# MENSURATION

# USEFUL MEASUREMENTS.

*A measurement* is an ascertained dimension, as the length, breadth, thickness, depth, extent, quantity, capacity, etc., of a thing as determined by measuring.

*Mensuration is the art of measuring things which occupy space;* the art is partly mechanical and partly mathematical.

*There are three kinds of quantity in space, viz., length, surface* and *solidity;* and there are three distinct modes of measurement, viz., *mechanical measurement, geometrical construction* and *algebraical calculations.* The last two modes are done by calculations, while in mechanical measurements they are made by the direct application of rules and special measuring instruments.

*Lengths are measured on lines, and the measure of a length of a line is the ratio or relation which the line bears to a recognized unit of length*—the inch, foot or mile determined by reference to brass rods kept by the United States Government at Washington as a standard. The use of the " rules " is called *direct measurement.*

*The second kind of quantity to be measured is surface.* This sort of measurement is never done directly or mechanically, but always by the measurement of lines, as will be seen both under this division and under the sections relating to geometry.

*The third species of quantity is solidity.* Direct measurement of solid quantities consists simply in filling a vessel of known capacity, like a bushel or gallon measure, until all is measured. The geometrical mode of computing solids is the one hereafter shown by examples and illustrations.

## SURFACES.

*A surface* is the exterior part of anything that has length and breadth, as the surface of a cylinder. *The area* of any figure is the measure of its surface or the space contained within the bounds of that surface, without any regard to the thickness.

TO FIND THE AREA OF A TRIANGLE.

A Triangle is a figure bounded by three sides, and is half a parallelogram; hence the

RULE.—*Multiply the base by half the perpendicular height.*

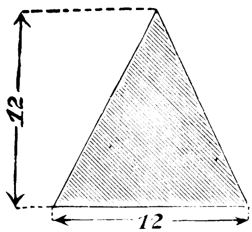


Fig. 6.

EXAMPLE.—The base of the triangle is 12 feet, and it is also 12 feet high; what is its area?

Half the height=6 feet; and 12×6=72 square feet area.

## SURFACES.

### To find the Area of a Trapezium.

A Trapezium is any four-sided figure that is neither a rectangle, like a square or oblong, nor a parallelogram.

Rule.—1. *Join two of its opposite angles, and thus divide it into two triangles.*

2. *Measure this line and call it the base of each triangle.*

3. *Measure the perpendicular height of each triangle above the base line.*

4. *Then find the area of each triangle by the previous rule; their sum is the area of the whole figure.*

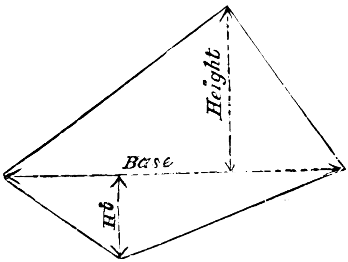


Fig. 7.

### To find the Area of a Trapezoid.

A Trapezoid is a trapezium having two of its sides parallel.

Rule.—*Multiply half the sum of the two parallel sides by the perpendicular distance between them.*

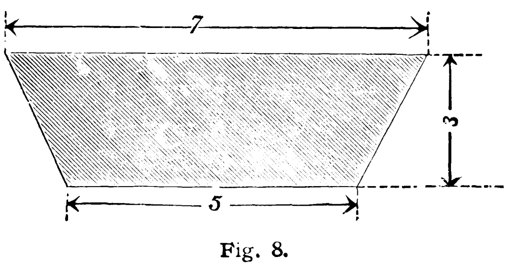


Fig. 8.

USEFUL MEASUREMENTS.

Let the figure be the trapezoid, the sides 7 and 5 being parallel; and 3 the perpendicular distance between them.

EXAMPLE.—Find the area of the above trapezoid, the parallels being 7 feet and 5 feet, and the perpendicular height being 3 feet.

$$\begin{array}{r} 7 \\ 5 \\ \hline 2)12 \\ \hline 6 \end{array}$$

And $6 \times 3 = 18$ square feet.

TO FIND THE AREA OF A SQUARE.

A Square is a figure having all its angles right angles and all its sides equal.

RULE.—*Multiply the base by the height; that is, multiply the length by the breadth.*

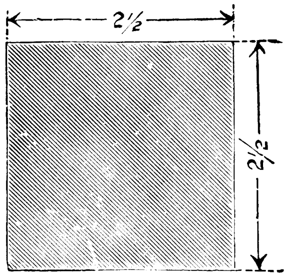


Fig. 9.

EXAMPLE.—What is the area of a square whose side is 2½ feet?

$$\begin{array}{r} 2.5 \\ 2.5 \\ \hline 125 \\ 50\phantom{0} \\ \hline \end{array}$$

Answer, 6.25 square feet.

## SURFACES.

TO FIND THE AREA OF A RECTANGLE.

A rectangle is a figure whose angles are all right angles, but whose sides are not equal; only the opposite sides are equal.

RULE.—*Multiply the length by the breadth.*

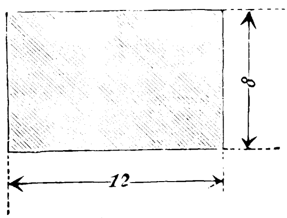


Fig. 10.

EXAMPLE.—What is the area of a rectangular figure whose base is 12 feet and height 8 feet?

$$\begin{array}{r} 12 \\ 8 \\ \hline \end{array}$$

Answer, 96 square feet.

TO FIND THE AREA OF A PARALLELOGRAM.

A Parallelogram is a figure whose opposite sides are parallel, the square and oblong are parallelograms; so also are other four-sided figures whose angles are *not* right angles. It is these latter whose area we now want to find.

RULE.—*Multiply the base by the perpendicular height.*

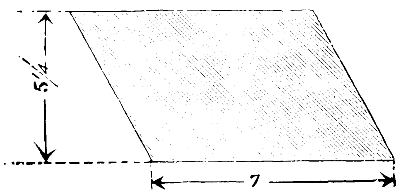


Fig. 11.

USEFUL MEASUREMENTS.

EXAMPLE.—Find the area of a parallelogram whose base is 7 feet and height $5\frac{1}{4}$ feet?

$$\begin{array}{r} 5.25 \\ 7 \\ \hline \end{array}$$

Answer, 36.75 square feet.

TO FIND THE AREA OF A POLYGON.

RULE.—*Multiply the sum of the sides, or perimeter of the polygon, by the perpendicular dropped from its center to one of its sides, and half the product will be the area.* This rule applies to all regular polygons.

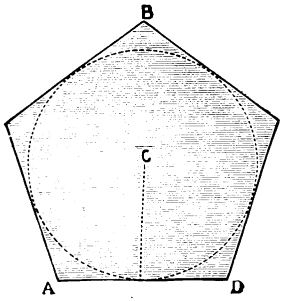


Fig. 12.

EXAMPLE.—What is the area of a regular pentagon, or five-sided figure, *B A D* whose side *A D* is 9 feet and the perpendicular *C E* is 6 feet?

$$\begin{array}{r} 9 \\ 5 \\ \hline 45 \text{ the perimeter.} \\ 6 \\ \hline 2\,)\,270 \\ \hline \end{array}$$

Answer, 135 feet.

# THE CIRCLE.

The circle is a plane figure, comprehended by a single curve line, called its *circumference*, every part of which is equally distant from a point called the *center*. Of course, all lines drawn from the center to the circumference are equal to each other.

## .7854

" Why is the decimal .7854 used to ascertain the area of a circle or round opening ? " is a question frequently asked. Now, if you will divide a square inch into 10,000 parts, then describe a circle one inch in diameter and divide that into ten thousandths of an inch, you will find that you have 7854 of such squares, each one-thousandth of an inch, hence the decimal .7854 is used as a " constant " or multiplier, after squaring the diameter, and the result is the area of the circle.

## 3.1416

The Greek letter $\pi$, called pi, is used to represent 3.1416, the circumference of a circle whose diameter is 1. The circumference of a circle equals the diameter multiplied by 3.1416, nearly. Another approximate proportion is $\frac{22}{7}$, and another still nearer is $\frac{355}{113}$.

