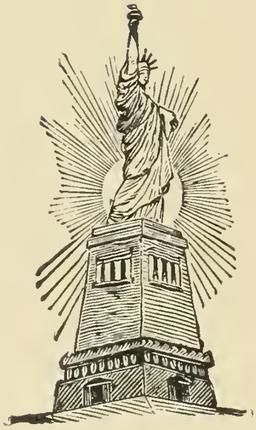
HAND BOOK

OF

CALCULATIONS

FOR

ENGINEERS.



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JAMES WATT

HAND BOOK
OF
CALCULATIONS
FOR
ENGINEERS
AND
FIREMEN.

RELATING TO

THE STEAM ENGINE, THE STEAM BOILER, PUMPS, SHAFTING, ETC.

COMPRISING THE ELEMENTS OF MECHANICAL PHILOSOPHY, MENSURATION, GEOMETRY, ALGEBRA, ARITHMETICAL SIGNS, AND TABLES.

UNITED STATES WEIGHTS, MEASURES AND MONEY; TABLES OF WAGES, WITH COPIOUS NOTES, EXPLANATIONS AND HELP RULES USEFUL FOR AN ENGINEER.

AND FOR REFERENCE, TABLES OF SQUARES AND CUBES, SQUARE AND CUBE ROOTS, CIRCUMFERENCE AND AREAS OF CIRCLES, TABLES OF WEIGHTS OF METALS AND PIPES, TABLES OF PRESSURES OF STEAM, ETC., ETC., ETC.

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FOR THE BOILER ROOM.

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INTRODUCTION.

"I would give a thousand dollars if I knew the principles upon which my engine works."

This was the remark of a western engineer made to a gentleman who was admiring the performance of the steam plant under the charge of the former. "I can attend to every necessary thing about my whole apparatus; engine, boilers, pumps, pipes, and do all that is expected of an engineer, but I don't know *why* the steam does its work, and I would give a thousand dollars *to know*."

This work is prepared for those who, like the engineer whose words are quoted, wish *to know*, and are willing to pay the cost, in money and study.

Abraham Lincoln once said, in the early days of his opening manhood, with the warm enthusiasm characteristic of his noble mind, "That man who furnishes me with a good book is my best friend;" at the age of 18 he was the proud owner of six volumes.

The desire has been strong indeed, in the mind of the author, while compiling this work, upon a single page of which, at times, several days have been spent, that it might come to many aspiring men, with the same potent good, as the few books which Abraham Lincoln had access to in his early struggling days.

In the wide expanse of mathematics it has been a task of the utmost difficulty for the author to lay out a road that would not too soon weary or discourage the student; if he had his wish he would gladly advance step by step with his pupil, and much better explain, by word and gesture and emphasis, the great principles which underlie the operations of mechanics; to do this would be impossible, so he writes his admonition in two short words: In case of obstacles, "GO ON." If some rule or process seems too hard to learn, go around the difficulty, always advancing, and, in time, return and conquer.

One thing of importance may here be said. The value of a teacher or instructor cannot be overestimated. Men were not made to do their work alone; they are created so that they need assistance and encouragement in every direction *except downwards;* to be helped and to help is the universal law. In no profession more than steam engineering does this law hold truer, and while the editor has written down the hard problems he has all the time, while making them as plain as possible to do so, had the secret wish that the learner might have at his side, when the book came to him, a kind and generous tutor, who could, and cheerfully would, go with him over the untravelled road.

There is a single unique Book in the world, two thousand years compiling, of which it is said that no person can be called foolish who diligently peruses its pages; so the author's topmost wish has been now to prepare a book *so elementary* and yet so wide in its scope that no engineer or fireman could justly be called ignorant who had carefully studied and become familiar with its pages. We quote for a motto—

"Education does not consist merely in storing the head with materials; that makes a lumber room of it; but in learning how to turn those materials into useful products; that makes a factory of it; and no man is educated unless his brain is a factory, with storeroom, machinery and material complete."

Hence in arranging the materials of this work, the author has aimed to give it a certain completeness and harmony with itself, from beginning to end; to make it "a factory, with storeroom, machinery and materials" so abundant in quantity and variety of stores, that it will answer every reasonable requirement.

In excuse for the extreme simplicity of some of the problems presented, the author owns that this feature of the book was incorporated in it through its having come to his knowledge, through a member of the board of U. S. government examiners, some years since, that some score of high class marine engineers had come very near losing their positions on account of their ignorance of many of the simplest items of information relating to their duties.

It was in consequence of an order received from headquarters at Washington for the re-examination of all the engineers in a certain department, in the Eastern division of the marine service; the order was peremptory, and the examinations to the number of 60 or 70 were held forthwith.

And it was a disagreeable fact that while few, or none, were really displaced, the positions of all these really competent engineers were in danger of being forfeited, because they *had forgotten the little things* they had acquired in earlier days.

Hence the truly wise student of this hand-book, even if of established reputation, will not despise the elementary rules and examples presented. Nor must the humble beginner despair of the most difficult. Both extremes will be found in the completed volume.

PLAN OF THE WORK.

The leading idea intended to be illustrated in the following successive "parts" or chapters is this: that in an informal and not too "dry" a method, engineers or those aspiring to be such shall be *taught to figure the problems* relating to the steam engine and boiler; the steam pump; shafting and pulleys; and all other calculations required in the varied duties of steam-engineering in its most intelligent and useful practice.

The first four or five parts of the work will be occupied exclusively with what may be called *the general principles of mathematics*—principles which are used in all times and places and in an infinite variety of machines, and their application to the use of man. Next, these elements will be illustrated by the practice of to-day in steam engineering in its various departments. Rules for calculating horse power of engines and boilers will be given in the plainest manner and fully illustrated by diagrams; rules for figuring the safety-valve pressure of boilers, strength of materials, size and capacity of pumps, etc., etc., with *help rules, notes and remarks* based upon the most approved practical experience.

The work will close with valuable and copious tables of *roots and powers of numbers,* and *diameters* and *circumferences* of circles, and all the data commonly found in the most advanced works written for mechanics; hence, the first part of the work, perhaps three quarters of it, will be *for instruction* and the other part *for reference.*

It must not be forgotten that *the elements only* of arithmetic, geometry, algebra, mensuration, etc., are to be introduced in the work, but it is upon these elements that the whole structure of mathematics rests, and form the groundwork where the most advanced and the most lowly beginner can meet with mutual respect.

It is planned that the ultimate result of this publication will be the compiling of a standard and valuable volume, containing all the mathematics relating to steam engineering necessary for an intelligent engineer in his daily practice; hence the author, ere the work proceeds too far, will be pleased to receive the helpful suggestions of his kindly reader as to the most desirable contents for such a comprehensive work.

For the space it occupies the explanation of the use of *formulas* or forms will be found to be most useful to the practical man, as it teaches him the *school language* of expressing calculations. This custom is the same as that followed by the physician in writing *aqua pura* instead of "pure water"; and the gardener giving Latin names to his plants instead of plain English terms. The use of formulæ is so universal that many publications, otherwise of great value to the engineer, are to him as a sealed book; but with the explanations to be found in this work a great part of the difficulty will be obviated.

At the issue of Part 1 the whole work is in manuscript, but it will be printed in 10 monthly parts. This is to accommodate the student, to whom a single Part will be the moderate allowance for a month's study, and also to allow such changes as may seem necessary to perfect the plan of the work before it is advanced to book form.

The index of the whole book will be issued with the last number, in convenient shape, and at that time a more formal preface will be written, in which due acknowledgement will be made for assistance from persons and authors whose advice and experience has been drawn upon.

One other item may be added, but not enlarged upon: that is the desire to give for a moderate cost, information of large value to the purchaser. An engineer who *can figure* and do it correctly is of more value than one who cannot, and this esteem is (between the reader and the author) expressed by larger compensation and longer service in one position.

ARITHMETICAL SIGNS.

The principal characters or marks used in arithmetical computations to denote some of the operations, are as follows :

$=$ *Equal to.* The sign of equality; as 100 cts. $=$ \$1—signifies that one hundred cents are equal to one dollar.

$-$ *Minus or Less.* The sign of subtraction; as $8-2=6$, that is, 8, less 2, is equal to 6.

$+$ *Plus or More.* The sign of addition; as $6+8=14$; that is, 6 added to 8, is equal to 14.

$\times$ *Multiplied by.* The sign of multiplication; as $7\times7=49$; that is, 7 multiplied by 7 is equal to 49.

$\div$ *Divided by.* The sign of division; as $16\div4$ 4; that is, 16 divided by 4 is equal to 4.

There are still other characters and marks which will be added as needed as the work progresses, but these are the principal ones.

ARITHMETICAL FORMULAS.

An arithmetical formula is a general rule of arithmetic expressed by signs.

The following 10 formulas include the elementary operations of arithmetic and follow from the succeeding illustrations.

1. *The* Sum=*all the parts added.*
2. *The* Difference=*the Minuend—the Subtrahend.*
3. *The* Minuend $=$ *the Subtrahend* $+$ *the Difference.*
4. *The* Subtrahend $=$ *the Minuend* $-$ *the Difference.*
5. *The* Product $=$ *the Multiplicand* $\times$ *the Multiplier.*
6. *The* Multiplicand $=$ *the Product* $\div$ *the Multiplier.*
7. *The* Multiplier $=$ *the Product* $\div$ *the Multiplicand.*
8. *The* Quotient $=$ *the Dividend* $\div$ *the Divisor.*
9. *The* Dividend $=$ *the Quotient* $\times$ *the Divisor.*
10. *The* Divisor $=$ *the Dividend* $\div$ *the Quotient.*

Formulas or formulæ, express the plural of *formula*—a Latin word which means, simply, *a form;* hence a formula is a form of stating a problem.

ARITHMETIC.

Arithmetic is the science or *orderly arrangement of numbers* and their application to the purposes of life. The processes of arithmetic are merely expedients for making easier the discovery of results, which every mechanic of ordinary ingenuity would find a means for discovering himself, if really called upon to set about the task, for it is possible for a man to be a good working engineer, and at the same time be quite ignorant of reading, writing or figuring; but experience shows that in order to advance in the confidence of others, it is very necessary to know something of the elements, or first things, of mathematics related directly or indirectly to steam.

Arithmetic is the science of numbers, and numbers treat of *magnitude* or *quantity*. Whatever is capable of increase or diminution is a magnitude or quantity; a sum of money, a weight, or a surface, is a quantity, being capable of increase or diminution. But as we cannot measure or determine any quantity, except by considering some other quantity of the same kind as known, and pointing out their mutual relation, the measurement of quantity or magnitude is reduced to this:

Fix at pleasure upon any known kind of magnitude of the same species as that which has to be determined, and consider it as *the measure* or *unit*.

If, for example, we wish to determine the magnitude of a sum of money we must take some piece of known value, as a dollar, which is the unit of money, and show how many such pieces are contained in the given sum.

The foot rule is the *unit* or measure *of length* most used for engineering purposes; the foot is divided into twelve inches and the inch is subdivided in half inches, quarter inches, eighths and sixteenths It is plain that into whatever number of parts the inch is divided, w shall equally have the whole inch if we take the whole of the parts of it; if it were divided into ten equal parts, then ten of these parts would make an inch.

The *unit of surface* in steam engineering is represented by the square inch.

The *unit of time* is in usual practice one minute; thus we say an engine makes so many revolutions per minute, and its performance is based upon that.

The *unit of work* is the force required to raise one pound, one foot high from the earth, in the atmosphere, no time being taken in the account; it is known as the foot pound.

Atmospheric pressure at the sea level is the *unit of pressure.*

The *unit of heat* is the amount of heat required to raise one pound of water one degree, usually from 32° to 33° Fahr.

The *unit of numbers* is the figure one (1).

These references to the different measures, or units, are made in view of their frequent use in ascertaining duties performed by steam engines and boilers. They enter into all engineering calculations in connection with Tables to be found elsewhere in this volume, and their utility will be clearly explained and readily understood from their combination with practical calculations elsewhere found in this volume.

Electric units. The unit of electric force is the volt; the unit of resistance is the ohm; the unit of current strength or volume, is the ampere; the unit of current quantity considered with reference to time is the coulomb; the electric unit of capacity is the farad; the unit of electric power is the watt, etc.

The measurement of electricity is one of the newest discoveries, to which a separate space will herewith be devoted, in which the electric units of force, resistance, etc., will enter into the practical problems relating to electric lighting.

NOTATION AND NUMERATION.

Notation in Arithmetic is the *writing down* of figures to express a number or numbers, and *Numeration* is *the reading of numbers* already written.

There are nine figures—1, 2, 3, 4, 5, 6, 7, 8 and 9 used in arithmetic, and the 0 (naught) to represent nothing.

The number 1 is called *the unit*. The number 9 is a collection of nine of these units.

By means of these 10 figures we can represent any number. When one of the figures stands by itself, it is called a *unit*; but if two of them stand together, the right hand one is still called a unit, but the left hand one is called *tens;* thus, 79 is a collection of 9 units and 7 sets of ten units each, or of 9 units and 70 units, or of 79 units, and is read as seventy-nine.

If three of them stand together, then the left hand one is called *hundreds;* thus 279 is read two hundred and seventy-nine.

To express larger numbers other orders of units are formed, the figure in the 4th place denoting *thousands;* in the 5th place *ten thousands;* these are called units of the fifth order.

The sixth place denotes hundred thousands, the seventh place denotes millions, etc.

The French method (which is the same as that used in the U. S.) of writing and reading large numbers is shown in the following

NUMERATION TABLE

Names of periods.	Billions.			Millions.			Thousands.			Units.				Thousandths.		
Order of Units.	Hundred-billions.	Ten-billions.	Billions.	Hundred-millions.	Ten-millions.	Millions.	Hundred-thousands.	Ten-thousands.	Thousands.	Hundreds.	Tens.	Units.	Decimal point.	Tenths.	Hundredths.	Thousandths.
	8	7	6,	5	4	3,	2	0	1,	2	8	2,	.	4	8	9

The number in the table is read eight hundred and seventy six billion, five hundred and forty-thiee million, two hundred and one thousand, two hundred and eighty-two, and four hundred and eighty-nine thousandths.

To express larger numbers other periods are formed in like manner, called Trillions, Quadrillions, Quintillions, Sextillions, Septillions, Octillions, Nonillions, Decillions. Each of these periods increase the values of all the figures to which it is added 1,000 times.

Figures are always read from left to right; thus, one million, one thousand and two is in figures 1,001,002, the figures 1, 1, and 2 occupying the 7th, the 4th and the 1st place, and cyphers the intermediate spaces. The "one million" at the left is read first and the unit "two" at the right is read last—and this is the universal rule with the important exception of *decimals*, hereafter explained.

In the table given it will be observed that the long row of figures are divided by commas (,). This is to aid in their ready reading. The first set is called units, the second thousands, the third millions, etc.

Beginning at units place, the orders on the right of the decimal point, express tenths, hundredths, thousandths, etc.

Examples for Practice.

Notation. Write in figures eight million, two hundred fifty-nine thousand eight hundred and ninety-two.

Ans. 8,259,892.

2. Write four hundred and sixty-two thousand and nine.

Ans. 462,009.

3. Write four billion, four million, four thousand and four.

Ans. 4,004,004,004.

4. Write six hundred and two.

5. Write sixteen thousand, seven hundred and ninety two.

6. Write six hundred and eight thousand four hundred and seventy-nine.

Numeration. Read the following numbers:

1. 19.
2. 406.
3. 9,206.
4. 90,009.
5. 896,724.
6. 7,428,940.
7. 63,178,392.

This system is called Arabic Notation from the fact that it was introduced into Europe in the 10th century by the Arabs.

Its great law is that ten units in any order make one unit of the next order.

And the moving a figure one place either increases or diminishes its value by the uniform scale of ten.

Hence it is called the Decimal system from the Latin word *decem,* which means *ten.*

ROMAN NOTATION.

This is the method of expressing numbers by letters.

I,	V,	X,	L,	C,	D,	M,
1,	5,	10,	50,	100,	500,	1,000

1. Repeating a letter repeats its value, thus: I=1, II=2.
2. Placing a letter of less value before one of greater value diminishes the value of the greater by the less; thus, IV=4, IX=9, XL=40.

3. Placing the less after the greater increases the value of the greater by that of the less; thus, VI=6, XI=11, LX=60.

4. Placing a horizontal line over a letter increases its value a thousand times; thus, $\overline{\mathrm{IV}}$=4000, $\overline{\mathrm{M}}$=1,000,000,

ADDITION TABLE.

1 and	2 and	3 and	4 and	5 and
1 are 2	1 are 3	1 are 4	1 are 5	1 are 6
2 " 3	2 " 4	2 " 5	2 " 6	2 " 7
3 " 4	3 " 5	3 " 6	3 " 7	3 " 8
4 " 5	4 " 6	4 " 7	4 " 8	4 " 9
5 " 6	5 " 7	5 " 8	5 " 9	5 " 10
6 " 7	6 " 8	6 " 9	6 " 10	6 " 11
7 " 8	7 " 9	7 " 10	7 " 11	7 " 12
8 " 9	8 " 10	8 " 11	8 " 12	8 " 13
9 " 10	9 " 11	9 " 12	9 " 13	9 " 14
10 " 11	10 " 12	10 " 13	10 " 14	10 " 15
6 and	**7 and**	**8 and**	**9 and**	**10 and**
1 are 7	1 " 8	1 are 9	1 are 10	1 are 11
2 " 8	2 " 9	2 " 10	2 " 11	2 " 12
3 " 9	3 " 10	3 " 11	3 " 12	3 " 13
4 " 10	4 " 11	4 " 12	4 " 13	4 " 14
5 " 11	5 " 12	5 " 13	5 " 14	5 " 15
6 " 12	6 " 13	6 " 14	6 " 15	6 " 16
7 " 13	7 " 14	7 " 15	7 " 16	7 " 17
8 " 14	8 " 15	8 " 16	8 " 17	8 " 18
9 " 15	9 " 16	9 " 17	9 " 18	9 " 19
10 " 16	10 " 17	10 " 18	10 " 19	10 " 20

ADDITION.

The first process of arithmetic is Addition; and here the first steps are made by counting upon the fingers as an aid to the perceptions of the total amount of the quantity that has to be expressed. Persons even of considerable mathemetical experience will often find themselves counting their fingers, or pressing them down successively on the table in order to assist their memory in performing addition.

For example, if we hold up 5 fingers of one hand and 3 of the other and are asked how much 5 and 3 amount to we at once see that the number is 8, as we actually or mentally count the other three fingers from 5.

But the best course is to commit very thoroughly to memory an addition table, just as the multiplication table is now commonly committed to memory by arithmetical students. A table of this kind is here introduced, and it should be gone over and over again until its indications are as familiar to the memory as the letters of the alphabet, and until the operation of addition can be performed without the necessity of mental effort. The table is so plain as scarcely to require explanation. The sign of addition is + It is called plus, or *more.*

The sum or amount of any calculation no matter how small or large contains as many *units* as all the numbers added.

Addition is uniting two or more numbers into one. The result of the addition is called the Sum or Amount. In addition the only thing to be careful about except the correct doing of the sum, is to place the unit figures under the unit figure above it, the tens under the tens, etc.

Rule.

After writing the figures down so that units are under units, tens under tens, etc.:

Begin at the right hand, up and down row, add the column and write the sum underneath if less than ten.

If however the sum is ten or more write the right hand figure underneath, and add the number expressed by the other figure or figures with the numbers of the next column.

Write the whole of the last column.

Examples for Practice.

7,060	248,124	13,579,802
9,420	4,321	83
1,743	889,876	478,652
4,004	457,902	87,547,289
22,227 Ans.		

Use great care in placing the numbers in vertical lines, as irregularity in writing them down is the cause of mistakes.

Rule for Proving the Correctness of the Sums.

Add the columns from the top *downward,* and if the sum is the same as when *added up* then the answer is right.

Add and prove the following numbers :

684 32 257 20. Ans. 993.

42 89 22 99 ?

1006 7008 01 62 ?

TABLE OF UNITS.

The unit of *money* in the U. S. is one *dollar.*

The unit of *length* is *one foot.*

The unit of *surface* is the *square inch.*

The unit of *work* is the *foot pound.*

The unit of *heat* is *one degree, Fahrenheit.*

The unit of *numbers* is the *figure* 1.

The unit of electric power is the *watt.*

SUBTRACTION TABLE.

1 from	2 from	3 from	4 from	5 from
1 leaves 0	2 leaves 0	3 leaves 0	4 leaves 0	5 leaves 0
2 " 1	3 " 1	4 " 1	5 " 1	6 " 1
3 " 2	4 " 2	5 " 2	6 " 2	7 " 2
4 " 3	5 " 3	6 " 3	7 " 3	8 " 3
5 " 4	6 " 4	7 " 4	8 " 4	9 " 4
6 " 5	7 " 5	8 " 5	9 " 5	10 " 5
7 " 6	8 " 6	9 " 6	10 " 6	11 " 6
8 " 7	9 " 7	10 " 7	11 " 7	12 " 7
9 " 8	10 " 8	11 " 8	12 " 8	13 " 8
10 " 9	11 " 9	12 " 9	13 " 9	14 " 9
11 " 10	12 " 10	13 " 10	14 " 10	15 " 10

6 from	7 from	8 from	9 from	10 from
6 leaves 0	7 leaves 0	8 leaves 0	9 leaves 0	10 leaves 0
7 " 1	8 " 1	9 " 1	10 " 1	11 " 1
8 " 2	9 " 2	10 " 2	11 " 2	12 " 2
9 " 3	10 " 3	11 " 3	12 " 3	13 " 3
10 " 4	11 " 4	12 " 4	13 " 4	14 " 4
11 " 5	12 " 5	13 " 5	14 " 5	15 " 5
12 " 6	13 " 6	14 " 6	15 " 6	16 " 6
13 " 7	14 " 7	15 " 7	16 " 7	17 " 7
14 " 8	15 " 8	16 " 8	17 " 8	18 " 8
15 " 9	16 " 9	17 " 9	18 " 9	19 " 9
16 " 10	17 " 10	18 " 10	19 " 10	20 " 10

SUBTRACTION.

Subtraction is taking one number from another.

As in addition, care must be used in placing the units under the units, the tens under the tens, etc.

The answer is called the remainder or the difference.

The sign of subtraction is (—) Example: 98—22=76.

Subtraction is the opposite of addition—one "takes from" while the other "adds to."

Rule.

Write down the sum so that the units stand under the units, the tens under the tens, etc., etc.

Begin with the units, and take the under from the upper figure and put the remainder beneath the line.

But if the lower figure is the largest add ten to the upper figure, and then subtract and put the remainder down—this borrowed 10 must be deducted from the next column of figures where it is represented by 1.

Examples for Practice.

892	89,672	89,642,706
46	46,379	48,765,421
846 remainder.		

Note.

In the first example 892—46 the 6 is larger than 2; borrow 10, which makes it twelve, and then deduct the 6; the answer is 6. The borrowed 10 reduces the 9 to 8, so the next deduction is 4 from 8=4 is the answer.

RULE FOR PROVING THE CORRECTNESS OF THE SUBTRACTION.

Add the remainder, or difference, to the smaller amount of the two sums and if the two are equal to the larger, then the subtraction has been correctly done.

Example.	898		246	
	246	Now then,	652	
	—		—	
	652		898	correct Ans.

EXAMPLES, CONSISTING OF NOTATION, ADDITION AND SUBTRACTION.

1. Add together twenty-seven thousand four hundred and twenty-eight; ninety-one thousand eight hundred and seventy-nine; sixty-five thousand two hundred and fifty-nine; and thirty-seven thousand and eight. Ans. 221,574.

2. Add seven hundred billions, nine hundred and one thousand; forty millions thirty thousand and ten; five hundred thousand; eight hundred and ninety-one millions and twelve; twenty-four millions two hundred and one thousand and six hundred and forty-four; and two hundred and ninety-three billions, nine hundred and ninety-two millions, eight hundred and sixty-seven thousand, three hundred and twenty-nine; five billions, fifty millions, five hundred thousand and five. Ans. 1,000 Billions, or 1 Trillion.

NOTE.—This sum is best done by the aid of *the numeration table.* It is given for practice to form a habit of accuracy in doing long calculations.

3. From sixty-four thousands two hundred and ten millions nine hundred and twenty thousands six hundred and fifty-one: take twenty-nine thousand five hundred and fifty-four millions, three hundred and seventy-four thousand six hundred and eighty-eight. Ans. 34,656,545,963.

4. From ninety billions, four hundred millions, seven thousand and six: take nine billions, one hundred millions, five thousand nine hundred and fifty-six. Ans. 81,300,001,050.

MULTIPLICATION TABLE.

Once	2 times	3 times	4 times	5 times	6 times
1 is 1	1 are 2	1 are 3	1 are 4	1 are 5	1 are 6
2 " 2	2 " 4	2 " 6	2 " 8	2 " 10	2 " 12
3 " 3	3 " 6	3 " 9	3 " 12	3 " 15	3 " 18
4 " 4	4 " 8	4 " 12	4 " 16	4 " 20	4 " 24
5 " 5	5 " 10	5 " 15	5 " 20	5 " 25	5 " 30
6 " 6	6 " 12	6 " 18	6 " 24	6 " 30	6 " 36
7 " 7	7 " 14	7 " 21	7 " 28	7 " 35	7 " 42
8 " 8	8 " 16	8 " 24	8 " 32	8 " 40	8 " 48
9 " 9	9 " 18	9 " 27	9 " 36	9 " 45	9 " 54
10 " 10	10 " 20	10 " 30	10 " 40	10 " 50	10 " 60
11 " 11	11 " 22	11 " 33	11 " 44	11 " 55	11 " 66
12 " 12	12 " 24	12 " 36	12 " 48	12 " 60	12 " 72

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

MULTIPLICATION.

Multiplication is finding the amount of one number increased as many times as there are units in another.

The number to be multiplied or increased is called the *Multiplicand.*

The *Multiplier* is the number by which we multiply. It shows how many times the multiplicand is to be increased.

The answer is called the *Product.*

The multiplier and multiplicand which produce the product are called its *Factors.* This is a word frequently used in mathematical works and its meaning should be remembered.

The sign of multiplication is $\times$ and is read "times" or multiplied by; thus 6×8 is read, 6 times 8 is 48, or, 6 multiplied by 8 is 48.

The principle of multiplication is the same as addition, thus $3\times8=24$ is the same as $8+8+8=24$.

Rule for Multiplying.

Place the unit figure of the multiplier under the unit figure of the multiplicand and proceed as in the following:

Examples. Multiply 846 by 8; and 487,692 by 143.
Arrange them thus:

```
                 487,692
                     143
  846            -------
    8            1463076
  ---           1950768
6,768           487692
                ----------
                69,739,956
```

But if the multiplier has ciphers at its end then place it as in the following:

Multiply 83567 by 50; and 898 by 2800.

```
                          898
                         2800
                        ------
   83567               718400
      50              1796
  -------             -------
4,178,350            2,514,400
```

Examples for Practice.

1.	Multiply	4,896,780	by	9.
2.	"	94,200,642	"	12.
3.	"	843,217,896	"	800.
4.	"	4,980	"	1,276.
5.	"	76	"	7,854.
6.	"	34,571,248	"	9,876.

The product and the multiplicand must be in like numbers. Thus, 10 times 8 gallons of *oil* must be 80 gallons of *oil.* 4 times 5 *dollars* must be 20 *dollars*; hence the multiplier must be the *number* and not the *thing* to be multiplied.

In finding the cost of 6 tons of coal at 7 dollars per ton the 7 *dollars* are taken 6 times, and not multiplied by 6 tons.

When the multiplier is 10, 100, 1000, etc., the product may be obtained at once by annexing to the multiplicand as many ciphers as there are in the multiplier.

Example.

1. Multiply 486 by 100.

Now 486 with 00 added=48,600.

2. 6,842×10,000=how many? Ans. 68,420,000.

To prove the result in multiplication multiply the multiplier by the multiplicand, and if the product is the same in both cases then the answer is right.

DIVISION TABLE.

1 in	2 in	3 in	4 in	5 in
1, 1 time	2, 1 time	3, 1 time	4. 1 time	5, 1 time
2, 2 times	4, 2 times	6, 2 times	8, 2 times	10, 2 times
3, 3 "	6, 3 "	9, 3 "	12, 3 "	15, 3 "
4, 4 "	8, 4 "	12, 4 "	16, 4 "	20, 4 "
5, 5 "	10, 5 "	15, 5 "	20, 5 "	25, 5 "
6, 6 "	12, 6 "	18, 6 "	24, 6 "	30, 6 "
7, 7 "	14, 7 "	21, 7 "	28, 7 "	35, 7 "
8, 8 "	16, 8 "	24, 8 "	32, 8 "	40, 8 "
9, 9 "	18, 9 "	27, 9 "	36, 9 "	45, 9 "
10, 10 "	20, 10 "	30, 10 "	40, 10 "	50, 10 "
6 in	**7 in**	**8 in**	**9 in**	**10 in**
6, 1 time	7, 1 time	8, 1 time	9, 1 time	10, 1 time
12, 2 times	14, 2 times	16, 2 times	18, 2 times	20, 2 times
18, 3 "	21, 3 "	24, 3 "	27, 3 "	30, 3 "
24, 4 "	28, 4 "	32, 4 "	36, 4 "	40, 4 "
30, 5 "	35, 5 "	40, 5 "	45, 5 "	50, 5 "
36, 6 "	42, 6 "	48, 6 "	54, 6 "	60, 6 "
42, 7 "	49, 7 "	56, 7 "	63, 7 "	70, 7 "
48, 8 "	56, 8 "	64, 8 "	72, 8 "	80, 8 "
54, 9 "	63, 9 "	72, 9 "	81, 9 "	90, 9 "
60, 10 "	70, 10 "	80, 10 "	90, 10 "	100, 10 "

DIVISION.

When one number has to be divided by another number the first one is called the *dividend,* and the second one the *divisor,* and the result or answer is called the *quotient.*

1. *To divide any number up to* 12. Put the dividend down with the divisor to the left of it, with a small curved line separating it, as in the following:

Divide by 6)7,865,432

1,310,905—2

Here at the last we have to say 6 into 32 goes 5 times and 2 over; always place the number that is over as above, separated from the quotient by a small line or else put it as a fraction, thus 2/6, the top figure being the remainder and the bottom figure the divisor, when it should be put close to the quotient; thus—1,310,905$\frac{2}{6}$.

2. *To divide by any number up to* 12 *with a cipher or ciphers after it* as 20, 70, 90, 500, 7,000, etc.

Place the sum down as in the last example, then mark off from the right of the dividend as many figures as there are ciphers in the divisor; also mark off the cyphers in the divisor; then divide the remaining figures by the number remaining in the divisor; thus:—

EXAMPLE.

Divide 9,876,804 by 40.

40)9,876,804

246,920—4

The 4 cut off from the dividend is put down as a remainder, or it might have been put down as $\frac{4}{40}$ or $\frac{1}{10}$.

EXAMPLE.

Divide 129,876,347 by 1200.

$$\begin{array}{r} 1200)129,876,347 \\ \hline 108,230\text{—}347 \text{ or } \frac{347}{1200}. \end{array}$$

Here there is a remainder of 3 and 47 cut off. The three must always be put before the 47 making it a remainder of 347 altogether.

3. *To divide by any number that can be broken up into two factors* as 18, 24, 36, 72, 144, etc. 18 is 3 times 6; then 3 and 6 are called factors of 18; twice 9 are 18, then 2 and 9 are also factors of 18 Generally any two numbers which when multiplied together come to the given number, are called factors of that given number.

EXAMPLE.

Divide 868.224 by 24.

Here 4 times 6=24, therefore 4 and 6 are the factors.

Divide first by 4 and then the quotient by 6 as follows :

$$24\left\{\begin{array}{r} 4)868,224 \\ \hline 6)217,056 \end{array}\right.$$
$$\begin{array}{r} \hline 36,176 \end{array}$$

EXAMPLE.

Divide 9,824.671 by 63.

63=7 times 9.

$$63\left\{\begin{array}{r} 7)9,824,671 \\ \hline 9)1,403,524\text{—}3 \end{array}\right\}10$$
$$\begin{array}{r} \hline 155,947\text{—}1 \end{array}$$

Here after the division by 7 there are 3 over; and after the division by 9 there is 1 over. What is the full remainder for the sum ? *To find the full remainder*, multiply *the first divisor* by the *last remainder* and add the first remainder.

That is 7 multiplied by 1=7, and 3 added to 7=10.

4. *To divide by any number not included in the last three cases.*

This is common long division as it is called.

Rule.

Write the divisor at the left of the dividend and proceed as in the following:

Example.

Divide 726,981 by 7,645.

```
7,645)726981(95
      68805
      -----
       38931
       38225
       -----
         706   Ans. 95 706/7645.
```

Examples for Exercise.

1.— 76,298,764,833 by 9.
2.—120,047,629,817 " 20.
3.— 9,876,548,210 " 48.
4.— 3,247,617,219 " 63.
5.— 7,140,712,614 " 41.
6.— 329,817,298 " 107.
7.—247,698,672,437 " 987.
8.— 2,610,014,723 " 2406.
9.— 10,781,493,987 " 7854.

Multiplying the dividend, or dividing the divisor by any number, multiplies the quotient by the same number.

Dividing the dividend, or multiplying the divisor by any number, divides the quotient by the same number.

Dividing or multiplying both the dividend and divisor by the same number does not change the quotient.

TABLES OF WEIGHTS AND MEASURES REQUIRED BY ENGINEERS.

AVOIRDUPOIS, or ORDINARY COMMERCIAL WEIGHT.

This table is used for nearly all articles estimated by weight, except gold, silver and jewels.

TABLE.

16 drams (dr.)	make 1 ounce,	oz.
16 ounces,	1 pound,	lb.
25 pounds,	1 quarter,	qr.
4 quarters or 100 lbs.,	1 hundred-weight,	cwt.
20 hundred-weight,	1 ton,	T.

LONG MEASURE, or LINEAR MEASURE.

This is used in estimating distances and the length of articles

TABLE.

12 inches (in.)	make 1 foot	ft.
3 feet,	1 yard,	yd.
5½ yards,	1 rod,	rd.
40 rods,	1 furlong,	fur.
8 furlongs,	1 common mile,	m.

SURFACE, or SQUARE MEASURE.

This is used in estimating surfaces.

TABLE.

144 square inches (sq. in.)	make 1 square foot,	sq. ft.
9 square feet,	1 square yard,	sq. yd.
30¼ square yards,	1 square rod or perch,	P.
160 square rods or perches,	1 acre,	A.
640 acres,	1 square mile,	M.

MEASURE OF CAPACITY, or LIQUID MEASURE.

This is used in measuring all kinds of liquids.

TABLE.

4 gills (gi.) make	1 pint,	pt.
2 pints	1 quart,	qt.
4 quarts	1 gallon,	gal.

DRY MEASURE.

This is used in measuring grain, roots, fruit, *coal*, etc.

TABLE.

2 pints (pt.) make	1 quart,	qt.
8 quarts,	1 peck,	pk.
4 pecks,	1 bushel,	bu.

NOTE.

The *chaldron*, a measure of 36 bushels, formerly employed with some kinds of coal, is now seldom used.

CIRCULAR MEASURE.

This is used for measuring angles.

TABLE.

60 seconds (″) make	1 minute,	′
60 minutes,	1 degree,	°
360 degrees,	1 circum.,	C.

NOTE.

The circumference of every circle, whatever, is supposed to be divided into 360 equal parts, called *degrees*.

A degree is $\frac{1}{360}$ of the circumference of any circle, small or large.

A quadrant is a fourth of a circumference, or an arc of 90 degrees.

A degree is divided into 60 parts called minutes expressed by sign (′) and each minute is divided into 60 seconds expressed by (″) so that the circumference of any circle contains 21,600 minutes, or 1,296,000 seconds.

TABLE OF WAGES.

FOR CALCULATING WAGES FROM ONE HOUR TO SIX DAYS AT FROM $1.00 TO $20 PER WEEK.

For 6 Days	1 Day.	2 Days.	3 Days.	4 Days.	5 Days.	1 Hour.	2 Hours.	3 Hours.	4 Hours.	5 Hours.	6 Hours.	7 Hours.	8 Hours.	9 Hours.
$3.00	.50	1.00	1.50	2.00	2.50	.05	.10	.15	.20	.25	.30	.35	.40	.45
3.50	.58⅓	1.16⅔	1.75	2.33⅓	2.91⅔	.05⅚	.11⅔	.17½	23⅓	.29⅙	.35	.40⅚	.46⅔	.52½
4.00	.66⅔	1.33⅓	2.00	2.66⅔	3.33⅓	.06⅔	.13⅓	.20	.26⅔	.33⅓	.40	.46⅔	.53⅓	.60
4.50	.75	1.50	2.25	3.00	3.75	.07½	.15	.22½	.30	.37½	.45	.52½	.60	.67½
5.00	.83⅓	1.66⅔	2.50	3.33⅓	4.16⅔	.08⅓	.16⅔	.25	.33⅓	.41⅔	.50	.58⅓	.66⅔	.75
6.00	1.00	2.00	3.00	4.00	5.00	.10	.20	.30	.40	.50	.60	.70	.80	.90
7.00	1.16⅔	2.33⅓	3.50	4.66⅔	5.83⅓	.11⅔	.23⅓	.35	.46⅔	.58⅓	.70	.81⅔	.93⅓	1.05
7.50	1.25	2.50	3.75	5.00	6.25	.12½	.25	.37½	.50	.62½	.75	.87½	1.00	1.12½
8.00	1.33⅓	2.66⅔	4.00	5.33⅓	6.66⅔	.13⅓	.26⅔	.40	.53⅓	.66⅔	.80	.93⅓	1.06⅔	1.20
9.00	1.50	3.00	4.50	6.00	7.50	.15	.30	.45	.60	.75	.90	1.05	1.20	1.35
10.00	1.66⅔	3.33⅓	5.00	6.66⅔	8.33⅓	.16⅔	.33⅓	.50	.66⅔	.83⅓	1.00	1.16⅔	1.33⅓	1.50
11.00	1.83⅓	3.66⅔	5.50	7.33⅓	9.16⅔	.18⅓	.36⅔	.55	.73⅓	.91⅔	1.10	1.28⅓	1.46⅔	1.65
12.00	2.00	4.00	6.00	8.00	10.00	.20	.40	.60	.80	1.00	1.20	1.40	1.60	1.80
13.00	2.16⅔	4.33⅓	6.50	8.66⅔	10.83⅓	.21⅔	.43⅓	.65	.86⅔	1.08⅓	1.30	1.51⅔	1.73⅓	1.95
14.00	2.33⅓	4.66⅔	7.00	9.33⅓	11.66⅔	.23⅓	.46⅔	.70	.93⅓	1.16⅔	1.40	1.63⅓	1.86⅔	2.10
15.00	2.50	5.00	7.50	10.00	12.50	.25	.50	.75	1.00	1.25	1.50	1.75	2.00	2.25
16.00	2.66⅔	5.33⅓	8.00	10.66⅔	13.33⅓	.26⅔	.53⅓	.80	1.06⅔	1.33⅓	1.60	1.86⅔	2.13⅓	2.40
17.00	2.83⅓	5.66⅔	8.50	11.33⅓	14.16⅔	.28⅓	.56⅔	.85	1.13⅓	1.41⅔	1.70	1.98⅓	2.26⅔	2.55
18.00	3.00	6.00	9.00	12.00	15.00	.30	.60	.90	1.20	1.50	1.80	2.10	2.40	2.70
20.00	3.33⅓	6.66⅔	10.00	13.33⅓	16.66⅔	.33⅓	.66⅔	1.00	1.33⅓	1.66⅔	2.00	2.33⅓	2.66⅔	3.00

☞ For Examples under this rule see pages 43 and 44.

SOLID MEASURE, or CUBIC MEASURE.

This is used in measuring bodies, or things having length, breadth and height or depth.

TABLE.

1728 cubic inches (cu. in.)	make	1 cubic foot,	cu. ft.
27 cubic feet,		1 cubic yard,	cu. yd.
128 cubic feet,		1 cord,	C.

TROY WEIGHT.

This is used for weighing gold, silver and jewels.

TABLE.

24 grains (gr.)	make	1 pennyweight,	pwt.
20 pennyweights,		1 ounce,	oz.
12 ounces,		1 pound,	lb.

A *caret,* for gold-weight, is 4 grains; for diamond-weight, is 3.2 grains.

APOTHECARIES WEIGHT.

SOLID MEASURE.	FLUID MEASURE.
20 Grains (gr) = 1 scruple (sc)	60 minims or drops = 1 fluid dram
3 Scruples = 1 dram (dr.).	8 Fluid drams = 1 fluid ounce.
8 Drams = 1 ounce (oz.).	16 Fluid ounces = 1 pint.
12 Ounces = 1 pound (lb.).	8 Pints = 1 gallon.

NOTE.

Apothecaries, in mixing medicines, use the *pound, ounce* (oz.), and *grain,* of this weight; but divide the ounce into 8 *drams* (dr.), each equal to three *scruples* (sc.), each scruple being equal to 20 *grains.*

TIME MEASURE.

Time is used in measuring portions of duration.

TABLE.

60 seconds (sec.) make	1 minute,	m.
60 minutes,	1 hour,	h.
24 hours,	1 day,	d.
365 days,	1 common year,	c. y.
366 days,	1 leap year,	l. y.

Also, 7 days make 1 *week*, 12 calendar months 1 *year*, and 100 years 1 *century*.

THE LONG TON FOR WEIGHING COAL.

Formerly, 112 pounds, or 4 quarters of 28 pounds each, were reckoned a hundred-weight, and 2240 pounds a ton, now called the long ton. This is now seldom employed in this country, except *at the mines for coal*, or at the United States Custom-houses for goods imported from Great Britain, in which country such weight continues to be used.

CALENDAR OF MONTHS AND DAYS IN A YEAR.

January,	1st	mo.	31 days.	July,	7th	mo.	31 days.
February,	2d	"	28 or 29.	August,	8th	"	31 "
March,	3d	"	31 days.	September,	9th	"	30 "
April,	4th	"	30 "	October,	10th	"	31 "
May,	5th	"	31 "	November,	11th	"	30 "
June,	6th	"	30 "	December,	12th	"	31 "

MISCELLANEOUS MEASURES.

COUNTING.

12 units make	1	dozen.
12 dozen,	1	gross.
20 units,	1	score.
5 scores,	1	hundred.

PAPER.

24 sheets make	1	quire.
20 quires,	1	ream.
2 reams,	1	bundle.
5 bundles,	1	bale.

USEFUL NUMBERS FOR ENGINEERS.

12 inches make one *lineal* foot. 144 square inches make one *square* foot. 1728 cubic inches make one *cubic* foot.

6 feet in length=1 fathom.

CUBIC INCHES IN BUSHELS AND GALLONS.

The standard bushel of the *United States* contains 2150.42 cubic inches; and the Imperial bushel of *Great Britain,* 2218.192 cubic inches.

The standard liquid gallon of the *United States* contains 231 cubic inches, and the Imperial gallon of *Great Britain,* 277.274 cubic inches. The latter is used below.

WEIGHTS OF WATER.

One gallon of fresh water weighs 10 lbs.
One gallon of sea water weighs $10\frac{1}{4}$ lbs.
One gallon=$\frac{16}{100}$th of a cubic foot.
One cubic foot=$6\frac{1}{4}$ gallons.
One cubic foot of fresh water weighs $62\frac{1}{2}$ lbs.=1000 ozs.
One cubic foot of sea water weighs 64 lbs.

A CORD OF WOOD.

A pile of wood 8 feet long, 4 feet wide, and 4 feet high, is a cord. A cord foot (c. f.) is 1 foot in length of this pile, or 16 cubic feet.

MEASUREMENTS OF GOVERNMENT LAND.

640 acres or 1 square mile make *one* section of land; 320 acres=$\frac{1}{2}$ section; 160 acres=$\frac{1}{4}$ section.

WEIGHTS OF METALS.

Wrought Iron,	$3\frac{6}{100}$	cubic	inches	=1 lb.,	or 1	cu. in.	=.2778	of a lb.
st Iron,	$3\frac{9}{100}$	"	"	=1	"	"	=.257	"
el, soft,	$3\frac{5}{100}$	"	"	=1	"	"	=.2814	"
ass,	$3\frac{3}{100}$	"	"	=1	"	"	=.3	"

UNITED STATES MONEY.

TABLE.

10 mills are	1 cent,	ct.
10 cents are	1 dime,	d.
10 dimes or 100 cents are	1 dollar,	dol. or $.
10 dollars are	1 eagle,	E.

The dollar is the unit; hence dollars are written with the *sign* $ prefixed to them and *the decimal point* placed after them.

Cents occupy hundredths place on the right of the decimal point and occupy two places, hence if the number to be expressed is less than 10 a cipher must be prefixed to the figure denoting them; one dollar and nine cents is written $1.09.

Mills occupy the place of thousandths. In business calculations, if the mills in the result are 5 or more, they are considered a *cent;* if less than 5 they are omitted.

STERLING OR ENGLISH MONEY.

TABLE.

4 farthings (qr. or far.) make	1 penny	d.
12 pence	1 shilling,	s.
20 shillings,	1 pound or sovereign	£
10 florins (fl.)	1 pound,	£

FRENCH MONEY.

TABLE.

10 centimes = 1 decime.
10 decimes = 1 franc.

The unit of French money is the franc, the value of which in U. S. money is 19.3 cents, or about $\frac{1}{5}$ of a dollar.

The Money Unit of the German Empire is the *mark,* which is divided into 100 pennies. The value of a mark is $0.238, or nearly $\frac{1}{4}$.

Canada money is expressed in dollars, cents and mills, which have the nominal value of the corresponding denominations of U. S. money.

ROMAN TABLE.

I. denotes	One.	XVII. denotes	Seventeen.
II.	Two.	XVIII.	Eighteen.
III.	Three.	XIX.	Nineteen.
IV.	Four.	XX.	Twenty.
V.	Five.	XXX.	Thirty.
VI.	Six.	XL.	Forty.
VII.	Seven.	L.	Fifty.
VIII.	Eight.	LX.	Sixty.
IX.	Nine.	LXX.	Seventy.
X.	Ten.	LXXX.	Eighty.
XI.	Eleven.	XC.	Ninety.
XII.	Twelve.	C.	One hundred.
XIII.	Thirteen.	D.	Five hundred.
XIV.	Fourteen.	M.	One thousand.
XV.	Fifteen.	$\overline{\text{X}}$.	Ten thousand.
XVI.	Sixteen.	$\overline{\text{M}}$.	One million.

TABLE OF ALIQUOT PARTS.

Of a $.		Of a Ton.		Of a cwt.		Of an Acre.		Of a Month.	
cts.	$	cwt.	ton.	lb.	cwt.	rd.	A.	d.	m.
50 =	$\frac{1}{2}$	10 =	$\frac{1}{2}$	50 =	$\frac{1}{2}$	80 =	$\frac{1}{2}$	15 =	$\frac{1}{2}$
$33\frac{1}{3}$ =	$\frac{1}{3}$	5 =	$\frac{1}{4}$	25 =	$\frac{1}{4}$	40 =	$\frac{1}{4}$	10 =	$\frac{1}{3}$
25 =	$\frac{1}{4}$	4 =	$\frac{1}{5}$	20 =	$\frac{1}{5}$	32 =	$\frac{1}{5}$	$7\frac{1}{2}$ =	$\frac{1}{4}$
$16\frac{2}{3}$ =	$\frac{1}{6}$	$2\frac{1}{2}$ =	$\frac{1}{8}$	$12\frac{1}{2}$ =	$\frac{1}{8}$	20 =	$\frac{1}{8}$	6 =	$\frac{1}{5}$
$12\frac{1}{2}$ =	$\frac{1}{8}$	2 =	$\frac{1}{10}$	10 =	$\frac{1}{10}$	16 =	$\frac{1}{10}$	5 =	$\frac{1}{6}$
10 =	$\frac{1}{10}$	1 =	$\frac{1}{20}$	5 =	$\frac{1}{20}$	8 =	$\frac{1}{20}$	3 =	$\frac{1}{10}$

NOTE.

An Aliquot part of a number is an exact divisor of it; thus, 2, 4 and 8 are exact divisors of 16.

MISCELLANEOUS MEASURES.

3 inches = 1 palm.	3.28 Feet = 1 meter.
4 " = 1 hand.	6 " = 1 fathom.
6 " = 1 span.	830 Fathoms = 1 mile.
18 " = 1 cubit.	3 Knots = 1 marine league.
21.8 " = 1 Bible cubit.	60 Knots } =1 degree.
$2\frac{1}{2}$ Feet = 1 military pace.	$69\frac{1}{2}$ Statute miles } =1 degree.
3 " = 1 common pace.	991.12 Miles } =1 degree.
	$\frac{1}{48}$ of an inch=a hair's breadth.

TABLE.

Showing relative value of French and English measures of length.

French.		English.
Milimeter, . . .	= . . .	0.03937 inches.
Contimetre, . . .	= . . .	0.39371 "
Decimetre, . . .	= . . .	3.93710 "
Metre, ...	= . . .	39.37100 "

In the French system of weights and measures, which has been legalized by special act of the U. S. Congress, the *metre, litre, gramme*, etc., are increased or decreased by the following words prefixed to them:

Milli	expresses	the 1,000th part.			
Centi	"	" 100th	"		
Deci	"	" 10th	"		
Deca	"	10	times	the	value.
Hecato	"	100	"	"	"
Chilio	"	1,000	"	"	"
Myrio	"	10,000	"	"	"

The following approximate measures, though not strictly accurate, are often useful in practical life.

45 drops of water, or a common teaspoonful=1 fluid drachm.

A common tablespoonful=$\frac{1}{2}$ fluid ounce.

A small teacupful, or 1 gill=4 fluid ounces.

A pint of pure wate=1 pound.

4 tablespoonfuls, or a wine glass=$\frac{1}{2}$ gill.

A common-sized tumbler=$\frac{1}{2}$ pint.

4 teaspoonfuls=1 tablespoonful.

REDUCTION.

Reduction is changing compound numbers from one denomination to another without altering their values. It is of two kinds, Descending and Ascending.

Reduction Descending is changing higher denominations to lower, as tons to pounds. Reduction Ascending is changing lower to higher denominations as cents to dollars.

To reduce higher denominations to lower.

Rule.

Multiply the number of the highest denomination given, by the number required of the next lower denomination to make one of that higher, and to the product add the number, if any, of the lower denomination.

Proceed in like manner till the whole is reduced to the required denomination.

Example in Troy Weights.

Reduce 63 lb. 0 oz. 10 pwt., to pennyweights.

OPERATION.

63 lb. 0 oz. 10 pwt.
12
———
126
63
———
756 oz.
20
———
15120
10
———
15130 pwt., *Ans.*

Since in 1 pound there are 12 ounces, in 63 pounds there are 63 times 12 ounces, or 756 ounces.

Since in 1 ounce there are 20 penny-weights, in 756 ounces there are 756 times 20 penny-weights: and 10 penny-weights added, make 15130 penny-weights.

Example in Avoirdupois Weight.

Reduce six tons, eight hundred weight, three quarters to lbs.

```
   6  T. 8 cwt. 3 qrs.
  20
 ---
 120
   8 add above.
 ---
 128 cwt.
   4
 ---
 512
   3
 ---
 515 qrs.
  25
 ----
 2575
1030
-----
12875 lbs. Answer.
```

Examples for Practice.

1. Reduce 116 tons 68 lbs. to ounces.
2. Reduce 208 tons 42 lbs. to pounds.
3. Reduce 180 degrees of the circle to seconds.
4. Reduce 365 d. 5 h. 48 m. 50. sec. to seconds.
5. Reduce 75 b. 3 pk. 5 qt. to quarts.

Note.

Expertness in this rule of arithmetic is of considerable importance, as it enters into a vast number of practical questions in every department of manufacturing as well as engineering.

To reduce lower denominations to higher.

RULE.

Divide the given number by the number of its denomination required to make one of the next higher, and reserve the remainder, if any.

Proceed in like manner with the quotient, and so continue until the whole is reduced to the required denomination.

The number of the required denomination, with the several remainders, if any, will be the answer.

EXAMPLES.

1. Bring 98,704,623 lbs. to tons and lbs.

2000)98704623

49352 Tons, 623 lbs.

2. Bring 9876 lbs. coal to the long ton, cwt., qrs. and lbs.

2240)9876(4 tons.
8960

112)916(8 cwt.
896

28)20(0 qrs.

Ans. 4 tons 8 cwts. 0 qrs. 20 lbs.

PROOF.

Reduction Ascending and Descending *prove* each other; for one is the reverse of the other.

NOTES.

A simple number is one which expresses one or more units of the same denomination.

A compound number expresses units of two or more denominations of the same kind, as 5 yards, 1 foot, 4 inches—or example, page 41, 6 T., 8 cwt., 3 qrs.,—these are compound numbers; but *ten oxen,* or *five dollars,* are simple numbers.

Example.

76,245 gills to gallons, etc.

4)76245
———
2)19061—1 gill.
———
4)9530—1 pint.
———
2382—2 quarts.

Ans. 2382 gallons, 2 quarts, 1 pint and 1 gill.

Examples for Exercise.

1. In 76,298 ounces how many tons, etc.
2. In 648,000 seconds how many degrees?
3. In 15,130 pennyweights how many pounds, etc.?
4. In 3,760,128 cubic inches how many cords?
5. In 785 pints how many gallons ?

EXAMPLES IN THE TABLE OF WAGES.

1. What is the amount of 7 weeks, $4\frac{1}{2}$ days work at 7 dollars per week.

7 weeks.
7 dollars.
———
49=7 weeks pay.
$4.66\frac{2}{3}$=4 days per table.
$58\frac{1}{3}$=5 hours or $\frac{1}{2}$ day per table.
———
54.25 Ans. Fifty-four dollars and 25 cents.

2. What is the amount of one week and $\frac{1}{2}$ day extra time at $18.00 per week ?

1 week = 18.00
5 hours = 1.50
———
19.50 Ans.

3. What do a boy's wages come to, for $5\frac{1}{2}$ days, at $5.00 per week ?

5 days = $4.16\frac{2}{3}$ per table.
5 hours = $41\frac{2}{3}$ per table.
———
$4.68\frac{1}{3}$ Ans. $4.68.

4. What do 46 days, 6 hours and a quarter, amount to at $17.00 pei week.

1 day per table = 2.83⅓
multiply by (×) 46 days.

15⅓ amount of fraction.
1698
1132

13033⅓=46 days.
170 =6 hours per table.
$7\frac{1}{12}$=¼ hour.

$13210\frac{5}{12}$ Ans. $132.10

1 hour 28⅓
divide by ¼
$7\frac{1}{12}$

Examples for Practice.

5.	How much	4	days	2½	hrs.	at $	8.00	per	week.	Ans.	$5.67
6.	"	306	"	0	"	"	9.00	"	"	"	459.00
7.	"	184	"	5	"	"	11.00	"	"	"	3[illegible].25
8.	"	11	"	0	"	"	4.00	"	"	"	
9.	"	39	"	6	"	"	15.00	"	"	"	
10.	"	1	"	2	"	"	12.00	"	"	"	
11.	"			7½	"	"	14.00	"	"	"	
12.	"			5	"	"	7.00	"	"	"	

Example.

In doing the sum for example 9, do it like this:

1 day at $15.00 per week is	$2.50
Multiply by 40 days,	40
	100.00
Deduct 4 hours at 25c.,	1.00
Answer,	$99.00

There are various "short cuts" in figuring wages, like the l st example, which it is well to become familiar with, so that in this important part of mathematics, both quickness and accuracy may be attained.

Note.

When the fraction *is less* than ½ cent it is the gain of the employer by the amount of the fraction—but, if the fraction is more (like ⅔) it is called a full cent and goes as a full cent to the employee.

NATURAL OR MECHANICAL PHILOSOPHY.

Natural philosophy is the science which treats of the laws of the material world; and it is this science, with which the engineer has to cooperate, in obtaining the best results from his professional skill. All the calculations relating to steam-engineering, are closely connected with the operations set forth in that department of knowledge which is thus termed.

"I have learned more about my business," said a trusted and competent engineer, to the author "from an old work on natural philosophy, which I own, than from all the other books I ever read." Hence it is worth the while, to consider a little, the foundation of this important part of an engineer's education.

Natural or Mechanical philosophy is divided into Mechanics, Hydrostics, Pneumatics and Electricity; the engineer in his daily practice is liable to be called upon to deal with one or all of them, for he has to do with machinery, treated under the head first named; with water, treated under the division, Hydrostatics; air (Pneumatics) and with Electricity; upon analysis it will appear that all the computations in this volume are practically used, in connection with one or more of these divisions.

Science shows that there are but few fundamental laws beneath all creation, and all observation proves that these basis principles are preserved through countless varying forms, therefore,——

Let it be particularly noted that there are but 68 elementary substances, known at the present day, to exist; these are platinum, gold, silver, copper, iron, lead, tin, sulphur, nickel, mercury, carbon, hydrogen, nitrogen, antimony, arsenic, bismuth, etc., etc. A substance which cannot be resolved into two or more different substances is called an elementary or simple body; as for example, neither water, coal, nor brass are elementary substances as each can be resolved into other forms of matter.

MATTER is any collection of substance existing by itself in a separate form. Matter appears to us in various shapes, which however can all be reduced to two classes, namely solids or fluids.

A SOLID offers resistance both to change of shape, and to change of bulk.

A FLUID is a body which offers no resistance to change of shape.

Fluids again, can be divided into liquids and vapors or gases. Water is the most familiar example of a liquid. A liquid can be poured in drops while a gas or vapor cannot. It is important to note that experiment proves that every vapor becomes a gas at a sufficiently high temperature and low pressure, and, on the other hand, every gas becomes a vapor, at sufficiently low and high pressure.

ATOMS. An atom is the smallest particle of matter known to exist, they are sometimes called molecules, and are so small that they cannot be divided.

CHEMISTRY treats of all which relates to these particles of matter, and to the changes of constitution produced by their action on each other. *The combustion of coal* is strictly a chemical process, as *the mass of fuel* is reduced to *particles* of gas and vapor by combination with oxygen, resulting in heat, which in turn expands water into steam, in the boiler.

Now we are brought, with our 68 original elementary substances, to those forces which act upon them, five in number; these will be explained in the next section, under the title of primary powers.

PRIMARY POWERS.

The following is a list of all the primary powers which, as yet, have been used by man in accomplishing his purpose in the wide domain of practical life. These are

1. Water power.
2. Wind power.
3. Tide power.
4. The power of combustion.
5. The power of vital action.

To this list may hereafter be added the power of the volcano and the internal heat of the earth; and besides these, science at the present time gives no evidence of any other

Gravitation, electricity, galvanism, magnetism and chemical affinity can never be employed as original sources of power. There is no more prevalent and mischievous error than to suppose that work can be had from these latter, and no engineer of intelligence will waste his life energy in trying to get "something from nothing" as he will be doing should he attempt the problem.

Even in the modern application of electricity it is apparent that it is but the resovoir (a storage battery) or the means of transfer by wires, of the power of combustion, or water, to the *work*.

The same must be said of the elastic force of steam, of air and of springs; and also of machinery; they are all but the active agents employed between *the primary power* and *the work*.

In all computations of power and the action of machines these first principles should always be borne in mind; it is not the engine which is the source of motion to the machinery, nor yet the steam, but the repulsive energy imparted to the expanding water from the burning fuel.

THE MECHANICAL POWERS.

We now proceed to consider the effect produced when these forces are made to act by the intervention of other bodies. These intermediate bodies are called *machines* and by the means of them the effect of a given force may be increased or diminished as desired.

Machines are divided into *simple* and *compound.* The simple machines or what are commonly called MECHANICAL POWERS, are six in number; viz.:

1. The lever.
2. The wheel and axle.
3. The pulley.
4. The inclined plane.
5. The screw.
6. The wedge.

These can in turn be reduced to three classes:

I. A solid body turning on an axis.
II. A flexible cord.
III. A hard and smooth inclined surface.

For the mechanism of the wheel and axle and of the pulley, merely combines the principle of *the lever* with the tension of the cords; the properties of the screw depend entirely on those of the lever and the inclined plane; and the case of the wedge is analogous to that of a body sustained between two inclined planes.

MACHINERY.

Compound machines are formed from two or more *simple* machines. *Tools* are the simplest implements of art; these when they become complicated in their structure become *machines,* and machines when they act with great power, take the name, generally speaking, of *engines.*

The advantage that man has gained by pressing into his service the great forces of nature, instead of depending on his own feeble arm, is evinced by the fact that aided by the steam engine one man can now accomplish as much labor as 27,000 Egyptians, working at the rate at which they built the pyramids (*Dapin*).

The mechanical powers will now be separately considered, it being remembered that *none of them create force,* but that they only modify and direct it, acting by certain great laws, established by the supreme Creator and generous Giver of the original sources, of both the Primary and Mechanical causes. He will labor most effectively and happily who studies these laws and acts in accordance with their principles, which are those laid down and explained in detail in books relating to Natural Philosophy.

THE LEVER.

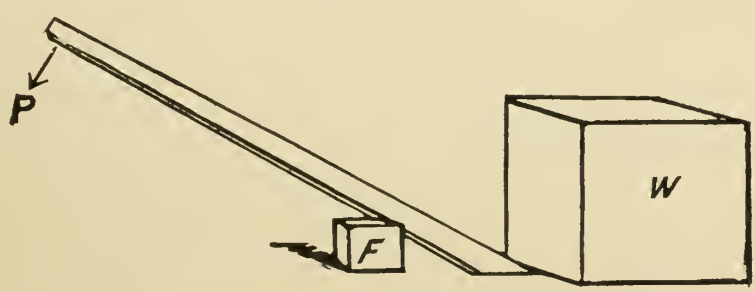


Fig. 1. Lever first kind,

THE LEVER.

The lever is an inflexible bar or rod, some point of which being supported, the rod itself is movable freely about that point as a center of motion.

This center of motion is called the FULCRUM or PROP.

In the lever three points are to be considered, viz.: the fulcrum or point about which the bar turns, the point where the force is applied, and the point where the weight is applied.

There are three varieties of the lever, according as the fulcram, the weight or the power is placed between the other two, but the action in every case is reducible to the same principle and the same general rule applies to them all.

NOTE.

When two forces act on each other by means of any machine, that which gives it motion is called THE POWER, that which receives it THE WEIGHT, hence, ——

In the diagrams the letter P is used to denote the point of application of the forces; the letter F denotes the fulcrum, or prop, and W the weight.

1st. When the fulcrum (F) is between the force (P) and the weight (W). Fig. 1.

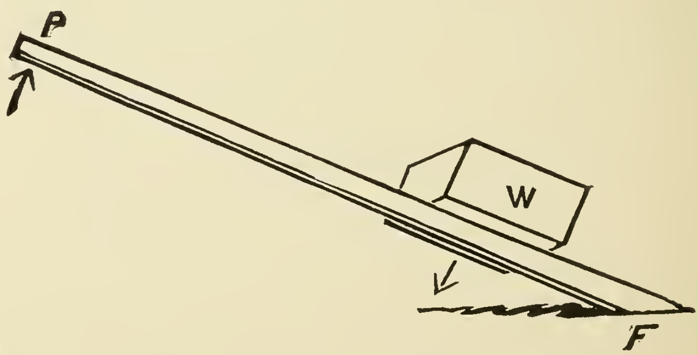


Fig. 2. Lever 2d kind.

2d. When the weight (W) is between the fulcrum (F) and the force (P). Fig 2.

THE LEVER.

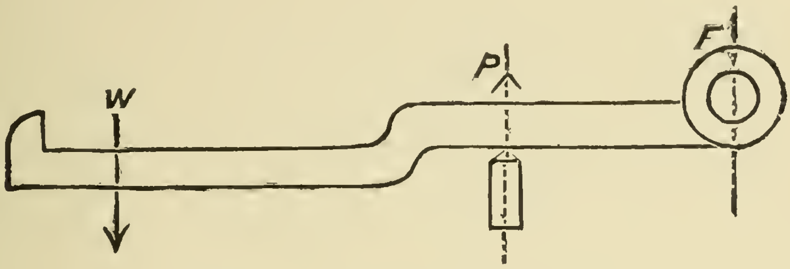


Fig. 3. Lever 3rd kind.

3rd. When the force (P) is between the fulcrum (F) and the weight (W). Fig. 3.

GENERAL RULE.

The force (P) multiplied by its distance from the fulcrum (F) is equal to the weight (W) multiplied by its distance from the fulcrum.

In the following examples the distances are figured in inches and the weight in pounds, the *unit of distance* in mechanics being one inch, and the *unit of weight* being one pound.

NOTE.

The following calculations are made on the supposition that the action of the mechanical powers is not impeded by their own weight, or by friction and resistance. Thus, in each calculation, in figuring *the problems relating to the safety-valve,* the weight of the valve, spindle and lever have to be taken into the estimate. A special rule (with illustrations) will be given in its proper place to show how these are to be provided for.

EXAMPLE.

What force applied at three feet from the fulcrum will balance a weight of 112 lbs. applied at 6 inches from the fulcrum (observe diagram of 1st form of lever). Here the leverages are 36 and 6 inches.

THE LEVER.

This is found by dividing 672 by 36.

112 lbs.	PROOF.
6 inches.	112 lbs. × 6 inches = 672.
——	$18\frac{2}{3}$ " × 36 " = 672.

$$\begin{array}{r} 36)672(18\frac{2}{3} \\ 36 \\ \hline 312 \\ 288 \\ \hline 24 \end{array} \quad \frac{24}{36} = \frac{2}{3}$$

That is, $18\frac{2}{3}$ lbs. applied at the end of a $3\frac{1}{2}$ foot bar with a fulcrum 6 inches from the point, will lift a box weighing 112 lbs.

EXAMPLE.

If 80 lbs. be applied at the extreme end of a 5 foot lever (with prop 1 foot from the point), what force is needed to balance the 80 lbs. The two leverages being 48 inches and 12 inches.

Now, multiply the force (P) 80 lbs., by the distance from the fulcrum (F) 48 inches and divide by 12 inches.

48 inches.	PROOF.
80 lbs.	48 × 80 lbs. = 3840
——	12 × 320 " = 3840
12 in.)3840	
——	
320 lbs.	

This is an example worked from the lever of the second kind.

THE LEVER.

Under the general rule given, it will be seen that under all circumstances *the force* multiplied by its distance from the fulcrum, is equal to—or balanced by, *the weight* multiplied by *its* distance from the fulcrum; 4 sub-rules are added which will cover all problems where only three of the numbers are known.

