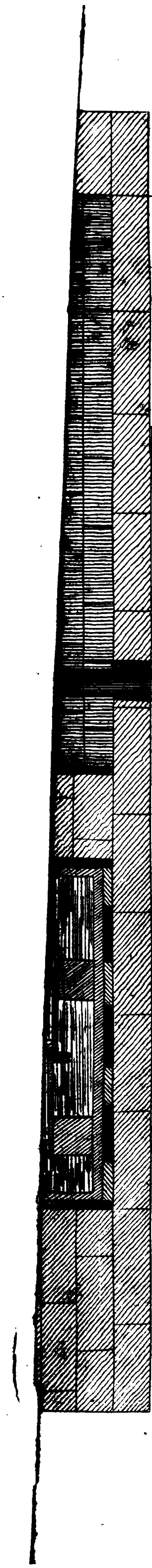

THE

SCIENCE OF MECHANICS,

AS APPLIED TO THE

Present Improvements in the Useful Arts

IN

EUROPE, AND IN THE UNITED STATES OF AMERICA:

ADAPTED AS A MANUAL

FOR MECHANICS AND MANUFACTURERS,

AND CONTAINING

TABLES AND CALCULATIONS OF GENERAL PRACTICAL UTILITY.

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PREFACE.

The recent improvements in machinery have given new and increasing importance to the science of Mechanics. The skill of modern artists seems almost to have endued wood and iron with a degree of intelligence, in the surprising operations accomplished by various machines. These improvements have advanced manufactures to a high relative rank in the scale of national interests. It is not the effeminate employment at the distaff of ancient times that is now understood by the term, Manufactures, but vast operations performed by means of mechanical inventions, whereby a common individual is enabled to accomplish more than the fabled labours of Hercules. So necessary to the wants of life at the present day are the products of machinery, that the Steam Engine has become almost as important as the plough; and the most remarkable achievements even in commercial intercourse are performed by its agency. Instead of indulging in the abstract and profitless investigations, once so common, philosophers seem now rather to delight in researches into nature for the purpose of making discoveries applicable to the useful arts.

The science of Mechanics truly demonstrates that "knowledge is power." By the aid of a few simple machines, combining the principles of the mechanical powers, the feeble strength of man is rendered adequate to moving with facility vast masses of matter, and to performing all the complicated and delicate operations of the useful arts, to which society is mainly indebted for the present advanced state of civilization and refinement. The importance of a knowledge of the science of Mechanics to the daily wants and comforts of almost every individual member of society, renders the study of it interesting to the scholar and the gentleman, as well as to those who are by profession devoted to its practical details.

The high price of labour in the United States has had a tendency to direct the genius of the people to all descriptions of mechanical inventions, from the simple apparatus for paring an apple, to the machinery for propelling a vessel of war. There is among all classes of people in this Republic a vivacity of inquiry, and an intelligence upon subjects relating to Mechanics—some of the most important improvements in Mechanism having been made by professional gentlemen and merchants. Indeed, all the energies of man are called forth in a youthful and flourishing country blessed with free institutions, and abounding with all the natural advantages which a variety of climates and a soil rich in vegetable and mineral productions can afford.* In such a country it becomes a pleasing though humble task to endeavour to advance the improvements in the useful arts, a cause in which success must be beneficial to the whole human race.

During a tour through the most interesting districts of England and France, my attention was principally directed to the latest improvements in mechanical inventions in those countries. Having had occasion previously to acquire a degree of information upon this subject, from personal observations, as well as from the writings of the best authors, a mass of notes and practi-

* "Youthful nations" (observes a late writer in the Quarterly Review) "will be quicker than Europe, and in our own vigorous children in the United States of America we already see the generations that in reason and industry are destined to stand beside Englishmen."

cal remarks became thus gradually collected. The extracts and tables gathered from various quarters must, of course, form a very considerable portion of an elementary work, in which it must also be very difficult to designate the name of each author, whose opinions may be quoted. Various Rules and Tables have been inserted, by means of which the engineer or mechanic may speedily perform most of the calculations that ordinarily occur in the practical details of his business.

There is probably no mode in which a greater amount of property may be more rapidly dissipated and wasted, except perhaps at the gaming table, than in the construction and management of mills and machinery by those incompetent to the task from a want of proper practica knowledge. Every false calculation is attended with costly expenditures, and loss of labour in manufacturing operations. At some of the American mills which have been erected only a few years, various kinds of machinery, abandoned after a course of unsuccessful experiments, may be found collected as rubbish, forming a sort of museum of injudicious and abortive contrivances.

The whole subject of this branch of Natural Philosophy, has been arranged in a manner that appeared the most favorable for explaining the first principles of the Science as practically applied to the useful arts, and for introducing such remarks in relation to them as personal observations—the result of no inconsiderable share of labour and expense, have enabled me to make. They are offered to the public, with the hope that they may prove serviceable in aiding intelligent freemen in their exertions for success in various branches of industry, and in accomplishing the "triumph of mind over matter."

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THE SCIENCE OF MECHANICS.

THE Sciences as they are termed, have been divided into three classes. The first class, relating to Matter and the properties of the various bodies with which we are acquainted by means of our senses, is called Natural Philosophy. The second class, relating to number quantity and computation, is called Mathematics; and lastly that which relates to mind or intellect, and the moral nature of man, is called Moral Philosophy.

The ancients divided Natural Philosophy into two classes, Rational and Practical. The one they considered as demonstrable by reason, whilst the other they seem to have regarded merely as presumptively true, or probable from their imperfect experiments performed by means of various instruments or machines. Whatever was demonstrable by accurate reasoning was referred to Geometry, and what was found to be practically true, although not thus demonstrable, to Mechanics. Sir Isaac Newton observes, that this inaccuracy of result should have been attributed rather to the artists themselves than assigned as the ground for a distinct division of the Science of Natural Philosophy; for whenever the demonstrations of science show a result different from that produced by nature, the error must be in the demonstration. The term "Mechanics" has continued to be applied to the *practical* operations of machinery and to the demonstrations of this branch of philosophy

In the theory of the mechanical powers, bodies are supposed to have surfaces perfectly smooth; levers to have no weight; cords to be perfectly pliable; the parts of machines to have no friction, and to possess strength adequate to sustaining the stress assigned to them in theory.

Since matter forms the material of which machines are constructed, as well as the subject upon which they must operate, in order to arrive at any certain calculations upon the effective force or operations of machines, a skillful mechanic must have a knowledge of the various properties of matter, and of the various laws and modifications to which it is subjected. Gravitation, Cohesion, Electricity, Galvanism and Heat have an influence not only upon the machines which he employs, but also upon the materials exposed to their action. Before entering upon the investigation of the laws of Motion and Force, upon which the Science of Mechanics is principally founded, we shall give a brief sketch of these Natural Powers as affecting the weight, strength, hardness, fluidity, and even forms of material substances.

Allowance must also be made for all the difference between theory and practice, arising from various causes. From the resistance of friction alone, it has been observed by Mr. Ferguson, there are few compound machines that do not require a third part more power to work them when loaded than is sufficient to constitute an equilibrium between the weight and power.

Galileo observes, that what appears very firm and succeeds well in models, may be very weak and infirm, or even may fall to pieces by its weight, when it comes to be executed in large dimensions according to the model. In order that machines, or animals, may have an equal relative strength, compared with their size, a very great and disproportionate increase must exist in their proportions or component parts. If a machine be increased in size, it must be subjected to greater stress merely to support the motion of the heavier parts. While the smaller insects, like the flea, can leap several hundred times their length, the utmost strength and activity of large animals will hardly enable them to bound over a space of more than four or five times their length. In architecture, where the appearance of solidity is no less regarded than real strength and firmness, it is even necessary, in order to preserve the due symmetry of a building, and to gratify a judicious eye and taste, to make columns of certain determinate proportions—lighter or heavier according to the style of architecture. Slender cast iron pillars, although made equally strong as stone of larger size, would excite in the beholder sensations of pain rather than of pleasure, if substituted to support the heavy entablature of a Doric or Ionic Portico.

MATTER.

Matter is defined to be a solid, inactive, and moveable substance, capable of being infinitely divided. As presented to our senses it appears in various states of density and fluidity, and in an infinite diversity of forms and colours. Although a state of rest appears to be natural to matter, yet upon experiment it is found to be subject to the action of two forces, which have a tendency to produce motion—one of which acts in attracting the particles of the same body together, to form one compact mass, as observable in the *strength* or *cohesion* of various substances, or the power which they possess in resisting fracture. The other force acts also upon every particle of a mass of matter, attracting it towards the centre of the earth. The former is called the attraction of cohesion, or aggregation,—" the law that moulds a tear;" the latter the attraction of gravitation, which " bids it trickle from its source." The earth which we inhabit is a vast globular mass of matter, possessing the property of attracting towards its centre all bodies situated near its surface. The force with which each specific body is thus caused to press towards this centre is called the *weight* of that body. This attraction is not peculiar to the earth, but is common to all masses of matter. Magnetic and other attractions are resident only in substances of particular species. In ascending lofty mountains it has been found that the mass of matter of which they are formed possesses in a small degree the same power of attraction as the earth itself, drawing the plumb line from its true direction, and causing it to incline to the side of the mountain A state of rest takes place among particles of matter only when the attraction of cohesion has drawn them together into the nearest possible contact, and when the attraction of gravitation has drawn them in a line towards the centre of the earth, until their descent is arrested by the resistance of other bodies of matter. In the first instance, the particles of matter contained in a body remain at rest from their mutual action and reaction as appears when two concurrent globules of mercury unite. In the second instance they remain at rest upon the surface of the earth. When bodies ascend they are acted upon by a force greater than that of the attraction of gravitation, and in a direction contrary to it, as is observable of smoke, steam, and other vapours, which are specifically lighter than the medium of the surrounding air, and are consequently buoyed up, or floated in it.

Of the minute division of matter there are many astonishing instances furnished both by nature and art. A grain of gold, it is stated, may be spread by the gold beater into a leaf containing fifty square inches, and this leaf may be divided into 500,000 parts; and by a microscope magnifying the diameter of an object 10 times and its area 100 times, the one hundredth part of each of these,—that is the fifty millionth part of a grain of gold, will be visible. The natural division of matter are still more wonderful, as observable in the diffusion of odoriferous substances in the atmosphere. The magnitude of a particle of musk, floating in the air, has been computed to be less than the $\frac{42}{1,000,000,000,000,000,000}$ part of a cubic inch. The minute division of animal substances according to Mr. Lewenhoeck is quite as remarkable, there being according to his observations more animalculæ in the milt of a cod-fish than there are men on the whole earth. The particles of blood forming the arterial circulation of one of these animalculæ, although small indeed, will be found to exceed the particles of light in bulk, in the proportion of mountains to grains of sand. Even the very rays of light are divisible by the prism into myriads of shades of colours. Delicate indeed must be the formation of the organ that is not only susceptible of impressions from particles so minute, but is capable of deriving from them "all the delights of vision."

The rays of light are so minute as almost to lead one to a conclusion that they are not a material substance. In regard to its inconceivable velocity through immense space, and in passing without obstruction through solid bodies with a momentum that bears no analogy to that of other moving substances, it appears not to be governed by the same laws as matter. Even the diamond, the hardest and most impenetrable of gems, does not obstruct the passage of the direct rays of the sun. The heat contained in its red rays are capable of exciting combustion after passing through a transparent sheet of ice.

CENTRE OF GRAVITY.

In every body there is a centre of gravity, or a point about which all its parts balance. If this centre be not supported the body will fall. It is by artful skill in adjusting this point that the apparent wonders of horsemanship and balancing are performed.

If a rod of iron be balanced upon a point, that point will be the centre of gravity. If bodies be hung upon this rod, so as to counterbalance each other, their respective weights will be to each other reciprocally as their distances from the the centre of gravity. Every practical mechanic well knows that the density, or weights of beams or rods are not uniform throughout their whole length; consequently that there must be a degree of uncertainty in calculating the exact weights in a foot of length of a piece of iron, wood, stone, &c. In practice the centre of gravity of beams, bars, &c. are found by balancing them over a prop. There being, however, many large unwieldy bodies, that cannot be thus balanced, the following Rules are given by which the centre of gravity may be pretty nearly ascertained by calculation.

Suppose a rod 11 inches long with a weight of 2lb. hung at one end, and a weight of 20lbs. hung at the other end; the centre of gravity, orthep oint on which the rods supporting these weights will be balanced is one inch from the greater weight and ten inches from the less.

$$20\times 1=20, \text{ and } 2\times 10=20$$

Therefore their weights are inversely as their distances from the centre of gravity. In order to find the centre of gravity of any number of bodies, first find the centre between two bodies; then the centre between that centre, and a third body, and so on for the fourth or fifth; the last centre found will be the common centre of all the bodies.

The centre of gravity of a triangle is in the straight line, drawn from any angle to the bisection of the opposite side, at the distance of $\frac{2}{3}$ of that line from the angle. This rule holds also true with regard to a pyramid of any number of sides, and to a cone.

The centre of gravity of a segment of a circle is in the radius which bisects it; and its distance from the centre of the circle, is 1-12 of the cube of its chord divided by the area of the segment.

The centre of gravity of a section of a circle is in the radius which bisects it; and its distance from the centre of the circle is a fourth proportional to the area, its chord, and $\frac{2}{3}$ of the radius.

Effect of Gravitation upon Falling Bodies.

The motion of a body falling freely by its own gravity is uniformly accelerated, its descent being at the rate of $16\frac{1}{10}$ feet at the end of the first second, $64\frac{4}{10}$ feet at the end of the second second, increasing as the squares of the times. A new impression being made upon the falling body at every instant by the continued action of the attraction of gravitation, and the effect of the former still remaining, the velocity must continually increase. The same force which accelerates the motion of a falling body, when acting upon one thrown upwards, must equally retard its ascent. The action of gravitation being uniform, in whatever time it generates a certain velocity in a falling body, it must in the same time destroy the same velocity in the ascending body. A ball, discharged upwards from a gun, would thus acquire the same velocity on reaching the earth in its descent, as when it left the muzzle of the gun.—This would hold true only *in vacuo*, as the resistance of the air has an evident effect in retarding the descent of falling bodies. In a vacuum formed by the air pump, a feather and a guinea will fall with equal velocities. The usual effect of gravitation is to produce such motion only, on the surface of the earth, as tends to bring matter into the relative state of rest in which we find it. Schemes of "perpetual motion" to be derived from the power of gravitation in the finite space between the surface and centre of the earth must consequently be visionary.

The curved lines described by bodies projected nearly horizontally, as the water from a pump, are caused by the joint action of two forces, which produce in the line of their descent what are termed parabolic curves. The lines of these curves, as they are caused to vary by the resistance of the atmosphere, and the effect of gravitation, are the subjects of study in the science of Gunnery.

The following Tables of the velocities acquired by falling bodies are calculated without allowance for the resistance of the air, which must retard the descent of all falling bodies more or less according to their densities.

The velocities are as the times, and the spaces fallen through as the squares of the times.

Therefore if the times be as the numbers,	1	2	3	4	&c.
The velocities will be also as	1	2	3	4	&c.
The spaces fallen through as their squares	1	4	9	16	&c.
And the spaces for each time as - -	1	3	5	7	&c.

	″	″	″	
If the first series of numbers be seconds of time	1	2	3	&c.
The velocities in feet will be . . .	$32\frac{1}{6}$	$64\frac{1}{3}$	$96\frac{1}{2}$	&c.
Spaces fallen through will be . . .	$16\frac{1}{12}$	$64\frac{1}{3}$	$144\frac{3}{4}$	&c.
Spaces for each second will be . . .	$16\frac{1}{12}$	$48\frac{1}{4}$	$80\frac{5}{12}$	&c.

Hutton.

The following Table shows the Spaces fallen through, and the Velocities acquired, at the end of each of 30 Seconds.

Time in Seconds.	SPACE.				VELOCITY.		
	Each Time.	As the Squares of the Time.	Fallen through in Feet & Inches.		As the Times.	Acquired in Feet & Inches.	
1	1	1	16	1	1	32	2
2	3	4	64	4	2	64	4
3	5	9	144	9	3	96	6
4	7	16	257	4	4	128	8
5	9	25	402	1	5	160	10
6	11	36	579	0	6	193	0
7	13	49	788	1	7	225	2
8	15	64	1029	4	8	257	4
9	17	81	1302	9	9	289	6
10	19	100	1608	4	10	321	8
11	21	121	1946	1	11	353	10
12	23	144	2316	0	12	386	0
13	25	169	2718	1	13	418	2
14	27	196	3152	4	14	450	4
15	29	225	3618	9	15	482	6
16	31	256	4117	4	16	514	8
17	33	289	4648	1	17	546	10
18	35	324	5211	0	18	579	0
19	37	361	5806	1	19	611	2
20	39	400	6433	4	20	643	4
21	41	441	7092	9	21	675	6
22	43	484	7784	4	22	707	8
23	45	529	8508	1	23	739	10
24	47	576	9264	0	24	772	0
25	49	625	10052	1	25	804	2
26	51	676	10872	4	26	836	4
27	53	729	11724	9	27	868	6
28	55	784	12609	4	28	900	8
29	57	841	13526	1	29	932	10
30	59	900	14475	0	30	965	0

EXAMPLES.

To find the space descended by a body in 7 ″ and the velocity acquired.

16 . 1×49 =788 feet. 1 inch of Space fallen through.
32 . 2×7 ″ =225 feet. 2 inches of velocity acquired

By referring to the above table at 7 ″ the answers will be found.

To find the time of generating a velocity of 100 feet per second and the whole space descended.

$100\times12=1200\div\overline{32\ .\ 2\times12}=3$ ″ $\frac{41}{386}$ Time.
3 ″ $\frac{41}{386}\times100=310\ .\ 6\div2=155\ .\ 3$ space descended.

The answers to these and other similar questions may be readily found from the table by the Rules of Proportion.

It is owing to the increased velocities of the falling weights of pile-driving engines, that the momentum or force of the blow becomes so effective. The power of the same weight or driver is increased in the ratio of the spaces fallen through in each second, as in the fourth column of the preceding table. It is therefore always desirable to increase the height for the fall of the driver as much as practicable, as the effect of the stroke from falling increases in the ratio of the square of the heights. A weight falling five feet will strike with only one sixteenth of the force of one that falls twenty feet. In descending inclined planes, bodies would acquire the same velocity which they acquire by falling freely through the perpendicular elevation of the planes, provided their descent were not impeded by friction.

One of the most useful inventions in Mechanics, the clock, owes its origin to the effect of gravitation upon the pendulum.

PENDULUM.

The times in which pendulums of different lengths perform their vibrations are as the square roots of their lengths. This rule is not true however, in all parts of the earth; as at the equator, where the effect of the centrifugal force of objects upon the surface of the globe is greatest, the power of gravitation is in a degree counteracted. The length of the pendulum required to vibrate seconds at London, is $\frac{1}{10}$ of an inch longer than at the equator. Hence gravity under the equator is to gravity in London, as 391 to 392. It has been found by many accurate experiments, that the pendulum vibrating seconds in the latitude of London is $39\frac{1}{8}$ inches long. The length of a pendulum to vibrate in any other given portions of time, may be found by the following Rule.

As the number of vibrations given, is to 60, so is the square root of the length of the pendulum that vibrates seconds, to the square root of the length of the pendulum that will oscillate the given number of vibrations;—or, as the square root of the length of the pendulum given, is to the square root of the length of the pendulum that vibrates seconds, so is 60 to the number of vibrations of the given pendulum.

Since the pendulum that vibrates seconds, or 60 times per minute, is $39\frac{1}{8}$ inches long, the calculation is rendered simple; for the $\sqrt{39\frac{1}{8}}\times 60=375$,* is a constant number, therefore 375, divided by the

* A table of Square and Cube Roots is given in the Appendix; a reference to which will facilitate calculations in which it may be required to extract these roots.

square root of the length of the pendulum, gives the vibrations per minute ; and divided by the vibrations per minute, gives the square root of the length of the pendulum.

EXAMPLES.

How many vibrations will a pendulum of 49 inches long make in a minute ?

$\sqrt{49}=7.$ $375\div7=53\frac{4}{7}$ vibrations per minute.

What length of pendulum will it require to make 90 vibrations in a minute?

$375\div90=14\,.\,16.$ $\overline{4\,.\,16}^2=17\,.\,3056$, inches long.

The vibrations of pendulums are subject to many irregularities, owing partly to the variable density and temperature of the air, and partly to the rigidity and friction of the rod, by which they are suspended. The expansion and contraction of the metallic rods of pendulums from heat and cold, causes clocks to go slower in summer, and faster in winter. The common remedy for this inconvenience is the raising or lowering of the bob of the pendulum, by means of the screw usually placed at the end of the pendulum rod for this purpose. Different metals are caused to expand by heat, and to contract from cold, in various degrees or extents. Advantage has been taken of this variation of expansibility, by using rods of different metals in the construction of pendulums, arranged in bars somewhat in the form of a gridiron, from which this sort of pendulum derives its name.

SPECIFIC GRAVITY.

The Specific Gravity of a body, is the proportional weight between that body and another of known density. The density of a body is its quantity of matter when the bulk is given, and the specific gravity is its weight compared with that of another body of the same magnitude. Rain water is admirably adapted to be the standard for a comparison of the Specific Gravities of various substances, as a solid or cubic foot of it weighs 1000 ounces avoirdupois, or 62½ pounds.

A body immersed in a fluid, if specifically heavier, will sink; and if it be specifically lighter, it will settle into the fluid until it has displaced a portion of it equal in weight to the solid. Thus a cubic foot of wood weighing 500 ounces, would sink in water only one half of its bulk, as it would then displace half a cubic foot of water which weighs 500 ounces. The same rule is applicable to a ship with its cargo, which displaces a bulk of water exactly equal in weight to that of the ship and its contents. Mr. Robertson, late librarian to the Royal Society, investigated the specific gravity of living men, in order to ascertain what quantity of buoyant materials would be necessary to keep a man afloat in water, supposing that most men were specifically heavier than river water. From trials which he made upon ten different persons, it appeared that their specific gravity was about $\frac{1}{8}$ less than water. With a knowledge of this fact, if persons who accidentally fall into the water could recover sufficient self-possession to throw themselves upon their backs, with their mouths only rising above the surface of the water, they might, in many cases, be able to sustain themselves until relieved. This experiment was illustrated by Dr. Franklin, in his account of being drawn across a pond, while floating upon its surface, by holding in his hands the string of a kite. It is only on account of the lungs being filled with water, that the bodies of drowned persons sink.

RULE FOR FINDING THE SPECIFIC GRAVITY OF A BODY.

PROBLEM I.

When the body is heavier than water.

Weigh it both in and out of water, and take the difference, which will be the weight lost in water; then say,

As the weight lost in water,
Is to the whole or absolute weight;
So is the specific gravity of water,
To the specific gravity of the body.

EXAMPLE.

What is the specific gravity of a stone which weighs 10 lbs. but in water only $6\frac{3}{4}$ lbs. water being 1000 ?

10 lbs—$6\frac{3}{4}=3\frac{1}{4}$ lbs. weight lost in water.
$3\frac{1}{4}$: 10: :1000: answer 3077 specific gravity.

PROBLEM II.

When the body is lighter than water.

Rule. Attach to it a piece of another body heavier than water, so that they may both sink together. Weigh the denser body and the compound mass separately, both in and out of water; then find how much each loses in water, by subtracting its weight in water, from its weight in air, and subtract the less of these remainders from the greater; then say,

As the last remainder
Is to the weight of the light body in air,
So is the specific gravity of water,
To the specific gravity of the body.

EXAMPLE.

What is the specific gravity of a piece of elm which weighs in air 15 lbs ; attached to it is a piece of copper weighing 18 lbs. in air, and 16 lbs. in water, and this compound weighs in water 6 lbs ?

33=18+15
 6   16
27— 2=25 last, remainder.

As 25: 15: :1000 : 600 answ. specific gravity of the elm.

PROBLEM III.

For a Fluid of any sort.

Take a piece of a substance or body of known specific gravity, weigh it both in and out of the fluid, finding the loss of weight by taking the difference of the two weights ; then say,

As the whole or absolute weight,
Is to the loss of weight;
So is the specific gravity of the solid,
To the specific gravity of the fluid.

EXAMPLE.

What is the specific gravity of a fluid in which a piece of east iron weighs 34.61 oz. and 40 oz. out of it ?

40 : 5.39: :7425 : 1000, specific gravity of the fluid.

PROBLEM IV.

To find the quantities of two ingredients in a given compound.

Rule. Take the three differences of every pair of the three specific gravities, viz. the specific gravities of the compound and each ingredient; and multiply each specific gravity by the difference of the other two; then say

As the greatest product
Is to the whole weight of the compound
So is each of the other two products,
To the weights of the two ingredients.

EXAMPLE.

A composition of 112 lbs. being made of tin and copper, the specific gravity of which is found to be 8784; required the quantity of each ingredient, the specific gravity of tin being 7320, and copper 9000.

8784 Composition, 9000 Copper, 7320 Tin.

9000—7320 = 1680 × 8784 = 14757120

8784—7320 = 1464 × 9000 = 13176000

9000—8784 = 214 × 7320 = 1566480

As 14757120 112 : 13176000 : 100 = Copper } forming the
112—100 = 12 = Tin } Composition.

A Table of Specific Gravities of Bodies, compared with Rain Water.

The comparative weight or specific gravity of almost every known substance has been ascertained by the preceding rules, by means of hydrostatic balances, hydrometers, or other instruments, and the results of these experiments have been arranged in the form of Tables. Rain Water, as before stated, has been taken as the standard for solids and liquids, and atmospheric air has been taken as a standard of the specific gravity of Gases.

Cubic foot.	Weight in oz.
Platina (pure)	23000
Fine Gold	19400
Standard Gold	17724
Quicksilver (common)	13600
Lead	11325
Fine Silver	11091
Standard Silver	10535
Copper	9000
Gun Metal	8784
Cast Brass	8000
Steel	7850
Iron, bar	7788
Iron, cast	7248
Manganese	8000
Cobalt	8600
Tin	7320
Woods.	
Boxwood	1030
Oak, hart	925
Ash	800
Maple	755
Fir	550
Ebony	1331
Lignumvitæ,	1333
Mahogany	1063
Charcoal	400
Cork	240
Stones and Earth.	
Iron Stone	3300 to 3500
Granite, hardest	3000
Do common	2700
Marble and Hard Stone	2700
Flint Glass	2570
Sand Stone	2520
Clay	2160
Brick	1300 to 2000
Common Earth	1900
Sand	1520
Coal	1100 to 1250
Slate	2700
Gunpowder	900
Beeswax	964
Sugar	1606
Liquids.	
Rain water	1000
Sea Water	1030
Blood (human)	1053
Olive Oil	0915
Linseed Oil	0940
Whale Oil	0923
Tallow	0923
Proof Spirits	0923
Alcohol	08[illegible]5
Gases.	
A cubic foot of atmospheric air, weighs 527 grs. about being nearly 840 times lighter than water.	$1\frac{1}{6}$
Carbonic acid Gas	$1\frac{3}{4}$
Hydrogen, the lightest of all substances. has only $\frac{1}{15}$ of the weight of Atmospheric Air.	

If an engineer wishes to move a certain block or pillar of granite, or even a brick building, as has been done in the United States, he may form an estimate of the weight by multiplying the number of cubic feet of materials by the number of ounces against each respectively, in the above table. The product in ounces being divided by 16, will give the weight in pounds Avoirdupois.—Sea water being heavier than fresh water, will cause a ship to float more buoyantly, and the difference of specific gravity between common air and Hydrogen, will cause balloons or large silken bags filled with this gas, to ascend and float in the air Heat has also the effect of rarifying a volume of air, and rendering it specifically lighter than the common atmospheric air.

TABLE OF THE WEIGHT OF SHEETS OR PLATES OF MALLEABLE AND CAST IRON, COPPER AND LEAD.

TABLE *of the Weight of a Square Foot of Cast and Malleable Iron, Copper and Lead, from* 1-16*th, to* 1 *Inch thick.*

Thick.	Cast Iron		Mall Iron.		Copper.		Lead.	
	Lbs.	*Oz.*	*Lbs.*	*Oz.*	*Lbs.*	*Oz.*	*Lbs.*	*Oz.*
1 Sixteenth	2	6.6	2	7.8	2	15	3	11
2 —	4	13.3	4	15.6	5	14	7	6
3 —	7	4.	7	7.4	8	13	11	1
4 —	9	10.6	9	15.2	11	12	14	12
5 —	12	1.3	12	7.1	14	11	18	7
6 —	14	8.	14	14.9	17	10	22	2
7 —	16	14.7	17	6.7	20	9	25	13
8 —	19	5.3	19	14.5	23	8	29	8
9 —	21	12.	22	6.3	26	7	33	3
10 —	24	2.7	24	14.2	29	6	36	14
11 —	26	9.3	27	6.	32	5	40	9
12 —	29	-	29	13.8	35	4	44	4
13 —	31	6.7	32	5.6	38	3	47	15
14 —	33	13.4	34	13.4	41	2	51	10
15 —	36	4.	37	5.3	44	1	55	5
1 Inch	38	10.7	39	13.1	47	-	59	-

TABLE *of the Weight of a Lineal Foot of Malleable and Cast Iron Bars, from 6-16ths to 3 Inches square.*

Sixteenths on the side	Area in Square Sixteenths.	MALL. IRON. *Ounces Weight.*	CAST IRON. *Ounces Weight.*	MALL. IRON. ROUND RODS. The 16ths on the side is the diameter of Rod. *Ounces Weight.*
6	36	7.4736	- - -	5.83
7	49	10.1724	- - -	7.99
8	64	13.2864	12.8960	10.43
9	81	16.8156	- - -	13.20
10	100	20.7600	- - - -	16,30
11	121	25.1196	- - -	19.72
12	144	29.8944	29.0160	23.47
13	169	35.0844	- - - -	27.53
14	196	40.6896	- - -	31.94
15	225	46.7100	- - - -	36.44
1 Inch	256	53.1456	51.5840	41.50
1	289	59.9964	- - -	46.80
2	324	67.2624	- - - -	52.47
3	361	74.9436	- - -	58.46
4	400	83.0400	80.6000	64,81
5	441	91.5516	- - - -	71.41
6	484	100.4784	- - -	78.37
7	529	109.8204	- - - -	85.66
8	576	119.5774	116.0640	93.27
9	625	129.7500	- - -	101.21
10	676	140.3376	- - - -	109.46
11	729	151.3404	- - -	118.05
12	784	162.7584	157.9760	126.95
13	841	174.5916	- - - -	136.19
14	900	186.8400	- - -	146.74
15	961	199.5036	- - - -	155.62
2 Inches	1024	212.5824	206.3360	165.82
1	1089	226.0764	- - -	176.34
2	1156	239.9856	- - - -	187.19
3	1225	254.3100	- - - -	198.36
4	1296	266.0496	261.1440	209.86
5	1369	284.2044	- - - -	221.68
6	1444	299.7744	- - -	233.83
7	1521	315.7596	- - - -	246.30
8	1600	332.1600	322.4000	259.09
9	1681	348.9756	- - -	272.20
10	1764	366.2064	- - - -	285.64
11	1849	383.8524	- - -	299.41
12	1936	401.9136	390.1040	313.49
13	2025	420.3900	- - - -	327.91
14	2116	439.2816	- - -	342.64
15	2209	458.5884	- - - -	357.70
3 Inches	2304	478.3104	464.2560	373.09

The foregoing tables have been calculated from Hutton's specific gravities; those of Cast and Malleable Iron, and Lead, agree very nearly with those given by other authors.

TABLE *of the weight of Bars of Flat Iron one foot in length, from which any greater length of this metal may be computed.*

Inches in width.	Inches in thickness. ¼	⅜	½	⅝	¾	⅞	1	1½
	lbs. av.	lbs.	lbs.	lbs	lbs.	lbs.	lbs.	lbs.
1	.83	1.25	1.66	2.08	2.5	2.91	—	
1⅛	.93	1.4	1.87	2.34	2.81	3.28	3.75	
1¼	1.04	1.56	2.08	2.6	3.12	3.64	4.16	
1⅜	1.14	1.71	2.29	2.86	3.4	4.01	4.58	
1½	1.25	1.87	2.5	3.12	3.75	4.37	5.	
1¾	1.45	2.18	2.91	3.64	4.37	5.1	5.83	
2	1.66	2.5	3.33	4.16	5.	5.83	6.66	
2¼	1.87	2.81	3.75	4.68	5.62	6.56	7.5	
2½	2.08	3.12	4.16	5.2	6.25	7.29	8.33	
2¾	2 29	3.43	4.58	5.72	9.87	8.02	9.16	
3	2.50	3.75	5.	6.25	7.5	8.75	10.	
Weight of Flat Bars of Steel, one foot in length.								
	¼	⅜	½	⅝	¾	⅞	1	1½
1	.852	1.27	1. 7	2.13				
1¼	1.06	1.59	2.13	2.66				
1½	1.27	1.91	2.55	3 19				
1¾	1.49	2.23	2.98	3.72				
2	1.7.	2.55	3. 4	4.26				
Weight of Square Bars of Steel, one foot in length.								
	¼	⅜	½	⅝	¾	⅞	1	1½
Square.	.2.13	.4.79	.8.55	1.33	1.91	2.61	3.4	7.67
Weight of Round Bars of Steel, one foot in length.								
	¼	⅜	½	⅝	¾	⅞	1	1½
Diameter.	.167	.376	.669	1.04	1.5	2.05	2.67	6.02

It is often desirable to form estimates of the weight of Iron necessary for constructing works, in which a considerable quantity of this metal may be required. The engineer, after having ascertained the diameters of the bars or bolts, and the lengths necesssary for his purposes, by referring to the preceding tables may calculate the weight and the cost of the iron which he may require.

A TABLE *showing how many fathoms, feet, and inches, of a rope of any size, under fourteen inches, makes a hundred weight.**

Rope Inches	Fath.	Ft.	In.	Inches	Fath.	Ft.	In.	Ropes Inches	Fath.	Ft.	In.
1	486	0	0	4¾	24	0	0	8	7	3	6
1¼	313	3	0	4½	21	3	0	8¼	7	0	8
1½	216	0	0	5	19	3	0	8½	6	4	3
1¾	159	3	0	5¼	17	4	0	8¾	6	2	1
2	124	3	0	5½	16	1	0	9	6	0	0
2¼	96	2	0	5¾	14	4	6	9¼	5	4	0
2½	77	3	0	6	13	3	0	9½	5	2	0
2¾	65	4	0	6¼	12	2	0	9¾	5	0	6
3	54	0	0	6½	11	3	0	10	4	5	0
3¼	45	5	2	6¾	10	4	0	10½	4	2	2
3½	39	3	0	7	9	4	6	11	4	0	3
3¾	34	3	9	7¼	9	1	6	12	3	2	3
4	30	1	6	7½	8	4	0	13	2	5	3
4¼	26	5	3	7¾	8	3	6	14	2	2	1

* Ropes are measured by their circumference in inches.

From the preceding Table, the weight of ropes may be readily calculated when the length and size is known, by the rules of Proportion.

EXAMPLE.

In a coil of 4½ inch rope, there are 48 fathoms, what will be the weight of the coil?

By the Table it appears that a rope of the dimension of 4½ inches weighs one cwt. for each 24 fathom of its length. Therefore as,

24 : 112 : : 48 : 224 lbs. Ans.

The following Table of the weight of cast iron pipes, gives the length of pipe according to the diameter of bore, as generally used in practice.

Diameter of bore in inches.

Thickness of metal in inches.

Length of pipe in feet.

Bore.	Thick.	Long.	Weight.			Bore.	Thick.	Long.	Weight.			Bore.	Thick.	Long.	Weight.			Bore.	Thick.	Long.	Weight.		
1	[illegible]	3ft6	0	0	12	5½	[illegible]	9	3	0	18	9	¾	9	6	0	2	13	1	9	11	2	12
	[illegible]	3ft6	0	0	21		[illegible]	9	3	3	7		1	9	8	0	26	13½	½	9	5	3	7
1½	[illegible]	4ft6	0	0	21		1	9	5	0	12	9½	½	9	4	0	18		[illegible]	9	7	1	12
	[illegible]	4ft6	0	1	4	6	[illegible]	9	2	0	0		[illegible]	9	5	1	0		[illegible]	9	8	3	16
2	[illegible]	6	0	1	8		[illegible]	9	2	2	21		[illegible]	9	6	1	6		1	9	11	3	24
	[illegible]	6	0	2	0		[illegible]	9	3	1	17		1	9	8	2	20	14	½	9	6	0	4
2½	[illegible]	6	0	1	16		[illegible]	9	4	0	16	10	½	9	4	1	10		[illegible]	9	7	2	16
	[illegible]	6	0	2	10		1	9	5	2	20		[illegible]	8	5	1	26		[illegible]	9	9	1	0
	[illegible]	6	0	3	10	6½	[illegible]	9	2	0	16		[illegible]	9	6	2	14		1	9	12	1	14
3	[illegible]	9	0	2	20		[illegible]	9	2	3	20		1	9	9	0	8	14½	½	9	6	0	24
	[illegible]	9	1	0	6		[illegible]	9	3	2	21	10½	[illegible]	9	4	2	14		[illegible]	9	7	3	14
	[illegible]	9	1	1	12		[illegible]	9	4	1	21		[illegible]	9	5	3	7		[illegible]	9	9	2	2
	[illegible]	9	1	3	6		1	9	6	0	14		[illegible]	9	7	0	0		1	9	12	3	6
	[illegible]	9	2	1	0	7	[illegible]	9	2	1	7		1	9	9	2	0	15	½	9	6	1	21
3½	[illegible]	9	0	3	0		[illegible]	9	3	0	7	11	[illegible]	9	4	3	14		[illegible]	9	8	0	14
	[illegible]	9	1	0	21		[illegible]	9	3	3	20		[illegible]	9	6	0	11		[illegible]	9	9	3	7
	[illegible]	9	1	2	14		[illegible]	9	4	3	5		[illegible]	9	7	1	7		1	9	13	0	26
	[illegible]	9	2	0	8		1	9	6	2	4		1	9	9	3	20	15½	1¼	9	16	3	5
	[illegible]	9	2	2	0	7½	[illegible]	9	2	2	4	11½	[illegible]	9	5	1	7		½	9	6	2	14
4	[illegible]	9	1	1	10		[illegible]	9	3	1	6		[illegible]	9	6	0	12		[illegible]	9	8	1	14
	[illegible]	9	1	3	12		[illegible]	9	4	0	22		[illegible]	9	7	2	8		[illegible]	9	10	0	10
	[illegible]	9	2	1	12		[illegible]	9	5	0	10		1	9	10	1	2	16	1	9	13	2	17
	[illegible]	9	2	3	21		1	9	7	0	0	12	[illegible]	9	5	0	24		1¼	9	17	1	6
4½	[illegible]	9	1	2	2	8	[illegible]	9	3	2	4		[illegible]	9	6	2	8		½	9	7	0	22
	[illegible]	9	2	0	4		[illegible]	9	4	1	25		[illegible]	9	7	3	20		[illegible]	9	8	3	7
	[illegible]	9	2	2	14		[illegible]	9	5	1	18		1	9	10	3	9		[illegible]	9	10	1	20
	[illegible]	9	3	0	21		1	9	7	1	16	12½	[illegible]	9	4	1	16		1	9	14	0	8
5	[illegible]	9	1	2	22	8½	[illegible]	9	3	3	2		[illegible]	9	6	3	9		1¼	9	17	3	14
	[illegible]	9	2	1	10		[illegible]	9	4	2	26		[illegible]	9	8	1	0		1½	9	21	3	4
	[illegible]	9	2	3	17		[illegible]	9	5	2	22		¾	9	11	0	21		2	9	29	3	21
	[illegible]	9	3	1	24		1	9	7	3	8	13	1	9	5	2	20						
5½	[illegible]	9	1	3	10	9	½	9	4	0	0		½	9	7	0	14						
	[illegible]	9	2	2	0		[illegible]	9	5	0	4		⅝	9	8	2	7						

The above Table is found to be of great use in making out estimates of cast iron pipes; for instance, it is required to know the weight of a range of pipes 225 feet long, 7½ inches diameter of bore, and metal ⅝ of an inch thick.

9)225

25 pipes in the whole length.

One pipe weighs 4. 0. 22., which multiplied by 25, is equal to 104. 3. 18. or 5 tons, 4 cwt. 3 quarters, 18 lbs. weight of the whole range.

To find the number of cubic inches contained in a solid body of very irregular dimensions, in order to calculate the weight of it, when its specific gravity is known, it is only necessary to immerse such irregular body in a vessel of water exactly filled to the brim. It will displace a quantity of water, and cause it to run over the sides of the vessel. The water thus displaced, if collected in another vessel, and measured, will indicate as many cubic inches in the solid body as there are cubic inches in the pints or gallons of water collected. The number of cubic inches in the pint or gallon, may be readily ascertained by reference to the table of measures.

In all the operations of the mechanical powers, gravitation has an important influence, and the effects of it should be well considered by the artist in his calculations, whenever he intends to construct machinery to operate with regularity, or "sweetly," as the engineers term it, when they can succeed in making a steam engine of 100 horse power work with so little jar or noise, that a person near it might not be aware of its movements, were they not visible. Card Cylinders should be accurately balanced to perform well. Even common water wheels will turn with a motion so irregular, after remaining for a time with one portion immersed and water soaked, while another portion becomes dry and light, that that they cannot be successfully used in many manufacturing operations. At every revolution the increased gravity of one side will hasten its motion in descending, while it will equally retard its ascent.

ATTRACTION OF COHESION.

Attraction of Cohesion, or the strength of various substances, is the second most obvious quality of matter, and one of the most important as connected with the operations of machines. A knowledge of the cohesive strength of various materials employed in architecture, as well as in the mechanic arts, is also highly important, as the safety of life and of property depends upon the due solidity and strength of buildings. Waste of materials must, on the other hand, ensue from a profuse use of them where not required. There are probably few carpenters who make any regular calculations relative to the weight that may be safely supported by the pieces of timber, upon which they work, when the dimensions and the distances between the bearings are given.

The attraction of Cohesion, or as it may be more succinctly termed, cohesion, exists among the most minute atoms of matter, which appear to the eye connected as one body, imparting to most substances a form of solidity, and constituting the force with which the particles resist separation. It is only by attention to this subject, that the due symmetry and strength is assigned to the various parts of machines. In the practical application of the mechanical powers, the force cannot be effectually applied to move the weight unless the lever, the wheel, or the screw be capable of supporting the accumulated stress transmittted through them, to act upon the weight.

Cohesive Strength of various Substances.

The Cohesive strength of a body being measured by the force required to cause the particles to separate, the greater the mass of particles, the greater must be the power required to tear them asunder.

Cohesive strength is destroyed in various ways; as by pressure, when the body is said to be crushed; by being drawn asunder, or broken; by torsion or twisting, and by abrasion or friction.

The strength of different materials in resisting compression is variously estimated, few accurate experiments having been made on this subject. According to Buchanan, in steel the cohesive strength and resistance to being crushed, appear to be nearly equal. Freestone has been found to support about 2000 lbs; Oak in some particular cases, more than 4000; American pine, 1600 lbs. and Elm, 1284 lbs. upon each square inch.

To find the load which a column or stick of timber might sustain when pressed in the direction of the length —Multiply the area of the section of the column or stick in inches by the weight which will crush one inch.—One fourth of this product is all that can be safely imposed upon them. See table of strength of woods.

Stiffness and Transverse strength of Beams, Bars, &c.

If a beam be supported at both ends, and loaded in the middle, it will bend, called technically, deflection. Most substances before they break, yield with a degree of elasticity to the force impressed upon them.—The stiffness of a beam follows laws very different from those which determine its strength. Beams of equal length, have their lateral stiffness, to bear a load at any point in their length without being bent, as the breadth and cube of the depth, while their lateral strength is only as the breadth and square of their depth.

Thus if a square beam measure twice as much on each side as another of equal length, it would be sixteen times as stiff, and eight times stronger.

EXAMPLE.

If a beam or shaft be four inches square throughout, and another five inches, both of equal lengths, what is their comparative stiffness.

The cube of 4 is 64. 64 × 4 = 256.

The cube of 5 is 125. 125 × 5 = 625 That is, the shaft of five inches is nearly two and an half times stiffer than that of four inches.

Beams of different lengths have their stiffness (to bear a load at any point in their length without bending) directly as the breadth and cube of the depth and inversely as the cube of the length.

Thus if a beam be twice as long as another of the same breadth and depth, it will have only ⅛ of the stiffness, while it will have one half of the strength. Supposing a tube, indefinitely thin, to be expanded into a tube of greater diameter, but of equal length, the quantity of matter remaining the same; the stiffness of the tube will be increased in the ratio of the square of the diameter. The quills in the wings of birds thus possess admirable stiffness combined with lightness. The stalks of all the grasses and many reeds, and the bones also of animals are similarly formed for stiffness and lightness. Upon the same principle cast iron pillars should be made hollow, the same weight of metal being rendered stiffer, as its diameter is increased, in the ratio of the cube of the diameter.

LONGITUDINAL STRENGTH.

For the measure of longitudinal cohesive strength, the number of pounds avoirdupois, which are just sufficient to tear asunder a rod or bundle of any substance one inch square is taken. From this it will be easy to compute the strength of the same materials of other dimensions.

The following are the results of experiments made by Mr. Emerson, which state the load that may be safely suspended by a square inch rod of each material.

	Pounds Avoirdupois.
Iron rod an inch square will suspend	76,400
Brass, - - - -	35,600
Hempen Rope - -	19,600
Ivory - -	15,700
Oak, Box, Yew, Plum-tree -	7,850
Elm, Ash, Beech - - -	6,070
Walnut - -	5,360
Red Fir, Holly, Elder, Crab -	5,000
Cherry, Hazel - - -	4,760
Alder, Ash, Birch, Willow, -	4,290
Lead - - - - -	430
Free Stone - - -	914

Mr. Emerson also gives the following practical rule, viz: that a cylinder whose diameter is given in inches, loaded to ¼ of its absolute strength, will carry as the square of their diameters in inches multiplied by cwts. as follows.

	Cwts.	
Iron -	135 ×	Square of diameter in inches.
Good Rope -	22 ×	" "
Oak - -	14 ×	" "
Fir -	9 ×	" "

Other experiments made by Mr. Barlow, make the strength of woods much greater than by the above table of Mr. Emerson's experiments. From an average derived from experiments performed by Mr. Barlow, it appears that the strength of direct cohesion of a square inch of Box is about - 20,000lbs.

Ash - - -	17,000 "
Teak - -	15,000 "
Fir - - -	12,000 "
Beech -	11,500 "
Oak - - -	10,000 "
Pear -	9,800 "
Mahogany - - -	8,000 "

Each of these weights may be taken as correct data for the absolute and ultimate strength of the fibres of the woods, and therefore if the weight that may be permanently borne with safety, be required, not more than one half, or at most, two thirds of the above weight must be used.

From experiments made by Mr. Brown on Welsh pig iron, it appears that " a bar of cast iron of this description 1¼ inch square, 3 feet 6 inches long, required a strain of 11 tons, 7 cwt. (25,424 lbs.) to tear it asunder, breaking exactly transverse, without being reduced in any part; was quite cold when broken, particles fine, of a dark bluish grey colour." This experiment shows that the cast iron sustained a weight equal to 16,265 lbs. to the square inch.

Of malleable iron, from an average of the result of numerous experiments made by different persons, the medium strength of a bar one inch square appears to be sufficient to suspend a weight of 27 tons. Muschenbroeck has described the methods he adopted for trying experiments. The woods were all formed into slips fitted to his apparatus, and part of the slip was cut away to a parallelopiped of $\frac{1}{5}$ of an inch square, and therefore $\frac{1}{25}$ of a square inch in section. The absolute strengths of a square inch from more than fifty experiments made with each are as follows:

Ash - - -	12,000
Locust Tree - -	20,100
Elm - - - -	13,200
Mulberry - -	12,500
Willow - - -	12,500
Fir - -	8,330
Walnut -	8,130
Pitch Pine - -	7,640
Cedar - .	4,880

It is stated by Mr. Penn, " as the result of numberless experiments, which he has had the opportunity of trying in the chain cable manufactory of Messrs. Brown, Logan & Co. of Liverpool, that a square bar of common iron will not bear more than 630 to 665 pounds weight to every one eighth of an inch of its dimensions, while a bar of the best cable iron of the same dimensions will bear from 780 to 800 pounds." About 30 tons to the square inch is commonly allowed to English chain cables. Some of the chains manufactured in the United States from the best American iron, it is stated, have borne a proof equal to forty tons on a bar of iron one inch square.

A knowledge of the strength of materials is of the utmost importance in navigation. The frail bark is destined to encounter upon the ocean the violence of adverse winds and waves, by which every timber of oak, and bolt of iron is subjected to great stress. Property to a vast amount is endangered by using insufficient materials, and the safety of anxious crews frequently depends on the strength even of a single cable.

The annexed table has been furnished me by Mr. Leslie, showing the relative strength and size of hempen and chain cables, and of anchors adapted to vessels of various dimensions. This table is computed as follows.—Double the cube root of the Register Tonnage, to find the circumference of the best Bower Hempen cable in inches. One eleventh of this circumference, is the diameter of a chain of equal strength. The Register Tonnage multiplied by 5½ gives the weight of the best Bower Anchor, and by 4½ for the small Bower, being ten pounds of anchor in the two Bowers, to the Ton Register. One eighth added to the cube root of the weight (in pounds) of any wooden stocked anchor will give the circumference in inches of a corresponding hempen cable.

Explanation and Use of the Table.

"To find the sizes of suitable Anchors, Cables, and Chains for double-decked Merchant Vessels of the usual build .

For the best Bower.—Find in the upper line, the Register tonnage: directly under this, in the second line, will be found the circumference of a Hempen Cable; in the fourth line, the diameter of a chain of equal strength; and in the fifth line, the weight of the Anchor.

For the small Bower.—Find the Register Tonnage in the lower line; directly above this will be found the size of the Anchor, Cable or Chain, in their respective lines.

For the Stream.—Find, in the fifth line, one third of the weight of the best Bower Anchor; directly above this will be found a suitable cable in the second line.

For the Kedge.—Find in the fifth line, one ninth of the weight of the best Bower Anchor; directly above this will be found the size of a suitable Hawser. Large vessels usually carry two Kedges, the second about two thirds of the weight of the first.

N. B. For vessels differing much from the usual build, and for single decked vessels, enter the table with the mean between four-fifths of the number of tons they could carry in dead weight, and the Register Tonnage.

EXAMPLE I.

Required to find the proper sized Anchors, Cables or Chains, for a double-decked vessel of 280 tons Register.

	Hempen Cable.		Chain.	Anchor.
Best Bower	13 in. circumference		$1\frac{3}{16}$ in. diam.	1550 lbs.
Small do.	12 in.	do.	$1\frac{1}{16}$ in. do.	1250
Stream	9 in.	do.	———	517
Kedge	6¼ in.	do.	———	170

EXAMPLE II.

Required to find the Anchors, Cables, &c. of a ship of 620 tons Register.

	Hempen Cable.		Chain.	Anchor.
Best Bower	17 in. circumference.		$1\frac{9}{16}$ in diam.	3400 lbs.
Small do.	16 in.	do.	$1\frac{7}{16}$ in. do.	2800
Stream	11¾ in.	do.	———	1133
Kedge	8 in.	do.	———	377
2d do.	7 in.	do.	———	250

EXAMPLE III.

Required to find the Anchors, Cables, &c. of a vessel of 135 *tons Register, which could only carry, in dead weight,* 106 *tons.**

	Hempen Cable.		Chain.	Anchor.
Best Bower	$9\frac{1}{2}$ in.	circumference.	$\frac{7}{8}$ in. diam.	600 lbs.
Small do.	9 in.	do.	$\frac{13}{16}$ in. do.	500
Stream	$6\frac{1}{2}$ in.	do.	———	200
Kedge	$4\frac{1}{2}$ in.	do.	———	67

*4-5ths of 106 is 85
Add Reg. Tonnage 135

1-2 of 220

Mean 110 Tonnage to be used in Table.

Remarks.—If a proper Chain Anchor, with short shank and arms, is used with a chain cable, one tenth may be deducted from the weight found in the table, which is calculated for Hemp Cables, and for wooden stocks. The weight of Anchor, in all cases, should be exclusive of Iron Stock, which adds nothing to the strength or security. Hemp Cables should be about nine fathoms in length for every inch in circumference; but chains of equal strength need not exceed three-fourths of that length. The size of the Kedge should not be larger than could be managed to advantage with a suitable Hawser, in the second Boat or Yawl. The Long Boat should be capable of carrying out a Bower Anchor and Cable, in case of getting ashore; for that purpose she should be a foot and a half in length, for every inch in circumference of the best Bower Cable; the breadth one-third of the length, and the depth one half of the breadth. If, for the convenience of stowing on deck, or any other cause, those dimensions should be varied, she should still be of equal capacity. A Yawl of about nine tenths of the length of the Long Boat could nest within her if necessary, and could manage a kedge one ninth of the weight of the best Bower Anchor. The Stream Anchor in merchantmen is generally about one third of the weight of the best Bower; the cable should be of rope, being often used for anchoring in deep water, in contrary currents, with calms or light winds. Vessels which have chains for both Bowers, should *not* be without a Hemp Stream Cable. It may be proper to observe that Chains should be kept as free from turns as possible, as they are very easily broken when kenked, and the swivels seldom turn unassisted, after being wet with salt water. Ships exceeding 600 tons, cannot conveniently purchase suitable sized Anchors, with the common windlass.

A line containing the circumference of chains is introduced into the table, it being more conveniently measused, and admitting of a greater subdivision; it may be used or not, as most convenient.

The comparative strength and proportions between Cables and Anchors, have been determined by the practice of centuries. The proportions of those to vessels, are more arbitrary, because these are, at times, tempests which scarcely any Anchors and Cables could withstand. Custom has however established, and reason requires that vessels of ordinary build, should have in her two Bower Anchors, at least, ten pounds to the Ton Register, with cables in proportion. When large ships for convenience, carry three or more Bower Anchors, but of smaller size, the aggregate weight should be still greater, each should in that case be at least four pounds to the Ton Register. Some nations indeed, have them much larger, but none have them smaller. Owners of vessels have often had to pay heavy damages for injury done to other vessels in consequence of the insufficiency of Cables and Anchors. After taking into consideration the disputes that often arise with underwriters, and the difficulty of procuring freight or effecting insurance in foreign ports from this cause, there can evidently be no economy in not providing vessels in a reasonable manner. Indeed, no other appendage of vessels is of such vital importance. Whoever thought their anchors and cables too large while riding in a dangerous roadstead, in a storm, when the life of every person on board was at stake? Vessels of war do not require so large Anchors and Cables as deep laden merchantmen of the same nominal Tonnage; still they (United States' ships) carry in Bower Anchors from 15 to 18 lbs. per ton: the larger classes of ships, for convenience, have them smaller in proportion, but have more in number. Line of Battle ships and Frigates carry six Bower Cables of 120 fathoms each, and 180 fathoms of Bower Chain, with four Bower Anchors. Sloops of War and under carry three Bower Cables and one Chain, with three Bower Anchors as large as those used in merchantmen. Although the above table was intended for merchant vessels, still, with the following modifications, it may be used for Vessels of War.

For three-decked ships of the line, the proper sized Bower Anchors, Cables and Chains, will be found against four-fifths of their tonnage in the *lower* tonnage line. For two deckers of the line, against six-sevenths of their tonnage in the *lower* line. For frigates, against the whole tonnage in the *lower* line. For sloops of War, and smaller square rigged vessels, against their tonnage found in the *upper* line, and for fore-and-aft rigged vessels, a cable, an anchor, and a chain, against their tonnage found in the *upper* line, and two anchors and two cables against their tonnage in the *lower* line. Ships of War have their Stream Anchor one-fourth of the Bower, and two Kedges, one eighth and one sixteenth of the same. The proper sized ropes will be found against those weights in the table.

TRANSVERSE STRENGTH OF BEAMS, BARS, &c.

If a piece of wood or beam 12 inches deep, and one inch broad support a given weight, another beam of the same depth, and double the breadth will support double the weight:—hence, beams of the same depth are to each other as their breadths.* If a beam 12 inches deep and one inch broad will support a given weight, another beam 24 inches deep and of the same breadth, will support four times the weight; hence, beams of equal breadths are to each other as the squares of their depths. Again, if a beam of given size, one foot long, support a known weight, another beam of the same size 2 feet long, will support one half the known weight;—hence in point of strength beams of equal dimensions are to each other inverselyas their lengths. The strength of beams is therefore directly as their breadths and square of their depths, and inversely as their lengths; and if cylindrical, as the cubes of their diameters.

BARLOW'S RULES FOR CALCULATING THE TRANSVERSE STRENGTH OF TIMBER.

Table of Multiplicands, for calculating the transverse strength of Timber.

English Oak : :	1426
American or Canadian do	1766
Ash : : :	2026
Beech : :	1556
Elm : : ;	1013
Pitch pine ; :	1632
Red pine ; :	1341
Fir or Spruce :	1100
Larch : : :	1127

PROBLEM I.

To find the ultimate transverse strength of any square or rectangular beam of timber, fixed at one end, and loaded at the other.

Rule.—Multiply the number in the table of Multiplicands, by the breadth and square of the depth, both in inches, and divide the product by the length, also in inches; the quotient will be the weight in pounds.†

EXAMPLE I.

What weight will it require to break a beam of fir, the breadth being 2 inches, depth 6 inches, and length 20 feet?

$$\frac{1100 \times 36 \times 2}{240} \; 330 \text{ lbs.}$$

* This does not hold exactly true as it regards stiffness. The fibres of the wood become more rigid and hard, by exposure to the air in narrow beams or joists, than if contained in the heart of one large beam, where they must remain more moist and more yielding. Twelve boards each of an inch in thickness, and a foot in depth if properly connected would on this account be somewhat stiffer than one beam a foot square, although perhaps not equally strong.

† When the beam is loaded uniformly throughout its length, the same rule will apply, only the result must be doubled.

EXAMPLE II.

What is the weight requisite to break a beam of Ash 7 inches square 3 feet from the wall, in which one end is inserted?

$$\frac{2026\times7\times49}{36}=19303\tfrac{10}{36}\text{ lbs.}$$

PROBLEM, II.

To compute the ultimate transverse strength of any rectangular beam, when supported at both ends and loaded in the centre.

Rule.—Multiply the number in the table of Multiplicands by the square of the depth in inches, and four times the breadth; divide that product by the length in inches, and the quotient will be the weight.

EXAMPLE I.

What weight will break a beam of English Oak 7 inches broad, 9 inches deep, and thirty feet between the props?

$$\frac{1426\times81\times28}{360}=8983\tfrac{288}{360}\text{ lbs.}$$

When the beam is uniformly loaded throughout its length, the result must be doubled, that is to say, it will support double the weight.

When the beam is fixed at both ends and loaded in the middle, one half of the result must be added, as the longitudinal, as well as the lateral strength of the beam is in this case brought into bearing; and if the weight is laid uniformly along its length, the result must be tripled.

The above problems are extracted from Barlow's essays. To each of these problems he gives a second rule in which the angle of deflection is considered. As the latter rules give higher result for the strength of beams than those above stated, they are omitted, it being both more simple and safe in practice, to follow the rules here given.

The above calculations are also made for the weights required actually to break the beams—not more than one half or two thirds of the result of these calculations, as before observed, should ever be permitted to rest upon the beams for a permanent load.

CAST IRON BEAMS.

Practical Problems for the Transverse Strength of Cast Iron Beams.
(From Tredgold on the strength of Cast Iron.)

PROBLEM I.

To find the breadth of an uniform cast iron beam to bear a given weight in the middle.

Rule 1st.—Multiply the length of bearing in feet, or the length between the supports, by the weight to be supported in pounds, and divide this product by 850 times the square of the depth in inches; the quotient will be the breadth in inches required.

Rule 2. Multiply the length of bearing in feet by the weight to b supported in pounds, and divide this product by 850 times the breadth in inches, and the square root of the quotient, will be the depth in inches.

The rules are the same for inclined as for horizontal beams, when the horizontal distance between the supports is taken for the length of bearing.

EXAMPLE I.

What should be the breadth of a beam 20 feet long, 15 inches deep to be loaded with 13 tons?

13 tons=29120 lbs. $\frac{29120 \times 20}{15.^2 \times 850}$=3,045 inches broad.

EXAMPLE II.

What should be the depth of a beam 20 feet long, 3 inches broad, equired to support a weight of 13 tons?

$\frac{29120 \times 20}{850 \times 3}$=225, the square root of which is =15, inches the depth required.

EXAMPLE III.

What are the cross sectional dimensions of a beam 30 feet long, and of sufficient strength to support a weight of 10 tons; the depth being twice the breadth?

10 tons=22400 lbs. length=30, 30×2=60,

$\frac{22400 \times 60}{850}$=1581, the cube root of which is nearly 11½, which is equal to the depth in inches; the breadth is the half of the depth=5¾ inches.

PROBLEM II.

To find the breadth of a cast iron beam, when the load is not in the middle between the supports.

Rule.—Multiply the short length, by the long length, and four times this product divided by the whole length between the supports will give the effective leverage of the load in feet; this quotient being used instead of the length, in any of the Rules in the foregoing Problem, the breadth and depth will be found by them.

EXAMPLE.

What are the cross sectional dimensions of a beam 12 feet long, supporting a weight of 15 tons, 3 feet from the one end, when the breadth is a fourth of the depth?

$$\frac{3\times9\times4}{12}=9.\quad 9\times4=36 \qquad 15\text{ tons}=33600\text{ lbs.}$$

$$\frac{33600\times36}{850}=1423,$$ the cube root of which $=11\frac{1}{4}$, the depth: the breadth will be $\frac{11\frac{1}{4}}{4}=2\frac{13}{16}$

PROBLEM III.

To find the breadth when the load is uniformly distributed over the length of the beam.

RULE.—The same rules apply as in Problem 1, only the divisor is changed from 850 to 1700; that is to say, when the load is uniformly distributed over the length of the beam, it supports double the weight that it can when the whole load is laid on the middle.

Examples in Problem 1 apply to this Problem, only changing the divisors, or halving the quotients.

PROBLEM IV.

To find the dimensions, when a cast iron beam is fixed at one end, and loaded at the other, or when it is supported at the middle, and loaded at both ends.

RULE.—Take the horizontal length of the projection of the beam when fixed at one end, for the length, and apply the Rules in Problem 1, only using the divisor 212 instead of 850.

When the beam is supported any where between the two ends, multiply the length from the prop, by the weight hung at the end, and apply the remainder of the Rule, as in Problem 1, only using 212 instead of 850.

When the load is uniformly distributed over the length of the projection, employ 425 instead of 212 as a divisor.

NOTE. The Rules of this Problem apply to the teeth of wheels, the length being the length of the teeth, and the depth the thickness of the teeth.