This decimal has been worked out to 36 places, as follows :

3.14159265358979323846264338327950288 4+

and called the Ludolphian number, because calculated by Ludolph Van Ceulen, a long time ago.

## USEFUL MEASUREMENTS.

TO FIND THE LENGTH OF THE CURVE LINE, CALLED THE CIRCLE; THAT IS, TO FIND THE CIRCUMFERENCE OF A CIRCLE.

RULE.—*Multiply* 3.1416 *by the diameter.*

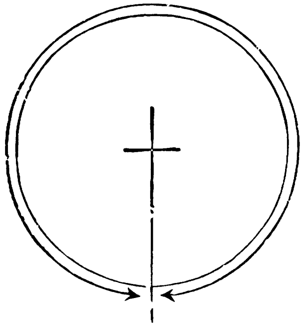

Fig. 13.

EXAMPLE—What is the circumference of a circle whose diameter is 3 inches?

$$\begin{array}{r} 3.1416 \\ 3 \\ \hline \end{array}$$

Answer, 9.4248 inches.

TO FIND THE DIAMETER OF A CIRCLE.

RULE.—(1) *Multiply the circumference by* 7 *and divide by* 22; or, (2) *Divide the circumference by* 3.1416.

EXAMPLE.

A pulley has a circumference of 50.30″, find its diameter?

$$\frac{50.30 \times 7}{22} = 16'' \text{ diameter. Answer.}$$

## THE CIRCLE.

### TO FIND THE AREA OF A CIRCLE.

RULE.—*Multiply the square of the diameter by* .7854.

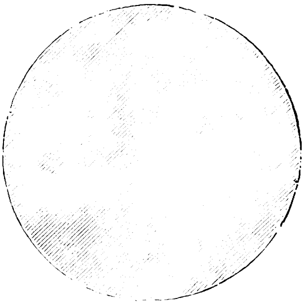

Fig. 14.

EXAMPLE.—The diameter of a circle is 3 inches, find its area.

| | |
|---|---|
| 3 | .7854 |
| 3 | 9 |
| 9 | Answer, 7.0686 square inches. |

EXAMPLE.—The diameter of a circle is 3.5 inches, find the area.

| | |
|---|---|
| 3.5 | .7854 |
| 3.5 | 12.25 |
| 175 | 39270 |
| 105 | 15708 |
| | 15708 |
| 12.25 | 7854 |
| | Answer, 9.621150 square inches. |

NOTE.—"In every branch of science our knowledge increases as the power of measurement becomes improved."

## USEFUL MEASUREMENTS.

TO FIND THE SECTIONAL AREA OF A RING OR PIPE.

RULE.—*From the area of the greater circle subtract that of the lesser.*

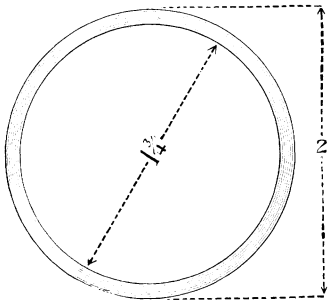


Fig. 15.

EXAMPLE.—A pipe has an external diameter of 2″ and an internal diameter of 1¾″, find its sectional area in square inches.

Thus area of 2″ = $2^2 \times .7854 = 3.1416$
" 1¾″ = $1\frac{3}{4}^2 \times .7854 = 2.4053$

Answer, .7363 square inches.

TO FIND THE AREA OF AN ELLIPSE.

RULE.—*Multiply .7854 by the product of the diameters.*

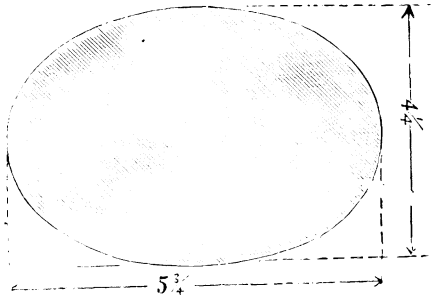


Fig. 16.

## THE CIRCLE.

### EXAMPLE.

What is the area of an ellipse whose diameters are $5\frac{3}{4}$ and $4\frac{1}{4}$?

```
  5.75                 24.4375
  4.25                   .7854
 -----               ---------
  2875                  977500
 1150                  1221875
2300                  1955000
------               1710625
24.4375              ---------
                     19.19321250
```

TO FIND THE SURFACE OR ENVELOPE OF A CYLINDER.

RULE.—*Multiply* 3.1416 *by the diameter, to find the circumference, and then by the height.*

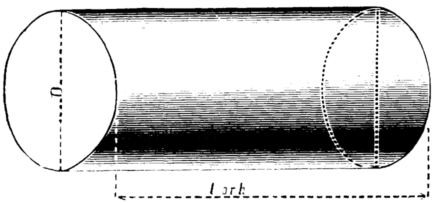

Fig. 17.

### EXAMPLE.

What is the surface of a cylinder whose diameter is 9 inches and height 15 inches.

```
  3.1416
       9
 -------
 28.2744 —circumference.
      15
 -------
 1413720
 282744
 -------
424.1160 area of surface in square inches.
```

USEFUL MEASUREMENTS.

TO FIND THE SURFACE OR ENVELOPE OF A SPHERE.

The surface of a sphere is equal to the convex surface of the circumscribing cylinder; hence the

RULE.—*Multiply* 3.1416 *by the diameter of the sphere, and this again by the diameter; because in this case the diameter is the height of the cylinder;*

*Or multiply* 3.1416 *by the square of the diameter of the sphere.*

EXAMPLE.

What is the surface of a sphere whose diameter is 3 feet? See figure page 73.

$$\begin{array}{r} 3.1416 \\ 9 = 3^2 \\ \hline 28.2744 \end{array}$$

28.2744 area of surface in square feet.

QUOTATION.—"Observe any of the best-known mechanics' pocket reference books after it has been used a few years, and there is always indisputable evidence that the arithmetical tables are used oftener than any other part of the contents. Though it may be well preserved in all other parts, the tables are worn to a useless condition."

# SOLIDS.

*A solid* is a body or magnitude which has three dimensions—length, breadth and thickness—being thus distinguished from a *surface*, which has but two dimensions, and from a line, which has but one ; the boundaries of solids are surfaces.

The measurement of a solid is called its solidity, capacity or content.

To find the solidity or capacity of any figure in the Cubical form.

Rule.—*Multiply the length by the breadth and by the depth.*

Examples.

A tank is 10 feet long, 6 feet broad and 3 feet deep; how many cubic feet of water will it hold?

$10 \times 6 \times 3 =$ Ans. 180 cubic feet.

A bar of iron is 24″ long, $6\frac{1}{2}$″ broad, and $2\frac{1}{4}$″ thick; how many cubic inches does it contain?

$24 \times 6.5 \times 2.25 =$ Ans. 351 cubic ins.

Find the cubical contents in inches of a shaft 3″ diameter and 15′ 0″ long?

$3^2 \times .7854 = 7.0686 \times 15 \times 12 =$ Ans. 1272.348 cubic ins.

## MEASUREMENTS OF SOLIDS.

A CUBE is a solid having six equal square sides. TO FIND THE CONTENTS—

RULE.—*Multiply the area of the base by the perpendicular height.*

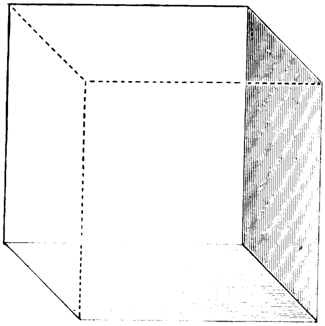

Fig. 18.

EX.—What is the contents of a cistern whose sides and depth are 3 feet 6 inches?

3′ 6″×3′ 6″×3′ 6″=42′ 10″ nearly (42.875 cubic feet).

TO FIND THE CONTENTS OF A RECTANGULAR SOLID.