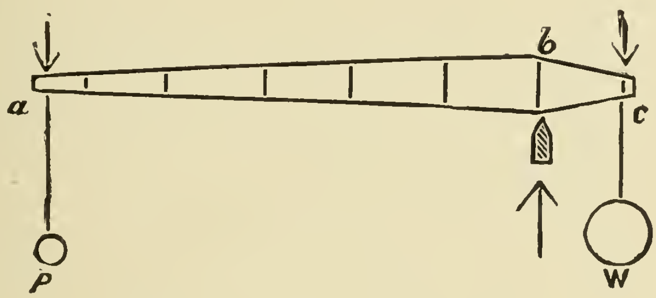


Fig. 4. Lever 1st kind.

To find the power (P) on any lever, when the weight (W) and two distances from the fulcrum (b) are given.

Sub-Rule 1.

Multiply the weight (W) by its distance from the fulcrum (b) and divide by the distance from P, to b.

The quotient is the power.

Example.

How much to balance 200 lbs., 18 inches from the fulcrum (b) to the end of the lever at (P). The whole length of the lever being 36 inches.

18 in.
200 lbs.

---

36 in.)3600(100 lbs. Answer.

The example given to illustrate the general rule is similar to this.

THE LEVER.

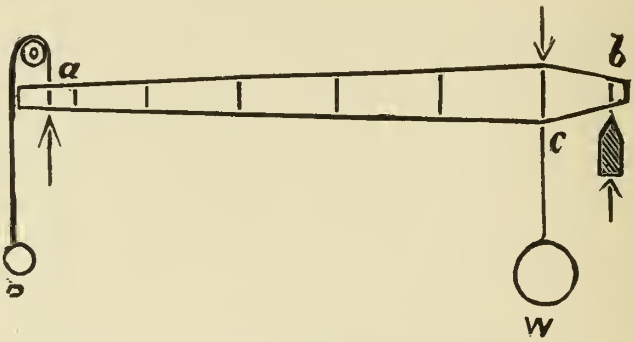


Fig. 5. Lever of the 2d kind.

To find the weight (W) when the power (P) and the two distances from the fulcrum (b) are given.

SUB-RULE 2.

Multiply the power (P) by its distance from the fulcrum (b) and divide by the distance of the weight (W) from the fulcrum. The quotient is the weight.

EXAMPLE.

If 480 lbs. be applied at the end of a lever, 135 inches from the fulcrum, what weight will it lift 45 inches distance from the fulcrum.

```
     480
     135
    ————
    2400
   1440
   480
   ————
45)64800(1440 lbs. Ans.
   45
   ——
   198
   180
   ———
    180
    180
```

PROOF.

1440 × 45 = 64,800.

480 × 135 = 64,800.

THE LEVER.

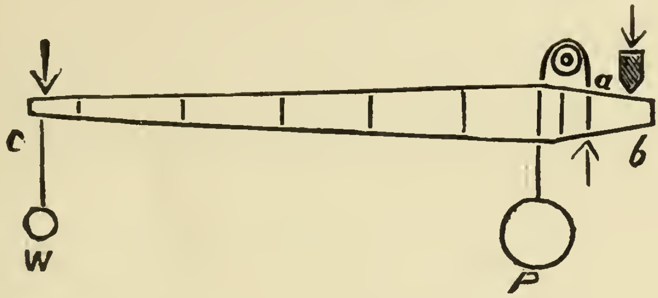


Fig. 6. Lever of the 3rd kind.

To find the distance of the power (P) from the fulcrum (b) the weight and its distance and the power being given.

SUB-RULE 3.

Multiply the weight (W) by its distance from the fulcrum and divide by the power.

EXAMPLE.

If a weight 900 lbs. be 12 inches from the fulcrum, at what distance must 80 lbs. be placed to balance it ?

```
    12                         PROOF.
     900                 900  12    10,800.
  ------                 135  80    10,800.
80)10800(135 inches Ans.
    80
    ---
    280
    240
    ---
     400
```

To find the distance of the weight from the fulcrum. The power and its distance from the fulcrum and weight being known.

SUB-RULE 4.

Multiply the power by its distance from the fulcrum and divide by the weight.

THE LEVER.

Example.

(Lever 3d kind.) If the power be 1,000 lbs., 3 inches from the fulcrum, at what distance must the weight (W) 120 lbs. be placed to balance it.

1,000 lbs. power.	PROOF.
3 in. distance.	1,000 3 = 3,000.
——	120 25 = 3,000.
120)3000	
——	
25 inches.	

Ans. 25 inches from the fulcrum.

The Leverage of the Power.

The ratio of the power end of the lever, to the length of the weight end, is called *the leverage of the power*.

The three varieties of the lever are shown in Fig. 4, 5 and 6, and in each case the lever is supposed to be seven feet long, and divided into feet.

The respective lengths (fig. 4) being 6 feet and 1 foot, the leverage is 6 to 1, or 6. In the second (fig. 5) it is 7 to 1, or 7; in the third one-seventh to 1, or 1-7, showing that in the first case the power balances 6 times its own amount; in the second case 7 times its amount; in the third case only one-seventh of itself, because it is nearer the fulcrum than the weight.

THE WHEEL AND AXLE, or PERPETUAL LEVER.

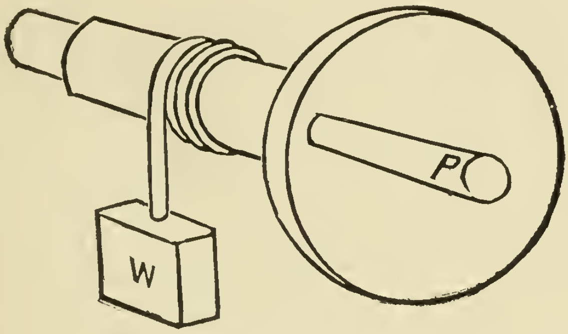


Fig. 7.

When a lever is applied to raise a weight, or to overcome a resistance, the space through which it acts at one time is small and the work must be accomplished by a succession of short and intermitting efforts. The common lever is, therefore, used only in cases where weights are required to be raised through short spaces. When a continuous motion is required, as in raising ore from the mine, or in weighing the anchor of a vessel, some contrivance must be adopted to remove the intermitting action of the lever and render it continuous. The *wheel and axle,* in its various forms, fully answers this purpose. It may be considered a revolving lever.

The wheel and axle may be likened, also, to a couple of pullies of different diameters united together on one axis, of which the larger is the wheel and the smaller the axle, with a common fulcrum.

The power of the wheel and axle is expressed by the number of times the diameter of the axle is contained in that of the wheel, as per the following

Rule.

Multiply the power at the edge of the wheel by its radius (half its diameter) and divide the product by the radius of the axle. The quotient is the weight that the power will raise.

THE WHEEL AND AXLE.

Example.

Required the weight that can be raised by a power of 50 lbs. applied at the circumference of a wheel of 5 feet diameter ($2\frac{1}{2}$ ft. radius) the weight to be attached to the end of a rope, which is to be wound around a barrel or axle 12 inches in diameter. Now then

$$
\begin{array}{rr}
 & 2\tfrac{1}{2} \text{ feet} = 30 \text{ inches.} \\
 & 50 \text{ lbs power.} \\
\hline
\text{Radius of axle } 6) & 1500 \\
\hline
 & 250 \text{ lbs. answer.}
\end{array}
$$

Note.

There are obviously two ways by which the power of the wheel and axle may be increased; either by increasing the diameter of the wheel or diminishing that of the axle.

The weight to be raised, the diameter of the axle and dameter of the wheel being given, to find the amount of power required to raise the weight.

Rule.

Multiply the weight to be raised by the radius of the axle, and divide the product by the radius of the wheel.

Example.

Required the power necessary to raise a weight of 400 lbs. by an axle of 10 inches, and wheel of 50 inches in diameter. Now, then:

$$
\begin{array}{rl}
\text{Weight} = & 400 \\
\tfrac{1}{2} \text{ diam. of axle} & 5 \\
\hline
\tfrac{1}{2} \text{ diam. of wheel } 25) & 2000(80 \text{ lbs. Ans.} \\
 & 2000
\end{array}
$$

THE WHEEL AND AXLE.

A ship's capstan is another form of the wheel and axle.

Example for Practice.

In weighing anchor 6 capstan bars are used; from center of capstan to point of pressure is 6 feet; diameter of axle of capstan = 24 inches. Now then, if each man exerts 80 lbs. with his bar.

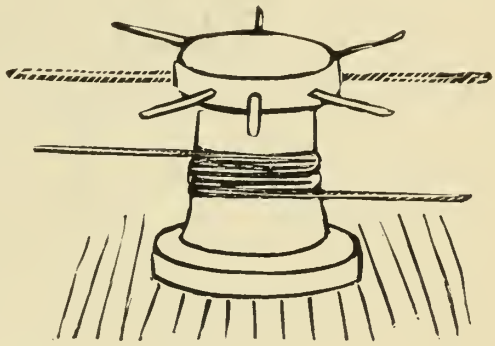


Fig. 8.

The leverage for force (radius of 12 ft. diam.)=6.
Number of men 6

36
Lbs. for each man 80

Divide by radius of axle 1)2880

2880 lbs. Ans.

If an allowance of ten per cent. is made for friction and the rigidity of the cord, the answer will be 2592 lbs. Ans.

Example for Practice.

The diameter of a steering wheel on a ship is 5 feet and the barrel is 15 inches in diameter. If a man applies a force equal to 200 lbs. what resistance would he overcome? Ans. 800 lbs.

THE CHINESE WHEEL AND AXLE.

To combine the requisite strength with moderate dimensions and great mechanical power has been accomplished by giving different thicknesses to different parts of the axle and carrying

THE WHEEL AND AXLE.

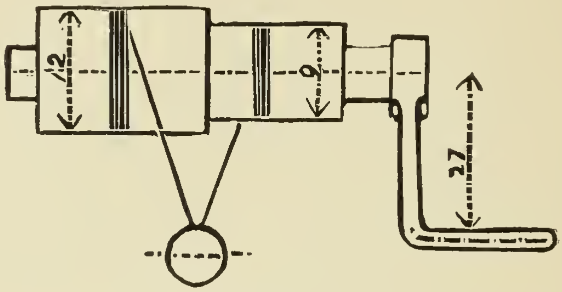


Fig. 9.

a rope which is coiled on the inner part through a pulley attached to the weight and coiling it in the opposite direction on the thicker part as in fig 9.

We see here exemplified the principle, that the weight sustained by a given power, may be increased as its velocity is diminished. By inspecting fig. 9 it will be seen that the rope connected with the thinner part of the axle *unwinds,* while that connected with the thicker part *winds up,* by which means the ascent of the weight may be rendered slow in any degree, and a proportionally greater quantity of matter may be added.

To find power in this arrangement follow the

Rule.

The power multiplied by the radius of the wheel, in feet, is equal to half the weight multiplied by the difference in the half diameters (radii) of the thicker and thinner parts of the axle. This will be made clear by the following

Example.

The diameters in fig. 9 are 1 foot and $\frac{3}{4}$ of a foot; the length of the handle 2 feet 3 inches; if the exertion put forth is equal to 80 lbs. what weight will be lifted.

Now then to follow the rule.

THE WHEEL AND AXLE.

The length of the handle 2,25 feet.
The power exerted 80 lbs.

$\frac{1}{2}$ the difference in the radii .0625)18000(2880 lbs. Ans.

```
.0625)18000(2880 lbs. Ans.
      1250
      ----
       5500
       5000
       ----
        5000
        5000
```

In all these examples the diameter of the rope has been supposed to be so small in comparison to that of the drum or barrel that it has been neglected; if it is a thick rope, then the leverage must be measured from *the center of the barrel to the center of the rope.*

EXAMPLE.

Wheel and axle, the barrel is 10″ in diameter, the rope is $1\frac{1}{2}$ inches in diameter, the crank handle is 15″ radius, and the weight to be lifted is 500. What force must be applied to the handle if 10 per cent. is to be added for friction. Now, then

Leverage of weight $5'' + \frac{3}{4}'' = 575$. Being radius of barrel and rope.

```
500×5,75=
      500 lbs.
15)287500(191⅔ lbs. Ans.
   15
   ---
   137
   135
   ---
    25
    15
    --
    10        10/15 = 2/3
```

Add for friction 19.17 = $210\frac{83}{100}$ Ans.

THE WHEEL AND AXLE.

These examples are worked in *decimal fractions,* the rules and examples of which will be given later.

To find the difference in the half diameter of the axle, (Fig. 9.) proceed thus : 1 foot — $\frac{3}{4}$ = $\frac{1}{4}$ foot; $\frac{1}{2}$ this for the radius= one-eighth foot, and half this is one-sixteenth, or in decimals .0625. (See example.)

THE PULLEY.

The pulley is a wheel over which a cord, or chain or band is passed, in order to transmit the force applied to the cord in another direction. The practical effect of the machine depends upon the rope, the wheel being introduced to *diminish* friction and the effect of imperfect flexibility, but the whole effect of imperfect flexibility and friction are not destroyed, although in calculations, we proceed as though they were.

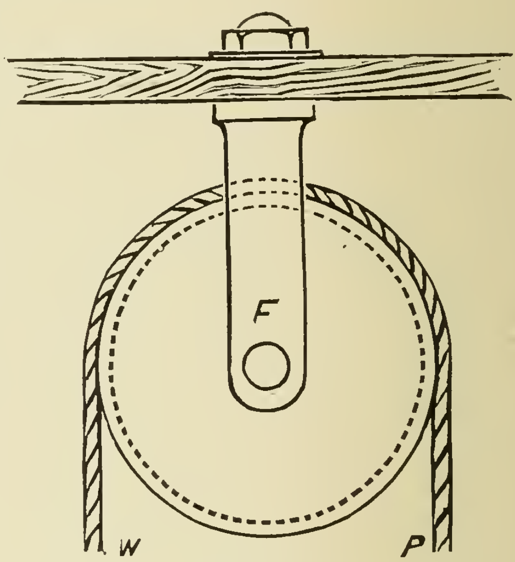


Fig. 10.

There is no mechanical advantage gained by a single rope over one or more fixed pullies; but this combination is of the greatest use by enabling us *to change the direction of the force.*

Pulleys are divided into *fixed* and *movable.* In the fixed pulley no mechanical advantage is gained, as already explained, but its use is of the greatest importance in accomplishing the work appropriate to the pulley, such as raising water from a well. Thus, it is far more convenient to raise a bucket from a well by drawing downward, as is the case where the rope passes over a fixed pulley above the head, than by drawing upward leaning over the curbing.

From its portable form, its cheapness and the facility with which it can be applied, especially in changing or modifying the direction of motion, the pulley is one of the most convenient and useful of the mechanical powers.

THE PULLEY.

It must be observed that in using any system of movable pullies, the whole weight of the pulleys themselves, together with the resistance occasioned by the friction and rigidity of the ropes all act against the power and so far lessen the weight which it is capable of raising.

The *moveable* pulley by distributing the weights into separate parts, is attended by mechanical advantages proportioned to the number of points of support. Movable pulleys may be arranged according to different systems which increase the efficacy of a given power in different degrees.

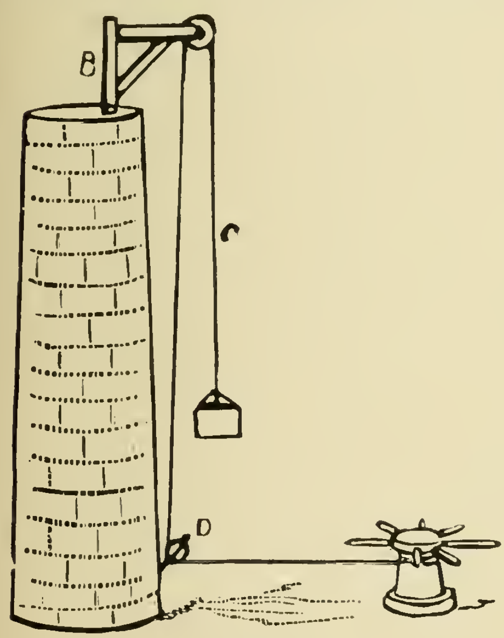


Fig. 11.

By means of the pulley great facilities are afforded in raising heavy weights, as boxes of merchandise or heavy blocks of stone. Fig. 11 represents a convenient method in building brick chimneys for steam plants which has been observed by the author, as used by Glasgow, Scotland, masons and builders.

The *crane* at B enables the workmen when the brick and mortar are raised, to swing it around to the point where it is to be laid or to a platform near it. The lower cord of the rope C D is connected with a wheel and axle; in the illustration, it may be seen, that instead of the wheel and axle we might fasten a horse to the rope, or attach a sweep to the top of the axis and join a team of horses to the end of it to expedite the work.

The employment of this device, in sufficiently large chimneys, enables the builder to dispense with the use of scaffolding, the workmen building into the corners of the chimney, as the work progresses, a ladder of $\frac{1}{2}$ or $\frac{3}{4}$ inch round iron every fifteen inches, to enable them to go up and down in the interior of the flue. Thus a large expense is saved in cost of scaffold, and the risk is less for the mason.

THE PULLEY.

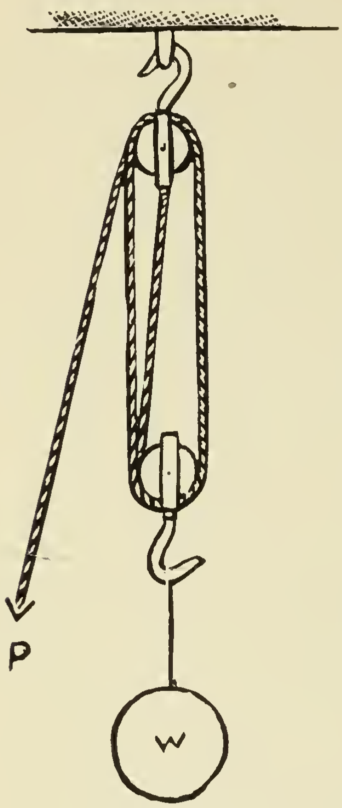


Fig. 12.

Fast and loose pullies. These are shown in Fig. 12 where the movable block A carries the weight with a fixed counterpart B. Here the rope is attached by one end to the fixed block and is passed over the movable and fixed pullies from one to the other in succession, the power being applied to the other end. This system is known as fast and loose pulley blocks.

The fixed end of the rope is sometimes fastened to the movable block.

To find the power necessary to balance the weight by the means of a system of fast and loose pulleys.

RULE 1.

Divide the weight by the number of ropes by which it is carried; that is by the number of ropes which proceed from the movable block. The quotient is the power required to balance the weight.

EXAMPLE.

A cylinder cover weighing 1200 lbs. is lifted by a pair of blocks of two sheaves each, the rope is fastened to the upper block.

Now, then, in two sheaves there are 4 ropes.

4)1200

300 lbs. will balance the weight of the cylinder head.

EXAMPLE.

A boiler weighing 6 tons has to be lifted by a pair of treble blocks; how much power must be applied at the end of the rope to balance the weight.

6 tons
2000

6)12000 lbs.

2000 lbs.

THE PULLEY.

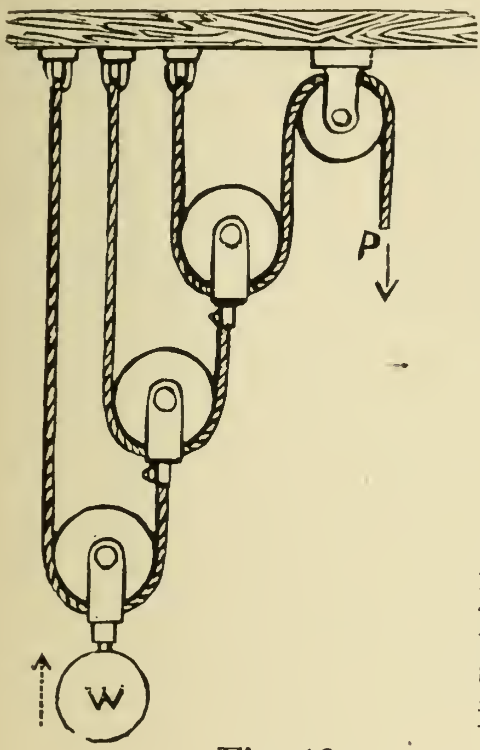


Fig. 13.

Sometimes the upper block has 4 sheaves and the lower 3, the rope being rove and fastened to the lower block, then when the stress comes, there will be 7 singles of the rope holding the weight up.

In this case the weight would be divided by 7.

In all the above cases, single rope and a single movable block have been used, but we may have several movable blocks each with its own rope.

EXAMPLE.

Let a pulley be fastened to a weight of 1200 lbs. and a rope fastened by one end to a beam, brought round the pulley, and the other end fastened to a second pulley; let a second rope be fastened to the beam, brought around this second pulley and fastened to a third pulley; let a third rope be fastened to the beam, brought round the third pulley and then up over a fixed pulley; what weight would put it in balance?

ANSWER.

In this case the 1200 lbs. is supported by two singles the first rope, hence each single rope bears a weight of 600 lbs.

This 600 is the weight the second movable pulley sustains; hence each single of the second rope bears a strain of $\frac{600}{2}=300$ lbs.

This 300 lbs. is the weight the third movable pulley sustains; hence each single of the third rope bears $\frac{300}{2}=150$ lbs. Answer.

In order to have the rules apply it is necessary to have the cords parallel with each other, as any other than a "straight pull" alters the mechanical efficiency.

THE PULLEY.

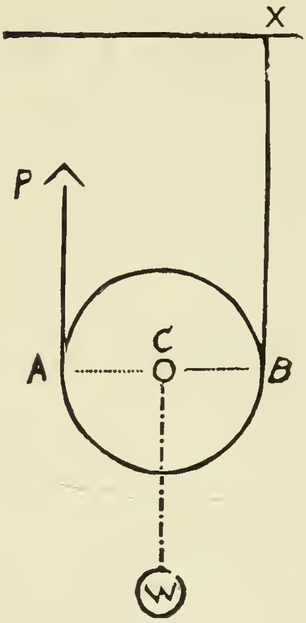


Fig. 14.

The single fixed pulley as shown in Fig. 10 acts like *a lever of the first kind,* and simply changes the direction of the forces without modifying the intensity of the power.

But the pulley may be employed as a lever of *the second kind* by suspending the weight to the axis of the pulley, and fixing one end of the cord to a spot as a fulcrum point X as shown in Fig. 14. Thus the power acts through the diameter, *A C B,* in which *B* is the fulcrum.

In acting as *a lever of the third kind,* the power is applied to the axis *a* in Fig. 15, one end of the cord being fixed at *b* and the weight attached to the other end, *c.*

In the last example the gain is $\frac{1}{2}$.

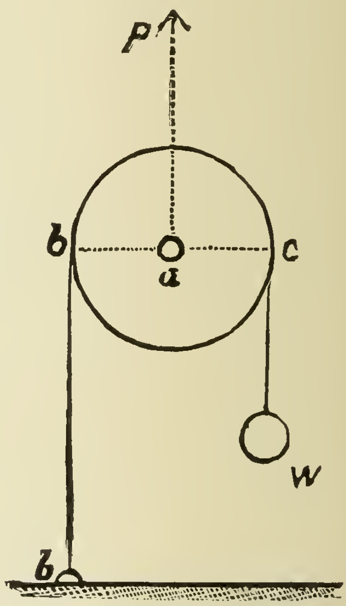


Fig. 15.

THE INCLINED PLANE.

The inclined plane is a slope, or a flat surface inclined to the horizon, on which weights may be raised. By such substitution of a sloping path for a direct upward line of ascent, a given weight can be raised by a power less than itself.

The inclined plane becomes a *mechanical power* in consequence of its supporting part of the weight, and of course leaving only a part to be supported by the power. Thus the power has to encounter only a portion of the force of gravity at a time; a portion which is greater or less according as the plane is more or less elevated.

The simplest example we have of the application of the inclined plane is that of a plank raised at the hinder end of a cart for the purpose of rolling in heavy articles, as barrels or hogsheads. Again, for another

Example.

When a horse is drawing a heavy load on a perfectly horizontal plane, his force is spent chiefly in overcoming friction, and the resistance of the air, as the force of gravitation can afford no resistance, in the direction in which the load is moving.

But when the horse is drawing a load up a hill he has not only these impediments to overcome but he lifts a part of the load. If the rise is 1 foot in 20, he lifts one twentieth of the load; if the ascent is one foot in four and the load is two tons, including his own weight, he lifts

$$4)4000$$

$$\overline{1000 \text{ lbs.}}$$

THE INCLINED PLANE.

Note.

The general principle for all calculations relating to the inclined plane may be thus stated. As the length of the plane is to the height or angle of inclination, so is the weight to the power: this principle will be understood by reference to that part of this work relating to Ratio and Proportion.

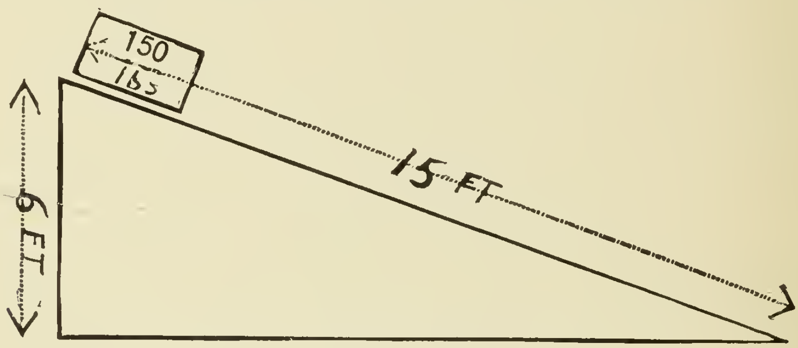


Fig. 16.

There are three elements of calculation in the inclined plane, the plane itself, the base or horizontal length and the height or vertical rise, together forming a right angled triangle. Fig. 16 exhibits an inclined plane.

To find the power necessary to raise a given weight, the length and heighth of the inclined plane being known.

Rule.

Multiply the weight by the height and divide by the length of the plane.

Example.

Required the power necessary to raise 1280 lbs. up an inclined plane 8 feet long and 5 feet high. Now then:

$$\begin{array}{r} 1280 \text{ lbs.} \\ 5 \text{ feet.} \\ \hline 8)6400 \\ \hline 800 \text{ lbs. Answer.} \end{array}$$

THE INCLINED PLANE.

The length and height of an inclined plane being known, to find the weight that a given power will support upon the plane.

Rule.

Multiply the power by the length of the plane and divide the product by the height. The quotient is the weight that the power will support.

Example.

The length of an inclined plane is 15 feet; the perpendicular height 6 feet: what force will be required to sustain a weight of 150 lbs.? Fig 16.

```
        150 lbs.
          6 feet.
        ---
    15)900(60 lbs. Answer.
        90
        --
         00
```

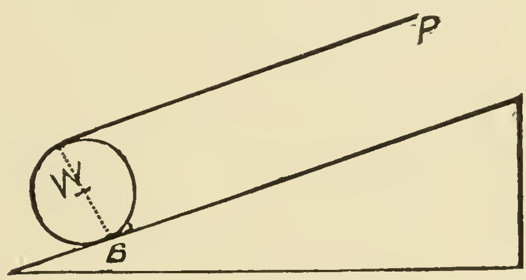


Fig. 17.

The principle of the lever as applied to the inclined plane may be seen illustrated in Fig. 17, where the power is applied at the end of a cord passed round and over the weight (W).

In this case there is the action of a movable pulley, combined with an inclined plane, the rolling weight moved by a cord, B P, lapped round it, representing a movable pulley with the weight attached to the axle. Thus the leverage of the power on the inclined plane can be doubled.

THE SCREW.

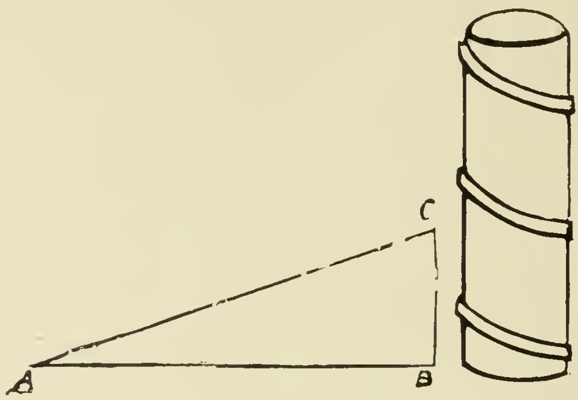


Fig. 18.

The screw is an inclined plane wrapped around a cylinder.

Take for example an inclined plane A, B, C, Fig. 18, and bend it into a circular form resting on its base, so that the ends meet. The incline may be continued winding upwards round the same axis and thus winding inclined planes of any length or height may be constructed.

The distance apart of two consecutive coils, measured from centre to centre, or from upper side to upper side, (literally the height of the inclined plane), for one revolution, is "the pitch" of the screw.

The screw is generally employed when severe pressure is to be exerted through small spaces; being subject to great loss from friction it usually exerts but a small power of itself, but derives its principal efficacy from the lever or wheel work with which it is very easily combined.

A screw in one revolution will descend a distance equal to its pitch, or the distance between two threads and the force applied to the screw will move through, in the same time the circumference of a circle whose diameter is twice the length of the lever. Hence the Rule.

THE SCREW.

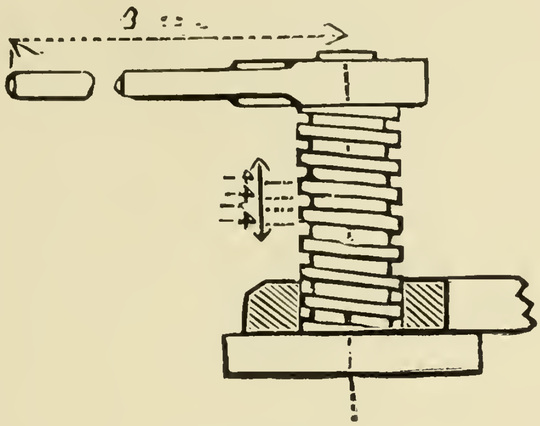


Fig. 19.

Rule.

The power multiplied by the circumference is equal to the weight multiplied by the pitch.

Example.

If the distance between the threads be ¼ inch and the force of 100 lbs. be applied at the end of a lever 3 feet in length; what weight will be moved by the screw? See the diagram Fig. 19.

Twice the length of the lever = 6 feet = 72 inches diam.

```
                     72
                    100 power.
                   ----
                   7200
                    3.14 to get circum.
                 ------
                  28800
                  7200
                 21600
                -------
divide by pitch 5)22608.00
     .25         --------
                 5)452160
                  -------
                   90432 Ans. in lbs.
```

THE SCREW.

If the pitch of screw and length of lever be given, what power will be required to move a given weight.

Rule.

The power multiplied by the circumference is equal to the weight multiplied by the pitch of screw.

Example.

If the pitch be $\frac{3}{4}$ of an inch and the lever 2 feet, how much power must be applied at the end of the lever to raise a weight of 6 tons.

6 tons=12000 lbs. ×$\frac{3}{4}$
3
———
4)36000
2×2=diam.×12=48 ———
inches×314=15072)90000(59$\frac{2}{3}$ lbs.
75360
———
146400
135648
———
10752

Note.

Cut or Fig. 20 gives a view of the winding path of the endless screw.

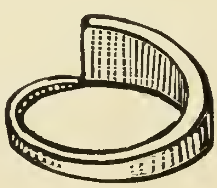


Fig. 20.

THE WEDGE.

The wedge is a pair of inclined planes united by their bases or back to back.

The wedge has a great advantage over all other mechanical powers in consequence of the way in which the power is applied to it, namely, by percussion, or a stroke, so that by the blow of a hammer or sledge almost any constant pressure is overcome.

If instead of moving a load on an inclined plane, the plane itself is moved beneath the load, it then becomes a wedge. All cutting and piercing instruments, such as knives, razors, scissors, chisels, nails, pins, needles, are wedges.

The use of the wedge is to separate two bodies by force or to divide into two a single body. In some cases the wedge is moved by blows; in others it is moved by pressure. The action by *simple pressure* is to be considered.

If the weight rests on a horizontal plane and a wedge be forced under it, when the wedge has penetrated its length, the weight will be lifted a height equal to the thickness of the butt end of the wedge, hence the Rule.

THE WEDGE.

Rule.

The power is equal to the weight, multiplied by the thickness of the wedge, divided by the length of the wedge.

Example.

A wedge 18 inches in length and 3 inches thick, is employed to lift a weight of 100 lbs.; what pressure must be used ?

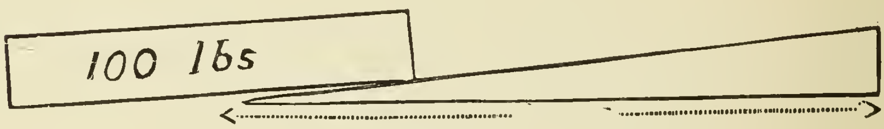


Fig. 21.

Now then—The weight = 100 lbs.
thickness = 3 inches.

divided by 18)300(16⅔ lbs. Ans.
18
120
108
12
18

If a wedge be 12 inches long and 3 inches thick, and the pressure employed be 100 lbs., what *weight* will be lifted. This is the method of figuring:

The power = 100
The length = 12

thickness 3)1200

400 lbs. Ans.

THE WEDGE.

The wedge is generally formed of either wood or metal introduced into a cleft already made to receive it, as shown in Fig. 22.

Fig. 22.

When two bodies are forced from one another by means of a wedge.

RULE.

Multiply the resisting power by half the thickness of the head or back of the wedge, and divide the product by the length of one of its inclined sides.

EXAMPLE.

The thickness of the back of a double wedge is 6 inches, and its length, through the middle is 10 inches: what is the power necessary to separate a substance having a resistance of 150 lbs.? Now then:

150 lbs. to be overcome.
$\frac{1}{2}$ thickness 3
———
10)450(45 lbs. Ans.

In many cases, the utility of the wedge depends upon that which is entirely omitted in the theory, viz. the *friction* which arises between its surface and the substance which it divides—as in the case of nails, etc. The power generally acts by successive blows, and is therefore subject to constant intermission, and but for the friction, the wedge would recoil between the intervals of the blows, with as much force as it had been driven forward, and the object of the labor would be constantly frustrated.

The rules for calculation do not apply to instances like the last described.

SIZES, STRENGTH, ETC., OF ROPE.

By reference to page 48 it will be observed that one of the three classes to which the mechanical powers may be reduced is that of a *flexible cord;* another name for the cord, or rope, is the *funicular machine.* Hence, the rules and calculations relating to ropes when used for the purpose of producing power, belong with those relating to the inclined plane and wheel and axle.

The size of a rope is designated by the circumference measured with a thread; thus a three inch rope measures three inches round.

Ropes are made of iron, steel, manila and hemp, all of which, even of the same size, vary greatly in strength, durability and safety.

All the tables given for strength of rope *must be more or less modified* by the time of service, the quality of material and method of manufacture; the strength of pieces from the same coil may vary one-quarter, and a few months service weakens rope from 20 to 50 per cent. A difference in the quality of hemp may also produce a difference of $\frac{1}{4}$ in the strength of rope of the same size.

TABLE.

Showing what weight a hemp rope will bear in safety.

Circumference.	Pounds.	Circumference.	Pounds.	Circumference.	Pounds.
1 in.	200	$3\frac{1}{2}$	2450	$5\frac{1}{2}$	6050
$1\frac{1}{4}$	312	$3\frac{3}{4}$	2812	$5\frac{3}{4}$	6612
$1\frac{1}{2}$	612	4	3200	6	7200
2	800	$4\frac{1}{4}$	4512	$6\frac{1}{4}$	7812
$2\frac{1}{4}$	1012	$4\frac{1}{2}$	4050	$6\frac{1}{2}$	8450
$2\frac{1}{2}$	1250	$4\frac{3}{4}$	4512	$6\frac{3}{4}$	9112
3	1800	5	5000	7	9800
$3\frac{1}{4}$	2111	$5\frac{1}{4}$	5512	8	12800

The strength of manila is about $\frac{1}{2}$ that of hemp.

SIZES, STRENGTH, ETC., OF ROPE.

To find the strength of ropes.

Rule.

Multiply the square of the circumference by 200, the product will be the weight in pounds the rope will bear with safety.

Example.

What weight will a 4 inch rope bear in safety ?

$4 \times 4 = 16$ the square of the girth or circumference.

Multiply by 200

3200 Ans. See Table for same result.

Table showing what weight a good hemp cable will bear in safety.

Circumference.	Pounds.	Circumference.	Pounds.	Circumference.	Pounds.
6.	4320.	9.50	10830.	13.	20280
6.50	5070.	10.	12000.	13.50	21870
7.	5880.	10.50	13230.	14.	23520
7.50	6750.	11.	14520.	14.50	25230
8.	7680.	11.50	15870.	15.	27000
8.50	8670.	12.	17280.	15.50	28830
9.	9720.	12.50	18750.		

To ascertain the strength of Cables.

Rule.

Multiply the square of the circumference, in inches, by 120 and the product is the weight the cable will bear, in pounds, with safety.

Example.

What weight will a 12 inch cable support with safety ?

$12 \times 12 = 144$

Multiply by 120

2880

144

17280 Ans.

SIZES, STRENGTH, ETC., OF ROPE.

Note.

Tables for strength of rope are frequently made to show *the breaking strain,* and then $\frac{1}{5}$ to $\frac{1}{7}$ taken as the safety limit. In the two tables given the allowance is already made, but for manila rope a further deduction should be made of $\frac{1}{2}$.

Wet ropes, if small, are a little more flexible than dry; if large a little less flexible.

Tarred ropes are stiffer by about $\frac{1}{6}$, and in cold weather somewhat more so. The stiffness of ropes increases after a little rest.

The girth of a rope and its circumference are the same.

IRON AND STEEL WIRE ROPE.

The use of a round endless wire rope running at a great velocity in a grooved sheave, in place of a flat belt running on a flat-faced pulley, constitutes *the transmission of power* by wire ropes. The distance to which this can be applied ranges from fifty feet up to about three miles.

Ropes of wire—steel and iron—are made up to three inches in diameter, but the ordinary range in the sizes used is small, being from $\frac{3}{8}$ diameter to $1\frac{1}{8}$ in a range of 3 to 250 horse power.

Two kinds of wire rope are manufactured. The most pliable variety contains 19 wires to the strand, and is generally used for hoisting and running rope; ropes with twelve wires and seven wires in the strand are stiffer, and are better adapted for standing rope, guys and rigging.

Wire rope is as pliable as new hemp of the the same strength. It is manufactured either with *a wire* or *rope center;* the latter is more pliable than the former and will wear better where there is short bending.

Table of Wire Rope.

Rope of 133 Wires (19 wires to a strand.)

Diam. Ins.	Circumf. Ins.	Pounds per foot run.	Breaking load, lbs.		Minimum diam. of drum in feet.	
			Iron.	Cast steel.	Iron.	Cast steel.
$2\frac{1}{4}$	$6\frac{3}{4}$	8.00	148000	310000	8	9
2	6	6.30	130000	250000	7	8
$1\frac{3}{4}$	$5\frac{1}{2}$	5.25	108000	212000	6.5	7.5
$1\frac{5}{8}$	5	4.10	88000	172000	5	6
$1\frac{1}{2}$	$4\frac{3}{4}$	3.65	78000	154000	4.75	5.5
$1\frac{3}{8}$	$4\frac{3}{8}$	3.00	66000	126000	4.5	..
$1\frac{1}{4}$	4	2.50	54000	104000	4	5
$1\frac{1}{8}$	$3\frac{1}{2}$	2.00	40000	84000	3.5	4.5
1	$3\frac{1}{8}$	1.58	32000	66000	3.	4
$\frac{7}{8}$	$2\frac{3}{4}$	1.20	23000	50000	2.75	3.75
$\frac{3}{4}$	$2\frac{1}{4}$	0.88	17280	36000	2.5	3.5
$\frac{5}{8}$	2	0.60	10260	28000	2	3
$\frac{9}{16}$	$1\frac{5}{8}$	0.44	8540	18000	1.75	2.75
$\frac{1}{2}$	$1\frac{1}{2}$	0.35	6960	15000	1.5	2
$\frac{3}{8}$	$1\frac{1}{4}$	0.26	5000	......	1	....

Rope of 49 Wires (7 wires to the strand.)

Diameter ins.	Circumf. Ins.	Pounds per foot run.	Breaking load, lbs.	
			Iron.	Cast steel.
$1\frac{1}{2}$	$4\frac{5}{8}$	3.37	72000	124000
$1\frac{3}{8}$	$4\frac{1}{4}$	2.77	60000	104000
$1\frac{1}{4}$	$3\frac{3}{4}$	2.28	50000	88000
$1\frac{1}{8}$	$3\frac{3}{8}$	1.82	40000	72000
1	3	1.50	32000	60000
$\frac{7}{8}$	$2\frac{5}{8}$	1.12	24600	44000
$\frac{3}{4}$	$2\frac{3}{8}$	0.88	17600	34000
$\frac{11}{16}$	$2\frac{1}{8}$	0.70	15200	28000
$\frac{5}{8}$	$1\frac{7}{8}$	0.57	11600	22000
$\frac{9}{16}$	$1\frac{5}{8}$	0.41	8200	16000
$\frac{1}{2}$	$1\frac{3}{8}$	0.31	5660	12000
$\frac{7}{16}$	$1\frac{1}{4}$	0.23	4260	.....
$\frac{3}{8}$	$1\frac{1}{8}$	0.19	3300	8000
$\frac{5}{16}$	1	0.16	2760	6000
$\frac{9}{32}$	$\frac{7}{8}$	0.125	2060	....

Note.

In the tables given (Jno. A. Roebling's Sons Cos.) take $\frac{1}{5}$ to $\frac{1}{7}$ as the safe working load.

SIZES, STRENGTH, ETC., OF ROPE.

Example.

What is the safe working load of a 2 inch cast steel wire rope. Now then:

For breaking weight see Table=28,000 lbs.
Divide by 7)28,000—for safety.

4,000 lbs. Ans.

GENERAL TABLE.

Breaking Strain of Rope.

3,000 lbs.	per square inch of section	for	manila.
6,000 "	"	"	hemp.
12,000 "	"	"	iron wire.
24,000 "	"	"	steel wire.

Rule.

Multiply area of the rope in square inches by the figures in the list for kind of rope.

Example.

What (by the above rule) is the breaking strain of a 5 inch manila rope. Now then:

5 inch rope=$1\frac{6}{10}$ nearly, diam.
The area of 1.6=2 inches nearly.
Multiply by 3000 per general rule.

6000 lbs.=Breaking strain.

CAUTION.

The utmost care must be exercised in the use of any tables or rules for strength and safety of rope of wire or hemp and iron chain—a judgment of materials, amount of wear, and finish of manufacture, as well as the known integrity of the makers—all have to be taken into the calculations.

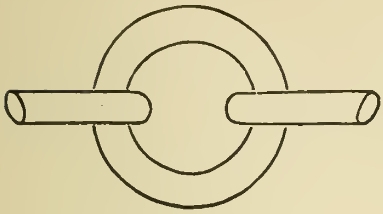


Fig. 23.

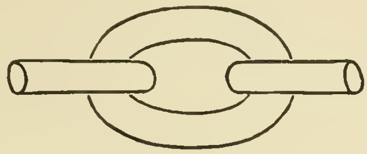


Fig. 24.

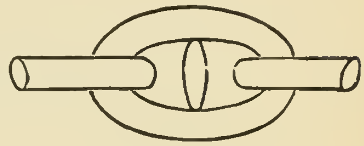


Fig. 25.

IRON CHAINS.

Chains are constructed of round rolled iron formed with open links, Figs. 23 & 24, or with stud links, Figs. 25, 26, 27 & 28.

The cuts represent different kinds of chain, viz., Fig. 23 the Circular Link; Fig. 24 the Oval Link; Fig. 25 the Oval Stud Link, with pointed stud; Fig. 26 the Oval Link, with broad headed stud; Fig. 27 the obtuse-angled Stud Link, and Fig. 28 the parallel sided Stud Link.

The standard proportions of the links of chains, in terms of the diameter of the bar iron from which they are made, are as follows:

	Extreme length.		Extreme width.
Stud-link,	6	Diameters,	3.6
Close-link,	5	"	3.5
Open-link,	6	"	3.5
Middle-link,	5.5	"	3.5
End-link,	6.5	"	4.5

Example.

What is the largest chain of the stud link pattern which can be made out of 1 inch iron?

Diam. of bar=1 inch.
Multiply by 6 length of link.

6 in.

and for width, multiply 1 in. by $3\frac{6}{10}$=3.6 inches.

Answer.—The links should be $6 \times 3\frac{6}{10}$, *or less.*

IRON CHAINS.

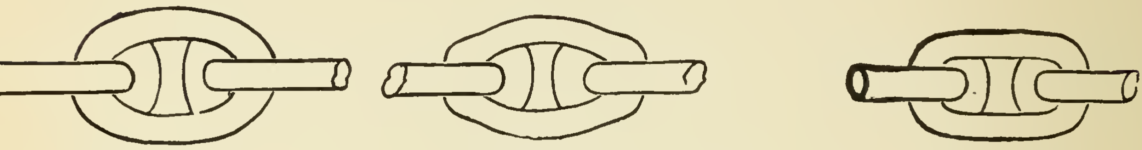


Fig. 26. Fig. 27. Fig. 28.

Trautwine's Table of Strength of Chains.

Chains of superior iron will require $\frac{1}{4}$ to $\frac{1}{3}$ more to break them.

Diam of rod of which the links are made,	Weight of chain per ft. run.	Breaking strain of the chain.		Diam of rod of which the links are made.	Weight of chain per ft. run.	Breaking strain of the chain.	
Ins.	Pds.	Pds.	Tons.	Ins.	Pds.	Pds.	Tons.
3-16	.5	1731	.773	1	10.7	49280	22.00
¼	.8	3069	1.37	1⅛	12.5	59226	26.44
5-16	1.	4794	2.14	1¼	16.	73114	32.64
⅜	1.7	6922	3.09	1⅜	18.3	88301	39.42
7-16	2.	9408	4.20	1½	21.7	105280	47.00
½	2.5	12320	5.50	1⅝	26.	123514	55.14
9-16	3.2	15590	6.96	1¾	28.	143293	63.97
⅝	4.3	19219	8.58	1⅞	32.	164505	73.44
11-16	5.	23274	10.39	2	38.	187152	83.55
¾	5.8	27687	12.36	2¼	54.	224448	100.2
13-16	6.7	32301	14.42	2½	71.	277088	123.7
⅞	8.	37632	16.80	2¾	88.	335328	149.7
15-16	9.	43277	19.32	3	105.	398944	178.1

Ton of 2240 lbs.

The weight of close link chain is about three times the weight of the bar from which it is made, for equal lengths.

KANE VON OTT.—An authority comparing the weight, cost and strength of the three materials, hemp, iron wire and chain iron, concludes that the proportion between the cost of hemp rope, wire rope and chain is as 2: 1: 3; and that therefore for equal resistance, wire rope is only half the cost of hemp rope, and a third of the cost of chains.

DECIMAL FRACTIONS.

A decimal fraction is one whose denominator is always 10 or 100 or 1000 or some other power as it is called of 10, but its numerator may be any number. For example $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$ are all three decimal fractions.

$\frac{1}{10}$	is written	.1	and is	in value	one-tenth	of a whole	number.
$\frac{7}{10}$	"	.7	"	"	seven-tenths	"	"
$\frac{1}{100}$	"	.01	"	"	one-hundreth	"	"
$\frac{1}{1000}$	"	.001	"	"	one-thousandth	"	"

So it will be seen that, in decimals, by placing a figure one place to the right makes it a tenth of what it was before, just as in whole numbers. Thus:

1000 is one thousand.
100 is one hundred.
10 is ten.
1 is one.
.1 is one-tenth.
.01 is one-hundreth.
.001 is one-thousandth.

If the fraction have a numerator other than 1. Then it is written thus; $\frac{5}{10}$ is expressed .5; $\frac{27}{100}$ is expressed .27; and $\frac{467}{1000}$ is expressed .467.

The use of the dot (.) is to separate the whole number from the decimal.

The first figure after the decimal point is always tenths; the second figure always hundreths; and the third figure thousandths, always decreasing towards the left in a tenfold ratio.

To bring a decimal fraction to a vulgar fraction. From the foregoing it is plain that all we have to do is to put the given decimal down as a numerator; and for a denominator put down the figure 1, with as many cyphers after it as there are figures in the given decimal; then reduce it to its lowest terms.

EXAMPLES.

Bring .25 to a vulgar fraction. $\frac{25}{100} = \frac{5}{20} = \frac{1}{4}$ Answer.
Bring .875 to a vulgar fraction. $\frac{875}{1000} = \frac{175}{200} = \frac{35}{40} = \frac{7}{8}$.
Bring .87500 to a vulgar fraction. $\frac{87500}{100000} = \frac{875}{1000}$

Hence it will be seen by the last example that annexing a cypher to a decimal does not increase its value at all. You add as many naughts to the right as you please without affecting the value of the decimal.

To bring a vulgar fraction to a decimal.

Attach any number of cyphers to the numerator, and divide this by the denominator, being sure to have a figure for each naught attached.

EXAMPLES.

Bring $\frac{1}{4}$ to a decimal.

$$\begin{array}{r} 4)100 \\ \hline .25 \text{ Answer.} \end{array}$$

Bring $\frac{15}{16}$ to a decimal.

$$16\left\{\begin{array}{r} 4)15.0000 \\ \hline 4)3.7500 \end{array}\right. \\ \overline{.9375}$$

EXAMPLES FOR EXERCISE.

1. Reduce $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ to decimals.
2. " $\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$ and $\frac{7}{8}$ to decimals.
3. " $\frac{15}{16}$, $\frac{13}{16}$, $\frac{11}{16}$, $\frac{9}{16}$, $\frac{7}{16}$, $\frac{5}{16}$, $\frac{3}{16}$ and $\frac{1}{16}$ to decimals.

Engineers sometimes find it convenient to reduce a decimal to a particular vulgar fraction, generally quarters, eighths, sixteenths or thirty-seconds. This is done thus:

Multiply the given decimal by the denominator you wish to bring it to, mark off as many decimals from right to left as were given, and whatever number is to the left of the decimal point is the required numerator.

EXAMPLES.

How many eights are there in .114 ?

$$\begin{array}{r} .114 \\ 8 \\ \hline .912 \end{array}$$

Answer. None, exactly, but nearly $\frac{1}{8}$.

How many sixteenths are there in .198 ?

$$\begin{array}{l} .198 \\ 16 \\ \hline 1188 \\ 198 \\ \hline 3.168 \end{array}$$

Answer, a little over $\frac{3}{16}$.

Sometimes in reducing a vulgar fraction to a decimal fraction the quotient never comes to an end, but the same number keeps on repeating itself as $\frac{1}{6} = 1.66666$, etc., without end. This is called a repeating decimal, is written $.1\dot{6}$. The dot over the 6 represents that it is a repeater.

A decimal fraction derives its name from the Latin word *decem*, ten, which denotes the nature of its numbers. It has for its denominator, a whole thing as a gallon, a pound, a yard, etc., which articles we suppose to be divided in tenths, hundredths; etc.

ADDITION OF DECIMALS.

Place the quantities down in such a manner that the decimal point of one line shall be exactly under that of every other line; then add up as in simple addition.

EXAMPLE.

Thus:—Add together 36.74, 2.98046, 176.4, 31.0071 and .08647.

$$\begin{array}{r@{.}l} 36 & 74 \\ 2 & 98046 \\ 176 & 4 \\ 31 & 0071 \\ & 08647 \\ \hline 247 & 21403 \end{array}$$

Examples for Exercise.

1. Add together 29.0146, 3146.05, 21.09, 6.20471 and 4.075.
2. " " 17.14, 3.9876, 207.10104, 13.1 and 146.
3. Find the sum of 241.01+13.98+1.90246+176.2007+14.-125.
4. Find the sum of 27.27+1.125+147.5+16.0125+170.9875.

SUBTRACTION OF DECIMALS.

Place the lines with decimal point under decimal point, as in Addition. If one line has more decimal figures than another, put naughts under the one that is deficient till they are equal then subtract as in simple subtraction.

Examples.

From 146.2004 take 98.9876.

```
146.2004
 98.9876
--------
 47.2128 Answer.
```

From 4.17 take 1.984625.

```
4.170000
1.984625
--------
2.185375 Answer.
```

Examples for Exercise.

1. From 46.24 take 17.09864.
2. " .2406 " .1400726.
3. Find the value of 240.−27.7065.
4. " " 19.72461−3.9827.

MULTIPLICATION OF DECIMALS.

Rule.

Multiply as in common multiplication without taking notice of the decimal point, add up and so get the product; then count all the figures after or at the right of the decimal points in the multiplier and multiplicand; count from the right towards the left of the product as many figures as the *sum* of the decimals just counted; put a decimal point before the figures and you have the answer.

EXAMPLE.

Multiply 27.62 by 5.713.

```
    27.62
    5.713
   ------
    8286
   2762
  19334
 13810
 ---------
 157.79306
```

The product first stood 15779306, but as there are altogether five decimal figures in the question, we count five beginning at the last or figure 6, and place a decimal point before the figure that stands in the fifth place. The answer is 157.79306.

EXAMPLE.

Multiply .00072 by 0.502.

```
 .00072
  ·0502
 ------
    144
  3600
 ------
  36144
```

The product is 36144, but as we have nine places of decimals in the example, we must have the same number of decimals in the product. This is done by putting cyphers to the *left* of the product. The answer is .000036144.

EXAMPLES FOR EXERCISE.

1. Multiply 724.02 by 23.14.
2. " 23.567 by 3.25.
3. " .3024 by .3055.
4. " .5652 by .0025.
5. " .0002 by .00101.
6. " 176401 by 76.43.

DIVISION OF DECIMALS.

1. *When the divisor is a whole number:* divide as in simple division, only when you come to the decimal point place a point under it in the quotient.

EXAMPLES.

Divide 763.5676 by 4.

```
4)763.5676
  --------
  190.8919
```

Divide 1537.27 by 8.

```
8)1537.27
  ---------
  192.15875
```

After saying 8 into 47 goes 5 times and 7 over, make this 7 into 70; 8 into 70 goes 8 times and 6 over; 8 into 60 goes 7 times and 4 over; 8 into 40 goes 5 times.

Divide 72.6432 by 24.

24 is 6 times 4. Divide by 6, and then the quotient by 4.

$$24\left\{\begin{array}{r} 6)72.6432 \\ \hline 4)12.1072 \end{array}\right.$$

$$\begin{array}{r} \hline 3.0268 \end{array} \text{ Answer.}$$

Divide 7196.148 by 1728.

```
1728)7196.148(4.1644 etc.
     6912
     ----
      2841
      1728
      -----
      11134
      10368
      -----
        7668
        6912
        ----
         7560
         6912
         ----
          648
```

or

$$1728\left\{\begin{array}{r} 12)7196.148 \\ \hline 12)599.679 \\ \hline 12)49.7325 \\ \hline 4.1644375 \end{array}\right.$$

DIVISION OF DECIMALS.

Here after the 8 is brought down it goes 4 times, and the remainder is 756; to this attach an 0, and let it go again, and so on as far as it is thought necessary.

When the number of decimal figures in the divisor is less than that in the dividend, divide without taking notice of the decimals; then *subtract* the number of decimals in the divisor from the number in the dividend; the remainder will be the number to mark off in the quotient.

EXAMPLES.

Divide 172.4025 by .5.

$$\begin{array}{r} .5)172.4025 \\ \hline 34.4805 \end{array}$$

Here we say 1 from 4 leaves 3: then mark off 3 decimals in answer.

Divide .0041275 by .25.

$$25\left\{\begin{array}{l} 5).0041275 \\ \hline 5)\quad 8255 \\ \hline \quad\quad 1651 \end{array}\right.$$

Here it is 2 from 7 leaves 5: mark off 5 in the quotient; we cannot because there are only 4; then attach a cypher to the left and it becomes .01651 Answer.

172.4025 by .5.

First shift the decimal back one place and it becomes 1724.-025 by .5.

$$\begin{array}{l} \text{Then } 5)1724.025 \\ \hline \quad 3448.05 \text{ which is the same as before.} \end{array}$$

Divide .0041275 by .25.

First shift the decimal back two places and it becomes 00.41275.

$$25\left\{\begin{array}{l} 5).41275 \\ \hline 5).08255 \\ \hline \quad .01651 \text{ (1651) which is the same as before.} \end{array}\right.$$

4. *When the decimals in the divisor are more than those in the dividend.* First equalize the decimals by attaching naughts to that which has the least; then leave out the points altogether and divide as in simple division, and the quotient is whole numbers. If there is a remainder after this, attach a naught to it and again divide; this will give the first decimal of the quotient; to the remainder again attach a naught; again divide for the second decimal figure and so on as far as may be thought necessary.

EXAMPLES.

Divide 1.1 by .275.

Equalize the decimal figures thus: 1.100 by .275, and then leave out the decimal point and divide thus:

```
275)1100(4
    1100
    ——— Answer 4 whole numbers.
```

1562.5 by .00025.

Equalize 1562.50000 by .00025, then leaving out the points divide as in Simple Division.

```
   ⎧ 5)156250000
25 ⎨    ————————
   ⎩ 5) 31250000
        ————————
         6250000 Answer.
```

Divide 147.24 by .84625.

Equalize 147.2400 by .84625.

```
84625)1472400(173.99, etc.
      84625
      ——————
      626150
      597325
      ——————
       337750
       253875
       ——————
        838750
        761625
        ——————
         771250
         761625
         ——————
```

Here it goes once, then seven times and then 3 times; and as there are no more figures left to bring down these 173 are whole numbers. To find the decimals attach a cypher to the remainder 83875, and it goes 9 times; this is put in the quotient as .9; to the remainder 77125 attach another cypher and it goes 9 again; put this 9 after the former one; attach another cypher to the remainder if necessary and continue as far as you please.

EXAMPLES FOR EXERCISE.

1. Divide 713.915 by 5.
2. " 39.5424 by 8.
3. " .936571 by 12.
4. " 2366.745 by 15.
5. " 87916.05 by 88.
6. " 375.4329 by 80.
7. " 17624 by .6725.
8. " 46.59005 by 7.25.
9. " 210.75 by 24.25.

UNITED STATES MONEY.

United States money is added, substracted and divided in all respects like Decimal Fractions.

50 cts. = $\$\frac{1}{2}$.	$12\frac{1}{2}$ cts. = $\$\frac{1}{8}$.
$33\frac{1}{3}$ " = $\$\frac{1}{3}$.	10 " = $\$\frac{1}{10}$.
25 " = $\$\frac{1}{4}$.	$8\frac{1}{3}$ " = $\$\frac{1}{12}$.
20 " = $\$\frac{1}{5}$.	$6\frac{1}{4}$ " = $\$\frac{1}{16}$.
$16\frac{2}{3}$ " = $\$\frac{1}{6}$.	5 " = $\$\frac{1}{20}$.

The dollar is the *unit* with the decimal point placed *after* it. *Cents* occupy two places, hence if the number to be expressed is *less* than 10 a cypher must be prefixed to the figure denoting them. Mills occupy the place of thousandths.

Example. Two dollars and eight cents is written $2.08.

PERMUTATION.

Permutation is the method for ascertaining how many different ways any given number of persons or things may be varied in their positions.

RULE.

Multiply all the terms of the natural series continually together, and the last product will be the number of changes which may be effected.

EXAMPLE.

How many positions in a row can 8 things be placed.

1 2 3 4 5 6 7 8

And $1\times2\times3\times4\times5\times6\times7\times8=40{,}320$ Ans.

MENSURATION.

Mensuration is the art of measuring things which occupy space; the art is partly mechanical, and partly mathematical, hence can be illustrated with drawings to aid in the better understanding of the arithmetical problems connected with the art.

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 can only be done by calculations, but in mechanical measurements they are made by the direct application of rules, tape-lines and chains.

Lengths are measured on lines, and the measure of a length of a line is the ratio which the line bears to a recognized *unit of length,* the inch, foot, or mile, determined by reference to brass rods kept by the U. S. 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 measurements 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.

MENSURATION.

To find the length of the curved line, called the circle; that is, to find the circumference of a circle.

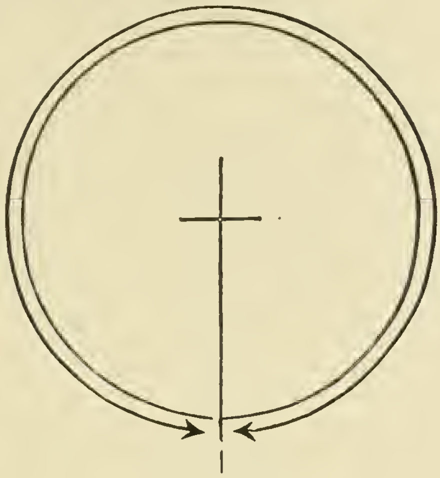


Fig. 29.

RULE.—Multiply 3.1416 by the diameter.

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.

EXAMPLE.

What is the circumference of a circle whose diameter is $4\frac{1}{2}$ inches ?

$$\begin{array}{r} 3.1416 \\ 4.5 \\ \hline 157080 \\ 125664 \\ \hline \end{array}$$

Answer, 14.13720 inches.

EXAMPLES FOR EXERCISE.

1.	Diameter	5 in.,	required the circumference?	Ans.	15.708
2.	"	5.6 in.	" "	"	17.59296
3.	"	2.5 in.	" "	"	7.854
4.	"	4 in.	" "	"	12.5664
5.	"	$3\frac{1}{4}$ in.	" "	"	10.2102
6.	"	$7\frac{5}{8}$ in.	" "	"	23.9547

MENSURATION.

To find the area of a circle.

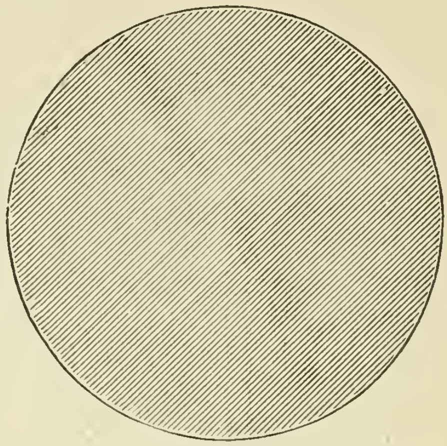


Fig. 30.

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

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.

A very easy method of multiplying by .7854 is shown by the following:—

```
12.25
    7
—————
8575
  8575
  17150=product of first line of
   17150        multiplication × 2.
—————————
9.621150
```

The method of procedure is as follows:—The number is multiplied first by 7 by common multiplication, this line is put down a second time, only removed one place to the right instead of to the left, as in ordinary multiplication. *This line* is now multiplied by 2, and its result put down one place to the right, this line is again put down one place to the right and the sum of these products is the same as if we had multiplied by .7854 in the ordinary manner. The process may be rendered clearer if the reason for the method is explained. If we put down the number 7, then one place to the right put it down again; then multiply it by 2 and put product one place to the right, then put this down again one place to the right, and add them all up, we clearly get the number 7854, therefore if we multiply in this order we get the same result as if .7854 had been used full out.

```
7
 7
 14
  14
----
7854
```

EXAMPLES.

```
3712816×.7854
      7
--------
25989712
 25989712
  51979424
   51979424
-------------
2916045.6864
```

```
46219872×.7854
       7
---------
323539104
 323539104
  647078208
   647078208
--------------
36301087.4688
```

EXAMPLES FOR EXERCISE.

1. The diameter of a circle is 5 inches, find its area.
   Answer, 19.635 square inches.
2. " of a circle is 4.6 inches, find its area.
   Answer, 16.619064 square inches.
3. " of a circle is $6\frac{7}{8}$ inches, find the area.
   Answer, 37.122421875 square inches.

MENSURATION.

To find the Circumference of an Ellipse.

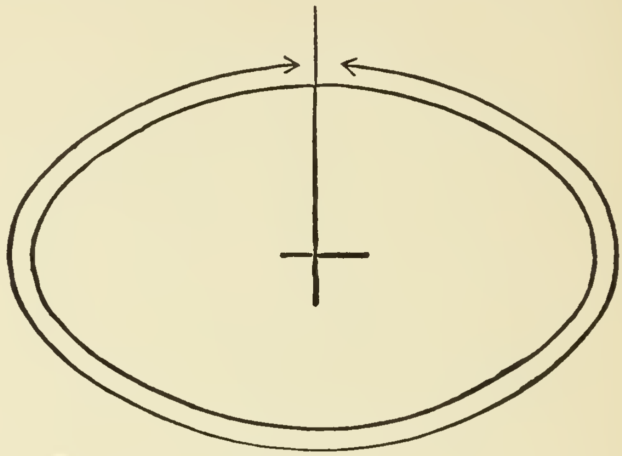


Fig. 31.

Rule.

Multiply 3.1416 by half the sum of the two diameters; the product will be the circumference nearly.

Example.

What is the circumference of an ellipse whose diameters are 9 and 7 feet?

9	3.1416
7	8
2)16	25.1328 feet, Answer.
8	

Example.

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

5.75	3.1416
4.25	5
2)10.00	15.7080
5	

MENSURATION.

To find the Area of an Ellipse.

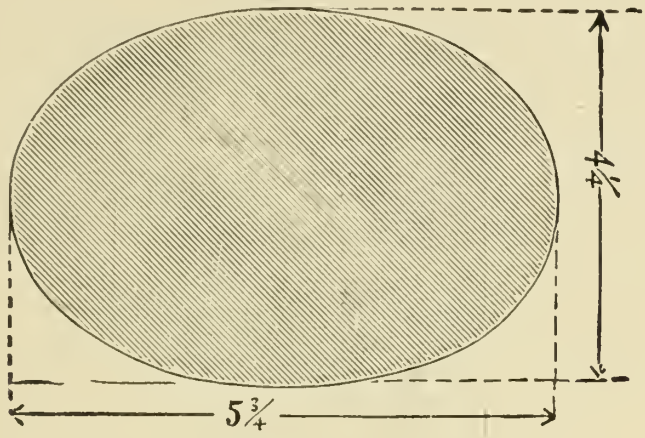


Fig. 32.

Rule.

Multiply .7854 by the product of the diameters.

Example.

What is the area of an ellipse whose diameter is $5\frac{3}{4}$ and $4\frac{1}{2}$?

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

Example.

What is the area of an ellipse whose diameters are 7 and 9 feet?

7	.7854
9	63
63	23562
	46124
	40.4802 square feet, Answer.

MENSURATION.

To find the area of a Square.

NOTE.

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

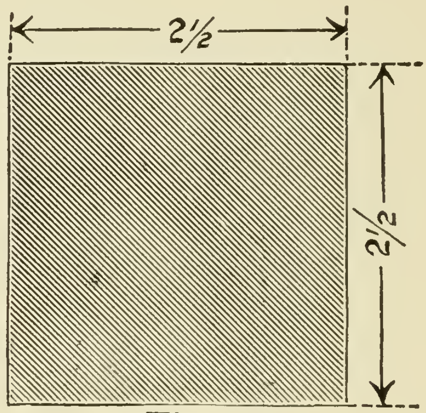


Fig. 33.