Example to this Note. Let the greatest power acting at the pitch line of the wheel be 6000 lbs. and the thickness of the teeth $1\frac{1}{2}$ inch, and the length of the teeth being $\frac{1}{4}$ foot, what is the breadth of the teeth requisite to support this stress?

$$\frac{6000\times.25}{212\times1.5^2}=\frac{1500}{477}=3.14$$ inches, the breadth; but to make the proper allowance for wearing by friction this quotient is doubled, or $6\frac{1}{2}$ inches=the breadth of the teeth, or face of the wheel.

PROBLEM V.

To find the diameter of a solid cylinder of cast iron to support a given weight in the middle—between the middle and the end,—and when the weight is uniformly distributed over the length;—also when fixed at one end.

When the weight is in the middle.

RULE.—Multiply the weight in lbs. by the length in feet, divide this product by 500, and the cube root of the quotient will be the diameter in inches.

When the weight is between the middle and the end.

RULE.—Multiply the short end by the long end; then multiply that product by 4 times the weight in lbs. Divide this product by 500 times the length in feet, and the cube root of the quotient will be the diameter in inches.

When the load is uniformly distributed over the length:

RULE.—Multiply the length in feet by the weight in lbs. and one tenth of the cube root of the product, will be the diameter in inches.

When fixed at one end and the load applied to the other.

RULE—Multiply the length in feet, by the weight in lbs. and the 5th part of the cube root of this product, will be the diameter in inches.

The strength of cast iron beams has been a more interesting subject of inquiry in England than in the United States, from the circumstance that such beams are in common use in the former country for supporting the floors and roofs of fire proof buildings. In the construction of most of the fire proof mills which I have visited, I did not observe any wood used, except for the doors. Not only are the beams and posts of cast iron, but even the very window sashes are formed of this metal. The stairs are made of hewn stone, and the floors are formed of smooth flag stones. Instead of joists laid from one beam to another to uphold the floors, arches of brick work are used, the abutments of which rest upon an iron ledge or lip projecting horizontally from the lower side of each cast iron beam. These beams are formed upon a plan most favourable to strength, having more than three times the weight of iron in the under side to resist fracture, that they have on the upper surface, where the stress tends rather to crush the particles. The beams resemble in shape a board an inch thick, and 15 to 18 inches wide, set upon its edge, with a horizontal lip on each side of the lower edge. They are formed upon the principles laid down in the foregoing rules for obtaining the greatest strength of the iron.

The beams are prevented from spreading asunder horizontally from the effect of the lateral pressure of the abutments of the arches, by strong bars of round malleable iron, secured at each end, where they pass through the beams, by screws and nuts.

Each of these beams are proved by a load of from 8 to 15 tons.—They are made in sections, from ten to twenty five feet long, according to the width of the building, and are supported by iron posts at the places where they are united.—An instance of the importance of a due attention to the transverse strength of iron employed as beams occured in Manchester three or four years since, where one wing of a fire proof cotton mill was destroyed by the fracture of a cast iron beam in an upper story. It broke while the work people were employed in the mill, and brought with it two ranges of arches. The iron beams, and arches beneath being unable to support the shock of the falling materials, gave way also; when all the materials and machinery sunk with accumulated force upon the succeeding arches below, involving one end of the mill in a mass of ruins, and burying beneath the rubbish a number of men, women, and children, together with the machines they were attending. Wooden beams when overloaded give evidence of their weakness by flexure, or emitting a cracking sound, and after this, although much weakened, may retain strength enough to be serviceable. The combination of arches with this brittle metal therefore renders great caution necessary in constructing one of these fire proof buildings.

I had an opportunity near Leeds, of viewing a fire proof woollen mill, in which a large quantity of wool had taken fire from spontaneous combustion. On entering the rooms after the fire had subsided, every thing appeared in its place; even to the iron frames of the machinery, the stone floors and brick arches having confined the flames to the interiour of the apartments. The walls appeared merely blackened by the smoke. The machinery, however, was greatly damaged by the heat and steam. Even the very glass remained nearly entire in most of the iron sashes. The fire, indeed, seemed to have spent its fury as harmlessly as if confined to the dusky arch and walls of a baker's oven.

STRENGTH OF IRON GUDGEONS AND JOURNALS OF SHAFTS.

The preceding Rules of Problem 5, will be found the most correct for finding the strength of Gudgeons.

Gudgeons are the spindles or points upon the ends of a shaft, serving to support them, and forming the axis upon which the shaft turns. Gudgeons support all the weight which rests upon the body of the shaft. It is always prudent to make the Gudgeons of shafts rather large in size to allow for wear, particularly when from their situation they are exposed to gritty substances.

The following Rule is given by Mr. Tredgold, for calculating the diameter of the gudgeons of wooden water wheels to have sufficient strength to sustain the weight of the wheel and load of water.

It is unnecessary in this instance to ascertain the weight to be supported by the gudgeons. The weight of wooden water wheels when water soaked can rarely be ascertained except by calculations, which at best must be imperfect. In England the water wheels are generally constructed of Iron, the price of timber being four fold of what it is in the United States. The actual weight of Iron water wheels is readily ascertained by the bills of castings, and wrought iron work usually done by the pound.

Rules for calculating the diameter of Gudgeons of wooden water wheels.

Multiply the diameter of the wheel in feet by the width, also in feet, to which add the square of half of the diameter. The cube root of the sum will be nearly equal to the diameter (in inches) of the gudgeon required.

EXAMPLE.

What should be the diameter of the Gudgeons to possess the requisite strength to support a wooden Water Wheel 12 feet diameter, and 7 feet wide?

$12 \times 7 = 84$

The square of $\frac{1}{2}$ of the diameter is $6 \times 6 = 36 \times 84 = 120$

The cube root of which (see cube root table) is 4.932, inches answer.

Buchanan's Rule for calculating the proper diameter of Gudgeons, where the weight of the Water Wheel or other superincumbent load is known.

"The cube root of the weight in cwts. is nearly equal to the diameter of the Gudgeon."

EXAMPLE.

Suppose a water wheel to weigh 12 tons 0 cwt. 3 qrs. what ought to be the diameter of a cast iron Gudgeon, sufficiently strong to support the wheel?

12 tons is 240 cwt, and 3 qrs. the cube root of which (see cube root table) is nearly 6.223 inches diameter, answer.

To ensure the strength of the Gudgeon particular care should be taken that the axis of it be exactly in a line with the axis of the shaft; otherwise, at one part of the revolution, the stress will be thrown to the inclined point of the gudgeon, and the motion of the wheel itself may be rendered unequal. If otherwise sufficiently strong a long gudgeon might be thus broken. It is an excellent plan to perfect a gudgeon inserted in a wooden shaft, to turn it the second time after it is secured in its place. It can be thus made exactly true. A long bearing adds much to the durablity of the gudgeon, while at the same time it does not increase the friction. From experiments that have been made, the resistance from friction is proportional rather to the pressure than the extent of surface The principal difficulty of long gudgeons however, as above stated, arises when the line of their axis does not correspond with that of the shaft.

COHESIVE STRENGTH OF MATERIALS TO RESIST TORSION OR TWISTING.

The strength of a cylinder or solid axle to resist torsion, or being wrenched asunder by twisting, is generally as the cube of its diameter. Thus if an iron cylinder or axle be double the diameter of another, it would require 8 times the force to wrench, or twist it off. It is mentioned by professor Robison, that when the matter of the axle is of a simple texture, like that of metals, he does not conceive that the length of the axle has any influence to render it more easily fractured by torsion. The probability, however, is, that as the lengths of the shafts are increased, there is a corresponding chance of an increase of the number of flaws or other imperfections of the metals, which impair their strength. The lateral adhesion of the fibres of wood being much inferior to their cohesion longitudinally, it is consequently much weaker to resist torsion, the fibres sliding upon one another very considerably before the fracture takes place.

In practice the effect of torsion is commonly the most destructive to the Journals of revolving shafts.

The Journal of a shaft is the round part or neck which revolves upon the support, serving both for an axis to the shaft, and for transmitting past this support the force applied to turning the shaft. It is obvious that this point of a shaft is exposed to be broken both by the weight it supports, and the force that twists it.

The strength of revolving shafts to resist torsion are directly as the cubes of their diameters and revolutions; and inversely, as the resistance they have to overcome. Mr. Robertson Buchanan, in his essay on the strength of shafts gives the following data, deduced from several experiments, viz. That the Fly Wheel Shaft of a 50 horse power engine, at 50 revolutions per minute, requires to be 7½ inches diameter, and therefore the cube of this diameter which is=421.1.875, serves as a mulitiplier to all other shafts in the same proportion: and taking this as a standard, he gives the following Multipliers, viz.

For the Shafts of a Steam Engine Water Wheel or any shaft connected with a first power : : :	400
For shafts inside of Mills, to drive smaller machinery, or connected with the shafts above : :	200
For the small Shafts of a Mill or machinery : :	100

From the foregoing, the following rule is derived, viz:

The number of horse power a shaft is equal to, is directly as the cube of the diameter and number of revolutions: and inversely as the above multipliers.

NOTE. Shafts here are understood as the Journals of Shafts, the bodies of Shafts being generally made square.

EXAMPLE I.

When the Fly Wheel Shaft of a 45 horse power Steam Engine makes 90 revolutions per minute, what should be the diameter of the Journal?

$$\frac{45\times400}{90}=200\sqrt[3]{200} \text{ gives } 5\tfrac{8}{10} \text{ inches diameter.}$$

EXAMPLE II.

The velocity of a Shaft connected with a first mover, is 80 revolutions per minute, and its diameter is 3 inches: what is its power?

$$\frac{3^3\times80}{400}=5.4 \text{ horse power.}$$

EXAMPLE III.

What will be the diameter of the shaft in the first example when used as a shaft of the second Multiplier?

$$\frac{5.8}{1.25}=4.64$$ or $45\times200=9000\div90=100$—The cube root of which (as per cube root table) gives $4\tfrac{6}{10}$ inches diameter.

The following Table gives the diameters of the Journals of Shafts immediately connected with a water wheel, Steam Engine, or other first moving power.

To find the diameters of Shafts, connected with the above Shafts, to drive smaller machinery inside of mills, called second movers,

Divide the number of inches given in the table by 1.25.

To find the proper diameters of the small light Shafts of a mill, or machinery, connected with the last described Shafts, and called third movers,

Divide the numbers in the Table by 1.56.

The upper line shows the number of revolutions per minute, and the left hand column the horse power. Where the lines intersect each other will be found the diameter in inches of a journal making the number of revolutions assigned to it in the upper line, and of a strength equal to the horse power also placed against it.

The following is a Table of the diameters of Shafts, being the First Movers, or having 400 for their multipliers.

TABLE.

Diameters of the Journals of first movers, or Shafts connected with a first power of a Steam Engine or Water Wheel.

Horses' Power.	REVOLUTIONS.																			
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105
	Inches Diameter.																			
4	5.5	4.8	4.5	4.	3.7	3.8	3.5	3.3	3.2	3.1	3.	2.9	2.9	2.8	2.7	2,7	2,6	2,6	2,6	2,5
5	5.9	5.1	4.7	4.4	4.1	3.9	3.7	3.6	3.5	3.3	3.3	3.2	3.1	3.	3.	2,9	2,9	2,8	2,8	2,7
6	6.3	5.5	5.	4.6	4.4	4.1	4.	3.8	3.7	3.6	3.5	3.5	3.4	3.3	3.2	3,2	3,	3,	2,9	2,9
7	6.6	5.8	5.2	4.9	4.6	4.4	4.2	4.	3.9	3.7	3.6	3.6	3.5	3.4	3.4	3,3	3,3	3,2	3,1	3,1
8	6.9	6.	5.5	5.1	4.8	4.6	4.4	4.2	4.1	4.	3.9	3.8	3.7	3.6	3.5	3,5	3,4	3,4	3,3	3,2
9	7.2	6.3	5.7	5.5	5.	4.8	4.5	4.4	4.2	4.1	4.	3.8	3.7	3.7	3.6	3,6	3,5	3,5	3,4	3,3
10	7.4	6.6	5.9	5.6	5.2	4.9	4.7	4.6	4.4	4.2	4.1	4.	3.9	3.8	3.7	3,7	3,6	3.6	3,5	3,4
12	7.9	6.9	6.3	5.8	5.6	5.4	5.2	5.	4.8	4.6	4.4	4.3	4.2	4.1	4.	3,9	3,8	3,8	3,7	3,6
14	8.3	7.2	6.7	6.2	5.9	5.6	5.4	5.2	5.	4.7	4.5	4.4	4.4	4.3	4.2	4,1	4,	4,	3,9	3,8
16	8.7	7.6	7.1	6.6	6.1	5.8	5.6	5.4	5.2	5.	4.8	4.7	4.6	4.5	4.4	4,4	4,3	4,3	4,1	4,
18	9.	7.9	7.5	7.	6.6	6.2	5.8	5.3	5.4	5.2	5.	4.9	4.8	4.7	4.6	4,5	4,4	4,3	4,2	4,2
20	9.3	8.1	7.4	7.2	6.6	6.4	5.9	5.7	5.6	5.4	5,2	5.1	5.	4.8	4.6	4,6	4,5	4,5	4,4	4,4
25	10.	8.5	8.	7.4	7.1	6.8	6.3	6.	5.9	5.6	5.5	5.4	5.3	5.2	5.1	4,9	4,8	4,7	4,6	4,6
30	10.7	9.3	8.4	7.9	7.4	7.1	6.9	6.7	6.5	6.3	5.9	5,8	5.7	5.6	5.5	5,3	5,2	5,1	5,	4,9
35	11.4	9.8	8.9	8.4	7.9	7.4	7.1	6.9	6.6	6.5	6.3	6.1	5.9	5.7	5.6	5,5	5,4	5,3	5,2	5,2
40	11.7	10.5	9.3	8.8	8.3	7.8	7.4	7.2	6.9	6.7	6.6	6.4	6.2	6.	5.9	5,8	5,7	5,6	5,6	5,5
45	12.	10.6	9.7	9.2	8,7	8.1	7.6	7.4	7.	6.8	6.7	6.5	6.4	6.2	6.1	6,	5,9	5,8	5,7	5,6
50	12.6	11.	10.	9.3	9.	8,5	8.	7.8	7 4	7.3	7.2	6.9	6.8	6.6	6.5	6,4	6,2	6,	5,9	5,8
55	13.4	11.4	10.4	9.8	9.1	8.8	8.4	8.	7.5	7.4	7.3	7.2	7.	6.7	6.6	6,5	6,3	6,2	6,1	6,
60	13.6	12.	10.8	10.	9.3	9.	8.6	8.2	7.7	7.6	7.4	7.3	7 2	6.9	6.8	6,8	6,7	6,6	6,4	6,2

There is so great a difference in the strength of cast iron (amounting in some instances to $\frac{1}{4}$) that it is always safest to calculate upon the weakest. The soft iron, such as is most easily cut by the file, is generally found to be more easily broken than the hard iron. I have observed that the cast iron shafts and wheels which come out of the moulds with a half vitrified crust of sand adhering firmly to their surface, usually prove of the strongest metal. The strength and hardness of cast iron depends in some measure upon the degree of heat to which it has been exposed when melted.

The fact is well known, that a cast iron rod or shaft will sustain more torsional stress than a malleable iron rod or shaft of the same dimensions. Cast iron is therefore preferable to malleable iron for shafts exposed to much stress by wrenching or twisting, as the wheel shafts of steamboats. But the strength of wrought iron to resist lateral pressure or sustain heavy weights is superiour to that of cast iron in the proportion of 14 to 9. For shafts of water wheels, therefore, wrought iron is preferable. The shafts of some of the cast iron water wheels which I have seen in England are formed of large hollow cylinders, by which a great increase of strength of the same weight of metal is obtained, being in the ratio of the cube of the diameters.

From the preceding rules and observations, the mill wright may easily calculate to make his shafts of the iron best suited to overcome the resistance to which they will be subject, and also to form the diameters of the journals of such shafts of proportions corresponding with the strength of the iron of which they are made. For example—What should be the diameter of a journal of malleable iron, to sustain an equal weight with a cast iron journal of seven inches diameter?

$7^3=343$, the cube of 7.

Malleable iron being stronger than cast iron to sustain lateral pressure, as above stated, in the ratio of 14 to 9; by the rules of proportion, 14 : 343 : : 9 : $220\frac{1}{2}$. Now the cube root of $220\frac{1}{2}$ (see the cube root table) 6.04 inches.

STRENGTH OF WHEELS.

The arms of wheels are as levers fixed at one end and loaded at the other, and consequently the greatest strain is upon the end of the arm next the axle; for this reason all the arms of wheels should be strongest at that part and tapering towards the rim.

The Rule for the breadth and thickness of arms, according to their length and number in the wheel, is as follows: (see Tredgold's Essay, page 114) Multiply the power or weight, acting at the end of the arm, by the cube of its length; the product of which divided by 2656 times the number of arms, multiplied by the deflection, will give the breadth and cube of the depth.

EXAMPLE.

Suppose the force acting at the circumference of a spur wheel to be 1600 lbs. the radius of a wheel 6 feet, and the number of arms 8; and let the deflection not exceed one tenth of an inch:

$$\frac{1600 \times 6^3}{2656 \times 8 \times 1} = 163 = \text{breadth and cube of the depth.}$$

Let the breadth be 2. 5 inches, therefore $\frac{163}{2.5}=65.2$, which is equal to the cube of the depth; now the cube root of 65.2 is nearly 4.03 inches; this, consequently, is the depth or dimension of each arm in the direction of the force.

NOTE.—When the depth at the rim is intended to be half that of the axis use 1640 as a divisor instead of 2656.

The teeth are as beams or cantilevers, fixed at one end, and loaded at the other, the rule applying direct to them; (see Tredgold's Essay, Art. 121) where the length of the beam is the length of the teeth, and the depth the thickness of the teeth. For the better explanation of the rule, the following example is given.

EXAMPLE.

The greatest power acting at the pitch line of the wheel is 6000 lbs. and the thickness of the teeth 1½ inch, the length of the teeth being 0.25 feet; it is required to determine the breadth of the teeth?

$$\frac{6000\times0.25}{212\times1{,}5^2}=\frac{1500}{477}=3.2 \text{ inches the breadth required.}$$

In order that the teeth may be capable of offering a sufficient resistance after being worn by friction, the breadth thus found should be doubled; therefore in the above Example the breadth should be 6.4, or 6½ inches.

Mr. Carmichael (see Robertson Buchanan on the teeth of Wheels) gives the following data gleaned from experiments, which are therefore valuable, and useful to the practical mechanic.

RULE.—Multiply the breadth of the teeth, by the square of the thickness and divide the product by the length; the quotient will be the proportional strength in horse power, with a velocity of 2.27 feet per second.

EXAMPLE.

What is the power of a wheel, the teeth of which are six inches broad, 1.5 inches thick, and 1.8 inch long, and revolving at the velocity of 3 feet per second?

$1.5\times1.5.=2.25$, the square of the thickness, multiplied by the breadth 6 inches gives $13.5\div1.8$ the length of the teeth gives 7.5 horse power as the strength at 2.27 feet per second.

Then by the rules of proportion, $2.27 : 7.5 :: 3 = \frac{7.5\times3}{2.27} = 9.91$ horse power as the strength at 3 feet per second.

TO FIND THE PITCH OF A WHEEL*.

RULE.—The pitch is found by multiplying the thickness by 2.1 and the length is found by multiplying the thickness by 1.2.

* The distance between the cogs or teeth of wheels, measuring from centre to centre of each cog or tooth, is called the Pitch of the wheel; a term derived from the circle or curved line on which these distances are measured.

EXAMPLE.

The thickness being 2 inches, what is the pitch and length?

$2\times2.1=4.2$ Pitch.

$2\times1.2=2.4$ Length.

The breadth of the teeth, as commonly executed by the best Masters, seems to be from about twice to thrice the pitch.

TABLE *of the Pitch, Thickness, Breadth, and Strength of Wheels.*

Pitch in Inches.	Thickness in Inches.	Breadth in Inches.	Length in Inches.	Horses Power at 2.27 feet per Second.	H. P. at 3 feet per Second.	H. P. at 6 feet per Second.	H P. at 11 feet per Second.
4.2	2.	8.	2.40	13.33	17.61	35.23	64.6
3.99	1.9	7.6	2.28	13.03	15.90	31.80	58.30
3.78	1.8	7.2	2.16	10.80	14.27	28.54	52.32
3.57	1.7	6.8	2.04	9.63	12.72	25.54	46.68
3.36	1.6	6.4	1.92	8.53	11.27	22.54	41.32
3.15	1.5	6.	1.80	7.50	9.91	19.28	36.33
2.94	1.4	5.6	1.68	6.53	8.63	17.26	31.64
2.73	1.3	5.2	1.56	5.63	7.44	14.88	27.28
2.52	1.2	4.8	1.44	4.80	6.34	12.68	23.24
2.31	1.1	4.4	1.32	4.03	5.32	10.64	19.54
2.10	1.	4.	1.20	3.33	4.40	8.81	16.14
1.89	.9	3.6	1.08	2.70	3.15	7.14	13.09
1.68	.8	3 2	.96	2 13	2.81	5.62	10.33
1.47	.7	2.8	.84	1.63	2.15	4.30	7.88
1.26	.6	2.4	72	1.20	1.59	3.18	5.83
1 05	.5	2.	.60	.83	1.10	2.20	4.03

It is favourable to the strength of wheels, when it becomes necessary to employ them in mills to increase the velocity of the motion of shafts, to make them of large diameters. Where small pinions are used a much greater stress is thrown upon the journals or gudgeons of shafts, arising partly from the greater direct pressure, and from the tendency which the oblique action of the teeth have particularly when somewhat worn, to produce great friction, and to force the pinion from the wheel, causing by the reaction both the pinion and the wheel to bear harder upon the journals. In all cases where the velocity of the motion of wheels is rapid, particular attention should be bestowed in fitting them correctly upon the shafts, that they may run without clatter. To obviate the latter inconvenience, wooden cogs are used to run upon iron teeth of a corresponding wheel—in this case it is particularly desirable for strength and durability to make wheels of large diameters.* When small wheels or

† The wood employed for cogs having only about ¼ of the strength of cast iron, and the strength of these materials being as the squares of their depth or thickness, wooden cogs should therefore be made twice the thickness of cast iron ones. The pitch of course must be greater in the same proportion.

pinions are used, the wear of the teeth is greatly increased, a loss of power takes place from excessive friction, the Shafts are caused to tremble, and the fixtures to sustain them must also be made very strong; and after all, the wheels will not operate to the satisfaction of those who construct them.—When wheels of large diameters are employed, the teeth and rims may be made much lighter in proportion as they are increased in diameter, as the stress upon the teeth of a wheel of four feet diameter is one half of that upon the teeth of a wheel of two feet diameter operating under the same circumstances in all respects.

Mr. Tredgold in his essay on the strength of Wheels, gives the following rules for the proportions of cog wheels made of cast iron, an attention to which will save the expense that is needlessly bestowed in making wheels much heavier than necessary. He observes that the patterns must not only be of such a form as to be sufficiently strong, calculating by the bulk of the parts, but also proportioned so that when the fluid metal is poured into the mould it may cool in every part at the same time. Otherwise the arms, or some other parts are subjected to such great stress from the unequal contraction of the iron after being cast, that they are ready to fly to pieces upon being struck with a hammer. The patterns he further observes should be made one eighth of an inch to the foot larger than the desired casting to allow for the contraction of the metal; and also tapered one sixteenth of an inch in a depth of six inches that they may rise freely without injuring the mould when the founder is drawing them out of the sand.

To Proportion the Ring, Arms and Centre of a Wheel.

Make the thickness of the ring that supports the teeth equal in thickness to that of one of the teeth near its root.

Make the arm at the part where it proceeds from the ring, of the same breadth and thickness of the ring, and at its junction let it be so formed as to take off any acute angle which would be apt to break off in the sand in moulding.

The arms should become larger as they approach the centre of the wheel,* and the eye should be made sufficiently strong to resist the driving of the wedges to secure it to the shaft, while on the other hand care must be taken not to make the eye so thick as to endanger unequal cooling. It should be somewhat broader than the breadth of the teeth, in order that it may be secured more firmly upon the shaft. When the ring is about an inch thick it is common to make the eye about one inch and a quarter thick, and one fifth broader than the ring.

When wheels are of a large size it is proper to have the centres and rims cast in distinct pieces, and afterwards united by bolts to prevent the bad effects of the unequal contraction of iron when cast. A

* The arms of wheels are as levers fixed to the shafts at one end with the weight applied at the other, like the handspike applied to turn the windlass of a ship.

good plan to preserve the arms of wheels unimpaired by this contraction is to give them a curved form.*

COHESION OF A SOLID AND FLUID.

The Attraction of Cohesion is not confined to solid bodies, but also takes place between a solid and a fluid, and between the particles of the same fluid. A drop of water will hang upon the end of a rod, and the particles will assume a spherical form.

The manufacture of shot depends upon the principle, that fluid substances have a tendency to assume a spherical form under the operation of the attraction of cohesion. Advantage has been taken of this tendency by pouring the melted lead, combined with a little antimony, through a sieve or screen. Each drop as it descends freely through the air becomes perfectly globular, and also becomes sufficiently cool and hard to retain its form after striking the water placed beneath to receive it. A very simple and ingenious application of the principle of gravitation is adopted to separate the imperfect shot from those which are perfectly round. An inclined plane is formed by a narrow board, upon which the shot is caused to roll down. Those globules which are not round, pursue a devious course, and fall off the sides of the board, while such as are perfect descend in straight lines to the bottom, whence they are taken to a revolving cylinder, in which they are inclosed, to be polished by their mutual attrition.

Drops of water, or of mercury, will unite on meeting, and form large drops. Water will rise of itself in small glass tubes to heights which are inversely as the diameter of the bores—an experiment easily made with tubes of glass in coloured water. Capillary glass tubes have been used instead of wicks in lamps to supply the oil. The ascent of sap in trees has been also attributed to this principle. Polished planes of metal, of about two inches diameter, besmeared with hot grease, have required in some experiments, eight or nine hundred pounds to separate them.

CRYSTALLIZATION.

The particles of all substances but such as are subject to the influence of animal and vegetable life, under the operation of the attraction of cohesion, have a tendency to unite in a beautiful and orderly arrangement of component atoms, called crystallization. Thus water, which is fluid at a certain temperature, always assumes a determinate form of cyrstals, shooting out at regular angles of 60 and 120 degrees when cooled below the freezing point. The flake of descending snow

* It has been common in the United States when forming the patterns of bevelled wheels, to make the rims much thicker than the arms. The certain effect of this formation is to impair the strength of the arms in a very great degree, from the unequal effects of contraction. A cast iron wheel of this description I once had broken into several pieces with a slight blow of a hammer. In such cases a wheel may be considered as bearing a resemblance to the philosophical toy called Prince Rupert's Drops, composed of drops of glass suddenly cooled after being melted, which are shivered into atoms if but a small portion of the top be broken, or if it be otherwise subjected to a sudden shock.

exhibits, on examination, this remarkable arrangement of spicular fibres. Common salt will form most beautiful crystals in the shape of regular cubes, as perfectly square as if cut by some skilful lapidary. Other bodies, such as the metals, may be liquified by heat, but on cooling will recover their cohesive force, and re-unite in polyhedral crystals. The grain of iron and other metals thus presents instances of crystallization Certain substances on being heated, readily assume the state of vapour, and during their condensation present regular crystalline forms; such as Camphor, Benzoin, &c. In this way the crystals of snow are produced. By carefully splitting crystals, which only afford smooth surfaces when broken in particular directions, the sides may be scaled off until the primitive form of the nucleus is observable. The science of crystallization is principally founded upon measuring the angles formed by the sides of these crystals, and determining their various figures by classes, such as cubical, &c.

The attraction of cohesion does not, however, extend its influence to all substances to cause them to have a tendency to unite when brought into contact. Thus neither mercury nor oil will unite with water. To this fact the art of Lithography, or printing from stones is indebted for its origin. If a piece of unpolished marble have a portion of its surface oiled, and be then immerssed in water, it will be found that the pores of the marble will be saturated with moisture in all parts except those besmeared with the oil. If printing ink, composed also of oily ingredients, be now applied, it will for the same reasons attach only to the oiled portions of the stone, leaving the wetted portions. Whatever figures, letters, or even landscapes, may be formed in oil upon the stone by the pencil of the painter, the impressions of them after having imbibed the ink, may be taken on paper, as from copperplate. Thus a surprising facility is obtained in the art of printing by which thousands of impressions, all exact copies of the hand writing, or original sketch upon the stone, may be thrown off in a few hours.

CHEMICAL ATTRACTION.

An attraction, acting at insensible distances, somewhat similar to that of Cohesion, exists between the particles of bodies entirely dissimilar in composition and qualities, producing remarkable compounds when allowed to unite. This attraction, exerted between particles of matter of dissimilar kinds is designated by the name of "Chemical Attraction, or affinity," to distinguish it from Cohesion, which causes the particles of the same kind of matter to unite. Potash and sulphuric acid are quite dissimilar in their qualities, and yet have a strong attraction for each other, forming a bitter salt without retaining the corrosive or hurtful qualities of either of the ingredients. Thus two substances which taken separately are destructive to animal life, form when united by their chemical attraction a new substance or compound quite harmless in its effects. The muriate of Soda, or common table Salt, one of the most useful articles classed among the necessaries of life, is produced from two equally powerful ingredients, muriatic acid and soda—a mineral alkali. Sulphuric acid and soda when united form the bitter Glauber Salts. The science of Chemistry is almost entirely founded upon this remarkable fact, that one body attracts other bodies unequally, and if brought together by mixture, each body singles out that for which it has the strongest attraction or affinity, and enters into union with it, leaving the other bodies forming the mixture to pursue a similar arrangement. Thus if nitric acid be poured upon a mixture of lime and magnesia, it dissolves the former instead of the latter. It even sometimes appears that the intervention of a third body will cause the union of two substances which have no direct attraction for each other. Oil and water immediately unite on adding an alkali, or potash, forming soap, and may be separated afterwards by introducing an acid, which has a stronger affinity for the potash than the oil, and the oil and water are then left disunited.

By chemical attraction two transparent æriform gases produce a solid when united. Sal Ammoniac, the solid salt well known in Commerce, is immediately formed when muriatic acid gas and ammoniacal gas are mingled together.* In this way two solids produce a fluid, as may be exemplified by experiments.†

So violent is the chemical action between certain substances that spontaneous combustion ensues when they come together. Highly concentrated acids and spirits of turpentine will thus flash violently into flame. Much caution is necessary in trying this experiment. The most important effects in the useful arts have frequently attended this violent action of chemical attraction. Waste cotton or wool mixed with certain oils and left carelessly in mills, have in numerous instances set fire to them, and a vast amount of property has in this way been lost. It should therefore be a subject of particular care to the manufacturer to have his waste cotton or wool every night carefully collected and carried out of his mill—a plan which unites both safety and neatness.

Quicksilver has a tendency to unite with most of the metals forming an *amalgam*. Advantage has been taken of this principle to extract gold and silver from the ores in which they are imbedded. The mercury is easily seperated again by heat from these metals.—Button gild-

* *To produce a solid from two fluids.* These experiments may be made both amusing and instructive.—Take two wine glasses, into one put a small quantity of sal ammoniac in powder, and into the other, a spoonful of common table salt;—add quicklime to the one, and sulphuric acid, to the other. From the former ammoniacal, and from the latter muriatic gas, will be evolved. Bring the two glasses close together, and cause the two gases proceeding from them to intermingle by funnel-shaped pieces of paper. The formation of a solid product will be displayed by the appearance of white fumes of great density.

† *To produce a solid from two fluids.* Let fall gradually concentrated sulphuric acid into a saturated solution of muriate of lime. A pungent vapour (muriatic acid gas) will arise and an almost solid compound (*sulphate of Lime*) be produced. The combination of water with quick lime is a familiar instance of converting a fluid into a solid.

To form a fluid from two solids, mix a little sugar of lead, (acetate of Lead) with an equal quantity of white vitriol (Sulphate of Zinc) both in fine powder. Stir them together with a piece of wood or glass, and no chemical changes will be perceptible : but if they be now rubbed together in a mortar the two solids will operate upon each other and become a fluid. Nitrate of Ammonia and Sulphate of soda will produce the same effect.

ing and other similar works are accomplished in the same way by amalgamating the gold with mercury, and spreading it over the article to be gilded. After the mercury is driven off by heat, the gold is left behind, adhering to the surface.

Chemical attraction indeed is often more powerful in its effects than cohesion itself, causing even iron and steel to unite with acids and become fluid, and wood to decompose under the effects of moisture. It must be apparent, therefore, that in the useful arts the most important results attend the action of chemical attraction; for it is of little avail if the artist form his machines of the strongest materials, if they are exposed to the action of decomposing agents. It is this chemical attraction and decomposition that is silently but continually operating upon the surface of the earth crumbling even the rocks, and putting a limit to the duration of all the works of man. The very air which we breathe posseses a tendency to unite with almost all the substances which it surrounds, producing changes in temperature, form and durability. The air is composed of two gases called nitrogen and oxygen, in the proportion of 79 parts of the former to 21 parts of the latter. The oxygen seems to be a most powerful antagonist to the attraction of cohesion, combining with the hardest metals, slowly converting them at low temperature into dust, and under high states of temperature, rapidly consuming them. Thus wood when heated to a certain degree unites with this gas, as exhibited in the instance of combustion;—were the atmosphere composed of pure oxygen instead of only one fourth part, the very grates and iron work of the furnaces would unite with the oxygen and would burn with a more brilliant light than the fuel placed upon them.

To protect woods and metals from the action of the air and moisture, various oils and varnishes are generally employed, which have at the same time been made to contribute to beauty by mixing them with pigments of various colours. These colours are frequently composed of the disintegrated particles of the metals produced by their chemical attraction, as the same metal united to different proportions of oxygen produces compounds called oxides, differing greatly in colour. Thus mercury forms a black and red oxide—iron a brown and red, manganese a *white* and *black*, and common lead a pure white, yellow, and red colour. Iron united by chemical attraction with certain acids forms Copperas; copper thus forms blue vitriol, and clay forms alum. The art of dying is indebted to chemical attraction for its greatest success.

To obviate the destructive effects of chemical attraction to machinery, it only remains for the engineer to protect the wood and metal as much as possible from moisture and damp air, producing decay and rust. If the air could be entirely excluded, and the temperature reduced, wood might perhaps be imperishable. In the bed of the river Thames piles have been discovered which were supposed to have been driven when the island was in the possession of the Romans. In the roofs of some of the ancient buildings in England, chesnut timber has been found in dry situations in a good state of preservation, after having endured a space of more than five hundred years from the time the buildings were erected. Whatever may be the solidity and strength of machines, however, their materials must yield eventually to the effects of this all destroying principle, which are often, in figurative language, imputed to the "corroding tooth of time."

Matter is subject also to the action or influence of other natural powers or principles, "which act upon material bodies, without being visible or tangible, or susceptible of being weighed by our balances," such as Electricity, Galvanism, Magnetism and Heat, of which little more is known than the facts of their existence as illustrated by various experiments. They do not operate upon matter uniformly at all times, like gravitation, but are only observable under peculiar circumstances. Thus the direct power or action of electricity is only apparent when its state of equal diffusion is disturbed, and it becomes collected by friction on various substances, or in the clouds. Galvanism, which appears when metallic plates are immersed in certain liquids, continues in full action but two or three years from the same plates. We shall treat of each of these principles in course.

ELECTRICITY.

If a piece of sealing wax and of dry warm flannel be rubbed against each other, they both exhibit a power of attracting and repelling light bodies. Glass rubbed with silk, and various other substances exhibits like phenomena. In these cases the bodies are said to be electrically excited; and if viewed in a dark room are luminous. All bodies do not possess this property, as on metals, no electricity is excited by friction. This fluid was first discovered by the Greeks from rubbing amber, called by them *electron*, from which the word electricity is derived. Many other substances have since been found to possess the same qualities as amber, such as wax, rosin, glass, silk, fur, worsted, &c.

When electricity passes from one body to another through the air, there is a peculiar odour, a slight noise, and a flash of light.—This is observable on applying the finger to the conductor of an electrical machine, and on a magnificent scale when this fluid passes from one cloud to another, or to the earth. From the similarity of the appearance of electricity and lightning our immortal countryman, Franklin, was induced by way of experiment to construct a kite with his handkerchief, having a small wire communicating with it by the string, and to fly it on the approach of a thunder storm. He was soon gratified by drawing sparks from his simple apparatus. The spark from the common eletrical machine bears probably the same proportion to the quantity of the fluid usually exhibited by a flash of lightning during a storm, as the noise of it does to the peal of thunder.

Metallic wires having been found to conduct off electricity from machines, Franklin with his accustomed sagacity applied metallic rods to conduct off the lightning from buildings. These rods composed of iron, copper, or other metal, are now generally affixed to the outer walls of buildings, reaching several feet above the highest point of the roof, and terminating in the earth below the foundation. Water being an excellent conductor as well as the metals, and extending in springs and subterraneous channels, affords the best termination to a lightning rod. It has been found that a conductor will protect from lightning a circular space, the diameter of which is four times the length of the rod itself, measured from the highest point of the object to which it is affixed. The rods ought therefore to be raised about ¼ of the diameter of the building above the highest parts of the roof. The points should be formed of copper, well gilded, to prevent decomposition or rust, by which they would be soon rendered blunt. Points have been found to attract and draw off lightning, whereas blunt bodies do not have this effect. It was for a long time argued that a blunt termination to conductors was on this account preferable, as the lightning was not thereby attracted to strike a building, while at the same time the conductors were equally efficacious in carrying off the fluid, if it should fall upon them. Experience has however decided in favour of points. The effects of electricity in the useful arts are inconsiderable compared with those of gravitation and cohesion. In the manufacture of cotton it however sometimes offers serious difficulties, as the fibres become during a dry frosty state of the atmosphere so electrical, as to diverge in every direction. The roving in such cases becomes stiff as it passes from the rollers and shoots over the vessels placed to receive it. Wooden vessels or cans, being non conductors, have sometimes been laid aside to substitute metallic ones, which being conductors, immediately deprive the cotton of its electricity and render it at once pliable and manageable. I have sometimes seen filmy fleeces of the cotton rise from machinery and move through the air towards the belts of the mill, and ceiling. To obviate all difficulties of this kind in the manufacture of this material, it is only necessary to introduce steam into the apartment, as the moisture will soon diffuse itself, and by rendering the fibres moist, will cause them to become conductors, when they cease to be electric.

In theory, electricity is considered to pervade every substance, but is only rendered sensible when accumulated in a body, or when a less quantity exists in it than in surrounding objects. Hence electricity has been distinguished by the term, *negative*, when there is a deficiency, and *positive*, when there is a redundancy. In the former case it attracts light objects, as if to obtain from them a supply. In the latter case it repels such objects. An amusing experiment will illustrate this principle of electrical attraction and repulsion. If a metallic plate be supended from the excited conductor of an electrical machine a few inches above a similar plate, resting upon a table, and light figures cut from paper be placed between them, the attraction and repulsion will alternately cause them to ascend to the upper plate, and to descend to the lower one, producing the spectacle of an animated dance.

GALVANISM.

Galvanism seems to be considered by modern chemists as a species of electricity excited by chemical action instead of friction. While Galvani, an Italian physician, was performing experiments on electricity, his wife accidentally observed that when the nerve of the leg of a frog suspended by a metallic hook was touched by a metal, it was thrown into violent convulsions. If a piece of silver and of zinc be placed one above and the other beneath the tongue, and they be made to touch each other at the edges, a peculiar sensation is excited, and a metallic taste is observable, which if applied to a nerve would produce an effect similar to that above stated. Volta supposed that this effect might be very greatly increased by using a number of pieces of metal arranged in pairs, substituting between each pair a moist piece of cloth. The effect he found, as he had conjectured, increased in proportion to the number of plates employed, and the apparatus he invented has since been called a *Voltaic pile*, or *galvanic battery* when the plates are placed in a horizontal trough filled with a diluted acid. When the opposite ends of the battery are made to communicate, a spark is observed to pass between them as often as they are brought together. Even gold and silver are caused to burn with a brilliant light if interposed in thin sheets between these points.

Galvanism is a most powerful agent in causing decomposition, as substances united by the strongest cohesive attraction, are easily separated by it. Water is converted by it into two gases, oxygen and hydrogen. These two gases after being thus obtained under a bell glass, may be fired by applying flame, when an explosion takes place and they again unite in the same proportions and form water. Thus water is proved, both by composition and decomposition, to be formed of two combustible elements, or gases, which have a tendency to burn. It is by this experiment demonstrated to be composed of two parts of hydrogen and one of oxygen. A most singular fact attending these experiments is, that the same gases are invariably given off from the same points of the connecting wires of the battery, the oxygen being given off from one of the points and hydrogen from the other, and may be collected seperately under inverted glasses placed over each point and immersed in the water.

In practice, the effects of galvanism upon machines are inconsiderable. The principal inconvenience arising from it is its tendency to decompose the iron bolts and fastenings of coppered ships. The bolts by which the planks of coppered ships are attached to the timbers were formerly of iron, which, being in contact with a great surface of copper upon the bottom of the vessels, immersed too in a solution of salt, which is favourable for exciting galvanism, were very soon destroyed, the iron being the metal most easily acted upon. Whenever pieces of metal are to be immersed in a saline solution and connected together, the same kind ought to be employed, that there may be no galvanic action, by which one or both may be destroyed. Accordingly copper bolts are now used instead of iron on the bottom of coppered ships. To save the copper at the expense of the decomposition of some cheaper metal, Sir Humphrey Davy placed plates of zinc and of iron upon a coppered ship that the action of the salt water might be exerted on them instead of on the copper itself. These metals being more readily decomposed by the excitation of the electricity or galvanism, the action upon them would be greatest. Although this was found to render the copper more durable, yet it deprived it of its most valuable quality of keeping clean and free from sea weeds and barnacles.—After a ship has been for a short time at sea, the copper exposed to the action of the sea water becomes perfectly bright, and offers but little resistance, compared with the grassy und shelly surface of the bottom of an uncoppered ship, in passing through the water.

MAGNETISM.

There are many points in which electricity and magnetism resemble each other, such as attraction and repulsion. Negative and positive electricity, and two magnetic poles, are always found to exist together.—They are however regarded as distinct fluids or principles. Magnetism is most strongly displayed by the loadstone, a sort of iron ore. Great masses of iron ore frequently exhibit magnetical properties.—Even bars of common iron acquire this property after being placed in certain situations. Thus tongs or pokers become magnetical after standing for a time in a vertical position, the upper end being the north pole, and the lower end the south pole. Heat dissipates this property, and percussion imparts it to several of the metals, as observable after they are hammered. The most remarkable quality of the magnet is polar attraction, or a tendency when allowed freedom of motion to point in a particular direction. A piece of soft clean iron is more powerfully attracted by the magnet than any other substance. It is only necessary to rub a needle or piece of iron with a magnet to impart this property to it. The attractive power of magnets for ned of iron or steel is often rendered surprisingly great by bending both magnetic poles to act together upon a piece of iron. These magnets from their form are called horse shoe magnets. One of this description which I saw in the museum at Haerlem sustained by its attractive power a weight of 200 lbs.

The most important application of magnetism is to the mariners compass, to which indeed the discovery of this western hemisphere may be attributed. Without it the mariner could not pursue his course amid darkness and storms over trackless oceans. The angles in field surveying are readily obtained by the compass.—Allowance is hower always made for the variations of the needle, which does not uniformly point directly north, or toward the pole of the earth, but varies with considerable regularity during a period of several years, sometimes pointing to the east and sometimes to the west of north. In different parts of the globe, this variation is found to exist in different degrees.—Tables of the variation of the compass, are published in most countries for correcting new surveys of the courses laid out on old plats.

Another useful application of magnetic attraction is to prevent the deleterious effects of the particles of iron or steel upon the lungs of the workpeople, who grind steel upon dry stones. The fine metallic dust which floats in the air, being inhaled, produces irritation upon the lungs and inflammations of the chest, by which the cutlers are commonly brought to a premature grave. Magnetic mouth pieces have been used to attract this steel dust from the air inspired. On a visit to the extensive grinding establishments of Sheffield, I did not observe however, a single instance in which this plan was adopted by the sickly looking work people,—so reckless are they become by habit of the pernicious consequences attendant on their branch of labour. Even the revolving fan and trunk to blow off the deleterious particles, except in a few of the apartments of these great establishments of Sheffield, are negligently dispensed with.

HEAT.

Heat is one of the most active and important agents of nature in producing changes and modifications of all material substances. It is the antagonist of Cohesion—solidity in all cases yielding to its irresistible effects. There are few subjects in Natural Philosophy, more generally interesting in theory, than the nature and properties of heat, and none more interesting and useful in practice. The effects of heat are of such vast importance in so many of the operations of the useful arts, and even to the daily wants of almost every individual, that a general outline of the leading principles or doctrines of this great natural agent, the most powerful within the control of man, will here be given.

The sensation produced by heat, is too well known to require illustration. The term Heat, is however employed to denote the cause of the sensation as well as the sensation itself. By chemists the term *Caloric* has been introduced to denote the cause, while the term Heat is still employed to express the sensation excited. Caloric is the most generally diffused agent in nature as well as the most active. All bodies contain more or less of it, upon which their *temperature* depends. Cold is supposed to be merely a state in which there is a deficiency of Caloric, and may therefore be considered a relative term connected with the abstraction of heat. It has a tendency to pass from one substance to another, in some cases slowly from particle to particle; in others it passes with the velocity of light, when it is said to *radiate*, or shoot forth as it were in rays—like air it has always a tendency to diffuse itself, till an equality of temperature is established.

Much speculation has existed among philosophers in regard to the nature of heat. It has by some been considered a fluid, by others a material, and by some an immaterial substance. By the most delicate scales, however, its ponderosity has not been detected. Most of the common effects resulting from the action of heat upon material substances, may be plausibly explained on the hypothesis that caloric is a subtile material fluid, the particles of which like those of electricity, mutually repel each other, and when interposed between the particles of bodies cause them to separate, as in the expansion, fusion and evaporation of bodies. It is natural to suppose that when a body is enlarged in bulk, that the enlargement is occasioned by the particles of other matter insinuated between the particles of the expanded body, by which they are repelled to a greater distance from one another. When this repulsion becomes extreme by the introduction of an excessive portion of heat, it is further natural to suppose that the particles of a solid body might assume a fluid or even an aeriform state. This theory seems further to be strengthened by the fact that almost all substances on being condensed or compressed in volume give out heat, as if it were forced or pressed out of such substances by the nearer approach of their particles. Steam on being condensed occupies only $\frac{1}{1800}$ part of its former volume, and a cubic inch of water thus condensed sets free a sufficient quantity of caloric, it has been stated, to heat a cubic inch of iron red hot, if the caloric could be collected and concentrated in the iron. Water again on passing from a fluid to a solid state sets free the heat which served to separate the particles so much as to allow them to move easily upon each other. The heat evolved in the case of the freezing of water has been computed to be sufficient to raise the temperature of the same bulk of water from the freezing to near the boiling point, could it be collected and concentrated. There are on the contrary phenomena which do not agree with this hypothesis; as the intense heat produced by the explosion of gunpowder, when a solid is suddenly converted into a great volume of gas, and other similar cases. Mr. Young very ingeniously argues that heat is not matter, from the fact that in boring large cannon, if the whole machinery be completely excluded from the air and contact with other conducting substances, a heat sufficient to make water boil, is obtainable by causing powerful friction, which may be continued for a long time by the operation. "If the heat in this case be neither received from the surrounding bodies, which it cannot be without a depression of their temperature; nor derived from the quantity already accumulated in the bodies themselves, which it could not be even if their capacities were diminished in any imaginable degree in the operation; there is no alternative but to allow that heat must be actually generated by friction; and if it is generated out of nothing, it cannot be matter nor even an immaterial or semi-material substance." This curious argument deserves for its ingenuity to be classed with the most sceptical syllogistical speculations of the ancient philosophers, as it neither allows heat to be material, nor immaterial. After volumes have been written on this subject, philosophers have at last been compelled to confine themselves to the facts ordinarily observable as attendant upon Heat.

It will be sufficient to give a brief view of some of the most important operations of caloric or heat as connected with the useful arts, by considering

1st, its most obvious effects,
2d, its mode of communication or diffusion,
3d, its sources, or the modes of generating it.

EFFECTS OF CALORIC.

The general effects of caloric are four, viz.

Expansion, *Liquefaction*, *Evaporation*, and *Incandescence*, or *Ignition.*

The most familiar effect of caloric upon bodies is expansion. When bodies are heated they are increased in bulk, and on being cooled return to their former dimensions. Of the principle states of natural bodies, solids are least expanded, and liquids next to them. The elastic vapours or fluids are vastly more expansible than liquids. Some of the most useful operations of art as well as of nature depend upon this law.

The expansion of various bodies has been ascertained by experiment. Dr. Ure has given the following table.

EXPANSION AND CONTRACTION FROM HEAT.

Expansion of materials by a change of temperature from 32º to 212º or from the freezing to the boiling point,—a range of 180º of Fahrenheit's Thermometer.

Iron, : : :	$\frac{1}{848}$
Steel, :	$\frac{1}{927}$
Gold, : : :	$\frac{1}{650}$
Copper, : : :	$\frac{1}{582}$
Tin, : : :	$\frac{1}{462}$
Lead, : : :	$\frac{1}{351}$
Glass, * : : :	$\frac{1}{1122}$
Mercury, † : :	$\frac{1}{55}$
Wood but little more than Glass	
Water, : : :	$\frac{1}{28}$
Alcohol, : : : :	$\frac{1}{9}$
Air and other aeriform fluids, :	$\frac{3}{8}$

or $\frac{1}{480}$ part of volume for each degree of increase of heat.

* Glass rods have been selected for measuring distances when great accuracy is required, to obviate, from their slight contraction, the usual effect produced by heat on iron chains, and other instruments of this description. Thus taking an iron chain at the temperature of 32 and 92, a range not unusual, as it is exposed to the heat of the sun and vicissitudes of cold in measuring, a variation of one foot in 2544 will take place—equal to about 2 feet to a mile.

†The great expansibility of mercury on the other hand, has rendered it peculiarly fitted for indicating by its expansion, the degree of cold or heat, as in the common thermometer.

EXPANSION.

In the useful arts advantage has been taken of the expansion of metals by heat in setting hoops upon casks, and the tire upon wheels. The iron hoop in such cases is made a little smaller than the circumference of the wooden part of the wheel. While expanded by a red heat it is put on, and is then suddenly cooled. The contraction of the iron band then binds the wooden segments of the wheel most firmly together. Cast iron and Glass are liable to be broken by this sudden contraction and expansion. Glass being a slow conductor of heat, when one surface or side of any vessel of this substance is suddenly heated, it is expanded before the heat passes through it to warm the opposite surface. An unequal expansion taking place, fracture must ensue. Looking glasses are thus broken by heating one spot on the surface by the flame of a lamp Rocks of granite are also readily crumbled into fragments by the expansive force of heat. For the effects of expansion on the pendulum rod. *See Pendulum.*

There are but few partial exceptions to the expansion of bodies by heat. While water is cooling to 40° it continues to contract in bulk and its coldest particles descend to the bottom.—When water is cooled below 40° it begins to expand again, and the particles cooled below this point become specifically lighter, and float at the surface. Thus in deep ponds and lakes the coldest particles always collect on the surface when the temperature of the water is reduced below 40°, while the bottom remains at 40°. For this reason fish are found to resort to the deep waters in winter where an uniform temperature prevails. Water still continues to expand while freezing with a force sufficient to burst bomb shells and cannon.—Ice is thus rendered $\frac{1}{8}$ specifically lighter than water—a most striking instance, it has been observed, of the wisdom of the Creator, as the ice would otherwise continue to accumulate in deep water, where it would not be affected by the warmth of the sun and air, until the fishes of lakes would be destroyed, and the whole period of a summer might be nearly passed before the ice in such situations might be dissolved. Iron continues to expand until it arrives at the melting point; but after it becomes liquified it contracts like water, and will float the unmelted masses upon its surface in the furnace. The expansion of bodies when heated alters their relative specific gravities. Warm air thus ascends from any part of the earth that is heated by the scorching rays of the sun, while the cold air rushes to supply its place, forming the refreshing breezes so grateful in allaying the fervid heat of summer. "Thus while one portion of the earth is cooled, the warm air that ascends, is wafted away to colder climates to mitigate the extremes of the seasons there. These silent, and often unobserved operations, are convincing demonstrations of the power, wisdom, and goodness of Providence.

Metallic plates are commonly found to expand and contract so much when employed to cover roofs that the nails become loose, or tear the metal. Great care is always required to shelter the nails, that are used to attach the sheets, from the rain, and to leave room for the expansion and contraction to take place freely without rending the metal.—Where sheet lead is used to cover flat roofs, it is the practice to form small ridges of wood one or two inches high over which the joints of the sheets are lapped. There is by this contrivance, room allowed for the expansion and contraction on the perpendicular sides of the ridges, without rending the nailed edges of the sheets.

So powerful is the effect of heat in expanding various substances that the strongest metals cannot withstand it. The expansion of the mass of masonry in Iron foundries will frequently break the large bars of malleable iron employed to bind them together, while on the contrary, if the strongest metals are subjected to a fixed tension when hot, and have not room or liberty to contract as they become cold they are broken.—Chains employed to support bridges should always be allowed liberty for expansion in summer, and contraction during the frosts of winter.

When metals are cast in moulds it must appear evident from the preceding observations, that unless the patterns are formed a little larger than the desired model, the contraction of the metal in the mould will render the casting too small in dimensions. Allowance is accordingly always made for cast iron of $\frac{1}{8}$ of an inch to the foot. If it be required to make a plate of cast iron one foot long, the pattern for forming the mould or impression in the sand must be one foot and $\frac{1}{8}$ of an inch in length, the contraction or shrinkage of melted iron on cooling being from an eighth to $\frac{3}{16}$ of an inch to each lineal foot.

THERMOMETER.

Various substances having been found to expand regularly upon being heated, thermometers have been constructed on this principle to indicate degrees of heat. Mercury, spirits of wine, &c. have been inclosed in glass balls terminating in long capillary, or very small tubes, in which the expansion or contraction of these substances are visible —The thermometer is an instrument too well known to require a description in this place.

The degrees marked on the scale of Fahrenheit's thermometer which is generally referred to in England, and the United States, commence at 32º below the freezing point of water,—the most intense cold known in England, in the time of Fahrenheit, the inventor of this instrument. This degree of cold was produced artificially by a mixture of snow and common salt. The boiling point of water, he fixed at 212º

Reaumur's scale, commonly used by the French, and other nations on the continent of Europe, commences at the freezing point of water, marked, 0, between which and the boiling point are 80º. Each degree of Fahrenheit's scale being equal to $\frac{4}{9}$ths of a degree of Reaumur's scale, it is only necessary to multiply the number of degrees of Fahrenheit above and below the freezing point, by 4 and divide by 9, when the sum obtained will indicate the number of degrees upon Fahrenheit's scale.

EXAMPLE.

What degree of Reaumur is equal to 50° of Fahrenheit's scale?

50°—32°=18×4÷9=8° Reaumur's scale.

To reduce the scale of Reaumur to agree with that of Fahrenheit, reverse the above rule, multiplying by 9, and dividing the product by 4.

EXAMPLE.

What degree of Fahrenheit's scale is 8° of Reaumur?

8×9÷4=18+32=50° Fahrenheit, answer.

Thermometers with two bulbs, and of various forms have been constructed to operate from the expansion of air. When both bulbs of the thermometer are exposed to the same temperature, it is not in the least affected. But if one of the bulbs be exposed to a warmer temperature than the other, the difference of temperature is shown with great exactness by the motion of the coloured fluid with which they are partly filled. Hence it is termed the *differential thermometer.*

PYROMETER.

The common mercurial thermometer not being calculated from its structure to withstand the action of intense heat, advantage has been taken of the regular scale of contraction of certain clays when exposed to degrees of heat which would melt glass and mercury. The pieces of clay, the contractions of which are to be measured for this purpose, are of a cylindrical form, flattened on one side, and are exactly fitted to a guage of brass, consisting of two straight pieces two feet long, fixed upon a plate, a little nearer each other at one end than at the other. As the piece of clay suffers contraction from exposure to heat, it will slide further in between the sides of the brass guage, which is marked with degrees to indicate the heat to which the clay has been exposed. This thermometer, or rather pyrometer, was the invention of Wedgewood.

Mr. Wedgewood found by various experiments that his pyrometer indicated one degree on the scale to 130° of Fahrenheit's scale. The temperature of a white heat visible by day light, which was found to correspond to 1077°, was taken as the commencement of Wedgewood's scale.

The following table shows the effect of different degrees of heat according to Wedgewood's and Fahrenheit's scales.

	Wedgewood's	Fahrenheit's
Greatest heat of an air furnace : :	160°	21877°
Cast Iron thoroughly melted : : :	150	20577
Greatest heat of a common smith's forge : :	125	17327
Welding heat of iron : : :	90 to 95	12777
Flint Glass furnace : : : :	70 to 114	
Settling heat of flint Glass : : :	29	4847
Fine Gold melts : : : : :	32	5237
Fine Silver melts : : : : :	28	4717
Brass melts : : : : :	21	3807

Red heat fully visible in day light	1077
Iron Red hot viewed by twilight	884
Heat of common fire	790
Quicksilver boils	660
Linseed Oil boils	600
Lead melts	594
Oil of turpentine boils	560
Sulphur melts	226
Water boils	212
A compound of 3 parts of tin, 5 of lead and 8 of Bismuth melts at *	209
Alcohol boils	174
Ether boils	98
Heat of the human body, and blood	98
Medium temperature of the Globe	50
Ice melts	32

The expansion and contraction of wood takes place from the presence of a degree of moisture as well as from heat and cold. The pannels of a wainscot, that have been set up above half a century, I have observed always to expand in summer and contract in winter in rooms that are warmed, while they remain nearly unaltered in such rooms as are not heated. The annual contraction each winter, as indicated by the retraction of the painted joints, is equal to about $\frac{1}{18}$ of an inch to the foot measuring across the fibres, while the longitudinal contraction is barely visible. The effects of contraction and expansion upon the wooden coverings of card cylinders is of tmuch importance, as the variations of their surfaces are frequently the cause of considerable losses to manufacturers. The work performed by the machine is at such times deteriorated in quality, and to restore regularity to the surface of the cylinders the wire teeth of the cards are sometimes ground down, by the application of boards or cylinders covered with emery,—as much in a few days as they would have been worn by their ordinary attrition in several years, while the amount of the cost of repairs bears an inconsiderable ratio to the loss of the operation for a time of the other subordinate machinery of the mill. Cast iron cylinders for cards were introduced a few years since to obviate this disadvantage of wooden cylinders, by William Hovey of Worcester, and have since been in common use in various parts of the United States. These iron cylinders are cast hollow in one piece, and being formed without joints upon their surfaces, the contraction and expansion operates uniformly upon all parts of the metal, and they consequently retain their shape. Although the first cost of such cylinders may be greater, yet the saving made in the prolonged wear of the teeth must render them in the end more profitable for use. The principal difficulty attending cast iron cylinders is in attaching to their

* Teaspoons made of this compound metal will melt when immersed in a cup of boiling Tea. I have seen these spoons for sale in London as a sort of philosophical toy to surprise the unwary, who will find only the handle of the spoon left between their fingers when they attempt to sip their tea. Jugglers use this compound to exhibit their power of holding melted metals in their naked hands with impunity.

surfaces in a proper manner the leather containing the wire teeth. This is commonly done by putting on the leather in fillets or bands passing around the circumference, with one end of each strip of fillet drawn through the cylinder and wound around a small roller secured within it, by which the leather may be tightened at pleasure.— Where the leather is not of uniform texture, the edges of these fillets have been found to rise into irregular ridges, which cannot be nailed down to the surface of the cast iron as they can be to the wooden cylinders. It may be considered impracticable to form wooden cylinders that will remain unaltered by changes of temperature. The best seasoned woods will expand and contract in breadth in the rooms of a mill, which are at one season of the year kept open and exposed to the ordinary moisture and heat of the atmosphere, while at another season they are artificially warmed by stoves, and heated air furnaces of the most drying tendency. It is stated by Mr. Bull, in his publication upon Fuel, that wood kept under cover in the most favourable circumstances will contain 8 per cent more of moisture or water at one season than at another in the course of the year.

In England, where steam pipes are used for warming the rooms of mills, the almost unavoidable leakage, or escape of a portion of the steam has a tendency to counteract the peculiarly drying effects produced by the stoves. For this reason, as well as for depriving cotton and wool of its electricity, and rendering the fibres more pliable for manufacturing, basins of water should be placed upon the stoves of a card room to generate steam.

It may be adopted as a most useful rule by the manufacturer to attend to the preparation of the wood for his card cylinders, causing it to be thoroughly baked, or kiln dried, and before it is used to have it left exposed to the air for a time; otherwise the expansion on a transition to damp air, might endanger the breaking the iron rims or hoops to which the wood is bolted. In this case the joints are crowded together so forcibly by the expansion, that the wood appears actually mashed by the pressure. Even after this, if exposed again to the hot air produced by stoves, the joints will open. For these reasons it is considered the best plan to form the pieces, or lags of the size adapted to receive each a sheet of the leather, in which case it is no disadvantage to leave an open joint between each sheet. This arrangement cannot of course be adopted where strips of card filleting are wound round the cylinders.

FLUIDITY.

It has been proved that bodies are expanded by heat. This enlargement continues under ordinary circumstances, until the heat arrives at a certain temperature, when the bodies become liquid, in which case they are said to be *melted*, *liquified* or *fused*. On the contrary, nearly all substances contract on the application of cold, which merely effects a withdrawal of heat, until they become solid, or congealed. In this way almost every solid may be rendered fluid, and almost every fluid solid. All liquids with the exception of Alcohol have been reduced to the solid state. It is supposed that this liquid would also become solid if its temperature could be reduced sufficiently. Mercury becomes a solid metal when cooled to a certain temperature.

The change from a solid to a fluid, and from a fluid to a solid state occurs at a certain temperature in every body. Thus ice melts at 32° sulphur at 218°. Every other substance has its point of liquefaction fixed. When such substance has arrived at this point of temperature, the whole of it does not become fluid at once but the melting goes on gradually. Dr. Black by the following experiment showed that a great quantity of heat is always entering melting substances, which produces no rise of temperature that can be discovered by the thermometer. He therefore gave it the name of *latent heat*. He put five ounces of pure water into a globular glass vessel, and the same weight of ice into another similar vessel.—Into each he placed a thermometer, and found the temperature of the vessel of ice 32° and water 33°. In about half a minute the thermometer assumed the temperature of the water, after which he observed the temperature of the water to rise gradually during half an hour, at the end of which the degree of heat indicated was 40°.