RULE.—*Multiply the length, breadth and height together.*

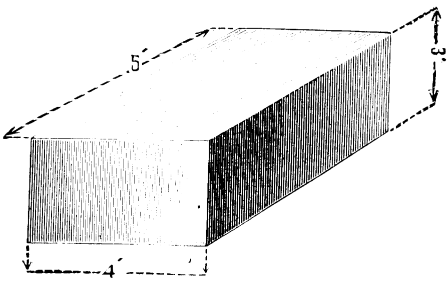


Fig. 19.

EXAMPLE.

What is the contents of a rectangular solid whose length is 5 feet, breadth 4 feet and height 3 feet?

5 feet
4 feet
—
20 square feet of base
3 feet
—
60 cubic feet

TO FIND THE CUBIC CONTENTS OF A SPHERE.

RULE.—*Multiply .7854 by the cube of the diameter, and then take ⅔ of the product.*

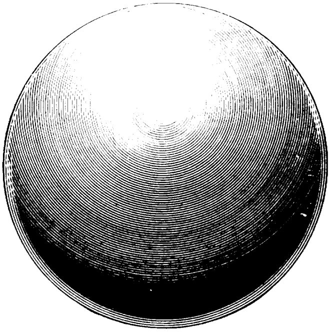

**Fig. 20.**

EX.—Find the cubic contents of a sphere whose diameter is 5 feet.

| | |
|---|---|
| 5 | .7854 |
| 5 | 125 |
| — | ——— |
| 25 | 39270 |
| 5 | 15708 |
| — | 7854 |
| $125 = 5^3$ | ——— |
| | 98.1750 |
| | 2 |
| | ——— |
| | 3)196.3500 |
| | ——— |

Answer, 65.4500 cubic feet.

USEFUL MEASUREMENTS.

The rule is only approximate, owing to the "repeating decimal" used in the calculations. Another rule is as follows:

*Multiply the cube of the diameter by* .5236, *or the cube of the circumference by* .016887, *and the product will be the solidity.*

TO FIND THE SOLIDITY OF A HEMISPHERE.

RULE.—*Multiply the square of the diameter by the radius, and multiply the product by* .5236, *which is the ratio between the solidity of a cube and that of a sphere, whose diameter is equal to one side of the cube.*

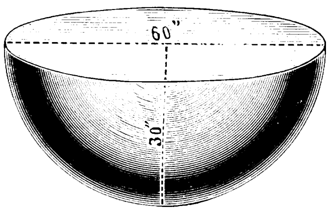


Fig. 21.

EXAMPLE.—How many cubic inches in a hemisphere whose diameter is 60 inches?

$60 \times 60 \times 30 \times .5236 = 56548.8$ cubic inches. Answer.

NOTE —The convex surface of a sphere may be found by multiplying the circumference by the diameter. Or, multiply the square of the diameter by 3.1416, and the product will be the convex surface.

The solidity of a sphere is equal to two-thirds of the solidity of its circumscribing cylinder.

The surface of a sphere is equal to 4 times the area of a circle of the same diameter as the sphere; or to the area of a circle whose diameter is double that of the sphere; or to the convex surface of the circumscribing cylinder.

## SOLIDITY OF A HEMISPHERE.

### TO FIND THE SOLIDITY OF A SEGMENT OF A SPHERE.

RULE 1.—*To three times the square of the radius of the segment's base, add the square of the depth or height; then multiply this sum by the depth, and the product by* .5236.

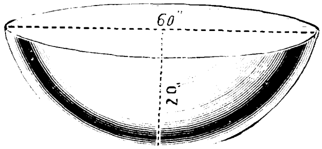


Fig. 22.

EXAMPLE.—How many cubic inches in a spherical segment which has a diameter of 60 inches and a depth of 20 inches?

$60 \div 2 = 30$ inches radius. $30 \times 30 \times 3 = 2700$; $2700 + (20 \times 20) = 3100$; $3100 \times 20 \times .5236 = 32463.2$, which is the number of cubic inches.

RULE 2.—*From three times the diameter of the sphere subtract twice the height of the segment; multiply the remainder by the square of the height, and that product by* .52361 *for the solidity.*

EXAMPLE.—If the diameter of a sphere be 3 feet 6 inches, what is the solidity of a segment whose height is 1 foot 3 inches? Ans. 6.545 feet.

$$\begin{aligned} \text{Now, } 3.5 \times 3 &= 10.5 \\ 1.25 \times 2 &= \underline{\ \ 2.5} \\ & \ \ \ \ \ 8 \end{aligned}$$

$1.25 \times 1.25 = 1.5625 \times 8 = 12.5$ Product.

Then, $12.5 \times .52361 = 6.545$ cubic feet.

NOTE.—When the segment is greater than a hemisphere, find the solidity of the lesser segment and subtract the same from the solidity of the entire sphere.

## USEFUL MEASUREMENTS.

### TO FIND THE CUBIC CONTENTS OF A SOLID CYLINDER.

RULE.—*Find the area of the base, and multiply this by the height or length.*

### EXAMPLE.

What is the cubic contents of a cylinder whose diameter is 4 feet, and height or length $7\frac{1}{2}$ feet?

```
 4        .7854
 4           16
——       ——————
16        47124
          7854
         ——————
         12.5664—area of base in square feet
             7.5  height or length in feet
         ——————
          628320
         879648
         ——————
Answer, 94.24800 cubic feet.
```

### TO FIND THE SOLIDITY OF A CYLINDRICAL RING.

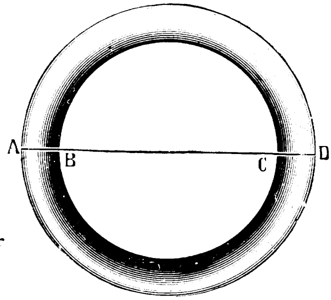


Fig. 23.

RULE.—*To the thickness of the ring, add the inner diameter; and this sum being multiplied by the square of the thickness, and the product again by 2.4674, will give the solidity.*

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NOTE.—The surface of a cylindrical ring may be found by the following rule: To the thickness of the ring, add the inner diameter; and this sum being multiplied by the thickness, and the product again by 9.8696, will give the surface required.

SOLIDITY OF A CYLINDRICAL RING

EXAMPLE.—What is the solidity of a cylindrical ring whose thickness *A B* or *C D* is 6, and the inner diameter *B C* 20 inches?

Here $(20+6)\times 6^2 \times 2.4674 = 26 \times 36 \times 2.4674 = 936 \times 2.4674 = 2309.4864$ inches, the solidity required.

TO FIND THE SOLIDITY OF A CONE.

RULE.—*Multiply the area of the base by the perpendicular height, and $\frac{1}{3}$ of the product will be the solidity.*

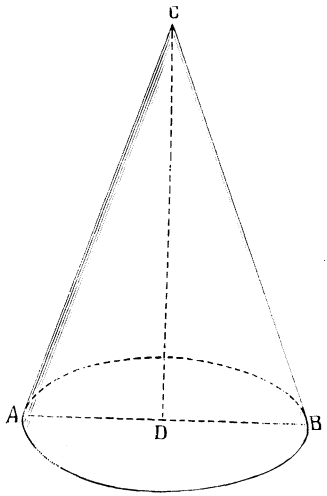



Fig. 24.

EXAMPLE.

1. Required, the solidity of the cone *A B C*; the diameter, *A B*, of the base being 12 feet, and the perpendicular altitude, *D C*, 18 feet 6 inches.

Here $.7854 \times 12^2 = .7854 \times 144 = 113.0976$, the area of the base; and $(113.0976 \times 18.5) \div 3 = 2092.3056 \div 3 = 697.4352$ feet, the solidity required.

## USEFUL MEASUREMENTS.

### TO FIND THE CUBIC CONTENTS OF A FRUSTRUM OF A CONE.

A frustrum of a cone is the lower portion of a cone left after the top piece is cut away.