RULE.

Multiply the base by the height; that is multiply the length by the breadth.

EXAMPLE.

What is the area of a square whose side is $2\frac{1}{2}$ feet?

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

Answer, 6.25 square feet.

To find the area of an Oblong.

NOTE.

An Oblong is a figure whose angles are all right angles, but whose sides are not all equal, only the opposite sides are equal.

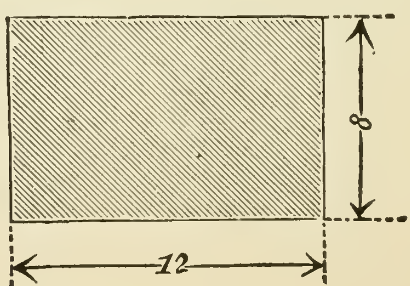


Fig. 34

MENSURATION.

RULE.

Multiply the length by the breadth.

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.

NOTE.

A Parallelogram is a figure whose opposite side 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.

EXAMPLE.

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

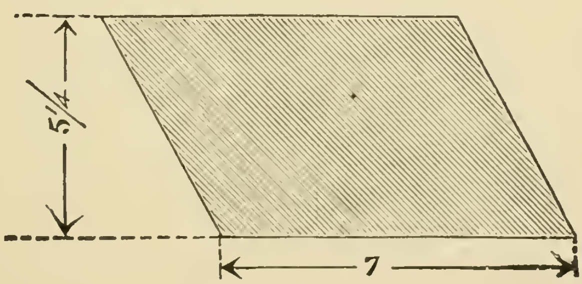


Fig. 35.

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

Answer, 36.75 square feet.

MENSURATION.

To find the area of a Triangle.

NOTE.

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.

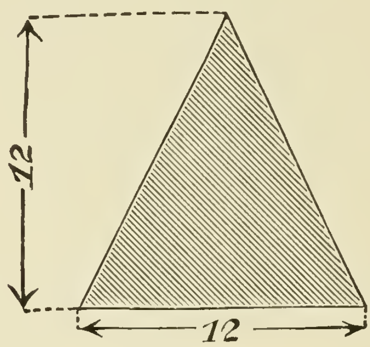


Fig. 36.

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 $12 \times 6 = 72$ square feet area.

To find the area of a Trapezium.

NOTE.

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

RULE.

Join two of its opposite angles, and thus divide it into two triangles.

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

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

MENSURATION.

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

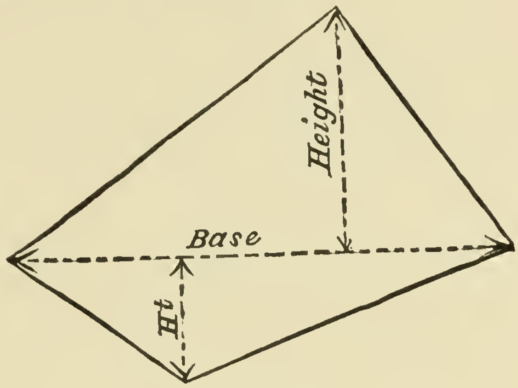


Fig. 37.

To find the area of a Trapezoid.

NOTE.

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.

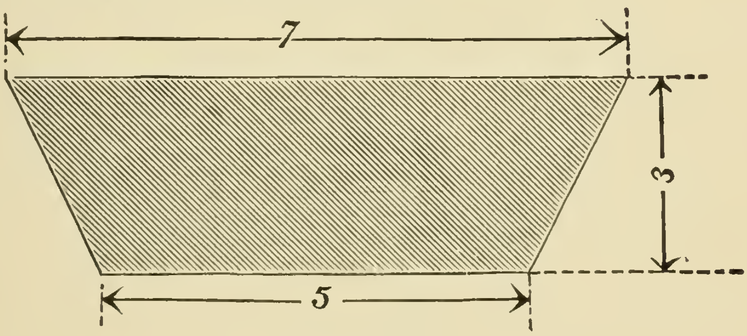


Fig. 38.

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.

MENSURATION.

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.

EXAMPLE.

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

$$
\begin{array}{r l}
3.1416 & \\
9 & \\
\hline
28.2744 & =\text{circumference.} \\
15 & \\
\hline
1413720 & \\
282744 & \\
\hline
424.1160 & \text{area of surface in square inches.}
\end{array}
$$

To find the Surface or Envelope of a Sphere.

NOTE.

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?

$$
\begin{array}{r l}
3.1416 & \\
9 & =3^2 \\
\hline
28.2744 & \text{area of surface in square feet.}
\end{array}
$$

CONTENTS OF SOLIDS.

To find the Contents of a Rectangular Solid.

RULE.

Multiply the length, breadth, and height together.

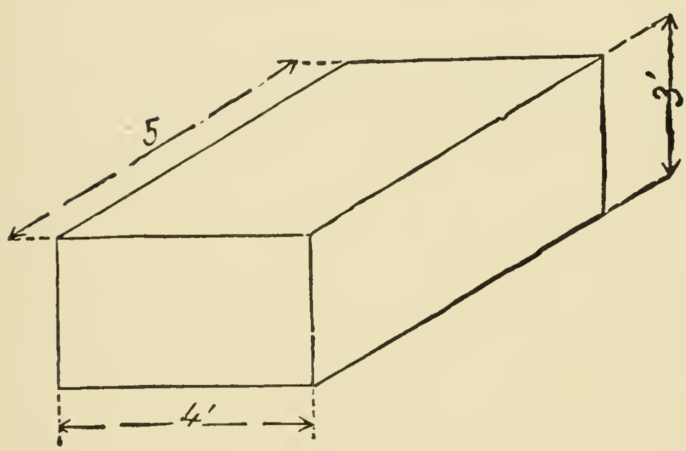


Fig. 39.

EXAMPLE.

What is the content 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

CONTENTS OF SOLIDS.

To find the cubic cantents of a Solid Cylinder.

RULE.

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

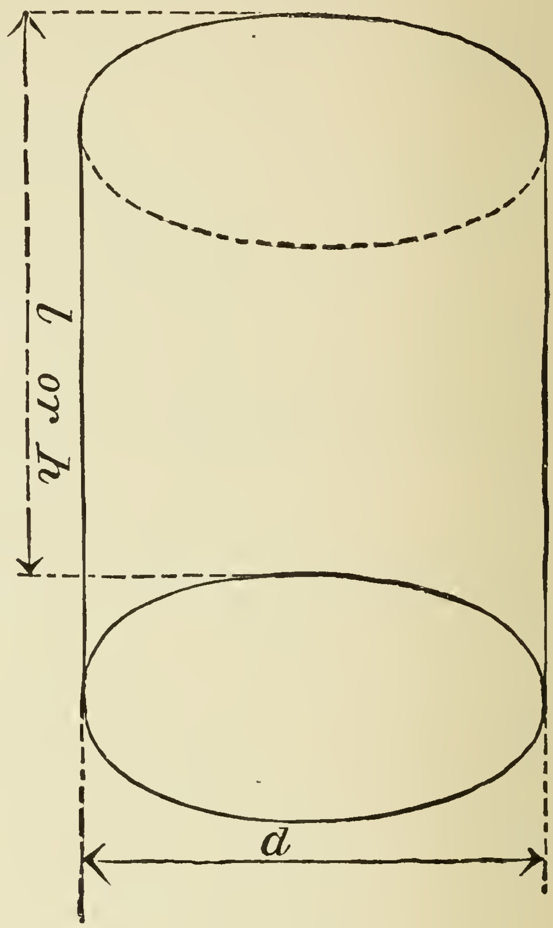


Fig. 40.

EXAMPLE.

What are 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 Cubic contents of a Sphere.

RULE.

Multiply .7854 by the cube of the diameter, and then take $\frac{2}{3}$ of the product.

EXAMPLE.

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

$$\begin{array}{r} 5 \\ 5 \\ \hline 25 \\ 5 \\ \hline 125 = 5^3 \end{array} \qquad \begin{array}{r} .7854 \\ 125 \\ \hline 39270 \\ 15708 \\ 7854 \\ \hline 98.1750 \\ 2 \\ \hline 3)196.3500 \\ \hline \end{array}$$

Answer, 65.4500 cubic feet.

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.")

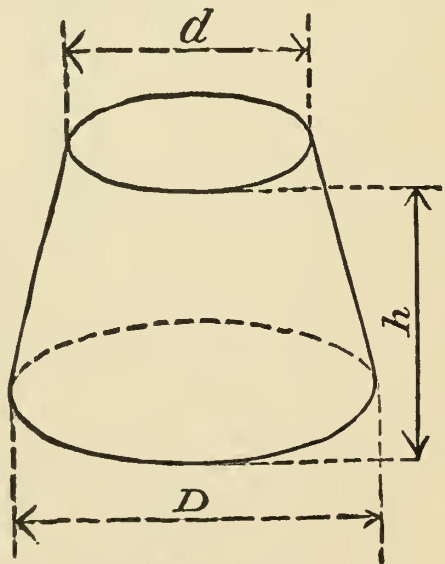


Fig. 41.

EXAMPLE.

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

$144 + 36 + 72 \times .7854 \times 1.33$

$252 \times .7854 \times 1.33 \times = 263.23$ &c. cubic inches.

VULGAR FRACTIONS.

A fraction means a part of anything. If an apple be cut into eight equal parts each part will be called an eighth of the whole apple, and is written $\frac{1}{8}$. This eighth is a fraction. If we had 3 or 5 or 7 of these pieces of the apple, we would represent it by $\frac{3}{8}$, $\frac{5}{8}$, or $\frac{7}{8}$, as the case might be. All these are fractions.

A vulgar fraction is always represented by two numbers (at least), one over the other and separated by a small horizontal line. The one above the line is always called the *Numerator,* and the one below the line the *Denominator.*

The denominator tells us how many parts the whole thing has been divided into, and the numerator tells us how many of those parts we have. Thus in the fraction $\frac{3}{8}$ above, the eight is the denominator, and shows that the apple has been divided into eight equal parts; and three is the numerator, and shows that we have three of those pieces or parts of the apple.

A proper fraction is one whose numerator is less than the denominator, as $\frac{3}{8}$ or $\frac{2}{5}$.

An improper fraction is one whose numerator is more than its denominator as $\frac{8}{3}$ or $\frac{5}{2}$.

$\frac{8}{3}$ means more than a whole one, because $\frac{3}{3}$ must be a whole one. Thus $\frac{8}{3}$ will be 3 thirds + 3 thirds + 2 thirds or $2\frac{2}{3}$, and this form of fraction is called *a mixed number.*

VULGAR FRACTIONS.

1. *To reduce an improper fraction to a mixed number* Divide the numerator by the denominator; the quotient is the whole number part, and the remainder is the numerator of the fractional part.

Example: $\frac{16}{7}=2\frac{2}{7}$. Example: $\frac{15}{3}=5$. Example: $\frac{27}{8}=3\frac{3}{8}$.

2. *To reduce a mixed number to an improper fraction.* Multiply the whole number part by the denominator, and add on the numerator; the result is the numerator of the improper fraction.

Example: $2\frac{2}{7}=\frac{16}{7}$. Example: $5\frac{1}{3}=\frac{16}{3}$. Example: $3\frac{3}{8}=\frac{27}{8}$.

3. *To reduce a fraction to its lowest terms.* Divide both numerator and denominator by the same number; if by so doing, there is no remainder.

Example.

Reduce $\frac{8}{12}$. Here 4 will divide both top and bottom without a remainder. Divide by 4.

$$4)\frac{8}{12}=\frac{2}{3}.$$

The meaning of this is, that if you divide a thing into 12 equal parts, and take 8 of them, you will have the same as if the thing had been divided into 3 equal parts and you had 2 of them.

Example.

Reduce $\frac{1728}{13824}$ to its lowest terms. First divide top and bottom by 12 and it becomes $\frac{144}{1152}$; then divide top and bottom again by 12 and it becomes $\frac{12}{96}$; 12 will again divide them and it becomes $\frac{1}{8}$, which is its lowest term.

Examples for Exercise.

Reduce to their lowest terms $\frac{6}{12}$; $\frac{14}{21}$; $\frac{18}{54}$; $\frac{144}{1728}$; $\frac{156}{169}$ and $\frac{4374}{5103}$.

4. To reverse the last rule. *To bring a fraction of any denominator to a fraction having a greater denominator.*

See how often the less will go into the greater denominator and multiply both numerator and denominator by it. The result is the required fraction.

EXAMPLE.

Bring $\frac{1}{2}$ to a fraction whose denominator is 8.

Here 2 goes in 8, 4 times; then multiply the numerator and denominator of $\frac{1}{2}$ by $4=\frac{4}{8}$, which is the required fraction.

EXAMPLE.

Bring $\frac{2}{3}$ to a fraction whose denominator is 15.

Here 3 goes into 15 five times; then $\frac{2}{3}$ becomes $\frac{10}{15}$.

5. If you have a fraction of a fraction, as $\frac{1}{2}$ of $\frac{1}{4}$, it is called a compound fraction, and should always be reduced to a simple fraction, by multiplying all the numerators together for a new numerator, and all the denominators together for a new denominator; then, if necessary, reduce this fraction to its lowest terms.

EXAMPLE.

$\frac{3}{4}$ of $\frac{2}{3}$ of $\frac{4}{9}$. Reduce this to a single fraction: $3\times2\times4=24$; and $4\times3\times9=108$.

Thus $\frac{24}{108}$ is the fraction. Reduce this $12\,)\frac{24}{108}=\frac{2}{9}$.

CANCELLATION.

This is a method of shortening problems by rejecting equal factors from the divisor and dividend.

The sign of cancellation is an oblique mark drawn across the face of a figure as $\cancel{4}$, $\cancel{6}$, $\cancel{2}$.

Cancellation means to leave out; if there are the same numbers in the numerator and the denominator they are to be left out.

EXAMPLE.

$\frac{3}{4}$ of $\frac{2}{3}$ of $\frac{4}{9}$. Here the 3 in the first numerator and the 3 in the 2d denominator are left out; also 4 of the first denominator and the last numerator, thus:

$$\text{Ans. } \frac{\cancel{3}}{\cancel{4}}\times\frac{2}{\cancel{3}}\times\frac{\cancel{4}}{9}=\frac{2}{9}$$

There is another way of cancellation.

EXAMPLE.—$\frac{2}{9}$ of $\frac{3}{8}$ of $\frac{14}{18}$ of $\frac{90}{170}$ = by cancellation, thus:

$$\frac{\cancel{2}}{\underset{3}{\cancel{9}}} \text{ of } \frac{\cancel{3}}{\underset{\underset{2}{\cancel{4}}}{\cancel{8}}} \text{ of } \frac{\overset{7}{\cancel{14}}}{\cancel{18}} \text{ of } \frac{\overset{5}{\cancel{90}}}{\underset{34}{\cancel{170}}} = \frac{7}{3\times2\times34} = \frac{7}{204}$$

The process is as follows:—The first numerator 2 will go into 8 the denominator of the second fraction 4 times; the denominator of the third fraction 18 will go into 90, the numerator of the last quantity 5 times. The numerator of the second fraction 3, will go into the denominator of the first fraction, 3 times; 5 will go into 170, 34 times; 2 will go into 4 twice, and 2 into 14, 7 times, and as we cannot find any more figures that can be divided without leaving a remainder we are at the end, and the quantities left must be collected into one expression. On examination we have 7 left on the top row, this is put down at the end as the final numerator; on the bottom we have 3, 2, and 34, these multiplied together give us 204, which is the final denominator.

RULES FOR CANCELLING.

1. Any numerator can be divided into any denominator provided no remainder is left, and *vice versa*, thus:

$$\frac{\cancel{3}}{5} \text{ of } \frac{4}{\underset{3}{\cancel{9}}} = \frac{4}{15} \qquad \Bigg| \qquad \frac{\cancel{3}}{\cancel{5}} \text{ of } \frac{\overset{\cancel{3}}{\cancel{15}}}{\underset{\underset{2}{\cancel{6}}}{\cancel{18}}} = \frac{1}{2}$$

2. Any numerator and denominator may be divided by the same number, provided no remainder is left, and the decreased value of such numerator and denominator be inserted in the place of those cancelled,—

$$\frac{\cancel{3}}{\underset{2}{\cancel{8}}} \text{ of } \frac{\overset{5}{\cancel{20}}}{31}$$

Here 8 is divided by 4, and 20 can also be divided by the same number without leaving any remainder. Answer $\frac{5}{62}$.

EXAMPLE.

$$\frac{\cancel{8}}{\underset{3}{\cancel{15}}} \text{ of } \frac{\cancel{5}}{\underset{\underset{2}{\cancel{4}}}{\cancel{32}}} \text{ of } \frac{\overset{7}{\cancel{14}}}{17} = \frac{7}{3\times2\times17} = \frac{7}{102}$$

Examples for Exercise.

Reduce to their simplest form the fractions:

1. $\frac{1}{2}$ of $\frac{2}{3}$ of $\frac{3}{4}$ of $\frac{4}{5}$.

This can be done by cancelling.

$$\frac{1}{\cancel{2}} \text{ of } \frac{\cancel{2}}{\cancel{3}} \text{ of } \frac{\cancel{3}}{\cancel{4}} \text{ of } \frac{\cancel{4}}{5} = \frac{1}{5} \text{ Answer.}$$

2. $\frac{3}{5}$ of $\frac{15}{16}$ of $\frac{4}{9}$.

By cancelling.

$$\frac{\cancel{3}}{\cancel{5}} \text{ of } \frac{\overset{3}{\cancel{15}}}{\underset{4}{\cancel{16}}} \text{ of } \frac{\cancel{4}}{\underset{3}{\cancel{9}}} = \frac{3}{4\times 3} = \frac{3}{12} = \frac{1}{4} \text{ Answer.}$$

3. $\frac{5}{7}$ of $\frac{1}{4}$ of $\frac{14}{15}$.

By cancelling.

$$\frac{\cancel{5}}{\cancel{7}} \text{ of } \frac{1}{\underset{2}{\cancel{4}}} \text{ of } \frac{\overset{\cancel{2}}{\cancel{14}}}{\underset{3}{\cancel{15}}} = \frac{1}{2\times 3} = \frac{1}{6} \text{ Answer.}$$

ADDITION OF FRACTIONS.

Add together $\frac{1}{8}$, $\frac{3}{8}$ and $\frac{5}{8}$. Here it is evident that the sum will be $\frac{9}{8}$ or $1\frac{1}{8}$. Hence the rule: Bring all the fractions to the same common denominator, add their numerators together for the new numerator, and reduce the resulting fraction to its simplest form.

Examples.

What is the sum of $\frac{1}{4}+\frac{1}{2}=\frac{1}{4}+\frac{2}{4}=\frac{3}{4}$ Ans.

What is the sum of $\frac{3}{4}+\frac{1}{2}+\frac{3}{8}+\frac{6}{8}=\frac{13}{8}=1\frac{5}{8}$.

To bring fractions having different denominators to fractions having one common denominator.

Rule.

1. Put all the denominators down in a row; cancel all that are alike except one; also cancel any that will divide into another one without remainder.

2. If there is any number that will divide two or more of those left, then divide by it, putting down those numbers also that cannot be divided. Repeat this till all the numbers are prime numbers.

3. Then multiply all these prime numbers together, and their product by all the divisors: the result will be the common denominator for all the fractions.

4. Lastly, divide this common denominator by the denominator of the first fraction, and multiply its quotient by its numerator; the product is the new numerator required. Repeat this for each fraction.

EXAMPLE.

$\frac{1}{2}$, $\frac{5}{6}$, $\frac{2}{3}$, $\frac{3}{8}$, $\frac{1}{3}$, $\frac{5}{8}$, $\frac{7}{12}$, $\frac{5}{16}$, $\frac{1}{8}$ and $\frac{3}{4}$. Bring these fractions to others having a common denominator.

2 6 3 8 3 8 12 16 8 4

There are 2 figures 3, cancel one of them, there are 3 figures 8, cancel 2 of them; next the 2, 8 and 4 will each go into 16, therefore they must be cancelled; the 6 and 3 also, because they will each divide into 12; then there only remain the 12 and 16, place them as below and divide them by 4. See Article 2 of rule

$$\begin{array}{r|rr} 4 & 12 & 16 \\ \hline & 3 & 4 \end{array}$$

Then multiply the 3 by the 4 = 12, and this 12 by the divisor 4 = 48, the common denominator.

Lastly, bring each fraction to one having the denominator 48 by rule (article 4) heretofore given.

$$\begin{array}{lcccccccccc} & \frac{1}{2} & \frac{5}{6} & \frac{2}{3} & \frac{3}{8} & \frac{1}{3} & \frac{5}{8} & \frac{7}{12} & \frac{5}{16} & \frac{1}{8} & \frac{3}{4} \\ \text{Ans.} & \frac{24}{48} & \frac{40}{48} & \frac{32}{48} & \frac{18}{48} & \frac{16}{48} & \frac{30}{48} & \frac{28}{48} & \frac{15}{48} & \frac{6}{48} & \frac{36}{48} \end{array}$$

EXAMPLE.—Add together $\frac{4}{5}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{7}{10}$ and $\frac{1}{2}$.

$$\begin{array}{r|l} 2 & ,\ 3,\ 4,\ 10, \\ \hline & 3,\ 2,\ 5 \end{array}$$

$$\begin{array}{rl} 5 & \\ 2 & \\ \hline 10 & \\ 3 & \\ \hline 30 & \\ 2 & \text{Divisor} \\ \hline 60 & \text{Common denominator} \end{array}$$

$$\frac{48+40+45+42+30}{60} = \frac{205}{60} = 3\frac{25}{60} = 3\frac{5}{12}.$$

Examples for Exercise.

1. Add together $\frac{1}{2}$, $\frac{3}{4}$, $\frac{1}{4}$, and $\frac{5}{8}$.
2. " " $\frac{3}{4}$, $\frac{5}{6}$, $\frac{3}{8}$, and $\frac{2}{3}$.
3. " " $\frac{4}{5}$, $\frac{7}{10}$, $\frac{5}{12}$ and $\frac{5}{6}$.
4. " " $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{5}{8}$, $\frac{7}{8}$, $\frac{13}{16}$ and $\frac{7}{16}$.
5. " " $\frac{3}{7}$, $\frac{2}{5}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{3}{10}$ and $\frac{5}{8}$.

SUBTRACTION OF FRACTIONS.

Bring the fractions to others having a common denominator, as in addition, and subtract their numerators.

Examples.

From $\frac{7}{8}$ subtract $\frac{3}{8} = \frac{4}{8} = \frac{1}{2}$.

From $\frac{1}{2}$ take $\frac{1}{6}$. $\frac{3-1}{6} = \frac{2}{6} = \frac{1}{3}$.

$\frac{7}{16} - \frac{3}{8} = \frac{7-6}{16} = \frac{1}{16}$.

What is the difference between $\frac{1}{2}$ of $\frac{3}{4}$ and $\frac{1}{4}$ of $1\frac{1}{2}$?

$\frac{1}{2}$ of $\frac{3}{4} = \frac{3}{8}$; and $\frac{1}{4}$ of $1\frac{1}{2} = \frac{1}{4}$ of $\frac{3}{2} = \frac{3}{8}$.

Therefore it is $\frac{3}{8} - \frac{3}{8} = 0$.

Which is the greater, $\frac{1}{3}$ of $\frac{9}{10}$ or $\frac{5}{6}$ of $\frac{8}{15}$?

$\frac{1}{3}$ of $\frac{9}{10} = \frac{3}{10}$; and $\frac{5}{6}$ of $\frac{8}{15} = \frac{4}{9}$.

Therefore it is $\frac{3}{10}$ and $\frac{4}{9}$.

$$\frac{27 \text{ and } 40}{90}$$

Then $\frac{5}{6}$ of $\frac{8}{15}$ is the greater by $\frac{13}{90}$.

Examples for Exercise.

1. $\frac{1}{2} - \frac{1}{4}$; $\frac{5}{8} - \frac{1}{2}$; $\frac{5}{6} - \frac{1}{12}$; $\frac{3}{8} - \frac{1}{4}$.
2. $\frac{5}{7} - \frac{2}{3}$; $\frac{3}{5} - \frac{2}{7}$. $\frac{7}{16} - \frac{1}{7}$.
3. What is the difference between $\frac{3}{7}$ of $\frac{5}{9}$ and $1\frac{1}{2}$ of $\frac{4}{9}$?
4. Which is the greatest, $3\frac{3}{8}$ of $2\frac{2}{9}$ or $8\frac{1}{3}$ of $1\frac{4}{5}$?

MULTIPLICATION OF FRACTIONS.

First bring each fraction to its simplest form; then multiply the numerators together for the new numerator, and the denominators together for the new denominator. Reduce the fraction to its simplest form.

Examples.

1. Multiply $\frac{4}{7}\times 1\frac{5}{16}$; that is $\frac{4}{7}\times\frac{21}{16}=\frac{84}{112}=\frac{21}{28}=\frac{3}{4}$, or by canceling

$$\frac{\overset{1}{\cancel{4}}}{\underset{1}{\cancel{7}}}\times\frac{\overset{3}{\cancel{21}}}{\underset{4}{\cancel{16}}}=\frac{3}{4}$$

The 4 cancels into the 16 four times, and the 7 into the 21 three times. Thus $1\times 3=3$, and $1\times 4=4$. Answer $\frac{3}{4}$.

2. $2\frac{1}{10}$ of $3\frac{4}{7}\times 6\frac{1}{8}$ of $\frac{8}{21}$.

$$\frac{\overset{3}{\cancel{21}}}{\underset{2}{\cancel{10}}}\text{ of }\frac{\overset{5}{\cancel{25}}}{\underset{1}{\cancel{7}}}\times\frac{\overset{7}{\cancel{49}}}{\underset{1}{\cancel{8}}}\text{ of }\frac{\overset{1}{\cancel{8}}}{\underset{3}{\cancel{21}}}$$

$$\frac{\overset{5}{\cancel{15}}}{2}\times\frac{7}{\underset{1}{\cancel{3}}}=\frac{35}{2}=17\tfrac{1}{2}\text{ Answer.}$$

Examples for Exercise.

1. Multiply $\frac{1}{2}\times\frac{1}{4}$; $\frac{3}{4}\times\frac{8}{9}$; $\frac{5}{16}\times\frac{8}{25}$.
2. " $1\frac{2}{3}\times 1\frac{4}{5}$; $5\frac{3}{5}\times 3\frac{3}{14}$; $4\frac{2}{7}\times 2\frac{1}{10}$.
3. " $\frac{1}{2}$ of $\frac{2}{3}$ of $\frac{3}{4}\times\frac{3}{5}$ of $\frac{5}{6}$ of $\frac{2}{7}$.

DIVISION OF FRACTIONS.

Reverse the divisor and proceed as in multiplication.

The object of inverting the divisor is convenience in multiplying.

After inverting the divisor, cancel the common factors.

Examples.

$\frac{3}{4}\div 1\frac{1}{8}$, that is, $\frac{3}{4}\div\frac{9}{8}$, reverse the $\frac{9}{8}$ and it becomes $\frac{8}{9}$; then the question is $\frac{3}{4}\times\frac{8}{9}=\frac{24}{36}=\frac{2}{3}$ Ans.

$4\frac{2}{7}$ of $\frac{14}{15}\div 3\frac{3}{4}$ of $3\frac{1}{5}$, that is $\frac{30}{7}$ of $\frac{14}{15}\div\frac{15}{4}$ of $\frac{16}{5}$; cancelling reduces the dividend to $\frac{4}{1}$ and the divisor to $\frac{12}{1}$ and we have $\frac{4}{1}\div\frac{12}{1}$, that is $\frac{4}{1}\div\frac{1}{12}=\frac{4}{12}=\frac{1}{3}$ Ans.

Examples for Exercise

1. $\frac{1}{2}\div\frac{1}{2}$; $\frac{2}{3}\div\frac{1}{4}$; $\frac{3}{4}\div\frac{1}{2}$; $\frac{4}{5}\div 1\frac{1}{4}$.
2. $3\frac{1}{4}\div\frac{4}{7}$. $5\frac{5}{6}\div 2\frac{1}{5}$; $9\frac{5}{8}\div 2\frac{3}{4}$.

TABLE

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES

Diam.	Area.	Circum.	Diam.	Area.	Circum.
0.0			3.0	7.0686	9.4248
.1	.007854	.31416	.1	7.5477	9.7389
.2	.031416	.62832	.2	8.0425	10.0531
.3	.070686	.94248	.3	8.5530	10.3673
.4	.12566	1.2566	.4	9.0792	10.6814
.5	.19735	1.5708	.5	9.6211	10.9956
.6	.28274	1.8850	.6	10.1788	11.3097
.7	.38485	2.1991	.7	10.7521	11.6239
.8	.50266	2.5133	.8	11.3411	11.9381
.9	.63617	2.8274	.9	11.9456	12.2522
1.0	.7854	3.1416	4.0	12.5664	12.5664
.1	.9503	3.4558	.1	13.2025	12.8805
.2	1.1310	3.7699	.2	13.8544	13.1947
.3	1.3273	4.0841	.3	14.5220	13.5088
.4	1.5394	4.3982	.4	15.2053	13.8230
.5	1.7671	4.7124	.5	15.9043	14.1372
.6	2.0106	5.0265	.6	16.6190	14.4513
.7	2.2698	5.3407	.7	17.3494	14.7655
.8	2.5447	5.6549	.8	18.0956	15.0796
.9	2.8353	5.9690	.9	18.8574	15.3938
2.0	3.1416	6.2832	5.0	19.6350	15.7080
.1	3.4636	6.5973	.1	20.4282	16.0221
.2	3.8013	6.9115	.2	21.2372	16.3363
.3	4.1548	7.2257	.3	22.0618	16.6504
.4	4.5239	7.5398	.4	22.9022	16.9646
.5	4.9087	7.8540	.5	23.7583	17.2788
.6	5.3093	8.1681	.6	24.6301	17.5929
.7	5.7256	8.4823	.7	25.5176	17.9071
.8	6.1575	8.7965	.8	26.4208	18.2212
.9	6.6052	9.1106	.9	27.3397	18.5354

TABLE—(Continued.)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
6.0	28.2743	18.8496	10.0	78.5398	31.4159
.1	29.2247	19.1637	.1	80.1185	31.7301
.2	30.1907	19.4779	.2	81.7128	32.0442
.3	31.1725	19.7920	.3	83.3229	32.3584
.4	32.1699	20.1062	.4	84.9487	32.6726
.5	33.1831	20.4204	.5	86.5901	32.9867
.6	34.2119	20.7345	.6	88.2473	33.3009
.7	35.2565	21.0487	.7	89.9202	33.6150
.8	36.3168	21.3628	.8	91.6088	33.9292
.9	37.3928	21.6770	.9	93.3132	34.2434
7.0	38.4845	21.9911	11.0	95.0332	34.5575
.1	39.5919	22.3053	.1	96.7689	34.8717
.2	40.7150	22.6195	.2	98.5203	35.1858
.3	41.8539	22.9336	.3	100.2875	35.5000
.4	43.0084	23.2478	.4	102.0703	35.8142
.5	44.1786	23.5619	.5	103.8689	36.1283
.6	45.3646	23.8761	.6	105.6832	36.4425
.7	46.5663	24.1903	.7	107.5132	36.7566
.8	47.7836	24.5044	.8	109 3588	37.0708
.9	49.0167	24.8186	.9	111.2202	37.3850
8.0	50.2655	25.1327	12.0	113.0973	37.6991
.1	51.5300	25.4469	.1	114.9901	38.0133
.2	52.8102	25.7611	.2	116.8987	38.3274
.3	54.1061	26.0752	.3	118.8229	38.6416
.4	55.4177	26.3894	.4	120.7628	38.9557
.5	56.7450	26.7035	.5	122.7185	39.2699
.6	58.0880	27.0177	.6	124.6898	39.5841
.7	59.4468	27.3319	.7	126.6769	39.8982
.8	60.8212	27.6460	.8	128.6796	40.2124
.9	62.2114	27.9602	.9	130.6981	40.5265
9.0	63.6173	28.2743	13.0	132.7323	40.8407
.1	65.0388	28.5885	.1	134.7822	41.1549
.2	66.4761	28.9027	.2	136.8478	41.4690
.3	67.9291	29.2168	.3	138.9291	41.7832
.4	69.3978	29.5310	.4	141.0261	42.0973
.5	70.8822	29.8451	.5	143.1388	42.4115
.6	72.3823	30.1593	.6	145.2672	42.7257
.7	73.8981	30.4734	.7	147.4114	43.0398
.8	75.4296	30.7876	.8	149.5712	43.3540
.9	76.9769	31.1018	.9	151.7468	43.6681

TABLE—(*Continued.*)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES

Diam.	Area.	Circum.	Diam.	Area.	Circum.
14.0	153.9380	43.9823	8.0	254.4690	56.5486
.1	156.1450	44.2965	.1	257.3043	56.8628
.2	158.3677	44.6106	.2	260.1553	57.1770
.3	160.6061	44.9248	.3	263.0220	57.4911
.4	162.8602	45.2389	.4	265.9044	57.8053
.5	165.1300	45.5531	.5	268.8025	58.1195
.6	167.4155	45.8673	.6	271.7164	58.4336
.7	169.7167	46.1814	.7	274.6459	58.7478
.8	172.0336	46.4956	.8	277.5911	59.0619
.9	174.3662	46.8097	.9	280.5521	59.3761
15.0	176.7146	47.1239	19.0	283.5287	59.6903
.1	179.0786	47.4380	.1	286.5211	60.0044
.2	181.4584	47.7522	.2	289.5292	60.3186
.3	183.8539	48.0664	.3	292.5530	60.6327
.4	186.2650	48.3805	.4	295.5925	60.9469
.5	188.6919	48.6947	.5	298.6477	61.2611
.6	191.1345	49.0088	.6	301.7186	61.5752
.7	193.5928	49.3230	.7	304.8052	61.8894
.8	196.0668	49.6372	.8	307.9075	62.2035
.9	198.5565	49.9513	.9	311.0255	62.5177
16.0	201.0619	50.2655	20.0	314.1593	62.8319
.1	203.5831	50.5796	.1	317.3087	63.1460
.2	206.1199	50.8938	.2	320.4739	63.4602
.3	208.6724	51.2080	.3	323.6547	63.7743
.4	211.2407	51.5221	.4	326.8513	64.0885
.5	213.8246	51.8363	.5	330.0636	64.4026
.6	216.4243	52.1504	.6	333.2916	64.7168
.7	219.0397	52.4646	.7	336.5353	65.0310
.8	221.6708	52.7788	.8	339.7947	65.3451
.9	224.3176	53.0929	.9	343.0698	65.6593
17.0	226.9801	53.4071	21.0	346.3606	65.9734
.1	229.6583	53.7212	.1	349.6671	66.2876
.2	232 3522	54.0354	.2	352.9894	66.6018
.3	235.0618	54.3496	.3	356.3273	66.9159
.4	237.7871	54.6637	.4	359.6809	67.2301
.5	240.5282	54.9779	.5	363.0503	67.5442
.6	243.2849	55.2920	.6	366.4354	67.8584
.7	246.0574	55.6062	.7	369.8361	68.1726
.8	248.8456	55.9203	.8	373.2526	68.4867
.9	251.6494	56.2345	.9	376.6848	68.8009

TABLE—(Continued.)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
22.0	380.1327	69.1150	26.0	530.9292	81.6814
.1	383.5963	69.4292	.1	535.0211	81.9956
.2	387.0756	69.7434	.2	539.1287	82.3097
.3	390.5707	70.0575	.3	543.2521	82.6239
.4	394.0814	70.3717	.4	547.3911	82.9380
.5	397.6078	70.6858	.5	551.5459	83.2522
.6	401.1500	71.0000	.6	555.7163	83.5664
.7	404.7078	71.3142	.7	559.9025	83.8805
.8	408.2814	71.6283	.8	564 1044	84.1947
.9	411.8707	71.9425	.9	568.3220	84.5088
23.0	415.4756	72.2566	27.0	572.5553	84.8230
.1	419.0993	72.5708	.1	576.8043	85.1372
.2	422.7327	72.8849	.2	581.0690	85.4513
.3	426.3848	73.1991	.3	585.3494	85.7655
.4	430.0526	73.5133	.4	589.6455	86.0796
.5	433.7361	73.8274	.5	593.9574	86.3938
.6	437.4354	74.1416	.6	598.2849	86.7080
.7	441.1503	74.4557	.7	602.6282	87.0221
.8	444.8809	74.7699	.8	606.9871	87.3363
.9	448.6273	75.0841	.9	611.3618	87.6504
24.0	452.3893	75.3982	28.0	615.7522	87.9646
.1	456.1671	75.7124	.1	620.1582	88.2788
.2	459.9606	76.0265	.2	624.5800	88.5929
.3	463.7698	76.3407	.3	629.0175	88.9071
.4	467.5947	76.6549	.4	633.4707	89.2212
.5	471.4352	76.9690	.5	637.9397	89.5354
.6	475.2916	77.2832	.6	642.4243	89.8495
.7	479.1636	77.5973	.7	646.9246	90.1637
.8	483.0513	77.9115	.8	651.4407	90.4779
.9	486.9547	78.2257	.9	655.9724	90.7920
25.0	490.8739	78.5398	29.0	660.5199	91.1063
.1	494.8087	78.8540	.1	665.0830	91.4203
.2	498.7592	79.1681	.2	669.6619	91.7345
.3	502.7255	79.4823	.3	674.2565	92.0487
.4	506.7075	79.7965	.4	678.8668	92.3628
.5	510.7052	80.1106	.5	683.4928	92.6770
.6	514.7185	80.4248	.6	688.1345	92.9911
.7	518.7476	80.7389	.7	692.7919	93.3053
.8	522.7924	81.0531	.8	697.4650	93.6195
.9	526.8529	81.3672	.9	702.1538	93.9336

TABLE—(*Continued.*)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES

Diam.	Area.	Circum.	Diam.	Area.	Circum.
30.0	706.8583	94.2478	34.0	907.9203	106.8142
.1	711.5786	94.5619	.1	913.2688	107.1283
.2	716.3145	94.8761	.2	918.6331	107.4425
.3	721.0662	95.1903	.3	924.0131	107.7566
.4	725.8336	95.5044	.4	929.4088	108.0708
.5	730.6167	95.8186	.5	934.8202	108.3849
.6	735.4154	96.1327	.6	940 2473	108.6991
.7	740.2299	96.4469	.7	945.6901	109.0133
.8	745.0601	96.7611	.8	951.1486	109.3274
.9	749.9060	97.0752	.9	956.6228	109.6416
31.0	754.7676	97.3894	35.0	962.1128	109.9557
.1	759.6450	97.7035	.1	967.6184	110.2699
.2	764.5380	98.0177	.2	973.1397	110.5841
.3	769.4467	98.3319	.3	978.6768	110.8982
.4	774.3712	98.6460	.4	984.2296	111.2124
.5	779.3113	98.9602	.5	989.7980	111.5265
.6	784.2672	99.2743	.6	995.3822	111.8407
.7	789.2388	99.5885	.7	1000.9821	112.1549
.8	794.2260	99.9026	.8	1006.5977	112.4690
.9	799.2290	100.2168	.9	1012.2290	112.7832
32.0	804.2477	100.5310	36.0	1017.8760	113.0973
.1	809.2821	100.8451	.1	1023.5387	113.4115
.2	814 3322	101.1593	.2	1029.2172	113.7257
.3	819.3980	101.4734	.3	1034.9113	114.0398
.4	824.4796	101.7876	.4	1040.6212	114.3540
.5	829.5768	102.1018	.5	1046.3467	114.6681
.6	834.6898	102.4159	.6	1052.0880	114.9823
.7	839.8185	102.7301	.7	1057.8449	115.2965
.8	844.9628	103.0442	.8	1063.6176	115.6106
.9	850.1229	103.3584	.9	1069.4060	115.9248
33.0	855.2986	103.6726	37.0	1075.2101	116.2389
.1	860.4902	103.9867	.1	1081.0299	116.5531
.2	865.6973	104.3009	.2	1086.8654	116.8672
.3	870.9202	104.6150	.3	1092.7166	117.1814
.4	876.1588	104.9292	.4	1098.5835	117.4956
.5	881.4131	105.2434	.5	1104.4662	117.8097
.6	886.6831	105.5575	.6	1110.3645	118.1239
.7	891.9688	105.8717	.7	1116.2786	118.4380
.8	897.2703	106.1858	.8	1122.2083	118.7522
.9	902.5874	106.5000	.9	1128.1538	119.0664

TABLE—(Continued.)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
38.0	1134.1149	119.3805	42.0	1385.4424	131.9469
.1	1140.0918	119.6947	.1	1392.0476	132.2611
.2	1146.0844	120.0088	.2	1398.6685	132.5752
.3	1152.0927	120.3230	.3	1405.3051	132.8894
.4	1158.1167	120.6372	.4	1411.9574	133.2035
.5	1164.1564	120.9513	.5	1418.6254	133.5177
.6	1170.2118	121.2655	.6	1425.3092	133.8318
.7	1176.2830	121.5796	.7	1432.0086	134.1460
.8	1182.3698	121.8938	.8	1438.7238	134.4602
.9	1188.4724	122.2080	.9	1445.4546	134.7743
39.0	1194.5906	122.5221	43.0	1452.2012	135.0885
.1	1200.7246	122.8363	.1	1458.9635	135.4026
.2	1206.8742	123.1504	.2	1465.7415	135.7168
.3	1213.0396	123.4646	.3	1472.5352	136.0310
.4	1219.2207	123.7788	.4	1479.3446	136.3451
.5	1225.4175	124.0929	.5	1486.1697	136.6593
.6	1231.6300	124.4071	.6	1493.0105	136.9734
.7	1237.8582	124.7212	.7	1499.8670	137.2876
.8	1244.1021	125.0354	.8	1506.7393	137.6018
.9	1250.3617	125.3495	.9	1513.6272	137.9159
40.0	1256.6371	125.6637	44.0	1520.5308	138.2301
.1	1262.9281	125.9779	.1	1527.4502	138.5442
.2	1269.2348	126.2920	.2	1534.3853	138.8584
.3	1275.5573	126.6062	.3	1541.3360	139.1726
.4	1281.8955	126.9203	.4	1548.3025	139.4867
.5	1288.2493	127.2345	.5	1555.2847	139.8009
.6	1294.3189	127.5487	.6	1562.2826	140.1153
.7	1301.0042	127.8628	.7	1569.2962	140.4292
.8	1307.4052	128.1770	.8	1576.3255	140.7434
.9	1313.8219	128.4911	.9	1583.3706	141.0575
41.0	1320.2543	128.8053	45.0	1590.4313	141.3717
.1	1326.7024	129.1195	.1	1597.5077	141.6858
.2	1333.1663	129.4336	.2	1604.5999	142.0000
.3	1339.6458	129.7478	.3	1611.7077	142.3142
.4	1346.1410	130.0619	.4	1618.8313	142.6283
.5	1352.6520	130.3761	.5	1625.9705	142.9425
.6	1359.1786	130.6903	.6	1633.1255	143.2566
.7	1365.7210	131.0044	.7	1640.2962	143.5708
.8	1372.2791	131.3186	.8	1647.4826	143.8849
.9	1378.8529	131.6227	.9	1654.6847	144.1991

TABLE—(Continued.)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
46.0	1661.9025	144.5133	50.0	1963.4954	157.0796
.1	1669.1360	144.8274	.1	1971.3572	157.3938
.2	1676.3853	145.1416	.2	1979.2348	157.7080
.3	1683.6502	145.4557	.3	1987.1280	158.0221
.4	1690.9308	145.7699	.4	1995.0370	158.3363
.5	1698.2272	146.0841	.5	2002.9617	158.6504
.6	1705.5392	146.3982	.6	2010.9020	158.9646
.7	1712.8670	146.7124	.7	2018.8581	159.2787
.8	1720.2105	147.0265	.8	2026.8299	159.5929
.9	1727.5697	147.3407	.9	2034.8174	159.9071
47.0	1734.9445	147.6550	51.0	2042.8206	160.2212
.1	1742.3351	147.9690	.1	2050.8395	160.5354
.2	1749.7414	148.2832	.2	2058.8742	160.8495
.3	1757.1635	148.5973	.3	2066.9245	161.1637
.4	1764.6012	148.9115	.4	2074.9905	161.4779
.5	1772.0546	149.2257	.5	2083.0723	161.7920
.6	1779.5237	149.5398	.6	2091.1697	162.1062
.7	1787.0086	149.8540	.7	2099.2829	162.4203
.8	1794.5091	150.1681	.8	2107.4118	162.7345
.9	1802.0254	150.4823	.9	2115.5563	163.0487
48.0	1809.5574	150.7964	52.0	2123.7166	163.3628
.1	1817.1050	151.1106	.1	2131.8926	163.6770
.2	1824.6684	151.4248	.2	2140.0843	163.9911
.3	1832.2475	151.7389	.3	2148.2917	164.3053
.4	1839.8423	152.0531	.4	2156.5149	164.6195
.5	1847.4528	152.3672	.5	2164.7537	164.9336
.6	1855.0790	152.6814	.6	2173.0082	165.2479
.7	1862.7210	152.9956	.7	2181.2785	165.5619
.8	1870.3786	153.3097	.8	2189.5644	165.8761
.9	1878.0519	153.6239	.9	2197.8661	166.1903
49.0	1885.7409	153.9380	53.0	2206.1834	166.5044
.1	1893.4457	154.2522	.1	2214.5165	166.8186
.2	1901.1662	154.5664	.2	2222.8653	167.1327
.3	1908.9024	154.8805	.3	2231.2298	167.4469
.4	1916.6543	155.1947	.4	2239.6100	167.7610
.5	1924.4218	155.5088	.5	2248.0059	168.0752
.6	1932.2051	155.8230	.6	2256.4175	168.3894
.7	1940.0042	156.1372	.7	2264.8448	168.7035
.8	1947.8189	156.4513	.8	2273.2879	169.0177
.9	1955.6493	156.7655	.9	2281.7466	169.3318

TABLE—(Continued.)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
54.0	2290.2210	169.6460	58.0	2642.0794	182.2124
.1	2298.7112	169.9602	.1	2651.1979	182.5265
.2	2307.2171	170.2743	.2	2660.3321	182.8407
.3	2315.7386	170.5885	.3	2669.4820	183.1549
.4	2324.2759	170.9026	.4	2678.6476	183.4690
.5	2332.8289	171.2168	.5	2687.8289	183.7832
.6	2341.3976	171.5310	.6	2697.0259	184.0973
.7	2349.9820	171.8451	.7	2706.2386	184.4115
.8	2258.5821	172.1593	.8	2715.4670	184.7256
.9	2367.1979	172.4735	.9	2724.7112	185.0398
55.0	2375.8294	172.7876	59.0	2733.9710	185.3540
.1	2384.4767	173.1017	.1	2743.2466	185.6681
.2	2393.1396	173.4159	.2	2752.5378	185.9823
.3	2401.8183	173.7301	.3	2761.8448	186.2964
.4	2410.5126	174.0442	.4	2771.1675	186.6106
.5	2419.2227	174.3584	.5	2780.5058	186.9248
.6	2427.9485	174.6726	.6	2789.8599	187.2389
.7	2436.6899	174.9867	.7	2799.2297	187.5531
.8	2445.4471	175.3009	.8	2808.6152	187.8672
.9	2454.2200	175.6150	.9	2818.0165	188.1814
56.0	2463.0086	175.9292	60.0	2827.4334	188.4956
.1	2471.8130	176.2433	.1	2836 8660	188.8097
.2	2480.6330	176.5575	.2	2846.3144	189.1239
.3	2489.4687	176.8717	.3	2855.7784	189.4380
.4	2498.3201	177.1858	.4	2865.2582	189.7522
.5	2507.1873	177.5000	.5	2874.7536	190.0664
.6	2516.0701	177.8141	.6	2884.2648	190.3805
.7	2524.9687	178.1283	.7	2893.7917	190.6947
.8	2533.8830	178.4425	.8	2903.3343	191.0088
.9	2542.8129	178.7566	.9	2912.8926	191.3230
57.0	2551.7586	179.0708	61.0	2922.4666	191.6372
.1	2560.7200	179.3849	.1	2932.0563	191.9513
.2	2569.6971	179.6991	.2	2941.6617	192.2655
.3	2578.6899	180.0133	.3	2951.2828	192.5796
.4	2587.6985	180.3274	.4	2960.9197	192.8938
.5	2596.7227	180.6416	.5	2970.5722	193.2079
.6	2605.7626	180.9557	.6	2980.2405	193.5221
.7	2614.8183	181.2699	.7	2989.9244	193.8363
.8	2623.8896	181.5841	.8	2999.6241	194.1504
.9	2632.9767	181.8982	.9	3009.3395	194.4646

TABLE—(Continued.)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
62.0	3019.0705	194.7787	66.0	3421.1944	207.3451
.1	3028.8173	195.0929	.1	3431.5695	207.6593
.2	3038.5798	195.4071	.2	3441.9603	207.9734
.3	3048.3580	195.7212	.3	3452.3669	208.2876
.4	3058.1520	196.0354	.4	3462.7891	208.6017
.5	3067.9616	196.3495	.5	3473.2270	208.9159
.6	3077.7869	196.6637	.6	3483.6807	209.2301
.7	3087.6279	196.9779	.7	3494.1500	209.5442
.8	3097.4847	197.2920	.8	3504.6351	209.8584
.9	3107.3571	197.6062	.9	3515.1359	210.1725
63.0	3117.2453	197.9203	67.0	3525.6524	210.4867
.1	3127.1492	198.2345	.1	3536.1845	210.8009
.2	3137.0688	198.5487	.2	3546.7324	211.1150
.3	3147.0040	198.8628	.3	3557.2960	211.4292
.4	3156.9550	199.1770	.4	3567.8754	211.7433
.5	3166.9217	199.4911	.5	3578.4704	212.0575
.6	3176.9043	199.8053	.6	3589.0811	212.3717
.7	3186.9023	200.1195	.7	3599.7075	212 6858
.8	3196.9161	200.4336	.8	3610.3497	213.0000
.9	3206.9456	200.7478	.9	3621.0075	213.3141
64.0	3216.9909	201.0620	68.0	3631.6811	213.6283
.1	3227.0518	201.3761	.1	3642.3704	213.9425
.2	3237.1285	201.6902	.2	3653.0754	214.2566
.3	3247.2222	202.0044	.3	3663.7960	214.5708
.4	3257.3289	202.3186	.4	3674.5324	214.8849
.5	3267.4527	202.6327	.5	3685.2845	215.1991
.6	3277.5922	202.9469	.6	3696.0523	215.5133
.7	3287.7474	203.2610	.7	3706.8359	215.8274
.8	3297.9183	203.5752	.8	3717.6351	216.1416
.9	3308.1049	203.8894	.9	3728.4500	216.4556
65.0	3318.3072	204.2035	69.0	3739.2807	216.7699
.1	3328.5253	204.5176	.1	3750.1270	217.0841
.2	3338.7590	204.8318	.2	3760.9891	217.3982
.3	3349.0085	205.1460	.3	3771.8668	217.7124
.4	3359.2736	205.4602	.4	3782.7603	218.0265
.5	3369.5545	205.7743	.5	3793.6695	218.3407
.6	3379.8510	206.0885	.6	3804.5944	218.6548
.7	3390.1633	206.4026	.7	3815.5350	218.9690
.8	3400.4913	206.7168	.8	3826.4913	219.2832
.9	3410.8350	207.0310	.9	3837.4633	219.5973

TABLE—(Continued.)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
70.0	3848.4510	219.9115	74.0	4300.8403	232.4779
.1	3859.4544	220.2256	.1	4312.4721	232.7920
.2	3870.4736	220.5398	.2	4324.1195	233.1062
.3	3881.5084	220.8540	.3	4335.7827	233.4203
.4	3892.5590	221.1681	.4	4347.4616	233.7345
.5	3903.6252	221.4823	.5	4359.1562	234.0487
.6	3914.7072	221.7964	.6	4370.8664	234.3628
.7	3925.8049	222.1106	.7	4382.5924	234.6770
.8	3936.9182	222.4248	.8	4394.3341	234.9911
.9	3948.0473	222.7389	.9	4406.0916	235.3053
71.0	3959.1921	223.0531	75.0	4417.8647	235.6194
.1	3970.3526	223.3672	.1	4429.6535	235.9336
.2	3981.5289	223.6814	.2	4441.4580	236.2478
.3	3992.7208	223.9956	.3	4453.2783	236.5619
.4	4003.9284	224.3097	.4	4465.1142	236.8761
.5	4015.1518	224.6239	.5	4476 9659	237.1902
.6	4026.3908	224.9380	.6	4488.8332	237.5044
.7	4037.6456	225.2522	.7	4500.7163	237.8186
.8	4048.9160	225.5664	.8	4512.6151	238.1327
.9	4060.2022	225.8805	.9	4524.5296	238.4469
72.0	4071.5041	226.1947	76.0	4536.4598	238.7610
.1	4082.8217	226.5088	.1	4548.4057	239.0752
.2	4094.1550	226.8230	.2	4560.3673	239.3894
.3	4105.5040	227.1371	.3	4572.3446	239.7035
.4	4116.8687	227.4513	.4	4584.3377	240.0177
.5	4128.2491	227.7655	.5	4596.3464	240.3318
.6	4139.6452	228.0796	.6	4608.3708	240.6460
.7	4151.0571	228.3938	.7	4620.4110	240.9602
.8	4162.4846	228.7079	.8	4632.4669	241.2743
.9	4173.9279	229.0221	.9	4644.5384	241.5885
73.0	4185.3868	229.3363	77.0	4656.6257	241.9026
.1	4196.8615	229.6504	.1	4668.7287	242.2168
.2	4208.3519	229.9646	.2	4680.8474	242.5310
.3	4219.8579	230.2787	.3	4692.9818	242.8451
.4	4231.3797	230.5929	.4	4705.1319	243.1592
.5	4242.9172	230.9071	.5	4717.2977	243.4734
.6	4254.4704	231.2212	.6	4729.4792	243.7876
.7	4266.0394	231.5354	.7	4741.6765	244.1017
.8	4277.6240	231.8395	.8	4753.8894	244.4159
.9	4289.2243	232.1637	.9	4766.1181	244.7301

TABLE—(Continued.)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
78.0	4778.3624	245.0442	82.0	5281.0173	257.6106
.1	4790.6225	245.3584	.1	5293.9056	257.9247
.2	4802.8983	245.6725	.2	5306.8097	258.2389
.3	4815.1897	245.9867	.3	5319.7295	258.5531
.4	4827.4969	246.3009	.4	5332.6650	258.8672
.5	4839.8189	246.6150	.5	5345.6162	259.1814
.6	4852.1584	246.9292	.6	5358.5832	259.4956
.7	4864.5128	247.2433	.7	5371.5658	259.8097
.8	4876.8828	247.5575	.8	5384.5641	260.1239
.9	4889.2685	247.8717	.9	5397.5782	260.4380
79.0	4901.6699	248.1858	83.0	5410.6079	260.7522
.1	4914.0871	248.5000	.1	5423.6534	261.0663
.2	4926.5199	248.8141	.2	5436.7146	261.3805
.3	4938.9685	249.1283	.3	5449.7915	261.6947
.4	4951.4328	249.4425	.4	5462.8840	262.0088
.5	4963.9127	249.7566	.5	5475.9923	262.3230
.6	4976.4084	250.0708	.6	5489.1163	262.6371
.7	4988.9198	250.3850	.7	5502.2561	262.9513
.8	5001.4469	250.6991	.8	5515.4115	263.2655
.9	5013.9897	251.0133	.9	5528.5826	263.5796
80.0	5026.5482	251.3274	84.0	5541.7694	263.8938
.1	5039.1225	251.6416	.1	5554.9720	264.2079
.2	5051.7124	251.9557	.2	5568.1902	264.5221
.3	5064.3180	252.2699	.3	5581.4242	264.8363
.4	5076.9394	252.5840	.4	5594.6739	265.1514
.5	5089.5764	252.8982	.5	5607.9392	265.4646
.6	5102.2292	253.2124	.6	5621.2203	265.7787
.7	5114.8977	253.5265	.7	5634.5171	266.0929
.8	5127.5819	253.8407	.8	5647.8296	266.4071
.9	5140.2818	254.1548	.9	5661.1578	266.7212
81.0	5152.9973	254.4690	85.0	5674.5017	267.0354
.1	5165.7287	254.7832	.1	5687.8614	267.3495
.2	5178.4757	255.0973	.2	5701.2367	267.6637
.3	5191.2384	255.4115	.3	5714.6277	267.9779
.4	5204.0168	255.7256	.4	5728.0345	268.2920
.5	5216.8110	256.0398	.5	5741.4569	268.6062
.6	5229.6208	256.3540	.6	5754.8951	268.9203
.7	5242.4463	256.6681	.7	5768.3490	269.2345
.8	5255.2876	256.9823	.8	5781.8185	269.5486
.9	5268.1446	257.2966	.9	5795.3038	269.8628

TABLE—(*Continued.*)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
86.0	5808.8048	270.2770	90.0	6361.7251	282.7433
.1	5822.3215	270.4911	.1	6375.8701	283.0575
.2	5835.8539	270.8053	.2	6390.0309	283.3717
.3	5849.4020	271.1194	.3	6404.2073	283.6858
.4	5862.9659	271.4336	.4	6418.3995	284.0000
.5	5876.5454	271.7478	.5	6432.6073	284.3141
.6	5890.1407	272.0619	.6	6446.8309	284.6283
.7	5903.7516	272.3761	.7	6461.0701	284.9425
.8	5917.3783	272.6902	.8	6475.3251	285.2566
.9	5931.0206	273.0044	.9	6489.5958	285.5708
87.0	5944.6787	273.3186	91.0	6503.8822	285.8849
.1	5958.3525	273.6327	.1	6518.1843	286.1991
.2	5972.0420	273.9469	.2	6532.5021	286.5133
.3	5985.7472	274.2610	.3	6546.8356	286.8274
.4	5999.4681	274.5752	.4	6561.1848	287.1416
.5	6013.2047	274.8894	.5	6575.5498	287.4557
.6	6026.9570	275.2035	.6	6589.9304	287.7699
.7	6040 7250	275.5177	.7	6604 3268	288.0840
.8	6054.5088	275.8318	.8	6618.7388	288.3982
.9	3068.3082	276.1460	.9	6633.1666	288.7124
88.0	6082.1234	276.4602	92.0	6647.6101	289.0265
.1	6095.9542	276.7743	.1	6662.0692	289.3407
.2	6109.8008	277.0885	.2	6676.5441	289.6548
.3	6123.6631	277.4026	.3	6691.0347	289.9690
.4	6137.5411	277.7168	.4	6705.5410	290.2832
.5	6151.4348	278.0309	.5	6720.0630	290.5973
.6	6165.3442	278.3451	.6	6734.6008	290.9115
.7	6179.2693	278.6563	.7	6749.1542	291.2256
.8	6193.2101	278.9740	.8	6763.7233	291.5398
.9	6207.1666	279.2876	.9	6778.3082	291.8540
89.0	6221.1389	279.6017	93.0	6792.9087	292.1681
.1	6235.1268	279.9159	.1	6807.5250	292.4823
.2	6249.1304	280.2301	.2	6822.1569	292.7964
.3	6263.1498	280.5442	.3	6836.8046	293.1106
.4	6277.1849	280.8584	.4	6851.4680	293.4248
.5	6291.2356	281.1725	.5	6866.1471	293.7389
.6	6305.3021	281.4867	.6	6880.8419	294.0531
.7	6319.3843	281.8009	.7	6895.5524	294.2672
.8	6333.4822	282.1150	.8	6910.2786	294.6814
.9	6347.5958	282.4292	.9	6925.0205	294.9956

TABLE—(Concluded.)

CONTAINING THE DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
94.0	6939.7782	295.3097	97.0	7389.8113	304.7345
.1	6954.5515	295.6239	.1	7405.0559	305.0486
.2	6969.3106	295.9380	.2	7420.3162	305.3628
.3	6984.1453	296.2522	.3	7435.5922	305.6770
.4	6998.9658	296.5663	.4	7450.8839	305.9911
.5	7013.8019	296.8805	.5	7466.1913	306.3053
.6	7028.6538	297.1947	.6	7481.5144	306.6194
.7	7043.5214	297.5088	.7	7496.8532	306.9336
.8	7058.4047	297.8230	.8	7521.2078	307.2478
.9	7073.3033	298.1371	.9	7527.5780	307.5619
95.0	7088.2184	298.4513	98.0	7542.9640	307.8761
.1	7103.1488	298.7655	.1	7558.3656	308.1902
.2	7118.1950	299.0796	.2	7573.7830	308.5044
.3	7133.0568	299.3938	.3	7589.2161	308.8186
.4	7148.0343	299.7079	.4	7604.6648	309.1327
.5	7163.0276	300.0221	.5	7620.1293	309.4469
.6	7178.0366	300.3363	.6	7635.6095	309.7610
.7	7193.0612	300.6504	.7	7651.1054	310.0752
.8	7208.1016	300.9646	.8	7666.6170	310.3894
.9	7223.1577	301.2787	.9	7682.1444	310.7035
96.0	7238.2295	301.5929	99.0	7697.6893	311.0177
.1	7253.3170	301.9071	.1	7713.2461	311.3318
.2	7268.4202	302.2212	.2	7728.8206	311.6460
.3	7283.5391	302.5354	.3	7744.4107	311.9602
.4	7298.6737	302.8405	.4	7760.0166	312.2743
.5	7313.8240	303.1637	.5	7775.6382	312.5885
.6	7328.9901	303.4779	.6	7791.2754	312.9026
.7	7344.1718	303.7920	.7	7806.9284	313.2168
.8	7359.3693	304.1062	.8	7822.5971	313.5309
.9	7374.5824	304.4203	.9	7838.2815	313.8451
			100.0	7853.9816	314.1593

GEOMETRY.

Geometry is one of the oldest and simplest of sciences; it may be defined as *the science of measurement;* Mensuration as already briefly outlined in this work, belongs properly under this division.

Geometry is *the root* from which all regular mathematical calculations issue. It has claimed the best thought of practical men from the times of the Greeks and Romans two thousand years ago; they derived their knowledge of the science from the Egyptians, who in turn were indebted to the Chaldeans and Hindoos in times beyond any authentic history; hence it was under the operations of the laws explained in geometry, that the pyramids of Egypt and the temples of Greece, were constructed, as well as the engines of war and appliances of peace of ancient times.

The elementary conceptions of geometry are few.

1. A point.
2. A line.
3. A surface.
4. A solid, and
5. An angle.

From these definitions, as data, a vast number of mathematical calculations have been deduced; of which a few of the most elementary will be explained and illustrated in this work; but these few will repay the attention of the student as *the mutual relation between practical engineering and geometry* is very intimate indeed—as will be apparent.

GEOMETRICAL DEFINITIONS.

A point is mere position, and has no magnitude.

A line is that which has extension in length only. The extremities of lines are points.

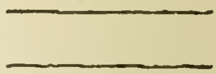
A surface is that which has extension in length and breadth only.

A solid is that which has extension in length, breadth and thickness.

An angle is the difference in the direction of two lines proceeding from the same point.

Lines, Surfaces, Angles and Solids constitute the different kinds of quantity called *geometrical* magnitudes.

Parallel lines are lines which have the same direction; hence parallel lines can never meet, however far they may be produced; for two lines taking the same direction cannot approach or recede from each other.



An *Axiom* is a self-evident truth, not only too simple to require, *but too simple to admit of demonstration.*

A *Proposition* is something which is either proposed to be done, or to be demonstrated, and is either a problem or a theorem.

A *Problem* is something proposed to be done.

A *Theorem* is something proposed to be demonstrated.

A *Hypothesis* is a supposition made with a view to draw from it some consequence which establishes the truth or falsehood of a proposition, or solves a problem.

A *Lemma* is something which is premised, or demonstrated, in order to render what follows more easy.

A *Corollary* is a consequent truth derived immediately from some preceding truth or demonstration.

A *Scholium* is a remark or observation made upon something going before it.

A *Postulate* is a problem, the solution of which is self-evident.

EXAMPLES OF POSTULATES.

Let it be granted—

I. That a straight line can be drawn from any one point to any other point;

II. That a straight line can be produced to any distance, or terminated at any point;

III. That the circumference of a circle can be described about any center, at any distance from that center.

ABBREVIATIONS.

The common algebraic signs are used in Geometry, and it is necessary that the student in geometry should understand some of the more simple operations of algebra. As the terms circle, angle, triangle, hypothesis, axiom, theorem, corollary, and definition are constantly occurring in a course of geometry, they are abbreviated as shown in the following list:

Addition is expressed by	$+$
Subtraction " "	$-$
Multiplication " "	$\times$
Equality and Equivalency are expressed by . .	$=$
Greater than, is expressed by	$>$
Less than, " "	$<$
Thus B is greater than A, is written . .	$B>A$
B is less than A " " . . .	$B<A$
A circle is expressed by	$\bigcirc$
An angle " "	L
A right angle is expressed by . . .	R. L
Degrees, minutes and seconds are expressed by .	$^{\circ}\ '\ ''$
A triangle is expressed by	$\triangle$
The term Hypothesis is expressed by . . .	(Hy.)
" Axiom " " . .	(Ax.)
" Theorem " " . . .	(Th.)
" Corollary " " . . .	(Cor.)
" Definition " " . . .	(Def.)
" Perpendicular is expressed by . . .	$\perp$
The difference of two quantities, when it is not known which is the greater, is expressed by the symbol .	$\sim$
Thus, the difference between A and B is written	$A \sim B$.

AXIOMS.

1. *Things which are equal to the same thing are equal to each other.*

2. *When equals are added to equals the whole are equal.*

3. *When equals are taken from equals the remainders are equal.*

4. *When equals are added to unequals the wholes are unequal.*

5. *When equals are taken from unequals the remainders are unequal.*

6. *Things which are double of the same thing, or equal things are equal to each other.*

7. *Things which are halves of the same thing, or of equal things, are equal to each other.*

8. *The whole is greater than any of its parts.*

9. *Every whole is equal to all its parts taken together.*

10. *Things which coincide, or fill the same space, are identical, or mutually equal in all their parts.*

11. *All right angles are equal to one another.*

12. *A straight line is the shortest distance between two points.*

13. *Two straight lines cannot inclose a space.*

ANGLES.

To make an angle apparent, the two lines must meet in a point, as *AB* and *AC*, which meet in the point *A*.

Fig. 43.

Angles are measured by degrees.

A *Degree* is one of the three hundred and sixty equal parts of the space about a point in a plane.