The glass containing the ice was left undisturbed ten hours and a half. At that time a small spongy mass of the ice remained unmelted in the upper part of the water. In a few minutes more the whole of the ice had become liquid, and the temperature of the water reached 40°. The temperature to which the two glasses were exposed, under precisely the same circumstances, was 47°. The water glass attained the temperature of 40° in half an hour, being an increase of 7°; the ice glass, after being exposed twenty one half hours, attained the same temperature. It is obvious that the ice glass must have received, during every half hour nearly the same quantity of heat which the water glass did, while its temperature was being raised 7°. The whole quantity of heat imparted to the ice glass will therefore be found by multiplying 21 by 7=147°. Only 8° degrees of this quantity could be detected in the water glass by a thermometer; consequently 147°—8°=139° or 140° must have been absorded to enable the ice to liquify.

He also ascertained that an equal quantity of heat, or 140° is set free from water when it assumes the solid form, or is frozen, thus confirming his previous experiment. This experiment may also be made upon heating water. If a regulur fire be kept under a vessel containing, for instance, a gallon of water, it will be found that after the temperature rises to 212° it will remain stationary at that point until the whole of the water is converted into steam, when the whole steam produced will also indicate no higher temperature than 212°. It is evident in this case, that all the heat that has passed into the water to convert it into steam has become latent, because it cannot be detected by the thermometer. If the steam produced by this one gallon of water be now condensed by causing it to enter into six gallons of water of the temperature of 50° the heat will again be evident, because it will raise the temperature of this quantity of water from 50° to 212°, making abundant allowance for waste of heat. In this case the gallon of water in the form of steam has imparted sufficient heat to raise the temperature of six gallons of water from 50° to 212° while at the same time its own temperature after condensation will remain the same as before, or 212°, as indicated by the thermometer.

This was a most interesting discovery, and will perpetuate the fame of Dr. Black with the present established philosophy of heat. It has been of great service in the useful arts in forwarding the improvements made by Messrs. Boulton and Watt on the steam engine, and in explaining the phenomena of steam, fluidity and evaporation, the theories of which were before involved in doubts and uncertainty. Dr. Black considered that the malleability of the metals depends on the latent heat which they contain. It may be separated from iron by violent hammering when the metal becomes brittle. From steel it can be separated not only by hammering but also by sudden cooling, when it becomes brittle and excessively hard.

The beneficial results of these principles of nature are most apparent in tempering the extremes of heat and cold of climates. The inhabitants of countries surrounded by water, although in higher latitudes, feel comparatively less of the severity of wintry frosts than those who dwell on continents in latitudes nearer the equator. Before the ocean water loses its common temperature and becomes cooled to the freezing point it imparts warmth to a great volume of the atmosphere above it; but on being converted into ice, it evolves a vast reserve of latent heat—equal to the heat that would pass off from the same bulk of ocean water, were it heated to near the boiling point, and afterwards allowed to yield its heat until its temperature subsided to the freezing point or 32°. On the contrary where masses of snow and ice are accumulated in winter on the surface of a continent, the great quantity of latent heat requisite to be absorbed to render congealed water fluid, retards the melting and prevents inundations that would otherwise spread desolation over every valley.

The relative quantities of heat which different bodies in the same state require to raise them to the same thermometrical temperature is called their *specific* heat.—The temperature of a pint of cold water at 50° and a pint of hot water at 100° after mixture is as near as possible half way between the extremes, or 75°. But if a pint of water at 50° and a pint of quicksilver at 100° be mixed, the resulting temperature is not 75° but 70°. The quicksilver in this case has lost 30° whereas the water has only gained 20°. Hence the capacity for heat, or the *specific heat* of quicksilver is less than that of water.

The absorption of caloric during the transition of a body from a solid to a fluid state enables us to account for the production of cold by what are called *freezing mixtures*. When a solid and a fluid, or two solids are mixed together, having a tendency to act upon each other so as to convert the solid rapidly into a fluid, it appears evident from the preceding observations, that heat must be absorbed from surrounding bodies, in contact with the mixture, to enable the solid to assume the liquid form. Common nitre dissolved in water, will reduce the temperature of the water 17°, and a mixture of three parts of muriate of lime with two parts of water, lowers the thermometer from 37° to Zero,—a remarkable instance of the production of cold by the process of dissolving a solid.

TABLE OF FRIGORIFIC MIXTURES PRODUCED BY LIQUEFACTION.

By dissolving salts.	Parts.	A Thermometer immersed in the mixture sinks.	Degrees of cold or reduction of temperature produced.
Nitrate of Ammonia, : :	1	From +50° to 4°	48
Water, : : : : - : : :	1		
Sulphate of Soda, or			
Glaubers Salts. : :	3	+50 to —2°	52
Diluted nitric Acid, :	2		
By dissolving Snow or Ice.			
Snow or pounded Ice, :	2	The thermometer sinks from	
Muriate of Soda, (table salt.)	1	any temperature to	0. or Zero.
Snow, : : : :	8	From +32° the	
Diluted muriatic acid, :	5	freezing point to	27° below zero
Snow, : : :	3	From +32° to	51° below zero
Potash, : : :	4		
Snow, : : : :	2	From —15°	68° do.
Muriate of Lime, : :	3		
Snow, : : : :	8	From —68°	91° do, being
Diluted Sulphuric acid,	10		

the greatest degree of cold that can be artificially produced.

Ice creams are usually made by Confectioners by immersing the cream in a mixture of ice and salt. The effect of the operation is much accelerated by frequently stirring this mixture. Potash will form with snow, as by the above table, a much more powerful freezing compound than salt.

TABLE OF TEMPERATURE AT WHICH VARIOUS LIQUIDS BECOME SOLID.

Sulphuric Ether - -	46°	below Zero.
Nitric Acid, - - - - -	45	"
Sulphuric Acid, - - -	45	"
Mercury - - - -	39	"
Nitric Acid, - - -	30	"
Common salt.25 parts, Water 75,	5°	above Zero.
Oil of Turpentine, - - -	14	
Common Salt, 6 do+water 94, -	25 *	
Vinegar - - - - - -	28	
Milk, - - - - - - -	30	
Water, - - - - - -	30 to 32	

* Hence salt water bays or rivers are not so soon frozen over in cold weather, as fresh water lakes and streams.

By applying heat to a fluid it continues to expand until it arrives at a certain temperature. Here it undergoes another change, the cohesion among its particles being so far overcome that it passes into a state of vapour. This point is commonly termed the Boiling Point, and the process, is called Evaporation, (being the third general effect of Caloric.) It beautifully illustrates the doctrine of latent heat. Fluids require that large quantities of sensible heat should enter into them and become latent to enable them to assume the expanded state of vapour. All evaporation consequently produces cold. It is on this account that showers in summer cool and refresh the earth, the evaporation of the water carrying off the superfluous heat from the surface of it.

Although the boiling or vaporific point of a fluid is always the same under the same circumstances, yet it is materially changed by the effect of pressure. Water will boil at 212º in a vessel in the open air, but if relieved of the pressure of the air by placing the vessel beneath the exhausted receiver of an air pump, (in vacuo, as it is termed) it will boil at a lower temperature than at blood heat, or 95º. Mr. Watt in a course of experiments on watery vapours found that a temperature of 70º was sufficient for the distillation of water. He used a small still which was about half filled with water, and securely joined to a receiver. As soon as the water was made to boil, the vapour filled the receiver, and expelled the air at the open aperture, which was then closed with a plug. On immersing the receiver (the vessel filled with the steam and connected with the still,) in cold water, the steam was immediately condensed, and a vacuum produced within it. On the application of the blaze of a lamp to the still, steam was produced, and the noise of boiling was distinctly heard in the still, although the top of it scarcely seemed warm to the hand—notwithstanding the apparent advantage of economy of fuel in this way, Mr. Watt found from this and other experiments, conducted with the greatest care, that although distillation may be effected with very little heat *in vacuo*, yet no real advantage in regard to the saving of fuel can be obtained, as the *latent heat* of the steam is increased in proportion to the diminution of sensible heat. Where it is required to distil articles of delicate flavour or qualities, and great excellence in the products of distillation is the principal object, distillation *in vacuo* has been practised with peculiar success. To perform this process on a large scale, it becomes necessary to use an exhausting syringe or air pump to maintain the vacuum. The following experiment readily proves that the boiling point is lowered as the pressure is diminished.

Take a glass flask, such for instance as those used for containing salad oil, which being thin are not readily broken by heat. Boil some water in it until the steam has driven out all the air from the upper part of it, and filled it with steam; then insert a cork tightly and plunge the flask into cold water. The water within it will commence boiling briskly, and will continue boiling for some time, but should it be taken out and plunged into boiling water the ebullition will cease. It will recommence on again being plunged into the cold water. In this experiment the air being expelled from the flask, and the mouth of it closed, the steam that remains in it is condensed, and leaves a vacuum above the water, which being thus relieved of the pressure of the atmosphere boils, although cooled by the application of a cold fluid to the vessel containing it. On plunging it into the hot water the steam generated within the flask ceases to be condensed and fills the vacuum in the same manner as common air, and exerts a similar elastic pressure.

DISTILLATION.

The principle upon which the process of the distillation of spirits and essences depends is the greater volatibility of the particles of these fluids than of the water or other liquids with which they may be mixed. Even water may be obtained by distillation free from all foreign substances by which its purity may be contaminated.—On board of English ships of war the apparatus for distilling sea water has been furnished, by which pure wholesome water may be readily obtained from this briny element. Alcohol, and various essences boil at a lower temperature than the water with which they may be mingled, and will first rise in vapour and pass into the condenser, commonly called the worm from its spiral shape, adopted to offer the greatest possible surface to the action of the refrigerating fluid or substance in which it is immersed.

The absorption of latent heat during the process of evaporation is extremely great.

A sufficient degree of cold may be produced by the excessive evaporation which takes place in a vacuum, to cause water to freeze even in summer beneath the exhausted receiver of an air pump. The latent heat is absorbed from the water so rapidly by that portion of it which is converted into vapour, that its temperature is reduced below the freezing point. In this experiment it is necessary to place some sulphuric acid within the bell glass of the air pump to absorb the vapour of the water as fast as it rises, otherwise the accumulation of it would soon fill the vacuum, and become equivalent to the pressure of the atmosphere. Ether being more readily evaporable, causes water placed in a vessel immersed in it to freeze rapidly.

Evaporation, it is well known, produces cold in the open air by absorbing latent heat. In the East Indies, ice is formed upon this principle in large quantities as an article of luxury, when the temperature of the air is several degrees above the freezing point. The evaporation of the water from the bottoms and sides of porous shallow earthern pans which they expose to the night winds, causes the water remaining in the pans to congeal into thin flakes of ice.

Sailors readily ascertain in the night from what quarter the wind blows merely by wetting their fingers and holding them up to the breeze. The evaporation that takes place from the parts acted upon by the immediate current of air causes them to feel cold, thus indicating the quarter from whence the current of air proceeds.

By the term condensation, as applied to vapours, is understood the withdrawal of the heat, or the cooling of them, by which they again resume a fluid state. This is observable when any cold body is brought into contact with steam,—drops of water usually collecting on the surface as the steam becomes condensed. During a moist state of the atmosphere the surface of a glass of cold water is covered with drops of water, like a sort of dew, collected from the damp air. This moisture has been sometimes supposed to have exuded through the pores of the vessel. Porous earthen ware, which actually allows the water to exude, has been used for wine coolers, having a tendency to keep the liquors which they contain in a cool state, the heat being absorbed by the evaporation from their surfaces. In damp weather, however, when the evaporation is diminished by the moisture with which the air is already loaded, (as in the instance of the condensation upon the surface of the glass,) this contrivance is attended with little advantage. For the same reason during the heats of summer, a moist state of the air, so well understood by the term *sultry*, impedes the evaporation from the surface of the body, when the heat becomes most oppressive. The process of perspiration admirably illustrates the effect of evaporation. The natural temperature of the body is kept nearly at 97° by the evaporation of a watery fluid, that exudes whenever excessive exercise or heat produces a warmth above this point. Sir Joseph Banks once made the experiment of the degree of heat, which the human body could bear without injury, by entering a room, the temperature of which was gradually raised until it became 52° hotter than boiling water, as indicated by the thermometers hung up in various parts of the room. He found that while in this room, the knobs of the doors, his watch chain, and all other metallic articles about his person, were so hot that he could not bear to touch them. Eggs placed upon a tin frame were roasted hard in twenty minutes, and a beef steak was over done in half an hour. Notwithstanding this extraordinary heat to which he was exposed, the temperature of his body was not perceptibly raised.*

The unhealthy chill, produced by the evaporation of the perspired moisture after exercise, may be attributed to the cold by which the body becomes too much reduced in temperature.

The cold produced by evaporation may be most sensibly demonstrated by dipping the hand in ether. It is even stated that small animals may be entirely deprived of vital heat, by exposure to a current of air while wet with this volatile fluid.

Connected with the subject of the formation and condensation of elastic vapours are many of the most interesting inventions of man, and the most practically important in Mechanics. In order that the operation of the Steam Engine, and the other applications of steam,

*Dry heated air communicates its heat slowly, and absorbs moisture, or promotes evaporation rapidly; therefore in the above experiment, the quantity of heat imparted from the air was equal to that withdrawn by evaporation.—Had the hot air been combined with steam at the same temperature, the effect of the latter to impede evaporation from the surface of the body, and its tendency to impart its heat more rapidly, would have soon destroyed life.

hereafter to be treated upon, may be more fully understood, most of the facts attendant upon the existence of this elastic vapour, and the principles that govern it, will be given at large while treating upon this subject.

STEAM.

Since the invention of the Steam Engine, the various properties of steam have been investigated with a zeal excited by the importance of its agency as applicable to the useful arts. The elastic vapour from heated water is commonly used, which arises when the water attains a certain temperature, called the boiling point.

BOILING POINTS.

Water ordinarily boils at 212° of Fahrenheit when placed nearly on a level with the sea. Ebullition, or boiling, is produced by the formation of vapour at the bottom of a vessel to which heat is applied. The vapour being lighter than the fluid, rises through it to the surface, and produces the agitation ordinarily observable. The boiling point of water differs according to the state or density of the air, or atmospheric pressure, more heat being required to make the water boil when the barometer stands at 31 inches than when it stands at 28 inches. When the atmospheric pressure is reduced, as on ascending mountains, less heat is sufficient to produce ebullition. On the top of a hill 520 feet above the level of the sea, water will boil at 211°, —exactly one degree less than when placed on a level with the sea; and on the top of Mont Blanc it has been found to boil at 187°.

It is only when the vapour is heated to the boiling point that it is properly termed steam, at which temperature it is invisible. As visible in the misty clouds, or the opaque vapour issuing from the warm medium of the boiler into a colder one, it is partially condensed into minute globules of water. However violently the fluid may boil, it does not become hotter after arriving at the boiling point, nor does the steam that arises from it indicate a warmer temperature than the fluid itself. Although a hot fire may have been burning beneath a boiler, and imparting heat to the water which it may contain for an hour or more, yet at the termination of the experiment, it will be found that the water will still indicate 212° and the steam proceeding from it precisely the same temperature.—It was this experiment which led Dr. Black to the discovery of *latent heat*, which most evidently exists in this case in a state that the thermometer does not detect. He found that with a regular fire, it required about five times as long to evaporate or convert into vapour the water, that it did to raise the heat of the water from 50° to the boiling point, $(212^\circ - 50^\circ \times 5 = 810^\circ)$. From this he inferred that 810° of heat was required merely to give water an aeriform state without increasing its temperature. Naturally concluding that this great quantity of latent heat would be rendered sensible when the steam returned again to the state of water, he caused it to be condensed in the worm of a still. He found accordingly that one pound of water in the form of steam imparted sufficient heat, when condensed, to 40 lbs. of water in the worm tub to raise its temperature 20º. 20º×40=800º of latent heat which gave nearly the result that he had before calculated More accurate experiments have since made the latent heat of steam equal to about 900º—a sufficient degree of heat to raise the temperature of the volume of condensed water, or of a solid body of an equal weight and capacity with water, to 900º, if it were possible to concentrate this heat within it. At this temperature it would be nearly red hot. The theory of the process of combustion was considered by Lavoisier as founded upon the same principle as the condensation of steam, the gases being similar to vapour in their high relation to heat, and evolving heat copiously on passing from an aeriform into liquid or solid states.

The great quantity of latent heat contained in Steam renders it remarkably well adapted for conveying caloric in a safe and convenient manner, by means of pipes, to considerable distances for warming rooms, heating water, or other useful purposes. Most of the large manufactories in England are warmed by steam pipes, which impart a peculiarly mild and agreeable temperature to the air. A large steam pipe of cast iron may commonly be seen extending from the boiler of the steam engine through the wall of the mill by the side of the revolving shaft, thus communicating both heat and motion from the same source. Steam pipes are commonly made of cast iron in sections connected by flanges and bolts, and are laid with particular care to allow each range of pipes to expandand contract freely when heated and cooled. Steam pipes for warming rooms are commonly arranged near the side walls, and floors; lead pipes will not answer for conveying steam unless they can be fitted to slide very freely when they are caused to expand and contract by heat. The least obstruction causes a permanent elongation of this yielding material, and they soon become distorted or disjointed.—Where the pipes are light and are properly laid, they may prove sufficiently durable. To prevent condensation and waste of steam before it reaches the place where it is to be used, the pipes may be inclosed in a flannel, or in a box filled with wood ashes which are excellent non conductors of heat. In all cases attention must be bestowed in laying the pipes with a sufficient descent to convey the condensed steam, if possible, back to the boiler; if not, a cistern or small reservoir must be attached to the pipe in some convenient place info which the condensed steam or water may flow. As it accumulates, it may be occasionally drawn off from this cistern, or a floating valve may cause it to be discharged whenever the water rises within it to a certain height.

In many of the largest dye houses in England, the blue vats for dying woollens are heated by steam. In some cases it is injected at once from the end of the pipe into the liquor, and in others it is applied to the sides of the cast iron vats, which have a space prepared around them inclosed by brick work, or otherwise to keep the steam in immediate contact with them. By the former mode the steam is condensed by the liquor with considerable noise as fast as it is discharged from the pipe, and increases the bulk of the liquor. If the orifice of the steam pipe be placed more than two or three feet below the surface of the water, the discharge of steam is impeded and the noise increased greatly. In all cases where steam is thrown into a fluid from the end of a pipe immersed in it, a *vacuum valve* should be attached to the boiler; otherwise should the steam be suddenly condensed within it, before the stop cock is closed to cut off the communication with the liquour to be heated, a vacuum will be formed in the boiler, whereby the liquor will be drawn through the pipe from the vat. An instance of this kind occurred within my knowledge, in which the boiler sucked up the contents of a blue vat, until it became completely filled. The vacuum valve is constructed similarly to a common safety valve, opening, however, internally.

It may sometimes happen that much inconvenience would attend the erection of boilers in the apartments of private houses intended for hot baths. In such cases recourse may be had to steam conveyed in pipes. It is also economically used for drying wet cloths in various processes of manufactures.

For culinary purposes one steam boiler may suffice to supply steam for all the operations of boiling required even for a large hospital. This plan is actually adopted in some of the most extensive hospitals in London.

In Northwich, in Cheshire, extensive works are erected for evaporating the brine of the salt pits, in the process of crystallizing salt, by applying steam to the salt pans instead of fire. Less agitation of the saline liquor is thus produced, and consequently the salt is allowed time to form larger and more beautiful cubical crystals.

During the mania for Joint Stock Companies in England, a Steam Washing Company was formed with a considerable capital for the purpose of washing clothes by the aid of steam upon an extensive scale.

TABLE OF THE BOILING POINTS OF SEVERAL OF THE MOST IMPORTANT LIQUIDS. (BY FAHRENHEIT'S SCALE.)

Ether, the most volatile fluid, boils at		100°
Alcohol, of the specific gravity	0.813	178½
Nitric Acid, " "	1.500	210
Water		212
Water saturated with sea salt		224½
Rectified Petroleum		306
Oil of Turpentine,		316
Sulphuric Acid	1.848	600
Sulphur		570
Linseed Oil *		640
Mercury		656

* In the process of bleaching it is necessary to subject the vessels containing the acid for forming the bleaching liquors to a certain heat. From the powerful action or corroding qualities of the ingredients used, leaden retorts or boilers are from necessity employed to contain them. Boilers of this metal being readily fused by the immediate application of fire, it has been found necessary to place them in hot sand, called a sand bath. Linseed Oil, however, has been found to answer better for imparting a regular heat to all bodies immersed in it, when it is not required to raise the temperature above 600 degrees.

The vapours arising from these liquids at their boiling points would not be compressed in volume if placed in air tight close tubes, and a weight equal to that of a column of mercury 30 inches high were allowed to press upon them—which is equivalent to the atmospheric pressure.

Mr. Watt and Mr. Clement found by experiments that the latent heat of steam is proportioned to the degree of pressure to which it is subjected, and that the latent heat contained in a given volume of it always diminishes as the sensible heat increases. Hence they drew this important inference, "*That equal weights of steam, of whatsoever temperature, contain equal quantities of heat.*"

Water confined in a close vessel may be heated many degrees above 212° without boiling. The steam at first generated, being unable to escape, exerts an additional pressure on the fluid and prevents ebullition. A strong metallic vessel must be used for this experiment, having a stopper loaded with a certain weight, called a safety valve, which may be lifted when the pressure of the steam against it attains sufficient elasticity or force to endanger bursting the vessel. This description of vessel is called *Papin's Digester*, it having been first used by Papin to melt or soften horn and bones. It has been ascertained by experiment that water heated in this way may have its temperature increased to 500°, and indeed might be made red hot, were it possible to construct vessels of sufficient strength to resist the force of the steam.

A remarkable experiment with this boiler illustrates the quantity of the latent heat required to produce steam. Mr. Watt placed a digester over a steady coal fire for half an hour with the valve open, and found on examination that an inch in depth of water had boiled away. He then restored that inch of water, and secured down the safety valve, and allowed it to remain on the fire half an hour as before. He then took it off the fire after the temperature had been increased many degrees above the boiling point, and opened the valve. The steam rushed out with great violence, making a shrieking noise for about two minutes. On opening the boiler he found that an inch of water was consumed as in the first instance. Hence it appeared that the same quantity of heat had entered into the water in each half hour, and that as much escaped in the two minutes after opening the valve, as had escaped in the first experiment when the vessel had been left open.

The following facts have been ascertained by experiments upon the formation and existence of steam, and will serve as data for facilitating many calculations upon this subject.

RECAPITULATION OF FACTS AND EXPERIMENTS RELATING TO STEAM.

Proposition 1st. A cubic inch of water forms very nearly a cubic foot of steam, when its elasticity is equal to 30 inches of mercury, or more exactly, water is caused to expand to about 1800 times its volume on being converted into steam.

17 gallons of water occupy a space of 4090 cubic feet when converted into steam, under the ordinary state of atmospheric pressure.

To ascertain what quantity of steam will be formed by a given quantity of water, say,

As 17 : 4090 : : so will be the given quantity to the answer.

To ascertain the quantity of water that will be formed by the condensation of a given number of cubic feet of steam, say,

As 4090 : 17 : so will be the given quantity to the answer.

2d. The time required to convert a given quantity of boiling water into steam is six times that required to raise it from the freezing to the boiling point, or from 32° to 212°, supposing the supply of heat to be uniform.

3d. 1 gallon of water in the state of steam will impart sufficient heat on being condensed to raise the temperature

of 6 gallons of water at 50° to 212°

or 18 gallons of water from 50 to 100, making abundant allowance for waste.

4th. After water is raised to the boiling point or 212°, it requires as much heat to give it the elastic form as would raise the same water 900° higher. If its volume were not changed by the heat—that is, if it could be prevented from expanding into steam, its temperature would become 1112° by the same quantity of caloric—a degree that would render it red hot.

5th. The same weight of water in the form of steam contains the same quantity of heat, whatever may be its temperature or density, the latent heat always diminishing as the sensible heat increases.

Rule for finding the quantity of Steam required to raise a given quantity of water to a given temperature.

Multiply the water to be warmed by the difference of temperature between the cold water, and that to which it is to be raised, for a dividend.

Then to the temperature of the steam add 900°, and from that sum take the required temperature of the water; this last remainder being made a divisor to the above dividend, the quantity will be the quantity of steam in the same terms as the water.

If the quantity of water be given in gallons, cubic feet, &c. the answer will be in the same measure.

EXAMPLE.

What quantity of steam at 212° will raise 100 gallons of water at 60° up to the boiling point or 212°?

212°—60°=152×100=15200

212°+900°=1112—212=900. 15200÷900 Ans. 17 gallons of water converted into steam will raise the temperature of 100 gallons from 60° to 212°.

Mr. Chaptal states that it may be laid down as a principle, that gases and vapours are equally dilatable and equally compressible. Common air expands about ⅜ by being heated from the freezing to the boiling point, or 212°.

Mr. Perkins observed to me, in conversation upon this subject, during a short visit which I made to his works near the Regent's Park, in London, for the purpose of seeing his Steam Engine and Steam Gun, that he had tried the experiment of heating a volume of steam for the purpose of ascertaining its expansible power when not connected with the boiling water to reinforce it. He stated that he could obtain no important or available power from the expansion of a given volume of insulated steam. In some recent experiments he has "heated steam to a temperature that would have given all the power that the highest steam is capable of exerting, which would have been 56,000 pounds to the square inch, if it had had its full quantum of water; yet the indicator showed a pressure of less than 75 pounds.* Had his boiler been filled with common air instead of steam, its expansion might have produced nearly the same expansive pressure when heated in a red hot boiler, as was the case at the temperature above stated.

The expansive force of steam depends therefore upon crowding a greater quantity of aqueous particles into a given space, by the application of heat to water, rather than upon the elasticity imparted by the heat to the steam itself. If a bladder be partly filled with common air and exposed to the heat of a fire it will be expanded; steam possesses an equally expansible power with common air, and gases; but it is necessary that heat should continue entering a quantity of water inclosed in a tight vessel, to convert it into vapour, until the space allowed for the expansion of it above the water becomes filled. The steam being still forced to rise from the water, and to enter the space already crowded with it, begins then to exert its power against the sides of the vessel that confines it.

6th. When a quantity of water is kept at the uniform temperature of 212° or the boiling point, and the mercury is 30 inches in the barometer, the depth evaporated in the boiler will be $1\frac{3}{10}$ inches per hour.

The quantity of steam formed, or the water evaporated, will also be jointly as the force of the vapour, answering to each degree of heat, and the surface.

The economy of steam for the use of the steam engine has been a subject that has excited much research and attention, and numerous experiments have been made for the purpose of ascertaining the most advantageous circumstances under which it can be employed. From an ignorance of some of the principal facts contained in the following table, which has been formed from various sources, many visionary schemes have been pursued by means of expensive experiments, most

* Mr. Perkins supposes that the bursting of steam boilers takes place frequently from the action of steam that has been exposed to intense heat after the water has been partially exhausted from the boiler. The great heat contained in this case in the steam will not, he supposes, descend and enter the water remaining in the bottom of the boiler; but should any agitation of the surface throw up a portion of this water into the heated steam, or should a supply of water be injected into it, the concentrated heat is readily imparted to the water, converting it into a great volume of steam in so instantaneous a manner that the safety valve will not afford it a sufficient vent, to relieve the sudden stress upon the boiler, in which case it must yield to the force of the steam, and the dreadful effects, usually attending the explosion of steam boilers, ensue.

of which have at last ended in disappointments—sometimes rendered severe by heavy losses.

The calculations and experiments made by Dalton, Ure and Oliver Evans of Philadelphia, are here collected and arranged in a comparative table, showing the elastic or expansive power of steam at various degrees of temperature from the boiling point or 212° up to 325° of Fahrenheit—also the weight of water in the form of vapour, contained in a cubic foot of steam at different temperatures and pressures. There appears to be a considerable difference in the result of the calculations of the above writers. The two former have given accurate accounts of the mode in which their experiments and calculations were made. Mr. Evans has not however given the mode by which he arrived at the results stated by him, and we are therefore induced to suppose that his table is theoretically rather than experimentally formed.

Comparative Table, *of the elastic force or pressure of Steam with its weight at various degrees of pressure and temperature.*

	Pressure of the steam, or the force which it will exert to enter into a vacuous space.						The force or pressure of steam to escape from a close vessel into the air, as through the safety valve of a common boiler.			
Temperature of Degrees Fahrenheit's thermometer.	Dalton's Table.			O. Evans' Table.	Ure's Table.		Dalton's Table.			Weight of vapour in a cubic foot of space taken from Rees Cyclopedia.
	Column of Mercury. Inches.	Column of Water. Ft. In.	Pressure per square Inch. lbs: oz.	Pressure per square Inch. lbs.	Inches of Mercury.	Pressure per sq. Inch. lbs oz.	Column of Mercury. The steam Inches.	Column of Water. equal to Ft. In.	Pressure per square Inch. the atmospheric pressure. lbs, oz.	
boiling. 212Ω	30,	33,10,75	14,10,6	212° 15	30,	14. 10,6				253 grains
215	31,83	35,11	15, 9		33,		1,83	2, 0	0, 15	267, 39
220	34,99	39, 6	17, 1		35,54		4,99	5, 7	2, 7	298, 88
225	38,20	43, 2	18,10		39,11		8,20	9, 4	4, 0	322, 15
230	41,75	47, 2	20, 7		43, 1		11,75	13, 4	5, 13	352, 09
235	45,58	51, 6	22, 5		47,22		15,58	17, 8	7, 11	384, 39
240	49,67	56, 1	24, 4	242° 30	51, 7	23, 4	19,67	22, 8	9, 10	418, 88
245	53,88	60,10	26, 4		56,34		23,88	27, 0	11, 10	454, 38
250	58,21	65,09	28, 8		61, 9		28,21	31, 11	13, 14	490, 90
255	62,85	71, 0	30,12		67,25		32,85	37, 2	16, 2	530, 33
260	67,73	76, 6	33, 2		72, 3		37,73	42, 8	18, 8	571, 18
265	72,76	82, 2	35, 9		78,		42,76	48, 4	20, 15	603, 60
270	77,85	87,11	38, 1	272° 60	86, 3	42, 24	47,85	54, 1	23, 7	656, 53
275	83,13	93,11	40,11		93,43		53,13	60, 1	26, 1	701, 06
280	88,75	100, 3	43, 7		101, 9		58,75	66, 5	28, 13	748, 45
285	94,35	106, 7	46, 3		112,		64,35	72, 9	31, 9	795, 68
290	100,12	113, 1	49, 0		120,15		70,12	79, 3	34, 6	844, 34
295	105,97	119, 8	51, 4		129,		75,97	85, 10	36, 10	893, 68
300	111,81	126, 4	54,12	302° 120	139, 7	67, 5	81,81	92, 6	40, 2	942, 93
305	117,68	132,11	57, 9		150,56		87,68	99, 1	42, 15	992, 43
310	123,53	139, 6	60, 8		161, 3		93,53	105, 8	45, 14	1041, 76
315	129,29	146, 1	64, 0	315° 160	173(about)	86,	99,29	112, 3	49, 6	1090, 24
320	135, 0	152, 6	66, 1				105,00	116, 5	51, 7	1138, 50
325	140,70	158,11	68,14	332° 240			110,70	125, 1	54, 4	1186, 57

It may be observed that the inequality of the progressive ratio of increase is attributable rather to the imperfection of thermometrical instruments than to irregularity in nature.

The last column showing the weight of steam, in grains, contained in a cubic foot of space, is founded principally upon calculations derived from the weight of a cubic foot of steam at the boiling point, which contains by experiment 253 grains of water.

It appears from the preceding table that there is a remarkable discrepancy in the result of the experiments made by each of the persons therein named. According to Dalton, the pressure of the steam is increased about 50 lbs. by an increase of 100°=to ½ lb. to each degree.
Ure " 71 " " 100°=to ¾ lb. "
Evans " 145 " " 100°=to 1½ lbs. "

According to Oliver Evans, the elastic power of steam is doubled by every 30° of additional temperature. His scale is probably much too high.

It has been frequently suggested by theorists that highly elastic steam, after exerting its force on the piston of a steam engine, might with great advantage be cooled to a certain extent, and then be returned again to the boiler. The fallacy of the doctrine of cooling steam, in order to inject it into the boiler instead of the supply of water, will appear evident on reference to the preceding table.

If it be required to cool a cubic foot of steam after it passes from beneath the piston of a steam engine, upon which it has been acting with an elastic force equal to 49.6 lbs. to the inch, at the temperature of 315°, so that the heat of the steam may be reduced to 215°, it will be found by the table that the weight of water held in suspension at the higher temperature and pressure is 1090 grains, and at the lower temperature only 267 grains, consequently, 1090—267=823 grains weight of steam will be absolutely condensed into water by the operation of cooling it from 315° to 215°—At the latter temperature the table indicates that the elastic force of the steam is also reduced to less than 1 lb. on the inch, from 49.6 lbs. pressure at the temperature of 315°, and that 823 grains weight of steam,=to ¾ of the steam, will be unavoidably condensed by the refrigeration.

If it be now required to force this attenuated cubic foot of steam into the same boiler from whence it proceeded, against the pressure of the steam tending to escape outwards with the force of 49.6 lbs. on the inch as before mentioned,—at the instant the valve is opened to make the injection, and the forcing piston is driven down, the steam to be injected will be compressed between the piston and the steam opposing its entrance into the opened injection valve, until its density becomes the same as that of the steam within the boiler; while at the same time its temperature will be raised by the compression (by proposition 5th) from 215° to 315°.

It would therefore appear that steam on being partially cooled becomes also partially condensed, and that the same force would be required to return the volume of steam of the reduced temperature into the boiler, which the same steam exerted on issuing therefrom, and that the steam would become as hot by compression at the instant it actually entered the boiler, as the steam contained within it. It will therefore follow that it would require the whole power of a high pressure steam engine to return its steam, however reduced in temperature, to the boiler, making no allowance for loss of power by friction.

One of the advantages of high pressure steam engines, in point of economy of fuel, may be perceived on examining the preceding table. When the water in the boiler is heated to 325° it will be observed by Dalton's table, which is the least favourable, that the pressure of the steam against the safety valve will be 54.$\frac{4}{10}$ lbs. on the square inch, which is more than double the expansive force of steam at the temperature 275°. The weight of vapour in a cubic foot of space at 325° (under the pressure of 54 lbs. on the inch) is 1186 grains, and at 275° (under the pressure 26 lbs.) is 701 grains. Thus to obtain an expansive force augmented in pressure on the piston two fold, it is necessary to convert into steam only about ⅔ more water; but the temperature of this quantity must be raised exactly 50° higher. By proposition 5, page 70 the same weight of water in the form of steam contains the same quantity of heat, whatever may be its temperature or density. It appears from the table, then, that it is necessary to increase the heat only 50° to double the power, while the same *weight* of steam actually absorbs no more heat than before from the fuel, and only ⅔ more steam is required. This would give in theory a saving of about one fifth of the fuel; but in practice it is found that much of the advantage of high pressure steam is lost, by excessive leakage through the joints of the boilers and packings; by the increased radiation from the heated parts of the engine, and the slower absorption of caloric from the fuel after the temperature of the boiler becomes considerably augmented.

WOOLF'S TABLE.

The following Table shows the pressure of Steam, according to its heat and expansion.

Steam predominating over the pressure of the atmosphere, upon a safety valve, if its elastic force be equal to	Lbs.	lbs. per square inch, requires to be maintained by a temperature equal to	Degrees.	degrees of heat by Fahrenheit, and at these respective degrees of heat, steam can expand to about	Times it volume	times its volume, and yet continue equal in its elasticity to the pressure of the atmosphere.
	5		227½		5	
	6		230¼		6	
	7		232¾		7	
	8		235¼		8	
	9		237½		9	
	10		239½		10	
	15		250½		15	
	20		259½		20	
	25		267		25	
	30		273		30	
	35		278		35	
	40		282		40	

IGNITION OR INCANDESCENCE.

The fourth obvious effect of Heat, termed *ignition* or *incandescence*, is the change of colour that takes place when substances are heated to a certain temperature, at which they become red hot, and emit light as well as heat. Incandescence must be distinguished from *combustion*, which is the result of not only an increased temperature, but of a chemical action between the body and the air, during which process a new compound is formed, and heat is produced.

The point of the thermometer, at which bodies become incandescent, varies according to circumstances; an object which is red hot in the dark, not being so in the day light. It is probably attributable to this circumstance, that the vulgar error has arisen, that the sunshine checks combustion. The superiour light of the sun causes a substance, that would appear red hot in a dark place, to assume a pale colour when exposed to its rays, and even flame and burning coals thus exposed, comparatively lose their glowing brightness.

Ignition in the dark is generally fixed at about 800°. As the heat is increased the emission of light also becomes greater, and the colour changes, first into red with a mixture of yellow, and lastly into a bright white, beyond which there is no change.

COMMUNICATION OF HEAT.

It has been previously stated that heat has a tendency to pass from one body to another in two ways;—by being *conducted*, as when one end of an iron rod is heated and the temperature gradually extends along it; and by *radiation*, when the heat passes off through the air like rays of light.

The communication of heat will therefore be considered as to its susceptibility of being *conducted* and *radiated* by different substances.

It is familiarly known that various substances transmit or conduct heat with more or less rapidity. If the ends of a piece of wood and of a rod of iron be placed in a fire, it will be found that the heat, extending along the rod, will soon render it too hot to be held in the hand, while no sensible heat will be felt from the wood, although in a state of combustion at one end. Those substances which receive heat readily, part with it readily, while those which are slow in receiving heat are slow in cooling. In general, the denser the substance, the more quickly does it conduct heat. Metals, the densest substances with which we are acquainted, conduct it readily, while light porous substances, having interstices of air among the particles, such for instance as cork, down, wood, &c. do so very slowly;—confined air, indeed, forms an excellent non-conductor of heat, although it allows radiated heat to pass so freely through it. Eider-down is on this account one of the best non-conductors of heat, as there is much air engaged or inclosed among its filmy fibres. Hair, wool, and feathers, are slow conductors and are therefore peculiarly fitted to confine animal heat. Garments made of wool are commonly said to keep out the cold; it may more properly be said that they confine the heat of the body, and prevent its escape.

Ice may be preserved from melting by the heat of summer for a considerable period by inclosing it in a double chest, having an interstice of air or a lining of powdered charcoal, which is also an excellent non-conductor of heat. These chests, called refrigerators, are made with an inner case of tin, having a bended tube to discharge the water produced by the melting of the ice, whereby a portion of the fluid always remains in the tube, and serves as a valve to cut off the communication with the external air. In this case, the non-conducting substances allow the external heat to penetrate very slowly to the interiour, to melt the ice contained within the chest, and meat or vegetable substances inclosed with it, may be preserved for a long time by the low temperature to which they will become reduced, whereby chemical action and decomposition is prevented. Wooden handles are usually placed upon tea pots to prevent the too rapid transmission of heat to the hand. Light snow contains much air inclosed among the delicate spiculae, or fibres, and is therefore an imperfect conductor. By this wise provision of Providence, the ground in the coldest regions of the globe is protected from being frozen to any considerable depth, and the snow is no sooner melted in the spring than vegetation puts forth, and summer seems at once to prevail. Thin glass conducts off heat very rapidly from warm rooms; but if double windows are used, inclosing between the two sets of sashes a thin sheet of air, the escape of the caloric is greatly impeded, for the reasons before stated.

In the construction of Ice houses it is important, in order to preserve the ice from melting, to form the sides and roof of non-conductors of heat, and to prepare drains for the water that may be formed by it on melting. Wood being a better non-conductor than stone or brick, the walls should be cased with this material, and the roof should be made double with the space between filled with straw. The exterior of the roof should also be painted white, or white-washed, this colour imbibing heat more slowly than black or dark colours, as will be hereafter shown.

There is a most remarkable difference in the facility with which solids and fluids conduct heat. In solids it is communicated from particle to particle until the whole mass becomes warmed. In fluids there being a free motion of the particles, as soon as one particle becomes heated it is caused to expand, whereby it becomes lighter and ascends from the heated part of the vessel with which it has been in contact, to the surface of the fluid, when another particle takes its place, and after being heated, that also becomes expanded and ascends, and thus in succession all the particles are brought in contact with the heated body. By this means the heat is *distributed* by currents in the fluids, and not by being communicated from particle to particle as in solids. The fact probably is, that the particles of fluids are in actual contact with each other only at a most minute point of their surfaces ; otherwise a friction would take place that would prevent fluidity. This being the case, heat cannot readily communicate from particle to particle of fluids, as of solids, the particles of which are in closer contact. The slow conducting power of fluids may be demonstrated by confining a piece of ice at the bottom of a thin glass tube, and filling it with water. If the blaze of a lamp be applied to the middle of the tube, the water may be made to boil for a considerable time without melting the ice, only a few inches below it. In this case the currents ascend from midway of the tube, (where the heat is applied) by which it is regularly distributed over the fluid in the upper portion of the tube ; but as the currents do not operate below this point, the ice remains at the bottom without receiving any heat communicated downwards from one particle to another. If a copper or iron wire be inserted into the tube, passing through the boiling water to the ice at the bottom, the heat will be immediately conducted to the ice, and it will begin to melt. Upon this principle copper rods have been attached to the lamps of light houses, exposed at one end to the heat of the blaze, with the other immersed in the oil. The heat is thus conducted along the rod to the oil, to keep it in a fluid state, which is necessary in order that it may be drawn up by the wick for combustion. By this expedient oil that is subject to being congealed by cold, is rendered readily consumable in lamps.

If the ice be placed at the surface of the fluid, the communication of heat by currents, is direct from the blaze to the ice, and it is soon melted. In this way the currents of the ocean convey the heat, that would not otherwise be diffused, to vast distances. The great moving body of water, called the Gulf Stream, in the Atlantic Ocean, operates on a magnificent scale precisely as in the above experiment. The fervid heat of the sun, imparted to the oceanwater under the tropics, is silently conveyed to act upon the icebergs, or vast islands of ice, floating on the surface of the ocean from regions of polar frost.

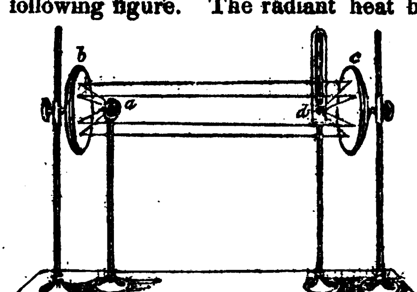
Heat is conveyed by the air in the same manner as by fluids, the currents of air, or winds serving to distribute it over the surface of the globe. The particles of air are put in motion, as before stated, by being expanded by heat, whereby they are rendered specifically lighter, and ascend.

When it becomes necessary to prevent the transmission of heat through the double doors of a fire proof vault, proper apertures, communicating with the external air, should be made to admit the cold air to enter at the bottom, between the two doors, and when heated, to ascend and pass off above the top, thus conveying away the heat that might endanger the safety of combustible articles contained within the vault. Mills and houses are sometimes warmed by heated air conveyed by pipes to the various apartments. This subject being of some importance in domestic economy, will be considered more at large, when treating of fuel, and heating rooms.

RADIATION OF HEAT.

Heat not only diffuses itself by communication from one particle of matter to another, but also flies off through the air in straight lines like rays of light, from its resemblance to which it is called *radiant heat*. The difference between *radiant* and *communicated* heat is apparent in rooms which are warmed by fire in open fire places, and in stoves. In the first instance, nearly all the communicated heat ascends by the flue of the chimney, forming the draft of hot air, and the radiant heat only enters the room, by which the air of it is comparatively but little warmed It is the property of radiant heat to pass through the air without heating it. To enjoy the warmth of the fire, the inmates of the apartment collect around the fire side, that the rays, or *radiant heat*, may fall upon them. In rooms warmed by stoves, the principal portion of the heat is *communicated* from the sides of the stoves to the air, whereby the air itself becomes heated, and distant parts of the room are rendered equally warm by the currents of air, which convey the heat as before stated. A portion of radiated heat, is imparted from a stove. The tremulous motion of the air adjacent to the surface of heated stoves, is owing to the heat communicated to the air in contact with them. The air is expanded by the heat, and is consequently rarer than the adjacent air. By a law of optics, the rays of light in passing through a transparent medium of unequal density being refracted, or bent out of a straight course, an object viewed through this medium appears as if disturbed, or trembling.

The rays of heat still further resemble those of light, in their susceptibility of being reflected from polished plates of metal, and of being concentrated, by concave metallic reflectors, into a focus. If a person stand by the side of a fire place, he will not feel the warmth of the radiated heat; but if polished metallic plates be held opposite to the fire, and are made to present a proper angle to it, the rays of heat may be reflected to reach the person and warm him. If large concave metallic mirrors be properly arranged, considerable heat may be collected into a focus, at a distance of several feet from the fire. The radiation of heat is most evidently demonstrated by two reflectors of polished tin plates, one foot in diameter, with a focal length of four and a half inches, placed twelve feet two inches apart, and exactly opposite each other. If an iron ball, heated so as not to appear luminious in the dark, be placed in the focus of one of the reflectors, and the bulb of a thermometer in that of the other, a portion of the rays of heat that diverge from the ball in every direction, will impinge on the concave mirror *b*, by which, from its shape adapted for this purpose, they are reflected in straight lines to the opposite concave reflector *c* whereby they are again reflected and brought to a focus, or point where all the rays meet to act upon the bulb of the thermometer *d* as in the following figure. The radiant heat by this experi-



ment is collected so as materially to affect the thermometer. It appeared by experiments made by Saussure and Pictet with these reflecting mirrors, that the temperature of the thermometer at *d* began to increase as soon as the ball *a* was set in its place, and continued rising from 4° of Reaumur's scale to 14½°, which it did in six minutes, another thermometer at the same distance from the heated ball, but not in the range of the focus of the reflectors, rose only from 4° to 6½°.

It may easily be proved that the thermometer placed in the focus of the reflector, *c* is not, in this case, affected by heat proceeding directly from the ball at *a* by arranging a screen in a line between the thermometer, *d* and the hot ball *a*, large enough to shield the bulb of the thermometer from the direct rays. No effect will be produced upon the thermometer by the intervention of the screen. A small cage of burning charcoal, or any hot substance whatever, may be used as a source of heat, instead of the ball, and the effect will be similar.

By these experiments it is demonstrated that all bodies are radiating caloric, whether their temperature be higher or lower. In the one case they radiate more than they receive; in the latter less. Some objects have the power of absorbing these rays of heat, others of allowing them to pass through them. The air, as before stated, affords an example of the latter case, and most solid substances, of the former. Other bodies, on the contrary reflect the rays, as in the instance of the polished metallic reflectors, which do not become hot themselves, although exposed to the rays of heat. The nature of the surface of bodies, whether smooth, or rough, black or white, has a remarkable effect in regard to the absorption, as well as radiation of heat. The more polished, resplendant, and white, the surface, the less will be the radiation; and on the contrary, the rougher the surface is, the greater it will be. Mr. Leslie has illustrated the power of surfaces of various kinds to radiate heat, by a very simple experiment with a tin cannister of four equal sides.—He covered one side with smoke, a second with paper, a third with glass, and left the fourth resplendent. He filled it with boiling water and exposed each side successively towards the concave reflector. Considering the effect of the blackened side as 100, he found that of the paper was 96, of the glass 90, and of the resplendent one only 12; so that bodies with blackened or dark surfaces, in this respect, produce about 8 times as much effect as those with resplendent surfaccs. This principle may be illustrated by polishing one half of the ball used in the experiment with the reflecting mirrors, or by painting one side of it black and the other white. When the dark side is turned toward the nearest reflecting mirror, the mercury of the thermometer will rise, and when the whitened side is turned towards it, the thermometer will indicate a reduction of heat. If a piece of ice be placed in the focus of one of the mirrors, instead of the hot ball, the mercury will fall below the degree of temperature of the surrounding bodies. In this case, the thermometer is warmer than the ice, as the ball was before warmer than the thermometer. The heat is therefore radiated from it, and is directed to the ice, which absorbs it, and does not radiate an equal quantity of heat in return. The mercury radiating more heat than it receives, consequently becomes colder. This effect is obvious to the senses in entering vaults, or cellars, with cold damp walls, to which the heat of the body is radiated, but which radiate comparatively but little heat. When the body is cooled by being moved rapidly, the heat is lost by communication, a greater number of the particles of air coming in contact successfully with the body, each of which receive from it a portion of heat. A windy day, therefore, always feels colder than a calm one, though of the same temperature.

The effects of certain colours in imbibing heat, is familiarly known by the experiment of placing cloth of different shades upon the snow, exposed to the rays of the sun. The darkest colours will be found, after exposure for a length of time, sunk more deeply into the snow, from the melting of it directly beneath the cloth, than the light colours, which will scarcely be affected at all by the sun. White hats are found cooler than those of a black colour, and even coaches are rendered much cooler, if the tops of them are painted white. As dark surfaces imbibe heat more readily than white, they in like manner part with their heat or caloric more readily. For this reason the blacks are not so well able to withstand the effects of cold northern climates, as the whites, the colour of the skin making a difference in parting with the heat of the body.

The communication and radiation of heat is of importance in the useful arts, principally in enabling us to guard against the loss of heat where it is desirable to have it retained. Bright polished metals, and light colours, have been found as before stated, to radiate heat slowly. Steam boilers and pipes, are caused to lose less heat by being whitewashed, and even the large pipes and cylinders of the steam engine have in some instances, been turned and polished for the same purpose. Steam pipes should be of bright metal, where it is merely required to convey steam to a distance from the boiler; but should be blackened when used to heat the air of the room. The bottom of the boiler should also be blackened, that the heat of the fire may not be reflected from it. It has been considered as a useful property of most kinds of fuel, that they blacken the surface of the metallic vessels, under which they are consumed.

After the water is warmed, it will retain its heat much longer in a resplendent, than in blackened vessel, for the reason before stated. Tea pots made of polished silver are well adapted to retaining heat. The following *Rules in relation to the communication, and Radiation of heat* may sometimes prove useful.

Those bodies which give out heat readily by communication, imbibe it as readilyin the same way, and are soon heated; while those which communicate slowly, receive slowly by communication.

Those bodies that radiate heat freely so as to cool quickly, receive it as freely, so that they are soon heated; on the contrary, those which radiate little, receive few of the rays of heat, and are slowly warmed

SOURCES OF HEAT.

Having treated of the effects of heat upon material substances, and the modes in which it is communicated, it remains to trace it to the sources from whence it proceeds, or is derived.

SOURCES OF HEAT, OR CALORIC.

The sun is the great natural source of heat, as well as of light, diffusing its mingled rays so intimately blended together, that until they were separated by the prism it was supposed they were indivisible. So equally does it distribute heat over the surface of the earth that the utmost range, as indicated by the scale of Fahrenheit's thermometer, does not exceed 170 degrees. In the warmest climate the thermometer placed in the shade sometimes rises as high as 110° or or 115° while in the coldest regions it rarely falls to 50° below the beginning of the scale, or zero. The average heat of the globe is about 50° above zero on Fahrenheit's scale, the extremes being not many degrees above or below this. By concentrating the rays of the sun by lens or concave mirrors, by combustion, freezing mixtures, and other artificial expedients, a range of temperature has been obtained from the extreme of 91° below zero, to 21,000° above it. The different modes of generating heat applicable to the useful arts are,

1st, *Mechanical action*, between solids.

2d, *Chemical action*, under which is included *combustion*, the most important of all others in a practical point of view.

MEANS OF GENERATING HEAT.

Friction is a most obvious mode of generating heat, as almost every substance is found to become warm when rubbed. The intensity of heat excited in this way is frequently sufficient to set on fire wood, and other combustible substances. Thus the inhabitants of the South Sea Islands practise this expedient for kindling their fires, rubbing two pieces of wood together violently until they blaze. Instances are frequently occurring of heat generated by friction when ever the wheels of a common carriage are not supplied with a proper lubricating substance. Near Worcester, a woollen mill was not long since entirely consumed by a fire originating from the friction of a revolving shaft.

According to experiments made by Sir Humphrey Davy, sufficient heat was produced by the friction of two pieces of ice upon each other, placed in an insulated apparatus, surrounded by ice, to cause them to melt.

The heat excited by percussion is quite equal in intensity to that produced by friction. A familiar instance of the generation of heat by percussion may be witnessed in the method which a blacksmith sometimes adopts to kindle his fire. He hammers a small rod of iron smartly for a few moments, whereby it becomes so much heated that a match may be lighted by it. A sufficiently high temperature can be produced by the sudden compression of air to set fire to inflammable bodies. A small syringe about as large in diameter as a gun barrel, having a little prepared tinder attached to the end of the piston or rammer, is sometimes used instead of flint and steel, for obtaining fire. The piston in this case only requires to be driven forcibly into the air-tight syringe, when the heat produced by the sudden compression of the air instantaneously kindles the tinder.

CHEMICAL ACTION AND COMBUSTION.

By the mixture of different substances a chemical action is produced, which is almost always attended by a change of temperature of the mixture. Thus when oil of vitriol (sulphuric acid) and water, or strong spirits (alcohol) and water, are mixed in equal quantities, heat is evolved. Vegetable and animal matter under certain circumstances undergo chemical changes, called *fermentation*, and *putrefaction*, during which much heat is produced. This mode of generating heat is not commonly adopted in practice except for the purposes of gardening. The bark from tan pits, and manure from stables are generally selected by gardeners, as being most easily procured, and producing considerable heat by the fermentation and putrefaction which they undergo. When stable manure is collected in masses the heat excited will be equal to 140°. Tanner's bark yields a more moderate and uniform temperature. By means of the warmth imparted by these materials, hot beds may be successfully managed, even during the intense frosts of a New-England winter, without the aid of stoves. In a hot bed about sixteen feet long, and of sufficient height to allow one to stand erect within it, the most tender exotic plants, have been in this way successfully preserved. The glasses of the hot bed are arranged in double sashes, upon the principle before described in reference to double windows, to prevent the escape of heat by the intervention of a thin sheet of confined air. In large green houses this plan, although somewhat more costly at first, might in the end prove more economical, by rendering a less quantity of fuel necessary for keeping up the proper temperature. The frame of the hot bed is constructed of North Carolina or pitch pine plank, grooved together. Hard pine, or other compact wood answers best, being a better conductor of the heat generated in this way, than white pine or other softer wood. This frame may be placed in some proper exposure to the sun with the north or back side near the garden wall, or close garden fence, leaving the space of about two feet between the wall and plank frame to receive the manure. A similar space is formed for the manure between each end of the frame, and the end walls, which are constructed with the tops sloping toward the front, with the same pitch or descent as that of the glasses. The front of the frame is also lined as high as the range of front glasses will allow, with the fermentable material, which is covered from view by fresh straw. The glasses may be conveniently covered and uncovered by attaching one side of the screen, formed of mats, to the highest part of the sashes, and the other end to a small round spar or roller, which is suspended from it at the bottom. By means of a cord inserted at the top of the screen, and descending beneath it upon the sashes, passing around the spar at the bottom, and returning to the top upon the upper surface of the screen, the operator will cause the spar to roll up the inclined plane formed by the top of the hot bed, and the mats to be wound regularly around the roller, like a curtain. It is only necessary to loosen this cord, when the roller will descend upon the inclined plane formed by the sloping glass, by its own weight, unwinding the mats in its descent, without further trouble to the operator. The weight of the spar attached to the mats also prevents them from being lifted by the winds. After thus furnishing heat to the hot bed during the winter, the manure is of equal value for purposes of husbandry or gardening in the spring. A very economical little green house may thus be formed and preserved from the effects of the frosts of winter, by means of the heat obtainable from substances by *chemical action.*

The chemical action that takes places among the particles of matter is frequently so violent as to produce instantaneous *combustion*, or flame. This is the last, and by far the most important source of heat.

COMBUSTION.

Various theories have been formed by philosophers in regard to the production of heat by chemical action and combustion, as before stated at page 53, but no theory has yet been advanced, which will satisfactorily account for all the various operations and effects ordinarily observable as attendant upon this wonderful process of nature. The theory of Lavoisier is plausible, and from its ingenuity deserves to be mentioned. He considers the heat imparted by combustion as analagous to the condensation of steam, air being generally converted by it into some denser form. A cubic inch of water if subjected to heat for a certain time, will fill a cubic foot of space, and exist as an aeriform vapour. Although a fire may have been for several minutes imparting heat to the water, to convert it into steam, yet the water and steam will at no time indicate an increased temperature after reaching the boiling point, should a thermometer be suspended in them. It is apparent, then, that a considerable quantity of heat must exist in the steam in a *latent* state, to keep the water suspended in the form of vapour. If the cubic foot of steam be now condensed, (as before stated when treating upon Steam,) all this heat will be set free again, which would be sufficient, as it has also been before shewn, to raise the temperature of the condensed volume of water to a red heat, if it were possible by any contrivance to collect and concentrate this latent heat within it. Combustion was considered by Lavoisier as a process somewhat similar to the condensation of steam, whereby various gases are converted from an aeriform to a fluid state, when they give out their latent heat.

It has been stated at page 50, that by means of the galvanic fire or fluid, water may be readily converted into an aeriform state, entirely different from that of steam. Water in this experiment is decomposed into its constituent elements, and converted into bubbles of air between the points of the wires immersed in it, and connected with the galvanic battery. These bubbles have been collected, on rising to the surface of the water, and have been found to consist of two sorts of gas; one of them is called *Hydrogen* gas, and the other *Oxygen* gas. By this and various other experiments, water is found to be composed of these two gases in the proportion of two parts of the former to one of the latter. If these two gases, obtainable by the decomposition of the water, be weighed and mingled together in the same proportion as formed from the water, they will *burn* with an explosion, and the sides of the vessel that contained them will be covered with drops of water, which if also collected will be found to weigh exactly as much as the two gases before combustion. Here then is a case in which water is decomposed so as to be converted into aeriform gases, which are capable of being again condensed into water by a process termed *combustion*, whereby a great quantity of light as well as heat is set free. In this case the heat is supposed to be derived from the condensation of the air or gases, as in the case of steam before described. Water is thus demonstrated to be composed of *two combustible* elements. When water is thrown in small quantities upon a hot fire it is sometimes partially decomposed, and contributes to augment the flame. When applied to fire in larger quantities, it is converted into steam, rapidly absorbing a vast quantity of *latent* heat which is necessary, as before observed, to convert it into vapour. When the heat is carried off in this way from a burning substance faster than it is generated by the process of combustion, the temperature of the substance must of course be reduced. Water will thus absorb heat from all bodies heated above 212º; but it has been found that combustible substances require in most cases to have their temperature maintained as high as 700º or 800º. The rapid evaporation of the water cooling them below this point, consequently checks their combustion, or extinguishes them.

Although the heat produced from the conversion of vapours or gases into fluids, or of fluids into solids, may be accounted for by the extrication of the latent heat set free by the process, yet the intense heat produced where the reverse of this takes place, as when a solid, like gunpowder, is converted into a volume of gas, remains without a satisfactory explanation. A blow pipe has been ingeniously contrived by Dr. Hare of Philadelphia, for causing a jet of the two gases above named to unite as they issue from the orifice of small tubes to form a jet of flame, like that observable when a common blow pipe is applied to a lamp. A most intense heat is thus obtainable, which will melt almost every substance exposed to the action of it. The heat of this compound blow pipe is surpassed only by that produced by the arc of flame between the points of the wires of a galvanic battery.

The chemical action, in the process of combustion, ordinarily takes place between an inflammable body and the air of the atmosphere. It may here be observed, that the air of the atmosphere has been found by chemists to consist of two descriptions of air or aeriform gas, mingled together in the proportion of

	By measure.	By weight.
Oxygen	21	23.3
Nitrogen	79	76.7
	100	100

If a candle or other inflammable body be placed while burning under an inverted glass filled with air, and suspended over water, in such a manner that the lower edge may come in contact with the surface of it, it will be found that the water will rise in the glass as a portion of the air unites with the inflammable substance, and forms a new compound with it. After a short time the candle will go out;—if the candle be lighted and again carefully inserted under the glass so as not to admit at the same time atmospheric air, the candle will be immediately extinguished. If in like manner small animals be placed under the same glass they will soon be thrown into convulsions and expire. It seems in this case then, that a certain portion of the atmospheric air is necessary to sustain flame, and for the purpose of breathing, to support animal life; and that another portion if it will neither sustain flame or life. The former air, or gas, is called oxygen, and the latter nitrogen. The more freely the air is admitted during the process of combustion, the more rapidly will the oxygen of the air combine with the inflammable material, and consequently the more intense will be the combustion. In practice, the beneficial effects of strong draughts to furnaces, are derived from this principle. Smoke is usually produced where the combustion is imperfect, from an inadequate supply of air, and is composed merely of the chared or coaly matter, driven off from the burning body by heat, in the state of a very fine powder. Whenever a furnace vents smoke, it is either an indication of some fault of construction, or that the fireman is prodigally wasteful of his fuel by crowding so much of it together, that the air cannot come in contact with all parts of it. The Argand lamp, so called from the first person who manufactured them, is formed with a hollow or circular wick, and a glass chimney, which causes a current of air against both the inside and outside of the blaze, whereby the combustion is rendered more complete, and the light more vivid.

It must be apparent from the above observations, that the vital part of the atmospheric air, necessary for respiration, is constantly diminishing from the vast consumption of it for supporting fires. By a wise provision of Providence, all vegetables emit from the under surfaces of their leaves the oxygen gas, and absorb from the air the new compound gas formed by combustion. The atmosphere is thus constantly replenished with pure air, and deprived of the mephitic gas produced by combustion, and the order of the universe is preserved.

Many lives have been lost, from an ignorance of the above facts, by exposure to the air of close rooms heated by charcoal fires contained in open vessels. It is frequently supposed that charcoal yields no destructive gas after it has become perfectly ignited and burns bright and clear. The contrary is the fact. The fire in this case is more rapidly exhausting the vital air contained in a close room, and at the same time the mephitic air formed by the union of the oxygen with the burning charcoal, accumulates with corresponding rapidity. The gas formed by this new combination is called by chemists, *carbonic acid gas.* It will neither support combustion, or respiration, and suffocation must therefore speedily ensue, when persons are confined in it. Animal heat has been attributed to a combustion of vital air in the lungs.

Having given a sketch of some of the principal facts attending the process of combustion, our subject next leads us to the consideration of the material substances usually employed for maintaing combustion, well known by the term, *fuel*, and the various modes in which these substances are most successfully applied in the useful arts. It may here be observed, that by means of various discoveries and improvements in the art of chemistry, almost all substances, including the metals, and even the diamond, have been found by experiments to be combustible.

COMBUSTIBLE SUBSTANCES.

Solid and fluid substances, only, were considered as inflammable, until within a short time, several gases have been discovered to burn readily.

Aeriform Combustible Substances.