RULE.—*Find the sum of the squares of the two diameters* (*d*, *D*), *add on to this the product of the two diameters multiplied by* .7854, *and by one-third the height* (*h*).

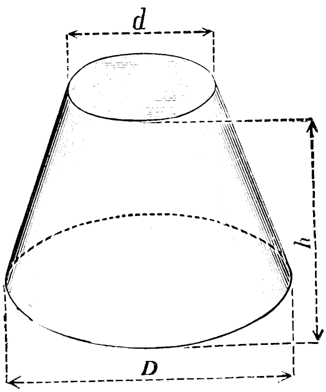



Fig. 25.

EXAMPLE.—Find the cubic contents of a safety-valve weight of the following dimensions: 12″ large diameter, 6″ small diameter, 4″ thick. Now:

$144 + 36 + 72 \times .7854 \times 1.33$
$252 \times .7854 \times 1.33 = 263.23$, etc., cubic inches.

### TO FIND THE SOLIDITY OF A PYRAMID.

Pyramids may be trilateral, quadrilateral, pentagonal, hexagonal, heptagonal, octagonal, etc., having three, four, five, six, seven, eight triangular sides, respectively.

SOLIDITY OF A PYRAMID.

The trilateral pyramid has three triangles. The quadrilateral pyramid has four triangles, and the pentagonal pyramid has five triangles, and so on.

RULE.—*Multiply the area of the base by one-third of the perpendicular height, and the product will be the solidity.*

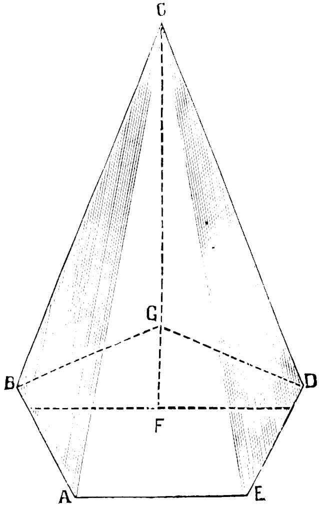



Fig. 26.

EXAMPLE.—What is the solidity of the regular pentagon pyramid *A B C D E*, each side of the base being 9 feet, and the perpendicular altitude, *F C*, 24 feet?

The area of the base, see page 64, is

$$135 \text{ feet} \times \tfrac{1}{3} \text{ of } 24 = 8$$
$$\underline{\phantom{0}8\phantom{0}}$$

Answer, 1080 feet, the solid contents.

## USEFUL MEASUREMENTS.

### TO FIND THE SOLIDITY OF AN IRREGULAR SOLID.

RULE.

*Divide the irregular solid into different figures; and the sum of their solidities, found by the preceding problems, will be the solidity required.*

*If the figure be a compound solid, whose two ends are equal plane figures, the solidity may be found by multiplying the area of one end by the length.*

*To find the solidity of a piece of wood or stone that is craggy or uneven, put it into a tub or cistern, and pour in as much water as will just cover it; then take it out and find the contents of that part of the vessel through which the water has descended, and it will be the solidity required.*

If a solid be large and very irregular, so that it cannot be measured by any of the above rules, the general way is to take lengths, in two or three different places; and their sum divided by their number, is considered as a mean length. A mean breadth and a mean depth are found by similar processes. Sometimes the length, breadth and depth taken in the middle are considered mean dimensions.

There are five regular solids which are shown in Figs. below. A regular solid is bounded by similar and regular plane figures. Regular solids may be circumscribed by spheres, and spheres may be inscribed in regular solids.

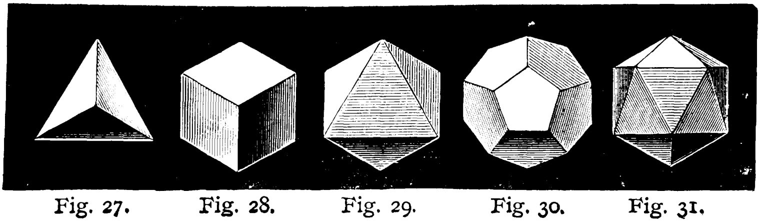


Fig. 27. Fig. 28. Fig. 29. Fig. 30. Fig. 31.

## THE FIVE REGULAR SOLIDS.

The *Tetrahedron* (fig. 27) is bounded by four equilateral triangles.

The *Hexahedron*, or cube (fig. 28), is bounded by six squares.

The *Octahedron* (fig. 29) is bounded by eight equilateral triangles.

The *Dodecahedron* (fig. 30) is bounded by twelve pentagons.

The *Icosahedron* (fig. 31) is bounded by twenty equilateral triangles.

## TO FIND THE SURFACE AND THE CUBIC CONTENTS OF ANY OF THE FIVE REGULAR SOLIDS.

RULE.—*For the surface, multiply the tabular area below, by the square of the edge of the solid.*

*For the contents, multiply the tabular contents below, by the cube of the given edge.*

### TABLE OF CONSTANTS.

### SURFACES AND CUBIC CONTENTS OF REGULAR SOLIDS.

| Number of Sides | NAME | Area. Edge = 1 | Contents. Edge = 1 |
|---|---|---|---|
| 4 | ......Tetrahedron........ | 1.7320 | 0.1178 |
| 6 | ......Hexahedron...... .. | 6.0000 | 1.0000 |
| 8 | ......Octahedron......... | 3.4641 | 0.4714 |
| 12 | ......Dodecahedron.... | 20.6458 | 7.6631 |
| 20 | ......Icosahedron.......... | 8.6603 | 2.1817 |

A constant is a quantity or multiplier which is assumed to be invariable.

# PARTS OF A CIRCLE.

The circumference of a circle is supposed to be divided into 360 degrees or divisions, and as the total angularity about the center is equal to four right angles, each right angle contains 90 degrees or 90°, and half a right angle contains 45°. Each degree is divided into 60 minutes, or 60′; and, for the sake of still further minuteness of measurement, each minute is divided into 60 seconds, or 60″. In a circle there are, therefore, 360×60×60=1,296,000 seconds.

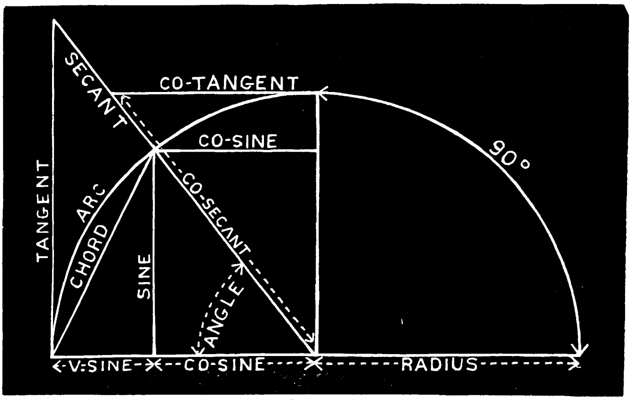



Fig. 32.

The above diagram exemplifies the relative positions of the

Sine, Tangent,
Cosine, Cotangent,
Versed sine, Secant, and
Cosecant

of an angle.

NOTE.—The circumferences of all circles contain the same number of degrees, but the greater the radius, the greater the absolute measures of a degree. The circumference of a fly-wheel or the circumference of the earth have the same number of degrees; yet the same number of degrees in each and every circumference is the measure of precisely the same angle.

DEFINITIONS OF PARTS OF A CIRCLE.

1. The *Complement* of an arc is 90° minus the arc.

2. The *Supplement* of an arc is 180° minus the arc.

3. The *Sine* of an angle, or of an arc, is a line drawn from one end of an arc, perpendicular to a diameter drawn through the other end.

4. The *Cosine* of an arc is the perpendicular distance from the center of the circle to the sine of the arc; or it is the same in magnitude as the sine of the complement of the arc

5 The *Tangent* of an arc is a line touching the circle in one extremity of the arc, and continued from thence to meet a line drawn through the center and the other extremity.

6. The *Cotangent* of an arc is the tangent of the complement of the arc. The *Co* is but a contraction of the word complement.