Angles are distinguished in respect to magnitude by the term Right, Acute and Obtuse Angles.

A *Right Angle* is that formed by one line meeting another, so as to make equal angles with that other.

Fig. 44.

The lines forming a right angle are *perpendicular to each other.*

An *Acute Angle* is less than a right angle.

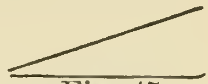


Fig. 45.

An *Obtuse Angle* is greater than a right angle.

Fig. 46.

Obtuse and acute angles are also called *oblique angles;* and lines which are neither parallel nor perpendicular to each other are called *oblique lines.*

The *Vertex* or *Apex* of an angle is the point in which the including lines meet.

An angle is commonly designated by a letter at its vertex; but when two or more angles have their vertices at the same point, they cannot be thus distinguished.

For example, when the three lines *AB, AC,* and *AD* meet in the common point *A,* we designate either of the angles formed, by three letters, placing that at the vertex between those at the opposite extremities of the including lines. Thus, we say, the angle *BAC,* etc.

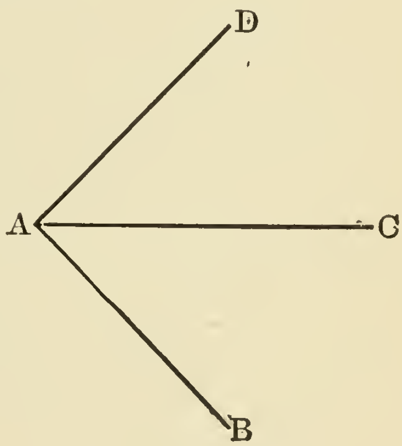


Fig. 47.

PLANE FIGURES.

A *Plane Figure,* in geometry, is a portion of a plane bounded by straight or curved lines, or by both combined.

A *Polygon* is a plane figure bounded by straight lines called the sides of the polygon. The least number of sides that can bound a polygon is three.

FIGURES OF THREE SIDES.

A *Triangle* is a polygon having three sides and three angles. *Tri* is a Latin prefix signifying three; hence a Triangle is literally a figure containing three angles.

A *Scalene Triangle* is one in which no two sides are equal.

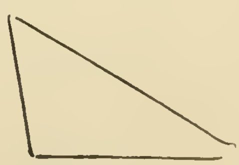


Fig. 48.

An *Isosceles Triangle* is one in which two of the sides are equal.

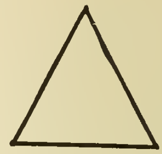


Fig. 49.

An *Equilateral Triangle* is one in which the three sides are equal.

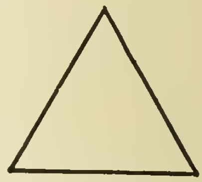


Fig. 50.

A *Right-Angled Triangle* is one which has one of the angles a right angle.

Fig. 51.

An *Obtuse-Angled Triangle* is one having an obtuse angle.

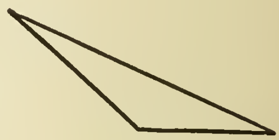


Fig. 52.

An *Equiangular Triangle* is one having its three angles equal.

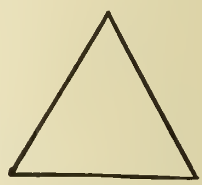


Fig. 53.

An *Acute-Angled Triangle* is one in which each angle is acute.

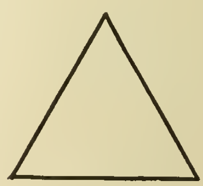


Fig. 54.

Equiangular triangles are also equal sided, and vice versa.

FIGURES OF FOUR SIDES.

A *Quadrilateral* is a polygon having four sides and four angles.

A *Parallelogram.* is a quadrilateral which has its opposite sides parallel.

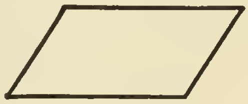


Fig. 55.

A *Rectangle* is a parallelogram having its angles right angles.

A *Square* is an equilateral rectangle.

Fig. 56.

A *Rhomboid* is an oblique-angled parallelogram.

A *Rhombus* is an equilateral rhomboid.

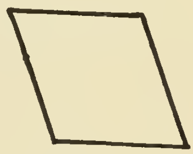


Fig 57.

A *Trapezium* is a quadrilateral having no two sides parallel.

Fig. 58.

A *Trapezoid* is a quadrilateral in which two opposite sides are parallel, and the other two oblique.

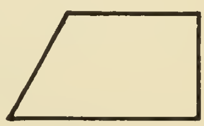


Fig. 59.

Polygons bounded by a greater number of sides than four are denominated only by the number of sides. A polygon of five sides is called a *Pentagon;* of six, a *Hexagon;* of seven, a *Heptagon;* of eight, an *Octagon;* of nine, a *Nonagon,* etc.

Diagonals of a polygon are lines joining the vertices of angles not adjacent.

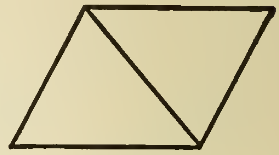


Fig. 60.

The *Perimeter* of a polygon is its boundary considered as a whole.

The *Base* of a polygon is the side upon which the polygon is supposed to stand.

The *Altitude* of a polygon is the perpendicular distance between the base and a side or angle opposite the base.

THE CIRCLE.

A *Circle* is a plane figure bounded by one uniformly curved line, all of the points in which are at the same distance from a certain point within, called the *Center*.

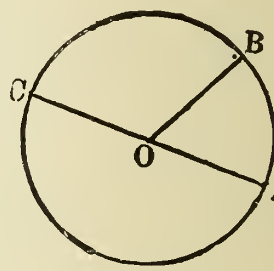


Fig. 61.

The *Circumference* of a circle is the curved line that bounds it.

The *Diameter* of a circle is a line passing through its center, and terminating at both ends in the circumference.

The *Radius* of a circle is a line extending from its center to any point in the circumference. It is one half of the diameter. All the diameters of a circle are equal, as are also all the radii.

An *Arc* of a circle is any portion of the circumference.

An angle having its vertex at the center of a circle is measured by the arc intercepted by its sides. Thus, the arc *AB* measures the angle *AOB;* and in general, to compare different angles, we have but to compare the arcs, included by their sides, of the equal circles having their centers at the vertices of the angles.

THE FIVE GEOMETRICAL SOLIDS.

There are five regular solids which are shown in Figs. 62, 63, 64, 65, and 66. A regular solid is bounded by similar and regular plane figures.

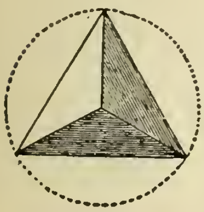


Fig. 62.

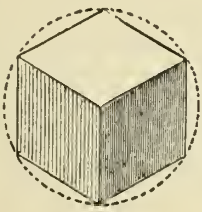


Fig. 63.

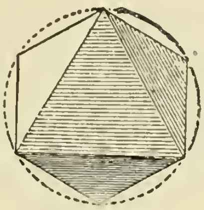


Fig. 64.

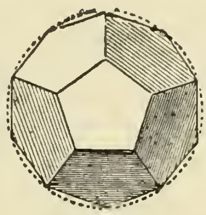


Fig. 65.

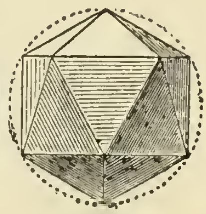


Fig. 66.

The *tetrahedron,* bounded by four equilateral triangles.

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

The *octahedron,* bounded by eight equilateral triangles

The *dodecahedron,* bounded by twelve pentagons.

The *icosahedron,* 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.

Regular solids may be circumscribed by spheres, and spheres may be inscribed in regular solids.

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

PLANE TRIGONOMETRY.

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.

The circumferences of all circles contain the same number of degrees, but the greater the radius the greater is 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.

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 whole circle there are, therefore, $360 \times 60 \times 60 = 1{,}296{,}000$ seconds. The annexed diagram, Fig. 67, exemplifies the relative positions of the

Sine, Tangent,

Co-sine, Co-Targent,

Versed Sine, Secant, and

Co-secant

of an angle.

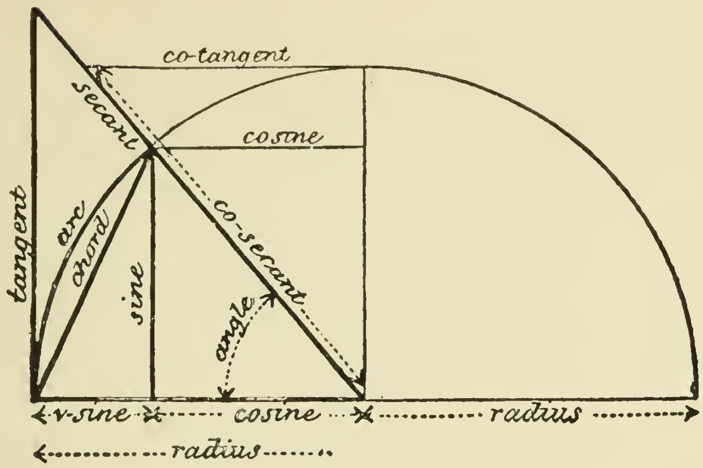


Fig. 67.

Definitions.

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.

Remark.—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.

GEOMETRICAL PROBLEMS.

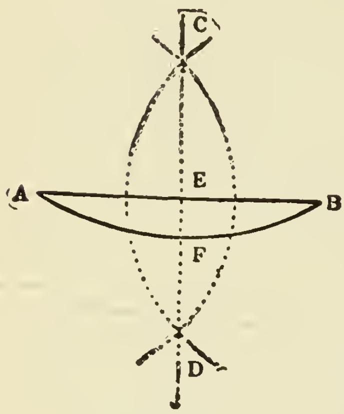


Fig. 68.

The following problems are to be solved by the use of the dividers and rule :

PROBLEM I. *To bisect* (cut in two) *a straight line, or an arc of a circle.* Fig. 68. From the ends A B as centers, describe arcs cutting each other at C and D, and draw C D, which cuts the line at E or the arc at F.

PROBLEM II. *To draw a perpendicular to a straight line, or a radial line to a circular arc,* Fig. 68. Operate as in the foregoing problem. The line C D is perpendicular to A B; the line C D is also radial to the arc A B.

PROBLEM III. *To draw a perpendicular to a straight line, from a given point in that line,* Fig. 69. With any radius from any given point A in the line B C, cut the line A B and C. Next, with a longer radius describe arcs from B and C, cutting each other at D, and draw the perpendicular D A.

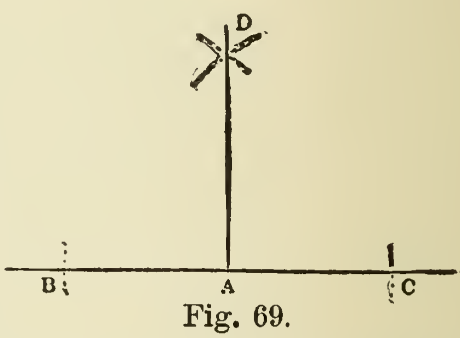


Fig. 69.

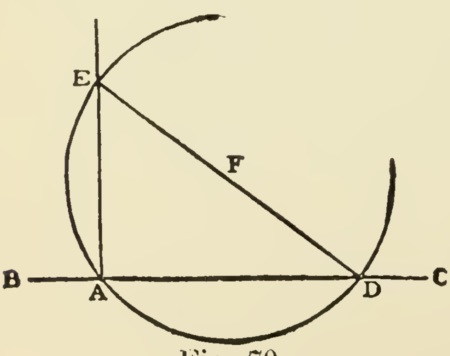


Fig. 70.

2d Method, Fig. 70. From any center F above B C, describe a circle passing through the given point A, and cutting the given line at D; draw D F, and produce it to cut the circle at E; and draw the perpendicular A E.

3d Method, Fig 71. From A describe an arc $E\ C$, and from E with the same radius, the arc $A\ C$, cutting the other at C; through C draw a line $E\ C\ D$ and set off $C\ D$ equal to $C\ E$, and through D draw the perpendicular $A\ D$.

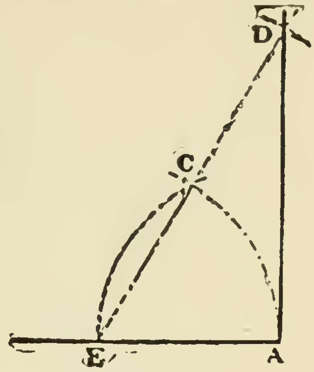


Fig. 71.

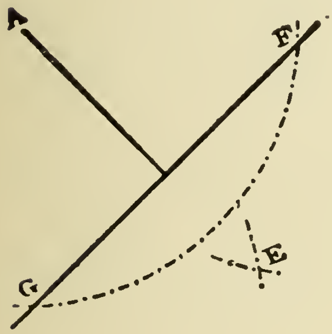


Fig. 72.

PROBLEM IV. *To draw a perpendicular to a straight line from any point without it,* Fig. 72. From the point A with a sufficient radius cut the given line at F and G; and from these points describe arcs cutting at E. Draw the perpendicular $A\ E$.

NOTE.

If there be no room below the line, the intersection may be taken above the line, that is to say, between the line and the given point.

2d Method, Fig. 73. From any two points $B\ C$ at some distance apart, in the given line, and with the radii $B\ A$, $C\ A$, respectively, describe arcs cutting at $A\ D$. Draw the perpendicular $A\ D$.

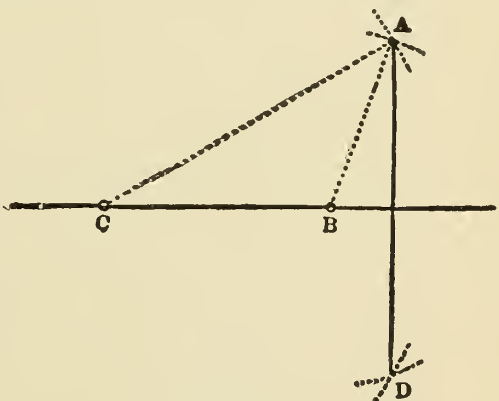


Fig. 73.

PROBLEM V. *To draw a parallel line through a given point,* Fig. 74. With a radius equal to the given point C from the given line $A\ B$, describe the arc D from B taken considerably distant from C. Draw the parallel through C to touch the arc D.

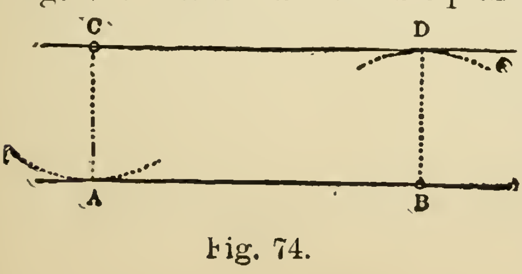


Fig. 74.

Second Method, Fig. 75. From *A*, the given point describe the arc *B D*, cutting the given line at *F;* from *F* with the same radius, describe the arc *E A*, and set off *F D* equal to *E A*. Draw the parallel through the points *A D*.

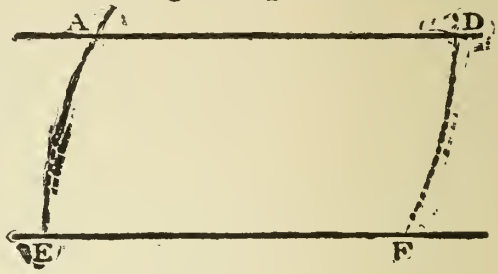


Fig. 75.

NOTE.

When a series of parallels are required perpendicular to a base line *A B*, they may be drawn as in figure 76 through points in the base line set off at the required distances apart. This method is convenient also where a succession of parallels are required to a given line *C D*, for the perpendicular may be drawn to it, and any number of parallels may be drawn on the perpendicular.

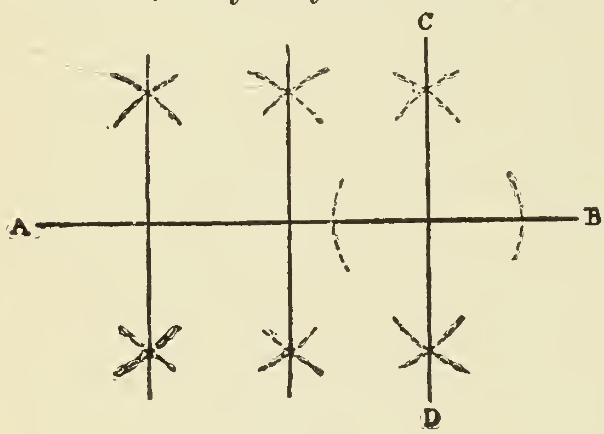


Fig. 76.

PROBLEM VI. *To divide a line into a number of equal parts,* Fig. 77.

To divide the line *A B* into, say 5 parts. From *A* and *B* draw parallels *A C, B D* on opposite sides; set off any convenient distance four times (one less than the given number), from *A* on *A C*, and on *B* on *B D;* join the first on *A C* to the fourth on *B D*, and so on. The lines so drawn divide *A B* as required.

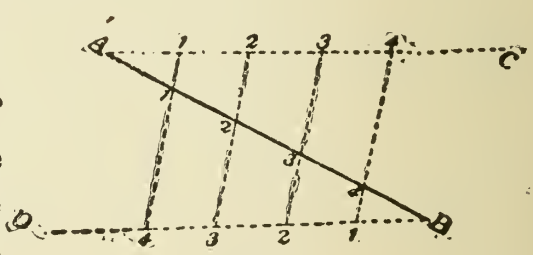


Fig. 77.

Second Method, Fig. 78. Draw the line at *A C*, at an angle from *A*, set off say, five equal parts; draw *B* 5, and draw parallels to it from the other points of division in *A C*. These parallels divide *A B* as required.

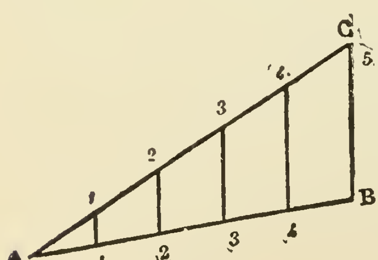


Fig. 78.

GEOMETRICAL PROBLEMS.

PROBLEM VII. Upon a straight line to draw an angle equal to a given angle, Fig. 79. Let *A* be the given angle and *F G* the line. With any radius from the points *A* and *F*, describe arcs *D E*, *I H*, cutting the sides of the angle *A* and the line *F G*.

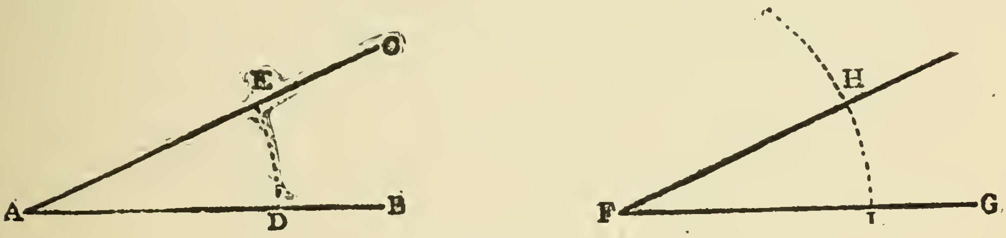


Fig. 79.

Set off the arc *I H* equal to *D E* and draw *F H*. The angle *F* is equal to *A* as required.

PROBLEM VIII. *To bisect an angle*, Fig. 80. Let *A C B* be the angle; on the center *C* cut the sides at *A B*. On *A* and *B* as centers describe arcs cutting at *D* dividing the angle into two equal parts.

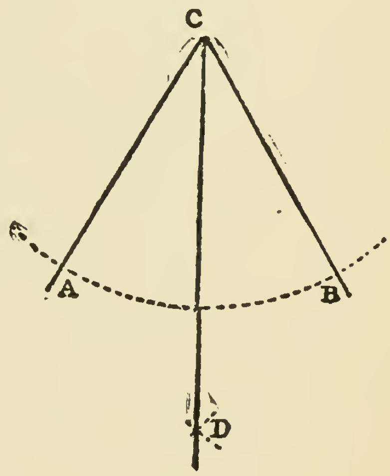


Fig. 80.

PROBLEM IX. *To find the center of a circle or of an arc of a circle.* First for a circle, Fig. 81. Draw the chord *A B*, bisect it by the perpendicular *C D*, bounded both ways by the circle; and bisect *C D* for the center *G*.

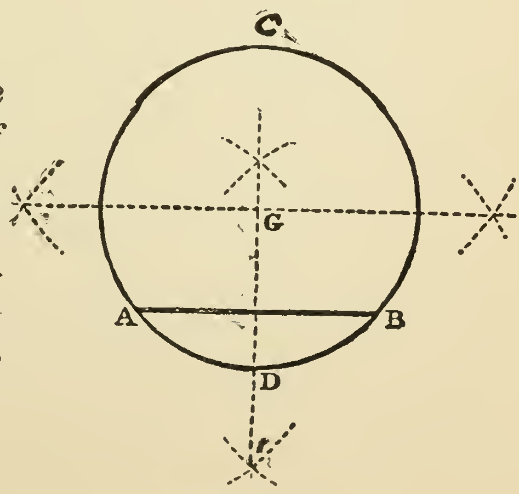


Fig. 81.

GEOMETRICAL PROBLEMS.

PROBLEM X. *Through two given points to describe an arc of a circle with a given radius*, Fi 82. On the points *A* and *B* as centers, /ith the given radius, describe arcs cutting at *C;* and from *C*, with the same radius, describe an arc *A B* as required.

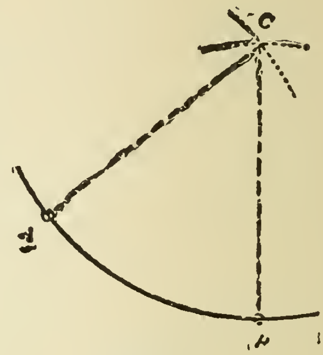


Fig. 82.

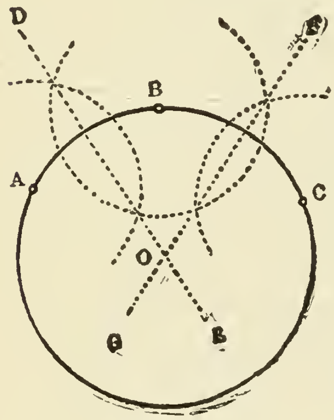


Fig. 83.

Second, for a circle or an arc, Fig. 83. Select three points *A B C* in the circumference, well apart; with the same radius; describe arcs from these three points cutting each other, and draw two lines *D E, F G,* through their intersections according to Fig. 68. The point where they cut is the center of the circle or arc.

PROBLEM XI. *To describe a circle passing through three given points,* Fig. 83. Let *A B C* be the given points and proceed as in last problem to find the center *O*, from which the circle may be described.

NOTE.

This problem is variously useful; in finding the diameter of a large fly wheel, or any other object of large diameter when only a part of the circumference is accessible; in striking out arches when the span and rise are given, etc.

PROBLEM XII. *To draw a tangent to a circle from a given point in the circumference,* Fig. 84. From *A* set off equal segments *A B, A D,* join *B D* and draw *A E,* parallel to it, for the tangent.

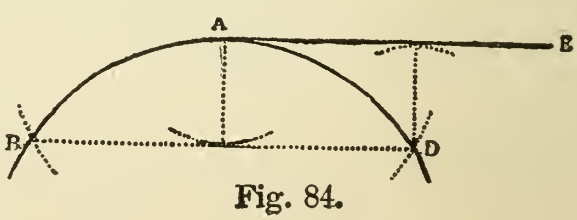


Fig. 84.

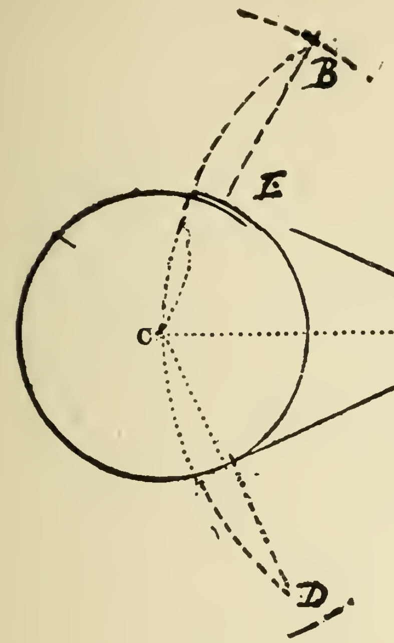


Fig. 85.

PROBLEM XIII. *To draw tangents to a circle from points without it,* Fig. 85. From A with the radius $A\ C$, describe an arc $B\ C\ D$, and from C with a radius equal to the diameter of the circle, cut the arc at $B\ D$; join $B\ C$, $C\ D$, cutting the circle at $E\ F$, and draw $A\ E$, $A\ F$, the tangents.

PROBLEM XIV. *Between two inclined lines to draw a series of circles touching these lines and touching each other,* Fig. 86. Bisect the inclination of the given lines $A\ B$, $C\ D$ by the line $N\ O$. From a point P in this line draw the perpendicular $P\ B$ to the line $A\ B$, and on P describe the circle $B\ D$, touching the lines and cutting the center line at E. From E draw $E\ F$ perpendicular to the center line, cutting $A\ B$ at F, and from F describe an arc $E\ G$, cutting $A\ B$ at G. Draw $G\ H$ parallel to $B\ P$, giving H, the center of the next circle, to be described with the radius $H\ E$, and so on for the next circle $I\ N$.

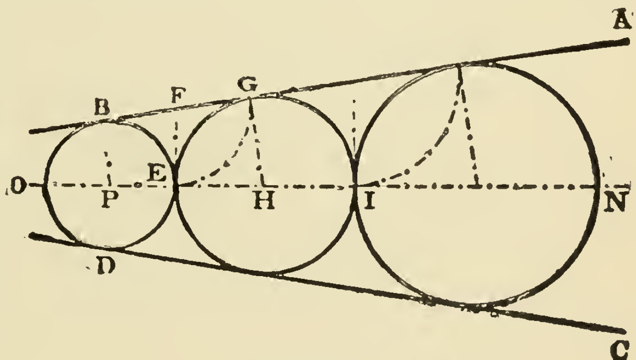


Fig. 86.

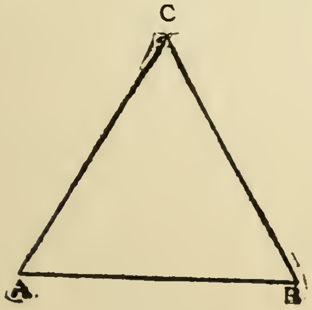


Fig. 87.

PROBLEM XV. *To construct a triangle on a given base, the sides being given.*

First. An equilateral triangle, Fig. 87. On the ends of a given base $A\ B$, with $A\ B$ as a radius describe arcs cutting at C, and draw $A\ C$, $C\ B$.

Second. A triangle of unequal sides, Fig. 88. On either end of the base A D with the side B as a radius, describe an arc; and with the side C as a radius on the other end of the base as a center describe arcs cutting the arc at E. Join A E, D E.

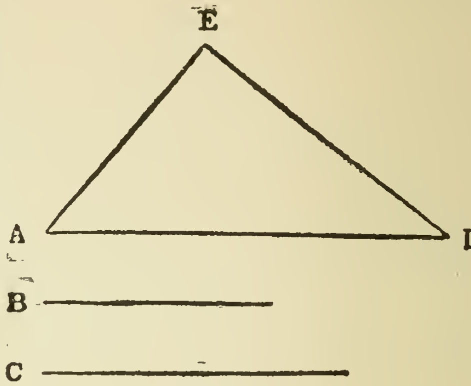


Fig. 88.

NOTE.

This construction may be used for finding the position of a point C or E at given distances from the ends of a base, not necessarily to form a triangle.

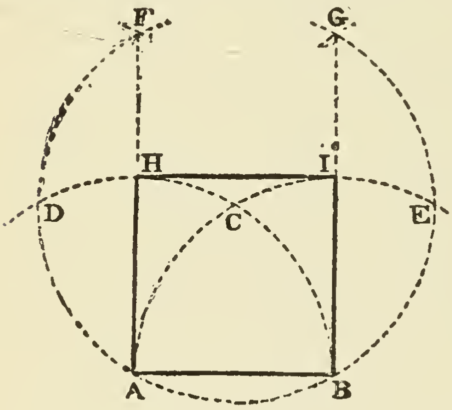


Fig. 89.

PROBLEM XVI. *To construct a square rectangle on a given straight line.*

First. A square, Fig. 89. On the ends A B as centers, with the line A B as radius, describe arcs cutting at C; on C describe arcs cutting the others at D E; and on D and E cut these at F G. Draw A F B G and join the intersections H I.

Second. A rectangle, Fig. 90. On the base E F draw the perpendiculars E H, F G, equal to the height of the rectangle and join G H.

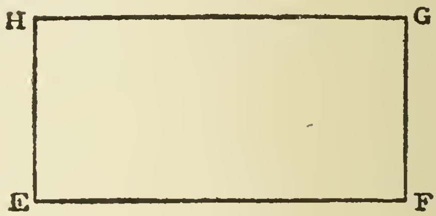


Fig 90.

PROBLEM XVII. *To construct a parallelogram of which the sides and one of the angles are given*, Fig. 91. Draw the side D E equal to the given length A, and set off the other side D F equal to the other length B, forming the given angle C. From E with D F as radius, describe an arc, and from F, with the radius D E cut the arc at G. Draw F G, E G. Or, the remaining sides may be drawn as parallels to D E, D F.

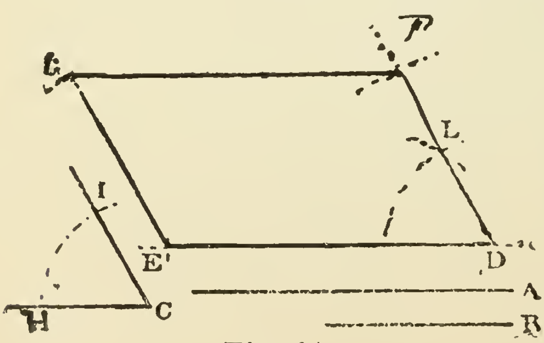


Fig. 91.

GEOMETRICAL PROBLEMS.

PROBLEM XVIII. *To describe a circle about a triangle,* Fig. 92.

Bisect two sides *A B, A C* of the triangle at *E F,* and from these points draw perpendiculars cutting at *K.* On the center *K,* with the radius *K A* draw the circle *A B C.*

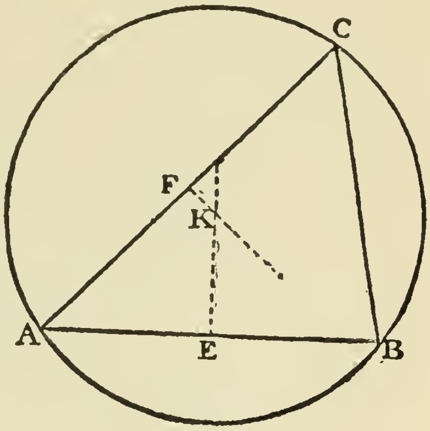


Fig. 92.

PROBLEM XIX. *To describe a circle about a square, and to inscribe a square in a circle,* Fig. 94.

First. To describe the circle. Draw the diagonals *A B, C D* of the square, cutting at *E;* on the center *E* with the radius *E A* describe the circle.

Second. To inscribe the square. Draw the two diameters *A B, C D* at right angles and join the points *A B, C D* to form the square.

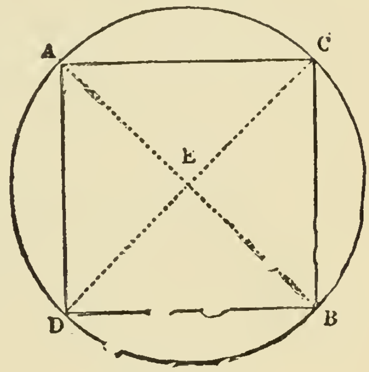


Fig. 93.

NOTE.

In the same way a circle may be described about a triangle.

PROBLEM XX. *To inscribe a circle on a square, and to describe a square about a circle,* Fig. 94.

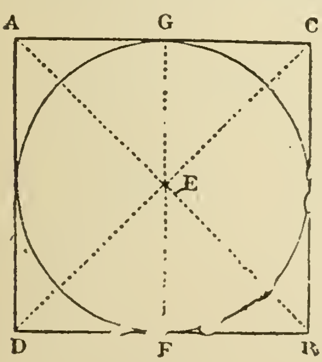


Fig. 94.

First. To inscribe the circle. Draw the diagonals *A B, C D* of the square, cutting at *E;* draw the perpendicular *E F* to one side, and with the radius *E F* describe the circle.

Second. To describe the square. Draw two diameters *A B, C D* at right angles, and produce them; bisect the angle *D E D* at the center by the diameter *F G,* and through *F* and *G* draw perpendiculars *A C, B D.* and join the points *A D* and *B C* where they cut the diagonals to complete the square.

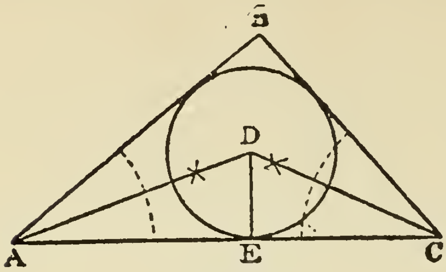


Fig. 95.

PROBLEM XXI. *To inscribe a circle in a triangle,* Fig. 95. Bisect two of the angles *A C* of the triangle by lines cutting at *D;* from *D* draw a perpendicular *D E* to any side, and with *D E* as radius describe a circle.

PROBLEM XXII. *To inscribe a pentagon in a circle,* Fig 96. Draw two diameters *A C, B D* at right angles cutting at *O;* bisect *A O* at *E,* and from *E* with radius *E B* cut the circumference at *G H* and with the same radius step round the circle to *I* and *K;* join the points to form the pentagon.

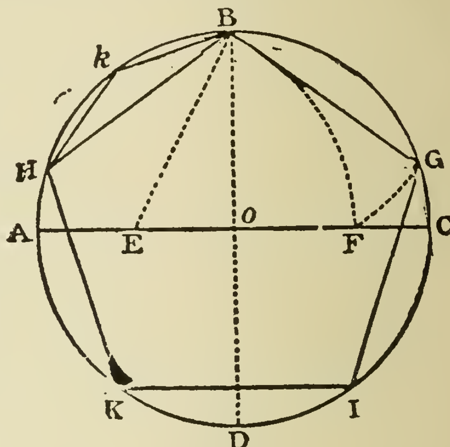


Fig. 96.

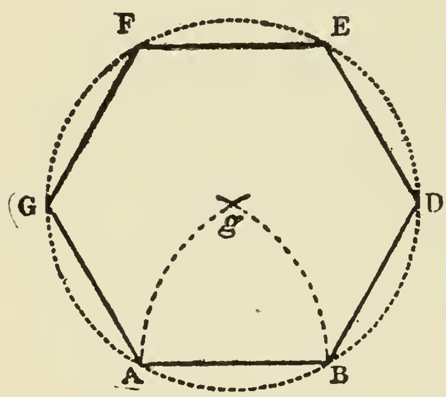


Fig. 97.

PROBLEM XXIII. *To construct a hexagon upon a given straight line,* Fig. 97. From *A* and *B* the ends of the given line describe arcs cutting at *G;* from *G* with the radius *G A* describe a circle. With the same radius set off the arcs *A G, G F* and *B D, D E.* Join the points so found to form the hexagon.

PROBLEM XXIV. *To inscribe a hexagon in a circle,* Fig. 98. Draw a diameter *A C B;* from *A* and *B* as centers with the radius of the circle *A C,* cut the circumference at *D, E, F, G,* and draw *A D, D E,* etc., to form the hexagon.

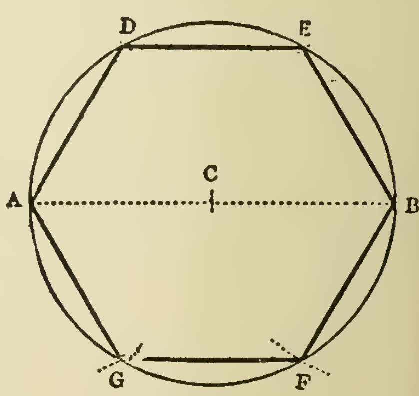


Fig. 98.

NOTE.

The points *D E,* etc., may be found by stepping the radius (with the dividers) six times round the circle.

PROBLEM XXV. *To describe an octagon on a given straight line,* Fig. 99. Produce the given line $A\ B$ both ways and draw perpendiculars $A\ E$, $B\ F$; bisect the external angles A and B by the lines $A\ H$, $B\ C$, which make equal to $A\ B$. Draw $C\ D$ and $H\ G$ parallel to $A\ E$ and equal to $A\ B$; from the center $G\ D$, with the radius $A\ B$, cut the perpendiculars at $E\ F$, and draw $E\ F$ to complete the hexagon.

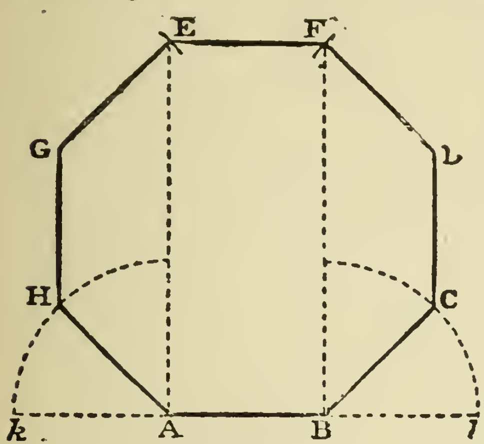


Fig. 99.

PROBLEM XXVI. *To convert a square into an octagon,* Fig. 100.

Draw the diagonals of the square cutting at e; from the corners $A\ B\ C\ D$, with $A\ e$ as radius, describe arcs cutting the sides at g, h, etc.; and join the points so found to complete the octagon.

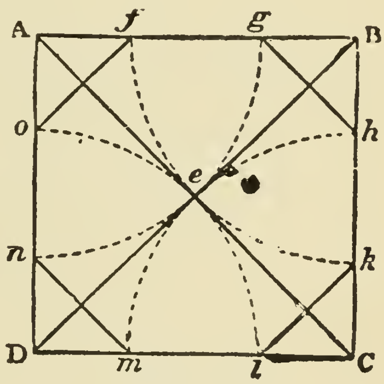


Fig. 100.

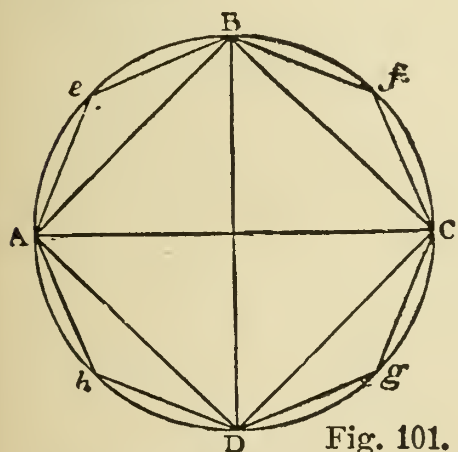


Fig. 101.

PROBLEM XXVII. *To inscribe an octagon in a circle,* Fig. 101.

Draw two diameters $A\ C$, $B\ D$, at right angles; bisect the arcs $A\ B$, $B\ C$, and C at e, f, etc., to form the octagon.

PROBLEM XXVIII. *To describe an octagon about a circle,* Fig. 102.

Describe a square about the given circle $A\ B$, draw perpendiculars h, k and C to the diagonals, touching the circle, to form the octagon. Or, the points h, k, etc., may be found by cutting the sides from the corners.

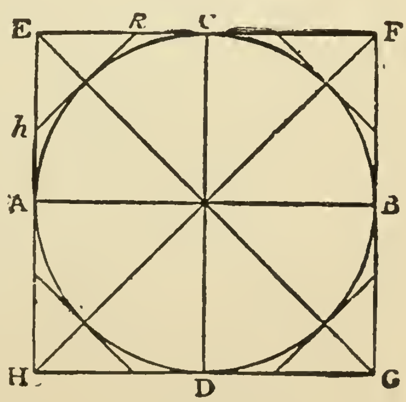


Fig. 102.

GEOMETRICAL PROBLEMS.

PROBLEM XXIX. *To describe an ellipse when the length and breadth are given,* Fig. 103. On the center *C,* with *A E* as radius, cut the axis *A B* at *F* and *G,* the foci; fix a couple of pins into the axis at *F* and *G,* and loop on a thread cr cord upon them equal in length to the axis *A B,* so as when stretched to reach the extremity *C* of the conjugate axis, as shown in dot-lining. Place a pencil or drawpoint inside the cord,

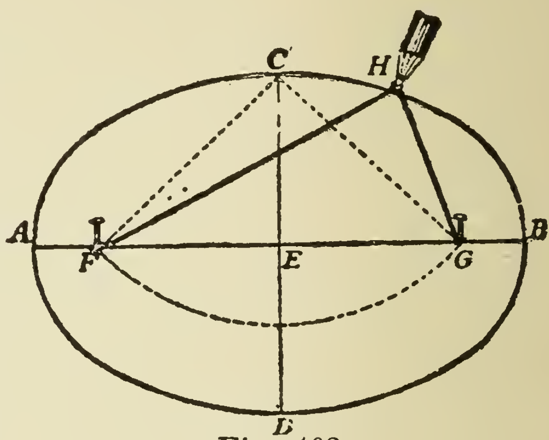


Fig. 103.

as at *H,* and guiding the pencil in this way, keeping the cord equally in tension, carry the pencil round the pins *F, G,* and so describe the ellipse.

NOTE.

The ellipse is an oval figure, like a circle in perspective. The line that divides it equally in the direction of its great length is the *transverse axis,* and the line which divides the opposite way is the *conjugate axis.*

Second Method. Along the straight edge of a piece of stiff paper mark off a distance *a c* equal to *A C,* half the transverse axis; and from the same point a distance *a b* equal to *C D,* half the conjugate axis. Place the slip so as to bring the point *b* on the line *A B* of the transverse axis, and the point *c* on the line *D E;* and set off on the drawing

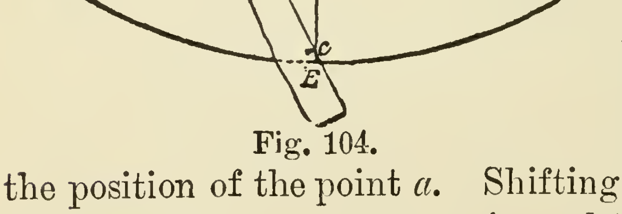


Fig. 104.

the position of the point *a.* Shifting the slip, so that the point *b* travels on the transverse axis, and the point *c* on the conjugate axis, any number of points in the curve may be found, through which the curve may be traced.

PROPORTION, OR THE RULE OF THREE.

The Rule of Three, or proportion, is one of the most useful in the whole range of mathematics; a rule by which, when three numbers are given, a fourth number is found, which bears the same relation to the third as the second does to the first; or a fourth number is found bearing the same relation to the third as the first does to the second.

Proportion is the relation of one quantity to another. This relation may be expressed either by the difference of the quantities or by their quotient. In the former case it is called arithmetical relation, in the latter geometrical proportion or simple proportion.

Proportion differs from *ratio*. *Ratio* is properly the relation of two magnitudes or quantities of one and the same kind; as the relation of 5 to 10 or 8 to 16. *Proportion* is the sameness or likeness of two such relations; thus 5 is to 10, as 8 to 16, or, A is to B as C is to D; that is, 5 bears the same relation to 10 as 8 does to 16. Hence we say such numbers are in proportion.

A *proportion* is an equality of ratios, and as *ratio* is the measure of the relations of two like quantities,

It is determined by dividing the first quantity by the second. Thus:

The ratio of 6 to 3 is 2, or of $8 to $2 is 4.

$$8 : 2 = 16 : 4, \text{ is a proportion.}$$

The equality is generally indicated by writing :: between the ratios, thus:

8 : 2 :: 16 : 4 indicates a proportion and is read, eight *is to* two, *as,* sixteen *is to* four.

NOTE.

The sign : is an abbreviated form of ÷ and has a like meaning.

In proportion, three quantities are given, the problem being to find the fourth, as 2 is to 4 as 6 is to what number—expressed thus: 2 : 4 :: 6 : ?

Now then: multiply the second term by the third term and divide this product by the first term.

$$4 \times 6 = 24.$$

$$24 \div 2 = 12, \text{ which is the required number.}$$

RULE.

Of the three given numbers, place that for the third term which is of the same kind with the answer sought.

Then consider, from the nature of the question, whether the answer will be greater or less than this term. If the answer is to be greater, place the greater of the two numbers for the second term, and the less number for the first term; but if it is to be less, place the less of the two remaining numbers for the second term, and the greater for the first; and in either case multiply the second and third terms together, and divide the product by the first for the answer, which will always be of the same denomination as the third term.

NOTE.

If the first and second terms contain different denominations, they must both be reduced to the same denomination; and compound numbers to INTEGERS of the lowest denomination contained in it.

EXAMPLE.

2. If 40 tons of iron cost $450, what will 130 tons cost?

Tons. Dolls. Tons.
40 : 450 :: 130
130

13500
450

40)5850|0

1462.5 dollars Ans.

The *Terms* of a ratio are the two numbers compared. The *Antecedent* is the first term of a ratio, the *Consequent* is the second term, and the two terms together are called a *Couplet*. An *Inverse Ratio* is the ratio formed by inverting the terms of a given ratio. Thus 8:9 is the *inverse* of 9:8.

Each term of a proportion is called a *Proportional;* the first and fourth terms are called *Extremes;* and the second and third term, *Means*. When the two means are the same number, that number is a *Mean Proportional* between the two extremes.

THERMO-DYNAMICS.

Heat is treated generally in scientific books under the heading of *thermo-dynamics.*

This term is made from two Greek words which signify, respectively heat-power; i. e., the power which is produced by the combustion or burning of fuel.

Without heat there would be no steam engine or steam boiler, and no engineer nor fireman; hence, the consideration of its nature and management and the calculations connected with its employment stand first in the order of subjects, *heat, water, steam,* now to be explained in their relations to mathematical calculations.

HEAT.

When two bodies in the neighborhood of each other have unequal temperatures, there exists between them a transfer of heat from the hotter of the two to the other.

The tendency towards an equalization, or towards an equilibrium of temperatures is universal, and the passage of heat takes place in three ways:

1. By radiation.
2. By conduction.
3. And by convection, or carriage from one place to another by heated currents.

RADIATION OF HEAT.

Radiant heat traverses air without heating it.

By means of a simple apparatus it has been ascertained that the proportion of the total heat radiated from different combustibles are as follows :

Radiated heat from		wood, ...	nearly $\frac{1}{4}$
do	do	wood charcoal	" $\frac{1}{2}$
do	do	oil, ...	" $\frac{1}{5}$

These values serve to show that radiation from heat is considerable; and that *flameless* carbon such as is wood charcoal, radiates more than oil, which is also nearly pure carbon, does with its more brilliant consumption.

THERMO-DYNAMICS.

The heat which is experienced by holding the hand near the flame of a candle, by its side, is the heat caused by *radiation*, while the heat felt by the hand held over the flame, is the heat conveyed by *convection*. But it is to be noticed that while the radiant heat is dissipated all round the flame, the diameter of the upward current is little more than that of the flame, and the conveyed heat is therefore concentrated in a narrow compass.

With respect to the heated bodies, apart from combustibles as such, the radiation or throwing out of heat implies the opposite process of absorption; and the radiators are likewise the best absorbents of heat. All bodies possess the property of radiating heat. The heat rays proceed *in straight lines*, and the intensity of the heat radiated from any one source of heat becomes less as the distance from the source of heat increases.

This decrease is governed by a great natural law, which is this: *the intensity decreases in the inverse ratio of the square of the distance;* that is to say, for example, that at any given distance from the source of radiation, the intensity of the radiant heat is four times as great as it is at twice the distance.

When a polished body like sheet tin, steel or silver is struck by a ray of light it absorbs a part of the heat and reflects the rest. The greater or less proportion of heat absorbed by the body is *the measure of its absorbing power*, and the reflected heat is the measure of its *reflecting power*.

The reflecting power of a body is the complement of its absorbing power; that is to say, that the sum of the absorbing and reflecting powers of all bodies is the same, which amounts to this, that a ray of heat striking a body is disposed of by absorption and reflection together, that which is not absorbed being naturally reflected.

CONDUCTION OF HEAT.

Conduction is the movement of heat through substances, or from one substance to another in contact with it. A body which conducts heat well is called a good conductor of heat; if it conducts heat slowly it is a bad conductor of heat. Bodies which are finely fibrous, as cotton, wool, wadding, finely divided charcoal, are the worst conductors of heat. Liquids and gases are bad conductors; but if suitable provision is made for the free circulation of fluids they may abstract heat very quickly by contact with heated surfaces acting by convection. The table contains the relative conducting powers of metals and earth according to M. Despretz.

RELATIVE INTERNAL CONDUCTING POWER OF METALS.

Substance.	Relative Conducting Powers.	Substance.	Relative Conducting Powers.
Gold	1000	Zinc..........	 363
Platinum	 981	Tin	 304
Silver..... ...	 973	Lead.........	 180
Copper	 892	Marble........	 24
Brass.........	 749	Porcelain......	 12
Cast Iron	 502	Terra Cotta...	 11
Wrought Iron .	 374		

CONVECTION OF HEAT.

Convected or carried heat is that which is transferred from one place to another by a current of liquid or gas; for example, by the products of combustion in a furnace towards the heating surface in the flues of a boiler.

THE MECHANICAL THEORY OF HEAT.

Heat and mechanical force are identical and convertible. Independently of the medium through which heat may be developed into mechanical action *the same quantity of heat* is resolved into *the same total quantity of work.*

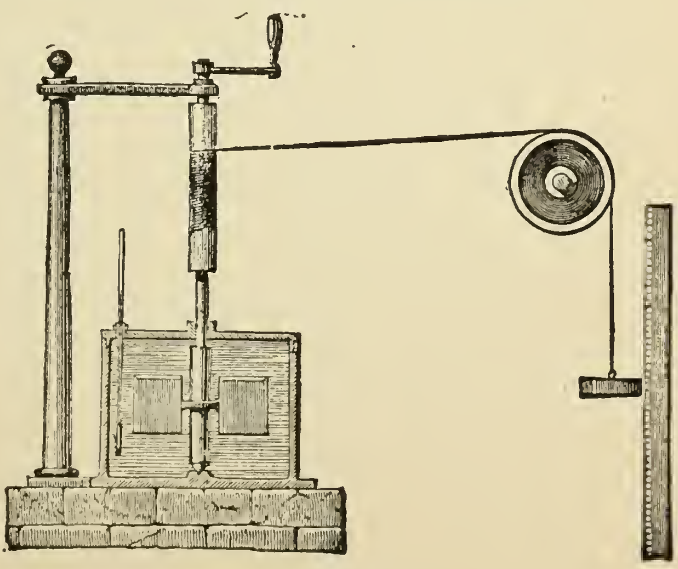


Fig. 105.

THERMO-DYNAMICS.

The unit of heat is that which is required to raise 1 lb. of water, at 39 degrees Fahr., 1 degree. If 2 lbs. of water be raised 1 degree or 1 lb. be raised 2 degrees in temperature, the expenditure of heat is the same in amount, namely, two degrees of heat, and to express the mechanical equivalent of heat the comparison lies between *the unit* of heat on the one part and the *unit of work*—a foot pound—on the other.

The most precise determination yet made of the numerical relation subsisting between heat and mechanical work was obtained by the following experiment by Dr. Jorles: He constructed an agitator, Fig. 105 consisting of a vertical shaft carrying a brass paddlewheel, of which the paddles revolved between stationary vanes, which served to prevent the liquid in the vessel from being bodily whirled in the direction of rotation. The vessel was filled with water and the agitator made to revolve by means of a cord wound round the upper part of the shaft and attached to a weight which descended in front of a scale by which the work done was measured. When all corrections had been applied, it was found that the heat communicated to the water by the agitation amounted to one pound degree Fahrenheit for every 772 foot pounds of work expended in producing it. Hence it was deduced that one unit of heat was capable of raising 772 lbs. weight 1 foot in height. The mechanical equivalent of heat, known as Jorles' equivalent, is 772 foot lbs. for 1 unit of heat. Sperm oil was also tried as the fluid medium and it yielded the same result as water.

According to the mechanical theory of heat, in its general form, heat, mechanical force, electricity, chemical affinity, light and sound are but *different manifestations of motion*—thus, the intense heat of the furnace is the result of an amazing rapidity of motion taking place among the particles during the decomposition of the mass of fuel.

THERMOMETERS.

The action of Thermometer is based on the change of volume to which bodies are subject with a change of temperature, and they serve, as their name implies, to measure temperature. Thermometers are filled with air, water, or mercury. Mercurial thermometers are the most convenient, because the most compact. They consist of a stem or tube of glass, formed with a bulbous expansion at the foot to contain the mercury, which expands into the tube. The stem being uniform in bore, and the apparent expansion of mercury in the tube being equal for equal increments of temperature, it follows that if the scale be graduated with equal intervals, these will indicate equal increments of temperature. A sufficient quantity of mercury having been introduced, it is boiled to expel air and moisture, and the tube is hermetically sealed. The freezing and the boiling points on the scale are then determined respectively by immersing the thermometer in melting ice and afterwards in the steam of water boiling under the mean atmospheric pressure, 14.7 lbs. per square inch, and marking the two heights of the column of mercury in the tube. The interval between these two points is divided into 180 degrees for Fahrenheit's scale, or 100 degrees for the Centigrade scale, and degrees of the same interval are continued above and below the standard points as far as may be necessary. It is to be noted that any inequalities in the bore of the glass must be allowed for by an adaptation of the lengths of the graduations. The rate of expansion of mercury is not strictly constant, but increases with the temperature, though, as already referred to, this irregularity is more or less nearly compensated by the varying rates of expansion of glass.

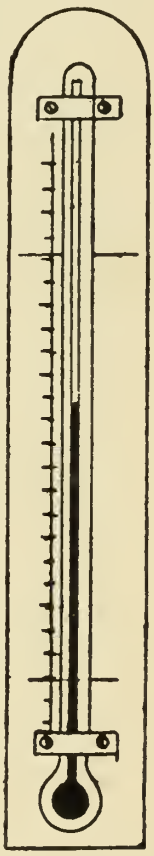


Fig. 106.

In the *Fahrenheit Thermometer*, used in Britain and America, the number 0° on the scale corresponds to the greatest degree of cold that could be artificially produced when the thermometer was originally introduced. 32° ("the freezing-point") corresponds to the temperature of melting ice, and 212°

THERMOMETERS.

to the temperature of pure boiling water—in both cases under the ordinary atmospheric pressure of 14.7 lbs. per square inch. Each division of the thermometer represents 1° Fahrenheit, and between 32° and 212° there are 180°.

THE MEASUREMENT OF HEAT.

Temperature means the sensible heat in anything, and is measured by the Thermometer.

There are three kinds of Thermometers in general use—Fahrenheit's, Centigrade, and Reaumur's.

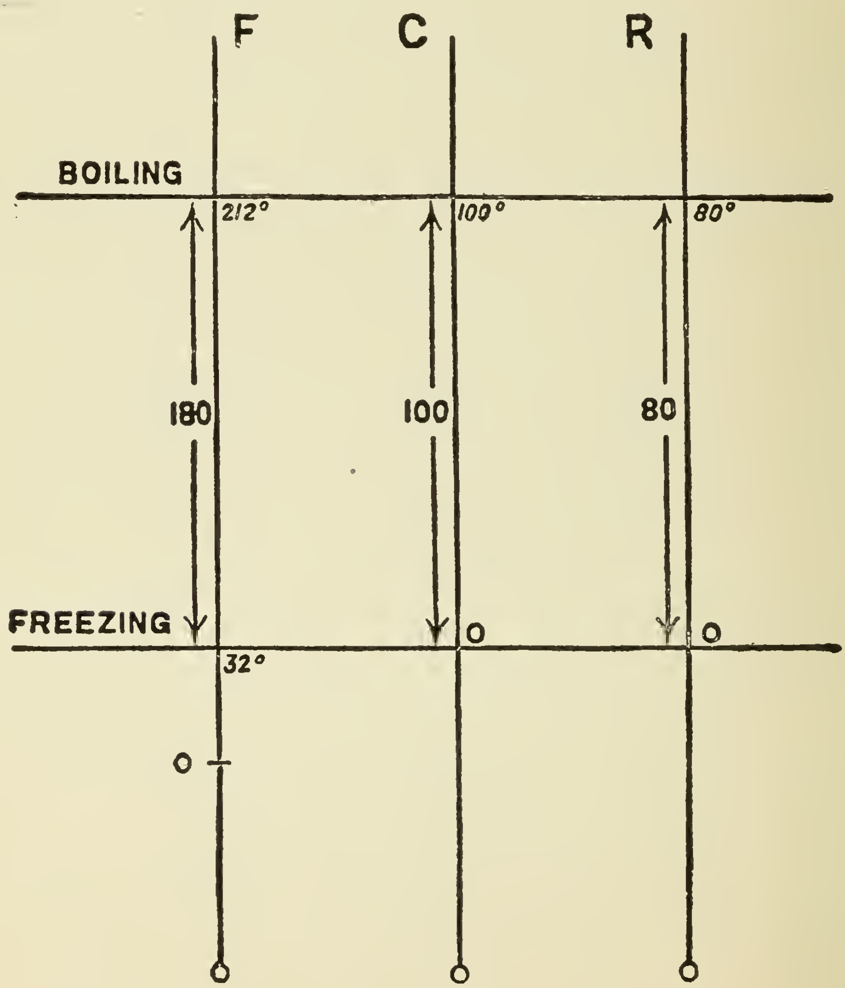


Fig. 107.

The 0 on these scales is called Zero, all above the 0 is plus, while all below is minus; thus a temperature of 10° below Zero is written −10°

THE MEASUREMENT OF HEAT.

In Fahrenheit's, the space between Freezing and Boiling points is divided into 180 degrees, Freezing being 32° and Boiling 212°.

In Centigrade, Freezing is 0 and Boiling 100°, the space being thus divided into 100 parts; hence its name.

In Reaumur's, Freezing is 0 and Boiling is 80°, the space being thus divided into 80 parts.

In the above diagram it is readily seen that

$$180° \text{ F} = 100° \text{ C} = 80° \text{ R};$$

from which we can get the rules for comparing degrees of temperature on one scale with the degrees on another.

In the *Centigrade Thermometer,* used in France and in most other countries in Europe, 0° corresponds to melting ice, and 100° to boiling water. From the freezing to the boiling point there are 100°

In the *Reaumur Thermometer,* used in Russia, Sweden, Turkey, and Egypt, 0° corresponds to melting ice, and 80° to boiling water. From the freezing to the boiling point there are 80°.

Centigrade temperatures are converted into Fahrenheit temperatures by multiplying the former by 9 and dividing by 5, and adding 32° to the quotient; and conversely, Fahrenheit temperatures are converted into Centigrade by deducting 32° and taking $\frac{5}{9}$ths of the remainder.

Reaumur degrees are multiplied by $\frac{5}{4}$ to convert them into the equivalent Centigrade degrees; conversely, $\frac{4}{5}$ths of the number of Centigrade degrees give their equivalent in Reaumur degrees.

Fahrenheit is converted into Reaumur by deducting 32° and taking $\frac{4}{9}$ths of the remainder, and Reaumur into Fahrenheit by multiplying by $\frac{9}{4}$, and adding 32° to the product.

PYROMETERS.

Pyrometers are employed to measure temperatures above the boiling point of mercury, about 676° F.

THERMO-DYNAMICS.

PYROMETER.

Wedgwood's pyrometer, invented in 1782, was founded on the property possessed by clay of contracting at high temperatures. The apparatus consists of a metallic groove, 24 inches long, the sides of which converge, being half an inch wide above and three-tenths below. The clay is made up into little cylinders or truncated cones, which fit the commencement of the groove after having been heated to low redness; their subsequent contraction by heat is determined by allowing them to slide from the top of the groove downwards till they arrive at a part of it through which they cannot pass.

In Daniell's pyrometer the temperature is measured by the expansion of a metal bar inclosed in a black-lead earthenware case, which is drilled out longitudinally to $\frac{3}{10}$ inch in diameter and $7\frac{1}{2}$ inches deep. A bar of platinum or soft iron, a little less in diameter, and an inch shorter than the bore, is placed in it and surmounted by a porcelain index $1\frac{1}{2}$ inches long, kept in its place by a strap of platinum and an earthenware wedge. When the instrument is heated, the bar, by its greater rate of expansion compared with the black-lead, presses forward the index, which is kept in its new situation by the strap and wedge until the instrument cools, when the observation can be taken by means of a scale.

Another means of estimation, based on the melting points of metals and metallic alloys, is applied simply by suspending in the heated medium a piece of metal or alloy of which the melting point is known, and if necessary, two or more pieces of different melting points, so as to ascertain, according to the pieces which are melted and those which continue in the solid state, within certain limits of temperature, the heat of the furnace. A list of melting points of metals and metallic alloys is given in a subsequent chapter.

THERMO-DYNAMICS.

LUMINOSITY AT HIGH TEMPERATURES.

The luminosity or shades of temperature have been observed by M. Pouillet by means of an air-pyrometer to be as follows:—

Shade.	Temperature. Fahrenheit.
Nascent Red...........................	977°
Dark Red..............................	1292
Nascent Cherry Red....................	1472
Cherry Red............................	1652
Bright Cherry Red.....................	1832
Very Deep Orange......................	2012
Bright Orange.........................	2192
White.................................	2372
"Sweating" White......................	2552
Dazzling White........................	2732

A bright bar of iron, slowly heated in contact with air, assumes the following tints at annexed temperatures (Claudel):

		Fahrenheit
1.	Cold iron at about.................	54°
2.	Yellow at..........................	437
3.	Orange at..........................	473
4.	Red at.............................	509
5.	Violet at..........................	531
6.	Indigo at..........................	550
7.	Blue at............................	559
8.	Green at...........................	630
9.	Oxide Gray (*gris d'oxyde*) at.......	752

HORSE POWER.

A horse power is merely an expression for a certain amount of work and involves three elements—

1. Force.
2. Space; and
3. Time.

If the force be expressed in pounds, and the space passed through in feet, then we have a solution of and the meaning for, the term *foot-pound;* from which it will be seen that a foot-pound is a resistance equal to *one pound moved upwards one foot.* The work done in lifting thirty pounds through a height of fifty feet is fifteen hundred foot-pounds.

Now if the foot-pounds required to do a certain amount of work involve a specified amount of time during which the work is performed and if this number of foot-pounds is divided by the equivalent number representing one horse power (which number will be dependent upon the time) then the resulting number will be the horse power developed.

EXAMPLE.

Suppose the 1500 foot-pounds just spoken of to have acted in one second. To find the horse power divide by 550, and the result will be the horse power.

A horse power is 33,000 foot-pounds, or, in other words 33,000 pounds lifted one foot in one minute, or one pound lifted 33,000 feet in one minute, or 550 lbs. lifted one foot in one second.

HORSE POWER OF THE STEAM ENGINE.

The capacity for work of a steam engine is expressed in the number of horse powers it is capable of developing.

HORSE POWER.

There are three kinds of horse power spoken and written about which engineers should learn to distinguish—these are

1. *Nominal,*
2. *Indicated,* and
3. *Effective.*

Engineers and others who have not carefully considered the matter, often use the above as synonymous—or having the same meaning; but in this they are wrong, as the meaning is very far from the same.

Nominal horse power is an expression which is gradually going out of use, and is merely a convenient mode of describing the *dimensions* of a steam engine for convenience of makers and purchasers of steam engines.

Indicated horse power is the true measure of the work done within the cylinder of the steam engine and is based upon no assumptions, but is actually calculated. The things necessary to be known in order to make the figures are:

1. The diameter of the cylinder in inches.

2. Length of stroke in feet.

3. The mean effective pressure—that is, *the average pressure* of the steam on the piston during the full length of the stroke; and

4. The number of revolutions per minute.

Effective horse power is the amount of work which an engine is capable of performing, and is the difference between the indicated horse power and horse power required to drive the engine when it is running unloaded.

NOTE.

Engine rating, guarantees, etc., are usually based upon the indicated horse power, owing to the ease and accuracy with which it can be determined.

RULE FOR CALCULATING HORSE POWER.

1. *Find the area of the piston.*

2. *Find the pressure in lbs. on the piston,* by multiplying the area by the pressure per square inch,

HORSE POWER.

3. *Find the space in feet travelled through by the piston per minute,* by multiplying the length of stroke in feet by twice the revolutions per minute.

4. *Find the foot-pounds done by the engine per minute,* by multiplying the pressure in lbs. (2) by the travel in feet (3).

5. *Find* the H. P. by dividing the foot-lbs. (4) by 33000.

EXAMPLE.

What is the horse power of an engine, the diameter of the cylinder being 16 inches, length of stroke 24 inches, revolutions per minute 120, and *the average pressure of steam* per square inch on the piston 45 lbs.?

ft. in.		
Diam. 1 4	.7854	stroke 2 feet.
12	256	No. of strokes 240
—	——	——
16 inches.	47124	480 travel of piston in feet.
16	39270	
—	15708	
96	———	
16	201.0624=area.	
—	45 lbs. pressure.	
Diam. 256 squared.	———	
	10053120	
	8042496	
	———	
	9047.8080=pressure on piston in lbs	

9047.8 lbs.
480 feet.
———
7238240
361912
———
33000 { 3)43429440 foot pounds.
———
11)14476480
———
131.6044

Ans. $131\frac{6}{11}$ horse power.

HORSE POWER.

Second Rule.

Instead of putting the work down step by step, it is more readily worked as follows: (1) *Square the diameter of the piston,* (2) *multiply it by the length of stroke in feet,* (3) *by twice the revolutions,* (4) *by the pressure per square inch,* (5) *and by* .0000238.

Example.

2. What is the horse power of an engine, the diameter of cylinder being 13 inches, length of stroke 12 inches, revolutions per minute 300, and the average pressure per square inch on the piston 67 lbs.?

```
       13 diameter in inches.
       13
       —
       39
      13
     ———
      169
        1  length of stroke in feet.
     ———
      169
        600 twice the revolutions, or number of strokes.
    ——————
   101400
       67 lbs. pressure per square inch.
   ——————
   709800
  608400
  ———————
  6793800
      238 constant multiplier.
 ————————
 54350400
203814
135876
——————————
161.6924400 horse power.      Ans. 161 7/10 H. P.
```

HORSE POWER.

NOTE.

This rule is the same as the first one except that *a constant multiplier is used.* This is found by dividing .7854 by 33000, which equals .0000238. This very considerably shortens the calculation as will be observed by comparing the two examples given under the rules, *i. e.*, the 16″x24″ and the 13″x12″ engine.