Hydrogen gas, which has been described as forming a principle constituent element of water, is one of the most inflammable of the gases, and most useful for the purpose of affording light. As it is prepared on a large scale, in many of the principal cities of Europe and of the United States, for lighting the streets, and houses, it is combined with coaly particles, or carbon, and is on this account called carburetted hydrogen, and also olefiant gas, from the circumstance of its forming an oil. It is conveyed by metallic pipes, like those for conveying water. This gas is formed by inclosing bituminous coal in large iron vessels, called retorts, arranged in furnaces, by the heat of which the volatile parts of the coal are caused to ascend in a gaseous form, and to pass off by pipes to the gasometer. This vessel in the gas works intended for lighting cities is constructed of sheet iron, and is generally of vast dimensions, the capacity of it being commonly equal to that of the hold of a ship of an hundred and fifty tons. It is suspended over a deep cistern, like an inverted tumbler over a basin of water, and is counterbalanced by weights connected with it by chains passing over pullies, and so arranged that it may rise and sink into the cistern as it is alternately filled with the gas or exhausted of it. Coal gas sometimes contains a little sulphur and other substances, which renders it better adapted for lighting streets and public buildings, than the close rooms of private houses. It is deprived, however, of most of these foreign substances, by causing it to pass through lime water. When impure this gas has a wonderful tendency to tarnish silver, covering in a short time the glittering array of plate displayed by the light of it at the windows of the silversmiths' shops, with a dingy film or crust, and rendering it as opaque in appearance as pewter.

To avoid these impurities of coal gas, whale oil is now commonly used in the iron retorts instead of coal. The oil is made to trickle into hot retorts from whence it passes into the gasometer as before mentioned. The economy of gas illumination may be judged of by a statement showing the products of one chaldron of the best coal.

Products of a Chaldron of Coal, employed for making Coal Gas.

1¼ chaldrons of coke.
24 gallons of tar, and ammoniacal liquor.
12,000 cubic feet of coal gas.

Four or five cubical feet of this gas are required per hour to produce about as much light as an argand lamp, or six wax candles. One chaldron of coals will yield sufficient gas to maintain this light for about 11 days, burning night and day. It is stated that when more than sixty lights are required, a coal gas apparatus will be found profitable.

A gallon of whale oil affords 100 cubical feet of oil gas, and one and a half cubical foot will burn for an hour, and yield as much light as an argand lamp. A gallon of whale oil will therefore form sufficient gas for a light equal to that of an argand burner for 66 hours. Oil gas appears to possess as much illuminating power as about thrice its volume of coal gas; therefore, if a chaldron of coal yields 12000 cubical feet of gas, and a gallon of oil 100 feet, 40 gallons of oil may be considered equal to a chaldron of coals. This gas has been compressed into portable lamps, and distributed in this way for use.

The most injurious effects, which attend the combustion of gaseous substances, take place in coal mines. It is stated by Sir H. Davy, that when the carburetted hydrogen gas becomes accumulated in any part of the gallery or chamber of a mine, so as to be mixed with common air, the presence of a lighted candle, or lamp, causes it to explode, and to destroy, injure, or burn whatever is exposed to its violence. The miners are either immediately killed by the explosion, and thrown with the horses and machinery through the shaft into the air, the mine becoming as it were, an enormous piece of artillery, from which they are projected; or they are gradually suffocated, and undergo a more painful death from the carbonic acid and nitrogen remaining in the mine after the explosion of the *fire damp*, as the miners term it; or what, though it appears the mildest, is the most severe fate, they are burned or maimed, and rendered incapable of labour and healthy enjoyment for life.

Pursuing a course of experiments in order to discover a remedy for this dreadful evil, Sir H. Davy found, upon the principles before stated, that burning bodies were immediately extinguished if any part of them were cooled below the temperature necessary for their combustion, and that by cooling flame in the same manner it would cease to burn. This he effected by causing the flame to pass through fine wire gauze, which is an excellent conductor and radiator of heat, and is consequently possessed of the cooling power requisite for this purpose. If a piece of brass or iron wire gauze be brought down upon the flame of a candle, or what is more analogous to the present subject, upon an inflamed jet of coal gas, it will cut off the flame midway. It may be easily shown that the cooled gaseous matter passes through the wire gauze by again lighting it upon the upper surface, or the experiment may be rendered more striking by holding the gauze just above a jet of gas, and inflaming it after it has ascended through it upon the upper surface, where it will continue burning without following the stream of gas through the wires to the mouth of the jet pipe. The *miners safety lamp* is thus merely a candle placed within a wire gauze or cage, which may be immersed in an explosive mixture of carburetted hydrogen in a coal mine, without communicating the blaze through the cold metallic tissue. The dangerous gas may sometimes be seen burning with a lambent blue flame within the wire cage, as it enters through the apertures of the wires, thus safely contributing to furnish a friendly light to the miners while they work, instead of destructive explosions. By this discovery Sir H. Davy has truly rendered himself a benefactor of mankind.

FLUID COMBUSTIBLE SUBSTANCES.

Under this head may be classed the oils, alcohol, tallow, and such substances as melt before they undergo the process of combustion. These substances are generally found so difficult to be procured in large quantities, and so costly, that the use of them is principally confined to lamps for affording lights. Where it is desirable to maintain a regular heat in order to keep glue or other similar substances at the boiling point, a common lamp or argand burner, with a tin funnel, may be economically employed. In this way the common lamp is employed, as is familiarly known in the nursery. Alcohol or spirits of wine yields an intensely hot blaze unaccompanied by smoke, and is often burned in various culinary operations, in which it is required to boil or dress hot viands or liquids. Alcohol was much used during the expedition under Captain Parry to the polar regions; by means of it he was enabled to refresh his men, when benumbed by exposure to the cold upon the open ice, with warm and palateable food. This mode of using alcohol, may be recommended as much more favourable to health and comfort, than the *internal* application of its stimulating powers.

Fluid combustibles are also employed by mineralogists for melting small particles of mineral substances, and by jewellers for soldering metals. In this case the blaze is caused to act, by means of the blow pipe, upon one point with a most intense heat. The principle upon which the blow pipe acts is by supplying a small fine current of air upon the blaze, the combustion of which, by the abundant supply of oxygen at this point, is rendered more intense, and the consequent heat greater.

SOLID COMBUSTIBLE SUBSTANCES.

Wood, charcoal, peat or turf, and coal, are the principal combustibles commonly used. Wood yields a lively blaze, and like peat and bituminous coal is generally accompanied by smoke when the combustion is not complete. Charcoal and anthracite coal yield comparatively little blaze and smoke, and are therefore better adapted for many purposes than the other combustibles. Peat is not used where a supply of coals or wood can be obtained. We shall therefore confine ourselves to the investigation of the qualities and comparative advantages of the other kinds of Fuel. It may be observed that charcoal and coke are formed on nearly similar principles, the wood in the one case being allowed to burn until the heat has driven off the moisture and blazing qualities, when it is carefully covered up with turf or other incombustible substances to exclude the air and check combustion; after which it is withdrawn in the state of charcoal: bituminous coal in the other case is converted into coke by allowing it to blaze until the blazing particles are consumed, when the remaining mass is extinguished by covering it with turf, as in the preceding instance, or by inclosing it in an air tight oven. Coke may be used like charcoal, to which it is very similar in composition, each of them being nearly pure carbon,—in fact the same substance as the diamond.

Power of different kinds of fuel to generate steam.

There is a great difference in the quantity of heat given out by fossil coals, as well as by the various woods, while burning. The best New-Castle coals have been found to yield more heat than the coals dug in most other parts of England. It is stated by a late English writer that ordinary Scotch coals have proved inferior to the New Castle coal in a ratio nearly as 4 to 3. This statement is made from the relative quantities of steam produced during a number of experiments, and differs materially from that given by Mr. Bull of Philadelphia in his publication upon Fuel, who formed his standard of comparison upon the relative degrees of heat imparted to the air of a close insulated chamber. His experiments give a result of nearly equal temperature communicated to the air of the chamber by the combustion of some small specimens of New Castle and Scotch coals. If he had added experiments upon the best forms of boilers for generating steam by anthracite coal, and had given a table of the relative quantities of water which the different sorts of fuel enumerated by him would convert into steam, his observations might have had additional value. The results of some of his experiments, and his mode of performing them, will be given when treating of the subject of warming the air of rooms, at page 93.

According to a late English writer, it appears that taking one cwt. of New-Castle coal as a standard, the following is the value of other sorts of fuel.

		cwts.		cwt.	
1 cwt.	of New Castle coal, is equal to	2½	to	3	of wood.
1 "	" " "	2			of culm.

1 lb. " is required to convert { 7 lbs. of boiling water, or 6 lbs. of cold water into steam.

1 bushel " { will raise 20 millions of pounds one foot high by means of Bolton and Watt's steam engines.

1 do. " { by one of Woolf's steam engines, has raised, it is stated, above 50 millions of pounds one foot high.

It requires from 10 to 18 pounds of coals per hour for each horse power of a steam engine, according to the strength of the fuel, the tightness of the joints and packings, the proper construction of boilers and furnaces, and the manner in which the furnace is supplied.

Mr. Marshal, of Leeds, stated to me, that for one of his largest engines, of 70 horse power, he consumed a stone (14 lbs.) of ordinary coal, of such quality as is found in the vicinity of Leeds, for each horse power per hour. The furnace of the engine alluded to is fed by a hopper with the utmost regularity attainable by machinery, the coals falling upon grates set in a circular form, like a large horizontal wheel. These grates are caused to turn beneath the boiler with a slow motion, imparted from the engine, each portion passing under the hopper at every revolution to receive a supply of coals. By this contrivance a hopper may be so replenished as to require only the occasional attendance of a fireman, and the fuel is distributed so equally upon the turning grates that the air has free access to promote the combustion of it, and no part is wasted in smoke. This apparatus is called Brunton's fire regulator.

The agent of Messrs. Boulton & Watt, at the Soho Foundry, stated to me, in answer to my inquiry upon this subject, that he calculated that about 10 lbs. of the best coal per hour for each horse power was sufficient for operating their steam engines, while actually in motion. In this case additional fuel would be required to heat the water in the boilers, and to maintain the steam during the intermission of work hours.

In the United States pine wood is chiefly used in the furnaces of steam boats, and of most of the manufactories upon the seaboard of the northern and eastern states. The coal mines of Virginia furnish the principal supply of coal to these sections of the country. Large quantities, however, are imported from England. It appears from the best information which I have been able to procure from various parts of the United States that the high pressure engines, which are commonly used for the manufactories, require a little more than 1¼ bushels of coal per day of 12 ordinary working hours, or nearly 10 bs. of damp coal per hour, for each horse power.

Calling 128 cubic feet, or 8 feet running measure, a cord, a high pressure engine under ordinary circumstances, requires of Pine Wood such as is commonly used for steam engines, 10 inches to 1 foot running measure, per day for each horse power.

When pine wood, which from its superiour bituminous qualities is found to generate nearly as much steam as an equal quantity of Oak, costs at the furnace door 5 dollars per cord, the expense for this kind of fuel will be from 50 to 62½ cents per day for each horse power. Where wood is dearer or cheaper than this in various parts of the United States, the expense will be proportionately augmented or diminished.

A 25 horse power steam engine at Pittsburg, requires about 40 bushels of coal per day, the cost of which delivered does not exceed four cents per bushel, making the expense for fuel of a 25 horse engine about one dollar and sixty cents per day, or 6½ cents per day for each horse power,—only ⅛ of the cost of the same fuel on the seaboard of the northern states. The country around Pittsburgh seems destined in future ages to become the greatest manufacturing district of the world, from its peculiar local advantages of cheapness of fuel, and of provisions, and the abundance of iron ore found there. Iron castings can be sold there nearly twenty per cent cheaper than in Manchester in England. Coals in this great manufacturing city cost the manufacturers 10*s* 6*d* sterling per ton, equal to about 9 cents per bushel,—more than 100 per cent dearer than in Pittsburgh.

From the above data, those who are desirous of forming a comparative estimate of the cheapness of wood and coals for fuel for steam engines may make calculations with tolerable accuracy.

Anthracite coal, it has been ascertained, will produce inconsiderable effects in generating steam, in comparison with bituminous coal, when used in the common furnace of a steam engine. By an experiment made with Rhode Island coal, several years since, in the furnace of one of the North River steam boats, it was found that the quantity of steam generated, was only sufficient to cause the paddle wheels to revolve slowly in the dock. A large steam engine, it is stated, is at present in operation in the city of New York, for which anthracite coal is used. Although bituminous coal is more favourable for producing steam from the circumstance that it burns more rapidly, and the flame arising from it glides along the boilers in immediate contact with them, imparting heat by communication as well as by radiation, yet by means of tubular boilers placed as near as possible to the surface of the ignited coal, and shallow furnaces of large dimensions, these disadvantages might be overcome. Although double the quantity of anthracite coal may be required to be in a state of combustion at one time, yet its superiour durability in the furnace might render an equal weight of it nearly as efficacious for producing an equal quantity of steam as bituminous coal. A hundred pounds of Lehigh coal have been found to yield sufficient heat to melt more than half of its weight of cast iron in a cupola or blast furnace; even in a common stove, I have by way of experiment melted a pound of this metal in six minutes, in which period the whole quantity fell through the grates in a liquid state into a shovel placed beneath to receive it. There can be but little doubt, that a fuel capable of producing such intense heat would be capable of generating steam in sufficient quantities for steam engines, were proper boilers and furnaces constructed for the use of it.

This description of coal I have found to answer exceedingly well in some experiments with small furnaces and boilers for generating steam, to be employed in the processes of manufacturing woollen cloth. In the experiments alluded to, a sheet iron cylindrical stove, 20 inches in diameter and five feet high, lined with fire brick, is employed. The boiler consists of a sheet iron cylinder, about 10 inches diameter, and four feet in length, placed vertically in the furnace with the lower end as near the grate as the convenience of supplying fuel will allow. The top of this cylindrical boiler projects a few inches through the top of the stove, with a safety valve and eduction pipe. The cold water is supplied by a small leaden pipe, from a vessel of water in a room above, merely by turning a cock; and the quantity of water in the boiler is ascertained by two small cocks, one inserted near the top of the boiler, and the other as low as is found prudent to exhaust the water. By the former it may be ascertained when the boiler is sufficiently full, and by the latter when it requires to be filled. These cocks are inserted into short iron tubes, or pieces of a gun barrel screwed into the boiler, and passing through the brick lining to the exterior of the stove. The sheet iron furnace is made in two parts for convenience of laying the fire brick, which are arranged vertically. Should the heat proceeding from it render the apartment uncomfortably warm, the whole interior of this furnace may be lined with common bricks, which are slow conductors of heat. In cold weather the heat proceeding from this apparatus will be sufficient to keep the apartment warm without requiring the expense of another fire. The draught passes off by a pipe proceeding from the side of the furnace, and near the top of it, as in common anthracite coal stoves. A very economical portable steam boiler may thus be made, which for many purposes of manufacturing, heating baths, &c. will be found convenient and useful.

When the anthracite coal is burned in open grates, the currents of cold air passing over the surface of it, have the effect of reducing the temperature below the point at which combustion will take place. Close stoves lined with clay, or fire bricks, which are slow conductors of heat, are peculiarly well calculated to obviate this difficulty. Whenever the temperature of the burning coal is reduced below about 900° by contact with the cold air, or with the sides of the stove or boiler, it becomes black, and ceases to burn. An expedient of this nature has been resorted to with success to prevent bituminous coal from burning to waste in contact with the backs of a blacksmith's forge. For this purpose the back is formed of cast iron with a cavity to contain water, whereby this part of the forge never becomes heated hotter than boiling water, or 212°, and the coals lying in immediate contact with the back are cooled by it below the temperature at which they will burn. The coals that are usually wasted in this part of a blacksmith's forge are thus saved.

THE EFFECTS OF DIFFERENT SORTS OF FUEL IN HEATING THE AIR OF ROOMS.

The experiments made by Mr. Bull, of Philadelphia, upon the combustion of fuel were founded upon the quantity of heat or tempe rature imparted to the air of a small chamber, and maintained for a certain time. He burnt, in his experiments, a pound of fuel in a small stove, provided with a crooked funnel or pipe of sufficient length to give out all the heat, before the draught passed it off out of the apartment, leaving the last end of the pipe always cold. He appears to have performed his experiments with much ingenuity, and with sufficient accuracy. The table published by him of the results will only show the value of the combustible substances for the purpose of warming rooms, without indicating their value in other respects as applicable to the useful arts, or even to culinary purposes.

The chamber which Mr. Bull prepared for the purpose of his experiments was eight feet square, containing 512 cubic feet of air. It was constructed, within a larger room, of boards grooved together in the most perfect manner for rendering it tight, and cutting off the communication with the air of the external room. The fuel upon which he made his experiments was consumed in a small cylindrical stove, twelve inches high, and four inches diameter, made of common sheet iron lined with clay. The pipe of the stove, made of extra thin *black* tin for radiating as well as communicating heat in the most favourable manner, was two inches diameter and forty two feet long, with several elbows. The standard taken by him was shell bark hickory, which is heavier than any other wood in his table, and disengages during its combustion, an equal quantity of heat from any given weight. The comparative numbers express the value of one cord of each of the woods, one ton of the anthracite coals, and one hundred bushels of the bituminous coals, charcoal, and coke. The column of comparative values he found in this manner "The value of a given quantity of fuel is directly proportional to the *time* that a given weight of it maintained the air of the room, at a given temperature, and also to its *weight.*"

The comparative value, for producing heat, of the different sorts of fuel in the table may be found, by assuming a price for the hickory as sold in the market for one cord of 128 cubic feet. Supposing the cord of shell bark hickory to be 6 dollars, it is required to ascertain by the table the equivalent price for a cord of red heart hickory. The comparative value of the former is 100 and of the latter 81. Then, as 100 : 600::81 : 4.86=four dollars eighty-six cents; at which price the red heart hickory would be as cheap as the shell bark hickory.

"A mere examination of the comparative numbers, will show that a cord of white birch is 52 per cent. less in value than a cord of shell bark hickory, and the difference *per cent.* may be calculated from the comparative numbers between any two articles sold at the same price."

In like manner the comparative value of a ton of Lehigh coal may be found by the rules of proportion. As 100, the standard of a cord of hickory, is to $6.00, the price of it in the market, so is 99 the comparative value of this coal for emitting heat, to the answer, $5.94, which shows them to be nearly of the same value, supposing each article to be consumed under nearly the same circumstances.

The comparison of a ton of Lehigh coal at seven dollars, with one hundred bushels of New-Castle coal at thirty-five dollars, the price of each description of coal at that time in the Philadelphia market, will give the following result, greatly in favor of the American article. As 99 : $700: :198 : $14,00.—that is, one hundred bushels of New-Castle coal, costing thirty-five dollars, will impart twice as much heat to a room when burned in a close stove as one ton of Lehigh coal, by which a ton of Lehigh coal at seven dollars appears to be of equal value, for this purpose, to 50 bushels of New-Castle coal, costing seventeen dollars and fifty cents. The American coal is therefore actually cheaper, when used for heating rooms by close stoves, than the English coal, by 150 *per cent.*" Indeed the value of anthracite coal for heating rooms by means of close stoves has been found, by experience, so evidently superiour in point of economy, to that of other sorts of fuel, that it has already come into very general use. During the past winter considerable quantities of Lehigh coal have been sold in Rhode-Island as high as half a cent per pound, and the consumers have been afterwards subjected to the expense of transporting it, twelve or fifteen miles in some instances, to the cotton mills in which it is now generally used for fuel.

The manufacturers prefer this coal for the safety and cleanliness with which it may be burned in stoves lined with fire bricks. Much caution and attention is required when wood is used for fuel for warming cotton mills, as it at one time produces sudden flashes of flame, heating the stove pipes nearly red hot, while at another the flame as suddenly subsides. Anthracite coal, on the contrary, produces a heat so steady and uniform, that it is sometimes left burning in the stoves during the coldest nights of winter, by which means the proper temperature of the air is regularly maintained until morning, and the hands are enabled to recommence labour without loss of time.

Having consumed several tons of Rhode Island and Lehigh coal during the past winter, their comparative value I have found to be nearly as follows. When Rhode Island coal costs $5\frac{50}{100}$ dollars per ton, and Lehigh coal 8 dollars, the same quantity of heat may be obtained from the same cost of fuel, or a ton of the Rhode-Island coal is actually worth a little less than $\frac{3}{4}$ of a ton of Lehigh coal, which gives nearly the same result as obtained by the experiments of Mr. Bull.

Rhode-Island coal requires more attention during its combustion, and unless stirred occasionally to free it of the crust of ashes, which prevents the pieces of coal from lying in contact with each other after their exterior carbonaceous matter is partially consumed away, it sometimes ceases to burn. When mixed with an equal quantity of the anthracite coal from Pennsylvania, the combustion is more perfect, and but little carbonaceous residuum remains.

Common names of Woods and Coals.	Specific Gravities of Dry Wood.	Avoirdupoise lbs. of dry wood in one cord.	Product of Charcoal from 100 parts of dry wood by weight.	Bushels of charcoal from 1 cord of dry wood.	Time 100 of heat were maintained by the combustion of 1 lb. of each article. H.	M.	Value of specified quantities of each article compared with shell-bark Hickory.
					H.	M.	Cord.
WHITE ASH,	.772	3450	25.74	31	6	40	77
APPLE TREE,	.697	3115	25	33	6	40	70
WHITE BEACH,	.724	3236	19.62	23	6		65
BLACK BIRCH,	.697	3115	19.40	27	6		68
WHITE BIRCH,	.530	2369	19.	24	6		48
BUTTER-NUT,	.567	2534	20.79	50	6		51
RED CEDAR,	.565	2525	24.72	30	6	40	56
AMERICAN CHESNUT,	.522	2333	25.29	27	6	40	52
WILD CHERRY,	.597	2668	21.70	26	6	10	55
DOG WOOD,	.815	3643	21.	34	6	10	75
WHITE ELM,	.580	2592	24.85	36	6	40	58
SHELL-BARK HICKORY,	1.000	4469	26.22	32	6	40	100
PIG-NUT HICKORY,	.949	4241	25.22	32	6	40	95
RED-HEART HICKORY,	.829	3705	22.90	39	6	30	81
WITCH-HAZEL,	.784	3505	21.40	25	6	10	72
AMERICAN HORNBEAM,	.720	3218	19.	30	6		65
HARD MAPLE,	.644	2878	21.43	27	6	10	60
SOFT MAPLE.	.597	2668	20.64	28	6		54
CHESNUT WHITE OAK,	.885	3955	22.76	36	6	30	86
WHITE OAK,	.855	3821	21.62	39	6	20	81
SHELL-BARK WHITE OAK,	.775	3464	22.50	32	6	20	74
BARREN SCRUB OAK,	.747	3339	21.27	38	6	30	73
PIN OAK,	.747	3339	22.22	32	6	20	71
SCRUB BLACK OAK,	.728	3254	23.80	38	6	30	71
RED OAK,	.728	3254	22.43	30	6	20	69
BARREN OAK,	.694	3102	22.37	29	6	20	66
ROCK CHESNUT OAK,	.678	3030	20.86	28	6		61
YELLOW OAK,	.653	2919	21.60	41	6	10	60
YELLOW PINE, (SOFT,)	.551	2463	23.75	33	6	30	54
PITCH PINE,	.426	1904	26.76	33	6	40	43
WHITE PINE,	.418	1868	24.35	30	6	40	42
YELLOW POPLAR,	.563	2516	21.81	27	6	10	52
LOMBARDY POPLAR,	.397	1774	25.	34	6	40	40
SASSAFRAS,	.618	2762	22.58	28	6	20	59
SYCAMORE,	.535	2391	23.60	29	6	30	52
BLACK WALNUT,	.681	3044	22.56	31	6	20	65
	Specific Gravities of dry coal	Pounds of dry coal in one bushel.					
							Ton.
LEHIGH COAL,	1.494	78.61			13	10	99
LACAWAXEN COAL,	1.400	73.67			13	10	99
RHODE-ISLAND COAL,	1.438	75.67			9	30	71
SCHUYLKILL COAL,	1.453	76.46			13	40	103
SUSQUEHANNA COAL,	1.373	72.25			13	10	99
SWATARA COAL,	1.459	76.77			11	20	85
WORCESTER COAL,	2.104	110.71			7	50	59
							100 bush
CANNEL COAL,	1.240	65.25			10	30	230
LIVERPOOL COAL,	1.331	70.04			9	10	215
NEWCASTLE COAL,	1.204	63.35			9	20	198
SCOTCH COAL,	1.140	59.99			9	30	191
KARTHAUS COAL,	1.263	66.46			9	20	208
RICHMOND COAL,	1.246	65.56			9	20	205
STONY CREEK COAL,	1.396	73.46			9	50	243
HICKORY CHARCOAL,	.625	32.89			15		136
MAPLE CHARCOAL,	.431	22.68			15		114
OAK CHARCOAL,	.401	21.10			15		106
PINE CHARCOAL,	.285	15.			15		75
COKE,	.557	29.31			12	50	126
Composition of two parts Lehigh Coal, one Charcoal, and one Clay, by weight,					13	30	

In the preceding table the weight of the mineral coal is given in its dry state. In ordinary calculations the weight of coals is estimated in the damp state, as commonly used from the mines. The anthracite from its peculiarly close glassy texture, imbibes but little moisture. The weight of a bushel of bituminous coals will generally average nearly ¼ more when damp than when dry, as stated in Mr. Bull's table.

A bushel of Richmond coal under ordinary circumstances is supposed to weigh	- - -	76 lbs.
Do. New-Castle Coal,	- -	about 80 do.
Do. Anthracite Coal,	- -	81 do.

Mr. Bull also extended his inquiries into the comparative advantages of close stoves and open fire places for heating the air of his little chamber. He considered that when the same stove and pipe was used, as in his preceding experiments, that the whole heat given out by the burning fuel was imparted to the air of the room, and that there was consequently no loss of heat by the flue or otherwise. Assuming then this stove and long funnel as the standard, he has given the following results :

Each apparatus required, to maintain the room at the same temperature, and for the same time,

	Weight of Fuel. lbs.
SHEET IRON CYLINDER STOVE, as before described, with 42 feet of 2 inch pipe as used in the course of experiments on fuel - - - -	1.
No. 1. OPEN CHIMNEY FIRE PLACE, of ordinary construction for burning wood. - -	10.
2. OPEN PARLOUR GRATE, of ordinary construction, for burning Anthracite coal. - -	5.55
3. OPEN FRANKLIN STOVE, with one elbow joint, and 5 feet of pipe, diameter 6 inches. - -	2.70
4. CAST IRON TEN PLATE STOVE, with one elbow joint and 5 feet of pipe - - - - - -	2.22
5. SHEET IRON CYLINDER STOVE, inside coated with clay with one elbow joint, and five feet of pipe, diameter 2 inches - - - - - -	1.49
6. SHEET IRON CYLINDER STOVE, with 3 elbows and 13½ feet of pipe, diameter 2 inches. - -	1.28
7. SHEET IRON CYLINDER STOVE, with 3 elbows and 13½ feet of pipe, all horizontal. - - -	1.22
8. SHEET IRON CYLINDER STOVE, with 9 elbows and 13½ feet of pipe. - - - - - -	1.05

The preceding table shows that it costs ten times as much to heat rooms by means of ordinary open fire places, as by close stoves with long pipes or funnels ; and that an open parlour grate comparatively requires five times the expense for fuel, and an open Franklin stove nearly three times the expense, to impart an equal degree of heat to the air of an apartment.

Some sorts of green wood were found by Mr. Bull to contain 42 per cent. of moisture. In burning 100 lbs. of green wood it is therefore necessary to convert into steam 42 lbs. of water, which must absorb a very considerable proportion of all the heat produced.

But few persons are aware of the great loss attending the use of green wood for fuel;—otherwise more attention would certainly be bestowed in procuring perfectly seasoned wood, not only for boilers and furnaces, but also for purposes of domestic economy. Taking Mr. Bull's statement of the quantity of water contained in green wood at 42 per cent. the following calculations will demonstrate how little heat will be actually given out during combustion. It has been before stated that one pound of New-Castle coal is required to convert 6 lbs. of water into steam, and that 2½ lbs. of wood will impart as much heat as one pound of coals. To convert 42 pounds of water into steam will therefore require all the heat produced by the combustion of 17½ pounds of wood. Deducting 42 pounds of water from the gross weight of 100 lbs. of green wood leaves but

58 lbs. of dry wood.
17½ lbs. of do. required to evaporate 42 lbs. of water.

40½ lbs. of wood only remains from which heat is obtainable.

Sixty per cent. of the weight of green wood is therefore entirely lost, and it is accordingly found, that unless such wood be kept constantly piled upon the hearth, there will not be sufficient heat produced to maintain combustion, and the fire will expire among the blackened brands.

The principal objection urged against the use of closé stoves is the confined dry air produced by them. It is well known that air, which passes over iron or bricks heated red hot, acquires a disagreeable odour, and produces a harsh sensation upon the lungs, accompanied by a tendency to cough. The clay or fire bricks, with which anthracite coal stoves are lined, being slow conductors of heat, are peculiarly well adapted for keeping the external parts of the stove at a temperature which will not have the disagreeable effect upon the air above mentioned. Whenever the heat of a stove does not exceed 300°, the air is not rendered unpleasant for respiration. On this account steam pipes produce a temperature at once mild and agreeable.

The objection to the confined and unpleasant air, usually proceeding from close stoves in small apartments, may be in a great measure obviated by introducing the hot air from a stove or furnace placed in the basement of the building. The stove in this case is inclosed by brickwork with an interstice around it for the free circulation of the air, which is admitted to come in contact with the heated sides of it. After becoming heated the air ascends, and is conveyed by means of flues or pipes to the several apartments, into which it is commonly dis charged through an aperture in the wall near the floor. A shutter of soap stone, sliding in a groove, serves to exclude the hot air when not required. Much inconvenience and danger sometimes attend the attempts to adapt this apparatus to warming houses not originally calculated for it. The same object may be more economically attained by placing the stove in the principal entry or hall of a dwelling-house. The warm air will diffuse itself through every apartment, which communicates with the hall or entry, with surprising regularity. The circulation of the currents of warm air into each room may be shown by holding the blaze of a candle near the top of the doorway, and placing another directly under it upon the floor. The uppermost flame will be drawn into the apartment by the current of warm air entering, while the cold air rushing out will cause the flame of the lower candle to incline in an opposite direction. Several rooms and chambers may thus be rendered comfortably warm by one fire. The stove pipe may be safely conducted through the floors or partitions to the nearest chimney, by inserting in them blocks of free stone with circular apertures adapted to the size of the pipe. Should the plan of the dwelling house admit of placing the stove in the basement or cellar immediately below the entry, the inconveniences arising from the light dust and ashes, usually attendant upon the burning of anthracite coal, may be also avoided. The stove in this case is inclosed in a sort of brick closet, as before described, with proper apertures for the admission of the cold air, and for supplying the necessary fuel. The aperture in the free stone, let into the floor, must be made not only sufficiently large to admit the pipe, but also to allow about two inches space around it, for the ascent of the warm air.

After an experiment for several years of this mode of heating the air of a dwelling-house, the writer feels a confidence in recommending it both for economy of fuel and for the mild and agreeable temperature imparted to the air of every apartment. The constant circulation of fresh air, admitted from the stove, and from the occasional opening of the doors of the entry communicating with the external air, prevents the unpleasant sensations so usually complained of in stove heated rooms.

It is stated that in winter each foot of surface of a glass window will cool from 1½ to 2 cubic feet of air per minute from the temperature of the room to that of the external air. The loss of heat through the window glass may thus be readily estimated. In addition allowance must be made for loss of heat by ventilation of the current of rarified air, that ascends the flue of the chimney together with the smoke. It may be readily supposed that a room would soon be entirely filled with cold air, were it to rush in as fast as rarified air is usually withdrawn by the common draught of the chimney. Yet it must be equally apparent that all the rarified air which thus escapes from a room, must be replaced by an equal quantity of cold external air rushing in through every crevice. The mouth or aperture of the flue of a chimney should therefore be contracted in depth, that the current of air may be thereby diminished in quantity, while it becomes accelerated in velocity. If the vent by the flue will allow more air to pass off than is admitted by the crevices, or otherwise, the ascending current must be proportionately retarded. If an apartment were constructed air tight the smoke mingled with rarified air could not escape by the chimney without leaving a partial vacuum, unless, indeed, the chimney were made of such disproportionate dimensions as to allow a counter current of cold air to descend on one side of it to take the place of the rarified air ascending on the other. The tighter the rooms are made, the more liable will they therefore be to the inconvenience arising from smoke. To construct large open flues to a room intended to be kept warm would appear almost as injudicious as to leave a crevice or a window open to admit cold air. Indeed this last plan is often actually adopted to cause chimnies of this description to carry smoke. One of the principal advantages, which a close stove possesses over an ordinary open fire place, is attributable to the small portion of hot air lost by the draught, which a very few ordinary crevices will amply supply. It is on this account rare that close stoves do not carry smoke, the inconveniences proceeding from which being frequently remedied by adopting the use of them. The common open Franklin stove having from its construction a narrow aperture or throat is often found to produce a remedy for the above evil.

If 150 cubic feet of air, be changed by ventilation each minute, and 100 cubic feet be cooled by the window glass, then 250 cubic feet of air must be warmed each minute, to maintain the room of the proposed temperature. The advantages of double windows to prevent loss of heat by communication has been before stated at page 76.

FLUES OF CHIMNIES, STOVE PIPES, &c.

The principle that governs the draughts of chimnies is the expansion of the heated volume of air, whereby it becomes specifically lighter than common air, and has a tendency to ascend. It must be apparent, then, that under precisely the same circumstances, all chimnies would carry off the smoke equally well; and the straighter and more perpendicular the flue, the better would this result be promoted. In cold weather the draught of a chimney is found to be stronger than in warm weather, for the obvious reason, that in this case, there is a greater difference in the specific gravity of the heated and cold air; for if the external air, and that within the flue, were exactly of the same temperature, the draught would cease. When the air within a chimney is colder than the external air a *descending* current will take place, because cold air is specifically heavier. All these changes may sometimes be observed in the draught of a chimney in the course of a day in summer. During the heat of midday the mass of bricks composing the flue, are comparatively colder than the atmosphere, and cool the air contained within it. The air in this case has a tendency to descend, and a downward current is observable. In the subsequent evening, as the air becomes cooler, the temperature of the brickwork and of the air contained within it becomes about the same as that of the external air, when a stagnation ensues. Before morning, however, the atmosphere becomes chilled and cooler than the chimney, when the air within it being comparatively the warmest, forms an ascending current. Many chimnies are found to discharge smoke into the apartment until the column of air within them becomes heated and rarefied by the kindling fuel. Should a chimney with a well constructed flue continue to smoke after this, the defect must then be attributed to some external cause, such as currents of wind eddying over the summit of some adjacent hill, or tall building, and descending upon the chimney top, thereby counteracting the tendency of the rarefied air within it to ascend. The only remedy in this case is to contract the chimney top, and to open side vents, or to cover the top with an arch, or lastly to extend it in height until the column of heated air will overcome the resistance opposed to its ascent. By increasing the perpendicular height of a column of heated air its tendency to ascend with velocity increases. This principle is well known, and practised upon in the construction of chimnies of furnaces. It may be illustrated by taking a spar or piece of timber, specifically lighter than water, and placing it vertically therein, when the deeper it is thus plunged the more buoyantly will it tend to rise. Horizontal brick flues, and metallic pipes, will prove effective for conveying smoke and rarefied air for considerable distances, provided the temperature of the aeriform fluids do not become cooled before they enter the perpendicular flue connected with the extreme end of the horizontal one. Having tried experiments both with stove pipes and brick flues above eighty feet in length extending through a Drying house, I found that they would each produce a good draught in the furnaces connected with them, arranged beneath the boilers of the adjacent dye house, as soon as they became sufficiently warm not to chill entirely the rarefied air within them.

In passing through some of the deep vallies near Huddersfield in England, the chimnies of several steam mills may be observed at a considerable distance from the mills and elevated high above them upon the steep declivity of the hill sides, being connected with the furnaces by sloping subterraneous flues. They appear like solitary towers, pouring forth smoke above the reach of the eddying blasts that sweep over the hill tops, and discharge the dusky volumes so high in the air that they do not hang over the vale in damp weather, shrouding it with an artificial twilight.

If the column of hot air be first allowed to ascend perpendicularly a proper height, the length of subsequent horizontal flues, or the coldness of them, will have immaterial effects upon the draught of air in the furnace.

Metallic stove pipes transmit caloric more readily, and are therefore better adapted for imparting heat from the combustion of fuel, than brick or stone flues. Indeed they transmit the heat so rapidly from the current of hot air passing within them, that unless large fires are maintained the supply of heat from the burning fuel will not be sufficient to keep the extreme ends of long pipes at a temperature to prevent condensation of moisture within them. When wood is consumed for fuel, a portion of this condensed moisture consists of pyroligneous acid,—one of the most powerful acids for corroding or rusting metals. It is often a subject of surprise to many to find their stove pipes, after being in use but a short time, converted to a mere crust of rust, and rendered unfit for use. This will always be found to be the case where the pipes are long, and the moisture drips from the joints. The dark liquid which thus distils, will be found to be nearly as black as ink, and to contain a large portion of iron actually dissolved and in solution. Where these appearances are presented to view the pipes will soon be wasted away. To obviate this disadvantage short pipes must be substituted which will not cool the vapour from the wood sufficiently to condense it; or more intense fires must be maintained in the stove, in which case the length of pipes may be extended without inconvenience an hundred feet or more, particularly if the whole extent of them be exposed only to the warmed air of the apartment. The anthracite coal yields no decomposing acid, or soot, and but little light ashes, to coat the inside of the stove pipe. The accumulation of soot is sometimes so great when wood is used for fuel, as nearly to form a non-conducting coat to prevent the heat from passing off through the metallic tubes. It is only when they are free from these non-conducting substances that the heat evolved by the combustion is imparted under the most favourable circumstances to the air of the hall or room. As a test that all the heat of the fuel is given out, the extremity of the pipe should feel cold when the hand is applied to it. It is possible that anthracite coal which contains much sulphur may sometimes produce a little sulphurous acid, that will have a slight effect upon iron stove pipes.

From the preceding observations it will appear that a sheet iron pipe connected with a stove in which anthracite coal is used will not only continue to yield heat more freely, but will last much longer, than when connected with a stove supplied with wood for fuel. Their comparative durability I have not yet had the opportunity of ascertaining. It must form, however, a considerable item in favour of the economy of burning this sort of coal. A stove pipe about 80 feet in length, and 9 inches in diameter, used in the dry house before referred to previous to erecting a brick flue therein, was nearly corroded through by the pyroligneous acid from a wood stove during one winter. Although brick flues for dry houses conduct heat slowly, yet by making them of larger size, and of three times the extent, as may be easily accomplished by means of a return flue between an under and upper one, the current of heated air through them becomes much slower, and more time is allowed for the heat to be communicated. When steam pipes are not used in the English drying rooms, brick flues of this description are commonly introduced.

In the construction of the furnaces aud flues of boilers so much depends upon the shape of the vessel, the sort of fuel to be used, and other circumstances, that no rules or directions will be found applicable to all cases. In general it may be observed that the construction of the furnace should be such as to admit the draught of air to come in contact in the most perfect possible manner with the burning fuel, while the boilers should be so arranged as to receive the immediate action of the blaze and heat radiated from the coal. Where the hot air is made to pass around the sides of a boiler, it has been the common practice to make the flues very narrow or contracted, in order to bring the current of heated air more closely in contact with the vessel. Much heat is lost by the increased rapidity with which the hot air is thus made to circulate around the boiler, whereby sufficient time is not allowed for it to give out its heat. On the contrary in proportion as the horizontal flues are made spacious, the hot air moves more slowly, and yields more of its heat during a longer period that it is kept in contact with the sides of the boiler. The flues should not be constructed to allow the heat to act on the side of the vessel above the water line, as the metals become materially injured by the heat after the water has been boiled away.

The grates for small anthracite coal stoves should always be constructed to fall in the manner of a trap door, that the cinders and slags, usually left in the furnace after the combustion of this description of coal, may be allowed to fall at once into the ash pit, without requiring the labour of picking them out in fragments. The form of grates should also be such, as to occasion the least possible obstruction to the passage of the air to the fuel, and at the same time to retain not only the requisite strength, while softened by the action of the fire, to sustain the fuel, but also to resist a tendency to become warped or distorted by the heat of it. This, it is obvious, can only be accomplished by making the grates thin and very deep, whereby the under surfaces will rapidly impart to the current of cold air, passing up between them, the heat communicated to their upper surfaces which are in contact with the burning fuel.

One of the most ingeniously contrived stoves for burning anthracite coal is that invented by Dr. Nott, of Schenectady. It is truly an elaborate production, constructed upon the most approved principles applicable to the economical use of caloric. He has combined science with taste in the arrangement of the parts of it. The lower portion or pedestal is formed of the best non-conductors of caloric to preserve the heat concentrated around the fuel, to render the combustion perfect, while the external parts do not become heated so hot as to affect the air of a room unpleasantly. The upper portion presents to view several pillars supporting an arch or canpoy. The circulation of the draught of hot air through all the columns, and other parts of the stove, exposes a surface equal to about forty feet of stove pipe, by means of which nearly the whole of the heat produced by the combustion of the fuel is imparted to the air of the room.

It is probable that before many years the high price of wood, together with the rapid advances made in improved modes of communicating heat to the apartments of private houses by means of anthracite coal, will in some measure supercede the use of ordinary open fire places, and that dwelling houses may at some future day be erected without the cumbersome masses of brickwork known by the appellation of stacks of chimnies, which occupy no inconsiderable portion of the interior of anciently constructed dwelling houses. With all the existing predilections for the cheerful appearance of a blazing hearth, were it possible to succeed in artificially creating in winter a mild and balmy air within a mansion, the inmates would soon cease to think, at one season more than at another, of gathering around the fire side.

MATTER.

Forms or Figures of Material Substances.

In the preceding pages, Matter has been considered as acted upon or modified by certain natural powers. It has been shown that Gravitation, Cohesion, Magnetism, Electricity, Galvanism and Heat, have most important effects upon all Solid Bodies, producing changes in their gravity, strength, hardness, fluidity, and even in their colours and forms. Our subject now leads us to the consideration of the various Forms or Figures of material substances as ordinarily presented to our view.

In the descriptions of the forms or figures of bodies, various terms are used, with the meaning of which the intelligent mechanic should be familiarly accquainted. These terms are given in the science of Geometry, which treats of quantity, extension, or magnitude, abstractedly considered. Indeed a knowledge of the first principles of Geometry should be acquired by all who wish to understand scientifically the principles of mechanics, or to be enabled to explain their views in relation to this subject in proper terms to be understood by others. The definitions in Geometry of such terms as are of most frequent occurrence will therefore be given. Although the following figures may be familiar to the eye of almost every one, yet the terms used to designate some of them may not be equally well known. Those who may have been long successfully, but unscientifically, operating upon them in practice, will at least have the satisfaction enjoyed by Moliere's Citizen, when he discovered that he had been speaking prose all his life time without knowing it.

DEFINITIONS IN GEOMETRY.

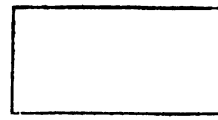
Geometry is a science which has for its object the measure of extension.

A *body*, or *solid*, is a figure of three dimensions, namely, length, breadth, and thickness. Hence surfaces are the extremities of solids; lines the extremities of surfaces; and points the extremities of lines.

A *Point* is that which has position, but not magnitude.

A *line* is length without breadth.

A *surface*, or *superficies*, is that which has length and breadth, without thickness.



Lines are either right, or curved, or mixed of these two

A *right, or straight line,* is the shortest way from one point to another.

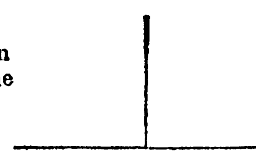
Every line which is neither a straight line, nor composed of straight lines, is a *curved line.*

Lines are either *parallel*, *oblique*, *perpendicular*, or *tangential.*

Parallel lines are always at the same distance, and never meet though ever so far produced.

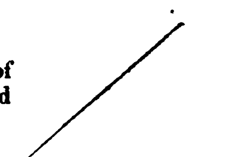
Oblique straight lines change their distance, and would meet, if produced on the side of the least distance.

One line is *perpendicular* to another, when it inclines not more on one side than on the other.



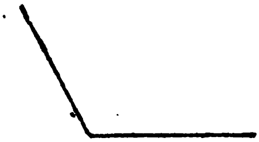
One line is *tangential*, or a *tangent* to another, when it touches it without cutting, if both be produced.

An *angle* is the inclination, or opening of two lines, having different directions, and meeting in a point.

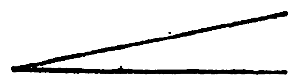


There are three kinds of Angles, viz. a *right* Angle,

An *Obtuse* angle,



And an *Acute* angle,



Superficies are either *plane*, or *curved.*

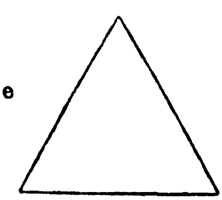
A *plane superficies*, or a *plane*, is a surface in which any two points being taken, the straight line joining those points lies wholly in that surface. But if not, it is *curved.*

Plane figures are bounded either by right lines or curves.

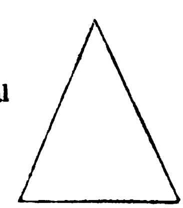
Plane figures, bounded by right lines, have names according to the number of their sides, or angles; for they have as many sides as angles ; the least number being three.

A figure of three sides and angles is called a *triangle*, of which there are several different kinds.

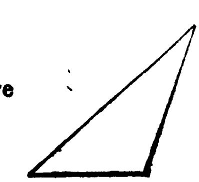
An Equilateral Triangle is that, whose three sides are equal.



An Isosceles Triangle is that which has two equal sides.



A scalene triangle is that whose three sides are all unequal.



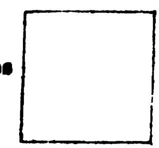
A right-angled triangle is that which has one right angle.

An obtuse-angled triangle has one obtuse angle.

An acute-angled triangle has all its three angles acute.

A figure of four sides and angles is called a Quadrangle, or quadrilateral.

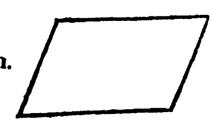
A square has all its sides equal, and its angles right angles.



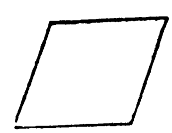
A parallelogram is a quadrilateral, which has both pair of its opposite sides parallel.

A rectangle is a parallelogram having all its angles right angles.

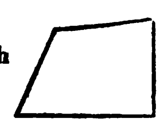
A rhomboid is an oblique-angled parallelogram.



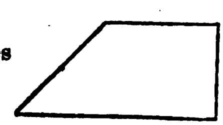
A rhombus is an equilateral rhomboid, having its sides equal, but its angles oblique.



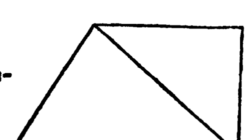
A trapezium is a quadrilateral, which has not both pair of its opposite sides parallel.



A trapezoid has only one pair of opposite sides parallel.



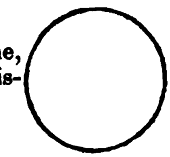
A diagonal is a right line joining any two opposite angles of a quadrilateral.



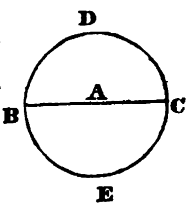
Plane figures having more than four sides are in general called Polygons; but they receive other particular names, according to the number of their sides or angles.

A pentagon is a polygon of five sides; a hexagon has six sides; a heptágon seven sides; an octagon eight sides; a nonagon nine sides; a decagon ten ; &c.

A circle is a plane figure, bounded by a curve line, called the circumference, which is every where equidistant from a certain point within, called the centre.



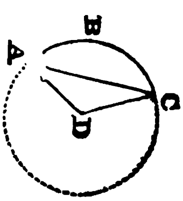
The *radius* of a circle is a right line, drawn from the centre A, to the circumference B D C E, and the diameter is a right line drawn through the centre, and terminating in the circumference on both sides, dividing a circle into two semicircles, as B C. The term *radii* is used for the plural of radius.



An arc of a circle is any part of the circumference; as A B C.

A chord is a right line A C, joining the extremities of an arc.

A segment is any part ~~of a~~ circle bounded by an arc A B C. and a chord A C.



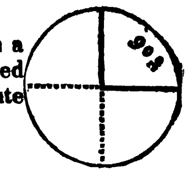
A Sector is any part of a circle, bounded by an arc, A B C, and two radii, drawn to its extremities, as C D, A D.

A quadrant is a *sector* forming a quarter of a circle.

The circumference of every circle is supposed to be divided into 360 equal parts, called degrees; each degree into 60 minutes, and each minute into 60 seconds. Hence a semicircle contains 180 degrees, (marked 180º) and a quadrant 90º.

The measure of a right-lined angle is an arc of any circle contained between the two lines which form that angle, the angular point being the centre of the circle. The angle is estimated by the number of degrees of the circumference of the circle contained in that arc. In a right angle, for instance, the two radii are perpendicular to each other, and intercept a quarter of the circumference of a circle. One fourth of 360 degrees is 90 degrees. Hence a right angle is an angle of 90 degrees.

Degrees are marked at the top of the figures with a small $^{\circ}$ There are 60 minutes to a degree marked above with $'$. There are 60 seconds to a minute marked $''$; Thus 90°, $40'$ $12''$.



Similar figures are those, that have all the angles of one equal to all the angles of the other, each to each, and the sides about the equal angles proportional.

The Perimeter of a figure is the sum of all its sides taken together.

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 which requires a solution.

A theorem is a truth which becomes evident by a process of reasoning called a *demonstration.*

A Lemma is something which is premised, or previously demonstrated, in order to render what follows more easy. The common name of *Proposition* is given indifferently to theorems, problems, and lemmas.

A Corollary is a consequent truth, gained immediately from some preceding truth or demonstration.

A Scholium is a remark, or observation, made upon something preceding it.

A hypothesis is a supposition made either in the enunciation of a proposition, or in the course of a demonstration.

An *Axiom* is a proposition, the truth of which is self evident, as,

1. Two quantities, each of which is equal to a third, are equal to one another.
2. The whole is greater than its parts.
3. The whole is equal to the sum of all its parts.
4. Only one straight line can be drawn between two points.

TABLES

Of the Superficial and Solid Dimensions, and Weights of Material Substances.

The dimensions and ponderosity of matter are calculated by measures and weights, peculiar standards of which have been adopted by almost every nation of the earth. Of the measure commonly understood by the term *foot*, there are nearly an hundred different kinds in use in various nations, and in various sections even of the same nation. In the United States there are three standards of a gallon, and two of a pound.

The gallon	Dry Measure	contains	268¾	cubic inches.
"	Ale Measure	"	282	"
"	Wine Measure	"	231	"

This variety is a constant source of inconvenience in commercial intercourse between one country and another, and of frequent perplexity even in the internal intercourse existing among the inhabitants of the same country. The *decimal system* adopted in France, possesses great advantages for simplicity. Attempts have been made in England to reduce Measures and Weights to more uniform and simple standards ; and the subject has been investigated in one of the official reports of Mr. Jefferson, while secretary of State, and also in a similar report of the present chief magistrate of the United States. From the strength of fixed habits and prejudices of the people, to be encountered on introducing new systems among them to regulate their daily commercial exchanges and customs, it appears that this subject is attended with more difficulties than philosophers are ready to imagine. Thus while new governments have been instituted, and various revolutions have attended the political institutions of all countries, the familiar customs and habits of childrens' games have remained, it is stated, for centuries the same. In France the new system has been altered occasionally to accommodate the existing customs of the people, and is still not generally used. Even in the United States, where a most convenient Decimal System has been applied to regulate the currency, the old standards of shillings and pence are still in general use. In almost every county of England peculiarities of Measures and Weights continue to exist, notwithstanding all the exertions made there to reform these abuses by penal laws.

The English Standards of Weights and Measures have been adopted in the United States. These, and the French weights and measures, being most commonly referred to in the treatises upon subjects relating to mechanics, are here inserted, arranged in tables that will often be found of practical utility.

MEASURE OF LENGTH, OR LONG MEASURE.

In.	*ft.*	*Yd.*	*Pl.*	*Fur.*	*M.*	*Lea.*	*Degree.*
12	= 1						
36	= 3	= 1					
198	= 16½	= 5½	= 1				
7920	= 660	= 220	= 40	= 1			
63.360	= 5280	= 1.760	= 320	= 8	= 1		
					= 3	= 1	
					= 69½	= to nearly	1

A fathom is 6 feet, and is only used to measure the depth of water.
A hand is 4 inches, and is used to measure the height of horses.

Measure of Land.

In measuring Land, Gunter's chain is used, which is in length,
4 rods, or
22 yards, or
66 feet; and contains 100 links, each 7.92 inches long.

Computation of the Length, and Fineness, of Cotton Yarn.

Yards.	*Threads.*	*Skeins.*	*Hanks.*	*Spyndle of cotton yarn.*
1½	= 1			
120	= 80	= 1		
840	= 560	= 7	= 1	
15.120	= 10.080	= 126	= 18	= 1

The fineness of cotton yarn is calculated by Nos. according to the number of Hanks of the yarn required to weigh a pound. When 30 hanks, or 210 skeins weigh exactly a pound, it is called No. 30 yarn. In the United States the term, *skein*, is erroneously applied to denote the No. of the yarn, instead of *Hank.*

Computation of the Length and Fineness of Woollen Yarn.

Yards.	*Knot.*	*Skein.*	*Run.*
80	= 1		
320	= 4	= 1	
1600	= 20	= 5	= 1

MEASURES OF LENGTH AND BREADTH OR SUPERFICIAL MEASURE.

sq. inches.		*sq. foot.*								
144	=	1	*sq. yard.*							
1.296	=	9	=	1	*sq. rod.*					
39.204	=	272¼	=	30¼	=	1	*rood.*			
1.568.160	=	10.890	=	1210	=	40	=	1	*acre.*	
6.272.640	=	43.560	=	4840	=	160	=	4	=	1

MEASURES OF LENGTH, BREADTH AND DEPTH, OR SOLID MEASURE.

Solids are measured by cubes, which are regular solid portions of matter of six square and equal sides, the corners or angles being right angles, and therefore equal. The common Die presents a familiar instance of a regular cube.

Cubes are calculated in inches, feet, yards, &c. the least solid measure being a cubic Inch.

cub. inches.		*cub. feet.*				
1728	=	1	*cub. yard.*			
46.656	=	27	=	1	*cub. fathom or square.*	
373.248	=	216	=	8	=	1

128=one cord of wood.
30=one cord of stone.
24¾ one perch of stone.
40 of round timber, or } =one Ton.
50 square timber }
40=in the admeasurement of ships to 1 Ton.*

* By a Statute Law of the United States, the tonnage of ships is calculated by the following rule.

"If the said ship or vessel be double decked, take the length thereof, from the fore part of the main stem to the after part of the stern post, above the upper deck, the breadth, thereof, at the broadest part above the main wales, half of which breadth shall be accounted the depth of such vessel, and shall then deduct from the length three fifths of the breadth, multiply the remainder by the breadth, and the product by the depth, and shall divide this last product by ninety-five, the quotient whereof shall be deemed the true contents or tonnage of such ship or vessel. And if such ship or vessel be single-decked, the said surveyor, or other person, shall take the length and breadth as above directed in respect to a double decked ship or vessel, shall deduct from the said length three fifths of the breadth and taking the depth from the under side of the deck plank to the ceiling in the hold, shall multiply and divide as aforesaid, and the quotient shall be deemed the tonnage of such ship or vessel.

QUANTITY OF GOODS TO COMPOSE A TON.

Extract from the By-Laws of the New-York Chamber of Commerce.—Resolved, That, when vessels are freighted by the ton, and no special agreement is made between the owner of the vessel and freighter of the goods, respecting the proportion of tonnage which each particular article shall be computed at, the following regulation shall be the standard of computation:

That the articles, the bulk of which shall compose a ton, to equal *a ton* of heavy materials, shall be in weight as follows: 1568 lbs. of coffee in casks, 1830 do. in bags, 1120 lb. of cocoa in casks, 1307 do. in bags.

952 lbs. of Pimento in casks, 1110 do. in bags.

Eight barrels of flour, of 196 lbs. each.

Six barrels of beef, pork, tallow, pickled fish, pitch tar and turpentine.

DRY MEASURE,

For Grain, Coals, Fruit, Roots, Salt, &c,

cub. inches.	*Gall.*		
268⅘	= 1	*bushel.*	
2.150⅖	= 8	= 1	

A Winchester bushel is 18½ inches diameter and 8 inches deep.

pints.	*gal.*			
8	= 1	*peck.*		
16	= 2	= 1	*bushel.*	
64	= 8	= 4	= 1	*quarter.*
512	= 64	= 32	= 8	= 1

The preceding measures are supposed to be *striken.* A heaped bushel, is one third more than a *striken* bushel.

36 bushels=1 Chaldron of coals in London, and as commonly heaped in the measure there, weigh 3136 lbs. Avoirdupois, or 87 lbs. to the bushel; as ordinarily measured, they weigh about 2988 lbs. or 83 lbs. to the bushel. The London standard of about 87 lbs. to the bushel, is generally applied to calculations of coal consumed by Steam Engines, in England.

ALE OR BEER MEASURE.*

cubic inches. 282 = 1 *gallon.*

pints.	*quarts.*					
2	= 1	*gal.*				
8	= 4	= 1	*barrel.*			
288	= 144	= 36	= 1	*hhds.*		
432	= 216	= 54	= 1½	= 1	*butt.*	
864	= 432	= 108	= 3	= 2	= 1	*tun.*
1728	= 864	= 216	= 6	= 4	= 2	= 1

Twenty hundred weight of pig and bar iron, pot ashes, sugar, logwood, fustic, Nicaragua wood, and all heavy dye-woods, rice, honey, copper ore, and all other heavy goods.

Sixteen hundred weight of coffee, cocoa, and dried codfish, in bulk, and twelve hundred weight of dried codfish in casks of any size.

Six hundred weight of ship bread in casks, seven hundred in bags, and eight hundred in bulk.

Two hundred gallons (wine measure) reckoning the full contents of the casks, of oil, wine, brandy, or any kind of liquors.

Twenty-two bushels of grain, peas or beans in casks.

Thirty-six bushels of do. in bulk.

Thirty six bushels of European Salt. Thirty-one bushels of salt from the West-Indies.

Twenty-nine bushels of sea coal.

Forty feet (cubic measure) of mahogany, square timber, oak plank, pine and other boards, beaver, furs, peltry, beeswax, cotton, wool, and bale goods of all kinds.

One hogshead of tobacco, and ten hundred weight of dry hides.

Eight hundred weight of China raw silk, ten hundred weight net bohea tea, and eight hundred green tea.

* Milk is sold by the Beer quart.

WINE MEASURE.

Wine measure is generally used in all calculations of capacity, unless Beer measure be expressly mentioned. Considerable errors might arise from a mistake in relation to these measures. There are possibly many persons who would be at a loss to decide, were they asked the question, which of the measures of a gallon is commonly used and referred to as the standard for calculations.

cubic inches.		*gallon.*
231	=	1

pints.	*quarts.*	*gal.*	*tier.*	*hhd.*	*pun.*	*pipe.*	*tun.*
2	= 1						
8	= 4	= 1					
336	= 168	= 42	= 1				
504	= 252	= 63	= 1½	= 1			
672	= 336	= 84	= 2	= 1⅓	= 1		
1008	= 504	= 126	= 3	= 2	= 1½	= 1	
2016	= 1008	= 252	= 6	= 4	= 3	= 2	= 1

12 Wine gallons of distilled water weigh exactly 100 lbs. Avoir.

The Wine gallon bears nearly the same proportion to the Ale gallon, as the pound Troy bears to the pound Avoirdupois.

TROY WEIGHT.

By which gold, silver, and jewels are weighed.

It has been observed that a distinction exists between the effect of gravity and that of weight. The effect of gravity is to cause a tendency in each particle of matter to descend with a certain velocity, whether the number or mass of particles be greater or less. Weight is equivalent to the effort necessary to be exerted in order to prevent a mass from obeying its gravity. The latter may be considered the tendency which a mass of matter, placed in a scale, has toward the centre of the earth ; the former, the counterpoise that prevents its descent. Thus weight depends on the mass, whereas gravity has no relation to it.

The standard of weights was originally taken from corns of wheat, for which reason, the lowest denomination of weights is still expressed by a "grain."

grains.	*dwt.*	*oz.*	*lbs.*
24	= 1		
480	= 20	= 1	
5760	= 240	= 12	= 1

marks, { *Dwt.* penny weight. *Oz.* ounce. *lb.* pound.

1 lb. Avoirdupois=7000 Grains.

The Apothecaries pound and ounce, and the pound and ounce Troy, are the same, only differently divided, and subdivided.

All the weights now used by Apothecaries, above grains, are Avoirdupois.

Pearls and diamonds are estimated by Jewellers by carats of weight. A carat is about $\frac{1}{150}$ of a troy ounce, or $3\frac{1}{5}$ troy grains.

The purity or fineness of Gold is also estimated by the carat. In this case, the whole mass is conceived to be divided into 24 equal parts ; i. e. twenty four carats, and the purity of the specimen is expressed by the number of carats of pure gold it contains. Thus, gold of 18 carats fine, means a compound of $\frac{18}{24}$ths of pure gold, and $\frac{6}{24}$ths of alloy of some other metal. It is rare, however, that gold can be obtained over $23\frac{1}{2}$ carats, on account of the difficulty of freeing it from foreign substances; 22 carats fine is standard gold.

AVOIRDUPOIS WEIGHT,

By which all metals, except gold and silver, are weighed, as well as most articles of commerce.

drams		oz.		lb.		qr.		cwt.		ton.
16	=	1								
256	=	16	=	1						
7.168	=	448	=	28	=	1				
28.672	=	1.792	=	112	=	4	=	1		
573.440	=	35.840	=	2240	=	80	=	20	=	1

The stone is generally estimated = 14 lbs.
" for butcher's meat and fish=8 lbs.
" for wool varies in almost every county in England.
" in Yorkshire = 16 lbs.

	oz.	dwt.	grains.	
1 lb. Avoirdupois is equal to	14.	11	15½	Troy.
1 oz. do "		18	5½	"
1 dram do "		1	3½	"

TABLE OF FRENCH WEIGHTS AND MEASURES.

The old and new French Weights and measures reduced to the English Standard.

The Paris pound, *poids de marc* of *Charlemagne*, contains 9216 Paris grains ; it is divided into 16 ounces, each ounce into 8 gross (or drams,) and each gros into 72 grains ; it is equal to 7561 English troy grains.

The English troy pound of 12 ounces, contains 5760 English troy grains, and is equal to 7021 Paris grains.

The English avoirdupois pound of 16 ounces, contains 7000 English troy grains, and is equal to 8538 Paris grains.

To reduce Paris grains to English troy grains, divide by 1.2189.

To reduce Paris ounces to English troy, divide by 1.015734 ; or the conversion may be made by means of the following Tables.

