{Ans.}$$

$$\text{Hence, }\frac{\overset{4}{\not 8\not 0}\times \overset{\overset{2}{\not 6}}{\not 6\not 0}\times \overset{\overset{1}{\not 5}}{\not 5\not 0}\times \overset{2}{\not 1\not 6}\times \overset{2}{\not 1\not 4}}{\underset{\underset{1}{\not 7}}{\not 7\not 0}\times \underset{\underset{1}{\not 5}}{\not 5\not 0}\times \underset{\underset{1}{\not 3}}{\not 2\not 4}\times \underset{1}{\not 2\not 0}}=\frac{4\times 2\times 1\times 2\times 2}{1\times 1\times 1\times 1}=\tfrac{32}{1}=32.\ \text{Ans.}$$

(14) (*a*)

```
576 ) 589824 ( 1024   Ans.
      576
      ----
       1382
       1152
       ----
        2304
        2304
        ----
```

(*b*)

```
43911 ) 369730620 ( 8420   Ans.
        351288
        ------
         184426
         175644
         ------
           87822
           87822
           -----
               0
```

(*c*)

```
505 ) 2527525 ( 5005   Ans.
      2525
      -------
         2525
         2525
         ----
```

(*d*) 1234)4961794302(4020·903 Ans.
4936
2579
2468
11143
11106
3702
3702

(15) (*a*)
1024
576
6144
7168
5120
589824 Ans.

(*b*)
5005
505
25025
250250
2527525 Ans.

(*c*)
43911
8420
878220
175644
351288
369730620 Ans

ARITHMETIC.

(PART 2.)

(1) See Art. **71.**

(2) See Art. **77.**

(3) See Art. **73.**

(4) See Art. **73.**

(5) See Art. **75.**

(6) $\frac{13}{8}$ is an improper fraction, since its numerator 13 is greater than its denominator 8.

(7) $4\frac{1}{2}$; $14\frac{3}{16}$; $85\frac{4}{19}$.

(8) To reduce a fraction to its lowest terms means to change its form without changing its value. In order to do this, we must divide both numerator and denominator by the same number until we can no longer find any number (except 1) which will divide both of these terms without a remainder.

To reduce the fraction $\frac{4}{8}$ to its lowest terms we divide both numerator and denominator by 4, and obtain as a result the fraction $\frac{1}{2}$. Thus, $\frac{4 \div 4}{8 \div 4} = \frac{1}{2}$; similarly, $\frac{4 \div 4}{16 \div 4} = \frac{1}{4}$; $\frac{8 \div 4}{32 \div 4} = \frac{2 \div 2}{8 \div 2} = \frac{1}{4}$; $\frac{32 \div 8}{64 \div 8} = \frac{4 \div 4}{8 \div 4} = \frac{1}{2}$. Ans.

(9) When the denominator of any number is not expressed, it is understood to be 1, so that $\frac{6}{1}$ is the same as $6 \div 1$, or 6. To reduce $\frac{6}{1}$ to an improper fraction whose denominator is 4, we must multiply both numerator and denominator by some number which will make the denominator of 6 equal to 4. Since this denominator is 1, by multiplying both terms of $\frac{6}{1}$ by 4 we shall have $\frac{6 \times 4}{1 \times 4} = \frac{24}{4}$, which has the *same value* as 6, but has a *different form*. Ans.

(**10**) In order to reduce a mixed number to an improper fraction, we must *multiply the whole number by the denominator of the fraction* and *add the numerator of the fraction to that product*. This *result* is the *numerator of the improper fraction*, of which the *denominator is the denominator of the fractional part of the mixed number*.

$7\frac{7}{8}$ means the same as $7 + \frac{7}{8}$. In 1 there are $\frac{8}{8}$, hence in 7 there are $7 \times \frac{8}{8} = \frac{56}{8}$; $\frac{56}{8}$ plus the $\frac{7}{8}$ of the mixed number $= \frac{56}{8} + \frac{7}{8} = \frac{63}{8}$, which is the required improper fraction.

$$13\frac{5}{16} = \frac{(13 \times 16) + 5}{16} = \frac{213}{16}; \; 10\frac{3}{4} = \frac{(10 \times 4) + 3}{4} = \frac{43}{4}.$$

(**11**) The value of a fraction is obtained by dividing the numerator by the denominator.