7. The *Secant* of an arc is a line drawn from the center of the circle to the extremity of the tangent.

8. The *Cosecant* of an arc is the secant of the complement.

9. The *Versed Sine* of an arc is the distance from the extremity of the arc to the foot of the sine.

For the sake of brevity these technical terms are contracted thus: for sine *AB*, we write *sin. AB;* for cosine *AB*, we write *cos. AB;* for tangent *AB*, we write *tan. AB*, etc.

NOTE.—*Trigonometry* is that portion of geometry which has for its object the measurement of triangles. When it treats of plane triangles it is called *Plane Trigonometry*, and as the engineer will continually meet in his studies of higher mathematics the terms used in plane trigonometry, it is advantageous for him to become familiar with some of the principles and definitions relating to this branch of mathematics.

# MEASURING MACHINES, TOOLS AND DEVICES.

The accuracy of a man's workmanship can usually be determined from knowing the kind of measuring instruments he employs. It is an old saying among mechanics that a blacksmith's "hair's-breadth" is anything less than a quarter of an inch. There used to be good ground for this statement, the reason being that the blacksmith measured with a square, the graduations of which were $\frac{1}{4}$ inch.

When a man begins to use a scale graduated to hundredths he finds, as soon as he learns to distinguish the marks, that there is considerable space included in $\frac{1}{100}$ of an inch.

When a man has used a micrometer caliper for a short time he learns to determine $\frac{1}{2}$ of $\frac{1}{1000}$ of an inch quite readily, and then begins to appreciate the value of fine measurements and close fits. In considering modern methods and comparing them with older practice, we are at once struck by the definiteness with which the sizes of parts are now fixed. The fitting of one part to another is no longer a question of working to gauges of which the absolute sizes are unknown, but of working to sizes which

NOTE.—In a device consisting of a short steel rod fitting into a hollow cylinder, the rod being three-quarters of an inch in diameter, it was found that the fit was so perfect that it would slide freely in and out, but if the rod was taken out and held in the hand for a few seconds, the slight expansion caused by the warmth of the hand was enough to render it impossible to insert the rod until it had been allowed by gradual cooling to regain its normal size.

MEASURING MACHINES AND TOOLS.

are definitely fixed and stated, and which are at any time capable of reproduction. To carry out this system means the general provision of instruments for accurate measurement which were formerly only to be found in a very few special establishments; it means the possession of skill in the use of such measuring appliances, and a cultivation of an appreciation of the value of small units.

Fig. 33 shows a side view of a standard End-Measuring Rod; these are formed of steel, hardened on the ends and accurately ground, so that the ends form sections of true spheres whose diameters are equal to those of the length of the rods. They are suitable for making internal measure-

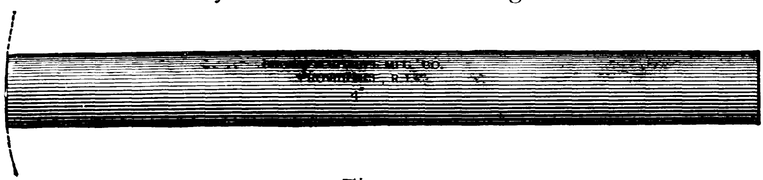


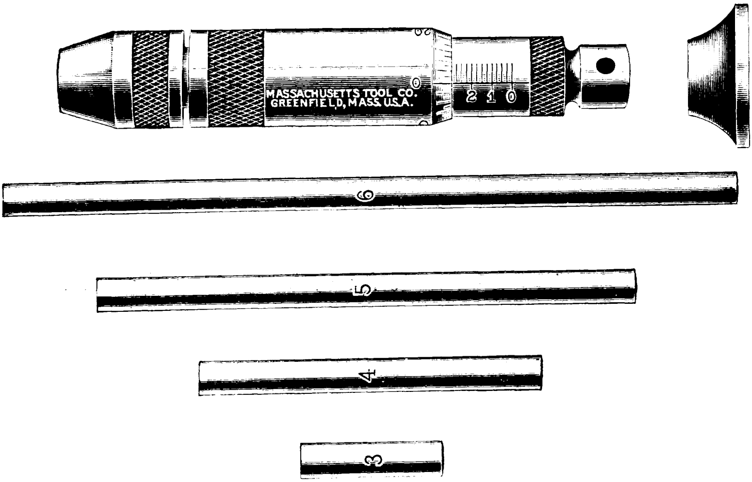
Fig. 33.

ments, as rings, cylinders, etc.; and, as reference tools, are particularly well adapted for setting calipers, comparing gauges, and work of a similar character. They are also suitable for measuring parallel surfaces, as the spherical ends will pass such surfaces without cramping, the same as spheres of like diameters.

Figs. 34 to 39 exhibit Inside Micrometer Gauges. These are adjustable, and designed for making internal measurements, and work of a similar character, and are also adapted for measuring parallel surfaces.

The device consists of a holder provided with a micrometer screw and thimble. The screw has a movement of ½″; and, by the use of the extension rods furnished, measurements from 3″ to 6″ can be made by the thousandths of an inch.

The extension rods vary by ½″, and each rod is provided with an adjusting nut and check-nut, which are set




Figs. 34 to 39.

to obtain the proper measurement of the given rod, and should be adjusted only when the point of that rod has become worn.

This instrument is provided with a micrometer screw and nut, and is graduated to read by half-thousandths.

Provision is made for adjustment to compensate for wear of the screw and measuring surfaces.

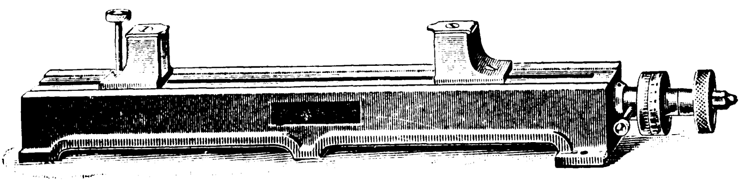


Fig. 40.

## MEASURING MACHINES.

Fig. 40 shows a standard form of measuring machine for use in the tool room in preparing templates, reamers, mandrels, etc. It will measure differences of the $\frac{1}{10000}$ of an inch. Adjustments in the machine provide for the wear of measuring points.

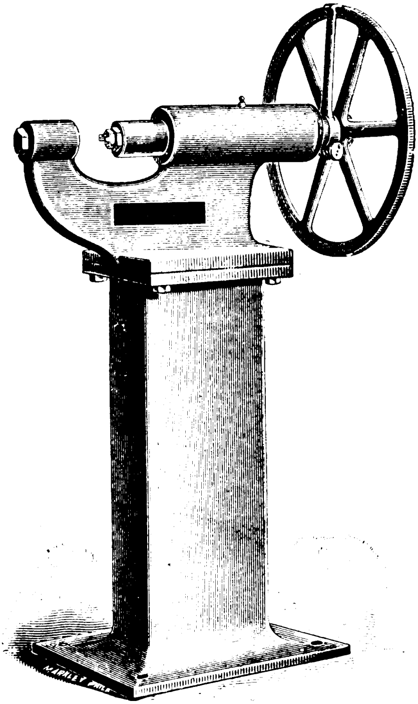


Fig. 41.

Calipering Machines are used to transmit sizes, and differ from fixed calipers in that they record as the size is approached, and show how much a piece is to be reduced.

Machines of this type are used in connection with standard sizes as an accurate pair of calipers, and have the features of a measuring machine, as they will measure accurately *above and below a certain size* after having been adjusted and the index, which is on the edge of the wheel, set for a standard size. The machine shown in fig. 41

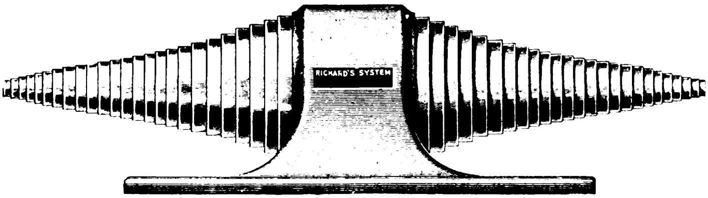



Fig. 42.

will caliper to 6 inches. The index wheel is divided to read to ten-thousandths of an inch.