EXAMPLE FOR PRACTICE.

3. What is the horse power of an engine, the diameter of cylinder being 24 inches, length of stroke 60 inches, revolutions per minute 60, and *the average pressure* being $43\frac{43}{100}$?
Ans.:

4. What is the horse power of an engine, the diameter of cylinder being 6 inches, length of stroke 9 inches, revolutions per minute 400, and *the average pressure* of steam on the piston being 45 lbs.? Ans.:

5. What is the horse power of a pair of engines, the diameter of the cylinder being 12 inches, length of stroke 30 inches, revolutions per minute 90, and *the average pressure* of steam 38 lbs.? Ans.:

IMPORTANT.

In the rules given for estimating the power of different forms of the steam engine, it will be observed that the area of the piston is a quantity which is known to a close fraction; the piston speed in feet per minute is assumed to be correct, and the reduction of the foot-pounds to horse power by dividing by 33,000 *is the same in all rules; but the average pressure of steam is the doubtful part of the calculation.*

The reasons for this are various, such as the varied expansion, wire-drawing, steam working against itself in the cylinder, condensation, cramping of the exhaust, etc., etc. These defects, as well as the average pressure of the steam (and the combined pressure of the steam and the vacuum) are clearly shown by the Indicator; hence, while the rules given are sufficiently close for every-day practice, it is important to bear in mind that all questions of the power of engines are much more accurately determined by the Indicator.

HORSE POWER.

Third Rule.

To compute horse power of engines by a short rule process.

Rule.

Multiply the diameter of the cylinder (in inches) by itself and by the distance in feet travelled by the piston per minute and divide by 42,000. The quotient gives the horse power *for each lb.* of mean effective pressure.

Example.

6. What is the horse power of a pair of 24x24 horizontal high pressure engines with 120 revolutions per minute.

```
24×24 = 576
2×120 =  240
        -----
        23040
       1152
       ------
42,000)138240(3.291
       126          2 for 2 cylinders.
       ---        -----
        122     6.582
         84
        ---
         384
         378
         ---
           60
           42
```

Ans. 6.582 for each lb. of mean effective pressure. To obtain total horse power, multiply by the number of lbs. of steam.

Fourth Rule.

To compute horse power of engine, by mean effective pressure, as shown by indicator.

HORSE POWER.

Rule.

Multiply the area of the piston, by the mean effective pressure per square inch, by the stroke in feet, by the number of strokes per minute (out and back being two strokes), and divide by 33,000. The quotient is the horse power.

Example.

7. What is the horse power of an engine, 9 inch bore of cylinder, 20 inch stroke, and 60 revolutions per minute, with mean effective pressure of 42 lbs.

Area of 9 inch per table = 636
M. E. P. 42

	1272	33,000)534240(16½ H. P.
	2544	33
	26712	204
Stroke	20	198
	12)534240	62
	44540	
Half revolutions	120	
	534240	

Rule for calculating Horse Power of Condensing Engines.

Proceed as in Rules and Examples on pages 161 and 162, adding 10 lbs. to the average pressure on the piston for the increased efficiency—above friction, etc.—for approximate advantage, gained by the use of the condenser.

Note.

Engine builders add from $\frac{1}{10}$ to $\frac{1}{4}$ to the nominal horse power of their engines as an approximation of the increased efficiency of their high pressure engines when fitted with condensing apparatus.

HORSE POWER.

Rule for finding the Horse Power of the Compound Engine.

Find the horse power of each cylinder separately, then add the two powers together; or in other words treat the two cylinders as you would two separate engines.

Note.

In a compound engine a second cylinder of three or four times the piston area is added, called the low pressure cylinder, into which the exhaust steam of the first or high pressure cylinder, instead of being thrown away, is passed and made to yield a further amount of work. The additional work thus obtained is roughly proportional to the mean effective pressure in the low pressure cylinder multiplied by the difference in area of the two pistons. By this means the power of the engine is increased, and the steam, when finally exhausted, is at a pressure so low that little or no unused work remains in it.

Example.

8. What is the H. P. of a compound engine whose high pressure cylinder is 16 inches in diameter, and low pressure 27 inches, with 16 inch stroke, and 250 revolutions per minute. Estimate the mean effective pressure as 70 lbs. for the 16 inch cylinder and 12 lbs. for the 27 inch cylinder. Now:

16″ area =	201	27″ area =	572.5 inches.
	70	pressure	12 lbs.
	14070		6870.0
feet traverse	666	feet traverse	666
	84420		41220
	84420		41220
	84420		41220
	33,000)9370620(284 nearly.		33,000)4575420(139 nearly.

Add 284 high pressure cylinder, non-condensing.
139 low " " "

423 total (nearly).

HORSE POWER OF THE COMPOUND ENGINE.

Example.

9. What is the horse power of a compound engine, diameter of high pressure cylinder $27\frac{1}{2}$ inches, and mean effective pressure throughout the stroke 36.95 lbs. per square inch. Diameter of low pressure cylinder 48 in., and mean effective pressure 7.35 lbs. per square inch, length of stroke 2 feet 6 inches, and revolutions per minute 75 ?

Find the H. P. of each cylinder separately, then add the two powers together.

H. P. of	high	pressure	=249.395 &c.
do.	low	do.	=151.139 &c.
Combined H. P.			=400.534

POWER OF THE LOCOMOTIVE.

The power of the locomotive is measured at the point where the wheel touches the rail, and is equal to the load the locomotive could lift out of a pit by means of a rope passed over a pulley, and attached to the outside of the tire of one of the driving wheels.

The term horse power is not generally used in speaking of the locomotive, as the difference in the work between it and the stationary engine is so great. The power of the locomotive resides in two places, first, the *adhesive power* which is derived from the weight on the driving wheels, and their friction and adhesion on the rails—it being remembered that the adhesion varies with the weight on the drivers and the state of the rail. Second, the *tractive power* of the locomotive, which is that derived from the pressure of the steam on the piston applied to the cranks and revolving wheels.

Rule to find the Horse Power of a Locomotive.

Multiply the area of the piston in square inches by 2 (there being 2 cylinders to each engine) also by *two-thirds* the boiler pressure as shown by the gauge; also by the number of revolutions per minute; also by the feet traversed by the piston. Divide by 33,000 and the amount will be the horse power.

HORSE POWER OF THE LOCOMOTIVE.

EXAMPLE.

10. The locomotive "A. G. Darwin" has 19 inch cylinders, 24 inch stroke, driving wheels 68 inches in diameter. It makes (with ease) 60 miles per hour, with boiler pressure 150 lbs. per square inch.

Area of piston 283.5×2 = 567 sq. inches.
$\frac{2}{3}$ boiler pressure = 100 lbs.

56700
300 revolutions.
17010000
4
33,000)68040000
2062 horse power.

**To find revolutions per minute.*
1 mile in 1 min. = 5280 ft. = 63360
divide by rim of driving wheel 68″
diam. = 213.6 inches. Now:
213.6÷63.360 = 300 nearly.

NOTE.

This engine weighs 120,000 lbs., of which 72,000 are on the drivers. By actual count it carried its own immense weight added to that of 8 heavy cars a mile in 47 seconds and several miles in 55, 58 and 60 seconds.

EXAMPLE.

11. What is the power of a locomotive with cylinders 19 inches bore, 30 inch stroke, diameter of drivers 72 inches, running speed 40 miles per hour, boiler pressure 160 lbs. per square inch.

Area of piston 19 inches (per table page 116)=283.5 inches.

Steam pressure, say in this example, six-tenths of 160 = 96 lbs.

Now then, per Rule:

$$\frac{283.5\times96\times170\times5\times12}{33000}=1359\tfrac{2}{3}\text{ nominal H. P.}$$

NOTE.

This must not be taken for *the locomotive power*, for it is not. This is the power which the engine would develope if the tires on the drivers were as gear wheels fitted to cogs on the track, so that they could not slip, and if the boiler could supply the steam.

Hence the rule given is merely approximate, as nothing can be told about the internal workings of the engines without a test carefully performed with the indicator—and the results of the latter are modified by the tractive or adhesive power.

NOTE.

Colburn's Rule for Calculating Power of Locomotives takes the full pressure of one cylinder instead of the mean average pressure of two.

RULE FOR FINDING THE HORSE POWER OF THE STEAM FIRE ENGINE.

Multiply the area of the piston by the average steam pressure in pounds per square inch; multiply this product by the travel of the piston in feet per minute, divide this product by 33000; seven-tenths of the quotient will be the horse power of the engine.

EXAMPLE.

12. Area of piston 8 inch diameter=50.27 in. (see page 115).
Stroke 8 inches, revolutions 150 per minute=200 feet travel.

Average steam pressure 100 lbs.

```
Now then:            50.27 area.
                        100 lbs. steam.
                     -------
                     5027.00
                          200 travel of piston in feet.
                     -------
33,000 foot-lbs.)100540000(30.4
                  99        ----
                  --        30.4
                  154         .7
                  132       ----
                  ---       21 28/100 horse power.
```

THE HORSE POWER OF THE STEAM BOILER.

A great deal of trouble has arisen from the application of this unit, the horse power, to the measurement of the capacity of steam boilers, for the boiler is only one part in the power-producing system. It furnishes the force. It is the magazine where is accumulated and stored the pressure obtained from the combustion of the coal.

Now some engines use steam much more economically than others, and a boiler which could furnish steam to develope power at the rate of 100 horses with the best of these, might not be able to do 40 horse power with the worst. Hence comes the question, what is the horse power of the boiler?

To meet the complication which arose from this cause a standard of evaporation of thirty pounds of water per hour, from feed water of 100° Fahrenheit into steam at 70 lbs. gauge pressure, has been adopted as a horse power for steam boilers Some engines can develope a horse power on this number of pounds of steam per hour, others cannot, while many require more hence it is about the present average capacity. Both engineers and steam users have received this standard with unanimity, and so-called "boiler tests," are based upon their evaporative capacity, expressed in lbs. of water per hour.

Square feet of heating surface is frequently used to express the horse power. This is figured from the number of square feet of boiler and tube surface exposed to the action of the fire; but this method is not at all accurate, as the same amount of exposed surface will under some circumstances produce several times as much steam as others, but for the ordinary tubular boiler fifteen square feet of heating surface has been held to be equal to one horse power.

The extent of the heating surface of a boiler depends on the length and diameter of the shell and the number and size of the tubes or flues.

When setting boilers in brick work, the practice is to rack in the side walls to the shell a few inches below the water line, and thus limit the heating surface. It is customary in calculating the heating surface of the shell, to consider that two-thirds of it is exposed to the action of heat.

HORSE POWER OF THE STEAM BOILER.

It is also customary to consider that the entire surface of the tubes or flues is exposed to the action of heat.

From the table given below, the heating surface of any boiler can be obtained with ease.

Table of Heating Surface of Boilers.

Diameter of Boiler Inches.	Two thirds heating surface of shell per ft. of length.	Diameter of tube or flue. Inches.	Whole external heating surface per ft. of length.
24	4.19	2	.524
26	4.54	2¼	.589
28	4.89	2½	.655
32	5.59	3	785
34	5.93	3¼	.850
36	6.28	3½	.916
40	6.98	4	1.05
42	7.33	4½	1.18
44	7.68	5	1.31
48	8.38	7	1.83
50	8.73	8	2.09
54	9.42	10	2.62
56	9.77	11	2.88
60	10.47	13	3.40
66	11.52	16	4.19
72	12.57	20	5.24

Rule for estimating Horse Power of Horizontal Tubular Steam Boilers.

Find the square feet of *heating surface* in the shell, heads and tubes, and divide by 15 for the nominal horse power.

Example.

What is the heating surface of a boiler having head 72 inches diameter, shell 18 feet long, with 100 tubes, 3½ inches in diameter? Now then:

```
                12)72 inches.
                   —
                   6 feet diameter.
 6             .7854
 6                36
 —             ─────
36             47124
              23562
              ─────
             28.2744 square feet of surface in one head.
```

HORSE POWER OF THE STEAM BOILER.

```
   12)3.50000
      -------
       .29167 feet diameter of the tube.
       3.1416
       ------
       175002
       29167
     116668
     29167
    87501
   ----------
   .916310472 feet circumference of 1 tube.
           18
   ----------
   7330483936
   916310472
  -----------
 16.493588656 square feet surface of 1 tube.
1649.3589 equals square feet surface in all the tubes.
   3.1416
        6
   ------
  18.8496 circumference of shell in feet.
       18
  -------
  1507968
  188496
  -------
 339.2928 square feet of surface of shell.
        2-thirds of shell
 --------
3)678.5856
 --------
 226.1952
1649.3589 tubes.
 --------
15)1875.5541
 --------
 125.        horse power, neglecting the heads.
```

ARITHMETICAL PROGRESSION.

ARITHMETICAL PROGRESSION is a series of numbers which succeed each other regularly, *increasing* or *diminishing* by a constant number or *common difference:*

As 1, 3, 5, 7, 9, &c. } increasing series.
15, 12, 9, 6, 3, &c. } decreasing series.

The numbers which form the series are called *terms.* The first and the last term are called the *extremes,* and the others are called the *means.*

In arithmetical progression, there are five things to be considered, viz.:

1, The first term.
2, The last term.
3, The common difference.
4, The number of terms.
5, The sum of all the terms.

These quantities are so related to each other, that when any three of them are given, the remaining two can be found.

Given the first term, the common difference, and the number of terms, to find the last term.

RULE.

Multiply the number of terms, *less one,* by the common difference, and to the product add the first term.

EXAMPLE.

What is the 20th term of the arithmetical progression, whose first term is one, the common difference $\frac{1}{2}$?

$20-1=19$ and $19\times\frac{1}{2}=9\frac{1}{2}$; and $9\frac{1}{2}+1=10\frac{1}{2}$. Ans.

Given the number of terms and the extremes, to find the common difference.

RULE.

Divide the difference of the extremes by one less than the number of terms.

ARITHMETICAL PROGRESSION.

Example.

The extremes are 3 and 29, and the number of terms 14, required the common difference.

$29-3=26$; and $26\div13=2$. Ans.

Given the common difference and extremes, to find the number of terms.

Rule.

Divide the difference of the extremes by the common difference, and to the quotient add *one.*

Example.

The first term of an arithmetical progression is 11, the last term 88, and the common difference 7. What is the number of terms?

$88-11=77$; and $77\div7=11$; $11+1=12$. Ans.

Given the extremes and the number of terms, to find the sum of all the terms.

Rule.

Multiply half the sum of the extremes by the number of terms.

Example.

How many times does the hammer of a clock strike in 12 hours.

$1+12=13=$the sum of extremes.

Then $12\times(13\div2)=78$. Ans.

WATER.

There are some underlying natural laws and other data relating to water which every engineer should thoroughly understand. Heat, *water,* steam, are the three properties with which he has first to deal; like the first rounds of a ladder they lead to higher lessons.

The scientific head under which water is treated is *Hydrostatics.* Hydraulics is one division of the general subject and means flowing water, not so applicable to steam engineering as the first term, which broadly means *the science of fluids,* of which water is the principal example.

WATER AS A STANDARD.

There are four notable temperatures for water, namely,

32° F.,	or	0° C.	= the freezing point under one atmosphere.
39°.1	or	4°	= the point of maximum density.
62°	or	16°.66	= the standard temperature.
212°	or	100°	= the boiling point, under one atmosphere.

The temperature 62° F. is the temperature of water used in calculating the specific gravity of bodies, with respect to the gravity or density of water as a basis, or as unity.

Weight of one cubic foot of Pure Water.

At 32° F.		= 62.418	pounds.
At 39°.1		= 62.425	"
At 62°	(Standard temperature)	= 62.355	"
At 212°		= 59.640	"

The weight of a cubic foot of water is, it may be added, about 1000 ounces (exactly 998.8 ounces), at the temperature of maximum density.

WATER.

The weight of water is usually taken in round numbers, for ordinary calculations, at 62.4 lbs. per cubic foot, which is the weight at 52°.3 F.; or it is taken at $62\frac{1}{2}$ lbs. per cubic foot, where precision is not required, equal to $\frac{1000}{16}$ lbs.

The weight of a cylindrical foot of water at 62° F. is 48.973 pounds.

Weight of one cubic inch of Pure Water.

At 32° F.	= .03612	pound,	or 0.5779	ounce.	
At 37°.1	= .036125	"	" 0.5780	"	
At 62°	= .03608	"	" 0.5773	"	or 252.595 grains.
At 212°	= .03451	"	" 0.5522	"	

The weight of one cylindrical inch of pure water at 62° F. is .02833 pounds, or 0.4533 ounce.

Volume of one pound of Pure Water.

At 32° F.	= .016021	cubic foot,	or 27.684	cubic inches.
At 39°.1	= .016019	"	" 27.680	"
At 62°	= .016037	"	" 27.712	"
At 212°	= .016770	"	" 28.978	"

The volume of one ounce of pure water at 62° F. is 1.732 cnbic inches.

WATER.

SEVERAL PRINCIPLES IMPORTANT TO KNOW.

Water is practically non-elastic. A pressure has been applied of 30,000 lbs. to the square inch and the contraction has been found to be less than one-twelfth. Experiment appears to show that for each atmosphere of pressure it is condensed 47½ millionth of its bulk.

Water at rest presses equally in all directions. This is a most remarkable property—solids pressing only downward, or in the direction of gravity—the upward direction of the pressure of water is equal to that pressing downwards, and the side pressure is also equal.

A given pressure or blow impressed on any portion of a mass of water confined in a vessel is distributed equally through all parts of the mass; for example, a plug forced inwards on a square inch of the surface of water, is suddenly communicated to every square inch of the vessel's surface, however large, and to every inch of the surface of any body immersed in it.

It is this principle which operates with such astonishing effect in hydrostatic presses, of which familiar examples are found in the hydraulic pumps, by the use of which boilers are tested. By the mere weight of a man's body when leaning on the extremity of a lever, a pressure may be produced of upwards of 2000 tons; it is the simplest and most easily applicable of all contrivances for increasing human power, and it is only limited by want of materials of sufficient strength to utilize it.

The surface of water at rest is horizontal. A familiar example of this may be noted in the fact that the water in a battery of boilers also seeks a uniform level, no matter how much the cylinders may vary in size.

WATER.

The pressure on any particle of water is proportioned to its depth below the surface, and as the side pressure is equal to the downward pressure, calculations on this principle are easily made. The pressure on a square foot at different depths are approximate, as in the following table.

Depth in feet.	Pressure on sq. foot.	Depth in feet.	Pressure on sq. foot.
8	500 lbs.	56	3500 lbs.
16	1000 "	64	4000 "
24	1500 "	72	4500 "
32	2000 "	80	5000 "
40	2500 "	88	5500 "
48	3000 "	96	6000 "

1 mile, or 5,280 feet, 330,000 lbs.
5 miles, 1,650,000 "

This table is based upon an allowance of $62\frac{1}{2}$ lbs. of water to the cubic foot, hence 8 feet $\times$ $62\frac{1}{2} = 500$, etc.

Water rises to the same level in the opposite arms of a recurved tube, hence water will rise in pipes as high as its source; this is the principle of carrying the water of an aqueduct through all the undulations of the ground.

Any quantity of water, however small, may be made to balance any quantity, however great. This is called the Hydrostatic Paradox, and is sometimes exemplified by pouring liquids into casks through long tubes inserted in the bung holes. As soon as the cask is full and the water rises in the pipe to a certain height the cask bursts with violence.

NOTE.

The increase of pressure, due to these peculiar natural laws, renders it necessary for the engineer to make due allowances on the strength of pipes and vessels used for containing or conveying water.

PUMPS.

The action of a pump is as follows: The piston or plunger by moving to one end, or out of the pump cylinder, leaves the space it occupied, or passed through, to be filled by something. As there is little or no air therein a partial vacuum is formed unless the supply to the pump is of sufficient force to follow the piston or plunger of its own accord. If this is not the case, however, as it is where the water level from which the pump obtains its supply is below the pump itself, there being a partial vacuum produced, the atmospheric pressure forces the water into the space displaced by the plunger or piston, continuing its flow until the end of stroke is reached.

The water then ceases to flow in, and the suction valve of the pump closes, forbidding the water flowing back the route it came. The piston or plunger then begins to return into the space it has just vacated, and which has become filled with water, and immediately meets with a resistance which would be insurmountable were the water not allowed to go somewhere.

Its only egress is by raising the discharge valve by its own pressure, and passing out through it. This discharge valve is in a pipe leading to the boiler, and in going out of the cylinder by that route the water must overcome boiler pressure and its own friction along the passages. Water is inert and cannot act of itself; so it must derive this power to flow into the feed pipe and boiler from the steam acting upon the steam piston of the pump. The steam piston and pump piston are at the two ends of the same rod. Therefore the steam pressure exerted upon the steam piston will be exerted upon the pump piston direct,

PUMPS.

There being no mechanical purchase in favor of the steam piston, it must have the greater area, otherwise one pressure would balance the other, and the pump would refuse to move.

For this reason, all boiler feed pumps have larger steam than water cylinder; generally, at least, 40 per cent. larger.

Water will flow into a boiler when the head or height from which it obtains its pressure is greater than the height of a water column represented by the pressure within the boiler, or where the pressure from the water works supply exceeds the pressure of the steam in the boiler.

Example.

What horse power will be required to deliver 1,000 imperial gallons per minute against a pressure of 80 pounds per square inch, suction lift 20 feet, allowing 20 per cent. friction ?

One-pound pressure is equal to a head of 2.31 feet. Hence the total head to which the water is to be lifted will be $2.31\times 80+20=204.8$ feet.

An imperial gallon weighs ten pounds and the horse power required to raise 1,000 imperial gallons per minute against a pressure and suction lift equal to a head of 204.8 feet will be

$$\frac{10\times 1,000\times 204.8}{33,000}=62.06 \text{ H. P. and}$$

$$62.06+20\% \text{ allowance for friction}=74.47 \text{ H. P.}$$

Rule to find the water capacity of a steam pump per hour.

1. Find the contents of the pump in cubic inches, by multiplying the area by the inches in strokes and by the fraction, it is full.

2. Find the cubic inches of water pumped per hour, by multiplying the contents of the pump by the strokes per minute and by 60 minutes.

3. Find the number of cubic feet of water by dividing the cubic inches by 1728.

PUMPS.

Example.

How many cubic feet of water will be pumped in an hour by a pump 6 *inches in diameter and* 10 *inch stroke, making* 60 *strokes per minute, the pump being* ¾ *full each stroke.* Now, then:

	.7854	
6×6=	36	diameter squared.
	47124	
	23562	
	28.2744	
	10	length of stroke.
	282.7440	
	60	strokes.
	16964.6400	
	60	minutes.
	1017878.4000	
	3	¾ full.
	4)3053635.2000	
	12)763408.8000	
1728	12)63617.4000	
	12)5301.4500	
	441.7875	Ans. 441¾ gallons nearly.

To find the pressure in pounds per square inch of a column of water.

Rule.

Multiply the height of the column of water in feet by .434.

PUMPS.

Example.

What is the pressure at the bottom of a column of water 440 feet high?

```
     440
     434
     ———
    1760
   1320
  1760
  ——————
  190.960/1000   Ans. 191 lbs. nearly
```

Note.

The correctness of this calculation is found by multiplying 191 by 2.31.

To find the height of a column of water, in feet, the pressure being known.

Rule.

Multiply pressure by the pressure shown on gauge by 2.31.

Example.

If pressure shown on the gauge is 95 lbs. to square inch, what is the height of the column of water?

```
    2.31
      95
    ————
    1155
   2079
  ——————
  219.45   Ans. 220 ft. nearly.
```

Note.

The correctness of this result is proved by multiplying 220 by .434.

To find the horse power necessary to pump water to a given height.

Rule.

Multiply the total weight of the water in pounds, by the height in feet, and divide the product by 33,000.

PUMPS.

Example.

What power is required to elevate 90,800 lbs. of water 45 ft.?

$$\begin{array}{r} 90{,}800 \\ 45 \\ \hline 454000 \\ 363200 \\ \hline \end{array}$$

$33{,}000)4086000(123\frac{27}{33}$ horse power.

Note.

This calculation allows the water to be raised in *one minute.* To raise the same amount in 60 minutes would require $\frac{1}{60}$th the power. Ans. Nearly 3 horse power.

To find quantity of water pumped in one minute running at 100 *feet of piston speed per minute.*

Rule.

Square the diameter of the water cylinder in inches, and multiply by 4. The answer will be in gallons.

Example.

What quantity of water will be pumped by a 4 inch water cylinder with piston travelling 100 feet per minute.

4 inch diam.=16 inches.
4
——
64 Ans. in gallons.

Note.

This is *an approximate,* not an exact quantity, as will be found by figuring the exact area of the piston 12.566 inches $\times$ 100×12 inches $\div 231 = 65\frac{64}{231}$; but the rule is nearer than the average practice of pumps, owing to leakage of air, etc.

To find the capacity of a water cylinder of a steam pump in gallons.

Rule.

Multiply the area in inches by the length of stroke (this gives the capacity in cubic inches). Next divide by 231 (which is the cubical contents of a U. S. gallon in inches) and the product is the capacity in gallons.

PUMPS.

Example.

What is the capacity of a cylinder 9 inches diameter and 10 inch stroke.

9 inch diameter=see table 63.617 area.

$$
\begin{array}{r}
63.617 \\
10 \\
\hline
231)636.170(2.\tfrac{75}{100} \\
462 \\
\hline
1741 \\
1617 \\
\hline
1247 \\
1155 \\
\hline
92
\end{array}
$$

Ans. in cubic inches. gallons.

To find the steam pressure required when the diameter of steam cylinder, diameter of pump cylinder, and water pressure are given.

Rule.

Multiply the area of the pump in inches by the pressure of water in pounds per square inch, and divide the product by the area of cylinder, plus one-fourth for friction.

Example.

6 inches diameter of pump cylinder, 100 pounds pressure per square inch, 70.88 area of steam cylinder.

$\frac{28.27 \times 100}{70.88} = 39.8 + \frac{1}{4} = 49.7$, nearly 50 lbs. pressure per square inch.

To find the diameter of cylinder required for a direct-acting steam pump.

Rule.

Multiply the area of pump-bucket or ram in inches by the pressure of water in pounds per square inch, and divide the product by the pressure of steam in pounds per square inch, and add one-fourth to one-half for friction.

PUMPS.

Example.

6 inches diameter of pump, 100 lbs. water pressure per square inch, 50 lbs. steam pressure.

6 inches diameter = 28.27 inches area,

$$\frac{28.27 \times 100}{50} = 56.54 \text{ inches, area of steam cylinder,}$$

add $\frac{1}{4}$=56.54+14.13=70.67=9½ inches diameter of steam cylinder, nearly.

To find the load on a pump:

Rule.

Multiply the area of pump in inches by the weight of the column of water in pounds per square inch.

Example.

Pump 3 inches in diameter; depth of well 30 feet.

3 inches diameter = 7.06 inches area,

$$\frac{30 \times 44}{100} = 13.2 \text{ lbs. pressure per square inch,}$$

$7.06 \times 13 = 91.78$ lbs. total pressure on pump.

To find the total amount of pressure that can be exerted in a steam pump.

Rule.

Multiply the area of the steam piston by the steam pressure.

Example.

What is the total amount of pressure in a pump cylinder 8½ inches diameter and 80 lbs. of steam ?

8½ inch diam.=per table 56.745 area,
80 lbs. to sq. in.

4539.600 Ans. 4.539$\frac{6}{10}$ lbs.

PUMPS.

To find the resistance of the water in the water cylinder.

RULE.

Multiply the area of the water piston in inches, by the pressure of water in pounds per square inch.

EXAMPLE.

What is the resistance to be overcome in a 7 inch diameter piston, working against a pressure of 110 lbs.

$$
\begin{array}{r}
7 \text{ in. diam.}=\text{(see table) } 38.484 \text{ square inches.} \\
110 \\
\hline
384840 \\
384840 \\
\hline
4.233\frac{240}{1000} \text{ lbs. Ans.}
\end{array}
$$

To find the number of horse power required to raise a given quantity of water in gallons to a given height in feet.

RULE.

Multiply the given number of gallons of water to be raised per minute by 10 (which is the weight of one gallon) and by the height the water has to be raised in feet, and divide the product by 33,000.

There is no account taken of *loss by leakage* or "*slip*," nor *friction* in any of these rules; these vary greatly according to the class and condition of pump, if it is working against a high or low lift, and the "slip" depending upon the class of valve used for the pump.

For well designed direct-acting horizontal pumps, one-tenth should be enough for "*slip*," for ordinary purposes, and 25 per cent. for *friction*, but when the suction is very long and the height to where the water is raised is great, one-third should be added; but if the pump is old and badly designed, as much as one-half must be added to the total amount required.

In an ordinary direct-acting steam pump one-fourth of the power required should be added, but if the delivery height is very great and the pipe very long one-half should be added.

PUMPS.

NOTES.

The space between the suction-valve and bucket, plunger or piston, as the case may be, should be as little as possible, consistent with ample waterway being given.

All passages should be as straight as possible, and when bends are necessary, the radius should be an easy one.

Sudden enlargements and contractions in the passages should be avoided, but if an alteration in size or shape of the passages is necessary, it should be made gradually.

Care should be taken that the suction-pipe should be the lowest point in the pump.

If the pump is required to raise hot water, there should be very little suction; in fact, it is best, if possible, to have the water running into the pump.

Long suction-pipes should always be provided with a foot-valve just above the windbore or strainer, in the well or pit.

All corners should be well rounded.

There should be as few flat surfaces as possible, and where there are any they should be well ribbed.

Joints in the suction-pipes and the suction part of the pump must be very carefully made, and perfectly tight.

Change of direction in the flow of water should be avoided as much as possible. After a current of water has received an impulse, it is necessary that the motion imparted should be continued with a uniform velocity throughout its whole course.

TABLE I.

Quantity of Water Discharged per Minute by Single-Cylinder Pumps, from 2 to 6-inch diameter, at 30 and 40 strokes per minute, 9, 10 and 12 inch stroke.

Diameter of Pump.	9-inch Stroke. Gallons per Minute.		10-inch Stroke. Gallons per Minute.		12-inch Stroke. Gallons per Minute.	
	30 Strokes.	40 Strokes.	30 Strokes.	40 Strokes.	30 Strokes.	40 Strokes.
in. 2	3.0	4.0	3.33	4.44	4.0	5.3
2½	4.6	6.25	5.21	6.94	6.25	8.33
3	6.7	8.93	7.44	9.92	8.93	11.9
3½	8.83	12.2	9.81	13.55	11.77	16.26
4	11.96	15.9	13.28	17.66	15.94	21.2
4½	15.2	20.3	16.88	22.55	20.26	27.6
5	18.75	25.0	20.83	27.77	25.0	33.33
5½	22.69	30.25	25.21	33.5	30.25	40.33
6	27.0	36.0	30.0	40.0	36.0	48.0

TABLE II.

Quantity of Water Discharged per Minute by Double-Cylinder Pumps, from 2 to 6-inch diameter, at 30 and 40 strokes per minute, 9, 10 and 12-inch stroke.

Diameter of Pump.	9-inch Stroke. Gallons per Minute.		10-inch Stroke. Gallons per Minute.		12-inch Stroke. Gallons per Minute.	
	30 Strokes.	40 Strokes.	30 Strokes.	40 Strokes.	30 Strokes.	40 Strokes.
in. 2	6.0	8.0	6.66	8.88	8.0	10.6
2½	9.38	12.5	10.42	13.88	12.5	16.66
3	13.4	17.86	14.88	19.84	17.86	23.8
3½	17.66	24.4	19.62	27.10	23.54	32.52
4	23.92	31.8	26.56	35.32	31.88	42.4
4½	30.4	40.6	33.76	45.1	40.52	54.12
5	37.5	50.0	41.66	55.54	50.0	66.66
5½	45.38	60.5	50.42	67.0	60.5	80.66
6	54.0	72.0	60.0	80.0	72.0	96.0

TABLE III.

PRESSURE OF WATER AT DIFFERENT HEADS IN LBS. PER SQUARE INCH.

Head of water in feet.	Head of water in yards.	Head of water in fathoms.	Head of water in metres.	Pressure in lbs. per square inch.	Head of water in feet.	Head of water in yards.	Head of water in fathoms.	Head of water in metres.	Pressure in lbs. per square inch.
10	3.33	1.66	3.04	4.33	150	50.0	25.0	45.7	64.9
20	6.66	3.33	6.09	8.66	160	53.3	26.6	48.7	69.3
30	10.0	5.0	9.14	12.9	170	56.6	28.3	51.8	73.6
40	13.3	6.66	12.1	17.3	180	60.0	30.0	54.8	77.9
50	16.6	8.33	15.2	21.6	190	63.3	31.6	57.9	82.3
60	20.0	10.0	18.2	25.9	200	66.6	33.3	60.9	86.6
70	23.3	11.6	21.3	30.3	210	70.0	35.0	64.0	90.9
80	26.6	13.3	24.3	34.6	220	73.3	36.6	67.0	95.3
90	30.0	15.0	27.4	38.9	230	76.6	38.3	70.1	99.6
100	33.3	16.6	30.4	43.3	240	80.0	40.0	73.1	103.9
110	36.6	18.3	33.5	47.6	250	83.3	41.6	76.2	108.3
120	40.0	20.0	36.5	51.9	260	86.6	43.3	79.2	112.6
130	43.3	21.6	39.6	56.3	270	90.0	45.0	82.2	116.9
140	46.6	23.3	42.6	60.6	280	93.3	46.6	85.3	121.3

TABLE IV.

OF THE DIAMETERS OF PIPES, SUFFICIENT IN SIZE TO DISCHARGE A REQUIRED QUANTITY OF WATER PER MINUTE.

Cubic feet.	Diameter in inches.	Cubic feet.	Diameter in inches.	Cubic feet.	Diameter in inches.
1	.96	18	4.07	130	10.94
2	1.36	20	4.29	140	11.35
3	1.66	25	4.80	150	11.75
4	1.92	30	5.25	160	12.14
5	2.15	35	5.67	170	12.51
6	2.35	40	6.07	180	12.67
7	2.60	45	6.53	190	13.23
8	2.72	50	6.80	200	13.57
9	2.88	55	7.12	225	14.40
10	3.04	60	7.43	250	15.17
11	3.18	70	8.03	275	15.91
12	3.33	80	8.60	300	16.62
13	3.46	90	9.10	350	17.95
14	3.60	100	9.60	400	19.20
15	3.72	110	10.06	500	20.46
16	3.84	120	10.51	600	23.51

EVOLUTION OR SQUARE ROOT.

This is one of the most important rules in the whole range of mathematics and well worth the careful attention of the student.

Given any power of a number to find its root. To familiarize oneself with the extracting of the square root it is well first to square a number and then work backward according to the Examples here given, and by long and frequent practise become expert in the calculation. But in first working square root it is undoubtedly better to secure the services of a teacher.

EXAMPLE.

Find the square root of 186624.

```
       18,66,24(432
       16
83   | 266
     | 249
862  | 1724
     | 1724
```

Proof

```
   432
   432
  ----
   864
  1296
 1728
 ------
 186624
```

Begin at the last figure 4, count two figures, and mark the second as shown in the Example; count two more, and mark the figure, and so on till there are no more figures; take the figures to the left of the last dot, 18, and find what number multiplied by itself will give 18; there is no number that will do so, for $4 \times 4 = 16$, is too small, and $5 \times 5 = 25$, is too large; we take the one that is too small, viz., 4, and place it in the quotient, and place its square 16 under the 18, subtract and bring down the next two figures 66. To get the divisor multiply the quotient 4 by $2 = 8$, place the 8 in the divisor, and say 8 into 26 goes 3 times, place the 3 after the 4 in the quotient, and also after the 8 in the divisor; multiply the 83 by the 3 in the quotient, and place the product under the 266 and subtract, then bring down the next two figures 24. To get the next divisor, multiply the quotient 43 by $2 = 86$; see how often 8 goes into 17, twice; place the 2 after the 43 of the quotient, and also after the 86 of the divisor; multiply the 862 by the 2, and put it under the 1724, then subtract. Answer, 432.

SQUARE ROOT.

Example.

Find the square root of 735.

	7,35(27.11 &c.		Proof. 2711
	4		2711
47	335		2711
	329		2711
541	600		18977
	541		5422
5421	5900		734.9522
	5421		
	&c.		

We proceed as before till we get the remainder 6, and we see it is not a perfect square; we wish the root to be taken to two or three places of decimal; there are no more figures to bring down, therefore, bring down two ciphers and proceed as in the first Example; to the remainder attach two more ciphers and proceed as before; and by attaching two ciphers to the remainder, you may carry it to any number of decimal places you please. In the above Example the answer is 27.11 &c.

Example.

Find the square root of 588.0625.

	5,88.06,25(24.25
	4
44	188
	176
482	1206
	964
4845	24225
	24225

In a decimal quantity like the above, the marking off differs from the former Examples. Instead of counting twos from right to left, we begin at the decimal point and count twos towards the left and towards the right. The rest of the work is similar to the other examples. Notice, that when the .06 is brought down, the figure for a quotient is a decimal.

SQUARE ROOT.

Example.

Find the square root of 7986.57246.

```
          79,86.57,24,6(89.3676 &c.
          64
  169    | 1586
         | 1521
  1783   |  6557
         |  5349
  17866  |  120824
         |  107196
  178727 |  1362860
         |  1251089
  1787346|  11177100
         |  10724076
             453024
```

Notice, the last figure is 6; always bring down two figures at a time, therefore bring down 60. The rest is similar to the former example.

Examples for Exercise.

1.	Find the square root of		589824.
2.	"	"	9876.
3.	"	"	15227.56
4.	"	"	698.532
5.	"	"	96118416
6.	"	"	123456
7.	"	"	170.3025
8.	"	"	17640.73205

In expressing the square root it is customary to use simply the mark ($\sqrt{}$) the 2 being understood.

All roots as well as powers of *one* are 1, as $\sqrt{1}=1$.

INVOLUTION

Is the raising a number (called the root) to any power. The powers of a number are its square, cube, 4th power, 5th power, etc.

$2\times2=4$	4 is the square or 2nd power of 2
$2\times2\times2=8$	8 is the cube or 3rd power of 2
$2\times2\times2\times2=16$	16 is the 4th power of 2.
&c.	&c.

Hence to square a number multiply it by itself.

SQUARE ROOT.

EXAMPLE.

What is the square of 27 (written 27^2)?

```
   27
   27
 ----
  189
  54
 ----
  729 Answer.
```

To cube a number, multiply the square of the number by the number again, that is, multiply the number by itself three times.

EXAMPLE. What is the cube of 50? (written 50^3)

```
    50
    50
  ----
  2500 the square
    50
------
125000 the cube.
```

The 4th, 5th, 6th, &c., power is found by multiplying the number by itself 4 times, 5 times, 6 times, &c., as the case may be.

EXAMPLE. What is the sixth power of 90? (written 90^6)

```
          90
          90
        ----
        8100    square
          90
      ------
      729000    cube
          90
    --------
    65610000    4th power
          90
  ----------
  5904900000    5th power
          90
------------
531441000000    6th power
```

ON THE SIGNS THAT REPRESENT THE ROOTS OF NUMBERS.

The Sign common to all roots is $\sqrt{}$ or $\sqrt{}$ and is known as the Radical Sign. If we require to express the square root of a number we simply put this sign before it, as $\sqrt{16}$, but if the number is made up of two or more terms, then we express the square root by the same in front, but with a line as far as the square root extends, as $\sqrt{9+7}$ or $\sqrt{4\ (19+6)}$.

The cube root is expressed by the same sign, with a 3 in the elbow, as $\sqrt[3]{8}$ or $\sqrt[3]{7\ (100-51}$.

All other roots in the same manner, the number of the root being put instead of the 3. As fifth root $\sqrt[5]{}$, and sixth root $\sqrt[6]{}$, &c.

In the above examples of the square root $9+7=16$, and the square root of 16 is 4.

The $4\ (19+6)=4\times25=100$, and the square root of 100 is 10.

The other way of expressing that the root is required, is by putting a fraction after and above the quantity, as $16^{\frac{1}{2}}$, which means the square root of 16, $(19+17)^{\frac{1}{2}}$, or $\{4\ (19+6)\}^{\frac{1}{2}}$ all of which mean the square root of the quantities to which they are attached.

The cube root, 4th root, 5th root, &c., are written in the same way, as $729^{\frac{1}{3}}=9$; $256^{\frac{1}{4}}=4$; $3125^{\frac{1}{5}}=5$; &c.

ON THE SIGNS REPRESENTING THE POWER OF NUMBERS.

6^2 is equal to $6\times6=36$; that is, 36 is the square of 6.

5^3 is equal to $5\times5\times5=125$; that is, 125 is the cube of 5.

4^4 is equal to $4\times4\times4\times4=256$, that is, 256 is the fourth power of 4.

In the above we have the powers that are most frequently met with; but of course you may have the 5th, 6th, or any higher power; but whatever the power, multiply the given number that number of times by itself, and you will be quite right; for an example, what is the value of 7^8? This is, 7 to the eighth power, or $7\times7\times7\times7\times7\times7\times7\times7=5764801$.

The power and the root are often combined, as $4^{\frac{3}{2}}$; this is read as the square root of 4 cubed. So the numerator figure represents the power, and the denominator figure represents the root. In this case 4 cubed=64, and the square root of 64=8. Answer.

Perhaps the most common form that an engineer will meet with this sign is in the following:—

$8^{\frac{2}{3}}$, which is read the cube root of 8 squared. Now 8 squared=64, and the cube root of 64 is 4. Answer.

Find the value of $20^{\frac{3}{2}}$.

20 cubed=8000; and square root of 8000=89.4 &c.

Example.

What is the value of $\dfrac{8^{\frac{2}{3}}+81}{3^{\frac{3}{2}}}$?

$8^{\frac{2}{3}}=\sqrt[3]{8^2}=\sqrt[3]{64}=4$; $81^{\frac{1}{2}}=9$; $3^{\frac{3}{2}}=\sqrt{3^3}=\sqrt{27}=5.2$ nearly.

Hence, $\dfrac{4+9}{5.2}=\dfrac{13}{5.2}=2.5$ or $2\frac{1}{2}$ Answer.

( ) are called *brackets,* and mean that all the quantities within them are to be put together first; thus, 7 (8−6+4×3) means that 6 must be subtracted from 8=2, and 4 times 3=12 added to this 2=14; and then this 14 is to be multiplied by 7=98.

CIRCULAR INCHES.

A circular inch is a circle whose diameter is one inch; instead of finding diameters in square inches it is frequently convenient to use the circular inch as per the following

Rule.

To find the circular inches in a circle: square the diameter of the circle in inches.

Examples.

1. How many circular inches are there in a safety valve whose diameter is $4\frac{1}{2}$ inches?

$4.5^2 = 4.5\times4.5 = 20\frac{1}{4}$ Answer.

CIRCULAR INCHES.

2. How many circular inches in a compound engine whose diameters are 31″ and 60″ ?

Answer, 31^2 and $60^2 = 4561$ circular inches.

3. The diameter of a piston is 24 inches, how many circular inches will that give ? Now

$24^2 = 24 \times 24 =$ Ans. 576 circular inches.

4. If two pistons of a compound engine are 26″ and 50″, what *ratio* will their areas bear to each other ?

Instead of finding the areas in square inches find them in circular inches.

$26^2 = 676$, and $50^2 = 2500$.

Hence as 676 : 2500 :: 1 : —— Answer, 1 to 3.7 nearly.

COMPOSITION OF AIR, ETC.

Air is composed of nitrogen and oxygen mixed mechanically and not chemically, (this is unlike water, the parts of which are combined chemically.) Out of every 100 volumes of air 79 parts are composed of nitrogen to 21 of oxygen, or by *weight*, 77 of nitrogen to 23 of oxygen.

150 cubic feet of air are necessary to burn 1 lb. of coal, but in practice double that quantity should be supplied to the furnace.

12 lbs. of air are required to burn 1 lb. of carbon.

36 lbs. of air are necessary to burn 1 lb. of hydrogen.

Hydrogen while burning is $4\frac{1}{4}$ times hotter than oxygen.

Hydrogen gives out more heat from the coal—part for part —but as there is so much more of the carbon we get the greatest amount of heat from it.

Coal will not burn without an admixture of air.

STEAM.

Steam, properly socalled, is *perfectly transparent* and colorless. The engineer and general reader have thus alike to bear in mind, that in dealing with steam (proper) they have to do with a gaseous body which eludes the sight as completely as the purest atmospheric atmosphere.

In popular language, the visible mist forming when a vapor is discharged into the air, as a little way from the spout of a boiling kettle, or in a dense cloud above an engine "blowing off" steam, is also called steam. This visible mist is however really of the nature of a cloud formed from the water, condensed from the vapor and enclosing minute particles of air, constituting an opaque and visible mass.

Perfect steam is, moreover, in no way moist, but is *dry;* the moisture sometimes showing upon a solid surface it touches, or that has been plunged into it being due to condensation.

The distinguishing properties of steam are, 1, *Its fluidity;* 2, *its mobility;* 3, *its elasticity,* and 4, *its equality of pressure* in every direction; that is, steam has a flow like water, it has a circulation within its own body, it is capable of compression and expansion, and when it is confined it presses equally upon all parts of the restraining vessel.

But perhaps *the rapidity* with which, at a given condition and temperature, it can be condensed and again formed makes its most useful property; while *the cheapness* and abundant supply of water from which steam is formed must not be overlooked.

Each atom of steam is composed of two gases which have neither taste nor color. An atom of steam is made up of the same materials and in the same proportion as an atom of water, *i. e., in volume* one part of oxygen to two of hydrogen, but *in weight* 89 of oxygen to 11 of hydrogen. In the safe opera-

STEAM.

tion of steam production these proportions do not and cannot change but by contact with certain substances, such as lime, baryta, strontium, soda and potash; *and at the temperature of red-hot iron* by contact with carbon, chlorine, phosphorus, iodine, zinc, tin, manganese and iron. The oxygen of the water forms a combination with these metals while the hydrogen is set free.

This process of separation of the two gases is called *disintegration* and is a chemical, not a mechanical change.

The difference in volume between water and steam at atmospheric pressure is as 1669 to 1; that is, a given quantity of water expanded into steam will occupy 1669 times the space it did before.

This is nearly one cubic foot and one cubic foot of steam at atmospheric pressure weighs .038 lbs.

SATURATED STEAM.

But a limited and gradual supply of heat can under any circumstances be made to enter water; its rate of absorption being really very slow and the process prolonged; and this is fortunate, in view of the risk, otherwise, of continual explosions. The tumultuous vaporizing of water is what we call boiling and there is a never-ceasing balancing between the heat and pressure within the steam vessel for the following reason:

Steam and water in a boiler are, so to say, at an equipoise; increase of heat will increase the quantity of water vaporized, and so, in a confined place, the density of the vapor; or on the other side an increase of pressure will compel a portion of the vapor already formed to resume the liquid state, hence a perpetual balancing of the two conditions.

Where the steam is produced over, or in communication with the water of a boiler, part of its density is produced by the presence of more or less finely divided water, or mist, held in suspension through it, hence the term "saturated steam." This quantity of loosely held vapor varies, as has been explained, according to temperature and pressure.

SATURATED STEAM.

By means of recorded observations of experiments on steam, and finding the mean of the most trustworthy results and calculations, some of which are intimated rather than detailed, very full tables of the properties of saturated and of superheated steam have been prepared. Of such a table for saturated steam, a brief abstract only can here be introduced.

The following table gives the properties of steam at different pressures—from 1 lb. to 300 lbs. "total pressure," *i. e.*, above vacuum.

The gauge pressure is about 15 pounds less than the total pressure, so that in using this table, 15 must be added to the pressure as given by the steam gauge.

Table of Properties of Saturated Steam.

Total pressure per square inch.	Temperature in degrees.	Total heat in degrees above 32°.	Latent heat in degrees.	Density or weight per cubic foot.	Volume of 1 lb. of steam.	Relative volume or No. of cubic feet of steam from 1 of water.
Lbs.	Fahr.	Fahr.	Fahr.	Lb.	Cubic feet.	Ratio of volume.
1	102.1	1,112.5	1,042.9	.0030	330.36	20,582
10	193.3	1,140.3	978.4	.0264	37.84	2,358
14	209.6	1,145.3	966.8	.0362	27.61	1,720
14.7	212.0	1,146.1	965.2	.0380	26.36	1,642
15	213.1	1,146.4	964.3	.0387	25.85	1,610
18	222.4	1,149.2	957.7	.0459	21.78	1,357
21	230.6	1,151.7	951.3	.0531	18.84	1,174
24	237.8	1,153.9	946.9	.0601	16.64	1,036
30	250.4	1,157.8	937.9	.0743	13.46	838
36	260.9	1,161.0	930.5	.0881	11.34	707
45	274.4	1,165.1	920.9	.1089	9.18	572
60	292.7	1,170.7	908.0	.1425	7.01	437
75	307.5	1,175.2	897.5	.1759	5.68	353
90	320.2	1,179.1	888.5	.2089	4.79	298
105	331.3	1,182.4	880.7	.2414	4.14	257
120	341.1	1,185.4	873.7	.2738	3.65	227
135	350.1	1,188.2	867.4	.3060	3.27	203
150	358.3	1,190.7	861.5	.3377	2.96	184
180	372.9	1,195.1	851.3	.4009	2.49	155
210	386.0	1,199.1	841.9	.4634	2.16	135
240	397.5	1,202.6	833.8	.5248	1.90	119
270	407.9	1,205.8	826.4	.5868	1.70	106
300	417.5	1,208.8	819.6	.6486	1.54	96

SUPERHEATED STEAM.

If the application of heat be continued after the steam has been removed from the contact with the water in the vessel, or the water has all been evaporated into steam, the state of saturation is left behind. The steam so separated and heated loses the moisture which may accompany it in the saturated state, and at a few degrees of added temperature acquires in full the character of a perfect gas; it is then said to be surcharged with heat.

Let steam in this condition be replaced in contact with the water in the boiler, or in any way be brought into free communication with it, the water having yet the original temperature and such steam would immediately evaporate and absorb a further portion of the water, transferring to this its excess of heat, and would become saturated, its temperature falling to that of the water.

NOTE.

Many conditions are described and problems stated where the term "saturated steam" is used; so let it be twice remembered that this expression denotes *the regular condition of steam formed over water,* and that such steam stands both at the condensing point and at the generating point, that is, it is condensed if the temperature falls and more water is evaporated if the temperature rises.

FORMATION OF STEAM UNDER PRESSURE.

At the sea level air has been found to weigh $14\frac{7}{10}$ lbs. per square inch, that is, with a surface like the piston of a cylinder with no air (i. e. a perfect vacuum) upon the other side, the pushing force is 14.7 lbs. for each square inch which the piston measures.

In making steam, this pressure of 14.7 lbs. to the square inch is overcome when water has been heated to 212° F.

At this temperature and with a sufficiently hot fire the mass of water larger or smaller changes to steam and passes into the atmosphere.

FORMATION OF STEAM UNDER PRESSURE.

If, however, the pressure on the surface of the water is increased to the weight of, say, $1\frac{1}{2}$ atmospheres, then steam only begins to form at 234°.

At 2 atmospheres pressure, steam forms at 250°; at $2\frac{1}{2}$, 264°; at 3, 274°; at 4, 292°; at 5, 306°; at 8, 340°; at 10, 357°; at 15, 389°; at 20, 415°, or about 294 lbs. per square inch. It need scarcely be said that this increased pressure on the water is caused by the confinement of the steam after its formation.

It will also be observed that the temperature rises more slowly than the pressure. For example, the pressures being advanced 5 lbs. per square inch, thus:

1 lb.	6 lbs.	11 lbs.	16 lbs.	21 lbs.	26 lbs.	31 lbs.	36 lbs.

the temperatures in Fahrenheit degrees are

$102°\frac{1}{10}$	$170°\frac{2}{10}$	197°8	216°3	230°6	242°3	252°2	260°9

LATENT HEAT OF STEAM.

It is impossible for steam to exist without heat. Heat imparts to water that repellant force we call expansion; in effect the heating of the water causes each particle to repel and antagonize and drive to the greatest possible distance every other particle of the mass.

In heating water a certain proportion of the heat which has been absorbed, is not shown by the thermometer or by touch, and there are two sorts or conditions of heat in the process of steam production operating upon water, 1 Sensible heat, 2 Latent or insensible heat; hence the constituent, or total heat of steam consists of its latent heat in addition to its sensible heat. In generating water into steam there is absorbed about *five and one-half times* as much heat as is required under atmospheric pressure, to raise the temperature of the water from freezing point, 32° Fah., to boiling point, 212° Fah., an amount of heat which if the water were a fixed solid would, it is said, render it *red hot* by daylight. Tested by a thermometer the steam will show only 212°, but by experiment 1000° nearly, have been added, which is stored up in some hidden unaccountable way and is called the *latent* heat of steam.

LATENT HEAT OF STEAM.

In calculations the expression *"the total heat"* represents units of heat when the weight of the steam is one pound.

A pound of steam is the same as a pound of water, i. e., a pound of water converted into steam still weighs 1 pound.

To trace the appropriation of all the heat that goes to the formation of a pound of steam, in the sensible and the latent state, in terms of heat units, as well as of foot-pounds, take for example one pound of water at 32° Fahrenheit, and convert it into saturated steam at 212° Fahrenheit. The first instalment of heat is the sensible heat, and it is required for elevating the temperature of the water to 212°, through 180°, which appropriates 180.9 units of heat, equivalent to 180.9×772, or 139,655 foot-pounds. (One heat unit $=$ 772 foot-pounds.)

Secondly, latent heat is applied in overcoming the molecular attraction, and separating the particles; that is to say, in the formation of steam, which appropriates 892.9 units of heat equal to 689,318 foot-pounds.

Thirdly, latent heat is applied in repelling the incumbent pressure, whether of the atmosphere or of the surrounding steam; that is to say, in raising a load of 14.7 lbs. per square inch, or 2116.4 lbs. on a square foot, through a cubic space of 26.36 cubic feet, being the volume of one pound of saturated steam. The work thus done is equal to 2116.4×26.36, or 55,788 foot-pounds, or its equivalent, 72.3 units of heat.

The second of the above appropriations of the heat was found by subtracting the sum of the first and third, which are both arrived at by direct observation, from the total heat.

The first appropriation of heat is thus seen to be the sensible heat, and the second and third together constitute the latent heat. The third, it may be added, is simply an expression of the mechanical labor necessary to disengage 26.36 cubic feet of steam, and force it into space against an atmospheric pressure of 2116.4 lbs. per square foot.

The appropriation of the heat expended in the generation of one pound of saturated steam at 212° F., from water supplied at 32° F., may be exhibited thus:—

To Generate one pound of Steam at 212° F.

	Units of heat.		Mechanical equivalent in foot-pounds.	
The sensible heat:—				
1. To raise the temperature of the water from 32° to 212° F.,		180.9		139,655
The latent heat:—				
2. In the formation of steam..............	892.935		689,346	
3. In resisting the incumbent atmospheric pressure of 14.7 lbs. per square inch, or 2116.4 lbs. per square foot........	72.265		55,788	
		965.2		745,134
Total or constituent heat..		1146.1		884,789

Rule for finding the Total Heat in Steam.

Multiply the temperature or sensible heat of the steam by .3 ($\frac{3}{10}$ths) and add it to 1115°.

Example.

Find the total and latent heat in steam that is 60 lbs. by the gauge.

60 lbs. by the gauge is equal to 75 lbs. gross (the 14.7 atmosphere being added, as, in gross 15 lbs.)

And 75 lbs. gross has 307° temperature (see Table), hence,

$$307° \times .3 = 92.1 + 1115° = 1207.1 \text{ total heat.}$$

$$1207.1 = \text{total heat.}$$
$$307 \quad = \text{sensible heat.}$$
$$\overline{900.1 \text{ latent heat.}}$$

Then, if we know the temperature of the feed water, and subtract this temperature from the total heat of the steam, the remainder will be the units of heat to each lb. of water turned into steam; to illustrate this see the following

Examples.

What are the total units of heat in steam of 212°

$212° \times .3 = 63.6 + 1115° = 1178.6°$ total heat.

What is the latent heat in this case?

1178.6=total heat.
212 =sensible heat.

966.6=latent heat.

Example.

If the steam in the boiler be 270° and the feed water be at 110° how many units of heat will it be necessary to add to this water to turn a lb. of it into steam ?

$270 \times .3 = 81 + 1115 = 1196$, less feed water $110 = 1086$ Ans.

Note.

The small variation between the results in the examples and the figures in the Table is caused by greater detail of calculation in one more than the other. In the examples the air pressure is extended at 15 lbs. per square inch and in the Tables at 14.7.

Let it be remembered that a Thermal unit (expressed by T. U.) is the raising of 1 lb. of water 1 degree, and that the mechanical force existing in each unit is 772 lbs.

OUTFLOW OF STEAM THROUGH AN ORIFICE.

The velocity of steam escaping from under pressure is known to be very great though few are aware that even under a moderate pressure of say twenty or thirty pounds to the square inch, it is equal to that of a projectile fired from a cannon.

A notable example of the high velocity of escaping steam is that of a steam whistle, in which a jet of steam little thicker than ordinary writing paper, produces a sound that can be heard further than the loudest thunder; a railroad whistle has often been heard eighteen to twenty miles, while thunder is seldom heard over ten or twelve miles. Every engineer knows how little his safety valve lifts, while the whole current of steam required to run his engine escapes therefrom.

Steam acts like a liquid in flowing through openings and tubes, and the velocity of flow is regulated by the same funda mental laws that govern liquids.

But, while the height through which the water falls can be ascertained by direct measurement, for steam it is necessary to make calculations. The following two tables embrace the results both of the figures and practical tests.

Velocity of Efflux of Steam into the Atmosphere.

Absolute initial pressure per square inch-	Outside pressure per square inch.	Ratio of expansion of nozzle.	Velocity of efflux, as at constant density.	Actual velocity of efflux, expanded.	Weight of steam discharged per minute per square inch.
lbs.	lbs.	ratio.	feet per second.	feet per second.	pounds.
25.37	14.7	1.624	863	1401	22.81
30	14.7	1.624	867	1408	26.84
40	14.7	1.624	874	1419	35.18
45	14.7	1.624	877	1424	39.78
50	14.7	1.624	880	1429	44.06
60	14.7	1.624	885	1437	52.59
70	14.7	1.624	889	1444	61.07
75	14.7	1.624	891	1447	65.30
90	14.7	1.624	895	1454	77.94
100	14.7	1.624	898	1459	86.34

Outflow of Steam:—From a given Absolute Initial Pressure into Various Lower Pressures.

Initial Pressure in Boiler, 75 lbs. per square inch.

Absolute pressure in boiler per square inch.	Outside pressure per square inch.	Rate of expansion in nozzle.	Velocity of efflux as constant density.	Actual velocity of efflux expanded.	Weight discharged per square inch of orifice per minute.
lbs.	lbs.	ratio.	feet per second	feet per second	pounds.
75	74	1.012	227.5	230	16.68
75	72	1.037	386.7	401	28.35
75	70	1.063	490	521	35.93
75	65	1.126	660	749	48.38
75	61.62	1.198	736	876	53.97
75	60	1.219	765	933	56.12
75	50	1.434	873	1252	64.
75	45	1.575	890	1401	65.24
75	43.46 (58 p. ct.)	1.624	890.6	1446.5	65.3
75	15	1.624	890.6	1446.5	65.3
75	0	1.624	890.6	1446.5	65.3

VELOCITY OF STEAM.

NOTE.

Practically the results do not agree exactly with the Tables. There is some waste of power from friction at the point of discharge. If the discharge pipe is short its length being no no more than its diameter and properly enlarged inside, there will be but little loss of power, whereas if the steam escapes through a pipe of considerable length, the steam will expand very considerable in passing its length, and while thus expanding exerts a back pressure on that back of it; thus retarding the velocity of that just entering the pipe and rendering the flow of steam correspondingly less.

VALUE OF EXHAUST STEAM.

Owing principally to its latent heat exhaust steam is of practically the same value as an equal quantity of direct steam of high pressure for heating in the winter season, and with proper arrangements, for many of the numberless operations carried on in textile and other manufactories. For all these purposes the pipes must necessarily be somewhat larger than they need be where direct steam of high pressure is used. In many cases where failure has resulted from an attempt to use exhaust for the above purposes, the result has been due to the use of a too contracted system of piping, and in other cases, to a wrongly designed system.

Where the demand for steam for which the exhaust may be used, or where the supply of exhaust is variable, automatic arrangements for making up the requisite quantity direct from the boilers can easily be constructed, so as to always insure the maximum degree of economy. When more heat than the exhaust can furnish is wanted, the proper amount needed to supply the demand is drawn from the boilers; when the exhaust furnishes more than is needed, it can be utilized to heat feed-water, or it can be used to warm a storage tank for hot water.

EXPANSION OF STEAM.

With open ports the expansive energy of steam acts from *the water in the boiler* as its fixed point or fulcrum, but after it is "cut off" it acts from the fixed ends of the cylinder.

EXPANSION OF STEAM.

When steam first enters the cylinder, the space it exists in becomes enlarged by that through which the piston moves, and again the supply from the boiler to the cylinder is "cut off" at an early period in "the stroke," not merely for avoiding waste, or to assure smoothness of action, but as a positive means for increasing the economical performance of the steam; *hence the whole process carried on within the cylinder is one of expansion.*

The beneficial results accruing from the use of steam, expansively, and the methods of calculations relating to it will be considered hereafter, under the heading THE INDICATOR.

TABLE.

NUMBER OF THERMAL UNITS IN ONE POUND OF WATER.

Temperature.	Number of thermal units.	Temperature.	Number of thermal units.	Temperature.	Number of thermal units.
35°	35.	150°	150.305	265°	266.774
40	40.001	155	155.339	270	271.878
45	45.002	160	160.374	275	276.985
50	50.003	165	165.413	280	282.095
55	55.006	170	170.453	285	287.210
60	60.009	175	175.497	290	292.329
65	65.014	180	180.542	295	297.452
70	70.020	185	185.591	300	302.580
75	75.027	190	190.643	305	307.712
80	80.036	195	195.697	310	312.848
85	85.045	200	200.753	315	317.988
90	90.055	205	205.813	320	323.134
95	95.067	210	210.874	325	328.284
100	100.080	215	215.939	330	333.438
105	105.095	220	221.	335	338.596
110	110.110	225	226.078	340	343.759
115	115.129	230	231.153	345	348.927
120	120.149	235	236.232	350	354.101
125	125.169	240	241.313	355	359.280
130	130.192	245	246.398	360	364.464
135	135.217	250	251.487	365	369.653
140	140.245	255	256.579	370	374.846
145	145.275	260	261.674	375	380.944

INJECTORS.

This appliance, which was invented by Giffard, is in many respects the most peculiar and interesting apparatus connected with the steam engine. It is an instrument which converts the energy of the steam into mechanical work *without the aid of any moving mechanism whatever.*

Before describing it, it is necessary to notice the difference between the velocity of steam escaping from a boiler, and water issuing from the same vessel under the same pressure of steam. It is impossible to give, in reasonable limits, an account of the theory and the rules by which it is determined, but it will suffice to say, that for the pressure usual to land boilers, the velocity of the steam is from 16 to 18 times, or even more, than that of water.

Suppose now that some of the steam were discharged from a boiler through a pipe at this high velocity, and that while in the act of discharge, it were condensed suddenly by passing through an intensely cold medium; the resulting water condensed from the steam would travel forward with the same velocity which it had already acquired when in the state of steam; and if the various particles of water could by any means be gathered together into a continuous stream they would be more than able to overcome and force back into the boiler any opposing stream of water of the same size directed against them from the water room of the boiler.

Now the velocity of the condensed steam is so great that it possesses not only energy enough to re-enter the boiler in the face of an opposing stream of water of its own size, *but it can also impart energy to a much larger mass of water,* so that this larger mass can also enter the boiler.

The injector is simply an instrument for allowing steam to rush from a boiler. and to suck up and mix for itself a stream of cold water, by which it is condensed, and to which it imparts so much of its own velocity that the combined mass of cold water and condensed steam enters into and feeds the boiler.

Fig. 108 shows an elementary form of such an injector. *A* is the section of a boiler, *B* a pipe leading from the steam space and terminating in a nozzle, *C* is the cold water pipe leading from the tank, and terminating in a hollow cone surrounding the steam nozzle. When the steam is turned on, and escapes from the lower edge *E* of the hollow cone, it creates a partial vacuum in the cone and in the pipe *C*. The water then rushes up the pipe and into the cone surrounding the nozzle, when it meets with the escaping steam, which it condenses.

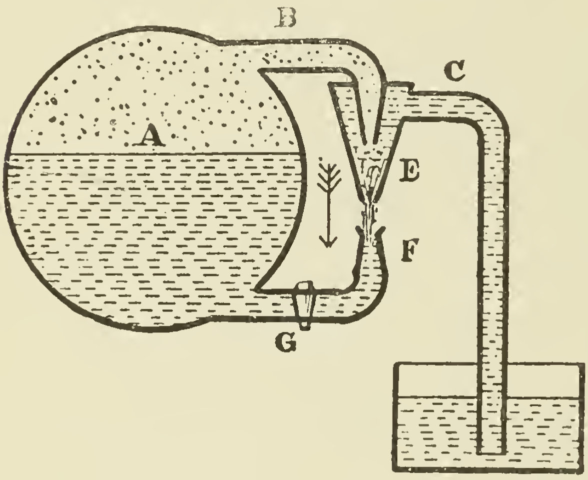


Fig. 108.

The particles of condensed steam, mingling with the water surrounding them, communicate their motion to the latter, and the combined mass is delivered with a high velocity into the feed pipe *F* and through the valve at *G* into the boiler. Such an injector, if properly proportioned, would work well for a fixed pressure of steam in the boiler, and for a fixed temperature of the feed water. In practice however these quantities vary, and injectors must be made to suit all such contingencies. For instance, when the pressure of the steam increases, the area in the opening of the steam nozzle must be increased and when the pressure decreases it must be made smaller.

There are very many forms of injectors. Fig. 109 illustrates one which is in quite common use. The steam and water supply pipes, nozzle and cone are rendered sufficiently clear by the drawing. The steam supply is varied by altering the position of the conical spindle *a*, which can be screwed towards or away from the mouth of the nozzle.

The water chamber *CC* is so arranged that it completely surrounds the steam nozzle. The supply of the water is varied by contracting or expanding the conical aperture below the mouth of the steam nozzle. This is accomplished by moving the conical sliding tube *E* backwards or forwards by means of the handwheel *D* and the rack and pinion.

INJECTORS.