To obtain the value of the fraction $\frac{13}{2}$, we divide the numerator, 13, by the denominator, 2. 2 is contained in 13 six times, with 1 remaining. This 1 remaining is written over the denominator 2, thereby making the fraction $\frac{1}{2}$, which is annexed to the whole number, 6, and we obtain $6\frac{1}{2}$ as the mixed number. The reason for performing this operation is the following: In 1 there are $\frac{2}{2}$ (two halves), and in $\frac{13}{2}$ (thirteen halves) there are as many units (1) as 2 is contained times in 13, which is 6, and $\frac{1}{2}$ (one-half) unit remaining. Hence, $\frac{13}{2} = 6 + \frac{1}{2} = 6\frac{1}{2}$, the required mixed number. Ans. $\frac{17}{4} = 4\frac{1}{4}$. Ans. $\frac{69}{16} = 4\frac{5}{16}$. Ans. $\frac{16}{8} = 2$. Ans. $\frac{67}{64} = 1\frac{3}{64}$. Ans.

(**12**) In division of fractions, *invert the divisor* (or, in other words, turn it upside down) *and proceed as in multiplication*.

(*a*) $35 \div \frac{5}{16} = \frac{35}{1} \times \frac{16}{5} = \frac{35 \times 16}{1 \times 5} = \frac{560}{5} = 112.$ Ans.

(*b*) $\frac{9}{16} \div 3 = \frac{9}{16} \div \frac{3}{1} = \frac{9}{16} \times \frac{1}{3} = \frac{9 \times 1}{16 \times 3} = \frac{9}{48} = \frac{3}{16}.$ Ans.

(*c*) $\frac{17}{2} \div 9 = \frac{17}{2} \div \frac{9}{1} = \frac{17}{2} \times \frac{1}{9} = \frac{17 \times 1}{2 \times 9} = \frac{17}{18}$. Ans.

(*d*) $\frac{113}{64} \div \frac{7}{16} = \frac{113}{64} \times \frac{16}{7} = \frac{113 \times 16}{64 \times 7} = \frac{1808}{448} = \frac{452}{112} =$

$$\frac{113}{28}$$

```
28 ) 1 1 3 ( 4 1/28   Ans.
     1 1 2
     -----
         1
```

(*e*) $15\frac{3}{4} \div 4\frac{3}{8} = ?$ Before proceeding with the division, reduce both of the mixed numbers to improper fractions. Thus, $15\frac{3}{4} = \frac{(15 \times 4) + 3}{4} = \frac{60 + 3}{4} = \frac{63}{4}$, and $4\frac{3}{8} = \frac{(4 \times 8) + 3}{8} = \frac{32 + 3}{8} = \frac{35}{8}$. The problem is now $\frac{63}{4} \div \frac{35}{8} = ?$ As before, invert the divisor and multiply; $\frac{63}{4} \div \frac{35}{8} = \frac{63}{4} \times \frac{8}{35} = \frac{63 \times 8}{4 \times 35} = \frac{504}{140} = \frac{252}{70} = \frac{126}{35} = \frac{18}{5}$.

$$\frac{18}{5}$$

```
5 ) 1 8 ( 3 3/5   Ans.
    1 5
    ---
      3
```

(**13**) $\frac{1}{8} + \frac{2}{8} + \frac{5}{8} = \frac{1 + 2 + 5}{8} = \frac{8}{8} = 1$. Ans.

When the *denominators* of the fractions to be added *are alike*, we know that the units are divided into the *same number of parts* (in this case *eighths*); we therefore *add the numerators* of the fractions to find the number of parts (eighths) taken or considered, thereby obtaining $\frac{8}{8}$ or 1 as the sum.

(**14**) When the *denominators* are *not alike* we know that the units are divided into *unequal parts*, so before adding them we must find a common denominator for the denominators of all the fractions. Reduce the fractions to fractions having this common denominator, add the numerators, and write the sum over the common denominator.

In this case, the least common denominator, or the least number that will contain all the denominators, is 16; hence, we must reduce all these fractions to sixteenths and then add their numerators.