Fig. 42 shows corrective gauge standards. These discs are employed for testing and correcting fixed gauges, for setting calipers, and also as a reference to prove dimensions within their range. Each disc is separate and is ground independently to size.

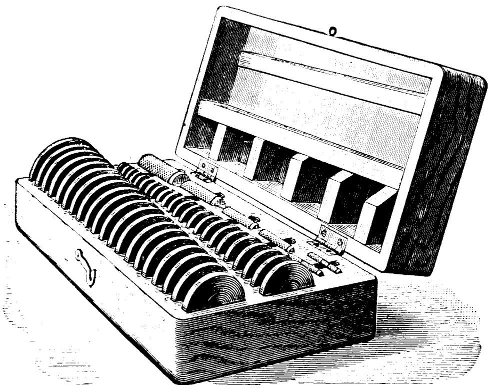


Fig. 43.

The introduction of accurate scientific methods into manufacturing and commercial processes involves the use

MEASURING TOOLS.

of a great variety of standards of far greater accuracy than formerly required. Fig. 42 is but one of very many measuring devices introduced to secure the essential accuracy.

Standard reference discs are shown in fig. 43. These are employed for testing and correcting fixed caliper gauges, for setting calipers, and also as a reference to

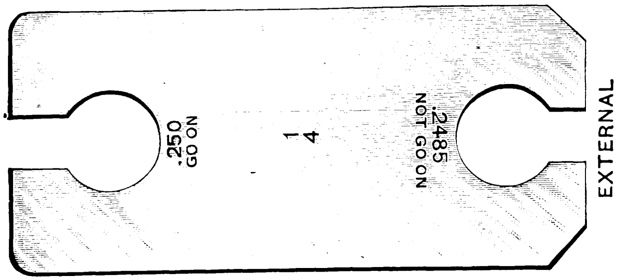



Fig. 44.

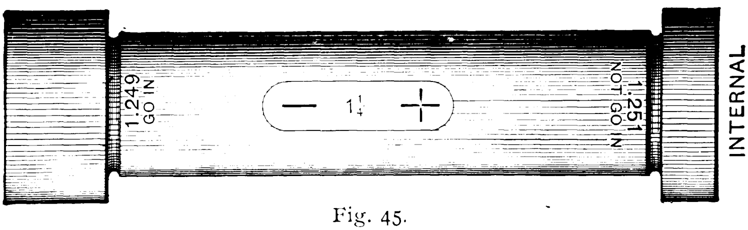



Fig. 45.

prove dimensions within their range. They are intended to serve principally as originals, not as working gauges.

The illustration represents "a set" of forty-five discs, ranging in size from ¼″ to 3″, inclusive, by 16ths, and four handles. The discs vary in width from ¼″ to ½″, according to the diameter, and afford ample contact surface.

The figures 44 and 45 represent the common form of internal and external limit gauges. Gauges of this type

MEASURING DEVICES.

are stamped with the words "go on" and "not go on," for the external, and "go in" and "not go in" for the internal; and, as the two ends are of different shape, the workman is enabled to easily and quickly distinguish the large from the small end without looking at the sizes stamped upon the gauge.

These gauges are not only used as references for finishing operations, but are of advantage in roughing work for finishing. When used in this way the same amount of stock is left on each piece, thus enabling the operator who finishes the pieces to work to better advantage than if they were of various sizes.

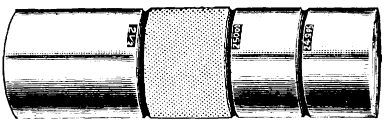


Fig. 46.

The fig. 46 shows a limit gauge as used in shop practice. It is stamped 2½, 2.500, 2.4995; the end marked 2½ is ground accurately to size, and is not used except as a reference standard, the calipers or measuring instruments being set by the ends marked 2.500, 2.4995. The difference between these is a limit of .0005, or the $\frac{1}{2000}$ part of an inch.

The advantages derived from the use of the limit gauges are being appreciated more and more; as, by their use the time consumed in testing and gauging is reduced to a minimum, and the duplication of parts is insured.

MEASURING DEVICES.

Fig. 47 shows an adjustable parallel measuring gauge. It measures from $\frac{1}{4}$ inch to 4 inches, and measurements over the above are got by placing a base beneath. The slide is tightened by the right-hand thumb nut and the scriber by the the left-hand one, by which both work inde-

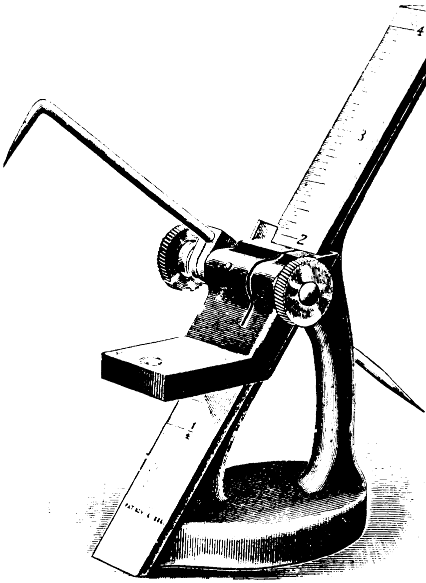


Fig. 47.

pendently of each other. It is graduated into 64 parts to the inch. The graduation on the tool is wider than the ordinary scale, it being on an incline, but the operator should read them just the same as a scale of 64ths, matching the line of the slide to the graduation on the incline.

## GAUGES.

English or Birmingham gauges, for sheet and plate steel and iron, are shown in figs. 48 and 49. The former indicates sizes from 1 to 32; the latter from 000 to 25. The illustrations are about two-thirds the real size.

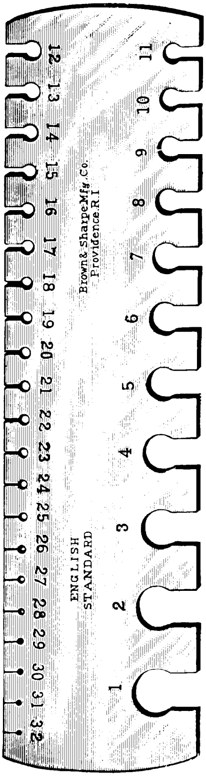



Fig. 48.

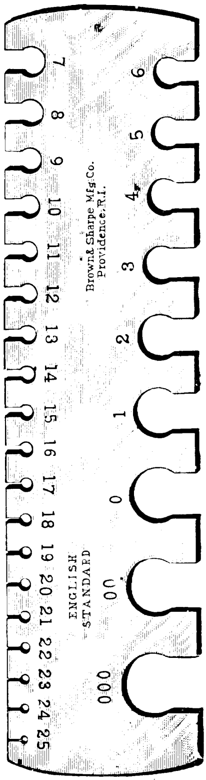



Fig. 49.

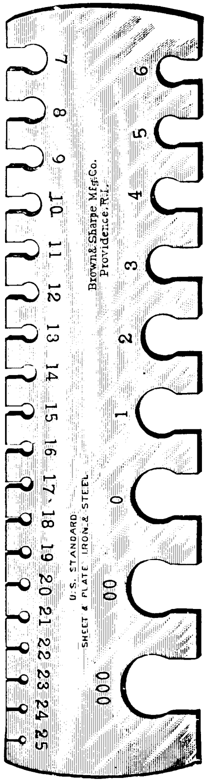



Fig. 50.

Fig. 50 represents, two-thirds actual size, the United States Standard Gauge for sheet and plate steel and iron, adopted by Congress March 3, 1893.

## GAUGES.

Figs. 51 and 52 are gauges for use in measuring twist drills and steel drill rods.