I. To reduce French to Englsh Troy Weight.

		English Troy Grains.
The Paris Pound	=	7561
Ounce	=	472.5625
Gros	=	59.0703
Grain	=	.8204

II. To reduce Paris Long measure to English.

		Eng. Inches.
The Paris Royal Foot of 12 Inches	=	12.7977
The Inch	=	1.0659
The line or one-twelfth of an Inch	=	.0074

III. To reduce French Cubic Measure to English.

		Eng. Cubical Feet.
The Paris Cubic Foot	=	1.211273
The Cubic Inch	=	.000700

IV. Measure of Capacity.

The Paris Pint contains 58.145 English cubical inches, and the English Wine Pint contains 28.875 cubical inches; or the Paris pint contains 2.0171082 English pints; therefore, to reduce the Paris pint to the English, multiply by 2.0171082.

Table *of the New French Weights and Measures.*

MEASURES OF LENGTH.

		English Inches.
Millimetre	=	.03937
Centimetre	=	.39370
Decimetre	=	3.93702
Metre	=	39.37023
Decametre	=	393.70226
Hecatometre	=	3937.02260
Chiliometre	=	39370.22601
Myriometre	=	393702.26014

		M.	P.	Y.	Ft.	In.
A Decametre is	=	0	0	10	2	9.7
A Hecatometre	=	0	0	109	1	.1
A Chiliometre	=	0	4	213	1	10.2
A Myriometre	=	6	1	156	0	.6

Eight Chiliometres are nearly five English miles.

MEASURES OF CAPACITY.

	English Cubic Inches
Millilitre	.06102
Centilitre	.61024
Decilitre	6.10244
Litre	61.10244
Decalitre	610.24429
Hecatolitre	6102.44288
Chiliolitre	61024.42878
Myriolitre	610244.28778

A Litre is nearly 2⅛ Wine Pints.
14 Decilitres are nearly 3 Wine Pints.
A Chiliolitre is a tun, 12.75 Wine gallons.

To reduce any of the above measures of Capacity to the English standard Gallons.

Divide the number of Cubic Inches in the table,
by 269⅛ for the gallon, Dry Measure.
282 " " Ale Measure.
231 " " Wine Measure.

WEIGHTS.

	English Grains
Milligramme	.0154
Centigramme	.1544
Decigramme	1.5444
Gramme	15.4440
Decagramme	154.4402
Hecatogramme	1544.4023
Chiliogramme (Kilogram)	15444.0234
Myriogramme	154440.2344

A Decagramme is 6 dwts. 10.44 gr. tr.; or 5.65 dr. avoir.
A Hecatogramme is 3 oz. 8.5 dr. avoir.
A Chiliogramme is 2 lbs. 3 oz. 5 dr. avoir.
A Myriogramme is 22 — 1.15. oz. avoir.
100 Myriogrammes are 1 Ton, wanting 32.8 lbs.

AGRARIAN MEASURES.

Are, 1 square Decametre	= 3.95 Perches.
Hecatare	= 2 Acres, 1 Rood, 30.1 Perches.

FIRE WOOD.

Decistre, 1-10th Stere	= 3.5317 cub. ft. English.
Stere, 1 Cubic Metre	= 35.3170 cub. ft.

In order to express decimal proportions in the above system, the following terms have been adopted.

Metre	is the element	of	Long Measures.
Are	"	"	Square Measure.
Stere	"	"	Solid Measure.
Litre	"	"	Measures of Capacity.
Gramme		"	Weights.

The term	Deca	prefixed denotes	10 times.
"	Heca	"	100 "
"	Chilio	"	1000 "
"	Myrio	"	10,000 "
"	Deci	"	the 10th part.
"	Centi	"	" 100th part.
"	Milli,	"	" 1000th part.

Thus Deca-metre signifies 10 metres, and
Deci-metre " 1-10th part of a metre.

MENSURATION.

MENSURATION OF SURFACES, AND OF THE SOLID CONTENTS OF BODIES.

In order to form estimates of the extent of surfaces and solid contents of portions of matter, various rules have been adopted, a few of which, the most common and useful in practice, are here inserted for convenience of reference. The areas or capacity of solid rectangular figures are readily calculated; but more intricacy attends the calculations of the surfaces or contents of many other bodies, as of circular cisterns, &c. With the following rules before him, the mechanic may speedily perform most of the calculations that ordinarily occur in the practical details of his business.

The following signs are used to abbreviate the terms of Arithmetical calculations.

EXPLANATION OF CHARACTERS

Commonly used to abbreviate arithmetical statements or calculations

$+$ Signifies Addition, as $5 + 3$ is 8.
$-$ ——— Subtraction, as $5 - 3$ is 2.
$\times$ ——— Multiplication, as 5×3 is 15.
$\div$ ——— Division, as $15 \div 3$ is 5.

$\frac{15}{3}$ ——— Division is also denoted by placing the dividend over a line, and the divisor under it as $\frac{15}{3}$ is $=15\div3=5$.

: :: : ——* Proportion, as 2 is to 3, so is 4 to 6, 2 : 3: :4 : 6.

= ——— Equality, as $5+3=8$.

$\sqrt{}$ ——— Square Root, as $\sqrt{9}=3$. That is, the square root of 9 is 3.

$\sqrt[3]{}$ ——— Cube Root, as $\sqrt[3]{27}=3$. " " cube root of 27 is 3.

3^2 Signifies that 3 is to be squared, as $3\times3=9$

3^3 ——— 3 is to be cubed, as $3\times3\times3=27$.

$\overline{5+3}\times3=24$. The *Bar* or *vinculum*, connects all the numbers over which it is drawn, or indicates that the numbers under it are to be taken together. Thus in the example, 5 added to $3=8\times3=24$.

PROBLEM I.

To find the area of any Parallelogram, whether it be a Square, a Rectangle, a Rhombus, or a Rhomboid.

See page 106, for definitions of these Figures.

RULE. Multiply the length by the perpendicular breadth or height, and the product will be the area.

EXAMPLE.

What is the area of a Rhomboid, the length A B being 7, the perpendicular B C being 4? See plate, figure 1.

$7\times4=28$ area of Rhomboid.

PROBLEM II.

To find the area of a Triangle.

RULE. Multiply the base by the perpendicular height, and take half the product for the area.

EXAMPLE.

What is the area of a Triangle, the base being 9, and the perpendicular $8\frac{1}{2}$?

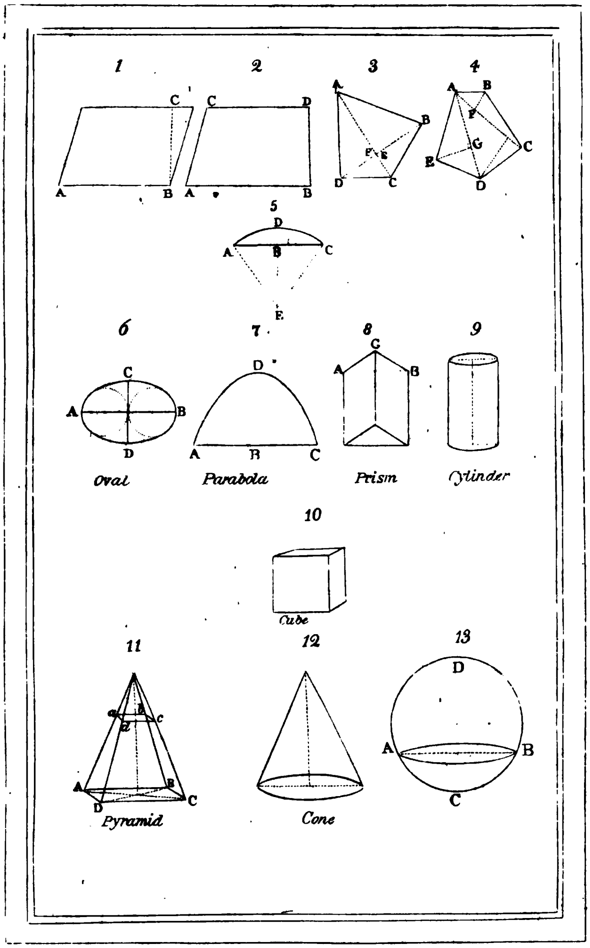
$$9\times8\frac{1}{2}=76\frac{1}{2}\quad\frac{76\frac{1}{2}}{2}=38\frac{1}{4}\text{ area.}$$

* These characters designate the Geometrical Proportion or Ratio. Arithmetical Ratio is indicated by the following characters. ·· :: ··

The comparison of the *difference* of two or more couplets of numbers is called the Arithmetical Ratio; as 2 ·· 4 : : 6 ·· 8.

The comparison of the Qnotients of two or more, Geometrical Ratio, as 2 ·· 4 : : 8 ·· 16

MENSURATION.



PROBLEM III.

To find the area of a Trapezoid.—See Plate Fig. 2.

RULE. Add together the two parallel sides; then multiply their sum by the perpendicular breadth, or the distance between them, and take half the product for the area.

EXAMPLE.

What is the area of a Trapezoid?

A B = 9 } parallel sides. C D = 8 } B D = 5 perpendicular.	$\overline{9+8}\times5=85$ and $\frac{85}{2}=42\frac{1}{2}$ area.

PROBLEM IV.

To find the area of any Trapezium. See Fig. 3.

RULE. Divide the Trapezium into two triangles by a diagonal; then find the areas of the triangles by Prob. 2. and add them together for the area of the Trapezium.

EXAMPLE.

What is the area of a Trapezium?

A C = 8 base of both triangles. D F = 4 } perpendiculars. B E = 5 }	$\overline{5+4}\times8=72$ and $\frac{72}{2}=36$ area.

PROBLEM V.

To find the area of an Irregular Polygon. See Fig. 4.

RULE. Draw Diagonals dividing the proposed Polygon into Trapeziums and Triangles; then find the areas of all these separately, and add them together for the contents of the whole Polygon.

EXAMPLE.

What is the area of an irregular Polygon?

A C = 9 } bases. A D = 8 } B F = 2 } D H = 4 } perpendiculars. E G = 3 }	$\overline{4+2}\times9=54$ $3\times8=24$ 78 $\frac{78}{2}=39$ area.

The principles of Field surveying are embraced by this rule.

PROBLEM VI.

To find the area of a regular Polygon.

Rule 1. Multiply the perimeter (or sum of the sides,) of the Polygon, by the perpendicular drawn from its centre on one of its sides, and take half the product for the area.

Rule 2. Square the side of the Polygon; then multiply that square by the tabular area set against its name in the following Table and the product will be the area.

EXAMPLE.

What is the area of a regular Nonagon, its sides being 5, and perpendicular 6.8686935?

By Rule 1.

$$45 \text{ perimeter} = 5 \times 9$$
$$45 \times 6.8686935 = 309.0912075$$
$$\text{now } \frac{309.09 \text{ \&c.}}{2} = 154.54 \text{ \&c. area.}$$

By Rule 2.

$$5^2 \times 6.1818242 = 154.5456 \text{ \&c. area.}$$

No. of sides	NAMES.	AREAS.
3	Trigon, or Triangle :	0,4330127
4	Tetragon, or Square :	1,0000000
5	Pentagon : :	1,7204774
6	Hexagon : :	2,5980762
7	Heptagon : :	3,6339124
8	Octagon : :	4,8284271
9	Nonagon : :	6,1818242
10	Decagon : :	7,6942088
11	Undecagon : :	9,3656399
12	Dodecagon :	11,1961524

PROBLEM VII.

To find the diameter and circumference of any Circle
The diameters being given to find the circumference.

This may be done by either of the three following proportions, viz. As 7 is to 22, so is the diameter to the circumference; or, As 1 is to 3,1416, so is the diameter to the circumference; or, As 113 is to 355, so is the diameter to the circumference.

EXAMPLE.

What is the circumference of a circle, its diameter being 6?

First, 7 : 22: :6 : 18,857 circumference.
Second, 1 : 3,1416: :6 : 18,8496 do.
Third, 113 : 355: :6 : 18,8495 do.

This last, (113 : 355) is the most exact proportion to find the circumference, from the diameter, or the diameter, from the circumference.

The circumference being given to find the diameter.

Rule. Reverse the above, and say,
as 22 is to 7, so is the circumference to the diameter.
Or as 3,1416 : 1: : so is the circumference to the diameter.
355 : 113: : so is the circumference to the diameter.

PROBLEM VIII.

To find the length of any arc of a Circle—See arc of a circle page 107.

Rule, Multiply the decimal ,01745 by the degrees in the given arc, and the product by the radius of the circle, for the length of the arc,

EXAMPLE.

What is the length of the arc of a Circle, the number of degrees being 25, and radius 7?

$.01745 \times 25 \times 7 = 3,05375$, length of arc.

Note. .01745 is found by dividing the circumference by 360° when the radius is 1 —— *i, e,* $\frac{6,2831854}{360} = ,01745$

PROBLEM IX.

To find the area of a Circle,

Rule 1, Multiply half the circumference by half the diameter, and the product is the area.

Rule 2 Square the diameter, and multiply that square by the decimal ·7854 for the area.

Rule 3. Square the circumference, and multiply that square by the decimal .07958.

16

EXAMPLE.

What is the area of a Circle, the diameter being 9, the circumference $= 28.27$, half of which is 14.135?

By Rule 1.	*By Rule* 2.
$14.135 \times 4.5 = 63.6075$	$9^2 \times .7854 = 63.6174$

By Rule 3.
$28.27^2 \times 07958 = 63.599$, &c.

Note. The first Rule of this Problem is found by the theorem of the triangle: for, supposing the circle to be a regular Polygon of an indefinite number of sides, the sum of the sides will be the perimeter of the circle; consequently, the radius of the circle will be the altitude, and the perimeter the base of the triangle, the area of which is found by $A \times \frac{1}{2} B$, or $\frac{1}{2} A \times B$, (A being the altitude and B the base,) therefore the area of the circle will be $\frac{1}{2}$ of the circle $\times \frac{1}{2}$ the diameter, or $\frac{1}{2}$ circle $\times$ radius.

The second Rule is deduced from the first and Prob. 7.: the first Rule is $\frac{D\ C}{4} =$ area (D C being the diameter and circumference) Prob. 7. is $3.1416\ D — C$, therefore the area is $\frac{3.1416\ D^2}{C}$ or — $.7854\ D^2$.

The third Rule is found thus: $D = \frac{C}{3.1416}$ and $A = \frac{D\ C}{4}$, therefore the area will be $\frac{C^2}{3.1416 \times 4}$ or $\frac{C^2}{12.5664}$ now the reciprocal of 12.5664 is .07958, or $\frac{A}{C^2} = .07958$; hence the rule $C^2 \times .07958 =$ area.

*The diameter, or circumference of a circle being given, the side of a square equal to the circle, may be found by the following short rules.**

RULE. If the diameter of a circle be given, multiply it by ,886, and the product will be the side of an equal square.

If the circumference be given, multiply it by ,282, and the product will be the side of an equal square.

* The *Squaring of the circle* is a Problem which has long puzzled philosophers, and no general rule has yet been discovered that will *exactly* accomplish this result. By the rules laid down, however, a sufficiently near approach to minute accuracy is made for all ordinary computations.

EXAMPLE

If the diameter of a circle be 12 inches, what is the side of a square equal to the circle?

$,886 \times 12 = 10.632$ inches $=$ side of the square required.

The circumference of a circle being 37.7 inches, what is the side of an equal square?

$37.7 \times ,282 = 10.631$ inches, $=$ side of the square required.

When the side of a square is given, to find the diameter of a circle equal to the given square.

RULE. Divide the side of the square by ,886, and the quotient will be the diameter of an equal circle.

EXAMPLE.

What must be the diameter of the aperture of a circular safety valve, to be equal to one measuring an inch square?

$1. \div ,886 = 1.127$ inch, very nearly, answer.

PROBLEM X.

To find the area of a circular Ring, or of the space included between the circumferences of two circles; the one being contained within the other.

RULE. Take the difference between the areas of the two circles, for the area of the Ring.

EXAMPLE.

What is the area of a Ring, the inside diameter being 5, and outside 7?

$$.7854 \times 7^2 = 38.4846$$
$$.7854 \times 5^2 = 19.6350$$

$18.8496 =$ area of ring, or $\frac{7+5}{2} = 6$ medium diameter, then $3.1416 \times 6 \times \frac{7-5}{2} = 18.84$ area, or $7^2 - 5^2 = 24$, then $7854 \times 24 = 18.84$ area.

PROBLEM XI.

To find the area of a Sector of a Circle.—See definitions page 107.

RULE 1. Multiply the radius, or half the diameter, by half the arc of the sector, for the area; or multiply the whole diameter by the whole arc of the sector, and take $\frac{1}{4}$ of the product.

RULE 2. Compute the area of the whole circle: then say, as 360° is to the degrees in the arc of the sector, so is the area of the whole circle, to the area of the sector.

EXAMPLE.

What is the area of the sector of a Circle, the radius A E being 5, and arc A D C 8? See Fig. 5.

Rule 1. $4 \times 5 = 20$ area, or $\frac{8 \times 10}{4} = 20$ area.

Rule 2. 78.5400=area of circle, then 360° : 92° 18′ : : 78.54 : 20 area, (92° 18′ is the portion of the circle contained in arc 8.)

PROBLEM XII.

To find the area of a Segment of a Circle.—See Fig. 5.

RULE 1. Find the area of the sector, having the same arc with the segment, by the 2d rule of last Problem. Find also the area of the triangle, formed by the chord of the segment and the two radii of the sector; then add these together for the answer, when the segment is greater than a semicircle; or subtract them, when it is less than a semicircle.

RULE 2. Divide the height of the segment by the diameter, and find the quotient in the column of heights in the following Table. Take out the corresponding area in the next column on the right hand; and multiply it by the square of the circle's diameter for the area of the segment.

When the quotient is not found exactly in the Table, proportion may be made between the next less and greater area, in the same manner as is done with any other Table.

EXAMPLE.

What is the area of the segment of a Circle, supposing the radius D E to be 10, chord A B C, 12, and arc A D C 73° 74′? Fig. 5.

Rule 1. .7854 × 400 = 314.16 area of whole circle, and 360° : 73° 74′ : : 314.16 : 6434054 area of sector. Half the chord is 6, and $\sqrt{10^2 - 6^2} = 8.$ = B E the height of the triangle.

Rule 2. 10 — 8 = 2 height of the segment. $\frac{2}{20} = .1$ the quotient; and opposite to it, in the right column of the following Table, is .04088, which multiplied by the square of the diameter, is .04088 × 20^2 = 16.352 area, nearly same area as found by Rule 1.

Table of the area of circular Segments.

Height	Area of Segment.	Height.	Area of Segment.	Height.	Area of Segment	Height.	Area of Segment.	Height.	Area of Segment.
.01	,00133	,11	,04701	,21	,11990	,31	,20738	,41	,30319
.02	,00375	,12	,05339	,22	.12811	,32	,21667	,42	,31304
.03	,00687	,13	,06000	,23	,13646	,33	,22603	,43	,32293
.04	,01054	,14	,06683	,24	,14494	,34	,23547	,44	,33284
.05	,01468	,15	,07387	,25	,15354	,35	,24498	,45	,34278
.06	,01924	,16	,08111	,26	,16226	,36	,25455	,46	,35274
.07	,02417	,17	,08853	,27	,17109	,37	,26418	,47	,36272
.08	,02944	,18	,09613	,28	,18002	,38	,27386	,48	,37270
.09	,03502	,19	,10390	,29	,18905	,39	,28359	,49	,38270
.10	,04088	,20	,11182	,30	,19817	,40	,29337	,50	,39270

PROBLEM XIII.

To measure long irregular Figures.

RULE. Take or measure the breadth at both ends, and at several places, at equal distances; then add together all these intermediate breadths, and half the two extremes; which sum multiply by the length, and divide by the number of parts for the area. If the perpendiculars or breadths be not at equal distances, compute all the parts separately, as so many trapezoids, and add them all together for the whole area.

EXAMPLE.

What is the area of an irregular figure, the breadths at equal distances being 8.2, 7.4, 9.2, 10.2, 8.6, and the whole length 39?

8.2
8.6

2) 16 8 sum of the extremes.

8.4 mean of the extremes. $8.4 + 7.4 + 9.2 + 10.2 = 35.2$ sum of the breadths, now $35.2 \times 39 = 1372.8$ which divided by the number of parts $= \frac{1372.8}{4} = 343.2$ area.

PROBLEM XIV.

To find the area of an Ellipsis or Oval.—See Fig. 6.

RULE. Multiply the longest diameter by the shortest; then multiply the product by the decimal .7854, for the area.

EXAMPLE.

What is the area of an Oval, its diameters being 7 and 5?

$7 \times 5 \times .7854 = 27.4890$ area.

PROBLEM XV.

To find the area of an Elliptic Segment.

RULE 1. Find the area of a corresponding circular segment, having the same height, and the same vertical axis or diameter; then say, as the said vertical axis is to the other axis parallel to the segment's base; so is the area of the circular segment before found, to the area of the elliptic segment sought.

RULE 2. Divide the height of the segment by the vertical axis of the ellipse, and find in the Table of circular segments, Prob. 12, the circular segment having the above quotient for its versed sine; then multiply together, this segment and the two axes of the ellipse.

EXAMPLE.

What is the area of an elliptic segment, its height being 2, vertical axis 20, and parallel axis 5?

Rule 1. 20)2 .1 gives $.04088 \times 20^2 = 16.352$ area of circular segment: 20 : 5 :: 16.352 : 4.0880 area of elliptic segment.

Rule 2. 20)2 .1 gives $.04088 \times 5 \times 20 = 4.0880$ area.

PROBLEM XVI.

To find the area of a Parabola, or its Segment. See Fig. 7.

RULE. Multiply the base by the perpendicular height; then take two-thirds of the product for the area.

EXAMPLE.

What is the area of a Parabola, its base being 6, and height 9?

$$6 \times 9 = \frac{54 \times 2}{3} = 36 \text{ area of segment.}$$

PROBLEM XVII.

To find the superficies of a Prism or Cylinder. See Fig 8 and 9.

Rule. Multiply the perimeter* of one end of the Prism, by the length of the solid, and the product will be the surface of all its sides. To which add also the area of the two ends of the Prism, when required.

Or, compute the areas of all the sides and ends separately and add them all together.

EXAMPLE.

What is the superficies of an equilateral triangular Prism, its length being 9, and side 3?

$3 \times 3 = 9$ perimeter, then $9 \times 9 = 81$ superficies, or $3 \times 9 = 27$ area of one side, and $27 \times 3 = 81$ superficies or areas of the 3 sides.

PROBLEM XVIII.

To find the surface of a Pyramid or Cone. See Fig. 11 and 12.

Rule. Multiply the perimeter of the base by the slant height, or length of the side, and half the product will be the surface of the sides, or the sum of the areas of all the triangles which form it. To which add the area of the end or base, if required.

EXAMPLE.

What is the surface of a Pyramid, its slant height being 20, and the perimeter of its base 15?

$$\frac{15 \times 20}{2} = 150 \text{ surface of pyramid.}$$

PROBLEM XIX.

To find the surface of the Frustrum of a Pyramid or Cone, being the lower part, when the top is cut off by a plane parallel to the base, as at a, b, c, *d.* Fig. 11.

Rule. Add together the perimeters of the two ends, and multiply their sum by the slant height, taking half the product for the an-

* The term, perimeter, is applied to the measure of the surfaces of irregular bodies as the term circumference is applied to that of regular circles.

swer,—As is evident, because the sides of the solid are trapezoids, having the opposite sides parallel.

EXAMPLE.

What is the surface of the frustrum of a Cone, the slant height being 12, the diameters 8 and 6?

$$3.1416 \times 8 = 25.13$$
$$3.1416 \times 6 = 18.85$$

43.98 perimeters of both ends,

$43.98 \times 12 = 527.76$, which halved, is 263.88, the surface of frustrum.

RULES

FOR THE MENSURATION OF THE SOLID CONTENTS OF BODIES.

Solids are measured by the cubic inch, foot, yard, &c. (for Table of which, see page 111.)

PROBLEM I.

To find the contents of a Cube. See Fig. 10.

RULE. Multiply the side by itself, and that product by the same side, and this last product will be the solid contents of the cube.

EXAMPLE.

How many cubic inches are there in a cubic foot?

$12 \times 12 \times 12 = 1728$ cubic inches, answer.

PROBLEM II.

To measure a Parallelopipedon, or a Solid having squared sides, but extending in length more than in Breadth and Thickness, as ordinary sticks of timber, &c.

RULE. Find the area of the base or end, then multiply that by the length, and it will give the solid content.

EXAMPLE.

How many feet board measure, does a stick of timber contain, 15 by 12 inches square, and thirty feet, or 360 inches in length.

$15 \times 12 \times 360 = 64800$ cubic inches $\div 144 = 450$ feet board measure, answer.

The most convenient Rule for reducing timber measure to board measure, is as follows.

Divide the area of the end of the piece of timber by 12, which will give the number of feet board measure in each foot of length of the timber, running measure. This product being multiplied by the length, will give the answer required.

How many feet, board measure, is contained in a piece of timber 12 by 12, and ten feet long?

$12 \times 12 = 144 \div 12 = 12$ feet board measure in one foot of the length $\times 10 = 120$ feet, answer.

In a piece of timber 10 × 10 and 20 feet long, how many feet board measure?

ft. in. *ft. in.*
$10 \times 10 = 100 \div 12 = 8.4 \times 20 = 166.8$ Answer.

PROBLEM III.

To find the solid content of any Prism or Cylinder.

Find the area of the base, or end, by Problem 9 if a cylinder, and by Problem 2 if a prism, as the figure of it may be, and multiply it by the length of the Prism or Cylinder, for the solid content.

EXAMPLE.

What is the solid content of a Cylinder, its diameter being 3, and length 7?
$.7854 \times 9 = 7.0686$ area, $7.0686 \times 7 = 49.4802$ solidity.

To find the contents of a Square Cistern in Gallons.

If it be required to find the contents in gallons, divide the product, in cubic inches, by 231 for gallons, wine measure
282 for " beer "
$268\frac{4}{5}$ for " dry "

Multiply the width by the depth and that product by the length, all in inches, and divide the last product by 231, the quotient will be the answer sought, in wine measure.

EXAMPLE.

What number of Wine Gallons will a Cistern 8 feet long, 5 feet wide, and 4 feet deep, contain?

```
feet.
8=96        96
5=60        60
            ----
4=48        5760
              48
            -----
            46080
           23040
           ------
231 )      276480  (1196..214/231 Gals. answer.
           231
           ---
            454
            231
            ----
            2238
            2079
            -----
             1590
             1386
             ----
              214
```

The following Rule will be found both convenient and simple for calculating the capacity of cylindrical cisterns.

Rule *for finding the contents, in Wine Gallons, of circular or Cylindrical Cisterns.*

Square the diameter (in inches) of the cistern, and multiply this sum by the depth, (also in inches) The product being multiplied by 34, and the 4 figures on the right hand being cut off, the answer will be had in gallons, Wine measure.

EXAMPLE.

What is the capacity of a rain water Cistern, 7 feet in diameter, and 6 feet deep?

$7 \times 12 = 84$ inches diameter.
$6 \times 12 = 72$ " deep.

$84 \times 84 \times 72 \times 34 = 1727.3088$, or $1727\frac{3}{10}$ Gallons.

If the Cisterns be tapering, as they usually are,

RULE Multiply the less diameter by the greater, both in inches, and to the *product* add ⅓ of the square of their difference. Multiply this sum by the depth, and the product by 34, cutting off 4 figures on the right hand as in the preceding example. The figures left will give the number of Gallons wine measure.

EXAMPLE.

What is the contents of a circular Cistern, 23 inches diameter at top, and 28 inches at bottom, and 30 inches deep.

```
 23          28
 28          23
----        ----
184           5 difference
 46           5
----        ----
644        3)25 square of the difference.
            ----
  8          8⅓
----
```

652×30×34=66.5040 or 66.½ Gals. answer.

PROBLEM IV.

To find the content of any Pyramid or Cone.—See Fig. 11 and 12.

RULE. Find the area of the base, and multiply that area by the perpendicular height; then take one-third of the product for the content.

EXAMPLE.

What is the content of a Cone, the area of its base being 9, and vertical height 17?

$$17 \times 9 = 153, \frac{153}{3} = 51 \text{ solid content.}$$

PROBLEM V.

To find the solidity of the Frustum of a Cone or Pyramid.

RULE. Add into one sum the areas of the two ends, and the mean proportional between them; and take one-third of that sum for a mean area; which being multiplied by the perpendicular height or length of the frustum, will give its content.

EXAMPLE.

What is the solidity of the frustum of a Cone, the vertical height 19, the areas of its ends being 12 and 9?

12
9
10.5 mean proportional.

3)31.5

$10.5 + 19 = 199.5$ solid content.

PROBLEM VI.

To find the surface of a Sphere, or of any Segment A B C. See Fig. 13.

Rule 1. Multiply the circumference of the Sphere by its diameter, and the product will be the whole surface of it.

Rule 2. Square the diameter, and multiply that square by 3.1416, for the surface.

Rule 3. Square the circumference; then either multiply that square by the decimal 3183, or divide it by 3.1416, for the surface.

Note. For the surface of a Segment or Frustum, multiply the whole circumference of the Sphere by the height of the part required.

EXAMPLE.

What is the superficial content of a Sphere, its diameter being 7?

Rule 1. { Circum. 22 / Diamr. 7 } $22 \times 7 = 154$ superf. cont.

Rule 2. $7^2 \times 3.1416 = 153.9384$ do.

Rule 3. { $22^2 + .3183 = 154.0572$ do.
or $\sqrt{\dfrac{22^2}{3.1416}} = 154.06$ do. }

PROBLEM VII.

To find the solidity of a Sphere or Globe.

Rule 1. Multiply the surface by the diameter, and take 1-6th of the product for the content; or, which is the same thing, multiply the square of the diameter by the circumference, and take 1-6th of the product.

Rule 2. Take the cube of the diameter, and multiply it by the decimal .5236, for the content.

Rule 3. Cube the circumference, and multiply it by .01688, for the content.

EXAMPLE.

What is the solid content of a Globe 7 inches diameter ?

This is the same diameter of the Sphere as in last Example, therefore the surface will be 154 inches.

Rule 1. $\frac{154\times7}{6}=179\frac{4}{6}$ or $\frac{7^2\times22}{6}=179\frac{4}{6}$ cub. cont.

Rule 2. $7^3=343\times.5236=179.5948$ cub. content.

Rule 3. $22^3=10648\times.01688=179.73824$ do.

PROBLEM VIII.

To find the solid content of a Spherical Segment A B C. See Fig. 13.

RULE 1. From 3 times the diameter of the Sphere, take double the height of the Segment; then multiply the remainder by the square of the height, and the product by the decimal .5236, for the content.

RULE 2. To 3 times the square of the radius of the Segment's base, add the square of its height; then multiply the sum by the height, and the product by .5236, for the content.

EXAMPLE.

What is the solid content of a Spherical Segment 2 feet high, taken from a Sphere 8 feet diameter ?

Rule 1. $8\times3=24-2\times2=20\times2^2=80\times.5236=41.888$, content.

RULE 2. The radius of sphere is 4, now $4^2=16$, and from the radius take the height of the segment, $4-2=2$, which $2^2=4$, therefore $16-4=12$ square of the radius of Segment's base.

$$\overline{12\times3+2^2}\times2\times.5236=41.888 \text{ content.}$$

TABLE

OF SQUARE AND CUBE ROOTS OF WHOLE NUMBERS AND FRACTIONAL PARTS.

IN various calculations, depending upon the Square and Cube Roots of Numbers, the following table will be found to afford much practical facility. Many persons are deterred from making these calculations, however necessary to their immediate purposes, from ignorance of the mode of accomplishing them, or more commonly from aversion to the labor of extracting these Roots.

For preparing the fractional numbers of the Table I am indebted to Mr. DANIEL SHELDON, of Providence, R. I. whose mathematical acquirements need only to be known to be more generally acknowledged.

TABLE

OF SQUARE AND CUBE ROOTS OF WHOLE NUMBERS, AND FRACTIONAL PARTS.

Number	√ Square Root.	∛ Cube Root	Number	√ Square Root.	∛ Cube Root	Number	√ Square Root	∛ Cube Root	Number	√ Square Root	∛ Cube Root
1.	1.000	1.000	14.25	3.775	2,424	35	5,916	3,271	88	9,380	4,447
1.25	1.118	1.077	14.50	3.808	2,438	36	6,000	3,301	89	9,433	4,464
1.50	1.224	1.144	14.75	3.840	2,452	37	6,082	3,332	90	9,486	4,481
1.75	1.323	1.205	15.	3.873	2,466	38	6.164	3,361	91	9,539	4,497
2.	1.414	1.260	15.25	3.905	2,480	39	6,244	3,391	92	9,591	4,514
2.25	1.500	1.310	15.50	3.937	2,493	40	6,324	3,419	93	9,643	4,530
2.50	1.581	1 357	15.75	3 968	2,506	41	6,403	3,448	94	9,695	4,546
2.75	1.658	1.401	16.	4.000	2,520	42	6,480	3,476	95	9,746	4,562
3.	1.732	1.442	16.25	4.031	2,533	43	6,557	3,503	96	9,797	4,578
3.25	1.803	1.481	16.50	4,062	2,546	44	6,633	3,530	97	9,848	4,594
3.50	1.871	1.518	16.75	4.092	2,558	45	6,708	3,556	98	9,899	4,610
3.75	1.936	1.554	17.	4.123	2,571	46	6,782	3,583	99	9,949	4,626
4.	2.000	1.587	17.25	4.153	2,584	47	6,855	3,608	100	10,000	4,641
4.25	2 061	1.620	17.50	4.183	2,596	48	6,928	3,634	101	10,049	4,657
4.50	2.121	1.651	17.75	4.213	2,608	49	7,000	3,659	102	10,099	4,672
4.75	2.179	1.681	18.	4.242	2,621	50	7,071	3,684	103	10,148	4,687
5.	2.236	1.710	18.25	4.272	2,633	51	7,141	3,708	104	10,198	4,702
5.25	2.291	1.738	18.50	4 301	2,645	52	7,211	3,732	105	10,246	4,717
5.50	2.345	1.765	18.75	4.330	2,656	53	7,280	3,756	106	10,295	4,732
5.75	2.398	1.791	19.	4.359	2,668	54	7,348	3,779	107	10,344	4,747
6.	2.449	1.817	19.25	4.387	2,680	55	7,416	3,802	108	10,392	4,762
6.25	2.500	1.842	19.50	4.416	2,692	56	7,483	3,825	109	10,440	4,776
6.50	2.549	1.866	19.75	4,444	2,703	57	7,549	3,848	110	10,488	4,791
6.75	2 598	1.890	20.	4.472	2,714	58	7,615	3,870	111	10,535	4,805
7.	2.646	1.913	20.25	4.500	2,725	59	7,681	3,892	112	10,583	4,820
7.25	2.692	1 935	20.50	4.527	2,737	60	7,745	3,914	113	10,630	4,834
7.50	2.739	1.957	20.75	4.555	2,748	61	7,810	3,936	114	10,677	4,884
7.75	2.784	1.979	21.	4.582	2,759	62	7,874	3,957	115	10,723	4,862
8.	2.828	2.000	21.25	4.610	2,769	63	7,937	3,979	116	10,770	4,876
8.25	2.872	2.021	21 50	4.637	2,781	64	8,000	4,000	117	10,816	4,890
8.50	2.915	2.041	21.75	4.663	2,791	65	8,062	4,020	118	10,862	4,904
8.75	2.958	2.061	22.	4.690	2,802	66	8,124	4,041	119	10,908	4,918
9.	3.000	2.080	22.25	4.717	2,813	67	8,185	4,061	120	10,954	4,932
9.25	3.041	2.099	22.50	4.743	2,823	68	8,246	4,081	121	11,000	4,946
9.50	3.082	2.118	22 75	4.769	2,833	69	8,306	4,101	122	11,045	4,959
9.75	3.122	2.136	23.	4.796	2,844	70	8,366	4,121	123	11,090	4,973
10.	3 162	2.154	23.25	4.822	2,854	71	8,426	4,140	124	11,135	4,986
10.25	3.201	2.172	23.50	4.848	2,864	72	8,485	4,160	125	11,180	5,000
10.50	3.240	2.190	23.75	4.873	2,874	73	8,544	4,179	126	11,224	5,013
10.75	3.279	2.207	24.	4.899	2,884	74	8,602	4.198	127	11,269	5,026
11.	3.316	2 224	24.25	4.924	2,894	75	8,660	4,217	128	11,313	5,039
11.25	3.354	2.241	24 50	4.949	2,904	76	8,717	4,235	129	11,357	5,052
11.50	3 391	2.257	24.75	4.975	2,914	77	8,774	4,254	130	11,401	5,065
11.75	3.428	2.273	25	5.000	2,924	78	8,831	4,272	131	11,445	5,078
12.	3 464	2.289	26	5.099	2,964	79	8,888	4,290	132	11,489	5.091
12.25	3.500	2.305	27	5.196	3,000	80	8,944	4,308	133	11,532	5,104
12.50	3.535	2.321	28	5.291	3,036	81	9,000	4,326	134	11,575	5,117
12.75	3.571	2.336	29	5.385	3,072	82	9,055	4,344	135	11,618	5,129
13.	3.605	2.351	30	5.477	3,107	83	9,110	4,362	136	11,661	5,142
13.25	3 640	2.366	31	5,567	3,141	84	9,165	4,379	137	11,704	5,155
13.50	3.674	2.381	32	5.656	3,174	85	9,219	4,396	138	11,747	5,167
13.75	3.708	2.396	33	5.744	3,207	86	9,273	4,414	139	11,789	5,180
14.	3.741	2.410	34	5.830	3,239	87	9,327	4,431	140	11,832	5,192

Number	Square Root	Cube Root	Number	Square Root	Cube Root	Number	Square Root	Cube Root	Number	Square Root	Cube Root
141	11,874	5,204	201	14,177	5,857	261	16,155	6,390	321	17.916	6.847
142	11,916	5,217	202	14,212	5,867	262	16,186	6,398	322	17,944	6,854
143	11,958	5,229	203	14,247	5,877	263	16,217	6,406	323	17,972	6,861
144	12,000	5,241	204	14,282	5,886	264	16,24	6,415	324	18,000	6,868
145	12,041	5,253	205	14,317	5,896	265	16,278	6,423	325	18,027	6,875
146	12,083	5,265	206	14,352	5,905	266	16,309	6,431	326	18,055	6,882
147	12,124	5,277	207	14,387	5,915	267	16,340	6,439	327	18,083	6,889
148	12,165	5,289	208	14,422	5,924	268	16,370	6,447	327	18,110	6,896
149	12,206	5,301	209	14,456	5,934	269	16,40	6,455	329	18,138	6.908
150	12,247	5,313	210	14,491	5,943	270	16,431	6,463	330	18,165	6,910
151	12,288	5,325	211	14,525	5,953	271	16,462	6,471	331	18.193	6,917
152	12,328	5,336	212	14,560	5,962	272	16,492	6,479	332	18,220	6,924
153	12,369	5,348	213	14,594	5,972	273	16,522	6,487	333	18,248	6,931
154	12,409	5,360	214	14,628	5,981	274	16,552	6,495	334	18,275	6,938
155	12,449	5,371	215	14,662	5,990	275	16,583	6,502	335	18,303	6,945
156	12,489	5,383	216	14,696	6,000	276	16,613	6,510	336	18,330	6,952
157	12,529	5.394	217	14,730	6,009	277	16,643	6,518	335	18,303	6,945
158	12,569	5,406	218	14,764	6,018	278	16,673	6,526	336	18,380	6,952
159	12,609	5,417	219	14,798	6,027	279	16,703	6,534	340	18,439	6,979
160	11,649	5,428	220	14,832	6,036	280	16,733	6,542	341	18,466	6,986
161	12,688	5,440	221	14,866	6,045	281	16,763	6,549	342	18,493	6,993
162	12,727	6,451	222	14,899	6,055	282	16,792	6,557	343	18,520	7,000
163	12,767	5,462	223	14,933	6,064	283	16,822	6,565	344	18,547	7,006
164	12,806	5,473	224	14,966	6,073	284	16,852	6,573	345	18,574	7,012
165	12,845	5,484	225	15,000	6,082	285	16,881	6,580	350	18,708	7,047
166	12,884	5,495	226	15,033	6,091	286	16,91	5,588	355	18,841	7,080
167	12,922	5,506	227	15,066	6,100	287	16,941	6,596	36	18.973	7,113
168	12,961	5,517	228	15,099	6,109	288	16,970	6,603	365	19,104	7,146
169	13,000	5,528	229	15,132	6,118	289	17,000	6,611	370	19,235	7,179
170	13,038	5,539	230	15,165	6,126	290	17,029	6,6 9	375	19,364	7,211
171	13,076	5,550	231	15,198	6,135	291	17,058	6,626	380	19,493	7,248
172	13,114	5,562	232	15,231	6,144	29	17,088	6,635	285	19,621	7,274
173	13,152	5,572	233	15,264	6,153	293	17,117	5,64	390	19.748	7,306
174	13,190	5,583	234	15,297	6,162	94	17, 46	6,649	395	19,874	7,337
175	13,228	5,593	235	15,329	6,171	95	17,175	6,656	400	20.000	7,368
176	13,266	5,604	236	15,362	6,179	296	17,204	6,664	405	20,124	7,398
177	13,304	5,615	237	15,394	6,188	297	17,233	9,671	410	20,248	7,428
178	13,341	5,625	238	15,427	6,197	298	17,262	6,679	415	20,371	7,459
179	13,379	5,635	239	15,459	6,205	299	17,29	6,686	420	20,493	7,486
180	13,416	5,646	240	15,491	6,214	300	17,320	6,694	425	20,615	7.518
181	13,453	5,656	241	15,524	6,223	301	17,349	6,701	430	20,736	7,547
182	13,490	5,667	242	15,556	6,231	30	17,378	6,709	435	20.856	7,576
183	13,527	5,677	243	15,588	6,240	303	17,406	6,716	440	20,976	7,605
184	13,564	5,688	244	15,620	6,248	304	17,435	6,722	445	21,095	7,634
185	13,601	5,698	245	15'652	6,257	305	17,464	6,731	450	21,213	7,663
186	13,638	5,708	246	15,684	6,265	306	17,492	6,738	455	21,330	7,691
187	13,674	5,718	247	15,716	6,274	307	16,52	6,745	460	21,447	7,719
188	13,711	5,728	248	15,748	6,282	308	17,549	6,753	465	21,563	7,747
189	13,747	5,738	249	15,779	6,291	309	17,578	6,760	470	21,679	7,774
190	13,784	5,748	250	15,811	6,299	310	17,606	5,767	475	21,794	7,802
191	13,820	5.758	251	15,842	6,307	311	17,635	6,775	480	21,908	7,829
192	13,856	5,768	252	15,874	6,316	312	17,663	6,782	485	22,022	7,856
193	13,892	5.778	253	15,905	6,324	313	17,69	6 789	490	22,135	7,883
194	13,928	5,788	254	15,937	6,333	314	17,720	6,796	495	22,248	7,910
195	13,964	5,798	255	15,968	6,341	315	17,748	6.804	500	22,360	7,937
196	14,000	5,808	256	16,000	6,349	316	17,776	6.811			
197	14,035	5,818	257	16,031	6,357	317	17,804	6-818			
198	14,071	5,828	258	16,062	6,366	318	17,832	6.825			
199	14,106	5,838	259	16,093	6,374	3 9	17,860	6.832			
200	14,142	5,848	260	16,124	6,382	320	17,888	6.839			

CHAPTER II.

FRICTION.

What has been premised relates to matter as forming the component parts of machines, as well as the subject of their action. A sketch of the effects of the principal natural Agents or Powers upon material substances, has also been given, and of the various Terms and Rules by which the forms, solidity, &c. of such substances are calculated. Before proceeding to the subjects of Motion and Power, upon which the Science of Mechanics is principally founded, we shall make a few observations upon Friction, that the Mechanician may be enabled to form estimates of the resistance to the motion of his machines, as well as of their strength, and of the various causes already pointed out, whereby the theory of their motion and equilibrium may be caused to give different results from those obtainable in practice.

A resistance to motion, and consequently loss of power, always takes place when solid substances come in contact with each other. This, it is obvious, must always be the case in the operation of machines. However smooth the surfaces of bodies may ordinarily appear, yet when examined more minutely, they present to view numerous rugged protuberances. By means of the solar microscope, the most delicately polished needle exhibits as rough an appearance as the bark of a tree, viewed by the naked eye. It has been before stated, while treating of crystallization, that the metals, and almost every other solid substance not under the influence of vegetable or animal life, are subject to a peculiar orderly arrangement of their component atoms, in the form of cubes, prisms, and other figures, all of which have sharp angular corners or edges. Vegetable substances are full of cavities or pores which form the sap vessels. When therefore the surfaces of these substances are in contact, they cannot slide or slip over each other, unless the power applied be sufficient to cause these angular points to be broken away, or the weight of the body to mount over them. After this has been once effected, a succession of angular protuberances will still remain, and oppose fresh obstacles to the motion of one body over the surface of another. Thus Friction has been found to be a *uniformly retarding force*, and as such must be taken into consideration in all calculations relating to the operation of machinery. There are certain vegetable and animal substances which from the spherical or other peculiar formation of their component particles offer but little resistance to solid bodies in passing over them, such as vegetable oils, fat, &c. By filling the cavities of solid bodies with these substances *friction* becomes materially diminished. The particles of fluid substances are supposed to be perfectly globular, and were it possible to cause the pivots or bearings of machines to rest upon fluids, the resistance from friction would be exceedingly diminished.

From numerous experiments made by Vince, Coulomb and others, it appears that the friction of bodies is not in proportion to the surfaces exposed. A solid body in the form of a common brick has been found to slide over a plane surface with the same degree of friction, whether placed upon its edge or flat side. Euler found the ratio of friction and the force of pressure on plane surfaces to be as 1 to 4;—that is, that the retarding power or resistance of friction, where one plane surface of wood passes over another, is equal to about $\frac{1}{4}$ of the weight; but that after the body is put in motion only one quarter of this friction, equal to $\frac{1}{8}$ of the weight, takes place. Fresh tallow diminishes friction one half on commencing motion, and to a much greater extent after motion is commenced. Where the arbors of shafts are well polished, and turn upon brass boxes properly oiled, the friction is diminished to $\frac{1}{30}$ or even $\frac{1}{40}$ of the pressure of the weight resting upon them. Coulomb found, by means of numerous experiments made upon *Rolling Cylinders*, that the resistance from friction on the same cylinder is proportional to the pressure, and that on rolling cylinders formed of the same substance, but of different diameters, the pressure being equal, the friction is inversely as the diameters;—that is, upon a cylinder measuring 3 inches diameter, and upon another measuring 6 inches diameter, subjected to the same pressure, the power required to overcome the friction and to roll the 3 inch cylinder would be found to be greater than that required to roll the 6 inch cylinder, in the proportion of 6 to 3. The experiments of the actual loss of power by friction of rolling bodies are few and unsatisfactory. The comparative loss of power that takes place from the friction of *sliding*, *revolving*, and *rolling* bodies, it has been stated, is as follows:

	per cent.
When the friction of a sliding body is equal to $\frac{1}{4}$ of the pressure, or	25
That of the revolving body is about - - - - -	15
" " rolling body " - - - - -	5

Large wheels are found to make the motion of a wagon more easy for a horse. A limit is assigned in practice for the size of carriage wheels, which is, that the axle should not be above the level of the draught, or breast of the horse.

In order to diminish friction it should be adopted as a general rule never to allow two substances of the same specific hardness to revolve one upon the other. The only exception to this rule is cast steel, which forms both excellent gudgeons or journals, and pillows to receive them. It has been found that the greater the difference in point of hardness between the metals which come in contact with each other, as journals, gudgeons, and their pillows, the less will be the abrasion from friction. It is for this reason that diamonds, the hardest of gems, are selected by watch-makers for the steps of the pivots of their wheel work. For light lathes, steel arbors are found to run upon leaden pillows with very little abrasion or loss of power from friction. In case however of neglect of oiling the parts, the lead soon becomes converted into a yellow oxide from the heat produced. In a cotton mill in Rhode-Island a light shaft revolving 150 times per minute has run for seven years upon a piece af thick sheet lead, supported by wood, without wearing away the lead, or the journal of the shaft. Lead however is an unsuitable material where there is weight or pressure to be sustained. In such cases, brass and pewter are commonly used. Of all materials for pillows or bushes, cast steel seems to have the preference.

The best composition for diminishing friction is the common soap stone, or *steatite*, reduced to powder, and mixed with oil. One part of black lead to 3 parts of lard forms also a good antiattrition compound.

It appears from various experiments, that the loss of power by friction of hard surfaces is in proportion to the weights or pressure of the bodies, rather than to the velocity with which they move. By increasing the velocity of revolving shafts a corresponding increase of friction does not take place. Mr. Roberts, of Manchester, found, by means of a machine contrived with much ingenuity expressly for the purpose of measuring the effect of the resistance of friction in retarding the motion of rolling bodies, that the resistance on an iron rail road *is the same for all velocities*. Agreeably to the result of his experiments, a steam carriage on a rail road would meet with no more resistance from friction in travelling a given distance, whether it moved at the rate of five or fifteen miles per hour. "A carriage may be propelled 20 miles in one hour with the same amount of force which would be necessary to propel it 20 miles in ten hours, provided the resistance of the atmosphere was out of the question. In other words, goods might be conveyed from Manchester to Liverpool, on a rail road, with very near the same expenditure of steam, whether they were carried two miles, or twenty miles an hour. A steam engine, which will propel twenty tons at 4 miles an hour, will, with the same expense of coals, propel ten tons at 8 miles an hour; so that, with the smaller load, it may make a journey to Liverpool and back, in the same time which would be occupied in going thither with the heavier load. There will be the same expenditure of steam in both cases, but, in the latter, a saving of half the time, which will frequently be of immense importance." Hence an interesting comparison has been drawn between the loss of power by friction upon rail roads, and by the resistance of water to the passage of boats

The resistance of water to the motion of a boat, it is stated, increases regularly in the ratio of the square of its velocity. This holds in some degree true where roads are composed of loose sandy soil, which is displaced before the wheels as they progress. The resistance to be overcome upon the ordinary roads in the United States will exceed ten fold of that to be overcome on a railroad. It is not so much the friction of the water upon the sides of a vessel that impedes her motion, as the actual displacing of a volume of water equal in weight to that of the vessel and cargo. Some late authors estimate the resistance of water to be nearly as the medium between the square and cube of the velocity of the body moving through it. Supposing the resistance of water to the motion of a boat to increase as the squares of the velocity, to augment the velocity from 4 to 8 miles per hour would require four times the power, and to augment it from 4 to 12 miles per hour, would requre nine times the power.

The following table, by a late English author, gives an interesting comparative statement of the relative loss of power produced by the friction of the wheels of a carriage upon a rail road, and by the resistance of water to the motion of a canal boat.

"We have found that a boat weighing with its load 15 *tons*, and a *wagon* of the *same weight*, the one on a canal, and the other on a rail way, would be impelled at the following rates by the following quantities of power, which are stated both in pounds and horse power—reckoning one horse power equal to 180 lbs.

	Boat on a Canal.		*Wagon on a Railway.*	
Miles per hour.	Power in lbs.	Horse power.	Power in lbs.	Horse power.
2	33	$\frac{1}{5}$	100	$\frac{1}{2}$
4	133	$\frac{2}{3}$	102	$\frac{1}{2}$
6	300	$1\frac{3}{4}$	105	$\frac{1}{2}$
8	533	3	109	$\frac{1}{2}$
12	1.200	7	120	$\frac{2}{3}$
16	2.133	12	137	$\frac{3}{4}$
20	3 325	18	158	1

It will be observed from the above table that it would require 7 horse power to impel a steam boat weighing 15 tons at the rate of 12 miles an hour. This gives a load of 2 tons to the horse power. The engine, if a low pressure one, with water and coals sufficient for 8 hours, would weigh nearly 10 tons, and the vessel would weigh at least 5; so that the whole power of the engine would be expended in impelling itself and the vessel, containing it at the same rate, and no *free power* would remain for freight without diminishing its velocity. Indeed in common steam vessels for passengers, going only eight or nine miles an hour, the vessel and engine may be considered as constituting the whole burden. Fifty passengers, weighing perhaps with their baggage, six or eight tons, form but a small portion of the comparative weight of a steam boat of 70 horse power, which, with the steam engine, boilers and fuel, must weigh at least 160 or 180 tons." It thus appears that a power of 70 horses is actually required in many steam boats to transport only 8 or 10 tons—the ordinary weight of fifty passengers considered as their freight, with the velocity of 9 miles per hour. The friction on a railway is so trifling that not one tenth of this power would be required to produce an equal effect. To attain the velocity of thirteen or fourteen miles per hour, being the rate at which some of the modern American steam boats move through still water, the power of the steam engines are increased to the surprising force of above 10 horses for each ton they transport, estimating the weight of the passengers and their luggage as the freight. It is impracticable to construct light boats to sustain advantageously the stress produced by the reciprocating movements of the internal machinery, which usually proves more destructive to the strength of this description of vessels than the violence of the elements which they are destined to encounter.

From what has been premised, it appears that there are two kinds of friction, one of which takes place when the bodies have simply a sliding motion; the other when one or both the bodies move by turning an axis. The peculiar movement of skates and sledges exhibits an instance of the former motion, and that of the wheels of carriages, of the latter. Of all natural solid bodies ice seems to occasion the least friction In Russia, ice boats are propelled by the force of a moderate breeze upon their sails with the surprising velocity of 30 miles per hour.

In the construction of machinery it is desirable that the parts coming in contact with each other should have a *rolling motion*, by which means the parts are disengaged without breaking down the eminences, or sliding over them. In the latter case the wear of the parts is generally in the ratio of the loss of power from the friction.

When one solid body is prevented rising, so as to slide over the minute irregularities of the surface of another body, the friction becomes intense, and great heat is produced.

When solid substances of different kinds are made to slide upon each other, although smeared with some unctious substance, a certain time is required in order that the friction may attain its maximum, the abraded particles becoming mixed with the tallow, and presenting rough points or angles. A singular effect attends the friction of two exquisitely polished surfaces upon each other, the resistance being increased in this case from a cohesion of the parts, which seems to take place under these circumstances.

The resistance of the atmosphere to the motion of all machines or bodies must necessarily vary greatly, according to the extent of surfaces exposed to the reaction of it, and the velocities of the moving bodies, or the currents of wind, &c.

Friction Wheels, are sometimes used to diminish the friction of the gudgeons of revolving shafts. This contrivance, however, is rarely applied to ordinary machinery, as these wheels occupy the room required for other working parts of the machine, and do not hold the gudgeon as firm as when resting on the pillow; while at the same time they are more liable to get out of order. In one instance in England, I observed friction rollers applied to the gudgeons of a heavy cast iron water wheel, to relieve the friction, and to prevent the consequent loss of power.

In establishing the Equilibrium of bodies, or when it is desired to counteract the effect of forces, friction is a positive advantage, as it in this case assists the power.

There are some few practical advantages arising from the resistance to motion produced by Friction, to compensate, in part, for the numerous mechanical disadvantages resulting from it. It is commonly resorted to for regulating the velocity of heavy bodies in descending inclined planes, that such bodies may not be dashed to pieces by a sudden shock at the termination of their descent. In transferring bricks from a wharf to the hold of a vessel, the friction upon an inclined plane, readily formed by means of a sloping board, will cause them to descend with any desired moderate velocity, according to the angle or inclination of the plane. Boxes, bags of grain, or other solid substances, may with dispatch be transferred in the same manner.

To prevent heavily laden carriages from pressing upon the horses in descending steep hills, an iron shoe, connected by a chain to the body of the carriage, is placed beneath the wheel to prevent it from turning on the axle. A very considerable friction is thus caused to take place upon the surface of the road, the wheel being made to slide over it. Nearly the same expedient has been resorted to in some instances in England, to retard the descent of wagons upon the inclined planes of rail roads, where stationary engines are not employed.

A very ingenious contrivance has been adopted to regulate the velocity of the descent of coal wagons upon one of the rail roads in Pennsylvania. A light piston rod, fitted to work air-tight within a small cylinder, is connected by a crank to the axle of the wagon. The piston being caused to work within this air-tight cylinder by the revolution of the axle fixed to the wheels, a partial vacuum is formed at each stroke upon one side of the piston, while at the same moment the confined air upon the other side of it, from its compression, opposes a considerable resistance. By opening and closing the stop cocks the admission and escape of the air from the chambers of the cylinder may be regulated at pleasure, and, consequently, the resistance opposed to the motion of the piston within the cylinder. The same results may be observed on a large scale when the valves of a steam engine are suddenly closed. The vacuum upon one side of the piston retains it with great force from ascending, while the pressure of the uncondensed steam opposes an equal or greater reaction upon the other side of it. It is in this way that the vast momentum of the large balance wheels, and of all the revolving shafts, and other wheels connected with them, are almost instantaneously stopped without producing a sudden shock upon the machinery,—a result that could not probably be accomplished so speedily in any other way.

The rifle ball owes its fatal precision of motion to the friction which takes place in the spirally grooved barrel, into which it is closely fitted by means of a piece of elastic leather or cloth. The friction of the spiral grooves within the barrel causes a rapid rotatory motion of the bullet when it leaves the muzzle, and should there happen to be any inequality upon its surface, that might cause it to diverge from a right line, this peculiar motion counteracts the effect of it. Every side is presented equally to the reaction of the air by means of the rotatory motion, and consequently no aberration will be produced. It is from the rotatory motion which a cannon ball acquires, in consequence of its friction against the bottom of the bore at the moment of discharge, that it seems to recover new force on striking the ground, rebounding from it often with destructive violence when its motion has apparently almost ceased. In this case the lower portion of the ball, having a rotatory motion in a direction opposite to the progressive motion, produces an acceleration in the motion of its centre, that is, of the progressive motion The remarkable perpendicular position which a top assumes when turning is also attributed to the friction that takes place on its pivot.

The loss of power, or the difference between the theoretical and practical results obtainable from the Mechanical Powers, may be estimated as follows.

On the simple Lever the resistance of friction is very small when the fulcrum is nicely adjusted to a steel edge, like that of a knife.

The Wheel and Axle, operating upon the same principles as the Lever, occasions inconsiderable friction. The stiffness of the cordage, however, and the friction of the gudgeons of the axis have an effect in most cases equal to about 8 or 10 per cent of the theoretical estimate.

The Pulley is attended with very considerable friction from the rigidity of cordage, and the friction of the small wheels or pulleys inclosed in the *blocks*. Under the most favorable circumstances it is rarely less than twenty per cent, and often exceeds fifty or sixty per cent of the power calculated upon, particularly where tarred cordage is employed.

Inclined Plane. When rolling bodies are made to ascend upon inclined planes without resorting to axles, the resistance of friction, for the reasons before stated, is inconsiderable When heavy bodies, however, are made to rest upon the axis of the rolling bodies, as upon the wheels of a carriage, the resistance of friction in ascending inclined planes takes place, in the same manner as upon plane surfaces. This is, indeed, almost the only mode by which the inclined plane is advantageously employed for raising heavy weights Marine railways are inclined planes, formed of cast iron, upon which heavy ships are raised while resting upon numerous small wheels. The immediate action of sliding bodies is too great to render this Mechanical Power generally available, in this way, in practice.

The Screw and Wedge operate upon principles precisely the same as those which relate to the Inclined Plane. About one third of the power, which is given in theory to the operation of the screw must be deducted, in order to arrive at the result which may be expected from the practical application of this Power. The friction is diminished when the thread of the screw is cut square. Wooden screws operate with much more friction than those formed of iron and steel, and in some cases not above one third of the theoretical effect is actually available, the remainder being lost in overcoming the resistance of friction.

It has been found difficult to form regular computations of the effective results obtainable from the use of the Wedge, both on account of the opening of the fissure, which generally extends into the body riven by its agency, thereby giving to each of the sides of the rift the effect of levers. The quantity of the force usually applied to a wedge is not so readily estimated as that which is applied to the other mechanical Powers, the wedge being generally driven by the momentum imparted by sudden blows from heavy bodies.

POWER.

Motion being consequent upon the exertion or action of forces, it seems proper first to consider some of the principal First Movers, or Mechanical Agents, placed by Nature under the control of man, who is enabled to employ them usefully for imparting motion and efficacy to machinery, or the various modifications of the mechanical powers.

Power and Force being terms of frequent occurrence, the definitions of them should be fixed with precision.

The powers by which a machine is put in motion, and by which that motion is kept up, are called *first movers*, or *moving powers*, or more familiarly, mechanical agents; and when various moving powers are applied to the same machine, the *resultant* of them, or the equivalent force, is called the moving force.

In explaining the operations of machines recourse is had to weights as forming intelligible standards both of the quantity of the force or moving power, and of the resistance to be overcome. The number of pounds which represent the moving force, is generally called the *Power*, and the number which represents the resistance, is called the *Weight*. In this way the various modes of applying a certain amount or quantity of power for moving the weight may be easily comprehended and calculated. Thus if 10 lbs. be placed upon the long end of the lever to raise 100 lbs. placed upon the short end of it, the lesser weight is the *power*, and the greater the *weight*. By the term Power is therefore understood the moving force, whatever it may be, and by the term Weight, the resistance to be overcome. In practical mechanics, power is the general term for that which causes motion or rest.

All the Natural Moving Powers applicable to the useful arts seem to be produced by the destruction of the state of equilibrium in which bodies remain at rest under the action of the forces of gravitation and cohesion. The power in these cases is not attributable directly to the effect of gravitation or of cohesion, but to the cause that in the first instance interrupts the state of rest in which bodies would otherwise remain undisturbed on the surface of the earth. Thus Water Power may be considered as originating from the heat of the sun that causes the water to expand into vapour, and to ascend, notwithstanding the effect of gravitation, and to assume a new station in the form of clouds. On parting with the heat these vapours lose the elastic form, and obey the impulse of gravitation, descending in rain, and returning in the channels of the rivers to the level of the ocean.

The motion of the winds is attributable to the solar heat, which rarifies various portions of the atmosphere, whereby ascending currents are produced in one place, while the adjacent colder air rushes horizontally to occupy the place of the ascending heated air.

Steam power in like manner is attributable to the heat which disturbs the state of rest in which water exists under the ordinary action of gravitation and cohesion. The particles of the water are caused to separate from each other, and to expand into an elastic vapour, which occupies 1800 times the original bulk of the water. This great increase of the volume of water produces an immediate elastic force pressing against the piston of a steam engine, or against any other object opposed to its action. It is also capable of displacing the portion of the atmosphere beneath the piston of a steam engine, forming the most ready mode by which a vacuum can be produced. The atmosphere, it is well known, exerts upon every body on the surface of the earth a pressure equal to that which such body would sustain if immersed about 33 feet beneath the surface of the sea, provided this experiment could be resorted to where no atmospheric pressure exists; in that case the water would press upon every surface exposed to it with a force equal to about 15 lbs. on each square inch. In the application of steam power, advantage is taken both of its elastic expansible force, as well as of the vacuum formed by the condensation of it. Heat under various modifications thus seems to be the original cause of Wind, Water, and Steam power. The various facts attending the formation and existence of the latter Power has been given at page 70, under the title Steam. The application of steam power will be considered in treating of the Steam Engine; and the application of the Power of Water, and of Wind, will also be considered more at large in the chapter upon Hydrodynamics and Pneumatics.