$\frac{1}{4} + \frac{3}{8} + \frac{5}{16} = ?$ To reduce the fraction $\frac{1}{4}$ to a fraction having 16 for a denominator, we must multiply both terms of the fraction by some number which will make the denominator 16. This number evidently is 4, hence, $\frac{1 \times 4}{4 \times 4} = \frac{4}{16}$.

Similarly, both terms of the fraction $\frac{3}{8}$ must be multiplied by 2 to make the denominator 16, and we have $\frac{3 \times 2}{8 \times 2} = \frac{6}{16}$. The fractions now have a common denominator 16; hence, we find their sum by adding the numerators and placing their sum over the common denominator, thus: $\frac{4}{16} + \frac{6}{16} + \frac{5}{16} = \frac{4 + 6 + 5}{16} = \frac{15}{16}$. Ans.

(**15**) When mixed numbers and whole numbers are to be added, add the fractional parts of the mixed numbers separately, and if the resulting fraction is an improper fraction, reduce it to a whole or mixed number. Next, add all the whole numbers, including the one obtained from the addition of the fractional parts, and annex to their sum the fraction of the mixed number obtained from reducing the improper fraction.

$42 + 31\frac{5}{8} + 9\frac{7}{16} = ?$ Reducing $\frac{5}{8}$ to a fraction having a denominator of 16, we have $\frac{5 \times 2}{8 \times 2} = \frac{10}{16}$. Adding the two fractional parts of the mixed numbers we have $\frac{10}{16} + \frac{7}{16} = \frac{10 + 7}{16} = \frac{17}{16} = 1\frac{1}{16}$.

The problem now becomes $42 + 31 + 9 + 1\frac{1}{16} = ?$

$$\begin{array}{r} 42 \\ 31 \\ 9 \\ 1\frac{1}{16} \\ \hline 83\frac{1}{16} \end{array} \text{ Ans.}$$

Adding all the whole numbers and the number obtained from adding the fractional parts of the mixed numbers, we obtain $83\frac{1}{16}$ as their sum.

(16) $29\frac{3}{4} + 50\frac{5}{8} + 41 + 69\frac{3}{16} = ?$ $\frac{3}{4} = \frac{3 \times 4}{4 \times 4} = \frac{12}{16}$.

$\frac{5}{8} = \frac{5 \times 2}{8 \times 2} = \frac{10}{16}$. $\frac{12}{16} + \frac{10}{16} + \frac{3}{16} = \frac{12 + 10 + 3}{16} = \frac{25}{16} = 1\frac{9}{16}$.

The problem now becomes $29 + 50 + 41 + 69 + 1\frac{9}{16} = ?$

29	square inches.
50	square inches.
41	square inches.
69	square inches.
$1\frac{9}{16}$	square inches.
$190\frac{9}{16}$	square inches. Ans.

(17) $\frac{7}{8}$ = value of the fraction, and 28 = the numerator. We find that 4 multiplied by 7 = 28, so multiplying 8, the denominator of the fraction, by 4, we have 32 for the required denominator, and $\frac{28}{32} = \frac{7}{8}$. Hence, 32 is the required denominator. Ans.

(18) (*a*) $\frac{7}{8} - \frac{7}{16} = ?$ When the *denominators* of fractions are *not alike*, it is evident that the units are divided into *unequal parts;* therefore, before subtracting, *reduce the fractions to fractions having a common denominator.* Then, *subtract the numerators and place the remainder over the common denominator.*

$$\frac{7 \times 2}{8 \times 2} = \frac{14}{16}. \quad \frac{14}{16} - \frac{7}{16} = \frac{14 - 7}{16} = \frac{7}{16}. \quad \text{Ans.}$$

(*b*) $13 - 7\frac{7}{16} = ?$ This problem may be solved in two ways:

First: $13 = 12\frac{16}{16}$, since $\frac{16}{16} = 1$ and $12\frac{16}{16} = 12 + \frac{16}{16} = 12 + 1 = 13$.