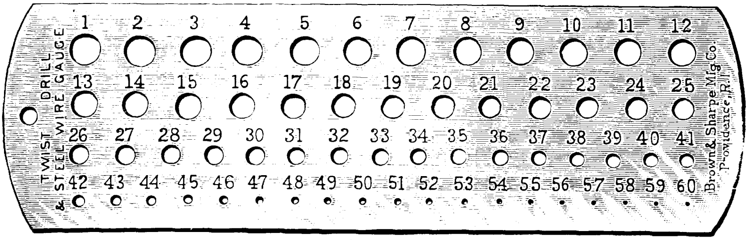



Fig. 51.

Gauge No. 51 is about $\frac{1}{16}''$ thick, $1\frac{5}{8}''$ wide, $5\frac{1}{4}''$ long, and contains gauge numbers from 1 to 60 inclusive.

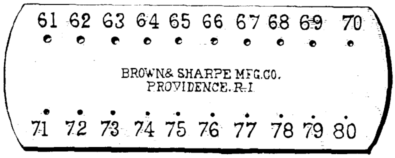



Fig. 52.

Gauge No. 52 is about $\frac{1}{16}''$ thick, $\frac{3}{4}''$ wide, $2''$ long, and contains gauge numbers from 61 to 80 inclusive.

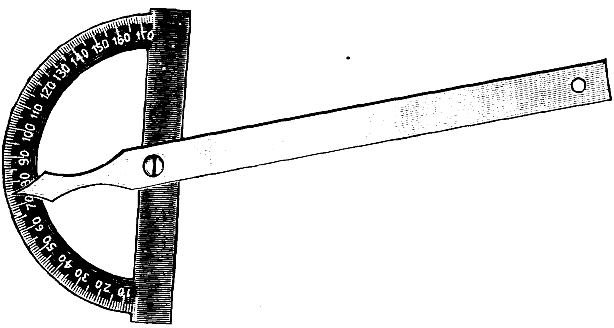


Fig. 53.

Fig. 53 shows an angle gauge, with the addition of a protractor and registering dial. It is a very useful tool for testing planed and finished parts.

## ANGLE-GAUGES.

Fig. 54 shows a simple form of bevel protractor operated on the same principles as that shown in the preceding illustration.

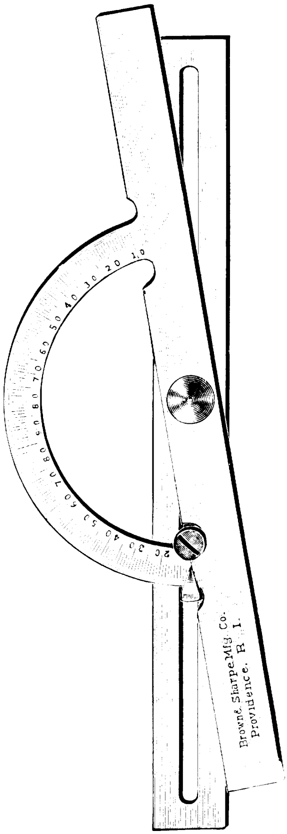



Fig. 54.

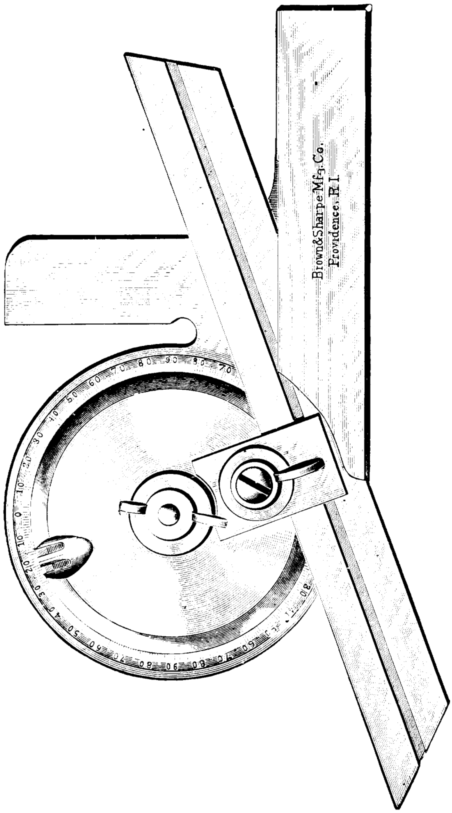



Fig. 55.

Fig. 55 shows still another form of the same device. In each of the above instruments the circles, or parts thereof, are divided into degrees.

USEFUL MEASUREMENTS.

This tool is well adapted for all classes of work where angles are to be laid out or established; one side of the stock is flat, thus permitting its being laid upon the paper or work. The dial is accurately graduated in degrees the entire circle. It turns on a large central stud, which is hardened and ground, and can be rigidly clamped by the thumb nut shown in cut.

The line of graduations is below the surface, thus protecting them from wear. The blade is about one-eighth inch thick, can be moved back and forth its entire length, and clamped independently of the dial, thus adapting the protractor for work where others cannot be used.

# THE VERNIER AND ITS USE.

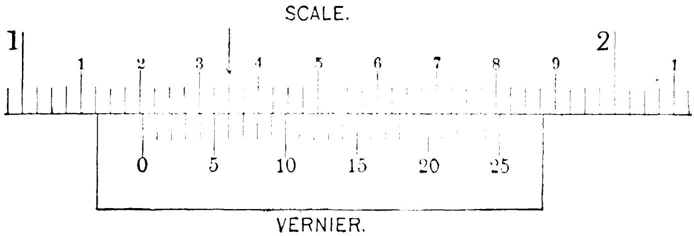



Fig. 56.

The Vernier is a small *movable scale* invented by Pierre Vernier in 1631, and used for measuring a fractional part of one of the equal divisions on the graduated *fixed scale*.

The Vernier consists, in its simplest form, of a small sliding scale, the divisions of which differ from those of the fixed or primary scale; the ingenuity of the invention has given a lasting and world-wide fame to the discoverer of its useful application.

THE VERNIER AND ITS USE.

On the scale of the tool is a line of graduations divided into inches and numbered 0, 1, 2, etc., each inch being divided into ten parts, and each tenth into four parts, making forty divisions to the inch.

On the sliding jaw is a line of divisions of twenty-five parts, numbered 0, 5, 10, 15, 20, 25. The twenty-five divisions on the Vernier correspond, in extreme length, to twenty-four divisions, or $\frac{24}{40}$ of an inch, on the scale; each

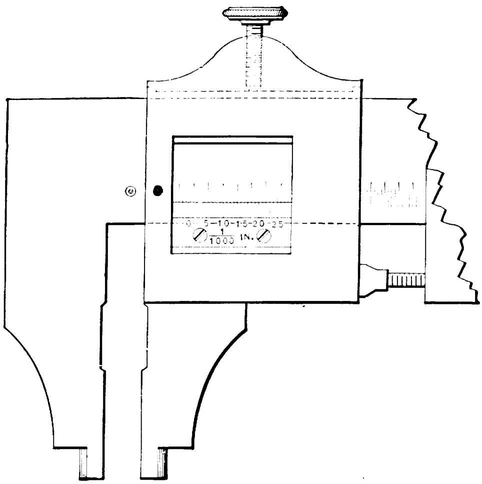


Fig. 57.

division on the Vernier is, therefore, $\frac{1}{25}$ of $\frac{1}{40}$, or $\frac{1}{1000}$ of an inch shorter than the corresponding division on the scale.

If the Vernier is moved until the line marked 0 on the Vernier coincides with that marked on the scale, then the next two lines to the right will differ from each other by $\frac{1}{1000}$ of an inch; and the difference will continue to increase $\frac{1}{1000}$ of an inch for each division, until the line 25 on the Vernier coincides with a line on the scale.

## USEFUL MEASUREMENTS.

Fig. 56 represents a Vernier caliper, showing the two scales, and in the note is an admirable explanation of its use, for which credit is due to Brown & Sharpe Manufacturing Co.