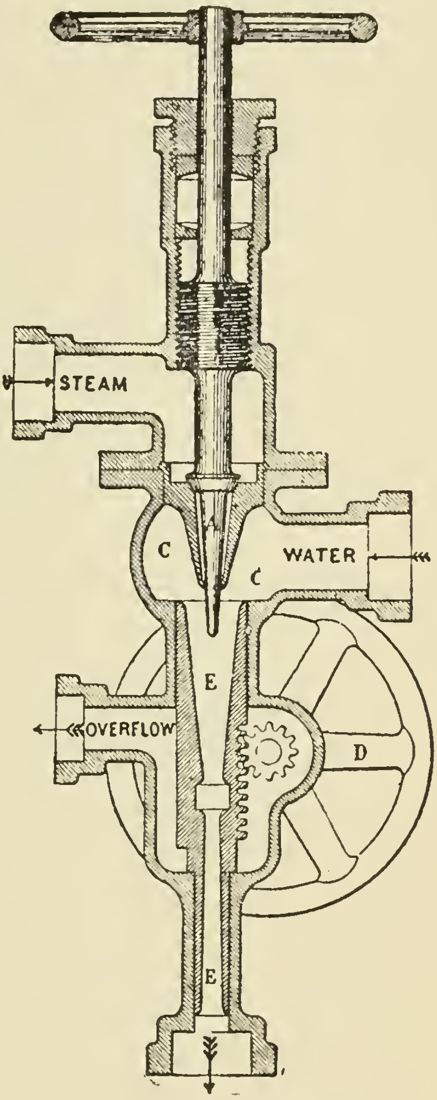


Fig. 109.

If the supply of steam is not properly adjusted to the water, some of the latter will escape at the aperture made in the sliding tube *E* into the overflow pipe. For instance, if the supply of steam be too small, the current will not have sufficient energy to enter the boiler, part of it will choke up the sliding tube and escape by the aperture. When this occurs it is only necessary *to turn on more steam or shut off some of the water.*

The efficiency of the injector is measured by the temperature of the current of feed water as it enters the boiler, compared with its temperature before it entered the injector. The less the rise in temperature, the more the energy of the steam is utilized.

Injectors are also used for other purposes besides feeding boilers. They are used to pump out cisterns and drain basins and have even served to pump out mines. In the latter case 80 gallons per minute have been raised 240 feet, which is probably the greatest amount of work which has been done by an injector.

NOTE.

In feeding a steam boiler with water two things are necessary: First, there is a certain amount of mechanical work to be done in forcing the water into the boiler. Second, the water is to be heated; both require a certain number of heat units and in the injector all the steam used for forcing the water is doubtless economically used, *but that used in heating the water may be considered a waste,* as compared to the use of the exhaust steam in a feed water heater.

GRAVITY.

We can not say what gravity *is*, but what it *does*,—namely, that it is something which gives to every particle of matter a tendency toward every other particle. This influence is conveyed from one body to another without any perceptible interval of time. If the action of gravitation is not instantaneous, it moves more than fifty millions of times faster than light.

Gravity extends to all known bodies in the universe, from the smallest to the greatest; by it all bodies are drawn toward the center of the earth, not because there is any peculiar property or power in the center, but because, the earth being a sphere, the *aggregate* effect of the attractions exerted by all its parts upon any body exterior to it, is such as to direct the body toward the center.

This property discovers itself, not only in the motion of falling bodies, but in the *pressure* exerted by one portion of matter upon another which sustains it; and bodies descending freely under its influence, whatever be their figure, dimensions or texture, are all *equally accelerated* in right lines perpendicular to the plane of the horizon. The apparent *inequality* of the action of gravity upon different species of matter near the surface of the earth arises entirely from the resistance which they meet with in their passage through the air. When this resistance is removed, (as in the exhausted receiver of an air-pump,) no such inequality is perceived; bodies of all kinds there descend with equal velocities; and a coin, a feather, and the smallest particle of matter, if let fall together, are observed to reach the bottom of the receiver exactly at the same instant.

The *weight* of a body is the force it exerts in consequence of its gravity, and is measured by its mechanical effects, such as bending a spring. We weigh a body by ascertaining the force required *to hold it back*, or to keep it from descending. Hence, weights are nothing more than *measures of the force of gravity* in different bodies.

GRAVITY.

It has been ascertained, by experiment, that a body falling freely from rest, will descend $16\frac{1}{12}$ feet in the first second of time, and will then have acquired a velocity, which, being continued uniformly, will carry it through $32\frac{1}{6}$ feet in the next second. Therefore, if the first series of numbers be expressed in seconds, 1″, 2″, 3″, &c., the velocities in feet will be $32\frac{1}{6}$, $64\frac{1}{3}$, $96\frac{1}{2}$, &c.; the spaces passed through as $16\frac{1}{12}$, $64\frac{1}{3}$, $144\frac{3}{4}$, &c., and the spaces for each second, $16\frac{1}{12}$, $48\frac{1}{4}$, $80\frac{5}{12}$, &c.

Table

Showing the Relation of Time, Space, and Velocity.

Time in seconds of the body's fall.	Velocity acquired at the end of that time.	Squares.	Space fallen through in that time.	Space.	Whole space fallen through in the last second of the fall.
1	32.16	1	16.08	1	16.08
2	64.33	4	64.33	3	48.25
3	96.5′	9	144.75	5	80.41
4	128.66	16	257.33	7	112.58
5	160.83	25	402.08	9	144.75
6	193.	36	579.	11	176.91
7	225.17	49	788.08	13	209.08
8	257.33	64	1029.33	15	241.25
9	289.5	81	1302.75	17	273.42
10	321.66	100	1946.08	19	305.58

Rule I.

To find the velocity a falling body will acquire in any given time.

Multiply the time, in seconds, by $32\frac{1}{6}$, and it will give the velocity acquired in feet, per second.

Example.

Required the velocity in 7 seconds.

$$32\tfrac{1}{6} \times 7 = 225\tfrac{1}{6} \text{ feet. Ans.}$$

GRAVITY.

Rule II.

To find the Velocity a Body will acquire by falling from any given height.

Multiply the space, in feet, by $64\frac{1}{3}$, the square root of the product will be the velocity acquired, in feet, per second.

Example.

Required the velocity which a ball has acquired in descending through 201 feet.

$$64\tfrac{1}{3} \times 201 = 12931;\ \sqrt{12931} = 113.7 \text{ feet. Ans.}$$

Rule III.

To find the Space through which a Body will fall in any given time.

Multiply the square of the time, in seconds, by $16\frac{1}{12}$, and it will give the space in feet.

Example.

Required the space fallen through in seven seconds.

$$16\tfrac{1}{12} \times 7^2 = 788\tfrac{1}{12} \text{ feet. Ans.}$$

Rule IV.

To find the Time which a Body will be in falling through a given space.

Divide the *square root* of the space fallen through by 4, and the quotient will be the time in which it was falling.

Example.

Required the time a body will be in falling through 402.08 feet of space.

$$\sqrt{402.08} = 20.049, \text{ and } 20.049 \div 4 = 5.012. \text{ Ans.}$$

Rule V.

The Velocity being given, to find the Space fallen through.

Divide the velocity by 8, and the square of the quotient will be the distance fallen through to acquire that velocity.

Example.

If the velocity of a cannon ball be 660 feet per second, from what height must a body fall to acquire the same velocity?

$$660 \div 8 = 82.5^2 = 6806.25 \text{ feet. Ans.}$$

SPECIFIC GRAVITY.

Rule VI.

To find the Time, the Velocity per second being given.

Divide the given velocity by 8, and one-fourth part of the quotient will be the answer.

Example.

How long must a bullet be falling to acquire a velocity of 480 feet?

$$480 \div 8 = 60 \div 4 = 15 \text{ seconds.} \quad \text{Ans.}$$

SPECIFIC GRAVITIES OF BODIES.

Every substance in nature has, under the same circumstances, a weight *specific* or peculiar to itself.

The Specific Gravity of a body is its weight compared with the weight of another body taken as a standard.

Water is the standard for all solids and liquids, and common air is the standard for gases.

The heaviest of all known substances is platinum, whose specific gravity, in its state of greatest condensation, is 22, water 1; and the lightest of all weighable bodies is hydrogen gas, whose specific gravity is $\frac{.073}{1000}$, common air being 1, but air is 818 times lighter than water. Hence by calculation it will be found that platinum is about 247,000 times as heavy as hydrogen and a wide range is allowed to the various bodies which lie between these extremes.

Specific gravity of a liquid is usually taken by means of a *specific gravity bottle,* graduated so as to contain exactly 1000 grains of pure water. If this be filled with spirits of wine and weighed in a balance, (together with a counterpoise for the weight of the bottle, which of course is constant,) it will weigh considerably less than 1000 grains; in fact, the bottle will contain only about 917 grains of proof spirit; therefore, taking the specific gravity of water as unity, 1 or 1.000, the specific gravity of spirits of wine is 0.917. If, on the other hand, the bottle be filled with sulphuric acid, it will weigh about 1850 grains; hence, the specific gravity of sulphuric acid is said to be 1.850.

SPECIFIC GRAVITY.

In taking the specific gravity of solids, advantage is taken of the important fact that when a solid is wholly immersed in water, it displaces a bulk of that liquid exactly equal to its own, and the solid appears to lose its weight; that is, it is supported by the surrounding water with a force exactly equal to the weight of the water displaced; hence, the difference of its weight in water from that of its weight in air must be the weight of an equal bulk of water.

Rule for finding the Specific Gravity of a Solid Body.

Weigh the solid in air and then in pure water.

The difference is the weight of water displaced and whose specific gravity is 1.000.

Then, as the difference of weight is to 1.000, so is the weight in air to the specific gravity; or divide the weight of the body in air by the difference between the weights in air and water.

Example.

A lump of glass is found to weigh in air 577 grains; it is then suspended by a horse hair from the bottom of the scale pan, and immersed in a vessel of pure water, when it is found to weigh 399.4 grains. What is its specific gravity?

```
577.0              Then, as 177.6 : 1 :: 577 : sp. gravity.
399.4                                  1
-----                                ---
177.6 the difference.      177.6)577.0(3.248, &c.
                                 5328
                                 ----
                                  4420
                                  3552
                                  ----
                                   8680
                                   7104
                                   ----
                                   15760
                                   14208
                                   -----
                                    1552
```

Answer, Specific gravity of glass is 3.248.

The Hydrometer *is an instrument constructed for the especial purpose of ascertaining the Specific Gravities of Liquids.*

TABLE OF SPECIFIC GRAVITIES.

Metals.

Iron, (cast)	7.207	Gold (22 carats)	17.481
" (wrought)	7.688	" (20 ")	15.709
Steel (soft)	7.780	Silver (pure, cast)	10.474
" (tempered)	7.840	" (hammered)	10.511
Lead (cast)	11.400	Mercury (60°)	13.580
" (sheet)	11.407	Pewter	7.248
Brass (cast)	8.384	Tin	7.293
" (wire drawn)	8.544	Zinc (cast)	7.215
Copper (sheet)	8.767	Platinum	21.500
" (cast)	8.607	Antimony	6.712
Gold (cast)	19.238	Arsenic	5.763
" (hammered)	19.361	Bronze (gun metal)	8.700

Stones and Earth.

Coal (Bituminous)	1.256	Lime	2.720
" (Anthracite)	1.436 1.640	Granite	2.625
		Marble	2.708
Charcoal	.441	Mica	2.800
Brick	1.900	Millstone	2.484
Clay	1.930	Nitre	1.900
Common Soil	1.984	Porcelain	2.385
Emery	4.000	Phosphorus	1.770
Glass	3.248	Pumice Stone	.915
Ivory	1.822	Salt	2.130
Grindstone	2.143	Sand	1.800
Diamond	3.521	Slate	2.672
Gypsum	2.168	Sulphur	2.033

Woods.

Ash	.845	Cherry	.715
Beech	.852	Cork	.240
Birch	.720	Elm	.671

TABLE OF SPECIFIC GRAVITIES.

Woods.

Oak	1.120	Poplar	.383
Pine (yellow)	.660	Walnut	.671
" (white)	.554	Willow	.585

Liquids.

Acid Sulphuric	1.851	Oil (linseed)	.932
" Muriatic	1.200	" (castor)	.961
Spirits of Wine	.917	Pure water	1.000
Alcohol	.790	Vinegar	1.080
Oil (turpentine)	.870	Milk	1.032
" (olive)	.915	Sea water	1.029
" (whale)	.923		

To find the weight of a cubic foot of anything contained in these tables.

RULE.

Multiply 62.5 lbs. (the weight of a cubic foot of pure water) by the specific gravity of the given body.

EXAMPLE.

What is the weight of a cubic foot of sea water?

```
  62.5 lbs.
 1.029 sp. gravity.
 -----
  5625
 1250
6250
 -----
```

Answer, 64.3125 lbs. is the actual weight; but 64 lbs. is taken in practice as the weight of a cubic foot of sea water.

SPECIFIC GRAVITY.

Example.

How many cubic feet of sea water will weigh a ton ?
Divide 2240 lbs. (1 ton) by 64 lbs.

$$64\left\{\begin{array}{r} 8)2240 \\ \hline 8)\ \ 280 \end{array}\right.$$

$$\begin{array}{r} \overline{\text{Ans.}\quad 35} \end{array}$$

Note.

35 cubic feet of sea water is always accounted to be a ton, as in sea water ballast for steamers, and in calculating displacement of ships.

Example.

What is the weight of a cubic foot of wrought iron ?

$$\begin{array}{rl} 62.5 & \text{lbs.} \\ 7.69 & \text{sp. gravity.} \\ \hline 5625 & \\ 3750 & \\ 4375 & \\ \hline \end{array}$$

Answer, 480.625 lbs.

480 lbs. in practice is the weight of 1 cubic foot of wrought iron.

Example.

What is the average weight of a cubic foot of Bituminous coal ?

$$\begin{array}{rl} 1.256 & \text{sp. gravity.} \\ 62.5 & \text{lbs.} \\ \hline 6280 & \\ 2512 & \\ 7536 & \\ \hline \end{array}$$

Answer, 78.5000 lbs.

SPECIFIC GRAVITY.

This 78.5 lbs. is the weight of a cubic foot in a *solid block*; but loose, as used for fuel, a cubic foot weighs about 49.7 lbs. which is the average of 13 kinds.

EXAMPLE.

What is the weight of a solid cast cylinder of copper, 4 inches diameter and 6 inches high?

8.607 sp. gravity.
62.5 lbs.
———
43035
17214
51642
———
537.9375 lbs. per cub. ft.
———
Say 538 lbs.

.7854
16 diam. squared.
———
47124
7854
———
12.5664 area of base.
6 high
———
75.3984 cu. in. in volume
———
Say 75.4 cubic inches.

Then, as 1728 cub. in. : 75.4 cub. in. :: 538 lbs. : Answer.

538
———
6032
2262
3770
———
1728 { 12)40565.2
———
12) 3380.433
———
12) 281.702
———
23.475 lbs.

Answer, 23½ lbs. nearly.

ELEMENTS OF ALGEBRA.

Algebra is a mathematical science which teaches the art of making calculations by letters and signs instead of figures.

The name comes from two Arabic words, *al gabron,* reduction of parts to a whole.

The letters and signs are called *Symbols.*

Quantities in algebra are expressed by *letters,* or by a combination of *letters* and *figures;* as a, b, c, $2x$, $3y$, $5z$, etc.

The first letters of the alphabet are used to express *known* quantities; the last letters, those which are *unknown.*

The *Letters* employed have no fixed numerical value of themselves. *Any* letter may represent any number, and the same letter may represent *different* numbers, but in each sum the same letter must always stand for the same amount.

The operations to be performed are expressed by the same signs as in Arithmetic; thus $+$ means Addition, $-$ expresses Subtraction, and $\times$ stands for Multiplication.

Thus $a+b$ denotes the sum of a and b and is read a plus b; $a-b$ means a less b; and $a\times b$ shows that a and b are to be multiplied together.

Multiplication is also denoted by a period between the factors as $a.b$. But the *multiplication of letters* is more commonly expressed by writing them together, the signs being omitted.

Example.—$7\,abc$ is the same as $7\times a\times b\times c$.

The sign of Division is $\div$, thus $a\div b$ is read a divided by b; but this is also expressed $\frac{a}{b}$; the sign of Equality is two short horizontal lines, as $a=b$ and is read a equals b.

The *Parenthesis* ( ) or *Vinculum* ——, indicates that the included quantities are taken *collectively* or as one quantity.

Example.—$3\,(a+b)$ and $3\overline{a+b}$ each denote that the sum of a and b is multiplied by 3.

The character $\therefore$ denotes *hence, therefore.*

A coefficient is a number or letter prefixed to a quantity, to show *how many times* the quantity is to be taken. Hence a coefficient is a *multiplier* or *factor;* thus in $5a$, 5 is a numeral coefficient of a.

When no numeral coefficient is expressed, 1 is always understood. Thus xy means $1xy$.

DEFINITIONS AND EXPLANATIONS.

An algebraic operation is combining quantities according to the principles of algebra.

A Theorem is a statement of a principle to be proved.

A Problem is something proposed to be done, as a question to be solved.

The *Expression of Equality* between two quantities is called an *Equation.*

An *Algebraic Expression* is any quantity expressed in algebraic language, as $3a$, $5a-7a$, etc.

The *Terms* of an algebraic expression are those parts which are connected by the signs $+$ and $-$.

Thus in $a+b$ there are two terms; in x, y and $z-a$ there are three.

A *Positive Quantity* is one that is to be *added* and has the sign $+$ prefixed to it, as $4a+3b$.

A *Negative Quantity* is one that is to be *subtracted* and has the sign $-$ prefixed to it, as $4a-3b$.

A *Simple Quantity* is a single letter, or several letters written together without the sign $+$ or $-$, as a, ab, $3\times y$.

A *Compound Quantity* is two or more simple quantities connected by the sign $+$ or $-$, as $3a+4b$, $2x-y$.

The *Axioms* in algebra are self-evident truths as exemplified on page 130.

ADVANTAGES OF ALGEBRA.

In algebra numbers are expressed by the letters of the alphabet and the advantage of the substitution is that we are enabled to pursue our investigations without being embarassed by the necessity of performing arithmetical operations at every step.

Thus, if a given number be represented by the letter a, we know that $2a$ will represent twice that number, and $\frac{1}{2}a$ the half of that number, whatever the value of a may be. In like manner if a be taken from a there will be nothing left and this result will equally hold whether a be 5 or 7, or 1000, or any other number whatever.

By the aid of algebra, therefore, we are enabled to analyze and determine the abstract properties of numbers, and we are also enabled to resolve many questions that by simple arithmetic would either be difficult or impossible.

A working engineer has but little practical use for a too extended acquaintance with algebra, as nearly all the algebraic rules have been transferred to ordinary arithmetical computation, but as the algebraic system is so inwoven into the school and college course of instruction it is well for every one to know something of the elements of the science, as a traveller in a foreign country is benefited by having some of the common words like bread, water, and the names of coin, even if he cannot comprehend the whole language.

ALGEBRAIC FORMS.

Arithmeticians for very many years have made a study of the use of *formulæ* (this is *Latin* for the word forms) in stating problems and rules; these forms are nearly all expressed in algebraic terms, as the prescriptions written for compounding by druggists are written in a dead language, it follows that one of the causes for so doing is the same, *i. e.*, the mystifying of those who have been practically educated outside the schools. The positive advantage however to be derived from the use of algebraic formulae is that it puts into a short space what otherwise might necessitate the use of a long verbal or written explanation.

Another advantage is that the memory retains the *form* of the expression much easier and longer than the longer method of expression.

It may be remarked that those engineers who once become accustomed to the method of use of formulae seldom abandon their use.

Examples Explaining the Solving of Formulæ.

1. If $x = a + b - c + d - f$; what must be the value of x when $a = 10$, $b = 7$, $c = 9$, $d = 4$, and $f = 6$?

First substitute the figures for the letters, thus:—

$x = 10 + 7 - 9 + 4 - 6$, then proceed as in the Arithmetical part.

$$x = 21 - 15 = 6 \text{ Answer.}$$

2. If $x = 4\,g + 2\,m - 7\,n - p + 3\,q$; find the value of x when $g = 5$; $m = 3$; $n = 6$; $p = 1$; and $q = 8$.

Here $4\,g = 4$ times $5 = 20$; $2\,m =$ twice $3 = 6$; $7\,n = 7$ times $6 = 42$; and $3\,q = 3$ times $8 = 24$;

$$\begin{aligned} \text{Hence, } x &= 20 + 6 - 42 - 1 + 24 \\ &= 50 - 43 \\ &= 7 \text{ Answer.} \end{aligned}$$

3. If $x = \frac{1}{2}\,a - \frac{1}{4}\,d + \frac{1}{5}\,c - \frac{3}{4}f$; find the value of x when $a = 10$; $d = 24$; $c = 25$; and $f = 12$.

As $a = 10$, then $\frac{1}{2}\,a = 5$; as $d = 24$, then $\frac{1}{4}\,d = 6$; as $c = 25$, then $\frac{1}{5}\,c = 5$; and as $f = 12$, then $\frac{3}{4}f = 9$.

$$\begin{aligned} \text{Hence, } x &= 5 - 6 + 5 - 9 \\ &= 10 - 15 \\ &= -5 \text{ Answer.} \end{aligned}$$

4. If $x = c - (\frac{s}{2} - p)$; find the value of x when $c = 8$ $s = 3\frac{1}{2}$ and $p = 1\frac{1}{2}$

$x = 8 - (\frac{3\frac{1}{2}}{2} - 1\frac{1}{2})$; here $3\frac{1}{2}$ is divided by $2 = 1\frac{3}{4}$

$$\begin{aligned} &= 8 - (1\tfrac{3}{4} - 1\tfrac{1}{2}) \\ &= 8 - \tfrac{1}{4} \\ &= 7\tfrac{3}{4} \text{ Answer.} \end{aligned}$$

FORMULÆ.

5. $x = a\,b + c\,d - e\,f$; where $a = 2$, $b = 3$, $c = 4$, $d = 5$, $e = 6$, and $f = 7$.

When two or more letters are joined together without any sign, it always means that they are multiplied together, hence the above becomes

$$\begin{aligned} x &= 2 \times 3 + 4 \times 5 - 6 \times 7 \\ &= 6 + 20 - 42 \\ &= 26 - 42 \\ &= -16 \text{ Answer.} \end{aligned}$$

6. $x = 4\,a\,b\,c - 5\,c\,d$; $a = 2$; $b = 5$; $c = 3$ and $d = 4$

$$\begin{aligned} &= 4 \times 2 \times 5 \times 3 - 5 \times 3 \times 4 \\ &= 120 - 60 \\ &= 60 \text{ Answer.} \end{aligned}$$

We have seen in the Algebraic part that such a quantity as $\frac{a}{b}$ means that a is to be divided by b; hence, if $a = 24$ and $b = 6$, then $\frac{a}{b} = \frac{24}{6} = 4$.

7. Then if $x = \dfrac{AB}{D - C}$; what is the value of x when $A = 6$; $B = 7$; $C = 10$; and $D = 16$?

$$x = \frac{6 \times 7}{16 - 10} = \frac{42}{6} = 7 \text{ Answer.}$$

8. What is the value of $1 + \dfrac{T + t - 64}{1000}$ when $T = 82$ and $t = 38$?

$$1 + \frac{82 + 38 - 64}{1000} = 1 + \frac{56}{1000} = 1 + .056$$
$$= 1.056 \text{ Answer.}$$

9. $12\dfrac{D^3 - d^3}{S}$ What is the value of this when $D = 14$, $d = 12$; and $S = 15$?

$$12\frac{14^3 - 12^3}{15} = 12\frac{2744 - 1728}{15} = 12 \times \frac{1016}{15} = \frac{12192}{15}$$
$$= 812.8. \text{ Answer.}$$

NOTE.

Instead of dividing 1016 by 15, and multiplying the quotient by 12, we prefer to first multiply 1016 by 12, and then divide by 15, because if you divide by 15 first you get a repeating

FORMULÆ.

decimal, whereas by dividing last you bring the answer out exact. The same is true for the following one also.

10. $L = \frac{(P - t)\ (T - t)}{P - T} \times .009\ C$; what is the value of L when P = 120; T = 67; t = 32 and C = 3375?

$$L = \frac{(120 - 32)\ (67 - 32)}{120 - 67} \times .009 \times 3375$$

$$= \frac{88 \times 35}{53} \times 30.375 = \frac{93555}{53} = 1765.1886, \text{ \&c.}$$

11. What is the value of U in the following:—

$U = 1115 + .3\ T - t$; if T = 320 and t = 120?

$= 1115 + .3 \times 320 - 120$

$= 1115 + 96.0 - 120$

$= 1211 - 120 = 1091$. Answer.

Note here, that the 320 must be multiplied by the .3 first; the result, 96, must then be added to 1115, and the 120 subtracted from their sum.

Also note, that in (8) (10) and (11) there is a capital T and a small t; also in (9) a capital D and a small d. In such cases the capital letter represents the larger quantity, and the small letter the smaller quantity.

FORMULA FOR DETERMING STRENGTH OF BOILERS.

$$P = \frac{t \times T}{D} \times 2$$

P = bursting pressure; t = thickness of plate; T = tensile strength of the iron or steel; D = diameter of shell.

Suppose your boiler to be 48-inch diameter of shell, of ¼ inch plate having a tensile strength of 60,000 pounds per square inch of cross section, the rupturing pressure would be

$$P = \frac{.25 \times 60{,}000}{48} \times 2 = 625 \text{ pounds.}$$

If the boiler is single riveted, it would be limited to ⅙ of the maximum strength, or 104.16 pounds. With double rivets and holes drilled instead of punched, a working pressure of 125 pounds might be allowed.

FORMULÆ.

Simple Formula for Horse Power of Engines.

$$\frac{P\ A\ T}{33{,}000}$$

P being the mean effective pressure in pounds per square inch, A the piston area in square inches, and T the piston travel in feet per minute.

ARITHMETICAL NOTES.

Mathematics embraces three departments, namely: (1) Arithmetic; (2) Geometry, including Trigonometry and Conic Sections; (3) Analysis, in which letters are used, including Algebra, Analytical Geometry and Calculus.

The first of the nine Arabic characters are called digits, from the Latin word *digitus,* a finger, owing to the fact that the ancients reckoned by counting the fingers.

Figures have two values, Simple and Local. The simple value of a figure is its value when standing in units' place. The local value of a figure is the value which arises from its location.

A continued fraction is a fraction whose numerator is 1 and whose denominator is a whole number plus a fraction whose numerator is also 1 and whose denominator is a similar fraction, and so on.

Example.

$$\frac{13}{54}=\cfrac{1}{4+\cfrac{1}{6+\frac{1}{2}}}$$

There are six cases of reduction: 1st. Numbers to fractions. 2d. Fractions to numbers. 3rd. To higher terms. 4th. To lower terms. 5th. Compound to simple. 6th. Complex to simple.

A circulating decimal is a decimal in which a figure, or set of figures is constantly repeated in the same order; as .333+ .727272.

Measures are of seven kinds: 1. Length. 2. Surface or area. 3. Solidity or capacity. 4. Weight, or force of gravity. 5. Time. 6. Angles. 7. Money, or value.

STRENGTH OF MATERIALS.

This is a general expression for the measure of capacity of resistance, possessed by solid masses or pieces of various kinds, to any causes tending to produce in them a permanent and disabling change of form or positive fracture.

As a matter of calculation its principal object is to determine the proper size and form of pieces which have to bear given loads, or on the other hand to determine the loads which can be safely applied to pieces whose dimensions and arrangement is already given.

The materials used in construction are chiefly of four kinds.

1. Timber,
2. Rock, or natural stones,
3. Brick, concrete, etc. (artificial stones).
4. Metals, especially iron.

All these resist fracture in whatever way, but the capability of resistance in a given case varies with chiefly the following: 1, the nature of the material and its quality; 2, the shape and dimensions of the piece used; 3, the manner of support from other parts; 4, the lines and direction of the force tending to produce rupture.

Materials of all kinds *owe their strength* to the action of these forces residing in and about the molecules of bodies (the molecular forces) but mainly to that one of these known as *cohesion;* certain modified results of cohesion, as toughness or tenacity, hardness, stiffness, and elasticity are also important elements and the strength is in the relation of the toughness and stiffness combined.

A piece of iron or timber may be subjected to strain or fracture in four ways: 1, it may be stretched, pulled or torn asunder, as a tie-rod or a steam boiler. This is called tensile strain or tension, and is a direct pull; resistance to this force is called *tensile strength.* 2, the iron or timber may be crushed in the direction of the length as in columns and truss beams. This is direct thrust, direct pressure or compression; and the resistance to it, *the crushing strength.* An example of this is found in the force tending to collapse the flues of a steam boiler. 3, it may be bent or broken across by a force perpendicular or oblique to its length, as in common beams and joists. This is transverse strain or flexion; resistance to it *the transverse strength.* 4, It may be twisted or wrenched off, in a direction about its axis, as in case of shafting. This is torsion; resistance to it *the torsional strength.*

Let it be noted, that any bending or breaking pressure is *a stress;* its effect on the piece *a strain;* briefly, then, the strength of a solid piece or body is the total resistance it can oppose to strain in that direction.

IMPORTANT PRINCIPLES RELATING TO STRENGTH OF MATERIALS.

A rod, rope or any body being pulled in the direction of its length, its cohesion can come into play only by reason of the opposite length being fixed; and the amount of cohesion excited is a reaction against the strain applied; up to the limit of strength the amount of cohesion is always exactly equal to the acting strain; at every moment the strain and reaction are equal throughout the whole length of the piece acted upon.

Where weight does not (as it must in any hanging rope or piece) come in to modify the result the piece must, when the limit of strength is exceeded, always part or yield at its weakest portion; that the tensile strength can never exceed that of such weakest portion.

Two fibres of like character equally stretched must exhibit double the strength of one. Generalizing this result, we say that the tensile strength of beams, rods, ropes, wires, etc., is, for each material, proportional to the area of the cross-section of the piece used. This is, accordingly, also termed the absolute strength.

When allowance for modifying influences is made, the laws of tensile strength become safe guides in practice, though the behavior of different materials in yielding to tension may vary considerably.

THE STRENGTH OF MATERIALS.

Any material, under a considerable tensile strain, becomes slightly elongated, not returning when the strain is taken off. This result is expressed by saying that the body possesses *extensibility.* It is doubtful whether in all materials, or in most, a result of this kind can be often or indefinitely repeated. But over this, the body lengthens a little by every pull in consequence of its elasticity; and this effect is not permanent, at least its whole amount is not so; the piece shortens again, when the strain is removed, by quite or nearly the amount of this lengthening.

If the body possesses that of *ductility*, when the limit of its extensibility and elasticity is reached, the particles upon the surface at the weakest point begin to slip upon each other; the body is by this action both permanently and sensibly lengthened or drawn out, and as this extension does not, as in wire-drawing proper, take place under circumstances favorable to increase of toughness, the strength is with the first yielding impaired; while, if the load be not then diminished, the yielding portion must be drawn rapidly smaller until it parts completely. Thus, for ductile materials, the load beyond which permanent change must occur is *the limit of strength.*

In metallic bars or links, timbers, &c., a considerable proportion of the actual strength is gained by means of the firm hold of the fibres laterally one upon another; as is proved by the fact that, of two ropes of like material and containing in their sections a like number of fibres, in one of which the fibres are twisted and in the other glued together, the strength of the latter is greater by at least one third.

In the tables of strength which follow, the piece experimented on is (unless otherwise specified) always one the transverse section of which presents an area of 1 square inch; and the limits of strength found, known by the loads required to secure fracture, are expressed in pounds weight avoirdupois.

THE STRENGTH OF MATERIALS.

1.—Metals.

Materials.	Limits of tensile strength.	Materials.	Limits of tensile strength.
Steel, best tempered	134,000—153,000	Iron, ship plates, average	44,000
Steel, cast, maximum	142,000	" cast	14,000 / 45,970
" shear	118,000	" cast, mean of American	31,800
" blister	104,000	Copper, wire	61,200
" puddled	67,200	" wrought	34,000
" plates, lengthwise	96,300	" cast, American	24,250
" plates, breadthwise	73,700	Platinum, wire	53,000
" razor	150,000	Silver, cast	40,000
Iron, wire	73,000—103,000	Gold, cast	20,000
" best Swedish bar	72,000	Tin, cast block	3,800
" bar, mean by Barlow	56,560	" Banca	2,122
" bar, inferior	30,000	Zinc	2,600
" boiler plates, average	51,000	Bismuth	2,900
		Lead, wire	2,580
		" cast	1,800

2.—Other Materials.

Glass, plate	9,400	Mortar, of 20 years	52
" flint	4,200	Roman cement, to blue stone	77
Hemp fibres, glued	9,200	Wood, box	14,000—24,000
Hemp fibres, twisted (rope)	6,400	" oak	10,000—25,000
Manila rope	3,200	" locust tree	20,100
Marble, different species	9,000 / 5,200	" elm	13,200
Stone, different species	1,000 / 350	" ash	12,000
Brick, well burned	750	" fir	8,330
		" cedar	4,880

THE STRENGTH OF MATERIALS.

Rule for Estimating Tensile Strength.

The strength, per square inch section, of any material being known, this becomes for such material the unit or coefficient of strength.

That is, the strength of a piece of any other section is (approximately, of course) found by multiplying the unit for that material by the number of square inches in the transverse section of the piece.

Example.

If a bar of iron 1 inch square is torn asunder by 60,000 lbs., what will be required to break a bar $3\frac{3}{4}$ inches square? Now then:

3.75		14.0625 square inches.
3.75.		60,000 tensile strength of 1 inch.
——	2000 lbs to	————
1875	Ton	843.750,0000
2625		————
1125		421+Tons Answer.
——		
14.0625 square inches in section of bar.		

Fatigue of Metals.

A matter of great practical interest is the weakening which materials undergo by repeated changes in their state of stress. It appears that in some if not all materials a limited amount of stress variation may be repeated time after time without apparent reduction in the strength of the piece; on the balance wheel of a watch for instance, tension and compression succeed each other for some 150 millions of times in a year, and the spring works for years without showing signs of deterioration. In such cases the stresses lie well within the elastic limits; on the other hand the toughest bar breaks after a small numbeı of bendings to and fro when these pass the elastic limits.

THE STEAM BOILER.

To whatever use heat is to be applied through the medium of steam, the apparatus for generating and retaining the steam is constructed on the same general principles for all purposes and is popularly termed *a boiler*.

The most common types of steam generators may be arranged under the following designations:

1. The plain cylinder boiler.
2. The cylinder-flue boiler.
3. The cylinder-tubular boiler.
4. The return-flue boiler.
5. The return-tubular boiler.
6. Water-tube boiler.
7. The locomotive boiler.
8. The sectional boiler.

The primary conditions which steam generators should fulfill are: 1. Strength to sustain the internal pressures to which they may be subjected. 2. Durability. 3. Economy or efficiency in evaporating qualities. 4. Economy of construction in materials and workmanship. 5. Adaptation to the particular circumstances of their use. 6. To these conditions must be added safety, which depends on form, construction, strength and quality of materials as well as management.

In many forms or classes of steam boilers, the steam generating apparatus is not complete until the boiler is set up in brick work, with an external furnace constructed for the combustion of the fuel, and external flues made for conducting the heated gases along the sides of the boiler; in others the boiler is ready for use as it comes from the manufacturer, having within the external shell all these necessary arrangements for combustion and draught.

In all cases certain appliances are necessary, such as the feed pump with the necessary pipes and attendants, the safety valve, grate bars, etc., so that a complete steam-producing apparatus requires much more than the single vessel called the boiler.

HORSE POWER.

Reference is made to pages 171, 172 and 173 for matter relating to horse power of the steam boiler, to which is now added the following rules and calculations:

To find the horse power of a cylinder boiler.

Rule.

Multiply $\frac{2}{3}$ the circumference in inches by the length in inches and divide by 144. The result is the heating surface in square feet. Divide this by 10 for nominal horse power.

Example.

What is the horse power in a plain cylinder boiler 40 feet long by 3 feet in diameter?

The circumference of 3 feet = 113 inches.
$\frac{2}{3}$rds of this = 75.3 inches.
Multiply by length, 40×12 in. = 480 "

$$\begin{array}{lr} \text{Now:} & 60240 \\ 144\left\{\begin{array}{l} 12)36144 \text{ divided by} \\ \overline{12)3012} \\ \end{array}\right. & \begin{array}{r} 3012 \\ \hline 361440 \end{array} \end{array}$$

$$\overline{251} \text{ sq. ft.} = 251 \div 10 = 25\tfrac{1}{10} \text{ H. P. Ans.}$$

To find the horse power of a vertical boiler.

1. Multiply the circumference of the fire box by its height above the grate, all in inches.

2. Multiply the combined circumference of all the tubes in inches by their length in inches.

3. Add to these two sums the area of the lower tube sheet, less the combined area in all the tubes—also in square inches.

4. Divide the whole sum by 144 to obtain the square feet of heating surface.

HORSE POWER.

To find the square feet of heating surface in a locomotive boiler.

Rule.

1. Multiply the length of the furnace plates by their height above the grates in inches.

2. Multiply the width in inches by their height in inches.

3. Multiply length of crown sheet in inches by its width in inches.

4. Multiply the combined circumference of all the tubes in inches by their length in inches.

5. From the sum of these four products subtract the area of all the tubes and the area of fire door.

6. Divide by 144 to get square feet of heating surface.

To find the horse power of a flue boiler.

Rule.

1. Multiply $\frac{2}{3}$ the circumference of shell in inches by the length in inches.

2. Multiply the combined circumference of the flues in inches by their length in inches.

3. Divide the sum of the products by 144, the result will be the heating surface in square feet.

4. Divide this by 12 to get nominal horse power.

Example.

What is the horse power of a boiler 42 inches in diameter and 30 feet long with two 12 inch flues ?

Circumference of $42'' = 131.9 \times \frac{2}{3} = 87.9$
Length of boiler in inches $42 \times 12 = 504$

$$\begin{array}{r} 87.9 \\ \times\ 504 \\ \hline 3516 \\ 4395 \\ \hline 443016 \end{array}$$

Now $443016 \div 144 = 307.6$
Divide $307\frac{6}{10}$ by $12 = 25$ H. P.

STRENGTH OF BOILER.

To find tne strength of a boiler.

Rule.

Multiply the tensile strength of the plate in lbs., by the thickness, in decimals of an inch; divide by diameter of the boiler in inches and multiply the product by 2; the answer will be the bursting pressure.

Example.

If a boiler be 48 inches in diameter and made of $\frac{1}{4}$ inch steel having a tensile (or tearing) strength of 60,000 to the square inch, then,

$$
\begin{array}{rr}
 & 60{,}000 \\
\text{thickness} & .25 \\
\hline
 & 300000 \\
 & 120000 \\
\hline
\text{diam. } 48'') & 15.00000 \\
\hline
 & 312\tfrac{1}{2} \\
\text{multiply} & 2 \\
\hline
\end{array}
$$

625 lbs. strength to the square inch.

Note.

In practice, if the boiler is single riveted, $\frac{1}{6}$th only of the above would be allowed as "safe" or $104\frac{16}{100}$ lbs. on the steam gauge—with double rows of rivets and rivet holes, drilled instead of punched, a working pressure of 125 lbs. would be allowed.

Factor of Safety.

This is the number which expresses the ratio of the strength of the boiler to the working strain.

The safe pressure depends upon the bursting stress or tensile strength of the plates, their thickness and the diameter of the boiler.

STRENGTH OF BOILERS.

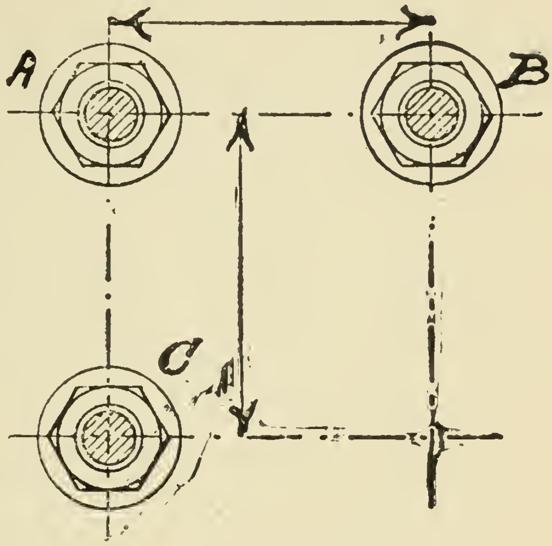


Fig. 110.

In ascertaining the pressure which is carried on the flat surface of a boiler, choose 3 stays as A B C in Fig. 110.

Measure from A to B, and from A to C. The product of these is the number of square inches held by one stay; then proceed as in the following rule and example:

To find the pressure on a certain number of stay bolts on a boiler.

RULE.

Find the number of square inches enclosed by four adjacent bolts and multiply this area by the pressure of the steam as indicated by the steam gauge. This will give the strain on one bolt. Multiply this by the number of bolts upon which it is desired to find the strain and the result will be the answer to the question.

EXAMPLE.

Suppose that the bolts are 4 inches apart, and that the gauge is 140 lbs., what is the strain on one stay bolt and what is it on 8 bolts?

	$4 \times 4 = 16$
pressure	140
	640
	16
	2.240
Number of bolts	8
	17.920 lbs.

NOTE.

The pressure on the surface does not include the space occupied by the area of the bolt, hence to be absolutely accurate that must be deducted.

WATER CAPACITY OF A BOILER.

To find the water capacity of a horizontal tubular boiler of any size.

Rule.

1. Multiply $\frac{2}{3}$ of the area of the head in inches by the length of the boiler in inches.

2. Deduct the area of a single tube multiplied by the number in the boiler multiplied by the length in inches.

3. Divide by 231 to reduce the answer to gallons.

Example.

How much water ($\frac{1}{3}$ being steam space) will a boiler contain 6 feet in diameter and 18 feet long, with 100 3 inch tubes.

The area of 6 feet in inches =	4071.5
and $\frac{2}{3}$rds of this is	2714.3
Multiply by length 18 by inches × 12 =	216
	162858
100 3 inch tubes to be deducted.	27143
No. ft. in.	
Area .7×100×18×12	54286
7×12 = 84	
	586288.8
8400×18 =	15120.0
231)571,1688	571,168.8
24,726 galls. Ans.	

To compute the grate bar surface of a boiler furnace.

Rule.

Multiply the length and the breadth in feet and the result will be square feet of grates.

Example.

What is the grate bar area of a furnace $4\frac{1}{2}$ feet wide and 5 feet deep ?

$$\begin{array}{r} 4.5 \\ 5 \\ \hline 22.5 \end{array}$$

22.5 Ans. = $22\frac{1}{2}$

STEAM SPACE OF A BOILER.

To find steam space of a horizontal boiler of any size.

RULE.

1. Multiply $\frac{1}{3}$ the area of the end of the boiler in inches by the length of the boiler in inches; the answer will be in cubic inches.

2. To reduce to cubic feet divide by 1728.

EXAMPLE.

How much steam space is there in a boiler 5 feet in diameter and 18 feet long ?

The area of 5 feet (per table) is 282704÷3 = 9423
The length of the boiler, 18 feet, made into inches = 216

		56538
		9423
		18846
		2035368

Now divide: 1728 { 12)2035368

12)169614

12)14134

$1.177\frac{10}{12}$th cubic ft. Ans.

NOTE.

These results are not absolutely accurate owing to discarding small fractions and not allowing for thickness of iron, but the calculations are sufficiently near to suit all practical purposes.

THE SAFETY VALVE.

The safety valve is a circular valve seated on the outside of the boiler and weighted to such an extent that when the pressure of the steam exceeds a certain point the valve is lifted and allows the steam to escape.

Safety valves can be loaded directly with weights, in which case they are called dead weight valves, or the load can be transmitted to the valve by a lever. An unauthorized addition of a few pounds to the weight of the former would make no appreciable addition to the blowing off pressure while a small addition to the weight at the end of the lever is multiplied several times at the valve.

In the case of locomotive and marine boilers the lever is weighted by means of a spring, the tension of which can be adjusted.

It may be defined, as also applying to all valves, that the *seat of the valve* is the fixed surface on which it rests or against which it presses, and *the face of a valve* is that part of the surface which comes in contact with the seat. The *spindle* is the small rod which projects upwards or downward from the middle of the valve, and so arranged that it causes the valve to raise and drop evenly upon its seat.

The effective pressure on the lever safety valve can be regulated within certain limits by sliding the weight along the arm and in the spring safety valve the pressure can be regulated by altering the tension of the spring.

Every boiler should be provided with two safety valves. The size of the opening into the boiler depends upon its steam producing qualities, the object to be attained being to reduce the pressure within the boiler to its safety point as quickly as possible.

Safety Valve Calculations.

This is a subject, while old, is ever new to the engineer, and the following rules are given in such a manner that any one who can add, subtract, divide and multiply and *read decimals* can

LEVER SAFETY VALVE.

soon acquire familiarity with the rules, and thus make them his own to use when he needs them, to adjust a safety valve or for other uses.

Reference is first made to the principles, rules and examples heretofore given relating to the lever (the safety valve is a lever of the third order) the rule of three, and to decimals. Next, in all problems it is well for the engineer to draw, roughly, if need be, a diagram of a safety valve somewhat after the form given in Fig. 111.

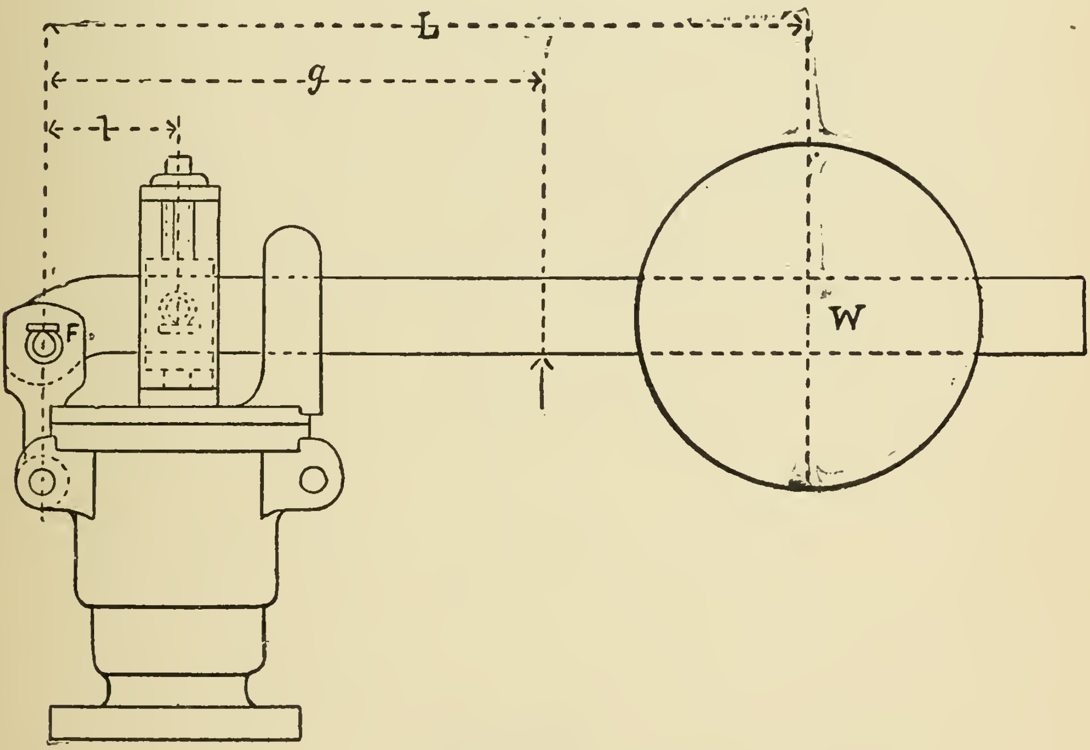


Fig. 111.

W denotes the weight on the lever in pounds; L, distance from center of weight to fulcrum in inches; *w*, weight of the lever itself in pounds; *g*, distance between center of gravity of lever and fulcrum in inches; *l*, the distance between center of valve and fulcrum in inches, and F the fulcrum.

In working out the problems the figures and dimensions as soon as known should be put upon the drawing so that the eye may assist in the calculations as they proceed from step to step.

LEVER SAFETY VALVE.

To find the weight of the valve, spindle, lever, etc., proceed as follows:

Take out the valve and spindle and weigh them and make a note of it, then put them back in place, connect the lever and drop it in place resting on the valve spindle, tie a string to the lever directly over the spindle, hook on the scales to the string and weigh the lever, to the weight of the lever add the weight of valve and spindle, or the weight may be found approximately by computation, by use of rules elsewhere given in this work under Mensuration, etc.

The following rules were recently issued by the United States board of supervising inspectors, on account of changes in the rules for granting licenses to engineers of steam vessels.

To find the weight required to load a given safety-valve to blow at any specified pressure.

1. Measure the diameter of the valve, if it is not known, and from this compute its area exposed to pressure.

2. Weigh the valve and its spindle. If it is not possible to do this, compute their weight from their dimensions as accurately as possible.

3. Weigh the lever, or compute its weight from its dimensions.

4. Ascertain the position of the centre of gravity of the lever by balancing it over a knife-edge, or some sharp-cornered article, and measuring the distance from the balancing point to the fulcrum.

5. Measure the distance from the center of the valve to the fulcrum.

6. Measure the distance from the fulcrum to the center of the weight.

Then compute the required weight as follows:

1. Multiply the pressure in pounds per square inch at which the valve is to be set by the area of the valve in square inches; set the product aside and designate it "quantity No. 1."

THE LEVER SAFETY VALVE.

2. Multiply the weight of the lever in pounds by the distance in inches of its center of gravity from the fulcrum; divide the product by the distance in inches from the center of the valve to the fulcrum, and add to the quotient the weight of the valve and spindle in pounds; set the sum aside and designate it "quantity No. 2."

3. Divide the distance in inches from the center of the valve to the fulcrum by the distance, also expressed in inches, from the center of the weight to the fulcrum; designate the quotient "quantity No. 3."

4. Subtract quantity No. 2 from No. 1, and multiply the difference by No. 3. The product will be the required weight in pounds.

To find the length of the lever, or distance from the fulcrum at which a given weight must be set to cause the valve to blow at any specified pressure.

The area of the valve in square inches, the weight of the valve, spindle and lever in pounds, the position of the center of gravity of the lever, and the distance from the center of the valve to the fulcrum, must be known, as in the first example.

Then compute the required length as follows:

1. Multiply the area of the valve in square inches by the pressure in pounds per square inch at which it is required to blow; set the product aside, and designate it "No. 1."

2. Multiply the weight of the lever in pounds by the distance in inches of its center of gravity from the fulcrum; divide the product by the distance in inches from the center of the valve to the fulcrum; add to the quotient the weight of the valve and spindle; set the sum aside, and designate it "No. 2."

3. Divide the distance in inches from the center of valve to fulcrum by the weight of the ball in pounds, and call the quotient "No. 3."

4. Subtract "No. 2" from "No. 1," and multiply the difference by "No. 3"; the product will express the distance in inches that the ball must be placed from the fulcrum to produce the required pressure.

THE LEVER SAFETY VALVE.

To find at what pressure a safety valve will commence to blow when the weight and its position on the lever are known.

The weight of valve, lever, position of centre of gravity of lever, etc., must be known as in both the preceding examples.

Then compute the pressure at which the valve will blow, as follows:

Multiply the weight of the lever by the distance of its center of gravity from the fulcrum; add to this product that obtained by multiplying the weight of the ball by its distance from the fulcrum; divide the sum of these two products by the distance from the center of the valve to the fulcrum, and add to the quotient so obtained the weight of the valve and spindle. Divide this sum by the area of the valve; the quotient will be the required blowing-off pressure in pounds per square inch.

EXAMPLE.

Suppose we have a safety valve, with a weight of 50 lbs. suspended 24 inches from the fulcrum; say the lever weighs 6 lbs., gravity center (balancing point) 15 inches from the fulcrum, weight of valve and spindle 2 lbs., and its center 4 inches from the fulcrum, and the diameter of the valve 2 inches, at what pressure will the valve open? Now then:—

Diameter of valve is 2 inches; its square is $2 \times 2 = 4$; its area is $0.7854 \times 4 = 3.1416$; the weight of the ball is 50 lbs., its distance from fulcrum is 24 inches, and $50 \times 24 = 1{,}200$; the weight of lever is 6 lbs., the center of gravity is 15 inches from the fulcrum, and $15 \times 6 = 90$; the weight of the valve is 2 lbs., and its distance is 4 inches from fulcrum, and $4 \times 2 = 8$; the area of the valve is 3.1416, and its center is 4 inches from fulcrum, then $4 \times 3.1416 = 12.5664$, and $1200 + 90 + 8 = 1298$, and 1298 divided by $12.5664 = 103.03$ lbs., or the pressure at which the valve will open.

NOTE.

The "moment" or leverage of the steam is the total pressure *acting upwards*, multiplied by the distance in inches from the pivot to the valve-stem. The moment or leverage of the ball *acting downwards* is the total weight of the ball multiplied by the distance in inches from the pivot to the center support of the ball.

When therefore the moment of the steam, which acts upwards, exceeds both the dead weight of the lever and valve, and also the moment of the ball holding the valve down, *then the valve rises and steam escapes.*

SIMPLE RULES RELATING TO THE SAFETY VALVE.

Now the weight of the lever and valve is of so little importance in the matter of pressure, that working engineers usually omit it from their calculations, which may wisely be done, as the simplest rules are generally the best for engineers.

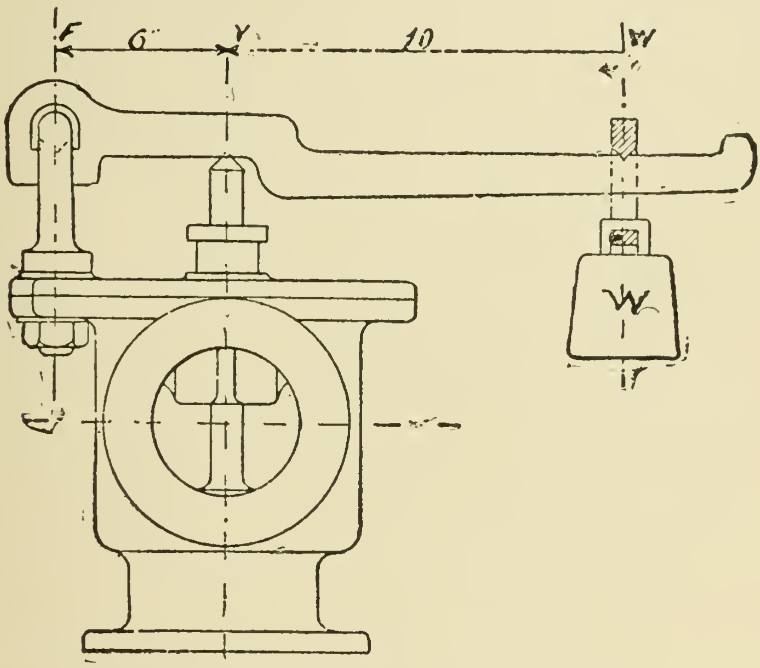


Fig. 112.

In the third form of the lever the power is at one end, the fulcrum at the other, and the resistance to be overcome somewhere between them.

Rule 1. Multiply the length of the lever by the power and divide the product by the short arm; the quotient is the resistance overcome.

Example.

The length of the lever is 16 inches, with a power equal to 30 lbs., acting at one end; what resistance will this power overcome, the short arm being 6 inches ?

The length of the lever,	16 inches.
Multiplied by the power,	30 lbs.
Divided by the short arm, 6	480
Answer,	80 lbs. resistance.

THE LEVER SAFETY VALVE.

The resistance, the short arm, and the power given, to find the length of the lever.

Rule 2. Multiply the resistance by the short arm, and divide the product by the power; the quotient is the length of the lever.

Example.

The short arm is one inch, the resistance to be overcome is 12 lbs., the power to be applied is 2 lbs.; required the length of the lever.

The resistance,	12 lbs.
Multiplied by short arm,	1 inch.
Divided by the power, 2 lbs.)	12
Answer	6 inches length of lever.

The resistance, the short arm, and the length of the lever to find the power.

Rule 3. Multiply the resistance by the short arm, and divide the product by the length of the lever; the quotient is the power required.

Example.

If you wish to weight the safety valve of a steam engine, 40 lbs., with a lever 10 inches long, what power must you apply, allowing the short arm to be two inches.

The resistance,	40 lbs.
Multiplied by the short arm,	2 inches.
Divided by the lever, 10)	80
Answer,	8 lbs. the power.

The power, length of the lever, and the resistance given, to find the short arm.

Rule 4. Multiply the length of the lever by the power, and divide the product by the resistance; the quotient is the length of the short arm.

THE LEVER SAFETY VALVE.

Example.

The length of the lever is 5 inches, with a power equal to 3 lbs. applied; the resistance to be overcome is 20 lbs.; required the length of the short arm.

Length of lever,	5 inches.
Multiplied by the power,	3 lbs.
Divided by resistance, 20 lbs.)	15

Answer, .75 inches, the length of short arm.

These rules can be learned easily, and will be found very useful for engineers. They comprise all the problems incident to setting a lever safety valve.

Other Rules Relating to the Safety Valve.

Rule for finding the pressure to raise the valve and ball.

Divide the lever (in inches) by the short arm (in inches), divide the weight of ball by the area of valve and multiply the two quotients together.

Example.

Area of valve $12\frac{1}{2}$ inches, length of lever 25 inches, length of short arm 2 inches, weight of ball 75 pounds, $75 \div 12\frac{1}{2} = 6$, $25 \div 2 = 12\frac{1}{2} \times 6 = 75$ pounds pressure per square inch to raise the lever.

Rule to find where to place the weight on the lever to allow the valve to open at a desired pressure.

Multiply the weight of lever by the horizontal distance of its center of gravity from fulcrum. (2) The weight of valve by distance from fulcrum. (3) Area of valve by steam pressure per square inch and by distance from fulcrum. Add together the first two products, subtract their sum from the third, and divide the difference by the weight of the ball.

To Test Correctness of Calculations.

The proper way to set the weight on a safety valve lever to test the figuring is to raise steam on the boiler to the pressure desired, as marked *on a correct steam gauge,* and adjust the weight so that the valve just "simmers." When a safety valve weight is set by "calculation," the valve never blows off at the proper pressure, being often some pounds out of truth, owing to friction of the parts.

CHIMNEYS.

A chimney promotes a flow of air through a furnace, because the hot air contained in the chimney is lighter than the surrounding atmosphere, which consequently endeavors to force its way into the chimney from below in order to restore the balance of pressure. The only way into the chimney is through the fire-bars and furnace, and in passing through these the air maintains the combustion, and at the same time becoming itself heated, makes the action of the chimney continuous.

In estimating the action of a chimney of a given size in producing a draught, the density, temperature, and volume of the products of combustion must be considered.

The draught increases directly as the area and as the square root of the height. If either is assumed or determined upon the other may be found from the formulæ,

$$\frac{120 \times \text{grate surface in sq. ft.}}{\sqrt{\text{height in feet}}} = \text{area in sq. inches.}$$

Example.

What should be the size (area in sq. inches) of a 100 feet chimney with grates $5\frac{1}{2}$ feet deep by 10 feet wide. Now then:

$$120 \times 5\tfrac{1}{2} \times 10 = 6{,}600$$

divide by 10 (the sq. root of 100) 660 sq. in.

660 sq. in. = 26 in. square, nearly.

To find the number of cubic feet of air in a chimney.

Rule.

Multiply the length in feet by area in feet or decimals of a foot and the answer will be the contents of air in cubic feet.

Example.

How much air will be contained in a chimney 90 feet high and 48 in. square flue?

$4 \times 4 = 16$ area in feet $\times 90 = 1440$ cubic feet Ans.

Example.

If it be an iron chimney 90 feet high and 24 inches in diameter?—then

Area 24 in. (per table) = 452.4 sq. in. = 3.141 sq. feet.
90

$282\frac{7}{10}$ths Ans.

THE STEAM ENGINE.

A steam engine may be defined as an apparatus for doing work by means of heat applied to water. The complete study of the steam engine involves an acquaintance with the sciences of pure and applied mechanics; of chemistry; of heat; as well as a knowledge of the theory of construction, and the strength of materials.

The steam engine as it exists to-day is the growth of two centuries of experiments and practical application of the mechanism to all sorts of work; the history of its successive steps of advancement, while full of interest, is too voluminous for this work.

In the future as well as in the past, questions relating to the influence on steam economy, of speed in the engine, of pressure and ratio of expansion of steam, or of superheating, must in the main, be settled by an appeal to experiment,—experiment guided and interpreted by the great underlying principles of thermo-dynamics and the theory of steam, outlined in preceding pages of this work.

In the steam engine, heat accomplishes work only by being let down from *a higher* to *a lower temperature.* A certain amount of *heat disappears* when changed into *work.*

Classification and Varieties of Engines.

The stationary engine is the most perfect form of the steam engine. In this type, economy of steam is carried to its highest degree; in the locomotive, the steam fire engine and other portable engines, and still more so, in the steam hammer, etc., it is impossible to apply many of those means by which steam, and consequently fuel, is economized.

Stationary engines are of two kinds, called respectively *low pressure* and *high pressure* engines. These terms do not refer to the initial pressure of steam in the cylinder but to *its final pressure.* The terms are, however, inappropriate, since they do not express the distinctive difference between the two varieties of engine. This difference may be briefly expressed as follows: The high pressure engine discharges its steam directly into the atmosphere; and consequently the steam on leaving the cylinder must possess an elastic force equal to, at least, 15 lbs. to the square inch. The whole of this force is of course wasted.

THE STEAM ENGINE.

The low pressure engine condenses its steam and discharges it as water; and consequently the pressure of the steam on leaving the cylinder may be much less than that of the atmosphere. Thus a large proportion of the steam wasted by the high pressure engine is utilized. The terms CONDENSING and NON-CONDENSING ENGINES are therefore much more appropriate than low and high pressure.

The difference in effect between the condensing and non-condensing engines, with equal pressure of steam and expansion, is solely that the condensing engine has the advantage of the effect produced by the vacuum or amount of atmospheric atmosphere removed, which varies according to the perfection of the machinery, from 10 to 13 lbs. per square inch; some of the waste heat however in the non-condensing engine is utilized by leading the exhaust steam through a heater.

SIMPLE AND COMPOUND ENGINES.

There is another classification of engines into *simple* and *compound*, the latter being those in which steam is used twice by being exhausted from one cylinder into another, while the former applies to all engines which use steam only once, whether they are double engines and have double sets of valve gear or not. Locomotives, steam fire engines and stationary engines which take their steam directly from the boiler and exhaust it into the atmosphere should be termed simple engines, regardless of the number of cylinders; hence the term single engine sometimes used is incorrect.

In the compound engine the steam is first admitted into the small or high pressure cylinder until the piston has moved through a certain distance, when the valve is so regulated that the communication with the boiler is cut off, the remainder of the space to be passed through by the piston being performed by the expansion of the steam, which, having done its work, escapes to the second, or condensing cylinder, where it does a proportionate amount of work and out of which it escapes into the condenser.

The receiver is a chamber between the cylinders of compound engines into which the steam from the high pressure cylinder escapes and from which it is admitted to the low pressure cylinder.

MARINE ENGINES.

A marine engine properly speaking is an engine designed to occupy a certain space in a vessel and to furnish a certain amount of power; hence the marine engine may be either condensing or non-condensing, vertical, horizontal or inclined, simple or compound. The most desirable class of marine engines are those that develop the greatest amount of power with a given area of piston and steam pressure, and that occupy *the least space.*

The pressure now commonly used at sea with improved types of steam engines may be said to vary from about 80 lbs. to 160 lbs. per square inch, and the consumption of coal from $1\frac{1}{2}$ lbs. to 2 lbs. per indicated horse power per hour.

To withstand such pressure, the shell plating of such boiler is made of a thickness of 1 inch or more; the end plates are usually about 14 per cent. thicker.

Generally the total heating surface in marine boilers is from 25 to 28 times the grate area and the tube surface is about $\frac{5}{6}$ths of this.

The tubes are about 6 feet long and 3 inches in diameter.

The heating surface is sometimes stated as varying from 16 to 20 square feet per nominal horse power, the indicated horse power being from 5 to 6 times the nominal horse power; or the heating surface may be stated as about 3 square feet per indicated horse power, the grate area being about $\frac{1}{26}$th of the heating surface, or from $\frac{1}{8}$th to $\frac{1}{10}$th of a square foot per indicated horse power.

The Rotary Engine.

Each of the types of engines named are still further divided into numerous varieties, often blending into each other and combining the essential principles of two or more systems, but all acting upon the same general law of pressure and expansion combined with the velocity of the piston regulated by the engine governor. From this general statement must be excluded the rotary engine, which works upon the sole property of the velocity of escaping steam. From the days of James Watt this system has been an experiment and never reduced to a working basis.

THE MECHANISM OF STEAM ENGINES.

The variety of form and arrangement of the parts of steam engines is so great that an extended knowledge of the mechanism of its various parts can only be gained by close observation of numerous engines, or working drawings.

The Cylinder.

The cylinder of a steam engine is the closed vessel in which the piston works backwards and forwards. It is so called because the interior is cylindrical in shape, though the form of the exterior is complicated by sundry additions. It is made of cast iron, the interior being carefully bored so as to form a smooth round surface for the passage of the piston. It consists

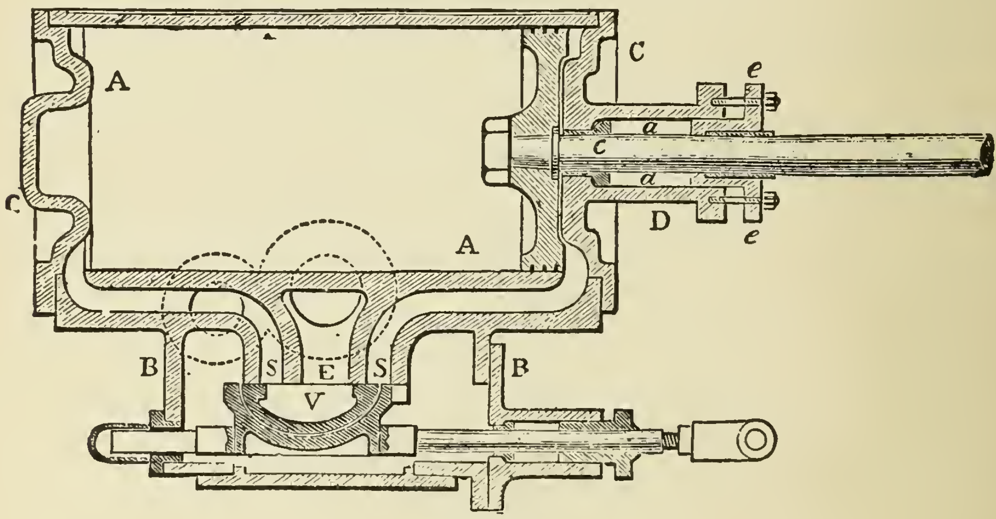


Fig. 113.

of the following parts. The cylindrical body AA, which is cast in one piece;—the steam chest BB, in the thicknesses of which are formed the two steam passages SS and the exhaust passage E;—the two covers CC, which are flanged, and which are attached to the body of the cylinder by means of studs and nuts. The cover through which the piston rod works is provided with a stuffing box D and gland *e*, to prevent the steam escaping round the rod. This object is accomplished in the following manner. The space *aa* between the rod and the inner cylindrical surface of the stuffing box is filled with plaited hemp saturated with tallow, or with one of the numerous patent packings now procurable. The gun-metal gland *e*, through which the piston rod passes, is forced up against the packing by means of the two nuts and screwed studs shown in the drawing. The

THE STEAM CYLINDER.

result is that the packing can be squeezed with any desired degree of tightness round the piston rod, and can thus prevent the escape of steam. The opening by which the piston rod passes through the substance of the cover is lined with a gun-metal bush, *c*. In many engines there is a stuffing box on the other cylinder cover, through which a prolongation of the piston rod works. The object of this arrangement is to prevent the piston bearing unequally on the lower side of the cylinder. It is also adopted in the case of condensing engines, when the plunger of the air-pump is driven direct from the piston. It will be noticed that the interior faces of the covers are cast so as to fit into the corresponding faces of the piston. The reason of this arrangement is, if the cover faces were not shaped correspondingly, there would be at each end of the stroke a large space to be filled with steam before the piston began to move, which steam would do no work till expansion began.