We can now subtract the whole numbers separately, and the fractions separately, and obtain $12 - 7 = 5$ and $\frac{16}{16} - \frac{7}{16} = \frac{16 - 7}{16} = \frac{9}{16}$. $5 + \frac{9}{16} = 5\frac{9}{16}$. Ans.

$$\begin{array}{r} 12\frac{16}{16} \\ 7\frac{7}{16} \\ \hline 5\frac{9}{16} \end{array}$$

Second: By reducing both numbers to improper fractions having a denominator of 16.

$13 = \frac{13}{1} = \frac{13 \times 16}{1 \times 16} = \frac{208}{16}$. $7\frac{7}{16} = \frac{(7 \times 16) + 7}{16} = \frac{112 + 7}{16} = \frac{119}{16}$.

Subtracting, we have $\frac{208}{16} - \frac{119}{16} = \frac{208 - 119}{16} = \frac{89}{16}$ and $\frac{89}{16} = 16)89(5\frac{9}{16}$, the same result that was obtained by the first method.

$$\begin{array}{r} 16)89(5\frac{9}{16} \\ \underline{80} \\ 9 \\ \overline{16} \end{array}$$

(*c*) $312\frac{9}{16} - 229\frac{5}{32} = ?$ We first reduce the fractions of the two mixed numbers to fractions having a common denominator. Doing this we have $\frac{9}{16} = \frac{9 \times 2}{16 \times 2} = \frac{18}{32}$. We can now subtract the whole numbers and fractions separately, and have $312 - 229 = 83$ and $\frac{18}{32} - \frac{5}{32} = \frac{18 - 5}{32} = \frac{13}{32}$. $83 + \frac{13}{32} = 83\frac{13}{32}$. Ans.

$$\begin{array}{r} 312\frac{18}{32} \\ 229\frac{5}{32} \\ \hline 83\frac{13}{32} \end{array}$$

ARITHMETIC.

(PART 3.)

tenths. hundredths.

(1) .0 8 = *Eight* **hundredths.**

tenths. hundredths. thousandths.

.1 3 1 = *One hundred thirty-one* **thousandths.**

tenths. hundredths. thousandths. ten-thousandths.

.0 0 0 1 = *One* **ten-thousandth.**

tenths. hundredths. thousandths. ten-thousandths. hundred-thousandths. millionths.

.0 0 0 0 2 7 = *Twenty-seven* **millionths.**

tenths. hundredths. thousandths. ten-thousandths.

.0 1 0 8 = *One hundred eight* **ten-thousandths.**

tenths.	hundredths.	thousandths.	ten-thousandths.

9 3.0 1 0 1 = Ninety-three, and *one hundred one* **ten-thousandths.**

In reading decimals, read the number just as you would if there were no ciphers before it. Then count from the decimal point towards the right, beginning with tenths, to as many places as there are figures, and the *name* of the last figure must be annexed to the previous reading of the figures to give the decimal reading. Thus, in the first example above, the simple reading of the figure is *eight*, and the name of its position in the decimal scale is **hundredths,** so that the decimal reading is *eight* **hundredths.** Similarly, the figures in the fourth example are ordinarily read *twenty-seven;* the name of the position of the figure 7 in the decimal scale is **millionths,** giving, therefore, the decimal reading as *twenty-seven* **millionths.**

If there should be a whole number before the decimal point, read it as you would read any whole number, and read the decimal as you would if the whole number were not there; or, read the whole number and then say "and" so many hundredths, thousandths, or whatever it may be, as "ninety-three, *and* one hundred one ten-thousandths."

(2) See Art. **139.**

(3) See Art. **153.**

(4) See Art. **160.**

(5) A fraction is one or more of the equal parts of a unit, and is expressed by a numerator and a denominator, while a decimal fraction is a number of *tenths*, *hundredths*, *thousandths*, etc., of a unit, and is expressed by placing a period (.), called a decimal point, to the left of the figures of the number, and omitting the denominator.

(6) See Art. **165**.