Various bodies, such as gun-powder, the gases, &c. are caused by the operation of Heat or chemical action, to expand with great violence, and to produce a vast available power. The power produced in this way is not, however, commonly used as a first mover for mechanical purposes.

The action of the force of gravitation after being daily counteracted by the attraction of the heavenly bodies, affords also a great natural power available by human ingenuity, by means of tide mills;—a power which must be vast indeed to raise such immense masses of water twice a day by the heaving undulations of the great oceans and seas.

A display of a small degree of power is observable in the operation or effects of electricity, galvanism, and magnetism. When the electric fluid escapes from the points of wires inclined in one direction at right angles with the arms of light wheels, delicately balanced on a centre, and placed on the excited conductor of an electrical machine, these light wheels will commence revolving with great rapidity. Having formed a machine of thin paper in the shape of a wind mill, I inserted these reversed points at right angles with the extremities of the arms, and found they would revolve as if affected by a breeze of wind, whenever connected with the electrical apparatus. The electric fluid, on escaping from the points of the wires and diverging into the air, meets with resistance from it, and each point is made to recoil. A motion is thus produced like that of the wheels exhibited in fire-works. The force with which the electric fluid acts in turning the wheel may afford some datum for calculating its momentum, and seems to be the strongest argument in favor of its materiality, as the mechanical action and reaction must in this case be equal.

The direct action or power of electricity, however, immediately ceases with the experiment, and the Galvanic fluid will continue to act only two or three years, without cessation, from the same plates.

A trifling but very remarkable degree of power is possessed by several species of vegetables, which display apparently a degree of sensibility, and sufficient powers of contraction, it is stated, in some cases to crush the flies that intrude into their blossoms.

The action of elastic Springs appears to be erroneously classed among the moving powers, or mechanical agents. A Spring has rather a tendency to react, than to produce original action, serving as a reservoir of the power applied to it, like the Balance wheel, to act after the moving power has ceased or is withdrawn. A spring being mere matter, it is evident, cannot bend itself, or give any of its parts motion when left undisturbed.

Animal Power.

Animal Power, or the moving power of animated beings, is a distinct source of motion dependant for its origin on none of the above laws. Athough the frames, and the muscles and tendons of animals, are all contrived with consummate skill upon the most perfect plans, with an unerring knowledge of mechanical powers, as machines to operate by levers and pulleys, yet this combination of animal mechanism, "so fearfully and wonderfully made," does not appear to be of itself the source of motion Like all other machines, it is the passive instrument of mechanical action, for in sleep and in death animal bodies lose their moving power. In what point of the body this moving power resides has not with certainty been ascertained, nor the mode of its action upon animal matter. Here it must be supposed that a mysterious connection takes place between matter and mind, or a certain intelligent power having no material essence. This moving power is familiarly known under the term, volition, the action of which upon matter transcends our comprehension. The power that first gives the impulse, causing the muscle to contract, is capable of receiving no direct reaction from it. Here the great principle of mechanics fails, for there is action upon the mass of muscles, and resistance, and yet action and reaction are not equal.

The effect of galvanism upon animal muscle has been supposed by some to resemble that of volition.

Volition thus seems to have command over matter, so far as portions of it can be controlled or moved by animal agency, as if it were a "divinity that stirs within us." The material arm first obeys the impulse of immaterial volition, and is directed in its motions by an intelligence that supersedes the common or natural causes of motion. It directs, with a knowledge of consequences, the action of matter upon matter, whereby the vast effects are produced observable in the construction of the massy pyramids, or in the formation of the artificial mole that stretches like some natural promontory into the sea. The powerful steam engine is produced to lend its aid, like the genius of eastern romance, to accomplish the will of the invisible magician that called it forth, drawing with facility loads that cause the ground to tremble with their weight, and buffetting and overcoming even the fury of the winds and waves.

STANDARDS FOR CALCULATING POWER.

The standard for calculating the power applied to machines has been most naturally derived from a reference to the power of a horse for ordinary labor. The *actual power* of a common horse, from an average of a great number of experiments of the working strength of this animal, has been estimated to be equal to raising 352 cubic feet of water, or 22,000 lbs. one foot high in a minute, working 8 hours per day, and moving at the rate of $2\frac{1}{2}$ miles per hour; or the same result is obtained by supposing a horse to be able to travel for 8 hours every day at the rate of $2\frac{1}{2}$ miles an hour, or 220 feet per minute, and during this time to raise a weight of 100 lbs. suspended over a pulley. In order, however, to prevent disappointments in the effective power calculated upon by purchasers of steam engines, Boulton & Watt adopted a much higher standard, equal to *fifty per cent. more than the actual power of an ordinary horse.*

Messrs. Boulton and Watt suppose a horse to be able to raise - - - - - - 32,000 lbs. 1 foot high per minute.

Désaguilliers supposes a horse to be able to raise only - - - - - - 27,500 lbs. do.

Smeaton, again, computes a horse power at 22,916 lbs. do,—which is about the standard of the actual power of a horse.

This great difference in the estimate of a horse power may be attributable in part to the real difference in the strength of this animal. A London dray horse is a gigantic animal, endowed with strength nearly adequate to performing the labor assigned by Boulton and Watt; while other horses, and perhaps an average of them, will not be able to perform more than is assigned by the standard of Mr. Smeaton. In contracting for Steam Engines of a certain horse power, it should always be specified which of the above standards are intended to be adopted as a rule for calculation.

Boulton & Watt in calculating the power of their Engines, actually allow for a force to act upon the piston of about double the effective force of a horse. The moving power applied to the piston according to their calculation, is equal to raising 44,000 lbs. 1 foot high in a minute, were the weight to be placed directly upon the top of the piston. The actual effective power available is, however, reduced by friction, and the force consumed in moving the air pump, and other parts of the engines, to 32,000 lbs. raised one foot high in a minute, as above stated. About one third of the power is thus lost, and the atmospheric pressure, although nearly equal to 15 lbs. on each square inch of the piston, gives a power available by means of the crank equal to only 10 lbs. on the square inch. A similar loss of power takes place in regard to the weight of water applied to the buckets of the water wheel, which is capable of raising but two thirds of the quantity of water that operates upon it to the level from which it falls.

The power of an able bodied man, working ordinary hours, is calculated from the results of various experiments made by Smeaton and others, to be equal to raising 60 cubic feet of water (weighing 62½ lbs. each) one foot high per minute, equal to about ⅙ of the horse power, by Smeaton's standard, and less than ⅛ of a horse power, according to Boulton and Watts' standard.

The following has been proved by numerous experiments, made in England and Scotland, to be the effective result of a one horse power applied to moving cotton machinery. The standard of Boulton and Watt, although it represents a much higher power than that of an ordinary horse, from having been first introduced into use has been generally adopted. It is of more importance to have one determinate rule for the measure of force, that will, under the most unfavorable circumstances of the condition of a machine, give a result equal to the power of a horse, than to introduce confusion by attempting to establish new and more exact standards.

1 horse power is calculated at a medium
" = to drive 100 throstle spindles, with preparation, for cotton yarn twist.
" = " 500 spindles, with preparation, for mule yarn, No. 48.
" = " 1000 spindles do. for mule yarn, No. 110, and for intermediate Nos. of yarn, in the same proportion.
" = " 12 Power Looms, with preparation.

It is stated by Smeaton that a strong horse is able to lift by means of a pump, 250 hhds. (63 gallons each) of water 10 feet high in one hour, at a maximum 12 gals. of water weigh 100* lbs. Thus the

* One gallon, wine measure, of *distilled water* weighs, by the most accurate experiments, exactly $8.\frac{317}{1000}$ lbs. avoirdupois, when the temperature of the water is at 62º of Fahrenheit's thermometer, and the mercury of the barometer stands at 30 inches. There are usually foreign substances dissolved or diffused in common water, which, taken

actual weight of water lifted is at the rate of 22,000 lbs. raised one foot high per minute. The standard of a horse power, as above stated, is 32,000 lbs. raised one foot high per minute.

At Lowell, in the state of Massachusetts, 24 cubic feet of water per second with a fall of 30 feet, has been found sufficient to operate 4000 spindles, with all the preparatory machinery, for spinning cotton yarn, about No. 30, together with the looms necessary for weaving the same. The spindles in use at that place are all of the sort called "dead spindles," requiring rather more power to operate them than the common English throstle spindles alluded to in the above table. The difference of power required for the dead spindle is probably as 4000 is to 4300, or 4400. Calling 4000 dead spindles equal to 4400 throstle spindles, the power required to operate them, together with the necessary preparatory machinery,

will be equal to that of - - - -	44 horses.
144 Looms (at 12 looms to the horse power,)	12 do.
	56 horse power.

A calculation of the efficient power of the quantity of water used (24 cubic feet per second, with a fall of 30 feet,) is here given, to show that the estimates of the power required to operate an equal amount of machinery will nearly coincide with that actually imparted by the water wheels. (See also the calculations upon the water wheel.)

24 cubic feet of water per second is equal to 1.440 cubic feet per minute.

$1440 \times 62\frac{1}{2}$ (the weight in lbs. of each cubic foot of water) gives 90.000 lbs. $\times$ 30 feet, the fall of water, $=$ 2.700.000 lbs. descending one foot per minute. Deduct $\frac{1}{3}$ for the loss of power by friction and otherwise, in applying the weight of water to the wheel, &c. and dividing the remainder by 32.000 lbs. (Boulton & Watt's standard) gives $56\frac{1}{4}$ horse power.

At the Hamilton mills in Lowell, where the fall of water is only about 12 feet, the same quantity of machinery is operated by using 60 cubic feet of water per second.

The $56\frac{1}{4}$ horse power required for one of the above mills would be sufficient to put in motion 56000 *mule spindles* with preparation for spinning yarn as fine as No. 110, or above 10.000 mule spindles for spinning yarn for warp and weft as fine as No. 48, together with 400 Looms to weave the same. It is partly in consequence of the great expense of power to operate throstle spindles, that the throstle twist commands a higher relative price in Manchester than yarn of the same fineness spun upon mules. One of the most extensive cotton mills in Manchester, owned by Mr Murray, contains ninety

into connexion with the fact that ordinary river and spring water commonly has a temperature of about 50° of Fahrenheit's thermometer, instead of 62° as above stated, will give the result of $8.\frac{350}{700} = 8\frac{1}{2}$ lbs. avoirdupois, as the weight of a gallon, wine measure, of common water as usually found in the climates of England and the United States. (See Hydrostatics.)

thousand mule spindles, which are operated for spinning yarn, from 200 to 250 hanks to the pound, by two steam engines rated at less than 80 horse power.

The rules for calculating the *Horse Power* of Steam Engines will be given when treating of the Steam Engine.

The calculations respecting the power of a horse, it has been observed, are rendered vague and uncertain by considering the power of the animal as a constant quantity, without making due allowance for the velocity with which he may move An ordinary horse commonly exerts a force of traction equal to 150 lbs. This is reduced to less than one half when he travels four miles an hour ;—to one ninth part when he travels eight miles an hour, and at twelve miles an hour his whole strength is barely sufficient to carry forward his own weight ; and his power of draught or traction nearly ceases when he travels with a speed of fourteen or fifteen miles an hour.

According to the variations of speed, Professor Leslie supposes that a horse moving only one mile per hour might pull with a force of 181 lbs ; at two miles per hour with a force ot about 150 lbs ; at three miles with 120 lbs ; at four miles with 96 lbs. At a dead pull, when the exertion is only continued for a few moments, a horse might exert a power of five or six hundred lbs. or more.

A horse, it is stated, can in general carry no more up a steep hill than three men can carry. This is the most unfavorable application of the strength of a horse, for if the hill be steep 3 men, each carrying a burden of 100 pounds, will ascend faster than a horse loaded with 300 pounds. A strong horse, by an effort, may succeed in drawing 2000 pounds up a steep hill, provided the ascent is short and the road good. The form of a horse is most favorable for draught on a horizontal plane. The forward part of his body is brought to operate by its gravity, as the power upon the bended lever, the hinder feet serving as the pivot or fulcrum. For this reason a horse is able to exert as much power in drawing a canal boat as 7 or 8 men.

The most favourable posture for the exertion of the muscular strength of man is the act of rowing a boat, in which position his power is applied on nearly the same principles as stated before of the horse, the whole weight of his body being extended nearly horizontally and operating by its gravity with leverage power.

Horse power is usually applied to mechanical purposes by means of a lever connected with a perpendicular shaft, which is turned by the horse as he traverses a circular walk or path.

The diameter for the walk of a horse-mill should not be less than 25 feet ; otherwise the line of the direction of the draught forms an acute angle with the lever, and not a right angle with it, as should be the case in order to apply the power with full effect. The bar to which the traces are attached should be secured so as to swivle, and favor the motion of the animal without producing an unequal resistance upon his shoulders. The geering must be also calculated to produce the desired motions when the horse proceeds at the rate of 2½ miles per hour.

Human Strength, or Power.

Desaguilliers states that the Power of a Man, applied in various ways, will produce the following results:

A man can raise by a good common pump, a hogshead=63 galls. of water 10 feet high in a minute, for a whole day.

A man of ordinary strength can turn a winch with a force of 30 pounds and with a velocity of 3½ feet in a second, for 10 hours a day.

Two men working at a windlass with handles at right angles, can raise 70 lbs. more easily than one can raise 30.

According to Mr. Buchanan's comparison, the force exerted in turning a winch being made equal to the unit, or standard,

The force as in pumping will be	=	.61
as in ringing,	=	1.36
in rowing	=	1.43

Porters are commonly able to carry from 200 to 300 pounds at the rate of 3 miles an hour.

By a careful adjustment of the weight low upon the hips, it is stated that Porters are able to move forward under a load of from 700 to 900 lbs.

Coulomb observes that the most advantageous weight, for a man of common strength to carry horizontally, is 111 pounds; or if he return unladen, 135 pounds. With wheel-barrows men will do half as much more work as with hods, as in the mode previously mentioned.

Surprising accounts are given of the strength of men to sustain weights of above 2000 lbs. by means of proper apparatus adjusted to the hips. The weights, however, in the cases stated, do not appear to have been sustained by muscular strength, but merely by placing the legs in the most favorable perpendicular position, whereby the bones receive the whole stress, with but little more muscular exertion than is required for maintaining them in an erect posture. The bones of the legs and the arch of the pelvis, although apparently so frail in form and texture, are constructed with such admirable science that it is supposed by anatomists they might sustain a weight of nearly 4000 pounds.

MOTION.

A state of Motion appears to be the natural condition of all masses of matter which are placed within the limits of our observation. Whether we regard the globe which we inhabit, or direct our attention to other similar masses of matter composing the planetary system, we find that these vast bodies are moving in their orbits with wonderful velocity. The fixed stars are the only objects which have been supposed not to partake of this "ceaseless action." This supposition may be attributed to an ignorance of facts connected with these heavenly bodies, situated at such remote distances from us, since it is known that the sun, the centre of the planetary system, has a motion on its own axis. As far therefore as our observations have been extended with any degree of certainty, matter appears no where actually to exist in a state of absolute rest.

Although all the matter of which the universe is composed has been for so many ages in continual motion in immense space, yet it must remain uncertain whether the motion communicated to them by the great First Cause would continue forever undiminished. It was the opinion of Sir Isaac Newton that the fabric of the universe (and of course all natural bodies) could not continue forever in motion if left to itself; but would require in process of time to have its motion re-established or renewed by the same hand that created it, and gave it the first impulse. This speculative opinion seems to have been controverted by La Place. The sun is the great source of the relative motion of matter upon the surfaces of the planets as well as the centre of motion to the orbs of the planetary system. If a planet were to be deprived of its rays, it is to be supposed, so far at least as can be judged from analogy, that the whole surface of it would exhibit the scene of stillness of a polar winter, where every object would be bound fast by frosts, and even the warm current of animal life would cease to circulate.

All the portions of matter upon the earth, which may be considered as finite space, are relatively at rest, and *inert*, possessing in themselves no power of locomotion, except what they may derive as before observed, from the impulse of gravitation, cohesion, electricity, heat, &c. These causes must, after a certain time, cease to produce motion in a body placed in finite space, because a body would cease to gravitate were it possible for it to descend to the centre of the earth,—the centre of gravitation; and two bodies moving towards each other must also eventually meet in finite space. Hence schemes, founded upon any any one of the moving powers for producing of itself perpetual motion, must be abandoned, like the visionary researches for the philosopher's stone which served for ages to amuse and delude the world; because infinite space is not within the control of man, and the resistance to the motion of material bodies arising from friction can by no human art be avoided or done away.

Matter, when once put in motion, will continue to move in a straight course, until obstructed, and when once stopped will remain at rest until some force is applied to it. We are therefore induced to suppose that matter cannot of itself produce any change of motion, and if once put in a state either of motion or rest, would continue in it forever, unless disturbed by some cause foreign to itself. This want of all power of self motion, and indifference to motion and rest, has been termed, *inertia*. There seems to be nearly the same scepticism among certain modern philosophers about the existence of *inertia* as once prevailed among the ancient philosophers about the proofs of their own existence.

It has been asked, how can a body which is confined by no obstacle, oppose a resistance? Does not this seem to imply that it would be capable of giving motion? By following up this mode of reasoning, and by drawing the suitable deductions therefrom, it may be made speciously to appear that mere matter might be able to move itself, if it could of itself exert a counter force or oppose a resistance to motion. Without attempting to enter into any of these speculations it may be sufficient to state the facts usually understood to be referred to by the term *inertia*.

No motion is ever destroyed or annihilated by the impinging of a solid body upon another at rest, although the inertia of such body may appear to *resist* the shock and to remain unmoved. Were a cannon ball to fall upon the earth, the motion of the ball would appear to be annihilated by the inertia of the mass of matter of which the earth is composed. Such however, it is well established in theory is not the fact, for the earth receives a degree of motion from a falling body equal to what is lost by such body, although from the relative magnitude of the masses no effect is observable. Every body therefore receives just as much motion as it destroys in the body that acts upon it.

Inertia is proportional to the quantity of matter contained in a body, and takes place in all directions in which an effort is made to move it.

It may be observed that the resistance of *inertia* differs from the resistance opposed by active forces, as observable when bodies moving in opposite directions impinge against each other. In this case, motion is counterbalanced or annihilated by opposing motion, and not by *inertia*. The application of the principles of collision of elastic and unelastic bodies is often required in the useful arts. Collision is most studiously avoided in the construction of all machines in which it is practicable to dispense with this destructive principle.

Whatever may be the theories of Motion, it is certain that all the advantageous results or gain in the effective application of forces by the use of machines, or the mechanical Powers, is entirely founded upon it, for it must ever be borne in mind as a fundamental maxim, that *whatever is gained in power is lost in VELOCITY*. The various devices of human ingenuity in inventing machines, whereby the motion of the moving power may be sacrificed to increase its slow but certain effect upon the weight, have given rise to the apothegm that "knowledge is power." The man who knows how to make or employ a machine whereby he can exert his whole force while traversing a space of 100 feet to act with constant effect in raising a heavy weight in the same time 1 foot, is possessed of a knowledge that will enable him to accomplish as much as would require the united and direct application of the force of 100 men. There is in this case no actual gain of power, strictly speaking, because the individual has moved, while pressing forward with his whole strength, over 100 times the space that would have been traversed by each one of the 100 men to produce the same result, and it must also be manifest that to raise the same weight the same quantity of actual power must be in both cases employed. There is however a manifest gain to this individual in point of economy and convenience, who is thus enabled, by his prolonged solitary exertions, to dispense with collecting the aid of so many persons. When the power of 1 pound, applied on the long end of the lever, counterbalances the weight of 2 pounds upon the opposite end of it, after both are put in motion the power will descend 2 feet while the weight is raised 1 foot. In this case it must be evident that it would require an equal force to raise 1 lb. 2 feet high as to raise 2 pounds 1 foot high. There is then no other gain from the application of the lever and other mechanical powers than that of convenience;—on the contrary there is an actual loss of power by the use of machinery equal to the amount of the friction. The power and the weight being always in some way connected together by the medium of the machine, if any motion be given to the power, the weight must be operated upon by it, and must also have a corresponding motion. A certain proportion is always found to subsist between the velocity with which the power descends in the vertical direction, and that with which the weight ascends in the vertical direction; a proportion that depends entirely upon the nature and construction of the machine. Making allowance for friction, the power will in all cases sustain the weight when it has the same ratio to it, that the velocity of the weight would have to that of the power, if both were put in motion in the direction in which they act. Thus if a weight of 100 pounds on being put in motion by means of the lever, or by the screw, &c. would move one foot, while the power equal to 1 pound would move 100 feet, the power and the weight will counterbalance each other. This principle has been repeated that it may be impressed upon the mind as being the very ground work of the science of which we are treating. Hence is derived the following Rule for calculating the effective results of the application of forces by means of the mechanical powers, and of all compound machines. It is truly the "golden rule" of mechanics.

The power multiplied by the space, through which it moves in the direction in which it acts, is equal to the weight multiplied by the space through which it moves, also in the direction in which it acts.

To this may be added the following axiom.

To every action of one body upon another there is an equal and contrary reaction; or, the mutual action of bodies on each other are equal, and in contrary directions, and are always to be estimated in the same right line.

The science of mechanics strictly considered, treats only of the *equilibrium* and *motion* of bodies, or of the effects produced upon bodies by the application of forces.

If a force be applied to a body absolutely at rest, the body will be caused to move in some determinate direction and with some determinate force, or it will remain unmoved. In the first case the body is submitted to the action of forces which *are not in equilibrium*, where motion must consequently ensue; in the latter case the action being counterbalanced by the resistance, or the action and reaction being equal, the state of rest remains undisturbed. Each of these states present so many important subjects for consideration, that this science has been divided into two branches, one of which treats of the action of forces which counteract each other, or are in equilibrium; the other treats of action of forces, which not being in equilibrium, or counterbalancing each other, produce every variety of motion. The former branch is termed *Statics*, from the Greek word signifying *standing still*;—the latter branch is termed, *Dynamics*, from a Greek word signifying, *force*. In the one case bodies are considered as at rest, and in the other, as in various states of motion produced by the action of forces.

Although fluids are material substances, and are governed by the same laws of motion as apply to solid bodies, yet there are so many peculiarities and important results attendant upon the lateral action and pressure of fluids that they are usually considered as forming distinct subdivisions of *Statics* and *Dynamics*, called *Hydrostatics* and *Hydrodynamics*, terms similarly derived from Greek words signifying *the state of rest of water*, and *the force of water*, resulting from its motion. The word *Hydraulics* is frequently used to express the latter branches of science, of which it seems more properly to form only the subdivision which treats of the construction of machines and engines to be acted upon by fluids, such as pipes or conduits, &c. together with the specific operation of the fluids in or upon them. These subjects, with that of Pneumatics, which relates to the action of ærial fluids, are among the most important in mechanics, as applicable to various purposes in the useful arts, and will hereafter be considered.

The limits and scope of this work will not allow us to enter at large into all the details of the laws of motion, and of the composition and decomposition of forces. Those who are desirous of examining this branch of science more fully, and are disposed to enjoy the luxury afforded by the investigation of truth by mathematical demonstrations, are referred to an excellent treatise upon this subject by Professor Farrar, of Cambridge.

We shall confine ourselves to a few observations upon the most simple states of Equilibrium and Motion, embraced under the terms Statics and Dynamics, including the composition and decomposition of forces.

Of Uniform Motion.

It should be observed, that in all calculations relating to motion, bodies are considered as composed of particles absolutely hard, and connected together in such a manner as not to yield or admit of such a change in their respective situations, by the exertion of any force whatever; and no allowance is made for the friction which always takes place in practice

A body is said to have a *uniform* motion when it continues to pass over equal spaces in equal times.

In order to compare the motions of two bodies which move uniformly, it is necessary to consider the space which each describes in the same determinate time, as one minute, one second, &c. This space is what is called the *velocity* of the body.

An interval of time being taken for unity, or the standard of comparison, if one body passes over 5 feet in a second and the other over 10 feet in a second, we say that the velocity of the first is 5 feet and that of the second 10 feet.

Forces, as before described, are the causes which either move, or tend to move a body, or to produce any change in their motion. The effect of force is to cause in each particle of a body a certain velocity.

Forces are measured by the quantity of motion or velocity which they are capable of imparting to a known mass multiplied by this mass. The quantity of motion of a body is therefore as the number of its particles or its *mass*, and its velocity. A body containing a mass of particles equal to 20 lbs. and moving with a velocity of 10 feet will have its quantity of motion represented by multiplying its weight by its velocity, as $20\times10=200$, which is the sum of its force, and is called its *momentum*. The momentum of moving bodies may thus be readily computed.

EXAMPLE.

Suppose a solid body weighing 20 lbs. to move with the velocity of 10 feet per second and another similar body weighing only 10 lbs. to move with the velocity of 20 feet per second, what will be the momentum of each, or their comparative effects were they to impinge against any third body.

lbs. ft.
$20\times10=200$ momentum.
$10\times20=200$ do. Their momentum is equal and consequently their effects would also be equal.

Of Equilibrium of Forces directly opposite.

If two equal forces act upon the same point of a body, in directions immediately opposite, they will keep that body at rest.

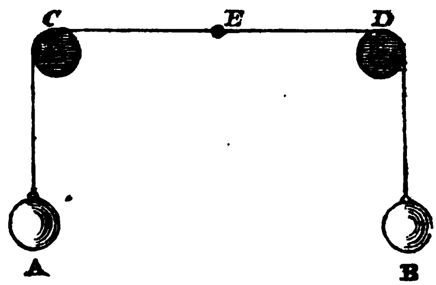
This may be illustrated when a solid body is balanced upon a point like a scale beam, so that it will not preponderate to either side. In this case the body remains stationary or at rest by the force of gravitation, producing in the body a tendency of motion toward the centre of the earth, which force is exactly counteracted by the resistance exerted by the support in upholding the body and preventing its descent.

This is the most simple example of equilibrium, and the truth of the principle appears to be self evident.

Composition and decomposition of Motion and Force.

It may in general be inferred, that when bodies are drawn in directions immediately opposite by two unequal forces, it is affected exactly in the same manner as if it were drawn by a single force equal to the difference between the two forces, and acting in the direction of the greater force.

Fig. 1.



Suppose A. B. in Fig. 1, to represent unequal weights suspended by flexible cords over two pullies C. D. In this case the point E in the cord will move horizontally either toward C or toward D according to the preponderance of the weight at A and at B, and the force with which it will tend to move in either of these directions will be in proportion to the difference of the weights. If the weight B be divided into two parts, one of which is equal to A, the other part will evidently be equal to the difference of the weights A and B, or the excess of the weight B above the weight A. Suppose the excess to be double the weight A, or to consist of two weights each equal to A. It will appear manifest that the weight A. acting in the direction E C must exactly balance one half of the weight B acting in the direction E D, whereby the combined effect of the weight A and ½ of the weight B is nothing, leaving the point E to be pulled in the direction E D by the excess of the greater weight B above the lesser weight A; the excess being equal to A, the same effect would be produced as if there were but one moving force at B equal to A.

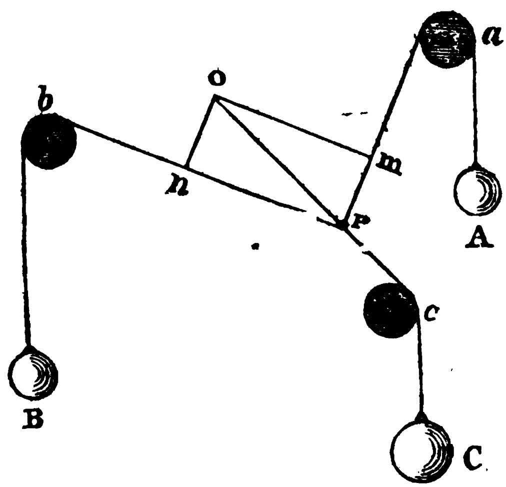
A single force, then, may be the result of the combined action of two or more forces, in which case it is called the *resultant*.

Compound Motion.

The process, by which a single force is found equivalent in its effects to two or more other forces, is called the *composition of forces*.

Two or more forces may be found whose combined effects are equivalent to that of a single given force. The process by which these are determined is called the *decomposition of force;* and the two or more forces which are equivalent to the single force, are called the *components*.

Fig. 2.



Let P be a fixed point to which three strings are attached; and let the strings P *a* and P *b* be passed over fixed grooved wheels or pulleys, and let any weights A and B be suspended from them. The point P is now drawn by two forces A and B in the directions P *a* and P *b*. It is required to find a single force that would produce the same effects upon it?

Take lengths P m and P n on the strings, so that they shall be in the same proportion as the weights A and B, that is, so that P m may bear the same ratio to P n as A bears to B. Supposing the pulleys a b c to be attached to a board, draw thereon the parallelogram P m o n. Draw also the diagonal o P. A single force acting in the direction of the diagonal P o, and having the same ratio to the weight A or B, as the diagonal P o, has to the side P m or P n of the parallelogram, will produce the same pressure on the point P as the combined actions produced by A and B. To prove this, let a third wheel or pulley c, be so placed that the thread P c shall, when stretched over it, be in a direction immediately opposite to P o, and suspend from it a weight c, which shall have the same proportion to A or B as the diagonal P o has to P m or P n. If the point P hitherto supposed to be fixed, be disengaged and left free to move, it will be found to maintain its position and remain at rest. Hence it follows, that the weight c neutralizes the effects of A and B, and keeps them in equilibrium. But it would also keep in equilibrium a force equal to c in the direction P o; from whence it follows, that a force equal to c in the direction P o is equivalent to the united actions of the forces A and B in the directions P m and P n. Hence the following important theorem in relation to forces acting on the same point in different directions.

"*If two forces acting on the same point in the direction of the sides of a parallelogram be proportional in their intensities to these sides, their* *united effects will be equivalent to that of a single force acting on the same point in the direction of the diagonal of that parallelogram, and whose intensity is proportional to the diagonal.*" This single force, in the direction of the diagonal, is therefore their resultant. This general proposition is the fundamental principle that governs all the calculations of motion and forces, and as such is of the utmost importance.

That two forces have but one resultant may be made very easily to appear, by producing the least alteration in the force C, either in its magnitude or in its direction. The point P, when disengaged, will no longer maintain its position, but will move until it settles into such a position that the magnitudes of the diagonal and sides of the corresponding parallelogram shall be proportional to those of the forces A B C. In like manner it may be shewn that if several forces act on the same point parallel and proportional to all the sides of a polygon taken in order, except one, a single force proportional to, and in direction of, that one side will be their resultant.

The same laws as above established in respect to the composition of forces or pressures, also apply to the *composition of motions*. Two impulses, which, separately communicated, will cause a body to move over the sides of a parallelogram as Pm Pn, Fig. 2, in the same time, would, if communicated at the same instant by a simultaneous impulse, cause the body to move over the diagonel P. o of the parallelogram in an equal time.

It must be evident that after the body is put in motion by the simultaneous action of the forces and is left to itself, the instant after the impulse is given, it must move in a straight course, as there is no cause to incline it one way rather than another. Accordingly as this body passes through P o without any thing to change its direction, the course must be P o, that is, the diagonal of the parallelogram P m o n.

A familiar instance of the composition of motion produced by the action of two forces is observable when a boat is rowed directly across a river that has a rapid current. The boat is impelled by the oars in a direction perpendicular to the banks, while it is moved by the force of the current in a direction parallel to the banks. Instead of arriving at the other bank at a point immediately opposite to where it started it reaches it at some point considerably below it. The boat moves obliquely, in fact in the diagonal of a parallelogram, P o fig. 2, one side of which is a straight line drawn across the river from the point from whence it started to the opposite bank, and the other side is so much of the bank itself, measured from the point opposite to that from whence the boat started to the place where it landed, being the distance which the current moved with the boat down the river in the time taken to cross it. This is an example of the *composition* of motion, whereby two forces, viz. that of the current and that imparted by the oars, produced one uniform rectilinear motion. An example of the decomposition of motion is exhibited if the boat on returning should ascend the river by the side of the bank to the point opposite to that from which it started in the first instance, and should then cross the river, after the current of the tide had ceased, in a direct course at right angles with the bank. This is, in fact, a *decomposition* or resolution of the diagonal motion above mentioned into its two components, viz. the two sides of the parallelogram of which it before described the diagonal.

A peculiar motion takes place when a body gradually receives the action from one force while it is under the continuous action of another force not opposing a resistance to its motion. When a cannon ball is discharged horizontally from the mouth of a cannon it is subject to the action of gravitation, which at the termination of one second after the discharge will cause it to descend toward the centre of the earth $16\frac{1}{12}$ and at the termination of the next second $64\frac{1}{16}$ feet, as stated in the table of falling bodies at page 12. The ball in this case describes a curved, descending line, instead of the diagonal of the parallelogram before described. This peculiar curved line is called a *parabolic curve*.

Centres of Oscillation and Percussion.

Although the centres of *oscillation* and *percussion* are generally treated of separately, yet the centres of both are in the same point, and the rules that apply to one apply generally to the other.

As in a solid body at rest, the whole weight may be considered as collected in the centre of gravity; so in regard to the same body in motion, the whole force may be considered as collected in its moving centre, which is also called the centre of motion. This applies to bodies moving in straight lines. When such bodies are suspended, like a pendulum, a portion of their mass has a greater relative motion than another portion nearer to the point of suspension, which peculiar motion is understood by the term *oscillation*, which is applied generally to the movements of the pendulum from the effect of gravitation upon it.

When a force is applied to a certain point of a rod oscillating like a pendulum, its whole motion and tendency to motion is stopped at once. This point, so taken, is called the *centre of oscillation*, when the motion of such body is considered; but when the effects of its momentum are considered, this point is called the *centre of percussion*. The centre of percussion is familiarly known in practice to the school boy who swings his bat to strike his ball. When the blow takes effect upon the ball and no shock or percussion is felt by the hand, the whole motion of the bat is imparted from this centre of percussion; but when the ball comes in contact with the extreme end of the bat, or at any other point except this centre, a severe shock to the arm takes place.

The centres of percussion in a beam, bar, &c. are easily found in the following way.

Suspend the body freely by a fixed point, and make it vibrate in small arcs, counting the number of vibrations it makes in any time, as a minute, and note the number of vibrations made in a minute. This number may be represented algebraically by the letter *n*; the distance of the centre of oscillation and percussion from the point of suspension will be $140850 \div n^2$ (which represents the square of the number of vibrations per minute)= inches.—For the length of a pendulum vibrating seconds, or 60 times in a minute, being $39\frac{1}{8}$ inches, (see *pendulum*, page 13,) and the lengths of the pendulums being reciprocally as the square of the number of vibrations made in the same time:—therefore, as

$n^2 : 60^2 :: 39\frac{1}{8}$: to the answer; that is the square of $60 = 3600 \times 39\frac{1}{8} = 140850 \div n^2 =$ to the distance in inches of the centre of oscillation below the axis of motion.

It is a remarkable fact that so unvarying and constant are the oscillations of the pendulums of the same length, which usually appear to have such desultory movements, that Measures of length, as the yard, foot, &c. are referred, by a statute law of England, to this standard as the most certain mode of determining their length, should the brass standard measures of the kingdom at any time be accidentally lost.

By attention to this subject a person who may not have a watch with a second hand to give the number of seconds for counting the revolutions of shafts, or for other purposes, may construct a pendulum by suspending a bullet from a string exactly $39\frac{1}{8}$ inches in length, which will oscillate regularly in each second of time. Or a person by the aid of his watch may in this way make a measure with tolerable accuracy 39 inches long, should he accidentally find it necessary to have recourse to a measure where he may not be able to obtain one.

Centre of Gyration.

The centre of Oscillation seems to differ from the centre of Gyration only in the circumstance that the former seems to be usually considered as produced by gravitation, and the latter when the motion is rotatory and is produced by any extraneous force. In respect to practical utility the centre of gyration is the same as the centres of oscillation and percussion.

“ Rule for finding the centre of Gyration.

If the distance of the centre of oscillation from the point of suspension or axis be multiplied by the distance of the centre of gravity from the same point, the square root of the product will be the distance of the centre of gyration from the axis or point of suspension.

EXAMPLE.

Let the centre of gravity be 4 feet from the axis, and the centre of oscillation 9 feet, then $4\times9=36$, and the square root of this is$=6$; therefore the centre of gyration is 6 feet from the point of suspension or axis."

This rule applies to the moving power of the water wheel, in respect to the suitable point on the wheel to which the segments of the geering should be attached, an example of which will be given in treating of the Water Wheel.

Rotatory Motion.

The tendency of all bodies in motion to move in straight lines, as before stated, produces a peculiar effect upon them when revolving round a fixed centre. In this case each particle would fly off were it not confined. This tendency is termed the *centrifugal* force The counteracting force of gravitation prevents this effect taking place in relation to the revolution of the earth, and the fixed arms or other parts of revolving bodies, by their cohesive strength, produce the same result in regard to other masses of matter. Gravitation is sometimes considered a *centripetal* force, because it produces an effect the reverse of centrifugal force.

The greater the velocity, the greater is the tendency of each particle of a revolving body to fly off;—that is, the greater is the centrifugal force. The momentum of a revolving body being as its quantity of matter and velocity, the rules that apply to the centrifugal force are therefore nearly the same as apply to bodies moving in straight lines.

Mr. Banks gives the following Rules for calculating the centrifugal force of balance or fly wheels.

Suppose two balance or fly wheels of the same weight, one of them 12 feet diameter, and revolving in 8 seconds; what must be the diameter of the other to possess the same force when it revolves in 3 seconds?

The diameter multiplied by the velocity of the first must be equal to the diameter also multiplied by the velocity of the second; therefore as $8^2 : 12 :: 3^2$: to the diameter;—that is, 12×3^2 (the square of the number of seconds)$=108\div8^2$ (the square of the number of seconds for one revolution of the given wheel)$=1.6875$ foot, the diameter of the second fly wheel at the circle of percussion or gyration.

Again, suppose two fly wheels of the same diameter, the one revolving in 3 seconds, and the other in 8 seconds; what will be the difference of their weights?

As 3^2 (the square of the seconds for one revolution of the small wheel) is to 8^2 so is the weight of the one to the weight of the other:

$\left.\begin{matrix}8^2=64\\3^2=9\end{matrix}\right\}$ as $9 : 64 :: 1=7\frac{1}{9}$; their weights will be to each other as $7\frac{1}{9}$ is to 1. The weight of the second wheel being known, divide the same by $7\frac{1}{9}$ and the quotient will be the weight of the first.

In the two preceding examples weight and velocity are taken seperately. The following Examples give the centrifugal force, when the weight and velocity are used.

Required the centrifugal force of a fly wheel of the diameter of 16 feet, velocity 50 revolutions per minute, and weight $3\frac{1}{2}$ tons ?

(3.1416)=circumference of a circle, the diameter being 1 (by problem 7, page 121)

16 feet=space a body falls through in one second of time

.833=decimal of a minute, time of one revolution.

$$\frac{16\times3.1416^2}{16\times\ .833^2} = \frac{157.9136}{11.1122} = 14.21 \text{ times the w't. in tons.}$$

The weight being $3\frac{1}{2}$ tons, therefore multiply $3.5 \times 14.21=49.73$ tons, the centrifugal force.

The Stones for grinding Table Knives at Sheffield are about 44 inches diameter, and weigh about half a ton; the velocity of the circumference is at the rate of 1250 yards in a minute, equal to 326 revolutions : required the centrifugal force ?

$22^2\times2=968$, the square root of which is 31.1 inches, or 2.59 feet, the diameter of the circle of gyration.

As 326 : 60::1 : .184 seconds, the time of one revolution.

$2.59\times3.1416^2=25.5622$

$16\times\ .184^2=\ .54169$. $25.5622\div54169=47.18$ times the weight of the stone. The stone weighing $\frac{1}{2}$ ton or $\frac{5}{10}$, therefore $47.18\div\frac{1}{2}$, or $47.18\times.5=23\frac{1}{2}$ tons centrifugal force.

It sometimes occurs when these stones are impaired in strength by flaws that they are unable to withstand this great centrifugal force, and are rent in pieces, the fragments passing with the most destructive violence through the partitions and ceilings of the rooms, and producing effects nearly as fatal as those resulting from a cannon ball.

MECHANICAL POWERS.

The principles of Motion and Power may now be considered as theoretically applied to raising heavy weights or overcoming resistance by means of certain machines called the "Mechanical Powers." From the preceding observations upon the loss of power by the friction attending the action of all material substances, &c. it will be perceived that the theoretical calculations of the operation of machines are caused to give very different results from those obtainable in practice.

The term, Power, is applied to denote the moving force, whatever it may be, and the term Weight the resistance to be overcome ; for more particular definitions of which see page 143. It may be proper also to repeat that there is no gain of actual power by the use of machines called the Mechanical Powers, such as the Lever, Screw, Pulley, &c. but merely a gain in convenience. By the aid of them a solitary individual is enabled by protracted and successive efforts of strength to raise as heavy masses as can be raised at once by the collected force of many men. Let it be supposed that the strength of one man, by means of ropes passing round pulleys, may prove adequate to move a loaded carriage which otherwise might have required the exertion of all the strength of six men. In this case, making no allowance for friction, a six fold *purchase* would be required; consequently the length of rope that would pass off from the tackle would be equal to six times the space through which the carriage would be moved. By using the same degree of exertion the individual would in this instance have to travel six times the distance traversed by the six men, and exert his whole force six times as long as they were engaged in accomplishing the same task. In like manner to draw up heavy ships from the water upon marine railways the horses are employed for hours, traversing in their circular a route several miles to move the vessel but a few yards. The sum of all the forces expended during a long period, and thus concentrated, will at last equal the resistance to be overcome. Precisely the same principles attend the application of the screw, lever, &c. The Mechanical Powers are therefore in effect only *simple machines for overcoming resistance by serving to transmit the continued application of force.*

The Mechanical Powers are now usually considered as seven in number, the effective force available by a simple rope having been classed among them. This Power appears principally to have effect when a rope is subjected to a tension between a fixed object at one end and the weight or resistance to be overcome at the other end. The power is then applied to the middle of the rope to draw it out of a right line. A very small force will in this case cause a very great tension in the rope; the effect will continue to diminish as the rope is drawn aside to form an acute angle at the point at which the moving power is applied. This application of a mechanical power is well understood and very commonly adopted, to facilitate various operations of hoisting, on board of ships. When, however, an addition is made to the number of the original Mechanical Powers, the Hydrostatic press might also with propriety be included, as it is one of the most simple and beautiful, as well as most effective machines placed within the control of man, by which force can often be more advantageously applied to produce greater results than can be obtained from the practical use of any of the Mechanical Powers. See Hydrostatic Press.

Besides the Rope Machine there are six other Mechanical Powers, viz. the Lever, Wheel and Axle, the Pulley, the Inclined Plane, the Wedge, and the Screw. When, however, the principles upon which these powers are applied are strictly examined, it will be found that the wheel and axle operate in the same way in effect as the lever, while both the wedge and the screw are only different applications of the inclined plane. To one or more of the laws which govern these simple machines, all of the effects of mechanical combinations are reducible.

Of the Lever.

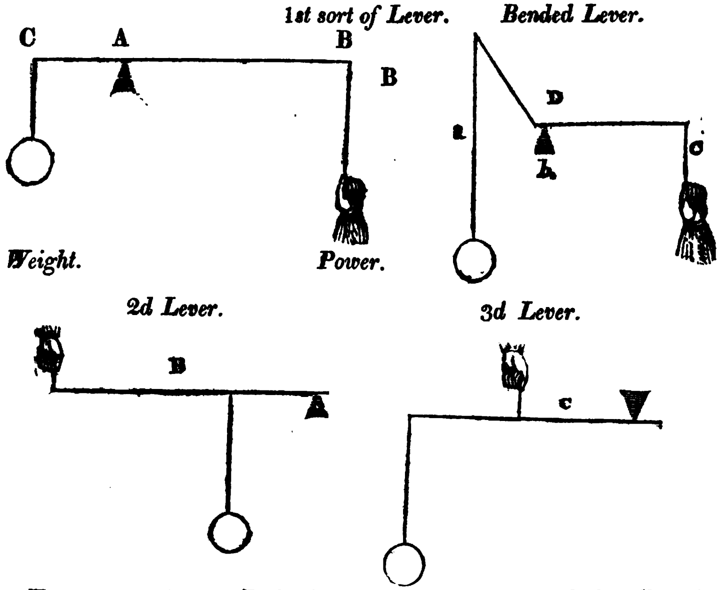
By the *Lever*, we understand an inflexible rod, of any figure whatever, so fixed at some point, A, as to admit of no other motion, by the action of the forces that are applied to it, but a motion of *rotation*, that is, a motion by which it turns about the fixed point A. This point is called the *fulcrum*.

The Lever is commonly considered as an inflexible line without mass and without gravity. In practice allowance must be made for the gravity of the parts of the lever; if the centre of gravity does not lie at the fulcrum it must be considered as a new force applied at this point according to a vertical direction.

Lever.

There are three kinds of Levers, as follows.

1st sort of Lever. *Bended Lever.*



The bended Lever, D. is similar to the first Lever A, in effect, in the line a. b. c. The effective power and weight on a Lever, is as the distance between the points of action B and C. and the fulcrum A, the distance being taken at right angles to the direction of the forces.

Rule to find the equilibrium between the Power and the weight on the Lever.

Multiply the weight by its distance from the fulcrum, prop or centre of motion, and the power by its distance from the same point; if the products are equal, the weight and power are in equilibrio ; if not, they are to each other as their products.

A common crow bar for raising stones is an instance of a *lever of the first kind.* Pincers, scissors, snuffers and all similar instruments, consist of two levers, of which the rivet by which they are united, is the common fulcrum. The steelyard or balance is another instance of a lever of this description.

In rowing a boat the oar presents a familiar instance of a *lever of the second kind*, the boat being the weight to be moved, the hands of the rower are applied at one end of the oar as the moving power, while the water, against which the blade presses, is the fulcrum.

In the *lever of the third kind*, the moving power is applied between the resistance and the fulcrum, and is consequently always employed to disadvantage when the object proposed is to augment the effect of the agent, or to overcome a greater force. But where it is an object to increase the velocity of motion in certain operations in which great force is not required ; as, for instance, in giving motion to the spinning wheel and foot lathe, or to the treadles of power looms for throwing the shuttle, &c. this sort of lever is found very useful. The structure of the limbs of animals present a remarkable instance of levers of this kind, in the animal economy facility and despatch being desirable rather than the exertion of very great strength.

Here again, the principles before stated apply, for there is a *gain in velocity*, but a loss in effective force. By the two other kinds of levers the reverse takes place, as there is a *loss in velocity*, but a gain in effective force.

EXAMPLE I.

A weight of 100 lbs. on one end of a lever, is 6 inches from the prop, and a weight of 20 lbs at the other end, is 25 inches from the prop. What additional weight must be added to the 20 lbs. to make it balance the 100 lbs ?

$100 \times 6 \div 25 = 24 - 20 = 4$ lbs. weight to be added.

EXAMPLE II.

A block of 960 lbs. is to be lifted by a lever 30 feet long, and the power to be applied is 60 lbs.—on what part of the lever must the fulcrum be placed ?

$\frac{960}{60} = 16$ lbs. that is, the weight is to the power as 16 is to 1;

therefore the whole length $\frac{30}{16+1} = 1\frac{13}{17}$, the distance from the block,

and $30 - 1\frac{13}{17} = 28\frac{4}{17}$, the distance from the power.

EXAMPLE III.

A Beam 32 feet long, and supported at both ends, bears a weight of 6 tons, 12 feet from one end. What proportion of weight does each of the supports bear ?

$12\times6=72\div32=2\frac{1}{4}$ tons, supported at end farthest from the weight.
$20\times6=120\div32=3\frac{3}{4}$ tons, supported at the end nearest the weight.

EXAMPLE IV.

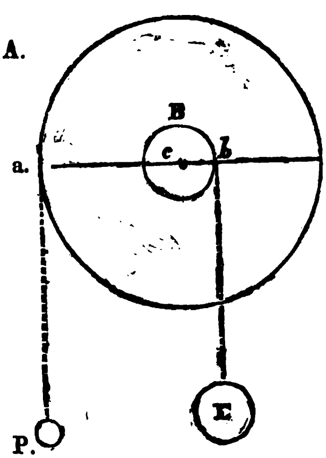
A Beam supported at both ends, and 16 feet long, carries a weight of 6 tons 3 feet from one end, and another weight of 4 tons, 2 feet from the other end : What proportion of weight does each of the supports bear ?

$$\frac{3\times6}{16}+\frac{14\times4}{16}=\frac{74}{16}=4\tfrac{10}{16}$$ tons, end at the 4 tons.

$$\frac{2\times4}{16}+\frac{13\times6}{16}=\frac{86}{16}=5\tfrac{5}{16}$$ tons, end at the 6 tons.

Of the Wheel and the Axle.

Fig. 1. A.

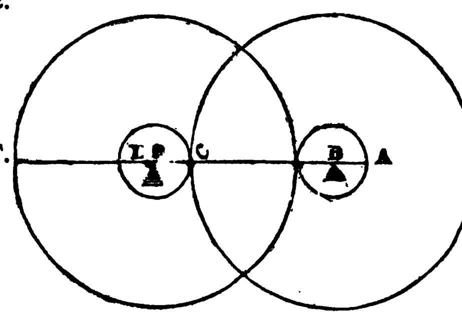


The next simple machine classed as one of the Mechanical Powers is the Wheel and Axle The force is commonly applied by means of ropes around the barrel or axle, and rim of the wheel ; but in mill geering the principle is put into practice with cog wheels, the teeth of which work into each other at the points where the ropes are applied in the first instance

a is the wheel, b a single round shaft, called the axle, both of which turn upon a common centre c. The power is applied at a, at the end of the lever a. b. resting upon the fulcrum c and raising the weight E.

When wheels with cogs are used to gain power, the same principle still operates. The end of the lever A B may be supposed to be the radius of the rope barrel, and the radius of the cog wheel, B C. The radius of the cog wheel or pinion working into the wheel is D. C, and the length of the arm of the wheel that operates as a lever winch is E. F.

Fig. 2.



If the distance between A B is only one-third of the distance between B C it is evident that the point at C will go through three times the space that will be passed through by the point at A, when the lever revolves upon the fulcrum B. The points D and F bear the same relation to each other. The short end D c acts upon the long end C B; and if the end F goes through 9 inches, the end D. c will go through 3 inches ; also the end C. If the end C go through 3 inches, A will go through only one inch: therefore the power is to the weight as 9 is to 1. That is, if 9 lbs be hung at the end of the arm A and 1 lb hung at the arm F, they will balance each other. When the reverse of this is made to take place and the power is considered as applied at A and the weight at F, the weight of 1 lb will move through nine inches, while the power of 9 lb. at A moves through one inch. From this it is evident, that if you gain power, you lose speed ; and by gaining speed, you lose power. Hence the following rule is deduced for finding the theoretical result of forces. Multiply the power applied by its velocity, and the weight to be raised by its velocity.

EXAMPLE I.

A weight of 94 tons is to be raised 360 feet in 15 minutes, by a power, the velocity of which is 220 feet per minute : What is the power required ?

$$\frac{360}{15}=24 \text{ feet per minute velocity of weight.}$$

$$\frac{24\times94=2256}{220}=10,2545 \text{ tons power required.}$$

EXAMPLE II.

A stone weighing 986 lbs. is required to be lifted : What power must be applied, when the power is to the weight as 9 is to 2 ?

$$\frac{986\times2}{9}=\frac{1972}{9}=219\tfrac{1}{9} \text{ pounds power.}$$

EXAMPLE III.

A power of 18 lbs. is applied to the winch of a crane, the length of which is 8 inches; the pinion makes 12 revolutions for 1 of the wheel, and the barrel is 6 inches diameter: What weight can be raised by this crane?

$$\frac{8\times2\times22}{7}=50.28 \text{ circumference of the winch's circle.}$$

$50.28\times12=603.36$ inches velocity of power on winch to 1 revolution of the barrel.

$$\frac{603.36\times18=10860.48}{6\times22\div7=18.857. \text{ say}=19}=571.604 \text{ answer in lbs. weight that}$$

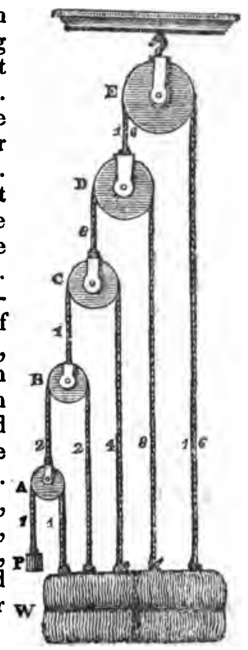
may be raised by a power of 18 lbs. applied to the winch of this crane.

The Wheel and Axle is used both in a horizontal and vertical position. When the axis is placed horizontally and levers are applied instead of the wheel and rope to turn it while lying in this position, the machine is called a *windlass.* The same machine placed in a vertical position is called a *capstan.* This last mode is one of the most advantageous for employing this Power, as a great number of workmen are thereby enabled to walk round the axle and work together, pushing the levers before them. In the common capstan and windlass it becomes necessary to intermit the application of the power as often as the rope traverses from one end of the axis to the other, which, it is obvious, must take place when the axis has made as many revolutions as it will contain folds of the rope. If the barrel be 36 inches in length and the rope be 1 inch in diameter, after 36 revolutions this result must take place. In a windlass for raising light weights one end of the axle or windlass is made tapering, that the rope may slip back thereon at each revolution. A very perfect capstan is now in use, by which the disadvantage of intermitting the application of the moving force in order to slip back the rope upon the barrel of the cylinder or axle, is entirely avoided In this improved machine the rope is made to encompass both the barrel of the axle to which the levers are affixed, and a corresponding axle placed by the side of it, and connected with it by a small intervening cog wheel acting upon the teeth of wheels secured to the ends of the two barrels in such a manner that they are both caused to turn together. Grooves are made in these axles like those on a common pulley, for receiving the rope and keeping it in one place upon the barrel continually. Thus the slack rope may be taken up by the attendant and the rope subjected to the tension remains in the grooves without traversing toward either end of the barrel of the axle. The rope passes alternately around one of the axles and then the other, a sufficient number of times to prevent the rope from slipping or recoiling when the machine is in operation. An iron axis is fitted to the small intermediate wheel to which the levers may also be applied. In this case from the small size of the wheel employed, a very great gain in effect can at pleasure be obtained, whenever the limited number of workmen at command, or the magnitude of the weight or resistance to be overcome renders the use of it necessary.

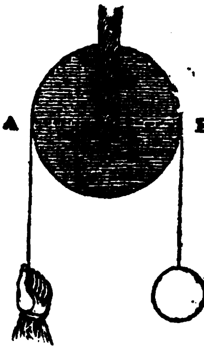
Of the Pulley or Block.

The pulley is formed by a wheel or cylinder having a groove round its circumference to receive a rope, and is usually secured in a case called a *block*, in which it revolves freely upon its axis. The term *block* is now generally employed, instead of *pulley*, by those who are most habituated to the practical use of this mechanical power. The mechanical effect of every pulley or system of pulleys is derived from this single principle, that the same flexible string must always suffer the same tension in every part of its length, whatever may be its direction.

The mode in which the Pulley operates, to increase the effect of the application of Power, is plainly illustrated by the following figure.

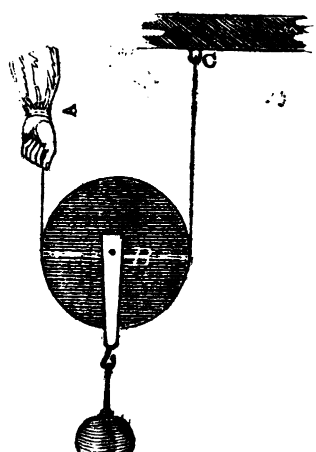


P is the power, and W is the weight held in suspension by it. The first rope P A passing over the pulley sustains a part of the weight equal to the power, P, as indicated by 1. 1. The tension of the second rope A B is twice that of the first, as it both supports the power P and its equivalent portion of the weight 1. 1. and therefore it sustains a part of the weight by means of the pulley B, equal to twice the power, as 2. 2. In like manner the third rope B C sustains the accumulated stress of 2. 2. upon one side of the pulley C, which is necessarily counterbalanced by an equal portion of the weight by the rope connected with it, equal to 4, the sum of which = 8, must again be supported by the pulley D together with an equivalent portion of the weight =8, and so on, each subsequent rope sustaining double that which is sustained by the preceding one. Supposing the figures to represent pounds, the first rope sustains only 1 lb. of the weight, the second 2 lbs. the third 4 lbs. the fourth, 8 lbs. and the fifth 16 lbs. which being added together make 31 lbs. or 31 times the power applied at P.



There are two kinds of pulleys, the *fixed* and *moveable*. By the *fixed Pulley* no power is gained, as the rope ascends with the weight on one side of the wheel, as much as the power descends upon the other, or it may be considered as a common scale beam of which A and B are the arms, and C the fulcrum. The only advantage derivable from the fixed pulley is a change of the direction in which the power may be applied.

The *moveable Pulley* operates as a lever of the second order, for if one end of a string be fixed to an immovable object, C, and the moving power be applied to the other end A, the strings being doubled around the pulley, and the ends parallel, the pulley that hangs between is a lever B the fixed end of the string C being the fulcrum, and the other A the moveable end of the lever, as in the following figure:



Hence the power A is double the distance from C that B is, and one half of the weight is supported by the stationary point C, and the other half by the power A. The power moves 2 feet, while the point B moves 1 foot, and consequently its effect upon the weight is as 2 to 1. This is all the advantage gained by one moveable Pulley, and for each additional pulley a corresponding increase of power is obtainable.

From this the following Rule is derived—Divide the weight to be raised by twice the number of moveable pulleys or shieves, and the quotient is the power required to raise the weight.

EXAMPLE I.

What power is requisite to lift 100 lbs. when the two blocks of three pulleys, or shieves each, are applied, one of the blocks being moveable and the other fixed ?

$3 \times 2 = 6$. $100 \div 6 = 16\frac{4}{6}$ lbs. the power required.

EXAMPLE II.

What weight will a power of 80 lbs. lift, when applied to a 4 and 5 shieved block and tackle, the 4 shieved block being moveable?

$4 \times 2 = 8. \quad 80 \times 8 = 640$ lbs. weight raised.

Great allowance must be made for the friction of common ropes and shieves of blocks, as stated when treating of friction. Mr. A. Holmes, a practical mechanician of Boston, stated to me, that in raising heavy weights by pulleys he had found the effect of the power applied by means of the pulley to fall short of the result of calculation about one half, when tarred cordage was employed. The most perfect pulleys, formed with friction rollers, and the most pliable ropes, lost 20 per cent. of the power assigned them in theory. With a five fold purchase block he applied under the most favorable circumstances, 25 lbs. to raise 100 lbs $\frac{1}{5}$ of the power being lost by friction.

The effective power gained by the use of pulleys may readily be calculated in practice by measuring the slack rope that is drawn off the pulleys, and the distance traversed in the same time by the weight. Then as two thirds of the length of the slack rope is to the distance traversed by the weight, so is the power to the weight. Where motion is to be produced, one-third is allowed as above to overcome the resistance of the ropes and shieves of the blocks.

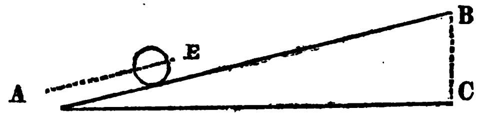
Suppose the slack rope to measure 27 feet and the space moved through by the weight or moveable pulley, to which the weight is attached, 3 feet; what is the power gained in practice by these blocks or pullies?

$27 - 9 = 18$. As 18 is to 3, $= 6$ to 1, or six fold power.

If then 100 lbs. power be applied to this tackle it will raise 600 lbs. weight.

Inclined Plane.

The gradual ascent of a road and railway is an instance of the inclined plane. The application of a small power continued for a length of time is capable by this means of raising with facility weights which would require a great force acting vertically. When the force applied is caused to act in the direction parallel to the inclined



plane A B, as represented by the line A E, upon the body, the power gained is in proportion to the length of the line A C, which is the base, compared with the perpendicular B C, the height. If A C be 40 feet, and B C 10 feet, then A C being four times B C, the power gained will be as 4 to 1, that is, the force capable of raising one pound perpendicularly to B will raise four pounds along the inclined plane A B, which being four times the length of B C, the force, as in the case of the lever ,must move through four times the distance. Hence the following Rule is derived. When the power acts parallel to the face of the inclined plane, the length of the plane is to the weight as the height of the plane is to the power.*

EXAMPLE I.

What power is requisite to move a weight of 100 lbs. up an inclined plane, 6 feet long and 4 feet high ?

If 6 : 4: :100 : $66\frac{2}{3}$ lbs. power, Answer.

EXAMPLE II.

A power of 68 lbs. moving at the rate of 200 feet per minute is applied to pull a certain weight up an inclined plane 37 feet long, and 12 feet high, at the rate of 50 feet per minute. What weight will this power be sufficient to draw up ?

As 12 : 37: :68×200 : 50×$838\frac{4}{6}$

$$\frac{68\times200\times37}{12\times50}=\frac{503200}{600}=838\tfrac{4}{6}\text{ lbs. weight.}$$

The inclined plane has been successfully used for raising the largest ships from the water. Iron rails are laid sloping beneath the water, over which the vessels are floated. A bed or cradle of strong timber provided with numerous small wheels, supports the vessel as she is gradually drawn forth by the power of one or more horses operating in a circuitous path, turning by means of a lever the vertical axis or capstan, the effect of which is greatly increased by means of wheel work.

The Wedge.

The wedge operates in a similar manner to the inclined plane, and the calculations for its power are subject to the same rules. In the one case the double inclined plane (the wedge) moves, and in the other the inclined plane remains fixed.

When the power acts perpendicularly upon the head of the wedge, the power is to the pressure on each side of the wedge, or the resistance, as the head of the wedge is to its side ; hence it is evident the thinner or sharper the wedge, the greater will be the power gained by the use of it. In the application of the wedge, additional power

* Allowance must be made here as in all cases for resistance of friction.

is gained when the split or rift opens, each side of which forms levers to facilitate the further entrance of the wedge into the rift. The wedge being seldom used as a power except for splitting wood and stones, and the resistance depending so much upon the various qualities of the materials upon which it is used, no calculations can be made with accuracy of its general practical effects.

The Screw.

The screw is chiefly used to obtain great pressures, or by its opposite action to raise heavy weights. It is considered as operating on the same principle as the inclined plane. The length of the inclined plane is the circumference of the cylinder, and the height the distance between the threads of the screw, commonly called the pitch. The rule therefore for calculating its power is, As the circumference of the screw to the distance between the threads, so is the weight to the power.