Owing to 1, the invisibility of steam, 2 the complications of the parts, and 3, inattention and thoughtlessness, very many engineers in charge, to say nothing of their assistants, do not know the method of entrance and exit of steam from the cylinders of their engines, and yet this is one of *the first things* to be learned.

To find cubic inches capacity of a steam cylinder.

RULE.

Multiply the length in inches by the area in inches; the answer is in cubic inches.

EXAMPLE.

What is the total capacity of a $15\frac{1}{2}$x30 inch steam cylinder?

$$
\begin{array}{rr}
15\tfrac{1}{2}'' \text{ Area} = & 188.6919 \text{ (See Table page 116)} \\
 & 30 \\
\hline
 & 12)5660.7570 \\
\hline
1728 \left\{ \right. & 12)47.17297 \\
\hline
 & 12)39.3108 \\
\hline
 & 3.2759 = \text{Ans. in cubic feet.}
\end{array}
$$

THE STEAM CYLINDER.

To find the diameter of a cylinder for any given horse power.

RULE.

Multiply horse power desired by 33,000, divide by piston speed in feet per minute and again by mean pressure in cylinder and the result will be the area of piston, which divided by .7854 will give the square of the diameter.

EXAMPLE.

75 horse power is desired from an engine running 120 turns per minute with cylinder 15 inches long, mean pressure 80 lbs.

```
                          75
                      33,000
                      ------
                      225000
                     225
                     -------
      piston feet 300)24750.00
                     --------
           pressure 80)8250.00
                      ---------
               .7854)1031.2500(131.3 = sq. of diam.
The square root is     7854
   131.3(11.4½ nearly  -----
   1                   24585
   ---                 23562
21) 31                 -----
    21                  10230
   ---                   7854
224)1030                -----
     896                 23760
    ---                  23562
```

Answer 11½ inches nearly.

DEFINITIONS.

1. MASS. This word denotes the quantity of matter contained in a body. 2. WEIGHT is the attraction which the earth exercises on a mass. 3. VELOCITY is the speed at which a body moves; i. e. the space which it traverses in a given time. MOTION. This word is employed in mathematics to denote movement on the part of a body and also takes account of the mass of the body moved—hence the terms *momentum* and *moment.* FORCE is any cause which produces the motion in a body.

THE STEAM CYLINDER.

To find the area of a piston, either water or steam.

RULE.

Square the diameter and multiply by .7854.

EXAMPLE.

What is the area of a piston $4\frac{1}{2}$ inches in diameter?

$$
\begin{array}{r}
4\tfrac{1}{2} \text{ squared} = 20.25 \\
.7854 \\
\hline
8100 \\
10125 \\
16200 \\
14175 \\
\hline
15.904350
\end{array}
\quad \text{Ans. } 15\tfrac{9}{10}\text{ths.}
$$

NOTE.

The use of the Tables of Diameters, etc., pages 114–126 may be illustrated in this problem. On page 114 the diameter 4.5 being given, the area is carried out 15.9043 = the above. In the next line 14.1372=*the circumference* of the same $4\frac{1}{2}$ inches.

PISTONS.

The piston is the metallic disc which accurately fits the bore of the cylinder, and which receives and transmits the pressure of the steam to the other moving parts of the engine.

The forms of pistons are innumerable, and depend altogether upon the purpose for which the engine is intended, and the size of the cylinder, which in different classes of engines varies from a few inches to over 9 feet in diameter. The chief points to attend to in the design of a piston are the following: it should be strong enough to withstand the pressure of the steam, and to hold the end of the piston rod immovably;—the packing round the circumference should be steam-tight, without causing undue friction, and not liable to get out of order;—the width of the circumferential portion should be such that the pressure per square inch—due, in the case of horizontal engines, to the weight of the piston—be not sufficient to cause undue wear of the inner surface of the cylinder.

THE STEAM CYLINDER.

The importance of keeping the surface of the cylinder true, and of keeping the piston in steam-tight contact with it, will be readily recognized when it is borne in mind that a leakage of steam past the piston means that during the whole time the engine is at work there is an open passage from the boiler to the condenser or outer air, through which steam is continuously escaping without doing any work.

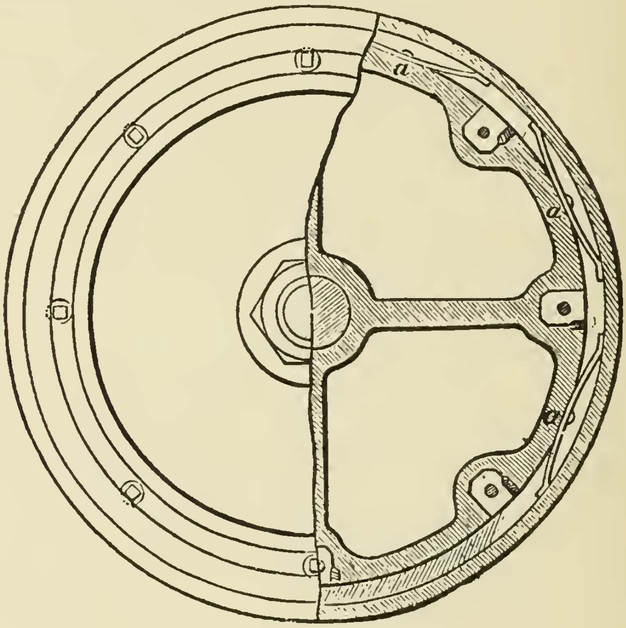


Fig. 114.

In the case of many engines, the packing ring is usually pressed against the barrel of the cylinder by means of a series of independent adjustable springs contained within the body of the piston. The spring ring, which is of considerable depth, is held up against the sides of the cylinder by a series of steel springs, *a a a*, Fig. 114. The joint in the ring is formed to prevent leakage. An oblique slot is taken out of the ring. A plate, fitted with a tongue piece, is fastened behind the slot, and the tongue piece, which slides in a groove, allows the ring to expand and contract, and at the same time makes a steam-tight joint. The ring, with its springs, is covered by a flat circular piece of iron called the junk ring, which is shown in plan on one half of Fig. 114. This enables the springs to be got at easily for examination and repair. The junk ring is attached to the body of the piston by bolts which work into brass nuts embedded in the metal of the piston. When the threads work loose, the nuts can be easily replaced.

Piston Rods.

The piston rod is the member which transmits the motion imparted to the piston to the mechanism outside the cylinder It consists of a truly cylindrical bar of wrought iron or steel, one end of which is fastened securely into the piston. The rod passes through the cylinder cover by means of a steam-tight stuffing box, as shown in Fig. 113, and the outer end terminates in the cross-head. There are various methods in vogue of fastening the rod into the body of the piston. Sometimes the end of the rod is turned cylindrical and a hole bored in the piston slightly less in diameter than the rod. The piston is then heated which causes it to expand, when the rod can be inserted. After cooling, the piston contracts, and holds the rod firmly in its place. In the majority of cases the end of the rod is turned conical as in Fig. 115, with a screw thread on the

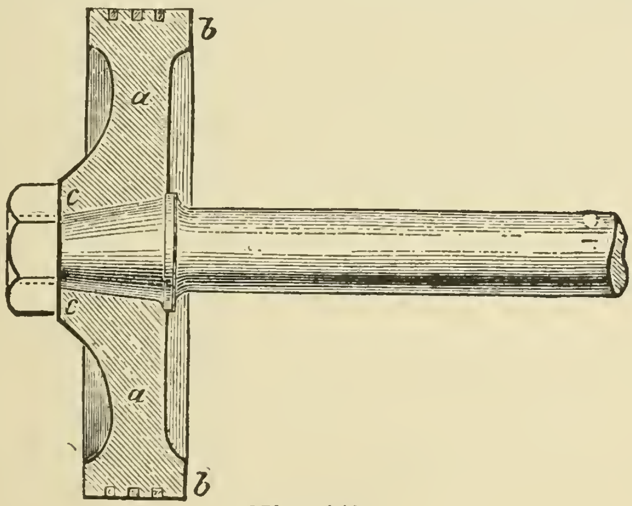


Fig. 115.

extreme end, by means of which, together with a nut, the rod is firmly embedded in a conical recess bored in the piston.

The strength of piston rods has to be fixed with special reference to the fact that they are subject to alternating strains. When the piston is making the stroke towards the crank shaft the rod is in compression, and when making the return stroke the rod is in tension. *The maximum stress per square inch of cross section at any part of the stroke is equal to the total pressure of the steam on the piston divided by the area of the rod.* It is usual in designing pieces of machinery which have to bear alternating strains of tension and compression to make them much stronger than would be necessary were the strain always of one sort.

Connecting Rods and Cranks.

The connecting rod is the link which enables the back and forth motion of the piston to be converted into the circular motion of the crank pin. It is a link or rod of metal so formed at the two ends that it can be jointed to both the cross-head and the crank-pin.

Fig. 116 represents a connecting rod, and its various details as used in a stationary engine. The parts surrounding the

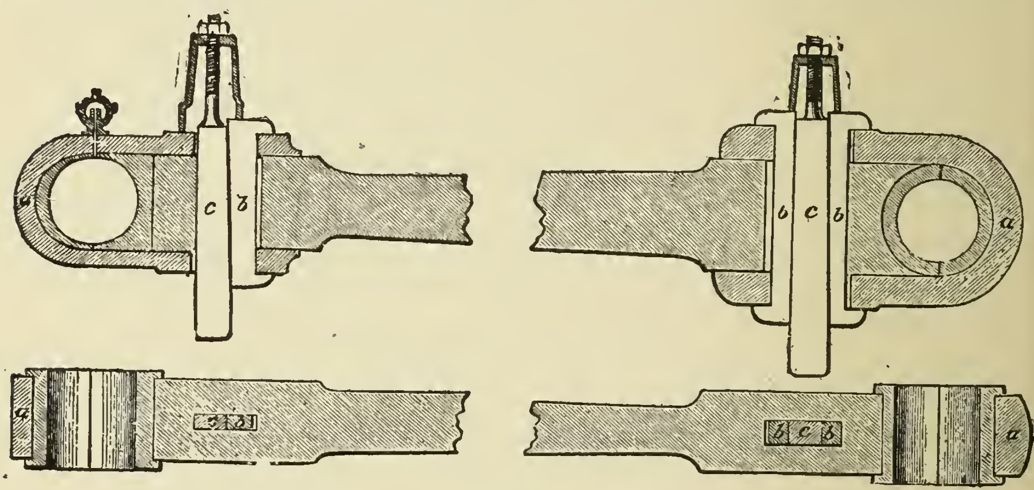


Fig. 116.

crank and cross-head pins are made of gun metal, brass, or white metal so as to diminish friction. They are made in separate pieces, called steps, and are held in place by the straps *aa*, which are fastened to the rods by means of the gibs *bb*, and the cotters *cc*. When the brasses wear they can be tightened up by driving in or screwing up the cotter, which draws up the strap, and thus tends to shorten the rod.

Cross-heads and Slide-bars.

The outer end of the piston rod is attached to the cross-head, or motion block, which serves the double purpose of forming the means of connection between the piston rod and the connecting rod, and of guiding the piston rod so as to keep it straight and in the line of the axis of the cylinder, in spite of the bending moment due to the angular position of the connecting rod.

The cross-head generally consists of three principal parts, viz. (1) the body which often contains a conical hole into which the coned end of the piston rod is fastened; (2) the part by

CROSS-HEADS AND SIDE-BARS.

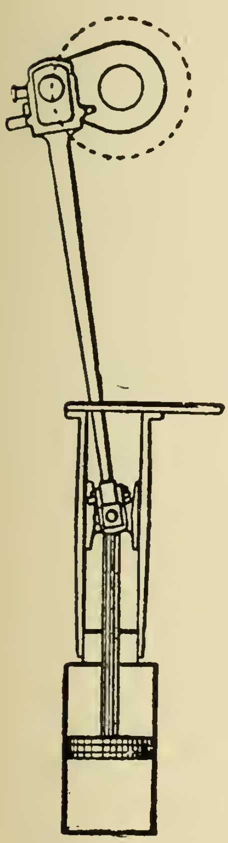


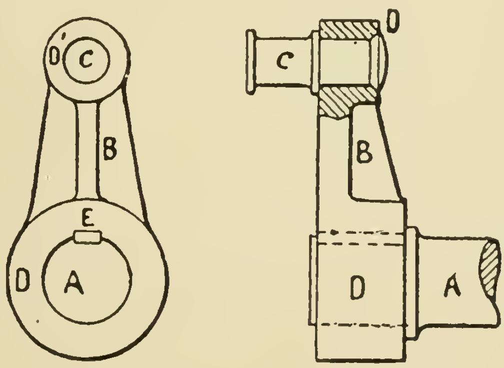
Fig. 117.

which the joint with the connecting rod is effected; and (3) the guides or motion blocks which travel between fixed bars parallel to the axis of the cylinder, called slide-bars, and which prevent the end of the piston rod from being deflected as the connecting rod assumes an angular position. Fig. 117 shows a piston rod, cross-head, slide-bars, and connecting rod in position.

Cranks and Eccentrics.

The crank is simply a lever of the first order, either attached to, or forged in one piece with the main shaft of the engine. By means of it, the reciprocating motion of the piston is finally converted into circular motion.

Fig. 118 shows two views of one of the simplest forms of crank; A is the crank shaft, *c* the crank pin. The distance from the center of A to the center of *c* is the length of the



A = crank shaft; C = crank pin; B = web;
D, D' = bosses; E = key

Fig. 118.

crank arm, which is, of course, equal to *half the stroke of the piston*. *B* is the web of the crank, *D, D'* the bosses. Cranks of this form are generally of cast iron, and are attached to the main shaft by means of a key *E*. The fastening of a movable

CRANKS AND ECCENTRICS.

crank on a shaft requires the greatest care, because all the stresses thrown on the crank are liable to reversion during each stroke, especially in the case of a slow-running engine working with a considerable cushion of steam. Very severe reversals of pressure also occur if water is allowed to accumulate in the cylinder. In such cases the piston is brought up dead before the end of the stroke is reached, while the crank endeavors to pull on, thus throwing a heavy strain on all the connections, and amongst others on the key. Cranks of this type in addition to being keyed are generally shrunk on to the shaft, or else are forced on by hydraulic pressure.

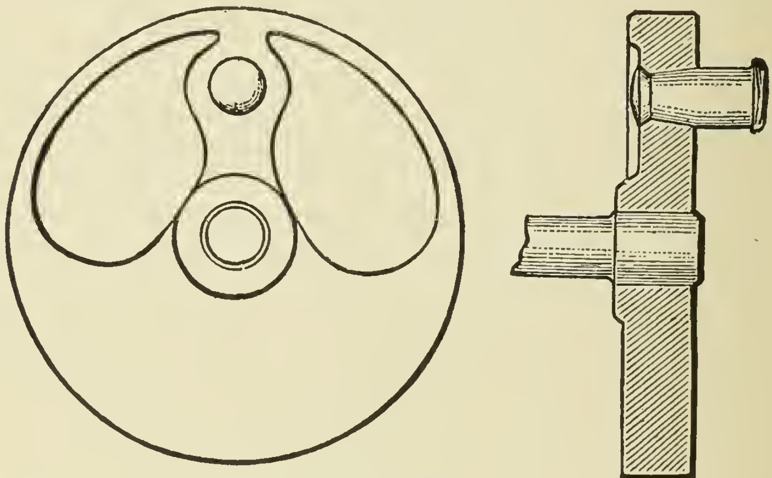


Fig. 119.

Fig. 119 shows an end elevation and cross-section of another form of cast-iron crank, called a disc crank. It is, as its name implies, formed of a disc of cast iron, attached to the shaft by the methods just described, and provided with a wrought iron or steel crank-pin. The portion of the disc opposite to the pin is usually much thicker and heavier than the remainder of the disc, this extra weight being used as a balance to the weights of the reciprocating parts.

The crank-pin is the portion of the engine which receives the greatest stress, and special care must therefore be given to its design and lubrication. See Cut 122.

THE ECCENTRIC.

There is a species of crank called the *eccentric,* in which the pin is so large that it completely envelopes the shaft. Such a crank is shown at Fig. 121 (B). The distance *ac* is the same

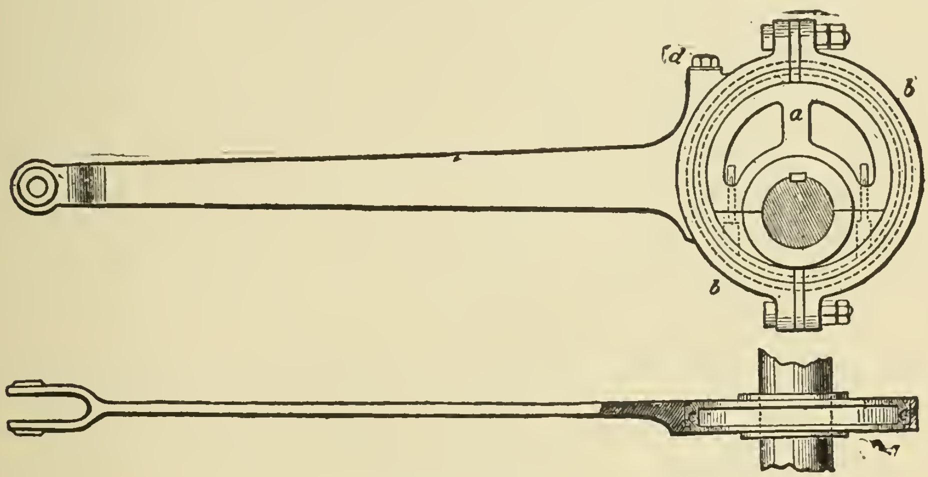


Fig. 120.

as at A, but the pin has assumed the diameter of the outer circle *de.* A crank is used for converting the forward and backward motion of the piston into circular motion; the eccentric, on the other hand, is usually employed for converting the circular motion of the main shaft back into rectilinear motion. With an eccentric, the distance *ac,* Fig. 121 (B), corresponding to the length of the crank arm, may be as small as we please. The most frequent uses to which eccentrics are put are to drive slide valves and pumps, the travels of which are very much less than that of the piston.

The distance *ac,* from the center of the shaft to the center of the eccentric, is called the half-throw or the eccentric radius of the eccentric, and *is equal in length to the half-travel of the part to be driven, such as the pump plunger, or slide-valve.*

Fig. 120 represents side elevation and a longitudinal section of an eccentric and rod as used for driving an ordinary slide-valve. The circular portion *a,* which corresponds to the crank pin, is called the sheave of the eccentric. It is usually made of cast iron in two halves, which are bolted together round the shaft, and keyed on in the proper position. The piece *bb* is called the strap, and corresponds with the big end of a connect-

THE ECCENTRIC.

ing rod. The strap is made of cast iron, or steel, according to circumstances, and is lined with a brass or white metal ring, where it comes in contact with the sheave. This ring is grooved, as shown in the section at *cc*, so as to prevent it from getting off the sheave. The strap is made in two halves bolted together so that it can be readily put on, or taken off the sheaf.

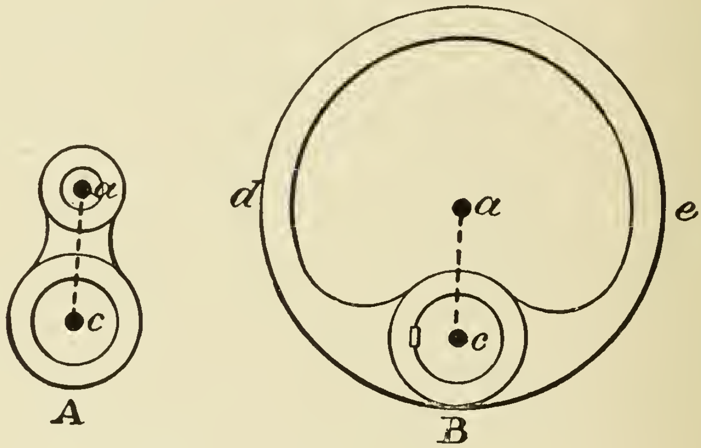


Fig. 121.

The ring around the eccentric is called *the eccentric strap.*

The rod connecting the strap to the part to be put in motion is the *eccentric rod.*

The hook at the end of the rod, by which it is connected with the rock-shaft of the valve motion is *the eccentric hook, or gab.*

The whole apparatus is the eccentric-gear.

Note.

Reciprocating motion is motion alternately up and down or backwards and forwards like the action of a piston rod.

Crank Shafts.

The shaft of the engine is the part which receives circular motion from the crank and the reciprocating pieces. By means of the shaft, the power generated in the cylinder is transmitted to the machinery intended to be driven. Thus, in the case of factory engines, a pulley is usually keyed on to the shaft, and by means of a leather belt passing over this pulley,

CRANK SHAFTS.

the various lines of shafting throughout the building are driven. In locomotive engines, the driving wheels are keyed direct on to the shaft, and rotate with it, and in the case of marine engines, the paddles or screw are also attached directly upon the shaft or its prolongation.

Shafts are subjected to a variety of strains. In the first place, they undergo bending stresses from any weights which may be attached to them, the most considerable of which is that of the fly-wheel, acting vertically downwards. Also the pull of the driving belt causes a bending stress, which acts in the line joining the driving and the driven shaft. The most important stresses, however, are due to the direct thrust and pull of the connecting rod, or rods, which, when at their maximum, act in the line of the axes of the cylinders.

JOURNALS.

The part of the shaft which is supported by the bearing is called the journal. The usual form of the journal of an engine crank is shown in Fig. 122. The part which runs in the bearings is turned so as to be truly cylindrical. The end play of the shaft is limited by the two raised collars. The length of the journal, or the distance between the inner faces of the collars, relatively to the diameter depends principally upon the number of revolutions which the shaft has to make per minute. For slow-running engines the length is sometimes equal to the diameter, whereas in cases of high speed it may be as much as from two to three times the diameter of the journal.

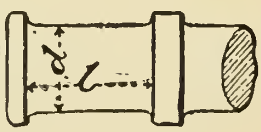


Fig. 122.

Great care must be taken in designing journals not to pass abruptly from one section of the metal to another. All such differences should be gradually rounded off as shown in Fig. 122.

The strains to which the journals of crank shafts are subjected are due to the combined action of the twisting forces and the transverse loads.

Shaft Bearings and Pedestals.

The bearing usually consists of brass steps supported by a cast-iron pedestal or plummer block. Fig. 123 shows three

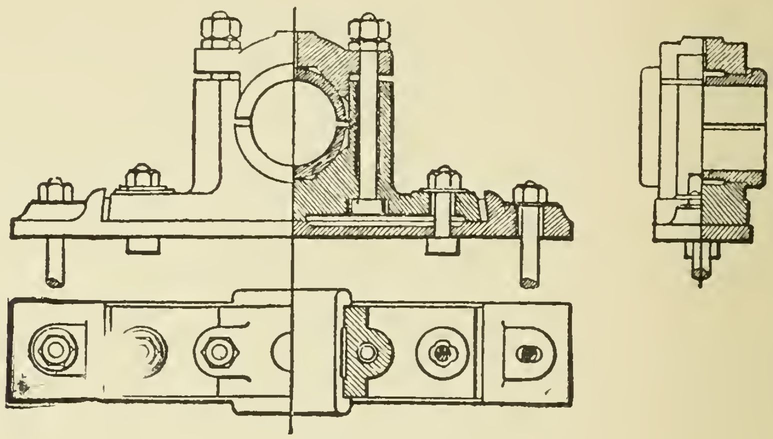


Fig. 123.

views in half elevation and half section of a common form of pedestal which is used with a masonry foundation. It consists of a wall plate which is bolted to the foundation and on which is fixed the pedestal proper. The nature of the arrangement and the means by which the steps are adjusted and secured are sufficiently explained by the drawing.

In most stationary engines one or both of the pedestals are attached to the cast-iron framework as shown in Fig. 124,

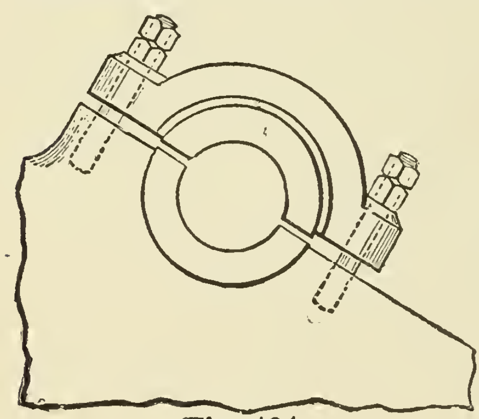


Fig. 124.

which represents the principal pedestal of a horizontal engine. In this case the steps are not divided horizontally, but in an oblique plane, so that the direction of the resultant force of the pull or thrust in the connecting rod and of the other forces which act on the shaft, may pass through the solid metal of the step and not through the junction between the steps.

In the case of locomotives the bearings are not fixed, but are free to slide up and down in a vertical plane, within the limits allowed by the springs. These bearings are called axle boxes. The whole weight of the engine is transmitted through them to the journals by means of the springs.

Governors.

If, during the working of a steam engine, the load were wholly or partially removed while the supply of steam to the cylinder remained undiminished, the engine would commence to race. If, on the contrary, the load were increased, the speed of the engine would be reduced below the proper rate. To prevent such variations in the speed, a contrivance called a governor is made use of which acts upon the steam supply in one of two ways; viz., either by partially closing or opening the throttle valve which regulates the flow of steam from the boiler; or else, by acting directly on the valve gear in such a way as to vary the point in the stroke where the steam is cut off, and thus alter the rate of expansion.

The most common form of governor was invented by Watt. It consists (see Fig. 125) of two heavy metal balls A, D, attached to two inclined arms, which latter are jointed at the point E, to the central vertical spindle. The latter is connected by gearing with the main shaft of the engine so as to revolve at a rate strictly proportional to that of the shaft. The effect of rotation is that the balls tend to fly away from the vertical spindle and, being controlled by the arms, they can only rise and fall in arcs of circles about the center E. Supposing that the velocity of rotation were increased beyond the normal rate, the balls would fly out and occupy some new position D′, at the same time lifting the collar H which slides on the central spindle and which is attached by the links L and K and to the ball arms M and N. Into the collar H gears the forked end of a bell crank lever which is connected by a link with the throttle valve. When H is lifted the link acts upon the throttle valve, partly closing it, and reducing the supply of steam; on the other hand when the balls fall, H falls also and the throttle valve is opened.

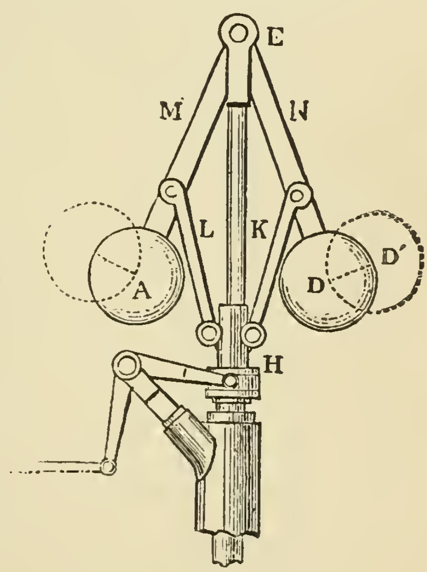


Fig. 125.

GOVERNORS.

Many advantages are found to attend the use of high-speed governors. They are more sensitive to alterations in speed, the parts may be made lighter and move with less friction. In order, however, to prevent the balls from flying out too far, in consequence of the increased speed of rotation, a weight, or else a spring is so arranged as to act on the ball arms in such a manner as to develope a radial force in the contrary direction to the line of action of the centrifugal force. Fig. 126 shows a loaded high-speed governor. Each ball is attached to two sets of links. The weight is arranged to slide on the central spindle, and presses directly upon the lower pair of ball links.

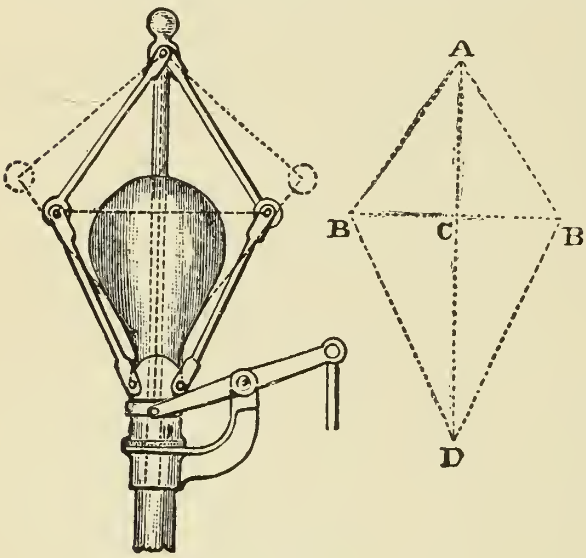


Fig. 126.

The forms of governors are so numerous that it has been impossible here to do more than explain the principles upon which they act.

Locomotive engines are never fitted with governors, but in marine engines they are very necessary, as racing may ensue whenever the propeller is partially out of water, or whenever the propeller or crank shaft may give way. On account of the motion on board ship, the forms of governors used on land engines could not be employed for marine purposes. Marine governors are of two principal sorts, viz. those that are actuated by variations in the water pressure at the stern of the ship, and those which depend for their motion on variations in the velocity of the engine. The former class only provide for cases due to the incomplete immersion of the propeller, but the latter will guard against every contingency. In consequence of the great size of the throttle valves and expansion gear of marine engines, an ordinary governor cannot conveniently be employed to act directly on the controlling parts; hence, in this class of engines, what are called steam governors are now generally employed.

GOVERNORS.

The governor proper is arranged to move the slide valve of a small steam cylinder, which, in its turn, actuates the throttle valve.

Fly-Wheels.

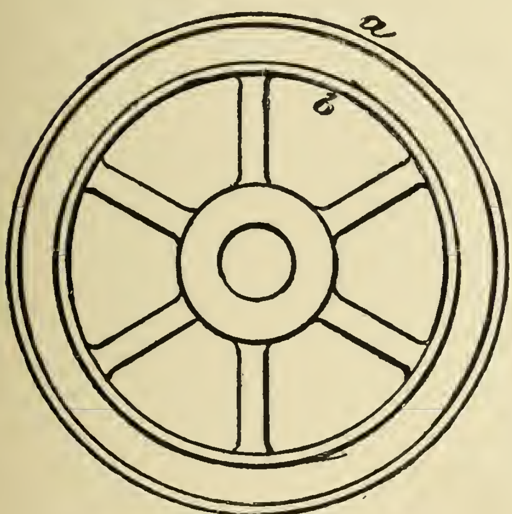


Fig. 127.

The fly-wheel is a wheel having a heavy rim. It is generally keyed to the crank axle of the engine, and is used for modifying the effects of any irregularity either in the driving power or in the resistance to be overcome. When, for instance, the driving power is in excess of the resistance to be overcome, the surplus is expended in increasing the velocity of the fly-wheel; and, *vice versâ,* when the resistance is in excess of the driving power, the energy stored up in the fly-wheel is expended in helping to overcome the resistance, during which operation its velocity is lowered.

The greater portion of the mass of a fly-wheel is concentrated in its rim, and when revolving, every particle of the rim is under the action of centrifugal force, and tends to fly away radially from the center; hence the rim, when in a state of revolution, resembles the condition of a ring put in a state of tension by a force *from within acting outwards.* The tension developed in the rim is opposed by the tensile strength of the metal of which it is formed, and should the former exceed the latter the rim will inevitably burst asunder, just as a boiler would burst if the steam pressure were too great for the strength of the shell plates.

ENGINE COUNTERS.

The following representation (Fig. 128) shows one form of an engine counter. It, or some other form of a counter, is used upon nearly all marine engines and very many land engines.

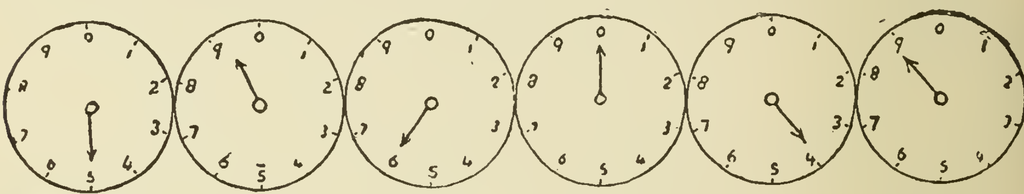


Fig. 128.

The operation of the device is simple and accurate. Each revolution of the engine moves the cogs of the right hand dial one notch, and upon the 10th stroke of the engine, it moves the pointer on the second dial to the figure one—all the dials at the beginning being placed at the zero. When the pointer on the second dial has completed nine and passes to the zero then at the same instant, the third dial registers one, indicating that the engine has completed 1,000 revolutions.

Whatever number of dials (or wheels) there may be, the right hand always records 10, the next to the left 100, the 3rd, 1,000; the 4th, 10,000; the 5th, 100,000; and the 6th, 1,000,000. Hence, the above having 6 dials, can register 1,000,000 revolutions.

What the pointers point at in the above, beginning at the left, and reading towards the right; 5, 9, 6, 0, 4, and 9 is 596049 revolutions.

Fig. 129 is the form now generally used; it has 7 dials, and is read from left to right, 9879460. From zero to zero will be **10,000,000.**

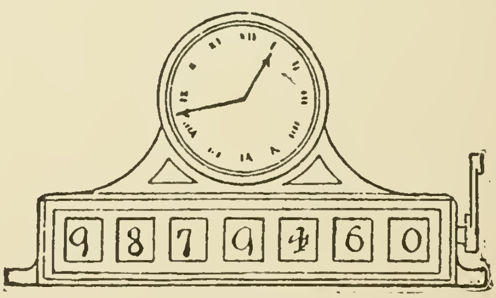


Fig. 129.

ENGINE COUNTERS.

When a counter has completed its full number of recording, all the numbers will show zero, to which must be added an imaginary *one*, making for 7 dials or wheels, ten millions—and the next stroke of the engine will begin a new series with 1, etc.

EXAMPLE OF USE OF THE ENGINE COUNTERS.

An engine counter stood at 967 at the commencement of a voyage, and after 9 days, 13 hours, 15 minutes, 42 seconds stood at 596049; how many revolutions per minute have been made by the engines ?

From 596049	Reduce 9 d. 13 h. 15 m. 42 s. to minutes.	
Take 967	24	
595082	229	Bring the 42 secs. to the decimal of a minute: Thus, $\frac{42}{60}$=.7; and place this .7 after the minutes,
	60	
	13755.7	

Then, 595082÷13755.7=43.26.

Answer, 43.26 revolutions per minute.

ILLUMINATING GAS.

The unit for measurement of light, either electric, gas, oil, or tallow light, is called *one candle power.* Light can be measured with great accuracy, owing to an invariable law, which is similar to the law of gravitation.

If two lights of unequal power be made to shine on the surface of a smooth plaster wall, and a book or card be interposed, the two shadows produced by the crossing of the rays will differ in blackness in the same degree as the powers of the two lights; *the stronger light will produce the darker shadow.*

To obtain the difference in power of the two lights, the stronger light must be moved backwards or the lesser light forward until both shadows are the same tint, which the eye can tell to great exactness.

ILLUMINATING GAS.

The Rule of Light.

The intensity, and consequent value of light is as the square of its distance.

Example.

Suppose a candle be 6 feet from the wall and a gas light 12 feet, to be of equal shades, then $6^2 = 36$ and $12^2 = 144$ making the gas light 4 times as great as the light of the candle, or one gas light to be equal to the light of four candles.

Example.

What amount of light at 10 feet distance will equal that of one candle at 2 feet distance from the point of equal light? Now, then: The square of 2 (2×2) is 4, and the square of 10 (10×10) is 100; so the amount of light is as 100 is to 4, or ($100 \div 4$) equals 25—the number of candles required at a distance of 10 feet to produce a light equal to one at 2 feet.

The Photometer and the Unit of Light.

The illuminating power of gas, electricity, oil, etc., is measured by an instrument called the photometer, and the unit of measurement as fixed by law and custom is *the consuming of* 120 *grains per hour of a sperm candle, of which it takes six to make one pound.* Deficiency of light and all impurities are shown by the instrument when reduced to the test of comparison here described.

Table showing the amount of Oxygen consumed by equal Lights.

Tallow candles	consume	.............12.0	feet of	oxygen	gas.
Wax	" "	.... 8.4	"	"	"
Paraffin oil	"	.... 6.8	"	"	"
Coal-gas	"	.... 5.4	"	"	"
Carbonized gas	"	.... 3.3	"	"	"

Table of the Cost of Equal Light from Different Materials.

21 ft.	of gas	costing	2	cts.	=1 lb. of dip candles	costing	12c.
25 "	"	"	$2\frac{1}{2}$	"	=1 " of composite candles	"	16c.
25 "	"	"	$2\frac{1}{2}$	"	=1 " of wax candles	"	41c.
175 "	"	"	18	"	=1 gallon of paraffin	"	100.

ILLUMINATING GAS.

TABLE OF HEAT PRODUCED BY DIFFERENT LIGHTS OF EQUAL POWER.

Tallow candles	505 lbs.	of water	warmed	10°	
Wax "	383 "	"	"	"	
Paraffin oil	361 "	"	"	"	
Coal gas	278 "	"	"	"	
Carbonized gas	195 "	"	"	"	

THE GAS METER.

The unit of quantity, for gas, is *the cubic foot,* and the machine for accomplishing the measurement is called the Gas Meter, of which there are two kinds, the wet meter, and the dry meter. As both are measures of volume, there is no difference between them, so far as economy is concerned, any more than when the measurements of liquids are effected by a copper or tin vessel.

THE INDEX OF THE GAS METER.

Fig. 130 is a drawing of the ordinary index used for meters

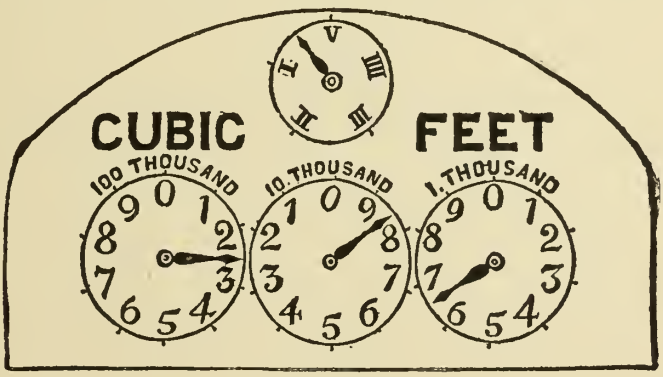


Fig. 130.

supplying up to 10 lights. When a larger capacity than these the index is provided with 4 and sometimes 5 dials. The hand on each index as shown in the figure moves round in same direction as the figures count; thus from 1 to 2 to 3, etc. The hand on the index (beginning at the left) moves to the right, that of the second turns to the left, that of the third turns to the right. In a new meter all the hands point to the cypher (0) at the top, which shows that no gas has been used. When

HOW TO READ A GAS METER.

the hand on the right index has moved to 1 it implies that 100 feet of gas have been used; when it reaches 6 it means 600 feet; and on completing the circuit at the top (0) it is 1000 feet: each time this hand passes round 1000 feet of gas have been used. Each of the other indexes are tenfold multipliers of each other. Single figures are placed on the face for want of room; thus, in the first 1 means 100; in the second 1 stands for 1000; in the third 1 means 10,000; and so on with the succeeding figures respectively. "Cents" is sometimes placed over the index to imply that 100 feet is the smallest quantity shown.

To read the meter, begin with the left index and *write down the quantity last past by the hand,* then write down the quantity last past on the second index; and proceed with the third in the same manner, when the figures as shown in the above illustration will be 28,600, being the cubic feet of gas used at that time; read the meter again next day (or at any other time) and the figures will read—say 29,300 feet; deduct the previous quantity from this amount, and the difference, 700 feet, is the quantity used since the last reading. If the hand of any index appears to be exactly on any one figure, you must *refer to the hand of the next index to the right of it,* and this will show if the other hand has passed the figure in doubt or not. Thus, if the second hand has completed its revolution, it implies the first has passed the figure; if the second has not completed its revolution, it implies the first has not passed the figure. This must be carefully observed to prevent mistakes.

There is sometimes a small index above the others, showing single feet. Generally 5 feet are indicated by each revolution, as in the above illustration; but no account of this is kept by the gas companies; it is only for experimental purposes; for instance, if you wish to know how much is used per hour or minute. Ten minutes' practice at reading meters (called taking the meter) will render the matter quite familiar, and it will be well for the engineer in charge to keep a daily register of the meter, as is done in most large establishments; it not only detects any wasteful use of gas by escape or otherwise, but will also show if the meter continues to work properly.

Points Relating to Gas Important for the Engineer to Know.

An engineer should have the same supervision of the gas consumed on the premises, as he does of the oil that is used, the fuel burned, etc., as a matter both of economy and of safety.

The lights in large establishments are generally turned out at the main and the burners turned off afterward. A saving of gas is effected by this system from two reasons, namely, by putting it out more quickly, and by preventing any escape from the fittings when not in use. Others prefer turning off the burners only, so as to have the gas always ready to light, if wanted in the night. As numberless explosions have happened through turning off at the main, *it is safest to keep the gas always on.*

The effect of distance being so important in matters of light (as *four times* the amount of light is required by only doubling the distance at which it is placed), lights should therefore be placed as near the object to be seen as conveniently may be, and not shine in the eyes of the observer.

It must be borne in mind that the meter indicates the quantity of gas which *passes* without any reference as to how it is used, and care must be used in preventing its waste and loss.

All the pipes placed in inaccessable places, such as beneath the flooring, should be of wrought iron to prevent "bagging" or falling into recesses, at intervals, in which the vapors often condense and obstruct the passage of the gas.

Every size of burner requires a definite amount of gas to produce the largest proportion of light: *light is as much sacrificed by using too little gas, as by using too much.*

No burner ought to be used out of doors without being protected by glass; sufficient air must nevertheless be admitted to all burners, or the combustion will be imperfect, the color of the light will be bad, and smoke will be produced.

Flickering is principally caused by insufficient pressure.

ILLUMINATING GAS.

A greater amount of light is produced from one large burner than from two small ones consuming the same quantity as the one large one. An argand burner consuming five feet of gas per hour under one-tenth of an inch pressure will produce the light of twelve candles; but a similar burner, so small as to require a pressure of one inch to consume the same quantity of gas, will only produce one-fourth that amount of light.

Whenever there is an odor of escaping gas emanating from the street, cellar, drain, cistern, sewer, or anywhere in immediate neighborhood of the consumer's premises, written notices should be sent without delay to the company, who will immediately attend to it for their own protection. Should there be signs of an escape *in the interior* of a building, immediate and prompt care must be employed. *Lights of any kind should be avoided,* the main tap turned off, the doors and upper parts of the windows opened (as gas by its lightness ascends and escapes very readily at the highest part of an apartment.) When the source of escape has been found, it can be temporarily stopped with a little grease, white lead or soap and afterwards substantially repaired. *A room can be more safely entered by crawling upon the hands and knees than by walking upright.*

The Engineer's Signal Code.

The sign O means a short, quick sound, while the dash — means a long sound.

Apply brakes, stop....................O
Release brakes, start ....OO
Back..................................OOO
Highway crossing signal...........— — OO or OO — —
Approaching station, — blast lasting 5 seconds.
Call for switchman.............. ..OOOO
Cattle on track.... ....— — — — —
Train has parted...................— O
Railroad crossing, same as approaching station.
For fuel..............................OOOOO
Bridge or tunnel warning ....OO —
Fire alarm ... .— OOOO
Will take side track.. . ...— — —

Red signifies danger; green signifies caution, go slowly; green and white signifies stop at flag stations for orders, for passengers or freight. One cap or torpedo on rail means stop immediately; two caps or torpedoes means reduce speed immediately and look out for danger signal.

TABLE

OF SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS.

Number.	Square.	Cube.	Square Root.	Cube Root.
1	1	1	1.0	1.0
2	4	8	1.414213	1.25992
3	9	27	1.732050	1.44225
4	16	64	2.0	1.58740
5	25	125	2.236068	1.70997
6	36	216	2.449489	1.81712
7	49	343	2.645751	1.91293
8	64	512	2.828427	2.0
9	81	729	3.0	2.08008
10	100	1000	3.162277	2.15443
11	121	1331	3.316624	2.22398
12	144	1728	3.464101	2.28942
13	169	2197	3.605551	2.35133
14	196	2744	3.741657	2.41014
15	225	3375	3.872983	2.46621
16	256	4096	4.0	2.51984
17	289	4913	4.123105	2.57128
18	324	5832	4.242640	2.62074
19	361	6859	4.358898	2.66840
20	400	8000	4.472136	2.71441
21	441	9261	4.582575	2.75892
22	484	10648	4.690415	2.80203
23	529	12167	4.795831	2.84386
24	576	13824	4.898979	2.88449
25	625	15625	5.0	2.92401
26	676	17576	5.099019	2.96249
27	729	19683	5.196152	3.0
28	784	21952	5.291502	3.03658
29	841	24389	5.385164	3.07231
30	900	27000	5.477225	3.10723
31	961	29791	5.567764	3.14138
32	1024	32768	5.656854	3.17480
33	1089	35937	5.744562	3.20753
34	1156	39304	5.830951	3.23961
35	1225	42875	5.916079	3.27106
36	1296	46656	6.0	3.30192
37	1369	50653	6.082762	3.33222
38	1444	54872	6.164414	3.36197
39	1521	59319	6.244998	3.39121
40	1600	64000	6.324555	3.41995

***TABLE*—(*Contiuued*)**

OF SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS.

Number.	Square.	Cube.	Square Root.	Cube Root.
41	1681	68921	6.403124	3.44821
42	1764	74088	6.480740	3.47602
43	1849	79507	6.557438	3.50339
44	1936	85184	6.633249	3.53034
45	2025	91125	6.708203	3.55689
46	2116	97336	6.782330	3.58304
47	2209	103823	6.855654	3.60882
48	2304	110592	6.928303	3.63424
49	2401	117649	7.0	3.65930
50	2500	125000	7.071067	3.68403
51	2601	132651	7.141428	3.70843
52	2704	140608	7.211102	3.73251
53	2809	148877	7.280109	3.75628
54	2916	157464	7.348469	3.77976
55	3025	166375	7.416198	3.80295
56	3136	175616	7.483314	3.82586
57	3249	185193	7.549834	3.84850
58	3364	195112	7.615773	3.87087
59	3481	205379	7.681145	3.89299
60	3600	216000	7.745966	3.91486
61	3721	226981	7.810249	3.93649
62	3844	238328	7.874007	3.95789
63	3969	250047	7.937253	3.97905
64	4096	262144	8.0	4.0
65	4225	274625	8.062257	4.02072
66	4356	287496	8.124038	4.04124
67	4489	300763	8.185352	4.06154
68	4624	314432	8.246211	4.08165
69	4761	328509	8.306623	4.10156
70	4900	343000	8.366600	4.12128
71	5041	357911	8.426149	4.14081
72	5184	373248	8.485281	4.16016
73	5329	389017	8.544003	4.17933
74	5476	405224	8.602325	4.19833
75	5625	421875	8.660254	4.21716
76	5776	438976	8.717797	4.23582
77	5929	456533	8.774964	4.25432
78	6084	474552	8.831760	4.27265
79	6241	493039	8.888194	4.29084
80	6400	512000	8.944271	4.30887

TABLE—(*Continued*)

OF SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS.

Number.	Square.	Cube.	Square Root.	Cube Root.
81	6561	531441	9.0	4.32674
82	6724	551368	9.055385	4.34448
83	6889	571787	9.110438	4.36207
84	7056	592704	9.165151	4.37951
85	7225	614125	9.219544	4.39683
86	7396	636056	9.273618	4.41400
87	7569	658503	9.327379	4.43104
88	7744	681472	9.380831	4.44796
89	7921	704969	9.433981	4.46474
90	8100	729000	9.486833	4.48140
91	8281	753571	9.539392	4.49794
92	8464	778688	9.591663	4.51435
93	8649	804357	9.643650	4.53065
94	8836	830584	9.695359	4.54683
95	9025	857375	9.746794	4.56290
96	9216	884736	9.797959	4.57785
97	9409	912673	9.848857	4.59470
98	9604	941192	9.899494	4.61043
99	9801	970299	9.949874	4.62606
100	10000	1000000	10.0	4.64158
101	10201	1030301	10.049875	4.65701
102	10404	1061208	10.099504	4.67233
103	10609	1092727	10.148891	4.68754
104	10816	1124864	10.198039	4.70266
105	11025	1157625	10.246950	4.71769
106	11236	1191016	10.295630	4.73262
107	11449	1225043	10.344080	4.74745
108	11664	1259712	10.392304	4.76220
109	11881	1295029	10.440306	4.77685
110	12100	1331000	10.488088	4.79142
111	12321	1367631	10.535653	4.80589
112	12544	1404928	10.583005	4.82028
113	12769	1442897	10.630145	4.83458
114	12996	1481544	10.677078	4.84880
115	13225	1520875	10.723805	4.86294
116	13456	1560896	10.770329	4.87699
117	13689	1601613	10.816653	4.89097
118	13924	1643032	10.862780	4.94086
119	14161	1685159	10.908712	4.91868
120	14400	1728000	10.954451	4.93242

TABLE—(*Continued*)

OF SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS.

Number.	Square.	Cube.	Square Root.	Cube Root.
121	14641	1771561	11.0	4.94608
122	14884	1815848	11.045361	4.95967
123	15129	1860867	11.090536	4.97319
124	15376	1906624	11.135528	4.98663
125	15625	1953125	11.180339	5.0
126	15876	2000376	11.224972	5.01329
127	16129	2048383	11.269427	5.02652
128	16384	2097152	11.313708	5.03968
129	16641	2146689	11.357816	5.05277
130	16900	2197000	11.401754	5.06579
131	17161	2248091	11.445523	5.07875
132	17424	2299968	11.489125	5.09164
133	17689	2352637	11.532562	5.10446
134	17956	2406104	11.575836	5.11723
135	18225	2460375	11.618950	5.12992
136	18496	2515456	11.661903	5.14256
137	18769	2571353	11.704699	5.15513
138	19044	2628072	11.747344	5.16764
139	19321	2685619	11.789826	5.18010
140	19600	2744000	11.832159	5.19249
141	19881	2803221	11.874342	5.20482
142	20164	2863288	11.916375	5.21710
143	20449	2924207	11.958260	5.22932
144	20736	2985984	12.0	5.24148
145	21025	3048625	12.041594	5.25358
146	21316	3112136	12.083046	5.26563
147	21609	3176523	12.123455	5.27763
148	21904	3241792	12.165525	5.28957
149	22201	3307949	12.266555	5.30145
150	22500	3375000	12.247448	5.31329
151	22801	3442951	12.288205	5.32507
152	23104	3511808	12.328828	5.33680
153	23409	3581577	12.369316	5.34848
154	23716	3652264	12.409673	5.36010
155	24025	3723875	12.449899	5.37168
156	24336	3796416	12.489996	5.38323
157	24649	3869893	12.529964	5.39469
158	24964	3944312	12.569805	5.40612
159	25281	4019679	12.609520	5.41750
160	25600	4096000	12.649110	5.42883

TABLE—(Continued)

OF SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS.

Number.	Square.	Cube.	Square Root.	Cube Root.
161	25921	4173281	12.688577	5.44012
162	26244	4251528	12.727922	5.45136
163	26569	4330747	12.767145	5.43255
164	26896	4410944	12.806248	5.47370
165	27225	4492125	12.845232	5.48480
166	27556	4574296	12.884098	5.49586
167	27889	4657463	12.922848	5.50687
168	28224	4741632	12.961481	5.51784
169	28561	4826809	13.0	5.52877
170	28900	4913000	13.038404	5.53965
171	29241	5000211	13.076696	5.55049
172	29584	5088448	13.114877	5.56129
173	29929	5177717	13.152946	5.57205
174	30276	5268024	13.190906	5.58277
175	30625	5359375	12.228756	5.59344
176	30976	5451776	13.266499	5.60407
177	31329	5545233	13.304134	5.61467
178	31684	5639752	13.341664	5.62522
179	32041	5735339	13.379088	5.63574
180	32400	5832000	13.416407	5.64621
181	32761	5929741	13.453624	5.65665
182	33124	6028568	13.490737	5.66705
183	33489	6128487	13.527749	5.67741
184	33856	6229504	13.564660	5.68773
185	34225	6331625	13.601470	5.69801
186	34596	6434856	13.638181	5.70826
187	34969	6539203	13.674794	5.71847
188	35344	6644672	13.711309	5.72865
189	35721	6751269	13.747727	5.73879
190	36100	6859000	13.784048	5.74889
191	36481	6967871	13.820275	5.75896
192	36864	7077888	13.856406	5.76899
193	37249	7189057	13.892444	5.77899
194	37636	7301384	13.928388	5.78896
195	38025	7414875	13.964240	5.79889
196	38416	7529536	14.0	5.80878
197	38809	7645373	14.035668	5.81864
198	39204	7762392	14.071247	5.82847
199	39601	7880599	14.106736	5.83827
200	40000	8000000	14.142135	5.84803

MELTING POINTS OF SOLIDS.

The metals are solid at ordinary temperatures, with the exception of mercury, which is liquid down to —39° F. Hydrogen, it is believed, is a metal in a gaseous form.

All the metals are liquid, at temperatures more or less elevated, and they probably turn into gas or vapor at very high temperatures. Their melting points range from 39 degrees below zero of Fahrenheit's scale, the melting, or rather the freezing, point of mercury, up to more than 3000 degrees, beyond the limits of measurement by any known pyrometer. Certain of the metals, as iron and platinum, become pasty and adhesive at temperatures much below their melting points. Two pieces of iron raised to a welding heat, are softened, and readily unite under the hammer; and pieces of platinum unite at a white heat.

Melting Points of Solids.

VARIOUS SUBSTANCES.	Melting Points.
Sulphurous acid	—148° F.
Carbonic acid	—108
Bromine	+9. 5
Turpentine	14
Hyponitric acid	16
Ice	32
Nitro-glycerine	45
Tallow	92
Phosphorus	112
Acetic acid	113
Stearine	109 to 120
Margaric acid	131 to 140
Wax, rough	142
" bleached	154
Iodine	225
Sulphur	239

MELTING POINTS OF SOLIDS.—(*Continued.*)

METALS.	Melting Points.
Mercury	−39° F
Potassium	144
Sodium	208
Lithium	356
Tin	442
Bismuth	507
Lead	617
Zinc	680 to 773
Antimony	810 to 1150
Bronze	1692
Silver	1832 to 1873
Copper	1996
Gold, standard	2156
Cast Iron, white	1922 to 2012
" " gray	2012 to 2786
Steel	2372 to 2552
Wrought Iron	2732
Hammered Iron	2912

SUNDRY ALLOYS OF TIN, LEAD, AND BISMUTH.	Melting Points.
3 Lead, 2 Tin, 5 Bismuth	199°
1 " 1 " 4 "	201
5 " 3 " 8 "	212
1 " 4 " 5 "	246
1 " 3	334
2 " 1 "	334
1 " 2 "	360 to 385
3 " 1 "	392
3 " 1 "	552

ALLOYS FOR FUSIBLE PLUGS.	Softens at	Melts at
2 Tin, 2 Lead	365° F.	372° F.
2 " 6 "	372	383
2 " 8 "	395½	406 to 410

THE BAROMETER

Consists of a glass tube closed at one end, a cup, and some mercury.

It will be noticed that the mercury in the cup is exposed to the pressure of the atmosphere, whereas that in the tube is not.

In considering the operation of a low pressure engine suppose the vacuum in the condenser to be perfect, the atmosphere pressing on the mercury will force it up the leg of the tube till it stands at 30 inches; therefore 30 inches of mercury means a perfect vacuum. As vapor increases in the condenser, it will flow on the top of the mercury and force it down.

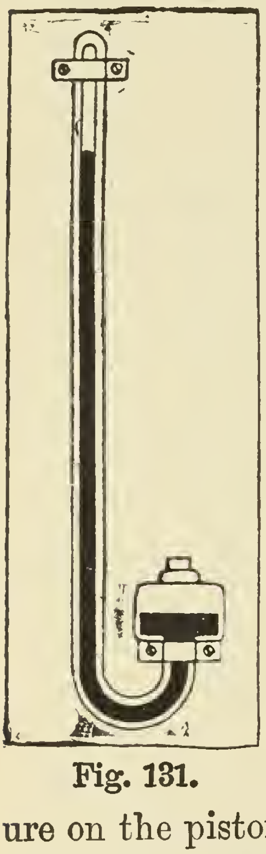


Fig. 131.

Again, when there is a perfect vacuum in the condenser or under the piston, if the atmosphere could be allowed to act on the upper face of the piston, it would force it down with a pressure of 15 lbs. per square inch; and as vapor arises it flows up the eduction pipe under the piston, and destroys so much of the atmospheric pressure. Hence, if the Barometer stands at 30 inches, we speak of 15 lbs. of vacuum; if at 28 inches, 14 lbs. of vacuum; and if at 25 inches, $12\frac{1}{2}$ lbs. of vacuum, and so on.

Instead of the atmosphere, steam of a pressure greater than that of the atmosphere is admitted to the piston; thus, if steam of 25 lbs. pressure is admitted, we speak of it as 10 lbs. above the atmosphere. If there were a perfect vacuum, it would exert 25 lbs. pressure on the piston; but if the mercury be at 26 inches, a pressure equal to 4 inches or 2 lbs. will be lost, or the *effective pressure* will be 23 lbs. per square inch, or as it is usually expressed:

10 lbs. of steam.
26 inches=13 lbs. of vacuum.
—
23 lbs. effective pressure.

A vacuum gauge is now used instead of a Barometer.

THE BAROMETER.

The weather Barometer is the instrument for showing the pressure of the air; when it stands at 30 inches, if pure water be boiled *in the open air*, and the Thermometer placed in it while boiling, the mercury will invariably stand at 212°. Sea water boiled under the same circumstances will send the mercury up to 213.2, or 1.2° more than pure water. This 1.2° must be due to the salt contained in the sea water, hence, for every degree of salt we may reckon an increase of 1.2° in the temperature of the boiling point, the Barometer remaining at 30 inches.

The following table shows the correct boiling point of salt water at the different degrees of density, when the Barometer stands at 30 inches.

Boiling Point of Salt Water.

				Degrees
Fresh Water	W	....	boiling point	212
Sea Water	$\frac{1}{33}$	solid matter........	"	213.2
......	$\frac{2}{33}$	"	"	214.4
......	$\frac{3}{33}$	"	"	215.5
......	$\frac{4}{33}$	"	"	216.7
......	$\frac{5}{33}$	"	"	217.9
......	$\frac{6}{33}$	"	"	219.1
......	$\frac{7}{33}$	"	"	220.3
......	$\frac{8}{33}$	"	"	221.5
......	$\frac{9}{33}$	"	"	222.7
......	$\frac{10}{33}$	"	"	223.8
......	$\frac{11}{33}$	"	"	225.0
Saturated. Salt deposited	$\frac{12}{33}$	"	"	226.1

Water that has $\frac{1}{33}$ part salt, has 5 oz. of salt per gall. of water.
" " $\frac{2}{33}$ " 10 oz. " " "
" " $\frac{3}{33}$ " 15 oz. " " "

In this table the Imperial Gallon is used.

THE HYDROMETER.

Hydrometer is the general name given to instruments for testing the density of liquids; but when the instrument is specially marked for testing the density of some particular liquid, it has a special name given to it; thus, the Hydrometer specially marked for testing the amount of water in milk, is called a *Lactometer,* meaning a "milk-measurer." In the same way the Hydrometer specially marked for testing the amount of salt in the boiler water, is called a *Salinometer,* meaning a "salt-measurer."

THE SALINOMETER.

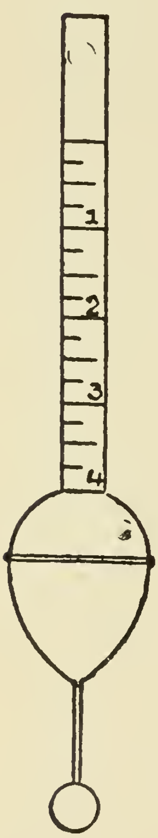


Fig. 132.

A salinometer is a glass or metal instrument by means of which the density of water is ascertained. It consists of a weighted bulb, to which is attached a graduated stem, and its action is to indicate the amount of salt held in solution in the water, by floating higher or lower; higher for density, lower for freshness. Some are graduated into 33rds, and some to 32nds, each representing about five ounces of salt to a gallon of water. Care must be taken to use the salinometer at the temperature for which it is marked, as the densities of fluids vary in proportion to their temperature.

200° being the usual temperature of the water in which these instruments are tested, so that they may be used almost immediately on the water from the boiler ceasing to boil.

Sea-water contains $\frac{1}{33}$ part salt, that is, if 33 pounds of sea water were evaporated, 1 pound of salt would remain; $\frac{1}{33}$ is for this reason taken as the unit by which to measure the density of the boiler water. If the water in the boiler has the same amount of salt in it as sea-water, we say it has 1 degree of salt; if it contains twice as much salt per gallon as sea-water, then it has two degrees of salt, that is $\frac{2}{33}$, &c.

ELECTRICITY.

The history of electricity, as a modern science, began nearly a century ago when Sir Humphrey Davy, in 1810, exhibited an electric light, produced by two small pieces of carbon and a powerful galvanic battery, and when, a few years later, Michael Faraday arrived at one of the greatest of discoveries, one that has been placed on a level with the discovery of the laws of gravitation. In brief, the discovery that electricity could be produced from magnetism by power. Faraday experimented with a great magnet belonging to the Royal Society consisting of 450 bars, each fifteen inches long, and succeeded in obtaining a current of sufficient strength to give sparks from the end of the wire forming the coils.

A host of inventors have labored with the principles discovered by Faraday in endeavoring to reduce them to practical use; in 1867 these experiments had so far advanced that the problem of electric lighting by means of the dynamo had been assured upon a commercial basis, and from that date the progress in what may be denominated industrial electricity has been marvellously rapid.

Two essential principles may be stated relating to this subject:

1. Electricity as an industrial agent has come to stay;

2. That the end reached after a century of scientific research has resulted in the acknowledgment that electricity is *an unknown thing;* it may be matter, it may be force, or both; but however produced, it may be considered one and the same thing. Hence, the engineer, who knows he is ignorant upon this mysterious subject is almost on a level with the greatest electrical expert. But it may be recalled that until the days of Watt, steam was an equally unknown agent, of which even now there are some things to be discovered—such as the true nature of latent heat, etc., and that some day an instrument like the steam engine indicator may be discovered which will illuminate the unknown nature of this mysterious agent.

ELECTRICITY.

The most accurate definition of electricity perhaps, is that it is simply *mechanical energy* changed into *electrical energy,* that is, that the power existing in the coal as it is consumed under the steam boiler, and the zinc, lead, etc., which is consumed in a primary battery is changed into another form of energy known as electricity.

Since every manifestation of energy is by means of motion, the conclusion seems inevitable that electricity is a mode of *molecular motion,* and in electricity this motion of the infinitely small particles are inconceivably swift, and beyond any printed or verbal description.

This small sum of accurate knowledge being the result of the most advanced science, it follows that the practical engineer will wisely confine himself to the duty of reducing to the best performance the various mechanisms belonging to his electric lighting and power plant.

Electrical Data and Definitions.

The student who is determined to add a knowledge of industrial electricity to his accomplishments must *first learn* the *names,* and *uses* of electrical appliances, and *the definition and meaning of electrical terms,* and by persistent endeavor master the subject from its beginning to its latest development.

The Dynamo, is the machine in ordinary use for producing electricity; when it is thus employed it is called a *dynamo-electric-machine,* but when the same apparatus is used to change the electricity into mechanical power it is called *a motor.*

The dynamo consists of the following principal parts: 1. The *armature,* which is the revolving portion. 2. The *field magnets,* which produce the field within which the armature revolves. 3. *The pole pieces.* 4. *The commutator* or *collector* 5. *The collecting brushes.*

ELECTRICAL DATA AND DEFINITIONS.

There are scores of forms in which dynamos are constructed and they are made of varying sizes but all upon the same general principle.

The dynamo, like all our electrical machines or batteries, are merely instruments for moving electricity from one place to another, or for causing electricity when accumulated or "bunched up" to do work in returning to its former level distribution.

Electro-motive force, sometimes written briefly (E. M. F.) is the name which is used to express the force which tends to move the electricity from one place to another.

When electricity is regarded as a fluid, its supposed flow or passage is called *a current,* and any substance through which it flows *a conductor.* Bodies offering such great resistance as practically to prevent the passage of electricity are named *insulators.* The path through which a current passes is termed *a circuit,* which when continuous is called *a closed circuit,* but when there is a break in it *an open circuit.*

Potential, is a term employed to express various degrees of electrical energy, or power of doing work, and is used with respect to electricity in the same way as the word *pressure* is applied to steam. *A difference of potential* (or pressure) between two points connected by a conductor, produces a passage of electricity, which is evidence that the potential of each point in the circuit is less than that of each preceding point; when there is no difference there ceases to be any transference between them. Hence the flow of electricity is like the flow of water collected in a reservoir. When there is no "head" there is no flowing outward of the fluid.