(7) To reduce the fraction $\frac{1}{2}$ to a decimal, we annex one cipher to the numerator, which makes it 1.0. Dividing 1.0, the numerator, by 2, the denominator, gives a quotient of .5, the decimal point being placed before the *one* figure of the quotient, or .5, since only *one* cipher was annexed to the numerator. Ans.

```
7
-
8)7.000
  .875   Ans.
```

```
 5
--
32)5.00000(.15625   Ans.
   32
   ---
   180
   160
   ---
    200        125/1000 = .125   Ans.
    192
    ---
      80
      64
      ---
      160
      160
      ---
```

Since $.65 = \frac{65}{100}$, then, $\frac{65}{100}$ must equal .65. Or, when the denominator is 10, 100, 1,000, etc., point off as many places in the numerator as there are ciphers in the denominator. Doing so, $\frac{65}{100} = .65$. Ans.

(8) $.875 = \frac{875}{1000} = \frac{175}{200} = \frac{7}{8}$ of a foot. 1 foot = 12 inches.

$$\frac{7}{8} \text{ of } 1 \text{ foot} = \frac{7}{\underset{2}{\not{8}}} \times \frac{\overset{3}{\not{12}}}{1} = \frac{21}{2} = 10\tfrac{1}{2} \text{ inches. Ans.}$$

(9) 12 inches = 1 foot.

$$\frac{3}{16} \text{ of an inch} = \frac{3}{16} \div 12 = \frac{\not{3}}{16} \times \frac{1}{\underset{4}{\not{12}}} = \frac{1}{64} \text{ of a foot.}$$

```
  1
 ---
 64)1.000000(.015625  Ans.
    64
    ---
    360
    320
    ---
     400
     384
     ---
      160
      128
      ---
       320
       320
       ---
```

Point off 6 decimal places in the quotient, since we annexed six ciphers to the dividend, the divisor containing no decimal places; hence, $6 - 0 = 6$ places to be pointed off.

(10) See Art. **174.** Applying rule in Art. **175,**

(*a*) $.7928 \times \frac{64}{64} = \frac{50.7392}{64} = \frac{51}{64}$. Ans.

(*b*) $.1416 \times \frac{32}{32} = \frac{4.5312}{32} = \frac{5}{32}$. Ans.

(*c*) $.47915 \times \frac{16}{16} = \frac{7.6664}{16} = \frac{8}{16}$. Ans.

(11) In subtraction of decimals, *place the decimal points directly under each other*, and proceed as in the subtraction of whole numbers, placing the *decimal point in the remainder directly under the decimal points above.*

```
(a)  709.6300
        .8514
     --------
     708.7786  Ans.
```

In the above example we proceed as follows: We cannot subtract 4 ten-thousandths from 0 ten-thousandths, and, as there are no thousandths, we take 1 hundredth from the 3 hundredths. 1 *hundredth* = 10 *thousandths* = 100 *ten-thousandths.* 4 ten-thousandths from 100 ten-thousandths leaves 96 ten-thousandths. 96 ten-thousandths = 9 *thousandths* + 6 *ten-thousandths.* Write the 6 ten-thousandths in the ten-thousandths place in the remainder. The next figure in the subtrahend is 1 thousandth. This must be subtracted from the 9 thousandths which is a part of the 1 hundredth taken previously from the 3 hundredths. Subtracting, we have 1 thousandth from 9 thousandths leaves 8 thousandths, the 8 being written in its place in the remainder. Next we have to subtract 5 hundredths from 2 hundredths (1 hundredth having been taken from the 3 hundredths makes it but 2 hundredths now). Since we cannot do this, we take 1 tenth from 6 tenths. 1 tenth (= 10 hundredths) + 2 hundredths = 12 hundredths. 5 hundredths from 12 hundredths leaves 7 hundredths. Write the 7 in the hundredths place in the remainder. Next we have to subtract 8 tenths from 5 tenths (5 tenths now, because 1 tenth was taken from the 6 tenths). Since this cannot be done, we take 1 unit from the 9 units. 1 *unit* = 10 *tenths;* 10 tenths + 5 tenths = 15 tenths, and 8 tenths from 15 tenths leaves 7 tenths. Write the 7 in the tenths place in the remainder. In the minuend we now have 708 units (1 unit having been taken away) and 0 units in the subtrahend. 0 units from 708 units leaves 708 units; hence, we write 708 in the remainder.

(*b*)		(*c*)		(*d*)	
	81.963		18.00		1.000
	1.700		.18		.001
	80.263 Ans.		17.82 Ans.		.999 Ans.