When the Screw turns, the cord or thread runs in a continued ascending line round the centre of the cylinder, and the greater the radius of the cylinder, the greater will be the length of the plane to its height, consequently the greater the effect.

A lever fixed to the end of a screw will act as a lever of the second order, and the power gained will be as its length to the radius of the cylinder: or the circumference of the circle described by it, to the circumference of the cylinder. Hence an addition to the rule is produced, which is—If a lever is used, the circumference of the circle described by the end of the lever is taken for, or instead of the circumference of the screw.

EXAMPLE I.

What is the power requisite to raise a weight of 8000 lbs. by a screw of 12 inches circumference and 1 inch pitch? As 12 : 1 :: 8000 : $666\frac{6}{12}$ lbs.=power at the circumference of the screw.

EXAMPLE II.

How much would be the power if a lever of 30 inches were applied to the screw?

The Lever of 30 inches=the radius or $\frac{1}{2}$ the diameter of the circle. The whole diameter is therefore 60 inches. As 7 : 22 :: 60 : $188\frac{4}{7}$ inches circumference of the circle described by the end of the lever. As $188\frac{4}{7}$: 1 :: 8000 : $42.\frac{560}{1320}$ lbs.=power, with a lever 30 inches long, Answer.

In calculating the practical effect of the application of power to common wooden screws, about $\frac{1}{2}$ of the theoretical result should be taken, as the resistance from the friction of the wood is excessive; but in the use of iron screws about $\frac{1}{3}$ of the theoretical power is thus lost. Screws have of late been successfully employed in raising ships from the water, as an economical substitute for the inclined plane, or marine railway.

When the threads of a screw are fitted to enter the teeth or cogs of a wheel in such a manner that each revolution of the screw brings a fresh cog forward into action, thus causing the wheel to turn slowly but constantly, it is termed the "perpetual screw." A great gain in the effects produced by the moving power is obtainable by the use of the perpetual screw. It has been found, however, in practice to be attended with so much friction and wear from the rubbing of the threads of the screw against the teeth of the wheel, that it is only used for machines operating with little stress. When used in mill geering and in heavy machines, the utmost attention is required in supplying oil to diminish friction. In several instances within my knowledge the threads of heavy iron screws have been destroyed by friction in a few hours, after they had once begun to wear.

HYDRODYNAMICS.

The pressure and force of Watery Fluids.

The term *Hydrodynamics* is derived from the Greek words signifying *water* and *power* or *force*, and is applied to designate that branch of natural philosophy which embraces the various phenomena exhibited by water and other fluids whether in motion or at rest It treats also of the construction of machines made to act upon water or other fluids, or to be acted upon by them as first movers. This branch of science, like that which treats of solid bodies, is generally subdivided into two classes called *Hydrostatics* and *Hydraulics*. The former considers fluids in the state of rest, resulting from the equal pressure of all their component particles, and the latter considers the motion and action of Fluids upon various machines or constructions, and also the formation of such machines or constructions as will sustain this action to the best advantage. For the derivation of the terms see page 154.

A *Fluid* is composed of material particles so slightly connected together by cohesion as to be readily transposed or separated by the least force, the peculiar motion of which is termed *flowing*.

In practice, water is the principal fluid to which this branch of science is commonly applied, although the same rules and principles are applicable to aerial fluids or gases, viscid fluids, and even to certain solid bodies having only a degree of fluidity, as the sands of the hour glass, and other similar substances. The aeriform fluids possess a remarkable degree of elasticity and compressibility, that renders their mechanical properties and action very different from those of liquids, which are nearly unelastic or incompressible. For this reason the mechanical properties of air are treated of distinctly under the title *Pneumatics*.

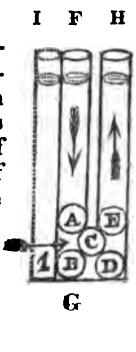
All fluid substances are probably composed of particles of a globular form; particles possessing irregular points or angles cannot so readily move over each other, and if mingled with fluids, either render them viscid or destroy fluidity. When the particles of fluids lose their globular form, as is the case when the metals, water, &c. undergo the process of crystallization, they are converted to absolute solids. Fluidity, as before stated at page 60, depends upon modifications of temperature, as almost all solids may be converted into fluids, and all fluids except alcohol have been reduced to the solid state.

The weight of fluids is as their quantities of matter, as is manifest,—each particle having weight of itself, and the weight being as the number of particles. The weight of given quantities of water is as follows:

1 cubic foot of rain water weighs 1000 ounces or 62½ lbs. Avoirdupois, at the temperature of 50° of Fahrenheit. See Specific Gravity, page 15.
1 cubic foot do. at the temperature of 60° weighs 62.353 lbs. the expansion by heat reducing its weight.
1 wine gallon of rain water, at the temperature of 50°, weighs 8⅓ lbs. avoirdupois, or
12 wine gallons do. weigh 100 lbs. avoirdupois.—See note, page 147.
1 English Imperial gallon of water weighs 10 lbs. avoirdupois.
1 cubic inch of distilled water at the temperature of 50° of Fahrenheit weighs 253 grains.

All the particles of a fluid being disposed to yield on the slightest difference of pressure, if every particle throughout the mass at the points of contact with adjacent particles were not pressed equally in all directions it would not remain at rest.—In a fluid at rest it follows, then, that if the particles press equally in all directions, they must press *laterally* or *sideways*, and even *upwards*. That fluids exert a lateral pressure may be practically demonstrated by holding the hand against the orifice in the side of a vessel filled with water. The upward pressure of fluids may be rendered remarkably evident to the senses by thrusting the hand into a basin filled with mercury.

The upward and lateral as well as the perpendicular pressure of fluids may be explained upon the principle before stated, that the particles of fluids are spherical, and separable and moveable by the slightest force.



Suppose F G H to be two upright tubes communicating with each other at the bottom. Let A B C D E represent the infinitely small globular particles of water with which the bended tube F H is filled. The globule A is pressed downwards with a force equal to the weight of water in the tube F, which weight is as the number of particles or height of the fluid above A. The globule being moveable by the slightest force, has a tendency to descend under the operation of this pressure. In the order in which spherical substances naturally arrange themselves, A cannot descend without operating as a wedge and crowding between the side of the tube and the particle C, which must be displaced the instant A begins to move, and must in turn displace the particles in contact with C on every side, because the elasticity or compressibility of the particles of water has been found to be so small as not to require being taken into account in calculations in Hydrostatics.

The weight or pressure of the column of water F will therefore be instantly transmitted through A C to act upon the inferiour particles with the additional weight of the particles A C. The particles B D will be crowded asunder by the force of C so as to act laterally against the sides of the tubes. The perpendicular action of A pressed between the side of the tube and C has at the same instant a tendency to press C laterally, and to force it between the particles E D, as a wedge. The least movement of A will therefore have immediate effect in forcing C between E D, and in pressing *upwards* the particle E, and reacting *downwards* upon D. The same results are familiarly observable when a ball, as in billiards, comes in contact with two other balls in passing between them, giving to each of the two a lateral motion. Were the tube H empty, the particle E having no force pressing it downwards but its own weight or gravity, would continue to ascend as long as the succession of particles at C press against those at E with a greater force than the weight or resistance of the superincumbent column of fluid in H. When the particles are forced up in H as high as in I, that is, when the fluid rises in H to a level with that in F, the pressure upon E and A will be equal, and consequently upon each side of C, which will then remain at rest. If there be an excess of pressure in either tube the particles at C will move either way and continue to *flow* until the equality of the pressure be restored.

The equal pressure of fluids appears to be susceptible of mathematical demonstration, by the rules that apply to the composition and decomposition of forces, by supposing the spherical particles to be represented by equal contiguous circles, and the pressure or forces acting and reacting upon them to be represented by the sides and diagonals of equilateral parallelograms described from centre to centre of each.

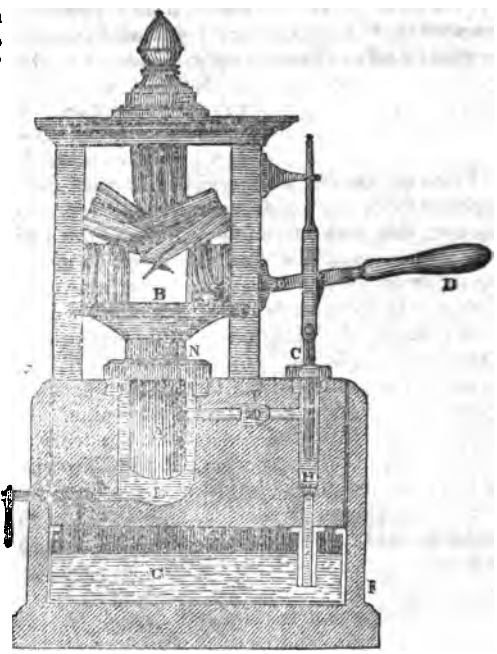
We have been thus particular in showing the pressure which exists among all the particles of any fluid in contact with each other or with solid bodies, because *equal pressure in every direction* is the fundamental principle of this branch of science, and nearly all we have to offer on this subject is a repetition of this principle as it is applied in various ways. It is expressly for considering the equal pressure of fluids that they are usually treated of distinctly from solid bodies. For this reason fluids will rise to equal heights in each end of bended tubes, as shown at F H, whatever may be the elevation of them—even if F H represented the altitude of two lofty mountains and the point C the lowest depths of an intermediate valley. The water from a fountain on the top of one of them, after descending in a pipe to the vale, would rise in the other end of the pipe, were it conducted up the side of the opposite mountain, to a level with the fountain from whence it flowed.

It has been generally supposed that the ancient Romans were ignorant of this fact, because they constructed their aqueducts for supplying their cities with water without regard to it. They formed level channels, raised upon successive tiers of arches to great heights across vallies, for the water to flow with a gentle open current. It can hardly be supposed that they were ignorant of this palpable fact when it appears that they made use of pipes to convey water, and were well acquainted with the principles that govern the motion of fluids in these pipes, from the laws which they established for regulating the length as well as the diameter of them for certain distances from the aqueducts, in order to equalize the distribution of the water by rendering the discharges uniformly retarded by friction. It seems quite as probable that they were compelled to erect these aqueducts from an inability to form pipes of sufficient size for conveying the vast quantity of water required for the supply of a great city. London at the present day derives its principal supply of water by an open channel or stream called the New River, which is conducted more than twenty miles across the country to that capital. It has proved one of the most profitable as well as one of the most useful hydraulic works of modern times. The water-works on the Schuylkill for supplying the city of Philadelphia with water are constructed upon a magnificent scale, and are creditable to the taste as well as to the skill and enterprise of the inhabitants of that city. In comparison with these works, those of Marli for supplying the fountains of Versailles, although constructed by a monarch having under his control the wealth of a nation, appear humble and insignificant.

One of the most surprising facts in Hydrostatics results from the *equal pressure* of fluids upon the surfaces exposed to the action of them. If one single particle of a mass of any closely confined fluid be subjected to a certain pressure, it will transmit the pressure to every particle of the mass, and against every part of a solid in physical contact with them. By means of the pressure thus diffused through a mass of fluid by the weight of only a pound of water, a weight of several thousand tons may be sustained. This principle may be illustrated by referring to the preceding figure. The equilibrium of the particles of the fluid in the bended tube F H, it is shown, takes place when they are on a level in each; that is when the pressures at A and E are equal. This will take place without regard to the form of the tubes or the size of them. If the side F represent the whole Atlantic ocean, and the fluid in H a column of equal height but only an inch in diameter, the equilibrium would remain undisturbed, as the particles at C would receive an equal pressure from their physical contact with the particles at E, acted upon by the height or pressure of the column H, as from contact with the particles at A. Suppose the mass of particles enlarged to any extent on the side F G, they would react upon the particles in the column F A with the same effect only as the side of the tube itself, because all the particles in F press against the side of the tube in proportion to the height of the fluid, and precisely the same effect would be the result of the pressure against the other side of the tube by the fluid in I. On removing this side of the tube, and substituting in place of it the fluid in I, they will exactly counterbalance each other—things equal to the same being equal to one another. The weight of the fluid in both I and F will therefore have no more effect upon C than that contained in F alone. Consequently the column H E sustains by its pressure on C, or any number of particles represented by C, the two columns of fluid, F, I, in equilibrium, although of infinitely greater weight than the actual weight of the fluid in H; and in the same manner it may be shown that the pressure of H E would sustain any number of columns of fluid each equal in height and weight to itself. If the column of water in H presses upon E with a force equal to 10 lbs. the fluid in all the other upright tubes communicating with it through C will be supported at the same height as in H; that is 10 lbs in H will sustain an equal weight in any given number of tubes. If there were then 1000 tubes of the same diameter as H and connected with it by C, the force of 10 lbs weight of water in H would counterbalance the same column of water, that is the same weight, in each of the 1000 tubes. $1000 \times 10 = 10{,}000$ lbs. pressure would thus be actually counterbalanced by only 10 lbs. applied in H to act upon C. *A quantity of water, however small, may be thus employed to balance a quantity of water, however great.*

This principle, from its surprising effects, has been called the *Hydrostatical paradox*, because it is a truth apparently contrary to the ordinary laws of nature, which govern the equilibrium of all material substances. The *Hydrostatic Press* is constructed upon this principle, being one of the most simple and beautiful machines for producing vast mechanical effects by means of a fluid. It illustrates most perfectly the axiom, that what is gained in Power is lost in Velocity, as the end of the lever D, connected with the force pump, traverses many feet to impart a motion to the moveable piston B A, that is scarcely perceptible.

The parts of the Hydrostatic Press are usually constructed of iron properly secured to preserve it in an erect position. A B represents a moveable piston fitted to the neck N so as to be water tight, and at the same time to allow the piston to slip up and down freely through it in the chamber L. The cap of the piston B is surmounted by a strong table to receive the articles to be subjected to the pressure, which takes place by the rising of the piston. A small tube connects the chamber of the cylinder L with that of a small force-pump H, having at the part I a valve opening towards the cylinder. D is the handle of the force pump C H, by which the water contained in the cistern G is drawn up through the valve at H and is forced through that at I into the cylinder L, and under the piston A.—Another valve is placed at K, which, when not confined by the adja-



cent screw acting upon it, allows the water to flow back again thro' the pipe M into the reservoir G. As the water is thus gradually drawn off, the piston A will descend and relieve the action or pressure. The pressure of the water upwards against the bottom of the piston at L will be to the pressure upon the water in H by means of the piston rod C, as the size of the under surface or bottom of the great piston A is to that of the small force pump H. The effect therefore is the same as in the preceding figure where the pressure is considered as arising merely from the weight of a column of fluid in H pressing against and sustaining 1000 or more columns of fluid of equal height and weight. If the piston C is ½ of an inch in diameter, and the cylinder A one foot, the pressure of the water on the bottom of the cylinder will be to the pressure of the smaller piston on the water at H as a square foot to a quarter of a square inch, that is, as 144 inches to ¼ of an inch, or as 576 to 1 ; if therefore the pressure of a ton weight be given by means of the lever D, the cylinder A will be moved or forced upwards against whatever is placed in the space above it, with the weight of 576 tons. By doubling the size of the bottom of the piston L N, double this effect will be produced by the pressure of the same force pump upon the water in H, or by doubling the power, by means of an extended lever applied upon the handle D, double the pressure will be transmitted by the water against the bottom of the piston A. Thus the mechanical effect of pressure may be increased without any other limits than the strength of the materials of the machine to sustain it. If a pressure of one ton be given by the force-pump of a quarter of an inch, and the piston A be a yard in diameter, the pressure upwards will be equal to the weight of twenty thousand seven hundred thirty-six tons. This great force, too powerful for the strength of any materials which we can employ in the construction of the machine, may be exerted or brought to bear upon one point by the agency of less than one pint of water. The purposes to which these presses are usually applied rarely require a force above five hundred tons pressure, and consequently in practice these machines are calculated to sustain the stress produced by about double of this weight, or ten or twelve hundred tons.

Water Level.

From the facility with which the particles of fluids yield to the slightest force impressed upon them, it follows, as a necessary consequence, that under the action of a uniform force, like that of gravitation, every particle will arrange itself so as to settle into *a level* with the adjacent particles, neither rising above nor sinking below them. The construction of *Levelling Instruments* depends on this principle. The fluid usually selected for this purpose is Alcohol, or spirit of wine, with which a glass tube is nearly filled, leaving in it a bubble of air. The orifice of the tube is then hermetically sealed, or closed by being melted by means of a blow-pipe. When the instrument is adjusted, the air bubble stands in the very middle of the tube. If the tube be not exactly level, the bubble will rise to the higher end. A telescope is attached to the tube with spiders threads stretched across the glasses to serve as sights. A socket joint, like that of a common surveyor's compass, allows of a motion in every direction, as the four screws in the parallel brass plates are operated to elevate or depress either end.

This instrument is principally employed in levelling roads and the beds for canals, and in ascertaining the descent of water courses for hydraulic works. When used it is set up like a surveyor's compass firmly upon its legs, and the tube is turned so as to stand directly above two of the screws in the parallel plates. By raising or depressing these screws the bubble is soon adjusted to maintain its position in the middle of the tube. The instrument is then turned horizontally on its pivot one fourth of a circle, or at right angles with its former position, when the tube will lie directly above the two remaining adjusting screws. The bubble is again brought by the screws to the middle of the tube, after which the instrument may be turned horizontally in any direction, and all objects that appear intersected by the cobweb stretched across the glasses will be on a level with the eye of the observer. The assistant may now take his position at a proper distance from the instrument, and hold up a staff erect upon the spot selected for commencing the survey, applying at the same time to the staff a sliding vane, or a piece of delicately folded white paper. The observer directs the assistant to slip the vane up or down till the white line appears to be intersected by the sights. He then measures the height of the vane from the ground, water, or other object, the level of which it is desired to ascertain, and notes it. The assistant is then directed to take another position favourable to the object in view, and to hold up the staff and vane, the height of which from the ground is measured as before. If the distance be short and only one station be required, the difference of the heights measured on the staff shows the ascent or descent between the two spots on which the staves were placed.

It is commonly necessary to take several stations with the level, in which case prepare three columns, one for registering the number of stations, and the other two for the measures of the heights taken on looking back and forward to view the vanes held by the assistant. Particular attention should be bestowed that the assistant change not his position, or that of the bottom of his staff, while the observer is moving his instrument from one station to another. The operation will thus go forward like a series of ascending or descending steps, and the calculations assume the form as in the following

EXAMPLE.

Stations.	Back Heights. *feet.*	*inches.*	Fore Heights. *feet.*	*inches.*	
1	4.	0.	2	6	
2	5.	4.	7	3	
3	0.	0.	3		*ft. in.*
	9.	4.	12.	9—9.4=3	5 descent.

The fore heights being greater, there is a descent below the apparent level of 3 feet 5 inches from the starting point, to the last point upon which the staff was placed. It should here be observed that there is a difference between the *true* and *apparent* level, caused by the curvature of the earth's surface. In levelling a mile, therefore, an error would be made, by the most accurate instruments, of about 8 inches, for the very obvious reason that the masts of a distant ship disappear below the *apparent* level of the ocean, although it is well known that the ship continues on the *true* level of its surface.

The curvature of the earth being nearly 8 inches to the mile, the following rule will give the proportionate allowance that should be made for any shorter distance. An English mile being 1760 yards, the square of this number is 3.097.600, which being divided by the diameter of the earth 13953280 yards, (expressed in the same measure) gives 0.222 of a yard, nearly; which being multiplied by 36, the number of inches in a yard, the product is 7.992 or nearly 8 inches.

RULE.

Then as 3097600 : 8 inches : : so is the square of any other distance: to the correction or allowance that should be made for curvature of the earth's surface.

Liquids of different weights, as water and quicksilver, will not stand at equal heights in bended tubes, formed like the letter U, if the quicksilver be made to occupy one branch of the tube, and the water the other. Mercury being 13½ times heavier than water, the relative heights of the respective columns will be to each other as their weights, that is, a column of mercury one inch in height will support a column of water 13½ inches high in the opposite branch of the tube. This effect will take place whatever may be the difference of of the size of each arm of the tube, or the relative weight or quantity of fluid in each. A ton of quicksilver may form the column one inch high in the larger branch of the U, and an ounce of water contained in the smaller branch will counterbalance it, provided only that the height of the column of water be 13½ inches.

Floating Power of Fluids.

The upward pressure of fluids against the bottom of any substance floating upon its surface is precisely equal to the weight of fluid displaced by such substance. This may be readily demonstrated by weighing any light body that will float, and placing it in a vessel filled exactly to the brim with water, and so situated that all the fluid which runs over the sides may be readily collected and weighed. A quantity of water will be displaced equal in bulk to the portion of the floating body immersed in it. If the water that runs over the brim be carefully collected and placed in one scale of a balance, and the floating substance itself in the other, they will exactly counterpoise each other. It is thus with a ship and cargo, which displace a quantity of water equal in weight to that of the ship and its contents. The reason of this is evident; for the particles of water in immediate contact with a floating body sustain the same pressure or weight whether they react against the mass of a ship of 500 tons, or against the mass of particles of the same fluid, occupying the same space, and weighing also 500 tons. In both cases the *upward* pressure must be equal to sustaining this weight, which is in effect the downward pressure; otherwise the mass would be projected from the surface of the fluid or would sink beneath it. This may be illustrated by taking a cubic foot of any heavy wood, and adjusting it to weigh 1000 ounces, which is the weight of a cubic foot of water. This cube of wood will remain at rest in any part of the water in which it may be immersed. Another cubic foot of wood weighing 500 ounces will settle into the water until one half of its bulk becomes immersed, as it will then displace half a cubic foot of water, which weighs 500 ounces. If the same cube of wood be now filled with lead until its weight amount to 1100 ounces, it will sink in the fluid, because the downward pressure exceeds by 100 ounces the upward pressure exerted by the inferiour particles, which yield, and are consequently displaced by it.

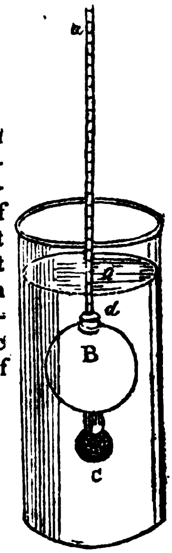
From the obvious fact that a solid body displaces a quantity of any fluid, in which it may be immersed, exactly equal to its own bulk, recourse may be had to a simple expedient for ascertaining or measuring the contents or bulk of substances of irregular dimensions, which cannot be readily calculated in any other way. It is only necessary to fill a tub or cistern to the brim with water, and to plunge the solid body to be measured into it. The water displaced by it will run over the brim, and must be carefully received into some suitable vessel to retain it The number of gallons, pints, &c. may be readily ascertained by the common wine or beer measures. By referring to the

Tables of Measures, at page 113, it will appear that the solid body contains as many cubic inches as there are cubic inches in the gallons or pints, &c. of the fluids measured.

It follows from these principles that if any body be weighed in the air, and then weighed in any liquid lighter than itself, it will appear to lose as much of its weight as an equal bulk of the liquid weighs. Thus if a piece of lead weighing a pound be suspended by a thread from one end of a scale beam and balanced, and be then allowed to sink in a vessel filled with water to the brim as before observed, a number of grains, equal to the weight of water which runs over the sides of the vessel, must be taken out of the opposite scale to restore the equilibrium. By weighing various bodies in the water their relative weights, called their *specific gravity* may be ascertained. See specific gravity, page 15.

The same principle also enables us to ascertain the specific gravity of the various fluids themselves compared with distilled water, which is taken as the unit standard. A cubic foot of water weighs 1000 ounces, and a cubic foot of Alcohol or spirit of wine weighs 835 ounces. In what is called *proof spirit*, it is required that the constituent parts of water and spirit should be equal, which gives a specific gravity of about 923 ounces to the cubic foot. The degree above or below proof is usually denoted by the number of gallons of water to be added or taken from 100 gallons of the liquor to bring it to the *proof* standard.

An instrument called the *Hydrometer*, a term derived from Greek words signifying the *measure of water*, is used for ascertaining expeditiously the relative proportion of alcohol contained in spirits. If mixtures of alcohol and water be made in various proportions, and thin glass or metallic balls be placed in each of the mixtures, by marking the points at which they remain immersed, and by noting the known proportions of alcohol and water in each case, similar unknown mixtures of alcohol and water may be ascertained by trying in them successively these floating balls. When any one of them is found to settle into the mixture to the mark thereon, it may be calculated that the mixture contains the same quantity of alcohol as noted in the previous experiment made with the same ball, provided the heat or temperature of the liquor be the same in both experiments. Instead however of using a large number of such balls, a single one with a long graduated stem is employed, upon which delicate weights may be lodged to cause the ball and some part of the stem to sink in any mixture of less specific gravity than pure water. B is the ball and *a* the stem of the Hydrometer. The weights placed upon the stem, with the subdivisions or lines marked on the side of the same, will indicate, in the same manner as the separate balls, the specific gravity of the liquid, and consequently its proportion of Alcohol. It is always used with a thermometer, as the temperature of the liquor has an important effect upon its specific gravity, which is denoted by a sliding scale accompanying the instrument.



This instrument, however, does not always give an accurate result in all cases, because when two substances of different specific gravities are mixed together, an arithmetical mean of the specific gravities of the two ingredients does not take place. Thus a pint of water and a pint of spirit of wine or alcohol do not make a quart, but *fall short of it* about $\frac{1}{40}$ part. On the other hand the bulk of substances is sometimes augmented. A cubic foot of lead melted with a cubic inch of tin, will make more than two cubic inches of the metallic compound.

RULES

For calculating the pressure of Fluids upon the bottom and sides of cubical and cylindrical vessels, and upon floodgates, embankments, pipes, &c.

The perpendicular pressure of any heavy fluid against the bottom upon which it rests is as its depth; for the pressure is as the weight, and the weight is as the height. Hence the following Rule is derived.

Rule for finding the pressure upon the flat bottom of any vessel, or upon the flat surface of any substance whatever immersed in a fluid.

Multiply the height of the column of fluid by the extent of surface on which it presses, and the product gives the mass which presses with the same weight as the fluid standing on that surface.

EXAMPLE.

What is the pressure upon the level bottom of a reservoir of water which by the plumb line is 10 feet deep, and is 30 feet square, the sides being perpendicular?

$30 \times 30 = 900$ feet area of the bottom.

$900 \times 10 = 9000$ cubic feet of water contained in the reservoir.

$9{,}000 \times 62\frac{1}{2}$ (the weight of each cubic foot of water)$=562{,}500$ lbs. answer.

To find the pressure of water against the perpendicular side of any Solid Body.

At a point in the side of a vessel midway between the surface of the water and the bottom, the pressure must be exactly half of what it is upon the bottom, because only half of the number of particles, that is, half of the height of the column of water is above this point. The perpendicular side of a cubical vessel filled with any fluid therefore sustains a horizontal pressure equal to one half of the weight of the column of fluid, that rests against it or upon an equal area of the level bottom. Above the middle of the side the pressure regularly diminishes to nothing, and below, it as regularly increases to the bottom of the vessel. This point, taken half way of the perpendicular height, will therefore give the medium horizontal pressure.

RULE.

Multiply the area or extent of surface exposed to the pressure of the fluid by half its depth, and the product will give the whole pressure the side sustains.

EXAMPLE.

If the gate of one of the Liverpool docks is 21 feet deep and 35 feet broad, what pressure does it sustain when the dock is full of water?

$35 \times 21 = 735$ feet, area of the gate, multiplied by $10\frac{1}{2}$ feet, one half of the depth of water resting against it, gives a product of 7717 cubic feet, each weighing $62\frac{1}{2}$ lbs.

$7717 \times 62\frac{1}{2} = 482312$ lbs. $\div$ $2240 = 215$ tons, 6 cwt. 1 qr. 12 lbs. pressure against one of the gates of the Liverpool Docks.

The pressure against this gate would not be greater if it confined the waters of a lake, and it would not be less if a thin column or sheet of water only an inch thick were made to rest against the whole surface of it, provided the *height* of the water were the same in both cases.

Each of the sides of a cubical vessel filled with water sustaining a pressure equal to one half of that upon the bottom, the four sides therefore sustain twice as much pressure as the bottom, and the four sides and bottom together, sustain a pressure equal to thrice the weight of water contained in the vessel.

The pressure of fluids against the perpendicular sides of a cylinder, or circular cistern, may be found by multiplying the curve surface by one half of the depth. The stress which takes place upon the hoops of a cistern may thus be calculated.

EXAMPLE.

What pressure do the hoops upon a circular cistern sustain, which is 96 inches diameter and 10 feet deep, when the cistern is filled with water?

First find the circumference by Problem 7, page 121.

7 : 22: :96 : 301 inches=nearly 25 feet, circumference of the cistern: 25×5 = 125×62½ = 7812½ lbs. pressure sustained by the hoops of the cistern.

Pressure of Fluids on oblique surfaces.

The pressure exerted by a heavy fluid against an oblique plane surface has for its measure the product of this surface into the distance of its centre of gravity from the surface of the fluid.

EXAMPLE.

What pressure will a board sustain, placed in a sloping direction, or diagonally through a vessel 9 feet deep, the bottom of which is 12 feet by 9 feet?

First find the length of the diagonal, by taking the cube root of the square of the bottom and side of the vessel.

12×12=144
9×9=81
225, the cube root of which is 15 feet = the length of the diagonal board.

15×9 = 135 feet area×4½ (one half of the depth of water) =607½× 62½ = 37969 lbs. pressure.

Upon this diagonal board there is both a *horizontal* pressure, equal to ½ of the weight of the column of water resting against it laterally, and also a *perpendicular* pressure equal to the average height of the mass of superincumbent fluid. The action of these two forces upon this diagonal board, which bisects the vessel and sustains one half of the fluid, imparts a pressure greater than ½ of the weight of the fluid. The area of the bottom is 12×9 and the whole weight of water upon it is 60750 lbs. one half of which is 30375 lbs.

37969—30375=6594 lbs. excess of pressure sustained by the diagonal board, being nearly equal to ⅛ of the weight of all the water which the whole vessel contains.

To prove the strength of vessels, pipes, &c. by the pressure of water.

For this purpose a small force pump is generally used, by which water is injected into the pipe or vessel to be proved, until the safety valve connected with it rises with the weight imposed upon it. Thus if it be required to prove the strength of a new boiler for a steam engine without incurring the danger, which would attend the bursting of it were steam to be employed for this purpose, it is only necessary to load the safety valve with as many pounds to each square inch of its surface as is intended for the test of the strength of the boiler. If the safety valve contain exactly an area of one square inch, and be loaded with the weight of one hundred pounds it is manifest that when it is lifted, the pressure of the water against every square inch of the interiour of the vessel must be equal to the weight with which the valve is loaded, the pressure of fluids acting equally in all directions. Even the strength of cannon may be tested in this way. During this experiment, it is stated, the drops of water ooze through the pores of the cast iron, and collect like a fine dew upon the surface of it.

Water pipes are calculated to stand a certain pressure, which is commonly estimated by the weight of a column of water of any given number of feet of perpendicular height. The safety-valve is generally made circular, 1 inch in diameter, and is loaded with a weight equal to the pressure required. For example,

It is required that a pipe should be able to sustain the pressure produced by a column of water within it 300 feet high, what weight placed upon the circular safety-valve, one inch in diameter, will be equivalent to this pressure?

300×12=3600 inches×.7854 (decimal of an inch contained in the area of a circular safety-valve 1 inch diameter) =2827.4400×1000 (ounces wt. cub. foot of water)÷1728 (No. of inches in cub. foot)= 1636¼ oz. or 102 lbs. 4¼ oz. weight required upon the safety-valve.*

The pressure of a column of water 50 feet high upon a circular safety-valve 1 inch diameter is 17.06 lbs. Hence, by the Rule of Proportion, the pressure of any other column of water of a given height may be found.

What is the pressure of a column of water 300 feet high upon a circular safety-valve 1 inch diameter?

As 50 : 17.06::300 : 102$\frac{36}{100}$ lbs. answer.—

In the United States wooden pipes are often used to convey water from fountains situated upon the side of some hill or mountain at considerable elevations above the level where the water is distributed for use. When the vents are all closed these pipes become filled, and are subjected to great stress, or are frequently burst, by the pressure of the column of water. In such cases, by means of a safety-valve constructed at a trifling expense, the pressure of the water may be exactly gauged to the strength of the pipes. The same observations apply with still greater force to the conveyance of water by the flexible leather tubes, or hose, usually employed in extinguishing fires, the bursting of which at some critical moment is attended with most disastrous consequences. In common fire engines operated by men there is less danger of bursting the hose than in Mill-Hydraulions, or force pumps operated by a water wheel or steam engine. In the latter case there is but little chance of a judicious application of the proper degree of power, and without the safety-valve to relieve and regulate the stress upon the hose, a degree of uncertainty must attend the operation of these useful hydraulic machines.

HYDRAULICS.

Hydraulics is that branch of Natural Philosophy, which treats of the *motions* of fluids, whether issuing from orifices in reservoirs, projected obliquely, or perpendicularly in Jet-d'eaux, or moving in

* For ordinary calculations the area of a circular safety-valve 1 inch in diameter may be called four fifths of a square inch. The pressure per square inch may be found by multiplying the number of pounds, with which the valve is loaded, by 5 and dividing the product by 4.

Rivers, canals, pipes, &c. It treats also of the action of fluids upon various solid bodies or machines, and of the action of machines upon fluids.

The motion of fluids is remarkably distinguished from that of solids; for when a solid substance moves, the whole mass moves together; but a fluid substance may be in motion, while some part of the mass may be at rest. The want of cohesion among the particles of fluids, as before observed, renders it necessary to support them laterally, to prevent them from spreading asunder. Thus although a mass of fluid produces no greater downward pressure than the aggregate of its own weight, in which respect its pressure resembles that of solid bodies, yet it exerts at the same time a lateral pressure. It is obvious, therefore, that peculiar constructions must be formed or adopted to resist the motion of fluids and to sustain their pressure.

This subject may be considered under the following heads:

1st. The natural motion of Fluids through various apertures, channels, pipes, &c., and the effective force imparted by this motion to various machines.

2d. The artificial modes of imparting motion to fluids by means of machines, as pumps, and other hydraulic engines.—

Before entering upon the subject of the motion of fluids, it may be proper to consider the resistance to their motion, which takes place from friction.

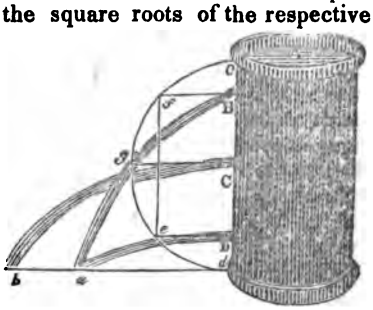
Friction of the particles of Fluids.

A certain degree of *friction* has been found to attend the motion of the particles of fluids in passing over solid bodies. This is observable in rivers, the currents of which at the bottom and sides are slower than at the central part of the main current. The friction of the particles composing the lower portion of the waves, which roll upon the sloping sands of a beach, causes the motion at the bottom to be retarded, while the tops of the waves still continue to oscillate freely, and to advance beyond their base, when they pitch forward upon the shore in wreaths of snow white foam. The friction of water in long pipes is so considerable, that it is necessary to make them $\frac{1}{5}$ larger in size than is required in theory—otherwise the actual discharge of water will be less than the calculated discharge. The particles of water in immediate contact with the sides of the pipe are supposed to form nearly a stationary lining over which the main current rolls with diminished friction. Sudden or sharp turns in currents of water tend also greatly to impede their motion. The friction of the particles of fluids upon each other is extremely small, as may easily be imagined when it is known that a power not greater than an ounce weight will put in motion a mass of many hundred tons floating or resting upon them.

On the discharge and motion of fluids through various orifices, apertures, pipes, &c.

There is a great difference between the theoretical calculations of the motions of fluids, and the results obtained in practice. In theory the velocity with which a fluid is discharged from the bottom or side of a vessel is calculated to be equal to that acquired by a heavy body in falling through a space equal to the height of the fluid above the orifice. This velocity as shown by the table at page 12, is as the square roots of the height. According to some very accurate experiments of Bossut, the actual discharge through a hole made in the side or bottom of the vessel, is to the theoretical, as 1 to 0.62, or nearly as 8 to 5. The discharge is therefore, in some cases, so much diminished by friction against the sides of the orifice that it is actually only 5-8ths of the calculated discharge. By varying the form of the orifice, the actual discharge of fluid is materially affected, being increased by means of short tapering tubes to nearly 7-8ths of the theoretical discharge.

The pressure of a fluid against the side of a vessel increases regularly with the depth below the surface, as before stated, but the quantity of fluid discharged when orifices are made at different depths in the side of the vessel are as the square roots of the respective depths. If a hole be made in the side of the vessel of water as at D, the whole pressure of the column above it, D A, will cause the water to gush out from D with the same force as if the water had been a solid, descending from A to D; that is, *as the square root of the height* A D. For the same reason, the water gushing from other orifices, as C



and B, would run in quantities and velocities proportionate to the *square root* of the depth of such orifices below the surface of the fluid. If the orifice D be four times as deep, below the surface A, as the orifice B, the quantity of water that issues from D will be to that which issues from B as 2 to 1, 2 being the square root of 4. So in like manner if D had been nine times deeper than B, 3 times the quantity of water would spout from D that would spout from B in the same time.

If a semicircle *d g c* be described upon the side of the vessel, so that *c* C *d*, may be the perpendicular diameter, and c the surface of the fluid, any lines drawn from this semicircle perpendicular to the side of the vessel, as *f* B, *g* C, and *e* D, will be proportionate to the horizontal distances to which the fluid will spout from the holes made at B C D. The curvilinear descent of the fluid at B *g a* will form a *parabola*, because it is impelled by two forces, one of which is the pressure of the fluid, which causes it to spout laterally, and the other is gravitation, which acts perpendicularly. If the water in the vessel be allowed to issue at D until the vessel is exhausted, the velocity of the stream gushing out will be uniformly retarded as the water subsides, whereby just double the time will be required to discharge the same quantity as if the vessel had been kept full.

The currents in rivers according to theory would be most accellerated near the bottom, for the reasons before stated; but the friction of the waters of a river upon its bed or channel retards the velocity so much by the eddies, &c. that the top of the stream actually moves fastest.

The following rules and tables for measuring the quantity of water running in rivers are extracted from Ree's Cyclopedia, and are of great importance in calculating the effective power of rivers with a given fall for various hydraulic works.

Directions for measuring the quantity of water running in a river or Canal.

Choose a part of the channel where the banks are of a determinate figure, and where they contract the channel to a uniform breadth and depth for a distance of thirty or forty feet or more, the longer the better, and the more regular the bed of the river, the more exact will be the result of the experiment.

Measure the breadth and average depth of the river, to find the area or section of the passage through which the water flows. Take these measures at several different points, and if there be any difference at different places, find the area at each place, and take the average between them. Then proceed to find the velocity of the motion by throwing into the stream any substances of the same specific gravity as the water, such as pieces of turnips, gooseberries, &c. which will sink to different depths in the stream, and will indicate the velocity of the current at such depths. These trials must be repeated several times, and the mean of the different results must be taken for the average velocity of the stream. The portion of the river selected for the experiment should be marked by strings stretched across it, by which the observer is enabled to note more accurately the instant when the floating substances pass the upper line and reach the lower one. By a stop watch or pendulum (see page 160) the number of seconds required for the stream to flow through the given length of channel, may thus be ascertained with considerable exactness.

Dr. Robinson gives the following table of the relative velocities of currents at the surface and bottom, and the mean between them, which will save the trouble of calculation in some of the most frequent questions of hydraulics. He takes the velocity of the surface of the middle of the stream, which is very easily measured, by any light small body, as a piece of cork, floating down upon it, or by a stream measurer. From this experiment he calculates the retarded velocity of the bottom of the stream, and finds the medium velocity by the following Rule. The velocity of the substance floating on the surface of the middle of the stream is taken in *inches* per *second*. From the square root of the number of inches per second he deducts unity, or 1, and then squares the remainder, which gives the velocity at the bottom, and he finds the mean velocity by taking the medium between these two sums.

Thus if the velocity of the surface in the middle of the stream be

25 inches per second, its square root is 5, from which if 1 be deducted, there remain 4. The square of this, or 16 inches per second, is the velocity at the bottom, and 25+16=41, one half of which is 20½, being the mean velocity, in feet per second.

TABLE

Of the average velocity of the current of Rivers, calculated from the velocity of the surface in the middle of the stream.

Velocity in inches per second.			Velocity in inches per second.		
Surface.	Bottom.	Mean.	Surface.	Bottom.	Mean.
1	0.000	0.5	31	20.857	25.924
2	0.172	1.081	32	21.678	26.839
3	0.537	1.768	33	22.506	27.753
4	1.	2.5	34	23.339	28.660
5	1.526	3.263	35	24.167	29.583
6	2.1	4.050	36	25.	30.5
7	2.709	4.854	37	25.827	31.413
8	3.342	5.67	38	26.667	32.333
9	4.	6.5	39	27.51	33.255
10	4.674	7.337	40	28.345	34.172
11	5.369	8.184	41	29.192	35.096
12	6.071	9.036	42	30.030	36.015
13	6.786	9.893	43	30.880	36.940
14	7.553	10.756	44	31.742	37.871
15	8.254	11.622	45	32,581	38.79
16	9.	12.5	46	33.432	39.716
17	9.753	13.376	47	34.293	40.646
18	10.463	14.231	48	35.151	41.570
19	11.283	15.141	49	36.	42.5
20	12.055	16.027	50	36.857	43.428
21	12.830	16.837	51	37.712	44.356
22	13.616	17.808	52	38.564	45.282
23	14.202	18.70	53	39.438	46.219
24	15.194	19.597	54	40.284	47.142
25	16.	20.5	55	41.165	48.082
26	16.802	21.401	56	42.016	49.008
27	17.606	22 303	57	42.968	49.984
28	18.421	23.210	58	43.771	50.886
29	19.228	24.114	59	44.636	51.818
30	20.044	25.022	60	45.509	52.754

When it is desired to measure the quantity of water afforded by a stream in order to calculate the power of it with a given fall for mill purposes, or the quantity of water it will afford per second for feeding canals, &c., it is usual to make the experiment during the droughts of summer, when the streams are diminished in their beds. It must be evident that this is the only proper time that can be taken for calculating the *regular power* afforded by a water fall. When a stream is measured during any stage of its floods, and the standard of its power is assumed from this admeasurement, disappointments will certainly follow. Whenever the flood-waters subside the mill wheel must remain idle for want of the calculated supply of water. During the droughts of summer a considerable river becomes so much diminished that it may be made to pass through a sluice way or over the edge of a plank, whereby the quantity of water may be very exactly measured. The Rules for measuring the quantity of water thus discharged through sluices under a given head, or over the edge of a board or weir, with the stream open at the top, will be also given, that either of these modes of admeasurement most convenient to the engineer may at pleasure be adopted, or all of them, to correct any error that might arise from taking one of the experiments singly.

The knowledge of the velocity at the bottom of a stream is of use to an engineer to enable him to judge of the action of a stream on its bed. Every kind of soil will bear a certain velocity without changing the form of the channel. A greater velocity would enable this water to tear it up and a smaller velocity would permit the deposite of more moveable materials from above.

It appears from observation, that a velocity of three inches *per* second at the bottom, will just begin to work upon fine clay fit for pottery, and however firm and compact it may be, it will tear it up. Yet no beds are more stable than clay, when the velocities do not exceed this; for the water soon takes away the impalpable particles of the superficial clay, leaving the particles of sand sticking by their lower half in the clay, which they now protect, making a very permanent bottom, if the stream does not bring down gravel or coarse sand, which will rub off this very thin crust and allow another layer to be worn off.

A velocity of six inches *per* second, will lift fine sand; eight inches will lift sand as coarse as linseed; twelve inches will sweep along fine gravel; twenty-four inches will roll along rounded pebbles an inch in diameter; and it requires three feet *per* second at the bottom to sweep along shivered angular stones of the size of an egg.

Rules for measuring the quantity of Water flowing through Sluices or Apertures.

In this, as in the former instances, we must multiply the area of the aperture by the velocity with which the water rushes through it.

The velocity of water flowing out of a horizontal aperture in the bottom of a cistern is as the Square Root of the height of water above the aperture; that is, the pressure, and consequently the depth, is as the square of the velocity; for the quantity flowing out in any given time is as the velocity, and the force required to produce a velocity in a certain quantity of matter in a given time, is also as that velocity; therefore the force must be as the square of the velocity.

A TABLE

Showing the Velocity in feet per minute (or per second by dividing by 60) with which water should issue from an aperture at any given depth beneath the surface, from 1 inch to 20 feet, calculated according to the Theory of Falling Bodies.

Depth.	Velocity per Minute	Depth.	Velocity per Minute.	Depth.	Velocity per Minute.
Inches.	Feet.	Inches.	Feet	Inches.	Feet.
1	138.6	19½	613.2	52	1002.0
1½	170.1	20	621.1	53	1011.6
2	196.2	20½	628.8	54	1020.8
2½	219.6	21	636.6	55	1030.2
3	240.6	21½	644.4	56	1039.2
3½	259.8	22	651.6	58	1057.8
4	277.8	22½	658.8	59	1066.8
4½	294.6	23	666.1	60	1076.1
5	310.3	23½	673.2	63	1102.8
5½	325.8	24	680.5	66	1127.9
6	340.2	25	694.2	69	1153.2
6½	354.0	26	708.0	72	1179.0
7	367.4	27	721.8	75	1203.0
7½	380.4	28	735.0	78	1227.0
8	392.7	29	748.2	81	1250.4
8½	405.0	30	760.9	84	1273.2
9	417.0	31	773.4	87	1296.0
9½	428.4	32	786.0	90	1317.9
10	439.3	33	798.1	93	1339.9
10½	450.1	34	810.0	96	1361.1
11	460.8	35	822.0	99	1382.4
11½	471.0	36	834.0	102	1403.0
12	481.2	37	844.8	105	1422.7
12½	491.4	38	856.1	108	1443.7
13	501.0	39	867.6	111	1463.4
13½	510.6	40	878.4	114	1483.4
14	519.6	41	889.2	117	1502.4
14½	529.2	42	900.0	120	1521.8
15	538.3	43	910.8	126	1559.4
15½	547.2	44	921.6	132	1596.1
16	555.6	45	931.9	138	1632.0
16½	564.0	46	942.0	144	1667,1
17	572.6	47	952.2	156	1735,2
17½	580.8	48	962.4	168	1800,6
18	589.3	49	972.6	180	1863,3
18½	597.6	50	982.2	192	1924,8
19	605.4	51	992.1	240	2152,2

This Table is made by extracting the Square Roots of the depth in inches, and multiplying it by 138.88 which gives the velocity in feet per minute. This product divided by 60, gives the number of feet per second. The proper allowance for the loss of velocity which arises from the friction of the particles of water against the edges of apertures of various forms is made in the following table to correct this theoretical discharge.

The true velocity must be found by multiplying the discharge given in the first table by some of the decimal numbers in the following table.

Description of the Apertures through which the water flows.		Ratio between the real velocity and the theoretic velocity, or that which is due to the whole depth, as shown by first table.
For orifices in a thin plate, - - - - -		.618
For the openings of sluices or apertures in the side or internal walls of the reservoir, without any side walls which can serve to conduct the particles of water in a stream to the aperture.		.636
For a short cylindrical pipe from two to four times as long as the bore.	1st. When it projects withinside the vessel and does not run with a full bore of water, but in form of a contracted vein within the tube.	.5137
	2d. When it projects withinside the vessel but runs with a full bore of water.	.681
	3d. When it does not project withinside the vessel.	.8125
For narrow openings, of which the bottom is on a level with that of the reservoir. Also for smaller openings of sluices when provided with side walls to conduct the water to the aperture. Also for the water-passage under bridges which have square piers with abrupt projections, which do not conduct the water regularly into the passage.		.860
For wide openings, of which the bottom is on a level with that of the reservoir; also for large sluices with conducting walls in the direction of the stream and for the water-way beneath bridges with pointed piers, which conduct the water into the passage.		.960

To apply these rules for gauging Sluices, the following measures must be taken.

1st. The perpendicular depth of the bottom of the aperture beneath the surface of the water.

2d. The perpendicular depth of the top of the aperture.

3. The horizontal width of the opening. Then taking the difference between the two first measures leaves the height of the opening.

If the aperture is not in a vertical plane, but inclined, as is frequently the case in Mill-Sluices, then the width of the opening must be measured on the slope; but the depths must always be taken perpendicularly beneath the surface of the water.

To make the calculation, find the mean velocity of the effluent water, by calculating the velocity due to the depth of the top of the aperture, and also for the bottom of the aperture and take a mean of the two.

When the height of the aperture is less than one-fourth of the whole depth, then the depth of the centre of the aperture will give very nearly the average velocity.

Having found the mean velocity in feet multiply it by the number of square feet in the area of the aperture and it will give the quantity discharged in cubic feet.

EXAMPLE.

A Sluice, which is four feet wide, is opened or drawn seven inches, and the depth of water above the centre of the orifice is ten feet. The edges of the sluice are cut sharp, so that the borders of the orifice are like a thin plate. What is the velocity and discharge *per* minute in cubic feet?

ft. ft.
$4 \times 7 = 28 \div 12 = 2{,}333$ feet for the area of the aperture.
ft.
$10 \times 12 = 120$ inches depth, velocity by 1st table 1521..8

This multiplied by $2\frac{1}{3}$, the square feet in the aperture gives 3550 cubic feet per minute for the theoretic discharge. The first column of the 2nd table shews that the real discharge is only .618 of the theoretic discharge, therefore multiply 3550 cubic feet by .618 gives 2194 cubic feet for the real discharge per minute.

Water-Gauge formed over the edge of a broad plank, or weir, the stream being open at the top.

In constructing this Water-Gauge the temporary dam or the weir should be of such a height as to pen up the water into a pond sufficiently large to check the natural current, and to cause it to flow with an almost imperceptible motion toward the aperture. If, however, there is a perceptible motion of the stream on the surface of the pond, it must be added, as in the example following. The water must have a free descent or fall from the aperture, and be allowed to flow away unobstructed.

Rules for measuring the quantity of Water which flows over a Weir, or through an aperture in the edge of a Board, the Stream being open at top.

Description of the Aperture. Note.—The Depths are supposed to be measured from the level surface of the water to the bottom of the aperture, in inches.	To find the mean velocity of the water running through the aperture in feet per minute. Rule.—Multiply the Square Root of the Depth in Inches by some one of the following numbers, according to the case.	To find the number of cubic feet discharged per minute through each Inch in width of the aperture. Rule.—Multiply the Sq're Root of the Cube of the Depth in Inches by some one of the following numbers according to the case.
For a small aperture in one side of a large reservoir, the bottom and sides of which do not correspond with the aperture, so as to lead the particles of water thereto in a stream; the edges of the aperture against which the water runs is supposed to be sharp and made of thin plate; the aperture not to exceed nine inches deep,	57.246	.39754
For an aperture under the same circumstances as the former, but made in a plank with edges from half to one Inch thick,	58.0493	.40312
For an aperture of great breadth and more than nine inches deep, such as the weir or dam in a river, it is supposed that the water runs over the edge of a plank or waste board one or two inches thick,	58.88	40886
For an aperture of which the bottom is on a level with the bottom of the reservoir, or for a weir which occupies the whole breadth of a river, and where the water flows over the top of a broad stone-wall so sloped as to conduct the water to the passage,	88.92	.6174
For the full discharge according to theory, supposing no loss from friction. Very large and deep weirs will come near to this,	92.592	.6430

It is extremely difficult to measure the exact height of the water above the bottom of the aperture, for the curvature of the surface of the water begins several feet up the stream before it arrives at the aperture; and there must be something arbitrary in the measurement, because the surface of the water, even where there is no curvature, is not horizontal but sloping, when the water is in motion. In such cases, the depth must be taken beneath the inclined surface of the water, if we suppose the same prolonged until it reaches the aperture, which can easily be done, by stretching a line along the surface of the water so as to correspond therewith at the part above, where the curvature commences.

We must also make some addition to the discharge, on account of the motion which the water possesses before it comes to the aperture: to do this with accuracy, we may measure the regular velocity of the stream, by throwing in floating bodies, and observing the distance they pass through in a given time, taking care that we make this observation at a part of the channel, where the surface is in a regular motion, and not in a state of acceleration, because what we want is the velocity of the water at that point where the curvature begins in consequence of the descent through the aperture. Now when the channel is not of a uniform breadth and depth, as in a Mill Dam for instance, the velocity of every part of the stream is different.

EXAMPLE.

Suppose the depth of the bottom of the aperture to be eight inches beneath the line of the surface of the water; that the width of the aperture is four feet, and that the aperture is in a thin plate, with sharp edges. Also that the stream is found to move with a velocity of thirty feet per minute, at the place where the surface of the water begins to deviate from its regular slope and to assume a curvature.

Then take the numbers 57.246 from the first case in the last table, and multiply it by 2.828, which is the Square Root of eight (the depth); thus $57.246 \times 2.828 = 162$ feet per minute for the mean velocity of the water; to this add 30 feet for the previous motion $= 192$ feet per minute. The area of the aperture is 8 Inches, or .666 feet$\times$4 feet$=$2.664 square feet. Multiply 192 feet velocity by 2.664 and we have 512.488 cubic feet per minute, for the quantity discharged.

Water Power.

Projects for erecting mills are usually undertaken in the United States during the Spring of the year, when the streams have abundance of water flowing in their channels. After a hasty view of a stream, and a survey of the fall of its waters, the purchases are too often concluded upon, and costly works are erected. The unfortunate proprietor is only convinced of his precipitancy, when it is too late to remedy the evil consequences of it, after finding that his wheels remain idle for want of the calculated supply of water during the months of the year when the days are longest, and the expenses of lights and fuel are not required. These mills may be seen in different parts of the country abandoned and desolate, standing as monuments of the folly of those who erected them. It is of the utmost importance to the prosperity of manufacturing operations that the moving power should be sufficient for operating the machinery at all seasons of the year. Where the labourers are compelled to remain idle for one or two months, they are during this period thrown upon their own resources for support, being compelled to consume the fruits of former seasons of industry. The best hands will therefore quit a manufacturing village, in which so material a disadvantage exists, in favour of another where the employment is more regular. The improvident and worthless will remain from an inability to remove their families, for whose support during the season of inactivity their employers are under the necessity of making advances, which are rarely repaid. Expensive fixtures for a mill should therefore never be commenced on small streams until the mill site is most carefully surveyed to ascertain the fall of the water, and the quantity of it that may be safely calculated upon during the long droughts of summer. On large streams even the superabundance of the floods of winter are sometimes of serious inconvenience, causing a suspension of the operation of a mill by backwater.

By the preceding Rules the quantity of water running in a stream may be measured; the force of it, with a given fall, to operate machinery, may be estimated in *horse power* as follows:

The mechanical effect produced by the descent of water is as the quantity and perpendicular descent. Were there no loss of power by friction, it is manifest that if 12 wine gallons of water, which weigh 100 lbs. were to descend six inches when nicely balanced on a scale beam, a corresponding upward motion would be produced in a weight of 100 lbs. placed in the opposite scale. The mechanical power of 12 gallons of water in descending 6 inches would therefore be measured by its mechanical effect in raising 100 lbs. 6 inches. But in the application of water to the best water-wheels there is a loss of $\frac{1}{3}$ of the power by friction, and only $\frac{2}{3}$ of the weight of water is effective. Therefore $\frac{1}{3}$ of the theoretical power is deducted to find the power available in practice.

EXAMPLE.

For calculating the Power of a Stream, after finding, by the preceding Rules the number of cubic feet of water furnished per minute.

What is the Power of a Mill Stream, which will supply during an ordinarily dry season 1800 cubic feet of water per minute, with a fall of 16 feet.

$1800 \times 62\frac{1}{2} = 112500$ lbs. descending 16 feet each minute.

112500×16—1.800.000 lbs. *momentum* per minute with a fall of 16 feet—A good breast wheel being able to raise only $\frac{2}{3}$ of the quantity of water which operates it to the level from which it descends upon the wheel, ⅓ of the power or force of the water is therefore wasted and lost, and only ⅔ of its weight is calculated upon as the actual available power. Hence by the Rules of Proportion,

As 3 : 2 : : 1800 000 : to the answer,=1200 000 lbs. raised 1 foot high per minute by the fall of this water. On referring to the standards for calculating Power at page 146, it will be perceived that Boulton & Watt estimate a *horse power* to be equal to a force that will raise 32000 lbs 1 foot high per minute.

1200 000÷32 000=37½ horse power, Answer.

Should the stream furnish only 900 cubic feet of water per minute by its regular natural current throughout the 24 hours, yet if the mill pond or reservoir be sufficiently large to retain the water which flows into it during the night, for use the ensuing day, it is evident that for the ordinary hours of daily labour the effective power of this stream will be doubled by means of such millpond, and will still be equal to 37½ horse power.

In the above example, 1800 cubic feet of water, the supply furnished by the stream each minute, is multiplied by 62½ lbs., the weight of a cubic foot of water. This product in lbs. is multiplied by the fall of 16 feet, which gives the theoretical power of the stream. The actual power is only two thirds of this, ⅓ being lost by friction, leakage, &c. If then the available power, adequate to raising 1200 000 lbs. 1 foot high per minute, be divided by 32000 lbs. raised 1 foot high, which is Boulton & Watt's standard of a horse power, the quotient will be the force of the stream.

Examples for calculating water power and the comparative effects produced by 1 horse power in operating several kinds of machinery are given at page 147, and 148, and also in treating of the *water wheel.*

The Water Rights on the Boston and Roxbury Mill Dam, are calculated by a certain quantity of grain ground into merchantable meal per hour. Each of these Water Rights is computed to furnish power sufficient to convert into meal eight bushels of rye per hour by one pair of mill stones.

Mill Ponds and Reservoirs of Water.

A large mill pond is very advantageous on small rivers, the natural currents of which are not sufficiently abundant at all seasons to furnish the requisite supply of water. It serves as a reservoir to collect and retain the water which flows into it during the night, for use the subsequent day, in effect, as before observed, doubling the power of the stream. Each acre of a mill pond one foot in depth, contains 43560 cubic feet of water weighing 62½ lbs. to the foot =2.722.500 lbs. of water, which with a fall of 10 feet give available force equal to 567 horse power, if the water were all applied in the course of one minute to the water wheels, or 567÷720, the number of minutes in a day of 12 hours, gives .787 or very nearly ⅘ of a horse power for each acre of water one foot deep, used with a fall of 10 feet, for one day. With this fall a mill pond containing 20 acres and susceptible of retaining a quantity of water of the same extent and 1 foot in depth, will give to the proprietor of the mill a command of a 15 horse power for one day independent of the ordinary supply of the stream. The depth of pond will not compensate for a deficiency in extent of surface, because in proportion as the surface of the water subsides or is drawn down, the height of the fall, and consequently the power, is diminished in an equal ratio. On this account Reservoirs constructed entirely above the level of the mill pond are peculiarly serviceable, a small extent of ground covered to a considerable depth with water being thus rendered equal to a great extent of ground covered with a shallow sheet of water.

Where large natural ponds or swamps can be converted into reservoirs for retaining the flood waters of winter for use during the droughts of summer, the water power of small streams may be surprisingly augmented. During 9 or 10 months of the year inconsiderable brooks yield sufficient water for important hydraulic operations. If, then, by means of artificial reservoirs the deficiency in the supply of water during the two or three months of summer can be obviated, and the winter torrents be made to swell the current of the summer brook, the stream at once becomes as important and effective as one much larger without these artificial resources. The great quantity of water which falls in a year upon a small surface of ground, would be sufficient to fill a large reservoir were there no waste by evaporation and leakage. It appears by a pluviometrical table published in Professor Silliman's Journal of Science and Arts, that for the 10 years preceding 1827, the quantity of water which fell in the form of rain and snow varied from 3½ feet to 4 feet per year, the average being very nearly 47 inches. This exceeds the average depth of rain in England for 10 years previous to 1825 by nearly 15 inches per year, although there are more wet or drizzly days in the course of the year in England than in the northern and middle States.

The expenses of constructing a reservoir may be rendered comparatively light should all the proprietors of the mill seats benefitted by it unitè to defray them. Even the amount of the very costs of litigation in some cases relating to water privileges would be sufficient, if judiciously expended in this way, to place at the control of both parties a greater additional water power than that for which they may be contending. Upon the head waters of one of the small rivers of Rhode-Island two reservoirs have been formed by the proprietors of the mill seats upon the stream, who became associated for this purpose under an act of incorporation for the more convenient management of their affairs, and the more permanent stability of the undertaking. The reservoirs in these instances are formed by dams 15 to 18 feet high, thrown across the narrow outlet of swamps, in which are retained the flood waters arising from the melting of the snows of winter, and from occasional showers during the other seasons of the year. One of these reservoirs, when full, covers above 150 acres, with an average depth of about 9 feet of water. The water power thus placed at the ready control of the manufacturers, whose mills are situated upon the river, may be estimated as follows:

150 acres 9 feet deep are equal to 1350 acres 1 foot deep. Allowing 10 per cent for loss by evaporation and leakage, there remain about 1200 superficial acres 1 foot deep, each acre of which with a fall of 10 feet is equal to about $\frac{3}{4}$ of a horse power for one day of 12 working hours. (See calculations of the power of water wheels.)

∴ $1200 \times \frac{3}{4} = 900$ horse power for one day or 20 horse power for 45 days with a fall of 10 feet. The whole descent of the river in the distance of a few miles being very nearly 200 feet, the aggregate power thus held at command is equal to that of 18,000 horses for one day, or of about 60 horses for 300 days of the year. The amount of this power is not so important as the useful mode in which it is applied. For each horse power artificially available for one or two months of the year, there will be a corresponding power naturally produced by the usual rains and flood waters for the remaining months of the year. When the operations of mills are impeded from a deficiency in the supply of water, the loss is much greater than that occasioned by the actual suspension of business for a limited number of days, because during a portion of the time the machinery is impelled with diminished speed; the actual stoppages take place at different hours of each day and the labor is desultory, while the operatives cannot undertake any other temporary business for their support. At a mill I once visited during a season of drought, on account of the smallness of the millpond the work appeared to be intermitted quite regularly about once an hour, when the pond became exhausted. All hands were regularly called to their machines after a lapse of about half an hour, when the millpond became filled again with water. By collecting the water in a spacious millpond or obtaining it from a reservoir during this period, all the persons employed in a mill are enabled to perform their work without such interruption.

On constructing Mill Dams.