In comparing hydraulics and electricity, it must be borne in mind that water in pipes has mass and weight, while electricity has none—the head or pressure of a stand pipe is what causes water to flow through pipes which offer resistance to the flow. We might call this pressure water-motive force, so in electricity the head or pressure, or as it is called, the electro-motive force (E. M. F.) will make the electricity move through the wire.

CONDUCTORS AND INSULATORS OF ELECTRICITY.

There is no substance so good a conductor of electricity as to be devoid of resistance, and there is no substance of so high a resistance as to be strictly a non-conductor.

Hence in the following list the substances named are placed in order, each conducting better than those below it on the list.

Silver.	
Copper.	
Gold.	
Zinc.	
Platinum.	
Iron.	
Tin.	Good Conductors.
Lead.	
Mercury.	
Charcoal.	
Acids.	
Water.	
The body.	
Cotton.	
Dry wood.	Partial Conductors.
Marble.	
Paper.	
Oils.	
Porcelain.	
Wool.	
Silk.	
Resin.	
Gutta Percha.	
Shellac.	Non-Conductors or Insulators.
Ebonite.	
Paraffine.	
Glass.	
Dry air.	
Worst conductor.	

ELECTRICAL DATA AND DEFINITIONS.

Positive and negative electricity are two convenient terms used to express different states in the formation of electricity. Bodies charged with electricity of *the same kind* repel one another, and bodies charged with electricity of *different kinds* attract each other.

Resistance, may be conveniently regarded as that which opposes or resists the passage of the current. Most metals offer but small resistance, and are called good conductors, while wood, stone, silk and glass offer varying degrees of resistance. The unit of resistance is *the ohm.*

UNITS OF ELECTRICAL MEASUREMENT.

It has been found essential to have certain units of measurements, solely adapted to express *the force, resistance and current* (so called) residing in electricity.

These units were agreed upon at a Congress of Electricians, which met in Paris in 1881 and 1884—the metric, or French system of notation was the one adopted in which

A gramme is equal to 15.432 grains (about $15\frac{4}{10}$).

A centimetre is equal to 0.3937 of an inch.

The three principal factors, *length, mass,* and *time* are indidated by C standing for *centimetre,* G for *gramme,* and S for *second* (of time); hence the method is generally called the "C. G. S. system" of electrical notation, and the C. G. S. unit represents *the work* accomplished by *the movement of a mass, equal to one gramme, through a space equal to one centimetre, in one second of time.*

In representing the large numbers containing many cyphers, necessary for calculations in electrical quantities, the method was adopted of writing an exponent equal to the number of cyphers, thus: 10^8 is the equivalent of 100,000,000, because 8 cyphers are added.

An exponent or figure placed to the right of a letter or figure, *above it,* as 10^9, indicates that the number is to be multiplied by itself, as in the example, 9 times.

The DYNE, or *absolute* unit of *force,* is the force which, in one second, can impart a velocity of one centimetre per second to a mass of one gramme.

ELECTRICAL DATA AND DEFINITIONS.

The Erg, or the *absolute* unit of *work*, is the work requisite to move a body one centimetre against a force of one dyne. There is an apparatus for measuring in *ergs* the work of an electric current.

The Volt *is the practical unit of electro-motive force,* which would cause a *current* of one *ampere* to flow against the *resistance* of one *ohm.* One volt is equal to 10^8 absolute units. The volt is named from Volta, the original inventor of the primary battery.

The Ohm is the unit of measure of resistance and is equal to 10^9 C. G. S. units and is approximately equal to the resistance of 129 yards of copper wire $\frac{1}{16}$th of an inch in diameter, or, differently stated, such a resistance as would limit an electro motive force of one volt to a current of one ampere, or to one coulomb per second. The term is given in honor of Ohm, who discovered the law which governs electric resistance.

The Ampere, the *unit of electric current,* or volume, is the *ampere* named after Ampere, who discovered and formulated the laws of electric currents. If an electro motive force of *one volt* be applied to send a current through a resistance of *one ohm,* the strength of current produced will be *one ampere.*

An *ampere per second* is equal to *one coulomb.* An ampere may also be defined by *the chemical decomposition the current can effect as measured by the quantity of hydrogen liberated, or metal deposited, shown in a device called the volta metre.* The latter really measures the coulombs and should properly be called a *coulomb metre.*

The Coulomb is the unit of *current quantity, considered with reference to time.* It is named after Coulomb, to whom is due the first attempt at accuracy in electric science; it represents the amount of electricity as would pass in one second in a circuit whose *resistance* is one *ohm,* under a *electro motive force* of one *volt.*

The Farad is the electric unit of *capacity,* (named after Faraday). It represents the storage of *one coulomb* of electricity in a condenser. The Farad equals 10^{-} C. G. S. units of capacity. The *micro farad* represents one-millionth of a farad and $=10^{-15}$ units of capacity.

ELECTRICAL DATA AND DEFINITIONS.

The WATT is the unit of *electric power,* named after James Watt, the inventor of the steam engine. The term volt-ampere means the same as the watt, as the latter is derived by multiplying the two together, hence one watt equals one volt multiplied into one ampere, which equals 10^7 C. G. S. units of power.

The JOULE is the electric unit of *heat.* It represents the heat developed in a conductor by one watt in one second.

THE ELECTRIC HORSE POWER.

The electric horse power, which is the equivalent of the mechanical horse power, is represented by 746 watts—equal to $746 \times 10^7 = 7{,}460{,}000{,}000$ C. G. S. units of power.

ELECTRIC MEASURING INSTRUMENTS.

These are various in their principles of action and machine construction. By their use, quantity, cost and the commercial value of the electric fluid, so called, can be determined to an absolute certainty; the devices are known chiefly as *voltmeters and ammeters;* voltmeters designating those which measure electro-motive force, the results being given in volts; and ammeters those which measure current strength, the results being given in amperes. Ammeters are also called *current meters* and *ampere meters.* There are also instruments of special construction designated as *electro-dynamo meters, coulomb meters and ohm meters.*

There are also instruments permanently placed in the circuit, like the steam gauge on the boiler, as a guide to the engineer or attendant to indicate deviations above or below a fixed E. M. F.—these are known as *potential indicators.* In the latter instruments a long pointer is bent downwards over a scale which indicates *to the right* five volts above, and to the left, five volts below, a certain standard indicated by zero; each of the numbers on the dial, 10, 20, 30, 40, 50, indicating about a volt, each volt space being subdivided into tenths.

Hints for the Engineer Relating to Electricity.

The difficulties that beset the electrical engineer are chiefly internal and invisible; they are caused by leakage, undue resistance in the conductor, and bad joints which lead to waste of energy and the dangerous production of heat; bare and exposed conductors should always be within plain sight and as far out of reach as possible; the necessity cannot be too strongly urged for guarding against the presence of moisture, and the employment of skilled and experienced electricians in first erecting and supervising the work before turning it over to the engineer in charge of the whole plant.

It is best to have a separate room for the dynamo and motive power, and if several dynamos are used it is equally important to have them all in one room.

It is well for the engineer in charge to have *an accurate and sensitive speed indicator,* capable of showing even the slightest variations.

A brush should never be lifted off the commutator while the dynamo is running.

Every binding screw should be examined, and if necessary, tightened every day, as they are liable to be loosened by even a slight continuous jar of the dynamo.

The dynamo can be cleaned off, from the dust, etc., by means of a paint brush and a pair of bellows used daily. Shafts and pullies running near the dynamo must be prevented by means of shields from throwing oil on the dynamo and especially the commutator.

It is advisable to run a new dynamo a few hours or even a day without any load, in order to have everything in proper working order before putting on the load, which should be done gradually.

The insulation of the coils of the dynamo should be practi ally perfect.

HINTS RELATING TO THE DYNAMO.

All conductors in the dynamo room should be firmly supported, well insulated, conveniently arranged for inspection, and marked or numbered ; the + sign on electrical machines indicates the positive pole, and the — sign indicates the negative pole; for convenience sake it were well to assume that *the electric current always flows from the positive pole of the generator through the external circuit back to the negative pole.*

The dynamo machine should be fixed in a dry place and it should be solidly set, the iron frame being *properly insulated* from the foundation, which is best done by *a dry wood* base plate.

It should run steadily and evenly as any variation shows in the lights.

It should not be exposed to dust or flyings.

It should be kept perfectly clean and its bearings well oiled.

TABLE.

WEIGHT OF CALENDERED IRON AND STEEL SHAFTING.

Diameter in Inches.	Weight per foot (for iron.)		Diameter in Inches.	Weight per foot (for iron.)
$\frac{5}{8}$	1.02		$2\frac{1}{4}$	13.25
$\frac{11}{16}$	1.25		$2\frac{5}{16}$	14.00
$\frac{3}{4}$	1.47		$2\frac{3}{8}$	14.76
$\frac{13}{16}$	1.74		$2\frac{7}{16}$	15.57
$\frac{7}{8}$	2.00		$2\frac{1}{2}$	16.37
$\frac{15}{16}$	2.30		$2\frac{9}{16}$	17.20
1	2.61		$2\frac{5}{8}$	18.03
$1\frac{1}{16}$	2.96		$2\frac{11}{16}$	18.91
$1\frac{1}{8}$	3.31		$2\frac{3}{4}$	19.79
$1\frac{3}{16}$	3.70		$2\frac{13}{16}$	20.71
$1\frac{1}{4}$	4.09		$2\frac{7}{8}$	21.63
$1\frac{5}{16}$	4.50		$2\frac{15}{16}$	22.60
$1\frac{3}{8}$	4.95		3	23.56
$1\frac{7}{16}$	5.41		$3\frac{1}{8}$	25.60
$1\frac{1}{2}$	5.89		$3\frac{3}{16}$	26.62
$1\frac{9}{16}$	6.40		$3\frac{1}{4}$	27.65
$1\frac{5}{8}$	6.91		$3\frac{3}{8}$	29.82
$1\frac{11}{16}$	7.45		$3\frac{7}{16}$	30.95
$1\frac{3}{4}$	8.01	IRON ONLY.	$3\frac{1}{2}$	32.07
$1\frac{13}{16}$	8.60		$3\frac{5}{8}$	34.40
$1\frac{7}{8}$	9.20		$3\frac{11}{16}$	35.60
$1\frac{15}{16}$	9.83		$3\frac{3}{4}$	36.81
2	10.47		$3\frac{7}{8}$	39.31
$2\frac{1}{16}$	11.15		$3\frac{15}{16}$	40.59
$2\frac{1}{8}$	11.82		4	41.88
$2\frac{3}{16}$	12.54			

CHIMNEYS.

The following table, calculated from approved formulæ by Wm. Kent, M. E., is based on the supposition that a commercial horse-power requires—as an average—the consumption of five pounds of coal per hour :

Sizes of Chimneys, with Approximate Horse-Power of Boilers.

Diameter in Inches.	Height of Chimneys and Commercial Horse Power.											Side of Square Inches.	Effective Area. Square Ft.	Actual Area. Square Ft.
	50 ft.	60	70	80	90	100	110	125	150	175	200			
18	23	25	27									16	0.97	1.77
21	35	38	41									19	1.47	2.41
24	49	54	58	62								22	2.08	3 14
27	65	72	78	83								24	2.78	3.98
30	84	92	100	107	113							27	3.58	4.91
33		115	125	133	141							30	4.48	5 94
36		141	152	163	173	182						32	5.47	7.07
39			183	196	208	219						35	6.57	8.36
42			216	231	245	258	271					38	7.76	9.62
48				311	330	348	365	389				43	10.44	12.57
54					427	449	472	503	551			48	13.51	15.90
60					536	565	593	632	692	748		54	16.98	19 64
66						694	728	776	849	918	981	59	20.83	23.76
72						835	876	934	1023	1105	1181	64	25.08	28.27
78							1038	1107	1212	1310	1400	70	29.73	33.18
84							1214	1294	1418	1531	1637	75	34.76	38.48
90								1496	1639	1770	1893	80	40.19	44.18
96									1876	2027	2167	86	46 01	50.27

Table of Size of Nails.

The following table will show at a glance the length of the various sizes and the number of nails in a pound; they are rated "3-penny" up to "20-penny." The first column gives the name, the second the length in inches, and the third the number per pound:—

3-penny,	1 inch,	557 nails per lb.
4 "	$1\frac{1}{4}$ "	353 " " "
5 "	$1\frac{2}{3}$ "	232 " " "
6 "	2 "	167 " " "
7 "	$2\frac{1}{4}$ "	141 " " "
8 "	$2\frac{1}{2}$ "	101 " " "
10 "	$2\frac{3}{4}$ "	98 " " "
12 "	3 "	54 " " "
20 "	$3\frac{1}{2}$ "	34 " " "
Spikes	4 "	16 " " "
"	$4\frac{1}{2}$ "	12 " " "
"	5 "	10 " " "
"	6 "	7 " " "
"	7 "	5 " " "

Table Showing the Number of Days.

From any Day of	To the same Day of next.											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
January	365	31	59	90	120	151	181	212	243	273	304	334
February	334	365	28	59	89	120	150	181	212	242	273	303
March	306	337	365	31	61	92	122	153	184	214	245	275
April	275	306	334	365	30	61	91	122	153	183	214	244
May	245	276	304	335	365	31	61	92	123	153	184	214
June	214	245	273	304	334	365	30	61	92	122	153	183
July	184	215	243	274	304	335	365	31	62	92	123	153
August	153	184	212	243	273	304	334	365	31	61	92	122
September	122	153	181	212	242	273	303	334	365	30	61	91
October	92	123	151	182	212	243	273	304	335	365	31	61
November	61	92	120	152	181	212	242	273	304	334	365	30
December	31	62	90	121	151	182	212	243	274	304	385	365

When February is included between the points of time, a day must be added in leap year.

Example.

1. How many days is it from the 10th day of March until the 16th day of October? Now then: find March in first column. Second, follow line of figures until column under "Oct."=214, add 6 days from the 10th to the 16th. Answer, 220 days.

2. How many working days from the 29th of July to the 14th of September?

From the 29th of July to 29th of Sept. per table,	62
Deduct the difference between 14th and 29th,	15
	47
Deduct each 7th day for Sunday,	7
Answer,	40 days

Note.

The above table is of great value when used in connection with the Table of Wages, to be found on page 33, especially for verification of pay rolls, as well as for other uses, both business and personal.

TRANSMISSION OF POWER.

Up to a certain limited distance, the useful effect of the energy created at a certain point can be best and most economically transferred by belting of various materials, pullies and shafting. For greater distances there are four principal methods in use for the transmission of power. These are

1. Electricity.
2. Water, (Hydraulic power.)
3. Air, (Pneumatic power.)
4. Wire Rope.

On the basis of many experimental determinations the following table has been computed, by Beringer of Germany, of representing *the commercial efficiency* of the different systems, under various conditions of distance and power, all the systems being supposed to be working to the best advantage.

TABLE OF COMMERCIAL EFFICIENCY.

Distance of transmission in feet.	Electricity.	Hydraulic.	Pneumatic.	Wire Rope.
300	.69	.50	.55	.96
1,500	.68	.50	.55	.93
3,000	.66	.50	.55	.90
15,000	.60	.40	.50	.60
30,000	.51	.35	.50	.36
60,000	.32	.20	.40	.13

In these tables the maximum of comparison is 100 between the (four) systems. It will be seen that wire rope is the most effective up to about three miles, beyond which electric and pneumatic transmission are most efficient.

As the fundamental problems of mechanical engineering are those relating to the generation, *transmission* and utilization of power, it were well for the engineer to study, with open-eyed attention, the problems now being worked out in this direction, especially in the new field of electric transmission of power.

BELTING AND PULLEYS.

Belts can be made of any flexible material, cloth, rubber, leather, and can be run in any way, at any angle, of any length, and any speed; 99 per cent. of all the power in the U. S. is transferred by belts and pullies, and yet all calculations relating to them are subject to one fault, they are not positive, owing to the variation in the friction and consequent slippage of the belts on the pullies.

Leather belting is the standard of comparison.

The average strain under which leather will break has been found by many experiments to be 3,200 pounds per square inch of cross-section. A good quality of leather will sustain a somewhat greater strain. In use on the pulleys, belts should not be subjected to a greater strain than one-eleventh their tensile strength, or about 290 pounds to the square inch or cross-section. This will be about 55 pounds average strain for every inch in width of single belt three-sixteenths inch thick. The strain allowed for all widths of belting—single, light double, and heavy double—is in direct proportion to the thickness of the belt.

The working adhesion of a belt to the pulley will be in proportion both to the number of square inches of belt contact with the surface of the smaller pulley, and also to the arc of the circumference of the pulley touched by the belt. This adhesion forms the basis of correct calculation in ascertaining the width of belt necessary to transmit a given horse-power. A single belt, three-sixteenths inch thick, subjected to the strain we have given as a safe rule—55 lbs. per inch in width—when touching one-half of the circumference of a turned iron pulley, will adhere one-half pound per square inch of the surface contact; while if it be a leather-covered pulley, the belt will adhere two-thirds of a pound per square inch of contact. If the belt touches but one-quarter of the circumference of the pulley, the adhesion is only one-quarter pound to the square inch of contact with the iron pulley, and one-third pound per square inch on the leather-covered pulley.

Horse Power Transmitted by Leather Belts.

In a single leather belt, not overstrained, a speed of 800 feet per minute for each inch in width is estimated to convey *one horse power.*

Examples.

1. What power can be transmitted by a belt 7 inches wide travelling 1200 feet per minute ?

$$1200\times7=8400$$

$$800)8400$$

$10\frac{1}{2}$ Ans. $10\frac{1}{2}$ horse power.

2. What power can be transmitted by a belt, single thickness, 14 in. wide, running at a speed of 575 feet per minute ?

$$2575\times14=36050$$

Divide 800)36050

45 horse power, nearly. Ans.

In a *double leather belt,* not overstrained, a speed of 550 feet for each inch in width will transmit 1 horse power.

Example.

What power will a double leather belt, $2\frac{1}{2}$ inches wide, running 4000 feet per minute transmit ?

$4000\times2\frac{1}{2}=10000$. Divide 10000 by $550=18\frac{1}{5}$ H. P. nearly.

For calculating length of belting before pullies are placed in position.

Add together *the diameters* of the two pullies and multiply the sum by 3.14159. To *half the result* thus obtained *add twice the distance* from the centre of one pulley (or shaft) to the centre of the other pulley (or shaft).

Example.

Given the distance between centres of pullies 28 ft. 8 in.; diameter of pullies 52 inches and 46 inches. What is the length of the belt ? Now then :

Add the diameters 52+46	=	98
Multiply 98 by 3.14159	=	307.87
Divide this by 2	=	153.98
Reduce this to feet; 12	=	12.83
Centres, 28′ 8″×2	=	57.33
Add the last two together	=	Ans. $70\frac{1}{16}$ feet.

Rules for Calculating Speed and Sizes of Pullies.

When two pullies are working together connected by a belt, the one which communicates the motion is called the driver and the one which receives it is called the driven pulley.

To find the size of the driving pulley: Multiply the diameter of the driven pulley by the number of revolutions it shall make and divide the product *by the revolutions of the driver.* The quotient will be the diameter of the driver.

To find the number of revolutions of the Driven Pulley: Multiply the diameter of the driver by its number of revolutions, and divide by diameter of driven. The quotient will be the number of revolutions of the driven.

The diameter and revolutions of the driver being given, to find the diameter of the driven that shall make a given number of revolutions: Multiply the diameter of the driver by its number of revolutions, and divide the product by the number of revolutions of the driven. The quotient will be the diameter of the driven.

Rules for Calculating the Size of Pullies for Ball Governors.

To find the diameter of the governor shaft pulley.

1. Multiply the number of the revolutions of the engine *by the diameter of the engine shaft pulley,* and divide the product by the number of the revolutions of the governor.

2. *To find the diameter of the engine shaft pulley.* Multiply the number of revolutions of the governor, *by the diameter of the governor shaft pulley,* and divide the product by the number of revolutions of the engine.

For finding the length of a roll of belting.

Take the over all diameter, and add to it the diameter of the hole in the centre of the roll; then divide the sum by two to find *the mean diameter;*—this multiplied by 3.1416 ($3\frac{1}{7}$th) will give the circumference. Next multiply this by the number of "laps" and the result is obtained in inches, and by dividing by 12 the length of the roll is obtained in feet.

Useful Points Relating to Belting.

The adhesion, one inch in width of the belt, has on the pulley is the number of pounds which each inch in width of belt is capable of raising or transmitting. Multiplying this by the velocity of the belt in feet per minute will give the total number of pounds each inch in width will raise or transmit one foot per minute. The answer is in foot pounds of which 33,000=1 horse power.

The thickness, as well as the width of belts, must be considered; consequently, a double belt must be used where it is necessary to transmit a greater power than possible with a narrow belt.

To increase the driving power of a belt, the pulleys may be enlarged in circumference, thus increasing the speed of the belt. This can often be done to advantage, provided that the speed be not carried above the safe limit.

The width of a belt needed depends on three conditions: 1st, the tension of the belt; 2d, the size of the smaller pulley and the proportion of the surface touched by the belt; 3d, the speed of the belt.

The leather in a belt should be pliable, of fine, close fibre, solid in its appearance, and of smooth, polished surface. The character of the workmanship should also be considered.

After the elastic limit of a leather belt is reached we may stretch it to the breaking point without getting it any tighter.

Belts derive their power to transmit motion from the friction between the surface of the belt and the pulley, *and from nothing else,* and are governed by the same laws as in friction between flat surfaces.

The friction increases regularly with the pressure; the more elastic the surface the greater the friction.

To obtain the greatest amount of power from belts, the pullies should be covered with leather; this will allow the belts to run very slack and give 25 per cent. more wear.

Pitch of the Teeth of Wheels.

The *pitch* of the teeth of wheels is the distance apart from centre to centre of the teeth, measured on the pitch circle.

The *pitch circle* or *pitch line* is the circle passing through the body of the teeth, which expresses the circumference of the wheel.

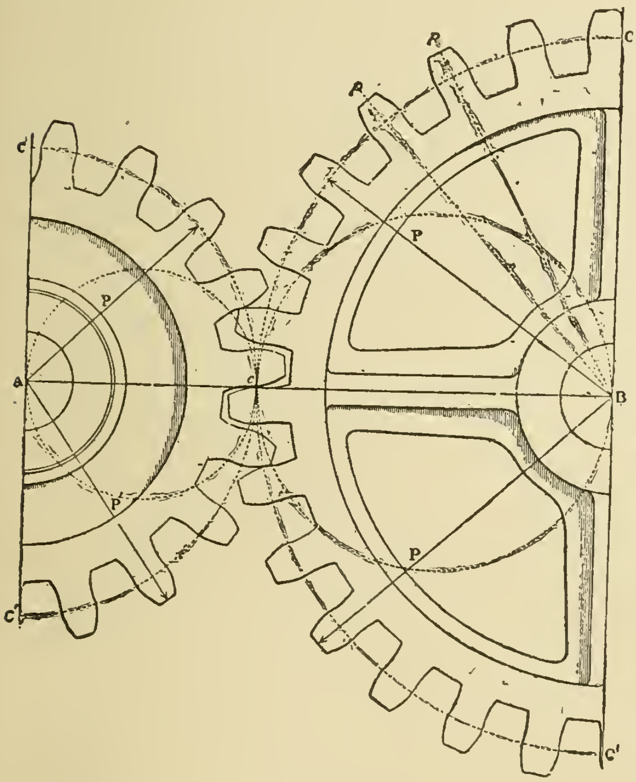


Fig. 133.

In the annexed Fig. 133, showing the halves of a wheel and a pinion in gear, A B is the line of centres, and C C and C C are the pitch circles touching at c; the divisions A c and B c, of the line of centres, being the pitch-radii of the wheels. The arc of the pitch-circle, between p and p, is *the pitch of the teeth,* and it comprises a tooth and a space.

In all *calculations for speed* of toothed gears, the estimates are based upon the pitch line, the latter standing in *the same place as the circumference of a pulley.*

THE PROPELLER WHEEL.

This is one of the most useful devices in the line of marine steam navigation; it ranks as an invention, next to the marine engine; it is to the steam vessel, what the exhaust-draught is to the locomotive, and its comparative proportions have been the subject of long and costly experiments.

The propeller wheel consists of 2, 3, or 4 spiral or twisted blades, fastened to the main driving shaft of the vessel, where it comes through the stuffing boxes at the stern.

The diameter of the propeller wheel is the diameter of the circle described by the extremities of the arms or blades.

THE PROPELLER WHEEL.

The pitch of the propeller, is the distance it would advance in a solid substance in one complete turn—like the turn of a screw. *A true pitched propeller,* is one whose blade has the same pitch throughout; *an increasing pitched propeller* has blades whose pitch increases towards the tip, the decrease at the base being usually from 10 to 15 or 16 per cent. on the pitch at the tip.

By "*slip*" is meant the difference between the actual advance of the propeller through the water, and the advance which would be made if the blades were working in a corresponding grooved solid body; hence *the apparent slip* is the difference between the velocity of the ship and the velocity of the screw—*the real slip* is the difference between the speed of the screw and the speed of the water fed to the screw. The latter is frequently modified by the propeller wheel turning in the "eddy" or column of water which follows the ship, instead of in the stationary water of the sea.

METHOD OF FINDING THE PITCH OF A PROPELLER.

To find the pitch of the blade, take a lath from the stern post, and put it just touching the leading edge of the blade,

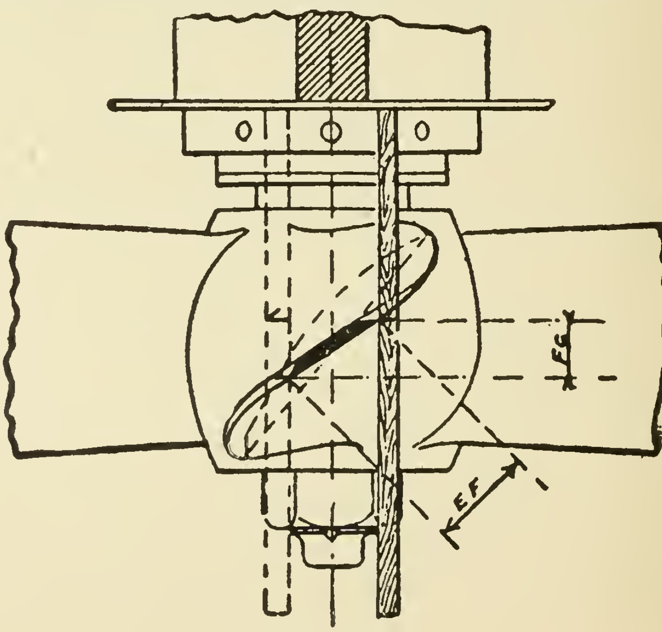


Fig. 134.

and scrieve the lath and blade, shift it to the following edge at a point on the blade exactly opposite where the first pop was put, scrieve the blade and lath again. The distance between

FINDING THE PITCH OF A PROPELLER.

the marks on the lath F G is piece of the pitch ; on the blade, E F piece of the thread ; square each of these, and subtract one result from the other ; now extract the square root of remainder, and this will give piece of circumference ; take the circumference of the propeller at the place where the measurements were taken, and make a proportion as follows :

As piece of circumference : whole circumference : : piece of the pitch : whole pitch. Answer.

The above may be made clearer to some by the following :

A c : C : : p : P

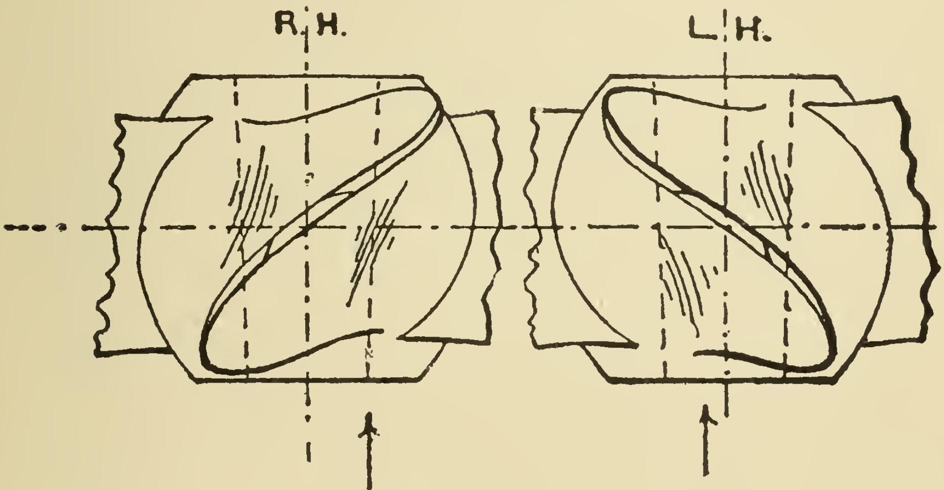


Fig. 135.

A left-handed propeller is a screw with a left-handed thread, and a right-handed one has a right-handed thread ; therefore, a left-handed propeller to move the ship ahead goes from right to left, and a right-handed propeller turns from left to right : *looking from the stern of the ship to the engine room and the engines passing the top centre.*

THE SLIDE VALVE.

Notwithstanding its extreme simplicity as a piece of mechanism, no part of the engine is more puzzling to the average engineer in those questions relating to the lap and lead best to be given it, the amount of clearance, the proper point of cut-off, etc., hence the following date is introduced to aid the student in acquiring the first points necessary to be known in practice. It is nearly always a matter of years of study and observation before one becomes familiar with the subject.

Putting an Engine on the Centre.

Place the engine in a position where the piston will have very nearly completed its outward stroke, and opposite some point on the cross-head (as a corner); make a mark upon the guide, as shown at A in the accompanying figure. Against the rim of the fly-wheel place a pointer as at B and make a mark upon the wheel opposite this pointer when the cross-head is in line with the mark A upon the guide. Now turn the engine over the centre until the cross-head is again in the same position on its downward stroke. This will bring the crank as much below the centre as it was above before, being now in the position indicated by the dotted lines; and the point C on the fly-wheel will be opposite the pointer and should be marked. Divide the distance between B and C accurately, and midway between them mark the point D. When D is brought opposite the point in the position which B occupies in the figure the engine will be upon the true centre.

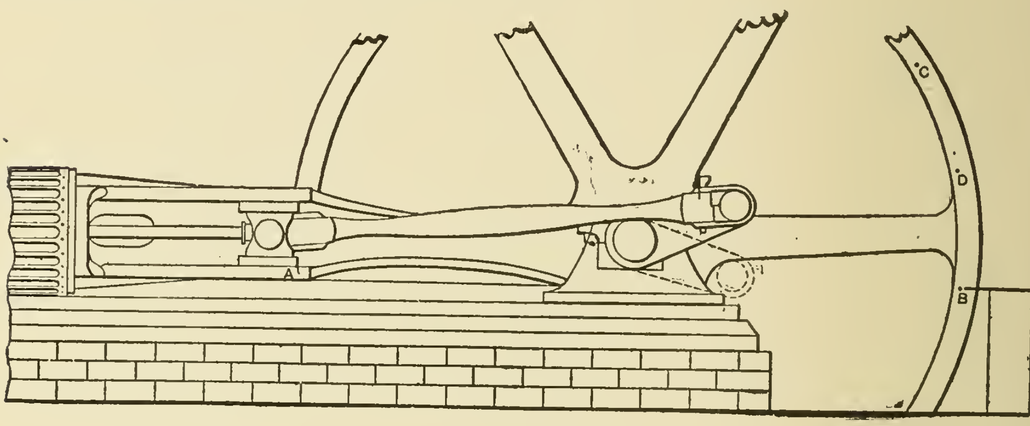


Fig. 136.

To place the Eccentric at right angles to the Crank when the Piston is at either end of the stroke.

1. Fasten a planed board at the eccentric side of the engine, in such a position that it will come under the eccentric rod.

2. Put on the straps and rod loosely.

3. Then hold, or fasten a pencil to the rod, and have an assistant turn the eccentric once around, holding the pencil so it will mark the exact travel of the rod on the board.

TO GET ECCENTRIC AT RIGHT ANGLES.

4. Find the centre of this line with a pair of dividers or a rule.

5. Turn the eccentric up until the pencil comes to the centre of line.

6. Now fasten the eccentric so it wont slip. It is now at right angles to the crank.

Directions for Setting the Slide Valve.

Putting everything very accurately in the central position is the quickest and easiest way to set all valves. The rule is especially true of the common slide valve. The dotted line at A B, Fig. 137, shows the centre of the valve and valve seat.

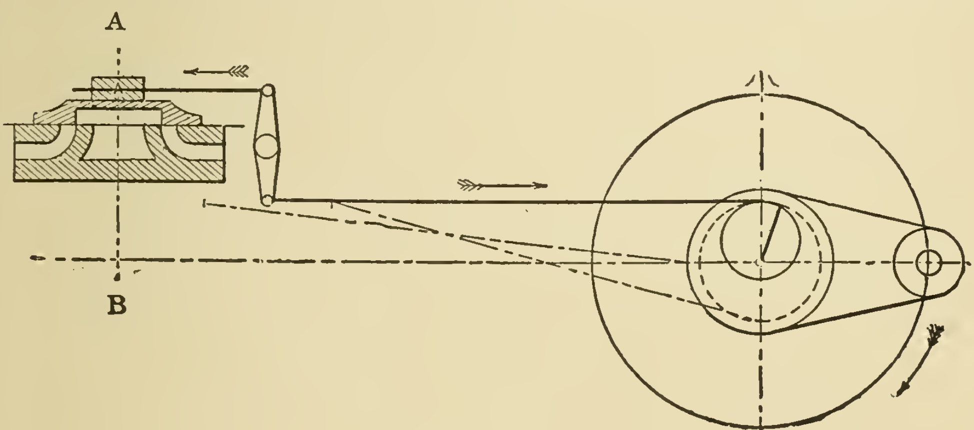


Fig. 137.

To set the Slide Valve.

Study directions for putting the engine on the dead centre and observe Figs. 137 and 138 which represent a common slide valve and the eccentric. The direction of motion is shown by the arrows.

1. Set the crank on the forward dead centre.

2. Next find the exact centre of the valve and mark it with a fine line in such a manner that the line will show on top of the valve; also find the centre of all the parts, as shown at A, Fig. 137; mark a fine line running up the side of the steam-chest so it can be seen above the valve.

TO SET THE SLIDE VALVE.

3. Then place the valve over the parts, as shown in Fig. 137, and bring line on valve and line on steam-chest, so they are together. This puts the valve in its central or neutral position.

4. Put in the rod and connect it to rocker-arm ; plumb the rocker with a plumb-line and bob, so that the centre of eccentric rod pin will be cut by the line, and screw jamb nuts up to the valve with the fingers ; now fasten the valve so it can't move. Valve, rocker and eccentric are now in the neutral position, and temporarily fasten.

5. The eccentric rod must now be brought into such a position that it will hook into the rocker-arm without moving it ; now turn the eccentric the way the engine is to run until it has the proper lead or opening. If accurately done, the valve is properly set. To prove it put the engine on the other centre, and if the lead is the same, fasten everything. The valve is set.

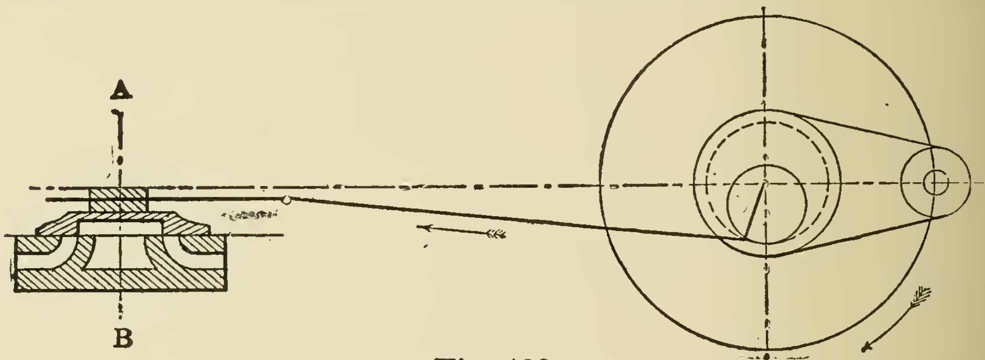


Fig. 138.

Fig. 138 shows the position of eccentric on a direct acting engine when both engines (Figs. 137 and 138) are running in the direction indicated by the arrows.

Emergency Rule for Setting Slide Valves.

If the eccentric slips around the shaft, or any other accident throws the valve-gear out of position, then,

1. Have some one roll the engine forward in the direction it runs until the crank is on the dead centre.

2. Open the cylinder cocks at each end.

3. Admit a small amount of steam into the steam-chest by opening the throttle slightly.

4. Roll the eccentric forward, *in the direction the engine runs,* until steam escapes from the cylinder cock at the end where the valve should begin to open.

EMERGENCY RULE FOR SETTING SLIDE VALVES.

5. Screw your eccentric fast to the shaft.

6. Roll your crank around to the next centre, and ascertain if steam escapes at the same point, at the opposite end of the cylinder. If so, the valve is in position for service, until an opportunity occurs to open the steam-chest and examine the valve-gear.

To take Laths from the Valve and Valve Seat.

This is done so that there may always be a permanent record kept of all sizes, &c., of the valve face.

Fig. 139.

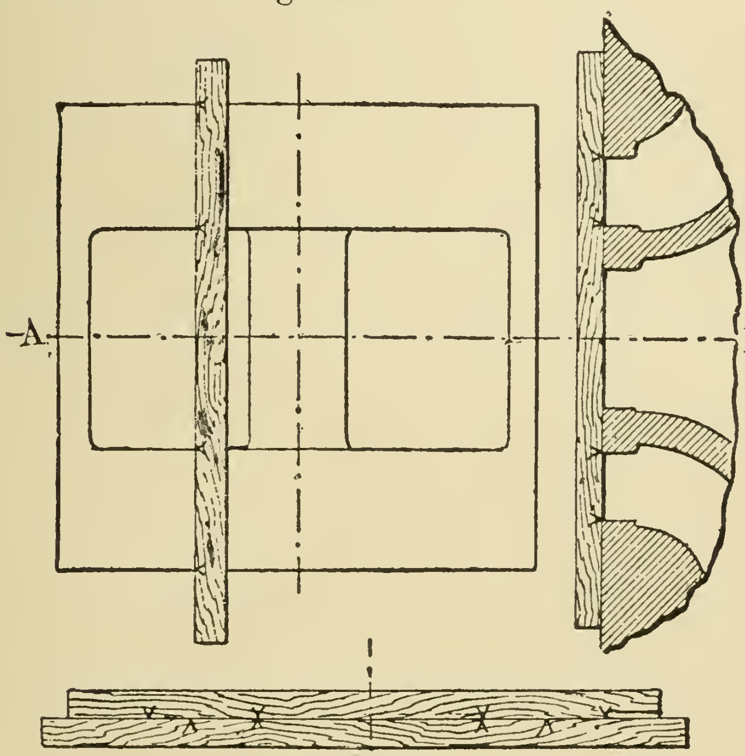


Fig. 140.

Fig. 141.

We will suppose that the valve is off and lying on its back on the engine room floor. Take a lath and lay it on the valve face and scrieve a mark at each edge of the valve faces (see Figure 140), that is at each steam and exhaust edge, next put a lath on the valve seat (Figure 139), and mark on it the position of the steam ports, bars and exhaust port. Now lay the laths alongside each other as in Figure 141; and see if both exhaust edges of the valve agree with the exhaust edges of the steam ports, if they do, well and good, it can be seen by these marks how much steam lap, &c., there is, as well making sure that everything is in its proper central position.

Steam Expansion.

When steam is admitted to a cylinder during a portion of the stroke, then cut off, and expanded in the cylinder, upon the piston, for the remainder of the stroke, the pressure on the piston, during the period of admission, is or ought to be uniform, *while the pressure during the period of expansion falls as the piston advances and the steam expands.* In engines in good working order, the expansion follows substantially the law of Boyle, or Mariotte, according to which *the pressure falls in the inverse ratio of the expansion,* the temperature remaining constant.

Substantially, it is said, for the actual changes of pressure seldom follow the law exactly. The pressure usually falls more rapidly in the first portion of the expansion, and less rapidly in the last portion, than is indicated by the law ; and thus the final pressure may be, and it usually is, greater than that which would be deduced from the ratio of expansion.

But the fullness of the expansion-curve shown on the indicator-diagram, near the end, compensates for the hollowness near the beginning ; and, sinking details, it is found that, practically, the area bounded by the curve is equal to that which would be bounded by a curve formed according to Mariotte's law.

It is, therefore assumed, for purposes of illustration and the calculation of power, that the expansion of steam in the cylinder takes place according to Mariotte's law.

That is to say, if steam of 20 lbs. pressure per square inch be allowed to expand *into double the space,* the pressure will be 10 lbs ; of triple, $6\frac{2}{3}$ lbs.; if 4 times, 5 lbs ; if 5 times, 4 lbs ; and so on. This theory would be literally correct did the temperature remain constant, but it is near enough to be considered all that is ever required, and from its extreme simplicity, is universally adopted.

STEAM EXPANSION.

In other words, the product of the volume and pressure is always constant. All calculations must be made in absolute pressures; 100 pounds by the gauge equals approximately 115 absolute. Starting with *one* volume at 115 pounds pressure and expanding to fill the second space, we should have two volumes at $57\frac{1}{2}$ pounds pressure. An expansion to three volumes would reduce the pressure to $38\frac{1}{3}$, and to four to $28\frac{3}{4}$. The products of the volumes and pressures are always constant:

Volumes		Pressures		
1	×	115	=	115
2	×	$57\frac{1}{2}$	=	115
3	×	$38\frac{1}{3}$	=	115
4	×	$28\frac{3}{4}$	=	115

It would take as many expansions to reduce a gauge pressure of 100 pounds to atmospheric pressure as 15 is contained in $115 = 7\frac{2}{3}$.

Gain From Steam Expansion.

If the flow of steam to an engine be cut off when the piston has made half its stroke, that is, if it is used expansively, it has been ascertained that the efficiency will be increased *one and one seventh times* beyond what it would have been if the steam at half stroke had been released into the atmosphere, and so on, as expressed in the following

Table.

Cutting off at $\frac{1}{10}$ the stroke, efficacy is increased 3.300 times.
Cutting off at $\frac{1}{8}$ the stroke, efficacy is increased 3.000 times.
Cutting off at $\frac{2}{10}$ the stroke, efficacy is increased 2.600 times.
Cutting off at $\frac{1}{4}$ the stroke, efficacy is increased 2.386 times.
Cutting off at $\frac{3}{10}$ the stroke, efficacy is increased 2.200 times.
Cutting off at $\frac{3}{8}$ the stroke, efficacy is increased 1.080 times.
Cutting off at $\frac{4}{10}$ the stroke, efficacy is increased 1.020 times.
Cutting off at $\frac{1}{2}$ the stroke, efficacy is increased 1.690 times.
Cutting off at $\frac{6}{10}$ the stroke, efficacy is increased 1.500 times.
Cutting off at $\frac{5}{8}$ the stroke, efficacy is increased 1.470 times.
Cutting off at $\frac{7}{10}$ the stroke, efficacy is increased 1.350 times.
Cutting off at $\frac{3}{4}$ the stroke, efficacy is increased 1.280 times.

THE STEAM ENGINE INDICATOR.

The indicator is an instrument used for the purpose of recording the pressure of the steam in the cylinder, at all points of the stroke, as the piston moves to and fro. This is done on a piece of paper secured to a revolving drum, by a pencil attached to the indicator piston.

The indicator is said to have been invented by James Watt, but it was at first vastly inferior in finish and accuracy to the improved forms of the Richards, Thompson, Crosby or Tabor indicators which are now largely in use; these are all substantially of the same construction and act upon the same principle.

Each consists of a small cylinder accurately bored out and fitted with a piston capable of working in the cylinder with little or no friction and yet practically steam tight; the piston rod is attached to a pair of light levers at the end of one of which is carried a pencil designed to move on a nearly up and down line.

The motion of the piston is controlled by a spring of known tension, several of which are furnished with each instrument; each spring is marked to show at what boiler pressure of steam it is to be used. The elasticity of the spring is such that each pound pressure on the piston causes the pencil to move a certain fractional part of an inch.

With Richard's Indicator there are 10 springs used; No. 1 will measure pressures from perfect vacuum, or 15 lbs. *below* the atmosphere to 10 lbs. *above* the atmosphere; No. 2 from $-$ 15 lbs. to $+$ $22\frac{1}{2}$ lbs.; No. 3 from $-$ 15 lbs. to $+$ 35 lbs.; No. 4 from $-$ 15 lbs. to $+$ 47 lbs.; No. 5 from $-$ 15 lbs. to $+$ 60 lbs.; and No. 6 from atmospheric pressure, or 0 lbs. to $+$ 86 lbs.; No. 7 from 0 to 100 lbs.; No. 8, 0 to 125 lbs.; No. 9. 0 to 150 lbs.; and No. 10, 0 to 175 lbs.

Attached to the instrument is another hollow cylinder which has a diameter of about two inches, around which is placed the paper, the ends passing underneath a piece of slit brass, fitted so that the paper can be held firmly after being wound round.

This cylinder is capable of a reciprocating or semi-rotative motion on its axis of such an extent that the extreme length of diagram may be 5 inches.

THE INDICATOR.

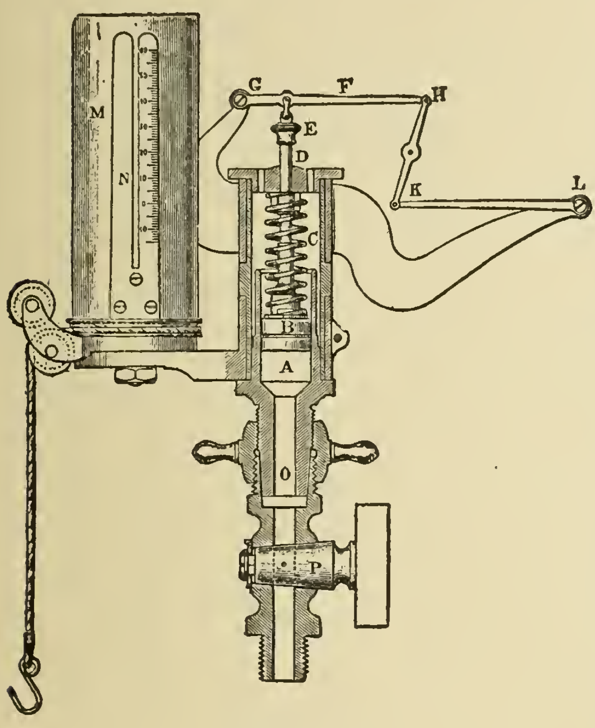


Fig. 142.

The part A is a steam cylinder containing a piston B. The part of the cylinder below the piston can be placed in connection with either end of the engine cylinder. Above the piston is a spiral spring, C. D is a piston, to the head of which, E, it would be easy to fasten a pencil, the point of which could be made to press against a piece of paper, and by its upward and downward motion register the steam pressure beneath the piston.

The diagram records the following facts and operations, viz.:

1. The exact point of the stroke at which steam is admitted.

2. The initial pressure of the steam in the cylinders, which being compared to the boiler pressure, shows us whether the steam pipes and passages are of the necessary dimensions.

3. The way in which the initial pressure is maintained or otherwise during the period of admission.

4. The point of cut-off.

5. The pressure during the whole period of expansion.

6. The point of release, *i.e.* when the exhaust is opened.

7. The rapidity with which the exhaust takes place, as shown by the nature of the exhaust curve.

8. The minimum back pressure, which in a condensing engine is also the test of the perfection of the vacuum, and in a non-condensing engine shows what the effect of the friction of the exhaust pipes and passages is in addition to the unavoidable pressure due to the atmosphere.

9. The period when the exhaust is closed.

10. The nature of the curve of compression.

11. The power which is being given off by the engine.

THE INDICATOR.

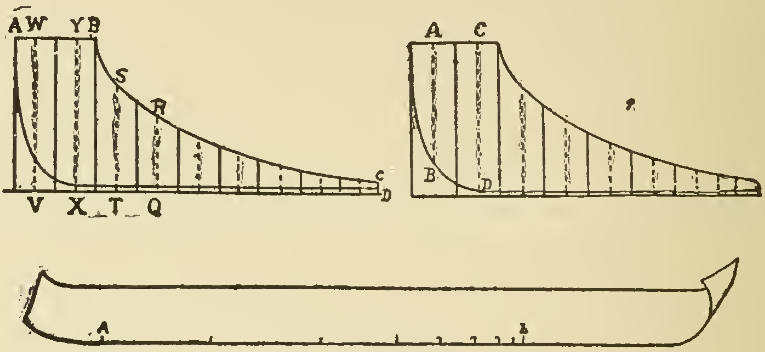


Fig. 143.

In the figure, *A B C D* represents a card taken from a non-condensing engine. To find the average pressure from it, we divide the line *V D* into equal spaces, as shown in the cut. Half way between every two vertical lines a dotted line is drawn, and *the length of each dotted line is taken to represent the average pressure between the vertical lines on either side of it.* Then the average of all the dotted lines will represent the average pressure during one stroke of the engine.

The most convenient method of measuring the dotted lines is by means of a long paper strip. Place the edge of it along the line *V W* and make a small mark opposite both *V* and *W*. Then move the paper strip so that the same edge lies along the line *X Y* and so that the mark that was opposite *V* now comes opposite *Y*. Then mark the point *X*, and so proceed. When the whole card has been measured in this way, the strip will look something like the lower cut of Fig. 143.

A is the first mark and *B* is the last. The distance *A B* is next measured, and the result is divided by the number of dotted lines that are laid off along it. This gives the average length of the dotted lines, and therefore it represents the average pressure during the stroke of the engine.

The length of the indicator diagram, multiplied by the average height of it, will give the area of it; so that after having found the average height (or width) of it we can find the area of it if we wish to. On the other hand, if we know the area of the card, we can find the average width of it by dividing the area by the length.

To work out an Indicator Card for a Low Pressure Engine.

1. Divide the Card into ten equal parts by lines perpendicular to the atmospheric line.

2. Measure the width of the card at the middle of every one of these parts on the scale.

3. Add these measurements together and divide the sum by ten, the result is the mean pressure on the piston per square inch throughout the stroke.

What is the mean pressure throughout the stroke in the following :—

Scale $\frac{1}{20}$ of an inch = 1 l

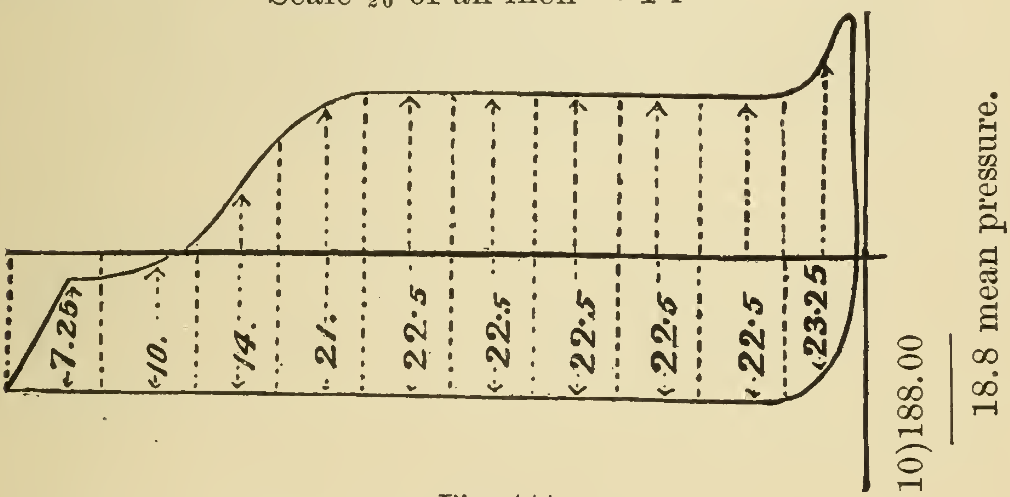


Fig. 144.

Answer, 18·8 lbs. per square inch.

If the diameter of the pair of cylinders from which the above diagram was taken was 52″, the length of stroke 42″, the revolutions per minute 41, the steam gauge showing 15 lbs., the vacuum gauge 21″, what is the indicated horse power ?

In finding the I. H. P. the heights of steam and vacuum gauges and the barometer are not needed, but they are generally noted on the paper on which the diagram is drawn.

The pressure shown by the steam gauge is useful to the engineer, because it enables him to see what is the loss of pressure between the boiler and the cylinder ; for instance, in the diagram in the full steam line is 12 lbs. above the atmospheric line, and the steam gauge showed 15 lbs. ; therefore there was a loss of 3 lbs. ; but for the purpose of finding the H. P., we only require to know the mean pressure throughout the stroke; in our diagram it is 18·8 lbs. Now then,

$$\frac{52^2 \times \cdot 7854 \times 18 \cdot 8 \times 287 \text{ feet}}{33{,}000} = 347.235 \text{ feet 1 cylinder.}$$

$$\frac{2}{694.470 \text{ for the pair.}}$$

EXAMPLES.

This cut represents a diagram taken by C. W. Simmons, from a $12'' \times 24''$ automatic engine, speed, 126 revolutions, scale 40 lbs. boiler pressure 78.6 lbs., M. E. P. 46.41 lbs., H. P. $80\frac{18}{100}$

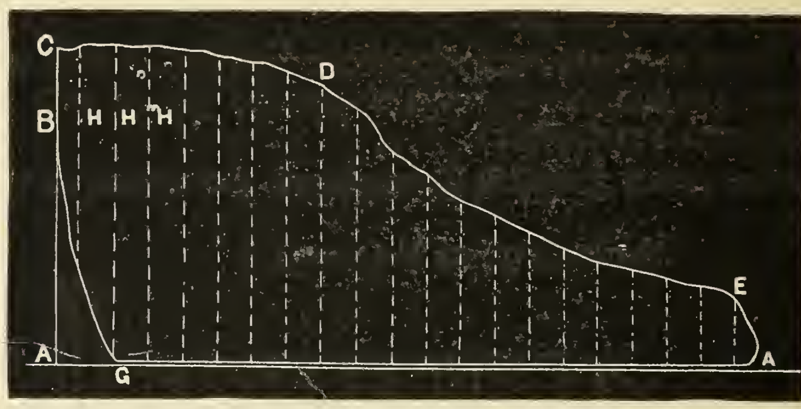


Fig. 145.

Explanation: A. A.—Atmospheric line, which is drawn with the atmosphere admitted to both sides of the indicator piston. B. C.—Admission line. C. D.—Steam line. D.—Point of cut-off. D. E.—Expansion curve. E.—Exhaust. E. F.—Exhaust line. F. G. Counter pressure line. G.—Point of exhaust closure. G. B.—Compression curve. H. H. H.—Lines drawn for the purpose of ascertaining the average pressure.

Example 2.—Find the mean effective pressure in the cylinder of a condensing steam engine when the pressure of steam on admission is 80 lbs. absolute, cut off at one-fourth of the stroke. Back pressure 3 lbs. per square inch.

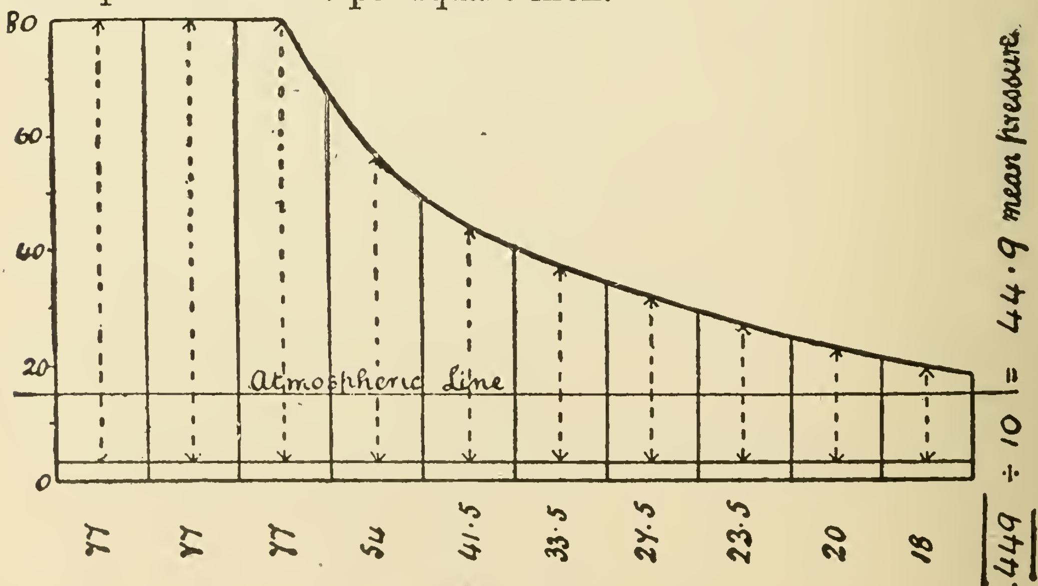


Fig. 146.

Principal Causes Affecting the Forms of Diagrams.

1. The friction of the steam pipes and ports.

2. The variable size of the opening of the steam ports as caused by the gradual motion of the slide valve.

3. The action of the sides of the cylinder in causing condensation and partial re-evaporation of some of the entering steam.

4. The steam contained in the clearance spaces which affects the curve of expansion.

5. The gradual opening of the exhaust port, which makes it necessary to release the steam too early in the stroke.

6. The friction of the exhaust passages.

7. The momentum of the moving parts which combined with cause 4 and also with the unavoidable nature of the simple slide valve driven by an eccentric, renders a curve of compression necessary.

The only absolute information the diagram conveys, whatever its form, is the pressure in the cylinder of the engine. All the other information to be had from it comes through a process of reasoning based upon experience and observation.

In order, also, that the diagram shall be correct, it is essential, first, that the motion of the drum and paper shall coincide exactly with that of the engine piston, and second, that the motion of the pencil shall correspond with the other motions described.

It is beyond the province of this work to much more than explain and illustrate the calculating of the diagram *after it shall have been obtained;* to do the latter accurately, it is necessary to use that skill which alone comes with practice.

Note.

The passage of steam into either end of a cylinder may be distinctly heard by putting a rule, a piece of wood or a piece of iron between the teeth, stopping the ears with the fingers, and putting the free end of the piece of wood or iron against the cylinder. Both ends of the cylinder may be "heard" in turn; both pillow blocks may be tested in the same manner for lost motion, and the steam-chest may be tried for end motion in the valve connection.

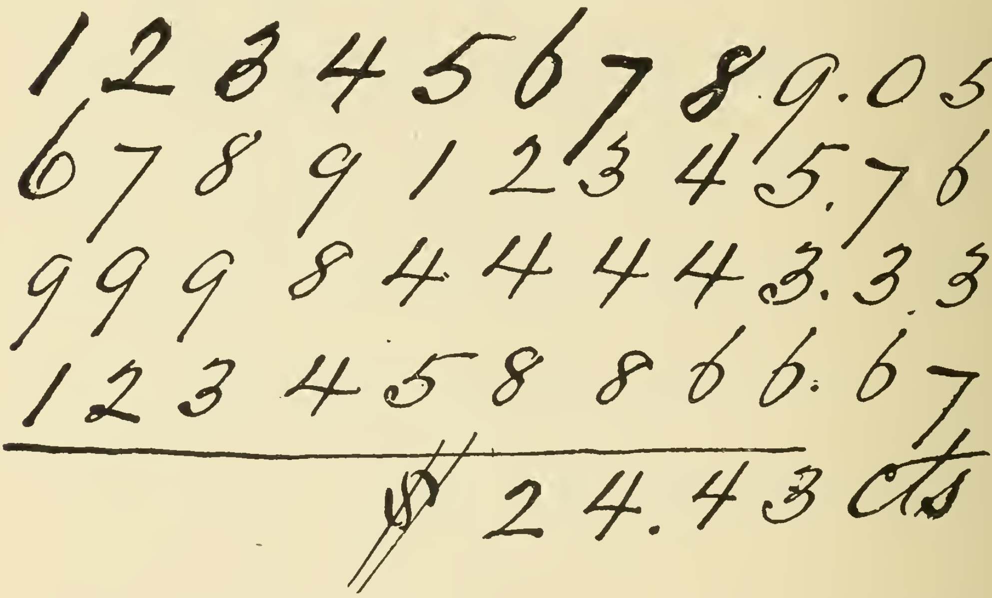
BUSINESS FORMS FOR ENGINEERS.

When the engineer comes in contact with men and the business of life, he needs another set of calculations from those he uses in dealing with the natural and mechanical forces. The following are designed to aid him in this direction, reference being made to the table of wages, page 33, and the table of days, page 295.

How to Make Figures.

Clearly made figures, neatly placed in their appropriate position for adding, subtracting and dividing, etc., are most agreeable to the eye, both of the maker and reader. It is worth much effort to acquire a ready faculty in this direction.

Fac Simile of the Author's Figures.



In this system of forming the numerals, it will be observed the heighth of the whole nine digits is nearly uniform *i. e.* the *o* which forms part of the 6 and the 9 is made as long as the cypher when placed alone; that the top of the 7 is lined with the top of the 8, the stem coming as far down as does the stem of the 9, while the stem of the 6 extends as far upwards as does that of the others downward.

The above specimen of *written figures* is presented as a model for practice in writing down the numerals.

Bills.

A Bill is a formal written statement of goods sold or services rendered, or both.

Every bill contains : 1. A date ; 2. The debtor's name ; 3. The creditor's name, after the words *Bought of,* or between the words *To* and *Dr.;* 4. The statement of goods sold or of services rendered, or of both, with prices and amounts.

When the bill is for goods, the expression *Bought of,* is generally employed ; when for services, or for both goods and services, the word *Dr.* is used. When this word is used, each item is usually preceded by the word *To.*

The bill is *made by the creditor,* and by him *presented to the debtor* for payment.

There are two parties to every bill, a *creditor* and a *debtor.*

The Debtor is the person who receives the goods or services or both, and who therefore owes for them.

The Creditor is the person who supplies the goods or renders the services, or does both.

When the debtor pays the bill, the creditor *receipts* it, or acknowledges the payment, by writing his name on the bill, under the words *Received Payment.*

Where to use Capital Letters.

1. Begin with a capital *the first word of every sentence.*

2. Begin with a capital *every proper name.*

3. Begin with a capital *titles of honor and respect.*

4. Begin with a capital *all appellations of God.*

5. Begin with a capital *the days of the week and months* of the year.

6. Write with capitals *the pronoun I and the interjection O.*

9. Begin with a capital *the words North, South, East, and West,* when they denote a section of country.

Business and Law Points.

The law compels no one to do impossibilities. Notes bear interest only when so worded. Agents are responsible to their principals for errors. Ignorance of the law excuses no one. Principals are responsible for the acts of their agents. Contracts made on Sunday cannot be enforced. A contract made with a minor is invalid. A contract made with a lunatic is void. It is a fraud to conceal a fraud. Signatures made with a lead-pencil are good in law. Each individual in a partnership is responsible for the whole amount of the debts of the firm. A receipt for money paid is not legally conclusive. An agreement without consideration is void. A note given by a minor is void. The acts of one partner bind all the others. It is not legally necessary to say on a note "for value received." A note drawn on Sunday is void.

Letters.

Every letter consists of six parts, as follows: 1. Date; 2. Address; 3. Salutation; 4. Body; 5. Subscription; 6. Superscription.

The Date is a statement of the place and time of writing.

The Address is the name of the person to whom the letter is written.

The Salutation is the brief expression of greeting which immediately precedes the body of the letter.

The Body of the letter is the communication itself. It consists of divisions, as there are subjects discussed.

The Subscription consists of expressions of regard or compliment with which the letter closes, and the signature.

The Superscription is the full and particular address written on the envelope.

Daily Memorandum Book.

Each engineer should keep a book of convenient size wherein to write down, from day to day, *all items of business engagements, new mechanical facts, rules and processes.* This corresponds to a journal in a set of books, and the items, if written *seriatim,* i. e. one after another, are evidence in a court of law.

Cash Received and Paid Out.

Money being the nerve centre of modern industry, it were well for the engineer to keep an accurate record of the smallest sum which passes through his hands *for any purpose.* This is best done in a separate book or memorandum, which may be called the cash-book. This can be ruled into one wide space and three small spaces—as shown in the example.

In these four spaces there should be kept. 1. The date. 2. The particulars of the cash transaction. 3. The cash received, and 4. Cash paid out.

Example.

Date.			Receiv'd $	cts	Paid out $	cts
1890.						
Jan.	1	*Cash on hand in Savings Bank .....*	100	00		
		" " " " currency and silver.	42	80		
		Paid one month's rent to W. J. Jones			40	00
	10	*Rec'd for sub-rent of W. Williams...*	18	00		
		Paid house expenses to date from Jan. 1			16	40
		" for subscript'n to paper for 1890			1	00
	11	*" dues to Engineer's Association to date....................*			2	58
		Rec'd for two week's wages M. Mfg. Co., $22.00................	44	00		
	15	*" from firm to buy files, etc......*	4	00		
		Paid for files, 75c.*; waste,* 1.25*; monkey wrench,* 1.00..........			3	00
		Paid for gaskets for boiler H. holes..			1	00
	20	*" plumber for work at house.....*			8	00
		" for stove $15*;* 1 *bbl. of flour* $6.			21	00
	24	*" payment on house and lot (total paid* $600)...............			25	00
		Rec'd interest on balance in Savings Bank.....................	4	80		
	25	*" two week's wages M. Mfg Co. @* $22.......................	44	00		
	31	*Paid family expenses to date........*			23	60
		" personal expenses for month, daily paper, car fare, etc...			4	00
		" to Savings Bank, (interest added)			4	80
		On hand..........................			112	22
			257	60	257	60

In this model the second month (Feb. 1890) would begin with *Cash on hand,* $112.22 and then the new month's entries would follow in their order.

BOOK OF RECORDS.

Month 189	Day of Week.	Av. B. Press. per gauge lbs.	Hours run.	Vacuum per gauge inches.	Piston Speed per min.	Ind. H. P.	Temp. of Hot Well.	Temp. of Feed.	Fuel Burned lbs.	Ashes.	Oil used.	
	MON.											
	TUES.											
	WED.											
	THU.											
	FRI.											
	SAT.											
	SUN.											

Records.

A general record or log book should be kept in which to record each time the engine is started and stopped.

There also should be noted the average steam pressure and vacuum for the day, the temperature of engine room, injection and discharge of water.

Pasted into this same record should be indicated diagrams worked up for each cylinder, care being taken that they represent, as nearly as possible, the average performance for the day.

A form of a diagram is here presented, which the engineer can follow in ruling a book to suit his own steam plant, modifying it so as to fit the surrounding circumstances.

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AND USEFUL DEFINITIONS.