(12) In subtracting a decimal from a fraction, or subtracting a fraction from a decimal, either reduce the fraction to a decimal before subtracting or reduce the decimal to a fraction and then subtract.

$$8\overline{)7\,000}$$

(*a*) $\frac{7}{8} - .807 = ?$ $\frac{7}{8}$ reduced to a decimal becomes .875

.875
.807
.068 Ans.

Subtracting .807 from .875, the remainder is .068, as shown.

(*b*) $.875 - \frac{3}{8} = ?$ Reducing .875 to a fraction we have $.875 = \frac{875}{1000} = \frac{175}{200} = \frac{35}{40} = \frac{7}{8}$; hence, $\frac{7}{8} - \frac{3}{8} = \frac{7-3}{8} = \frac{4}{8} = \frac{1}{2}$. Ans.

Or, by reducing $\frac{3}{8}$ to a decimal, $\frac{3}{8}$) 8) 3.000 = .375 and then subtracting, we obtain $.875 - .375 = .5 = \frac{5}{10} = \frac{1}{2}$, the same answer as above.

```
 .875
 .375
 ----
 .500  Ans.
```

(*c*) $(\frac{5}{32} + .435) - (\frac{21}{100} - .07) = ?$ We first perform the operations as indicated by the signs between the numbers enclosed by the parentheses. Reduce $\frac{5}{32}$ to a decimal and we obtain $\frac{5}{32} = .15625$ (see example 7).

Adding .15625 and .435,

```
      .15625
      .435
      ------
sum   .59125
```

$\frac{21}{100} = .21$; subtracting,

```
            .21
            .07
            ---
difference  .14
```

We are now prepared to perform the operation indicated by the minus sign between the parentheses, which is,

```
            .59125
            .14
            ------
difference  .45125  Ans.
```

(**13**) In addition of decimals the *decimal points must be placed directly under each other*, so that *tenths* will come *under tenths*, *hundredths under hundredths*, *thousandths under thousandths*, etc. The addition is then performed as in whole numbers, *the decimal point of the sum being placed directly under the decimal points above.*

```
 .125
 .7
 .089
 .4005
 .9
 .000027
 --------
2.214527  Ans.
```

(**14**) (*a*) $.875 \div \frac{1}{2} = .875 \div .5$ (since $\frac{1}{2} = .5$) $= 1.75$. Ans. Another way of solving this is to reduce .875 to its equivalent common fraction and then divide.

$.875 = \frac{7}{8}$, since $.875 = \frac{875}{1000} = \frac{175}{200} = \frac{35}{40} = \frac{7}{8}$; then, $\frac{7}{8} \div \frac{1}{2} = \frac{7}{\not{8}_4} \times \frac{\not{2}}{1} = \frac{7}{4} = 1\frac{3}{4}$. Since $\frac{3}{4} =$

```
4) 3.00 (.75,
   2 8
   ---
     20
     20
```

$1\frac{3}{4} = 1.75$, the same answer as above.

(*b*) $\frac{7}{8} \div .5 = \frac{7}{8} \div \frac{1}{2}$ (since $.5 = \frac{1}{2}$) $= \frac{7}{\not{8}_4} \times \frac{\not{2}}{1} = \frac{7}{4} = 1\frac{3}{4}$, or 1.75. Ans.

This can also be solved by reducing $\frac{7}{8}$ to its equivalent decimal and dividing by .5; $\frac{7}{8} = .875$; $.875 \div .5 = 1.75$. Since there are three decimal places in the dividend and one in the divisor, there are 3 − 1, or 2 decimal places in the quotient.

(*c*) $\frac{.375 \times \frac{1}{4}}{\frac{5}{16} - .125} = ?$ We shall solve this problem by first reducing the decimals to their equivalent common fractions.

$.375 = \frac{375}{1000} = \frac{75}{200} = \frac{15}{40} = \frac{3}{8}$. $\frac{3}{8} \times \frac{1}{4} = \frac{3}{32}$, or the value of the numerator of the fraction.