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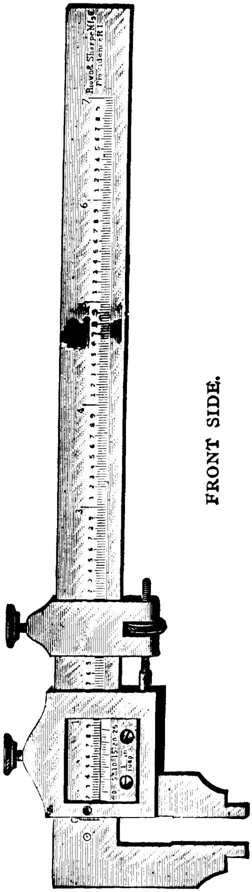
NOTE.—On the bar of the instrument is a line of inches, numbered 0, 1, 2, etc., each inch being divided into ten parts, and each tenth into four parts, making forty divisions to the inch. On the sliding jaw is a line of divisions of twenty-five parts, numbered 0, 5, 10, 15, 20, 25. The twenty-five parts on the Vernier correspond, in extreme length, with 24 parts, or twenty-four fortieths of the bar; consequently, each division on the Vernier is smaller than each division on the bar by .001 part of an inch. If the sliding jaw of the caliper is pushed up to the other, so that the line marked 0 on the Vernier corresponds with that marked 0 on the bar, then the two next lines to the right will differ from each other by .001 of an inch, and so the difference will continue to increase, .001 of an inch for each division, till they again correspond at the line marked 25 on the Vernier. To read the distance the caliper may be open, commence by noticing how many inches, tenths and parts of tenths the zero point on the Vernier has been moved from the zero point on the bar.

Now, count upon the Vernier the number of divisions, until one is found which coincides with one on the bar, which will be the number of thousandths to be added to the distance read off on the bar. The best way of expressing the value of the divisions on the bar is to call the tenths one hundred thousandths (.100), and the fourths of tenths, or fortieths, twenty-five thousandths (.025). Referring to the cut shown above, it will be seen that the jaw is open two-tenths and three-quarters, which is equal to two hundred and seventy-five thousandths (.275). Now, suppose the Vernier was moved to the right, so that the tenth division would coincide with the next one on the scale, which will make ten thousandths (.010) more to be added to two hundred and seventy-five thousandths (.275), making the jaws to be open two hundred and eighty-five thousandths (.285).

USEFUL MEASUREMENTS.

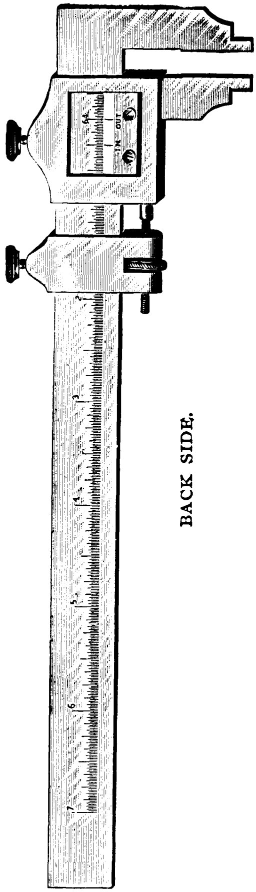
Figs. 58 and 59 represent the entire calipers of which the head only is shown in fig. 57.

These instruments are graduated on the front side to



FRONT SIDE.

Fig. 58.



BACK SIDE.

Fig. 59.

read, by means of the Vernier, to thousandths of an inch, and on the back to sixty-fourths of an inch; the jaws can be used for either outside or inside measurements; points

THE VERNIER AND ITS USE.

are placed on the bars and slide, so that dividers can be used to transfer distances. Verniers are applied to minute measuring instruments, as the sextant, barometer, etc.

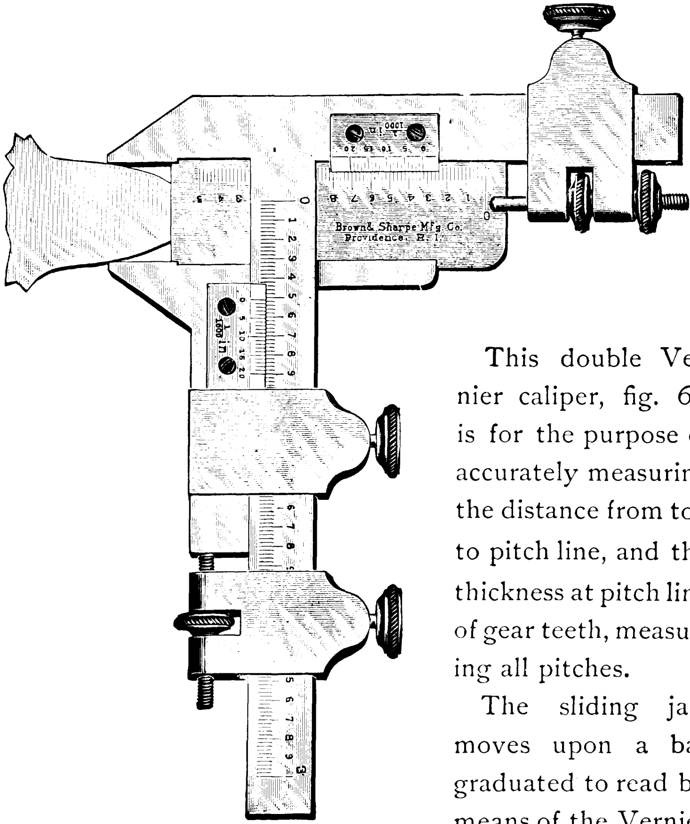



Fig. 60

This double Vernier caliper, fig. 60, is for the purpose of accurately measuring the distance from top to pitch line, and the thickness at pitch line of gear teeth, measuring all pitches.

The sliding jaw moves upon a bar graduated to read by means of the Vernier to thousandths of an inch. A tongue, moving at right angles with the jaws, is graduated in the same manner. Both the sliding jaw and tongue are provided with adjusting screws.

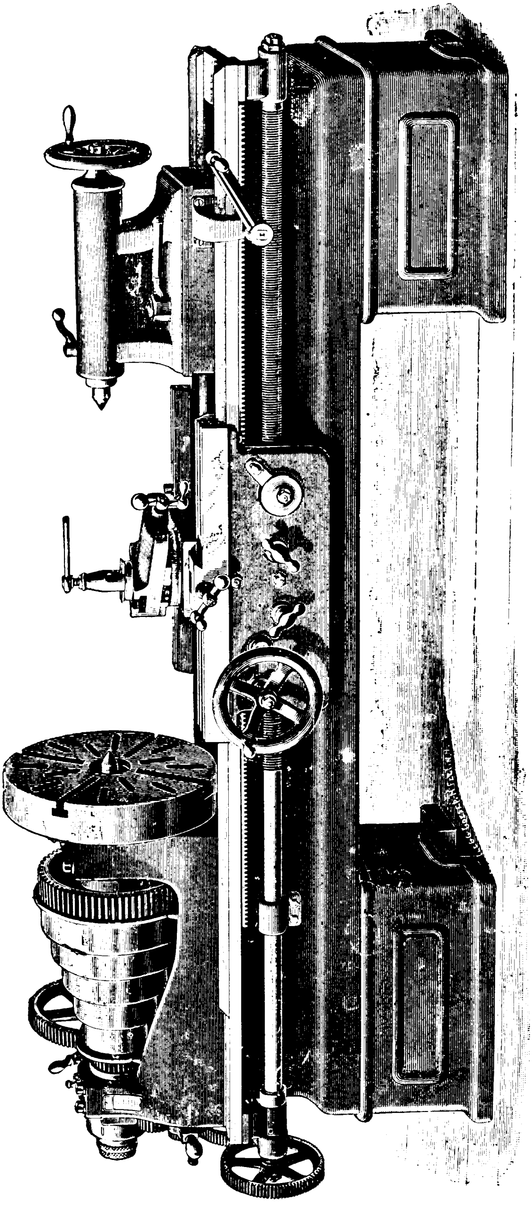


Fig. 61.