$.125 = \frac{125}{1000} = \frac{25}{200} = \frac{1}{8}$. Reducing $\frac{1}{8}$ to sixteenths, we have $\frac{1 \times 2}{8 \times 2} = \frac{2}{16}$. Then, $\frac{5}{16} - \frac{2}{16} = \frac{3}{16}$, or the value of the denominator of the fraction. The problem is now reduced to $\frac{\frac{3}{32}}{\frac{3}{16}} = ?$ $\frac{\frac{3}{32}}{\frac{3}{16}} = \frac{3}{32} \div \frac{3}{16} = \frac{\not{3}}{\not{32}_2} \times \frac{\not{16}}{\not{3}} = \frac{1}{2}$ or .5. Ans.

(15)

```
113                                 169
---                                 ---
256) 113.0000 (.4414+               196) 169.0000 (.8622+
     1024           Ans.                 1568           Ans.
     ----                                ----
      1060                                1220
      1024                                1176
      ----                                ----
        360                                 440
        256                                 392
        ---                                 ---
        1040                                 480
        1024                                 392
        ----                                 ---
          16                                  88
```

$\frac{1728}{2744}$

2744) 1728.0000 (.6297 + Ans.
16464
8160
5488
26720
24696
20240
19208
1032

$\frac{3375}{4096}$

4096) 3375.00000 (.82397 or .8240 — Ans.
32768
9820
8192
16280
12288
39920
36864
30560
28672

(16) (*a*) $.35 = \frac{35}{100} = \frac{7}{20}$. Ans.

(*b*) $.625 = \frac{625}{1000} = \frac{125}{200} = \frac{25}{40} = \frac{5}{8}$. Ans.

(*c*) $12.725 = 12\frac{725}{1000} = 12\frac{145}{200} = 12\frac{29}{40}$. Ans.

(*d*) $.00096 = \frac{96}{100000} = \frac{24}{25000} = \frac{6}{6250} = \frac{3}{3125}$. Ans.

ANSWERS TO QUESTIONS REQUIRING NUMERICAL CALCULATIONS.

MEASURING INSTRUMENTS.

(7) See rule, Art. **42.** The figure 2 is exposed on the barrel, which indicates the first decimal to be 2, thus. .2

One full space is also exposed, for which add 025

The fourth division line on the thimble coincides with the zero line on the barrel, which indicates. 003

Total, .228″

Ans.

(13) (*a*) See rule, Art. **65.** The unit is subdivided into 12 parts and the vernier has 6 divisions; thus, according to rule, $12 \times 6 = 72$ subdivisions can be obtained. Ans.

(*b*) In like manner, the vernier, Fig. 2 (*b*), gives $12 \times 12 = 144$ subdivisions of the unit. Ans.

(14) By rule, Art. **65,** the number of subdivisions obtainable is the product of the number of subdivisions of the true scale and the number of divisions of the vernier; consequently, the divisions necessary in a vernier to give a certain number of subdivisions must be equal to that number divided by the given number of divisions of the true scale, or, in the case under consideration, $\frac{64}{8} = 8$ divisions. Ans.

(15) By rule, Art. **65,**

$$50 \times 20 = 1,000 \text{ subdivisions.} \quad \text{Ans.}$$

(16) (*a*) See rule, Art. **66.** To the left of the zero point of the vernier there are 7 whole spaces of the true scale, which indicates.................. $\frac{7}{12}''$

The division line marked 4 of the vernier coincides with one of the true-scale division lines, which, since the vernier reads to 72ds, indicates...................... $\frac{4}{72}''$

Total, $\frac{46}{72}'' = \frac{23}{36}''$. Ans.

(*b*) See rule, Art. **66.** To the left of the zero point of the vernier there are 1 whole unit and 5 whole spaces of the true scale, indicating....................... $1\frac{5}{12}''$

The eighth division line of the vernier coincides with a division line of the true scale, indicating, since the vernier reads to 144ths.. $\frac{7}{144}''$

Total, $1\frac{67}{144}''$. Ans.

(17) See rule, Art. **69.** To the right of the zero point of the vernier there are 1 whole unit and 2 tenth divisions, indicating .... 1.200″

Moreover, 3 whole fortieth divisions, for each of which add .025″, thus.............. .075″

The tenth division line of the vernier coincides with a division line on the true scale, which, since the vernier reads to 1,000ths, means.................................. .009″

Total, 1.284″. Ans.

LATHE WORK.

PART 1.

(17) According to rule given in Art. **48,**

$$\tfrac{3}{12} = \tfrac{1}{4}''. \quad \text{Ans.}$$

(19) Dividing $1\frac{1}{8}$ by 12 to reduce inches per foot to inches per inch, we get $\frac{9}{8 \times 12} = \frac{9}{96} = \frac{3}{32}$ inch per inch. Multiplying by 6 gives $\frac{3}{32} \times 6 = \frac{18}{32} = \frac{9}{16}$ inch, the taper of the

6-inch piece. To turn this taper we must set the tailstock over one-half the amount of the taper, or $\frac{9}{16} \div 2 = \frac{9}{32}$ inch. Ans.

PART 2.

(20) According to the rule given in Art. **83,**

$$\frac{4}{12} = \frac{4}{12} \times \frac{5}{5} = \frac{20}{60}, \quad \text{Ans.}$$

or any 1 to 3 ratio can be used, as $\frac{18}{54}$, etc.

(21) By rule given in Art. **83,**

$$\frac{4}{9\frac{1}{2}} = \frac{4}{\frac{19}{2}} = \frac{8}{19} = \frac{8}{19} \times \frac{4}{4} = \frac{32}{76} = \frac{8}{19} \times \frac{5}{5} = \frac{40}{95}, \text{ etc.} \quad \text{Ans.}$$

(22) By rule given in Art. **86,**

$$4 : 10 = 40 : \text{gear on leadscrew};$$

from which

$$\text{Gear on leadscrew} = \frac{10 \times 40}{4} = 100 \text{ teeth.} \quad \text{Ans.}$$

(23) By rule given in Art. **86,**

$$6 : 15 :: 20 : \text{gear on leadscrew};$$

from which

$$\text{Gear on leadscrew} = \frac{15 \times 20}{6} = 50 \text{ teeth.} \quad \text{Ans.}$$

(24) By rule given in Art. **87,**

$$27 \div 3 = 9.$$

$$\frac{4}{9} = \frac{4}{9} \times \frac{10}{10} = \frac{40}{90}. \quad \text{Ans.}$$

PART 4.

(2) The diameter of the first cylinder is to that of the second as 2 to 3, and as the cutting speed changes in the same proportion as the diameters, the cutting speed in the second case is equal to

$$\frac{20 \times 3}{2} = 30 \text{ ft. per min.} \quad \text{Ans.}$$

(8) According to formula **1**,

$$S = \frac{\pi D R}{12} = \frac{3.1416 \times 8 \times 20}{12} = 41.888 \text{ ft. per min.,}$$

or 42 ft., approximately. Ans.

(9) According to formula **1**,

$$S = \frac{\pi D R}{12} = \frac{3.1416 \times 3 \times 100}{12} = 78.54 \text{ ft. per min.,}$$

or $78\frac{1}{2}$ ft., approximately. Ans.

(10) By formula **2**,

$$R = \frac{12 S}{\pi D} = \frac{12 \times 30}{3.1416 \times 1.5} = 76.394 \text{ rev. per min.,}$$

or 76 rev., approximately. Ans.

(11) By formula **2** and table, Art. **14**,

$$R = \frac{12 S}{\pi D} = \frac{12 \times 20}{3.1416 \times 1} = 76.394 \text{ rev. per min.,}$$

or 76 rev., approximately. Ans.

(12) By formula **3**,

$$T = \frac{L F}{R} = \frac{18 \times 10}{8} = 22\tfrac{1}{2} \text{ min.} \quad \text{Ans.}$$

(13) By formula **3**,

$$T = \frac{L F}{R} = \frac{50 \times 16}{15} = 53.33 \text{ min.,}$$

or $53\frac{1}{3}$ min., approximately. Ans.

(14) By formula **4**,

$$T = \frac{\pi D F L}{12 S} = \frac{3.1416 \times 10 \times 12 \times 72}{12 \times 40} = 56.548 \text{ min.,}$$

or 57 min., approximately. Ans.

INDEX.

NOTE.—All items in this index refer first to the section (see Preface, Vol. I) and then to the page of the section. Thus, "Arbors 6 40" means that arbors will be found on page 40 of section 6.