By the preceding Rules the quantity of water flowing in a stream may be measured, and the power of it with a given fall may be also ascertained by the Rules given at page 181 and 190. After having thus satisfied himself of the sufficiency of the Water Power, the engineer may proceed to select a site for the dam. On large rivers subjected to freshes it is an important consideration to fix upon a spot where the bed of the channel is composed of ledges of rocks, upon which the necessary works of the dam may be more firmly established than upon an earthy bed or channel. When the waters can be made to pour over the top of the milldam upon ledges of rocks below, the continual dashing and attrition of the falling waters are safely sustained. But when the bed of the stream is composed of earth, the force of water soon wears its way to great depths, unless artificial beds of timber and stone are substituted to sustain the immediate action of it. When artificial *aprons* are formed to receive the force of the the waterfall particular care should be taken to construct it sufficiently broad. A few years since a large mill dam in Rhode-Island was swept away and lost, merely from a fault of this kind in the original construction of it. When the river was swoln by long continued rains the accumulated waters in their descent overshot the apron, and formed an excavation many feet in depth immediately below the dam. The whole structure having been thus undermined, sunk into the abyss formed by the flood, and disappeared. Even the best constructed dams when erected upon a sandy or clayey soil, are subject to injury from the gradual action of the water upon the foundations on which they rest. In all cases of this kind piles should be driven into the ground to sustain the frame of the dam and platform, and heavy stones should be placed in courses arranged like the slates on a roof, with their up-stream ends lowest, for the distance of a few feet below the dam. It is also an excellent plan to cause the water to stand upon the apron by means of a ridge of stones or timber placed across the stream immediately below the dam. The glancing force of water can in no way be so effectually counteracted as by opposing to it a body of the same fluid, which offers an uniform resistance, particle to particle, in every direction of its motion. The durability of the apron is thus promoted by keeping it always immersed. The advantages obtainable from ledges of rocks are, commonly, counterbalanced by the expensive excavations of the rock necessary to form the trenches and wheel pits.

In England the mill dams are usually constructed of hewn freestone, laid in water lime, and secured by iron clamps. This mode of construction is rare in the United States, where the great cost of hewn stone and the comparatively low price of timber contribute to render the use of wooden materials more common In the few instances in which stone dams are erected in this country the junction of the stones is so imperfect as to render the use of a planked covering quite necessary for retaining the water. In constructing dams of every description upon a loose soil, pile-planking should be carefully driven into the solid earth along the face of the whole work, both to prevent waste by leakage and to render the foundations of the dam more secure by cutting off the small streams beneath the ground, which is loosened by them, and rendered more liable to be washed away by freshes. A waste or floodgate, formed in as many sections as may be deemed proper to admit of being easily raised when subjected to the increased pressure against them, should always be made for the purpose of drawing off the mill pond to execute repairs when necessary, as well as for venting the flood waters. The form of the dam, if practicable, should be made somewhat semicircular with the concave facing down the stream. In this case an arch is formed, and the pressure of the water cannot carry away the timber work of the frame unless the abutments fail. Another important advantage resulting from this form of construction is the check given to the violent impetuosity of the falling waters, which are thus brought to spend their force in rushing together in counteracting currents.

In laying the foundation of the walls to sustain the lower side of the embankment of the dam, the alluvial loose soil should be removed to the hard bottom or pan of earth. The wall of a dam should also be made much thicker at the bottom than at the top, and the whole slope or batter should be made on the lower face, the upper side, against which the embankment rests, being made perpendicular. A wall thus constructed possesses greater strength to support the pressure of the earth, and of the water of the mill pond resting against it, which under the operation of severe frosts have a tendency to overthrow it. The appearance of the wall of a mill dam with its lower side sloping is also more proper and agreeable to the eye, because it has a suitable inclination to withstand the weight of the mass leaning against it. Whenever embankments of dams or canals are to be made in loamy or gravelly soil, the surface of the ground should be thoroughly broken up by ploughing or otherwise, for the purpose of filling up mole or squirrel holes, or the holes formed by mouldering roots of trees, which cause excessive leakage and waste of water. The natural structure or arrangement of the ground is lighter and more porous than when once broken up and left to settle after being exposed to the action of the water, which has a tendency to consolidate it. This may be observed in digging a hole in the ground and returning the earth to the excavation. The same quantity of earth after being drenched with water will not be sufficient to fill the hole from which it was taken.

A mixture of loam and gravel forms the most permanent embankments to withstand the effects of currents of water, and although not so well adapted to prevent filtration as pure loam or clay, yet the embankments formed of it become less porous every year as the mass becomes filled with the alluvial deposits, or slime, brought down by the turbid freshes of winter and spring, until at last it becomes nearly impervious to water. The slope of embankments must depend upon the nature of the materials of which they are composed, and the situations in which they are placed in regard to exposure to the action of waves and currents. The lateral pressure which they sustain increases regularly according to the depths of water. Embankments, the sides of pipes, or of masonry, by which the pressure of fluids is to be sustained, should for this reason be made stronger the deeper they are laid. It would be a superfluous expense to make them as thick and strong at the top as at the bottom. By mathematical calculations it has been found that a wall or bank, having one side perpendicular and the other sloping to receive the pressure of the water, will be sufficient to resist the pressure, "if the square of its thickness at the base is to the square of its perpendicular height, as the weight of a given bulk of water, say a cubic foot, is to the weight of the same bulk of the material of which the bank is made;" for which see table of specific gravities, page 17. Thus if a wall be required

4 feet 9 inches high, and the material be sand stone, which is $2\frac{1}{2}$ times heavier than water, the thickness at the base should be to the height nearly in the proportion of 3 to $4\frac{3}{4}$ (the square of the thickness being $3\times3=9$, and the square of the height $4\frac{3}{4}\times4\frac{3}{4}=22\frac{9}{16}$, nearly as 1 to $2\frac{1}{2}$) If the material be earth or sand, it is manifest that other considerations must be regarded, such as the imperfect solidity of the material. The embankment of common earth will not withstand permanently the pressure of water unless the side slope at an angle of about 30 degrees, the base being to the perpendicular height as 2 to 1. The space allowed for the Waterfall of the Dam should be large, as the water will in such case have free vent during floods, without overflowing the abutments, and the average level of the water in the mill pond may be kept at a greater height, without causing back water upon the wheel of any mill above it. A waterfall of 2[illegible]0 feet in length being capable of discharging a much greater quantity of water than that of 100 feet, consequently the accumulation of water in the mill pond during a stage of flood would be less.

Mill Courses.

The canal to convey water to the mill should be of spacious breadth and depth. When a contracted canal is formed, a rapid current must flow through it to furnish the necessary supply of water, whereby the *head of water* must be reduced, and a consequent loss of power must be the result. In situations where irregular rocks abound, it may be more convenient to make a broad shallow trench, in which case the quantity of water flowing through it will be nearly the same, provided the area of the canal be equal. Thus a canal 12 feet broad and 4 feet deep (48 feet area) will deliver about the same quantity of water as one 8 feet broad and 6 feet (area also 48 feet.) The greatest disadvantage resulting from shallow canals is, that when the water in the mill pond becomes diminished, or drawn down, the canal will not allow a sufficient supply of water to flow through it. If the depth of water in an open canal be less than 4 feet, the passage of the water becomes also greatly obstructed, during the intensely cold nights of the Northern States, by the *anchor frost*, which shoots up in long slender spiculae from every pebble upon the bottom, sometimes uniting in a solid mass with the sheet of ice upon the surface.

The ends of the flooms, and the junction of the abutments of the dam with the timber work should be carefully secured by driving pile planking into the solid earth, leaving the ends of the plank sufficiently long to reach the top of the embankment. Mill dams are more frequently lost by inattention to pile planking than by any other fault of construction, as the water after working its way around the bulwarks intended to resist it soon enlarges the apertures, when the insinuating stream becomes suddenly a torrent, bursting through every impediment to its course, and sweeping away the whole structure, and even the mill itself, should it happen to be erected on the wall of the dam. For this reason it is always desirable to place a mill upon some secure bank, at a short distance from the dam, where the edifice will remain free from accidents by floods.

Where the soil in which the canal is to be excavated is composed of coarse gravel, care should be taken that the loose pebbles do not roll forward so as to form a bed between the base of the embankment and the natural surface of the ground. This will usually be the case as the laborers advance with the trenching, unless attention be bestowed to prevent it. Whenever the water rises in the canal against the embankment above the level of the natural soil, it will pass off freely through the stratum of loose pebbles, and the leakage will be excessive. The waste of water by leakage may be in a considerable degree obviated by lining the canal with clay, or with loam, where the former material is not at hand. The banks may be also consolidated while saturated with water, by thrusting into them long pointed iron bars.

Wheel Pit.

In the excavations upon the banks of a river for placing water wheels, it is usual to encounter springs of water. To obviate the difficulties attendant upon the influx of water the mill race should be completed in the first instance, by which the water will be effectually drained off. Should it be necessary, however, before this can be accomplished, to sink a wheel pit in which the intrusion of the gushing waters of numerous springs might occasion interruption to the progress of the necessary labor, the works should be advanced without intermission by night as well as by day; otherwise it will be necessary to consume a considerable portion of each morning to throw out the water which has flowed in during the night. It is usual to lay the floor or platform of the wheel pit upon sleepers of sufficient extent for the main walls to rest upon it, in order to prevent the constant agitation of the water from action upon the earth beneath the foundations, or undermining them.

The same observations apply to the mill race as to the canal. If they be made deep and wide, less fall will be required to carry off the water, as it will flow in a gentle full stream, instead of a rippled current. The depth of both the wheel pit and race should be governed by the depth of the bed of the river at the outlet of the race, and also by the usual tendency of the river to rise during a common rain storm, and to cause *back water* to impede the motion of the wheel.

Trunks or Penstocks for conveying water.

Where water is to be conveyed under ground, or in any tight trunk to a considerable distance, the ends of the trunk, if intended to be closed occasionally by a gate or otherwise, must be left open at the top. If a column of water extending horizontally one or two hundred feet were to be put in rapid motion through a tight trunk without any lateral vents, and the gate at the end were to be suddenly closed, the whole moving force of the water would operate against the gate, and also laterally against the sides of the trunk, with the same effect as a solid body of the same weight as the mass of water, and moving with the same velocity. The effect would be like that of a battering ram—no wooden trunk would be able to resist the shock. If, however, an opening were made at the top of the trunk next the gate, the water would spend its force in gushing upwards, and the head would then gradually subside without detriment to the works. If the gate were placed at the upper end instead of the lower end of the trunk, and were to be closed under similar circumstances without an opening for the air to descend, a vacuum, or an approach to a vacuum, would be for an instant created, by which the gate and sides of the trunk would be *crushed in*. Tight trunks having gates to shut off the water, must therefore be constructed with proper openings by which this pressure may be relieved, or they will soon be destroyed.

WATER WHEELS.

Water Wheels in England are commonly constructed of iron. This material being dearer in the United States, and all the necessary timber for constructing wooden water wheels being comparatively cheaper, the latter material is very generally employed. The iron water wheel possesses several important advantages over a wooden one. It is more durable, and from the small quantity of room occupied by the thin iron floats or buckets an iron wheel will contain more water than one of equal dimensions constructed of wood, and is consequently more effective. Iron shafts are frequently used for the axles of wooden water wheels, but they are liable to become loose, and are frequently broken; or should the wedges allow the wheel to slip upon the shaft, the teeth of the crown wheel or segments, or even the leading shaft may be destroyed. In one water wheel of this description I have known three iron axles or shafts to be inserted, the last being made of wrought iron withstood the stress upon it. It is commonly the practice in England at the present time to make the iron shafts of water wheels hollow and of large diameters. A wooden shaft with the arms of the water wheels properly secured to it, and with short projecting ends that will remain constantly wet by the dripping of the water during the motion of the wheel, may be considered almost as durable as iron. I have seen many wooden shafts taken out of old water wheels; but have never observed one of them to be decayed. It is recommended as the very best method of uniting the arms to the axis of the water wheel to have a cast iron centre piece, as used for an iron axis, to prevent weakening the wooden shaft by mortising the arms into it. In the United States shafts of the largest dimensions are obtainable, which will possess sufficient strength after the mortises are made to resist the stress upon them. The best shafts for water wheels now used in Rhode-Island, are of the hard pine imported from N. Carolina. Wood exposed to the action of the water is worn away gradually by the attrition. White pine however becomes covered with a slimy coat which shields it from the injurious action of the water, and is therefore more durable even than oak. In the construction of a wooden water wheel care should be taken to make it sufficiently strong in the first instance to prevent the working of the joints, as the bolt holes in this yielding material soon become enlarged, and the evil is rapidly augmented to an injurious extreme. The joints of water wheels of this description will work and creak like those of an old ship labouring in a heavy sea. If the whole circumference of a wheel be encompassed by strong iron hoops like a cask the strength and durability of it will be greatly increased.

The terms, *Head* and *Fall*, being frequently used in relation to the application of water to the water wheel, may here be defined. By Head is understood the distance from the surface of the water in the floom to the part of the wheel on which the water strikes. The Fall is the perpendicular descent from this part of the wheel to the bottom of it.

Of the great variety of water wheels we shall attempt the description of those only which are in most general use; viz. the *Undershot*, *Breast* and *Overshot* Wheels.

Undershot Wheel.

Upon undershot wheels the water acts merely by its impetus as it shoots against the floats, and not from its weight while resting in buckets, as on the overshot and breast wheel. The undershot wheel is the simplest and cheapest kind of water wheel, but it is employed only in situations where an abundant supply of water is obtainable. It will produce only one half of the effect of an overshot wheel operated on by an equal fall of water.

An undershot wheel performs the greatest quantity of work, or produces its maximum effect, when its circumference moves with about $\frac{3}{7}$ths of the velocity of the stream that drives it. It is important to ascertain the proper velocity with which the circumference of undershot wheels should move, in order to calculate the size of the cog wheels to produce the desired speed of the mill geering, and machinery connected with it. Dr. Brewster gives the following Table for determining the velocity of the stream with a given head, and the consequent velocity with which an undershot wheel should move when operated upon by by such stream to produce its maximum effect.

DR. BREWSTER'S MILL-WRIGHTS TABLE.

In which the velocity of the wheel is three-sevenths of the velocity of the water, and the effects of friction on the velocity of the stream reduced to computation, the water wheel being 15 feet diameter, and the mill stone 5 feet.

Height of the fall of water.	Velocity of the water per second, friction being considered	Velocity of the wheel per second, being 3-7ths that of the water.	Revolutions of the wheel per minute, its diameter being 15 feet.	Revolutions for millstone, for one of the wheel.	Teeth in the wheel and staves in the trundles,		Revolutions of the millstones per minutes by these staves and teeth.
Feet.	Rev. 100 parts of a foot.	Rev. 100 parts of a foot.	Rev. 100 parts of a foot.	Rev. 100 parts of a foot.	Teeth.	Staves.	Rev. 100 parts of a rev.
6	18.67	8.00	10.19	8.83	97	11	89.98
7	20.15	8.64	10.99	8.19	90	11	90.01
8	21.56	9.24	11.76	7.65	84	11	89.96
9	22.86	9 8()	12.47	7.22	72	10	90.03
10	24.10	10.33	13.15	6.84	82	12	89.95
11	25.27	10.80	13.79	6.53	85	13	90.05
12	26.40	11.31	14.40	6.25	•72	12	90 00
13	27.47	11.77	14.99	6.00	72	12	89.94
14	28.51	12.22	15.56	5.78	75	13	89.94
15	29.52	12 65	16.13	5.58	67	12	90.01
16	30.48	13.06	16.63	5.41	65	12	89.97
17	31.42	13.46	17.14	5.25	63	12	89.99
18	32.33	13.86	17.65	5 10	61	12	90.01
19	33.22	14.24	18.13	4.95	64	13	89.92
20	34.17	14.64	18.64	4.83	58	12	89.84

The number of floats upon an undershot wheel should be sufficient that two at least may always be in the circular sweep at the bottom of the wheel, that a succeeding float may be interposed to receive the action of the water before the first is withdrawn; so that the wheel may not remain an instant without impulse. If the floats move with $\frac{3}{7}$ths of the velocity of the stream, this calculation may be easily made.

Breast Wheel.

All kinds of hydraulic machines upon which the water cannot descend through a given space, unless the float board or bucket moves therewith, are considered by Mr. Smeaton as of the same nature with overshot wheels, and equal to them in power and effect. All those machines which receive the impulse or shock of the water, whether in a horizontal, perpendicular, or oblique direction, are to be considered of the same nature as undershot wheels. Therefore when the water strikes a wheel at a certain point below the level of the surface of the water in the mill pond, and then descends in the arc of a circle, pressing by its gravity upon the floats of the wheel, the effect will be equal to that of an undershot wheel where the head is equal to the difference of level between the surface of the water and the point at which it strikes the wheel, added to that of an overshot, with a fall equal to the difference of level between the point where the water strikes the wheel and the bottom of it Thus the breast wheel, and also the overshot wheel, is impelled not only by the weight of water, but also by its impetus or momentum. The breast wheel has float boards instead of buckets; nevertheless the water is retained by the sweep of the breast between the floats, so that buckets are virtually formed from which the water cannot escape except the wheel moves. Each of the portions of water contained in these spaces bears partly upon the breast, and partly upon the floats of the wheel. It is, however, impossible in practice to fit the sweep so accurately as entirely to prevent leakage Upon the breast wheel the water is applied against or just below the level of the axis. This kind of wheel is considered by the best engineers as inferior in effect to the overshot wheel, but much superiour to the undershot.

The sweep of the breast is generally constructed of wood in the United States; but in England it is commonly constructed of hewn stone formed with great accuracy to the shape of the circumference of the wheel, in order to prevent as much as possible the waste of water that takes place when it descends in the space left between the floats and the breast, without acting by its gravity upon the wheel.

Breast wheels are employed where the fall is inconsiderable, because the water is retained in such case for so short a time upon the wheel that it could not enter regular buckets, like those of an overshot wheel, and be discharged again, without wasting much of its power.

Overshot Wheel.

This description of water wheel being in most general use, and most effective, our observations will be principally confined to it. To Mr. Smeaton and Mr. Banks, the public are indebted for nearly all the experimental researches which have been made upon this subject. Their rules are adopted in most of the calculations herein made.

The effect of overshot wheels is intended to be derived entirely from the gravity of water, or as little as possible from its impetus. In theory the effect produced by pouring a given quantity of water, as 12 wine gallons weighing 100 lbs. avoirdupois, into the bucket of a water wheel, would be to raise an equal weight to the same height as that from which the water descended upon the wheel. In this case the arms of the wheel might be considered as a lever upon which the power and weight counterbalance each other In practice however Mr. Smeaton found by actual experiment that 100 lbs of water poured upon an overshot wheel would raise only 66⅔ lbs. to the original level from which the water descended, ⅓ of the power being lost by the friction, leakage and moving force retained by the water after being discharged from the buckets. Still greater loss attended his experiments upon the undershot wheel, which was found capable of raising only ⅓ of the weight of the water which operated upon it to the level of the original head in the floom. These experiments were made by means of pumps, and by weights and cords attended with but little friction. He found the greatest effect to be produced when the water was placed upon the top of the wheel and descended with it in the bucket to the bottom. Although the water when placed upon the wheel nearly over its axis produces apparently but little effect, yet it really operates with the same power in proportion to its *descent* as it does when it reaches the level of the axis of the wheel, where it rests upon the end of the horizontal arm or lever. When nearly over the axis of the wheel, the water in the bucket, although moving as fast as when it produces its greatest effect upon the end of the horizontal arm, may in the one case move 3 feet to descend only 1 foot, while in the other it descends nearly 1 foot in moving through an equal space. The effect produced by an equal descent of the water is the same in both instances, the only difference being in the time required to produce it. Buckets connected with an endless chain passing over a windlass, and descending perpendicularly when filled with water upon one side, and ascending inverted and empty upon the other, have been employed for imparting motion to machinery by means of the descent or gravity of water. On this machine each bucket of water descends through equal spaces in equal times, and consequently produces equal effects. The *chain buckets* are however attended with considerable friction and are rarely used as first movers for mechanical operations.

It is in vain to attempt by any contrivances in the form of water wheels to obtain a greater effect from a given fall of water than what is produced by its weight in descending from the given height. In the first instance attention should be bestowed in obtaining the greatest fall which the nature of the location of the mill site may render available. Fruitless regrets or very costly alterations must be the alternative, after the works are once completed; and power is always too valuable to be neglected where it can be easily obtained.

Application of the water to the overshot Wheel.

To produce the greatest effect from a water fall, it must be the sole aim of the engineer to apply the water so as to be incapable of descending without communicating motion to the wheel, until the water arrives at its lowest level, when it should leave the wheel entirely free. The overshot wheel was formerly used by conducting the water over the top of it to descend in the buckets. This plan is still in common use; but it has been found that although the buckets may be only half filled with the water, yet it soon begins to spill out of them as they descend, or is thrown out of them by the centrifugal force, whereby much of the power of the water is wasted by falling through the air without acting upon the wheel. The principle of the overshot wheel is now very generally carried into effect by constructing the floom to project nearly over the axis of the wheel, giving to the aperture through which the water flows a form calculated to cause the stream to gush in a reverted direction nearly at right angles with the arms of the wheel, and in a line corresponding with the edges of the elbow buckets. By this means the overshot wheel is made to revolve in the same manner as a breast wheel, and the disadvantage of spilling the water is obviated by constructing for it a sweep or breast. The overshot wheel is thus improved by combining in its construction the principal excellence of the breast wheel.

The effect produced by the impetus of the head of water dashing against the buckets being equal to only ½ of that produced by the descent of the water after having entered the buckets, it is therefore desirable to draw the water from the mill pond under no greater head than is sufficient to give it a velocity equal to that of the floats; otherwise a portion of the moving force of the wheel would be expended merely to overcome the inertia of the water, and to give it the same degree of motion as that possesed by the rim of the wheel. Four or five inches head will be sufficient to produce a velocity of above 4 feet per second, which is as fast as the circumference of most wheels should move, as will hereafter be shown.

Gate or Shuttle of the Water Wheel.

It has been found most advantageous to apply the water to overshot as well as breast wheels by drawing down the gate, that the water may flow over the top of it. The quantity poured upon the wheel is regulated by the shuttle, which is placed in the direction of a tangent to the circumference of the wheel, and is provided with a rack and pinion by which it can be raised or lowered by the action of the governor. The governor is sometimes made to act with less friction upon a *sluice*, which is hung upon pivots and is turned like a throttle valve of a steam engine. In this case the passage of the water to the gate is partially closed. If the sluice board be placed perpendicularly the pivots may be placed in the middle of it—if horizontally, ⅓ of the distance from the bottom. When the water runs over the top of the gate it would naturally fall toward the axis of the wheel, by which means the head would be not only entirely lost, but might even prove an impediment to the motion of the wheel. Much care has been of late taken to give the water a proper direction by shaping the orifice to a proper angle, and even by placing metallic plates or bars of iron horizontally across the bulkhead, arranged like a common window blind to give the water a reverted direction to coincide with the sharp edges of the elbows of the buckets. The spaces between the bars in many of the lately constructed works in England are shut up by a large sheet of leather, which is wound round a moveable roller at the top, and permanently secured at the bottom. The pivots at the ends of this roller are received at the lower ends of two racks, which are made to slide up and down by the action of two pinions fixed upon a common axis extending across the floom. In order to cause the roller to wind up the leather, a strap is wound round the extreme ends of the roller and carried above the water over a pulley and connected with a weight. The water runs over the top of the roller, and flows through the spaces between the grating into the buckets of the wheel; the descent of the water passing between the bars and striking the bottom of the buckets is found fully sufficient to produce the necessary velocity of the water.—Thus the utmost effect of the *fall* may be obtained with as little *head* as will be requisite to cause the water to impinge upon the wheel with proper velocity.

The gate is sometimes made to slide horizontally. This mode of applying water is attended with the disadvantage of always drawing under a fixed head, adapted to the lowest state of the millpond during droughts, while the benefit of ½ of this head, for the reasons before stated, is permanently lost during the other seasons of the year. The governor also operates irregularly in opening and closing this kind of gate, several revolutions being often required to produce a sufficient movement to obviate the play of the teeth of the geering and moveable joints, the weight of the gate not being suspended by them.

On the best form for the buckets of Overshot Wheels.

It is impossible to construct the buckets so that they will remain completely filled with water until they reach the bottom of the wheel. Mill-Wrights have therefore turned their chief attention to the determination of a form for the buckets which shall enable them to retain the water through a greater portion of the circumference of the wheel. These are called elbow-buckets, because each partition is formed by two boards which are put together with an angle or elbow. The rule for setting them out is to divide the wheel into the number of buckets it is intended to have; then take four-fifths of the space or interval between two partitions for the depth of the shrouding, that is, the breadth of the circular rings at the sides of the wheel, which form the ends of the buckets and are called the shrouds; whilst the planking, which forms the bottom of all the buckets is called the sole of the wheel. That board of each partition which is in the direction of a radius to the wheel, rises from the sole half the depth of the shroud. The other board of the buckets is so inclined, that its outer end advances as far as the line of the next radius-board. The loss of water at the lower part of the wheel, will very much depend upon the proportion of water which is poured into each bucket. It is evident, that if the buckets, of whatever form they are made, were totally filled when at the top of the wheel, they must begin to spill the water as soon as they depart from that position. But on the other hand, if only a part of each is filled with water, then it will bear a greater degree of inclination, and be a longer time before the water will begin to spill from the buckets. This is a reason for making large buckets and filling them only about half full.

It is the common practice in England to increase the number of water wheels in order to obtain a greater capacity of buckets. By substituting two wheels to receive the water instead of one, a little loss of power may take place from greater friction of the geering, but the stress attendant upon the movements of one ponderous wheel is obviated, while a much greater length of bucket is thus readily obtained, and the water is applied in a thin sheet with less loss of head. At the Stanley Mills, near Stroud in England, there are five iron water wheels each about 12 feet in length, making 60 feet in total length of buckets, although the stream is no larger than many in the United States upon which a single wheel is used for receiving the whole volume of water. It must be manifest that the wheels adopted in the one instance would be of an improper construction to be used in the other. When the manufacturer selects a model for constructing his water wheel, he should consider the manner in which the wheel is to be used, whether with a thin sheet of water or with a heavy one—if the latter, the mouths of the buckets should be made spacious, or in extreme cases it might be better to construct floats or risers without elbows. Wheels of this description with spiral floats or buckets have been in successful operation in Rhode-Island. The water wheels of the best construction have long shallow elbow buckets, for a thin sheet of water discharged into them. When the wheels are very long it is common to construct the floats in two sections, that they may not extend in one line through the whole length of the wheel, and receive the impulse of the water by sudden shocks, which might render its motion irregular.

There seems to prevail in the United States a greater want of knowledge in using water wheels judiciously, than in the construction of them. After the labours of a skillful millwright are terminated, and the water wheel is completed upon the best English models, the manufacturer too frequently overloads it, filling the buckets entirely full of water, instead of half full as originally intended. The buckets being formed with contracted opening, to retain the water as long as possible without spilling it, are soon found to be inadequate either to admit the quantity of water allowed to flow upon them, or to deliver the water that enters them when it has descended to the level of the mill race. The water on rushing into the apertures encounters the air contained within the buckets, which in escaping, throws it into foaming agitation, while the water on the contrary meets with the same obstruction in escaping again, and rises with the bucket to a greater or less height before it is discharged. The evil of the reaction of the air against the water as it enters the buckets may be partially remedied by forming blanks or breaks in the aperture at each end or in the middle of the gate, through which the water issues upon the wheel. As a general rule the "number of buckets to a wheel should be as few as possible, to retain the greatest quantity of water; and their mouths of only such a width as to admit the requisite quantity of water and at the same time to allow the air to escape."

Velocity of Water Wheels.

The weight of water allowed to flow upon a wheel should be so apportioned to the load or resistance to be overcome, that the circumference of the wheel may move with the velocity best calculated to produce a maximum effect. The velocity of the wheel may be so much increased that it will receive but little of the impulse of the water, which when left to fall freely in the air will descend 16 feet in one second, and if the float of the wheel were to descend 16 feet in one second, it is manifest the water would have no effect at all upon it. This is one of the principal causes of the loss of power from the use of undershot wheels, which move swiftly. If the wheel were to move only an inch in a second, the contrary extreme would be found very inconvenient in practice, on account of the heavy geering that would be required to gain the requisite speed, and the loss of power that would take place from friction. A medium has been adopted, which is stated by Smeaton to be "3 feet per second, as applicable to the highest overshot wheel as well as the lowest; though high wheels may deviate further from this rule than low ones can be admitted to do," Mr. Banks states "that the circumference of wheels of different sizes may move with velocities which are as the *square root of their diameters*, to produce their maximum effect, the water being applied near the top of the wheel." The velocity of wheels suitable for different falls of water may be readily found by this rule on referring to the table at page 134. *The square root of* 16 is 4

of 4 is 2

Therefore a wheel with a fall of 16 feet may move with double the velocity of another with a fall of only 4 feet, the diameters of the wheels corresponding with the fall, as in the following table.

Height of the overshot Water Wheel in proportion to the Fall.

A water wheel it is stated, by Banks, will produce the greatest effect when its diameter has such a proportion to the height of the fall that the water may be discharged upon the wheel at an angle of about 45°, the aperture of the gate being so formed as to shoot the water nearly at right angles with the arms or radii of the wheel. The following table, calculated upon this rule by a manufacturer of Rhode-Island, will give the height of water wheels suitable for falls of from 6 to 20 feet.

Fall of Water.	Diameter of Water Wheel suitable for the Fall.	
Feet	Feet.	Inches.
6	6	1
7	7.	3
8	8.	5
9	9.	7
10	10.	8
11	12.	0
12	13.	2
13	14.	4
14	15.	6
15	16.	8
16	17.	10
17	19.	1
18	20.	3
19	21.	6
20	22.	9

The proper diameter of a wheel for a fall of 16 feet appears to be 17 feet 10 inches. If the square root of the fall is taken for the velocity of the circumference of the wheel, according to the preceding directions, it should move at the rate of 4 feet per second;—and a wheel of 9 feet 10 inches diameter with a fall of 9 feet, should move at the rate of 3 per second.

In cases where great power is required, accompanied by a slow motion, to be immediately derived from the axis of the water wheel, the preceding table should not be used; for the larger the wheel, the greater will be the power that may in this way be derived from it, the long arms serving as levers. The larger, however, a wheel is made, the more floats or buckets it must have on its circumference; and as every bucket must be filled, or every float board struck by the water in succession, the more buckets or floats there are, the longer the wheel will be in performing one revolution; consequently all that is gained in power is lost in velocity; and as a certain speed is required for almost every description of machinery, it will be necessary to raise or accelerate the speed by cog wheels within the mill, by which, upon the principles stated at page 153, the power gained by the magnitude of the wheel must be lost in producing the desired velocity of the mill geering. For this reason great attention should be bestowed in proportioning the size of the undershot and breast wheel, not only to the fall or velocity of the stream, but to the speed of the geering or machinery to be operated by it.

The largest water wheel known is said to be in Wales. It is 50 feet in diameter, with buckets 6 feet in length, and is constructed principally of cast iron. At the works of Messrs Strutt, there is a very powerful breast wheel of the extraordinary width of 40 feet, and 12½ feet diameter.

Back Water.

In situations exposed to back water, breast wheels with straight or open float boards operate more freely than bucket wheels. The impediment to the motion of a wheel revolving in back water has been greatly diminished in several instances in Rhode-Island by forming valves in the floats or buckets, which close when filled with water, but fall open when inverted, whereby the air is admitted freely to displace the water without causing it to be lifted above the level of the water in the mill race. Spiral open float boards have also been most advantageously used in Rhode Island for obviating the effects of back water. Common breast-mills will bear about one foot of back water without much disadvantage. Mr. Smeaton mentions "having seen an instance of *six feet*." "It is a common thing to lay undershot wheels and breast wheels from six to twelve inches below the water level of the pond below, and is attended with good effect if judiciously applied, as the diameter of the wheel may be increased by it; and though it must always work in that depth of water, it will perform full as well" When the water quits the buckets of a wheel, it has been before observed, all the velocity which it retains is carried off and lost. It therefore seems probable that a few inches of back water may be driven off effectually by the momentum retained by the water after leaving the wheel, and that this is the only way in which the final power of the water may be beneficially expended or exhausted.

On the communication of power from the Water Wheel.

In order to ascertain the most favourable part of the water wheel for affixing the iron segments composing the pit wheel, English writers have entered into calculations founded upon the moving forces of a body revolving round a fixed axis. The point in which the principal moving force of a revolving body is collected is called the centre of gyration. When the same principles of calculation are applied to the moving force of bodies swinging like the pendulum, this point is termed the centre of oscillation (See page 160.)

In calculating the Circle of Gyration for affixing the segments upon a water wheel, several circumstances are taken into consideration, such as the weight of the different parts of the wheel, and of the water resting upon it, the length of the arms, &c. The following example is given.

EXAMPLE.

Required the diameter of the Circle of Gyration in a water wheel 30 feet diameter, the weight of the arms being 12 tons, shrouding 20 tons, and water in the buckets, while in operation, 15 tons?

30 feet diameter, semi-diameter or radius is 15 feet.

Shrouding $20 \times 15^2 = 4500 \times 2 = 9000$ } The opposite sides being taken
Arms $12 \times 15^2 \div 3 = 900 \times 2 = 1800$ } the product is multiplied by 2.

Water $15 \times 15^2 = 3375$

$20 \times 12 = 32 \times 2 = 64$

Water 15

79

$14175 \div 79 = 179$, the square root of which is $13\frac{4}{10}$ feet semi-diameter of the Circle of Gyration.

The above rule is somewhat complex, and must be in most cases in practice hypothetical. The weight of a wooden water wheel when soaked with water can only be estimated by conjecture. The weight of the different parts of a cast iron water wheel, however, may be ascertained with more certainty, the whole of it being generally furnished by the pound.

It seems that engineers in making the above calculations suppose the moving power to be imparted from the mass of the water wheel itself as well as from the water, whereas in fact the weight of the water in the buckets is the only moving power which the wheel transmits uniformly when once put in regular motion, as it neither expends nor acquires force. If the wheel were to exert its own momentum as well as that of the water in the buckets at a blow against any obstructing solid body, this point would undoubtedly be the most favourable for producing the greatest effect.

The segments have been attached to the shrouding by some engineers, by which the rim of the wheel is strengthened. The greatest objection to this plan is, that the teeth of the segments are kept constantly wet by descending into the tail-water, which prevents their receiving oil or tallow to diminish the wear and friction. If the segments attached to the arms of the wheel be formed of a little less diameter than the shrouding and sole of the wheel, leaving a proper space for the water, which may force its way through the joints of the lining to escape from within the hollow cylinder, formed by the interior of the wheel, the above calculations may generally be dispensed with.

Much diversity of opinion exists in relation to the most advantageous part of the segments or pit wheel, to which the geering of the mill should be applied. The first motion is commonly taken by a crown wheel upon an upright shaft, from the top of the pit-wheel. This plan is convenient, because the first upright shaft may be continued upwards through each floor of the mill. It is not, however, the most favorable point for obtaining the effective power of the water wheel. Whenever the mill geering is connected with any part of the circumference or side of the water wheel, except in the line drawn from the point on which the water acts in a direction through the axis of the wheel, it is manifest that the effect is produced upon the principle of the bended lever, and that consequently the gudgeons have to sustain not only the weight of the water wheel but also the stress produced by the weight of the water in the buckets. When the water acts upon one side of the wheel and the power is transmitted from the opposite side of it, the gudgeons must sustain just double the weight of the water. If the water, as at *a* fig. 1 page 166, press with a force equal to 5000 pounds, and the resistance of the mill geering applied at *b* be also equal to this weight, the gudgeons at *c* must sustain a pressure of double 5000 lbs. or 10,000 lbs. in addition to the weight of the water wheel. But if the resistance be interposed in some point in the line *a c*, the power of the water at *a* would have a tendency to diminish the weight upon the gudgeons at *c*, or even to lift them out of their bearings. This would actually be the effect if the segment wheels were made of small diameter, and the whole weight of the water wheel would be counterbalanced upon the fulcrum, formed of the teeth of the geering, by the water resting in the buckets upon the extremity of the arms of the wheel. By means of this *horizontal geering*, every pound of water poured into the buckets will relieve the gudgeons of about an equal weight. It has been supposed by some mill wrights that not only the weight of the water but the weight of the water wheel itself is thus brought into action upon the geering applied to it, and that there is actually a gain of power in this case. It will be perceived, upon the well known principles of mechanics explained at page 152, that whatever is thus gained in *power* is lost by the diminished *velocity* of the motion imparted, and to regain the speed, the power is necessarily absorbed by additional wheel work, attended with the disadvantage of increased friction. It is preferable to obtain the requisite speed of the mill geering as immediately as possible from the first mover, carefully avoiding, however, in all cases a resort to crown or spur wheels of small diameters, by which a considerable loss of power is produced from the lateral pressure or stress and friction of the teeth. In addition to the advantage gained by horizontal geering in saving the stress and friction upon the gudgeons, the power is commmunicated almost from the immediate point at which it is received by the buckets from the water, and the joints intervening between the different sections of the water wheel, are not affected or drawn asunder by the transmission of the force of the water, as is the case when the common modes of geering are applied. For this reason the wheel will prove far more durable, and will require less repairs than when the motion is communicated from the top or any other part of the circumference of the wheel. Another great advantage attending the horizontal geering is, that the bearings of the heavy shafts may rest upon the solid masonry of the wall of the wheel pit, and the speed may be increased to the desired velocity without connecting any part of the shafts, except the last upright one, with the timbers or floors of the mill, whereby the tremour so disagreeable, and often so injurious, not only to the operation of the machinery but even to the walls of the mill itself, may be in a great measure avoided.

The spur wheel is frequently employed for communicating motion from the water wheel, but is commonly attended with the disadvantageous mode of affixing it to the extreme end of the driven shaft, instead of the middle of it between the bearings or journals, as is conveniently accomplished by substituting the bevelled geer.

Upon water wheels of great dimensions, it is the usual practice to bolt two sets of segments, one upon each end of the wheel, to divide the stress equally between them and to prevent one end from becoming racked or twisted on the shaft by the load of water in the buckets.

Calculation of the Power of a Water Wheel.

The power of a water wheel is calculated from the weight of water which the buckets are capable of containing, and the distance descended by these buckets when thus filled. The *head* of water falling into the buckets is estimated to be only one half as effective, as the weight of the same water after it rests upon them. For this reason only one half of the head or descent of water before it strikes the buckets is measured. In most cases where the water is drawn over the top of the gate upon wheels with oblique elbow buckets, even this head should not be measured. The water, unless properly directed by plates of iron as described at page 212, acts against the elbow-buckets and actually obstructs the motion of the wheel.

It may be observed that the mode of estimating a moving force by the term *horse power* is exceedingly vague and indefinite, not only as regards the standards adopted, but also the forms and construction of the various machines to which the power is applied, and even the working condition of the same machines at different times. Thus a water wheel injudiciously constructed will not perform so well with the same quantity of water as another wheel upon a better plan, and this difference may again be done away by imperfections in the accuracy of the sweep of the breast, whereby much of the water may be wasted by leakage, &c. The same observations apply to steam engines which also produce different degrees of effective force under various circumstances. The effective power of the water wheel may be more readily measured than that of a steam engine, because the quantity of water power applied with a given fall may be more exactly ascertained than the state of the vacuum in an atmospheric engine, or of the elastic acting force transmitted uniformly to act upon the piston of a high pressure engine. The power of a given quantity of water poured upon an overshot water wheel has been found by experiments made by Mr. Smeaton, as stated at page 210, to be sufficient to raise a weight equal to that of two-thirds the quantity of water which acts upon it to the same height from which it falls; and if discharged against the floats of an undershot wheel, to raise one third of this quantity. Supposing the water wheels to be formed upon the best principles and to be in good order, we have then a ready standard of estimating the effectual *horse power* furnished by a stream by supposing it equal to raising ⅔ of the quantity by an overshot and ⅓ of the quantity by an undershot wheel to the height from which it falls. 528 cubic feet of water weighing 33000 lbs. raised one foot per minute is what is called a horse power for Steam Engines, Boulton & Watt having fixed their standard at 32,000 or 33,000 lbs. raised to this height per minute.

It is required to calculate the *power of a Wheel* 17 feet 10 inches diameter, with a fall of 16 feet, making 4.21 revolutions per minute, and having 38 buckets, each of the capacity of 22½ feet, and intended to contain 11¼ cubic feet of water.

EXAMPLE.

4.21×38=160 buckets×11¼ cubic feet of water each=1800 cubic feet of water will be required for this wheel. 1800×62½=112500 lbs. per minute descending 16 feet, or 112500×16=1800000 momentum 1 foot per minute. On an overshot wheel Smeaton states the power is to the effect as 3 to 2; on an undershot as 3 to 1.

As 3 : 2 : 1800000 : 1200000 raised 1 foot high effective power of this wheel. This effective momentum may be divided at pleasure by any of the standards of horse power that the engineer may choose. Boulton & Watt's standard is 32,000 or 33000 raised 1 foot high per minute.

1200000÷33000=36 Horse Power.

1200000÷44000=27 Horse Power, as calculated by some late writers, whose reasons for adopting this high standard after allowing previously for the loss of ⅓ of the power of the water are not explained. By assuming 44000 for the divisor, ½ of the power of the water is estimated as lost, instead of ⅓ as found to be the result by actual experiments made by Smeaton. Although the actual effect of the water applied on overshot wheels may not in some cases exceed ½ of the power, yet it seems a disproportionate allowance to calculate for the same loss of power by a water wheel as by a steam engine, in the operations of which there is a much greater resistance to motion, and consequent loss of power by friction, and by the reciprocating movements of beams, pistons, &c. than by the simple revolving motion of the water wheel.

It has been stated that "it has been found by repeated experiments that 600 cubic feet of water falling one foot, or 60 cubic feet falling 10 feet per minute on a good undershot wheel (or about half that quantity upon an overshot wheel) during 60 minutes is an ample allowance for grinding a bushel of wheat or rye, as this effect may be produced by 530 cubic feet of water falling 1 foot, or 53 cubic feet falling 10 feet per minute: or 600×60=36000 cubic feet of water falling 1 foot will grind a bushel of wheat or rye by means of an undershot wheel."

It appears from tables published by Mr. Fenwick that 786 gallons of water Ale measure per minute on an overshot wheel 10 feet diamter is sufficient to grind 1 boll, (4 bushels) of wheat or rye in 60 minutes.

786÷4=196½ Gals. × 10 feet fall × 60 minutes×282÷1728= 19240 cubic feet of water with a fall of 1 foot, is required to grind 1 bushel of rye or wheat by an overshot wheel. 19240×62½=1202500 momentum. Deducting ⅓ leaves 801667 effective force of the water on an overshot wheel÷60÷33000=nearly $\frac{5}{10}$ of a horse power continually applied for 60 minutes is required to grind 1 bushel of wheat or rye by an overshot wheel.

There are 43560 cubic feet of water in an acre of the surface of a mill pond 1 foot deep, and 36000 cubic feet with a fall of 1 foot being required to grind 1 bushel of wheat or rye by an undershot wheel, it may therefore be safely calculated that every superficial acre of water 1 foot deep in a mill pond will grind

1 bushel of rye or wheat for each foot of fall by an undershot wheel.
2 bushels " " " " overshot do.

It requires about 1200 cubic feet of water *per* minute descending 1 foot to operate a pair of falling stocks for milling cloth.

To find the power of a Stream, Reservoir or Mill Pond to grind wheat or rye, by an overshot wheel.

Multiply the cubic feet of water that such stream or pond may afford per hour by the virtual descent, (that is, half of the head before it strikes the overshot wheel, and the fall after it strikes it,) and divide the product by 20,000, and the quotient is the answer in bushels per hour that the stream will grind.

To calculate the dimensions of a Water Wheel suitable for a given stream.

EXAMPLE.

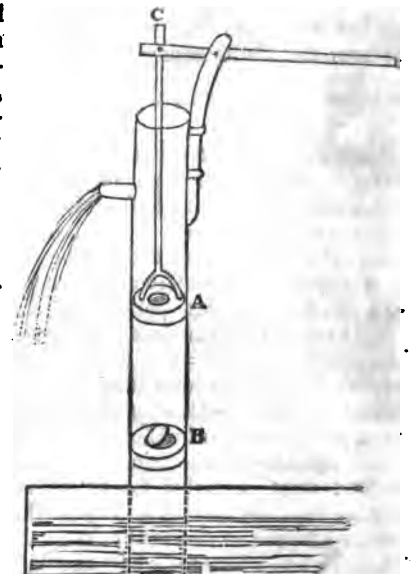
Suppose the fall of water to be 16 feet, and the regular supply to average 1800 cubic feet per minute. What should be the dimensions of a water wheel suitable for this stream?

For a fall of 16 feet, a wheel of 17 feet 10 inches diameter appears by the preceding table to be of the proper size. As 7 : 22 : : 17.10 : 57 feet circumference of wheel. The square root of 16 gives the velocity of 4 feet per second×60=240 feet per minute÷57= 4.21 revolutions per minute. Suppose the wheel to require 38 buckets;—then 38×4.21=160 buckets per minute to be filled. 1800 cubic feet of water divided among 160 buckets=11¼ cubic feet to each bucket. The buckets should not be filled above half full; therefore the capacity of each bucket should not be less than 22½ cubic feet. It now remains to determine upon the form of the bucket that may be deemed most desirable for retaining the quantity of water. This may be done by making a deep or shallow shrouding, and a proportionately longer or shorter bucket. Allowing the sectional end of the bucket to be 1¼ feet, the wheel should then be 18 feet long between the shrouding, 22½÷1¼=18. When the length of bucket is too great for one wheel it will of course be proper in practice to substitute two or more wheels.

Of the artificial modes of imparting motion to fluids. Pumps and other machines for raising water.

Of all the machines invented for raising water the common pump has been found the most convenient, and least expensive. There are three kinds of pumps, called the *suction*, the *lifting*, and the *forcing pump*. The suction pump raises the water by forming a vacuum, into which the pressure of the atmmosphere causes the water to ascend. This principle will be more fully explained when treating of the Barometer. In practice it has been found that a suction pump does not operate well where the piston or *upper box* works at a perpendicular height of more than 24 feet above the surface of the water. By lengthening the piston rod, however, the piston may be made to descend nearer to the surface of the water, whereby the water resting upon the upper valve in the cavity of the pump may be *lifted* to a much greater height. This is the usual construction of the common pump, which operates by *suction* to raise the water to the upper box, and then *lifts* it to the desired height. In the two first kinds of pumps the pistons have valves opening upwards, but in the forcing pump the piston is usually made solid.

The operation of the common pump may be briefly explained as follows. Let A represent the piston, or upper box as it is frequently called; B the lower box, both having the valves opening upwards, and fitted air tight in the barrel of the pump. When the piston A approaches B, the air contained in the chamber between them has no other way of escape except through the valve in A, which being made to open upwards the air passes freely through it. The piston A being now drawn up, the valve closes and prevents the air returning again to the chamber between A. B. A vacuum is thus formed in the chamber of the pump between A. B. into which the pressure of the atmosphere causes the water to rise, on the principle familiarly known in practice when a similar vacuum is formed in a short pipe or straw by the action of the mouth or lungs. The piston on its next descent displaces the water, as it did the air in the first instance, causing it to escape through the valve A above the piston, as it descends to B. On the next movement of the pump handle, the water



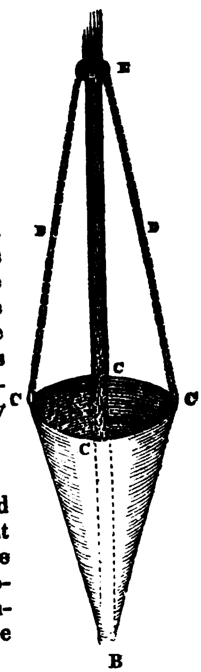
that has passed above the valve A is raised by it, and runs off from the nosle of the pump as long as this operation is repeated. There are a great variety of pumps and machines for raising water, which all operate nearly on this same principle.

The power required to raise water to any height by the pump, is as the perpendicular height and quantity raised in a given time. The volume of water raised at each stroke of the pump is equal to filling the capacity of the bore or chamber in which the piston works. When water is to be raised to a given height in pumps of different bores the power to work the pump should be increased or diminished in the ratio of the squares of the diameter of the chambers in which the pistons traverse. If the diameter of the bore of one pump be 2 inches, and that of another pump 4 inches, the increase of power requisite to raise water to equal heights in each will therefore be as 4 to 16, and the quantity raised will also be augmented in the same ratio. A pump will not require more power to work it if the bore be increased in size above or below the piston. The power of the lever is usually adapted to pumps to render the labour of pumping less fatiguing, and to apply the power more conveniently than by lifting the piston directly with the hands at each stroke. Mr. Ferguson has supposed that the most advantageous application of the lever for the handle of a common pump to be, when the power is increased five fold. He has given the following table, formed upon this calculation, of the diameter of the bore of a pump and the number of gallons (wine measure) per minute which may be raised with the same ease by a man of common strength to various heights, from 10 to 100 feet.

Table for constructing Pumps.

Height of the water raised in the pump above the surface of the water of the well.	Diameter of the bore.		Water raised in a minute in wine measure, by an ordinary man.	
feet.	*inches.*	*100 parts of an inch.*	*galls.*	*pints.*
10	6.	93	81	6
15	5.	66	54	4
20	4.	90	40	7
25	4.	38	32	6
30	4.	00	27	2
35	3.	70	23	3
40	3.	46	20	3
45	3.	27	18	1
50	3.	10	16	3
55	2.	95	14	7
60	2.	84	13	5
65	2.	72	12	4
70	2.	62	11	5
75	2.	53	10	7
80	2.	45	10	2
90	2.	31	9	1
100	2.	19	9	1

At the coal mines in Rhode-Island, a very simple and cheap valve for the piston of a pump has been in use for about two years, during which period it has been found to produce less friction than the pistons upon the plan in common use, while it has proved more durable, one of them having been operated more than five months without any repairs. It is made of thick leather in the form of a cone, as in the following sketch.



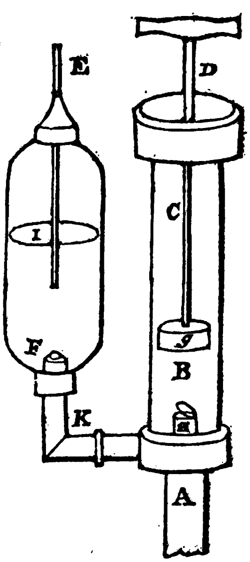
A conical leather bag, secured upon the end of the pump shaft at B by an iron ring which clasps it tight, being driven upon it forcibly. C the four leather ears to receive the ends of the four chains, which are secured to the pump rod by a ring at E. It is obvious that when the valve descends the leather bag must collapse or be pressed together in such a manner as to allow the water to pass it freely. The upper edge of the leather at C is contracted a little, so that when it ascends the sides of the leather are distended by the pressure of the water, and are adapted to fit exactly the sides of the chamber of the pump. The chains prevent the upper edges of the leather from settling down beneath the weight of water which may rest upon it.

In the above examples the water may be raised by a pump acting by *suction* to the height of about 30 feet, and the remainder of the height of the water must be *lifted* after passing above the upper valve or box. The water may be most conveniently raised the whole height at once by the force pump.

It is often convenient to place a pump in some particular room or building in which the water is constantly required for use, when the well or cistern from which the supply of water is to be obtained is at a distance from the building. By means of a large horizontal pipe, connected with the pump below the lower valve, the water may be drawn from such well or cistern almost as readily as if the end of the pump were placed perpendicularly therein. The principal difficulty attending this arrangement arises from the almost unavoidable imperfections in uniting the joints of the pipes to render them air tight, whereby the air enters and allows the water to settle down. It is more difficult to fit joints or valves to be air tight than to render them water tight, the air being a more subtile fluid than water. For this reason the valves should be placed as low as possible in common pumps that the column of water may rest upon them, and may not be dependant below them. The water will in this case be much longer in leaking through the valves than the air would be, while the action of the air in entering through the imperfect joints in the horizontal pipes will be also diminished, and it will consequently be rarely required to pour water into the pump to produce a sufficient exhaustion of the air, or *suction*, to cause it to operate. Iron pipes secured together by flanches and bolts are best adapted for this purpose; leaden pipes will answer equally well, if secured from the compression or distortion which this yielding material is liable to from the jar produced by the motion of the pump handle.

Forcing Pump.

The operation of the Forcing Pump is shewn in the following sketch.



D C is the piston rod, and *g* the piston, fitted air tight to the cylinder in which it is intended to work. When the piston *g* is raised, it will form a vacuum beneath it in the chamber B, and the water if not more than 34 feet below the piston will ascend through the pipe A to fill the chamber. In this operation the force pump may be made to perform the office of the suction pump. The chamber of the force pump B, is however, frequently immersed in water, or placed below the surface of it in such a situation that it will flow up through the valve at H, which opens upwards, whenever the piston ascends. After the chamber B is filled with water the force is applied to the piston rod D to drive down the piston upon the water, and to urge it to escape through the pipe K, because the valve at H opening upwards, closes and prevents its return to A. The height to which the water might be raised through a pipe K may be several hundred feet, being regulated only by the force applied upon the piston. When the piston is drawn up to allow the chamber of the pump to become again filled, the water would return through the pipe K were it not prevented by another valve at F. This valve also opens upwards and allows the water to ascend freely through it, but closes by its own weight and by that of the water above it the instant the piston ceases to act.

Air vessel for equalizing the discharge of water from pumps.

Water, as before stated, is nearly inelastic, and when confined in pipes and subjected to the action of a sudden force, it seems to display the same *inertia* or resistance to motion as solid bodies. The operation of a common pump is by starts, the whole mass of the column of water being suddenly put in motion and being as suddenly left to fall back upon the valves during the time the piston is withdrawn to make a new stroke. In this case the force necessary to put the whole mass of water in motion must be expended at every stroke, because if the column comes to a rest only for an instant, it must be put in motion again before the operation can be resumed. This apparently trifling inconvenience is really a very great mechanical disadvantage in the operation of pumping, causing a loss of power, and a straining of the pipes and of all parts of the machinery.

The air vessel F I, as shewn in the preceding figure, is a close vessel of any form which will retain air in the upper portion of it and water in the lower portion. As the pump A B C urges the water with a sudden motion into the vessel, the air yields and becomes compressed, admitting the water into the vessel in far less time than would be required to put a long column of it in motion. After the water is thus forced into the air vessel by the piston *g*, through the pipe K, the air in the upper part of the chamber above the surface of the water I becomes compressed into a smaller space, until the force of the stroke is spent, when its elasticity produces in it a continual tendency to regain its former bulk operating gradually like the springs of a travelling carriage to prevent the jolts or shocks, and to cause the water to be discharged through the pipe E, not in irregular jets ceasing the instant that the piston is withdrawn to repeat the stroke, but in an equable stream. The water will continue to issue until the air has regained so much space that its elasticity is only sufficient to balance the column of water or resistance in the pipe E. The air cannot escape at the pipe E because the water rises above it to I, and must therefore continue to occupy the upper part of the chamber, while the water flows into the bottom of the pipe E. A part of the water is merely retained in the air vessel during the active stroke of the piston to be gradually expelled during the return stroke. The air vessel is found to be peculiarly advantageous in forcing water through long pipes, and in cases in which a rapid motion is to be imparted to the water, as in common fire engines, and force-pumps.

The crank is the most favourable as it is the most common method for working pumps from a first mover which acts with a rotative motion, or by means of revolving wheels. The reciprocating motion obtainable from a crank is irregular, being very slow at its commencement and termination. This property is considerd a very great advantage in working pumps, because it puts the column of water in motion with a less sudden shock, accelerating the motion of the piston gradually and bringing it gradually to a state of rest. To put a column of water contained in a long pipe into instantaneous motion would require a vast force, and would produce destructive shocks which the strength of no materials could withstand. If an iron tube 200 feet in height were constructed as strong as a cannon to with stand the shock of a discharge whereby a heavy ball might be thrown horizontally one or two miles, yet if in this case the tube were filled with water, it is probable that the sides of it would yield and burst asunder, without projecting or dislodging the water contained in the tube. If however the same force could be brought to act gradually it would not only expel the mass of water but impart to it a very considerable velocity. It is for this reason that the crank and air vessel are deemed so favourable in aiding the operation of the pump, that a writer has even given it as his opinion that "by a judicious application of the crank, air vessel and fly wheel, the reciprocating motion of pumps may be completely remedied, and if a rotatory pump could be brought to perfection, it would have no superiority over an accurate pump with a straight barrel." Of course a machine with all these appendages would be found so bulky and expensive that a rotatory pump would prove more portable and economical without any of the disadvantages of a loss of power which must unavoidably result from a reciprocating motion.

We shall not here attempt a description of all the machines used in various ways for raising water. A few of the most common will be mentioned.

Chain Pump.

For raising water from the holds of ships the chain pump is sometimes used. Instead of the single piston *g*, as in the last figure, there are a succession of pistons connected with the flexible links of an iron chain. These pistons are made to ascend successively in the pump barrel, and after passing over a windlass or pulley to descend upon the other side, forming an endless chain; thus continually ascending in the pump barrel on one side, and raising the water in which the lower end of it is immersed, and descending on the other side to renew the operation. This pump is capable of being made to discharge great quantities of water, but is subject to considerable friction.

Archimide's Screw.

This machine may be readily formed by bending a tube spirally around a sloping shaft with one end immersed in the water. It thus resembles the worm used by distillers which if placed upon its side in a sloping position and made to revolve upon an axis like a screw will at each revolution scoop up the water in which the lower end may be partially immersed. The water keeps in the lower side of the spiral tube while turning, until it reaches the upper orifice where it is discharged. This machine has not been found to be so generally useful and advantageous in practice as might be supposed from theory. It is however used occasionally where from the situation of certain hydraulic works as coffer dams, &c. the use of a number of pumps worked by hand would be inconvenient. It is turned by means of an universal joint connected with cranks to be worked by several men.

The Rotative Pump.

Rotative pumps are formed with valves adapted to the inside of a cylindrical barrel, by which a reciprocating motion is avoided, as in common pumps, and a steady stream is produced by turning a crank.

The valves are made of two thin plates of metal fitted at right angles to each other in mortises in the axis, which passes through the barrel. This axis not being placed in the centre of the barrel, the valves slip back and forth through the mortises from their contact with the internal sides of the close barrel. It is stated by the manufacturers of this description of machine that their largest rotative engines, calculated to be set up in mills, will discharge 2600 gallons per minute. For mill purposes this machine is both powerful and capable of being conveniently applied or put in motion from any of the revolving wheels of the mill geering without requiring a crank movement. One of the principal advantages of this pump is that the reciprocating motion of piston rods, beams, &c. is avoided, by which as before observed an important saving of power is made.

Flash Wheel.

This machine appears to be very generally used in Holland for raising the water from the extensive marshes of that wonderful country by means of windmills. It is formed in all respects like a common breast wheel, but operates exactly the reverse of it; as it scoops up the water from the wheel pit, and carries it up against the sweep of the breast until it is discharged into a sort of floom prepared to receive it. It is a very effective machine for raising large quantities of water from a small depth. During a fresh breeze a windmill appears to produce from the canals that intersect those fertile but deeply sunken meadows, quite a rivulet of water, which flows covered with froth until it falls over the dikes into the level of the surrounding sea.

Raising Water by Pumps.

The quantity of water actually delivered by *pumping* will fall short of what may be calculated in theory from two causes; viz. friction and the usual escape or return of the water past the valves.

The resistance arising from the friction of the water flowing through pipes is directly as the velocity and inversely as the circumference of the pipe. The allowance usually made for the friction of water against the sides of pipes is taken as a standard for calculation at $\frac{1}{5}$ of the whole resistance, being a medium adapted to most cases of the conveyance of water through pipes. This resistance will be increased or diminished according to the size of the pipes and velocity of the water. Water should not be made to move with a velocity greater than 3 feet per second or 180 feet per minute through the contracted apertures or valves of pipes, because although a perfect fluid, yet when suddenly urged into rapid motion it reacts like solid bodies. This may be observed by moving the hand slowly and rapidly through water. In the one case resistance is barely perceptible, while in the other it is so great as to require a considerable effort of strength to overcome it. The pistons of pumps are commonly made to move with a velocity of 80 or 100 feet per minute. If the contracted apertures of pump valves be circular, then the diameter of the barrel being divided into 10 parts the diameter of the least opening of the valves or stop cocks, &c. should be 7 of those parts. These passages may of course be made relatively smaller if the piston moves slower.

About 10 per cent of the power applied in the operation of pumping is supposed to be lost in overcoming the inertia of the column of water and of the piston rods, piston, lever beam, &c. This loss arises from the unfavourable nature of all reciprocating motions, by which a mass of matter is suddenly put in motion and as suddenly stopped. In this respect the reciprocating pump is greatly inferior to the rotatory pump, by which not only the water but all the moving parts of the machine itself are continued in an uniform motion. A simple experiment will be sufficient to convince any one of the power required to maintain reciprocating movements, by attempting to impart a motion of this kind to a cannon ball or other heavy body, by moving it quickly back and forth. The utmost strength of a vigorous man would, indeed, be hardly sufficient to maintain a rapid reciprocating movement even of his own arm for any considerable length of time.

An allowance of 3 inches of each stroke of a common pump should also be made for the return of a part of the water before the valve fairly closes.

It appears, therefore, that $\frac{1}{5}$ more power will be actually required to raise water by a common pump than the power calculated upon in theory.

Examples for calculating the power and dimensions of Pumps necessary to raise given quantities of water to certain heights in a given time.

EXAMPLE I.

Required the power necessary to discharge 175 Ale gallons of water per minute from the top of a pipe 252 feet high into a reservoir?

1 Ale gallon of water weighs $10\frac{1}{2}$ lbs. avoirdupois nearly,

$175\times10\frac{1}{2}=1799$ lbs$\times252$ feet elevation$=453348$ lbs raised one foot high per minute. This number of lbs. being divided by the standard of a horse power, and $\frac{1}{5}$ added to the result will give the answer.

$453348\div32000=14\frac{1}{10}$ add $\frac{1}{5}$ for loss of power$=1.8+14\frac{1}{10}=16\frac{8}{10}$ Horse power.

EXAMPLE II.

Required the diameter of a pump with a stroke 2 feet in length and making 40 strokes per minute to fill in 30 minutes a cistern 20 feet square and 10 feet deep, placed on the top of a hill 60 feet high? Also the requisite power to produce this result?

$20\times20\times10=4000$ cubic feet contents of cistern.

$4000\div30=133.3$ cubic feet of water per minute

133.3×1000 oz. (the weight of a cubic foot of water) gives the weight in ounces, which divided by $16=8331.25$ lbs. Avoirdupois to be raised per minute.

40×2=80 feet, distance the piston moves in a minute
133.3 cubic feet of water per minute÷80=1.7 cubic feet each stroke
1.7×144=244.80÷.7854 (decimal area of a circular inch) =311.7 area of the piston in inches; now the square root of 311.7 is 17.6 inches diameter of pump required.

8331.25 lbs. raised 1 foot high per minute×60 feet elevation= 499875 lbs. raised 1 foot high per minute÷32000=15.6 horse power. Add $\frac{1}{5}$ for friction =18.7 horse power required.

EXAMPLE III.

How many cubic feet of water will be raised in an hour by a pump 8½ inches diameter, and 3½ feet stroke, making 18 strokes per minute?

Diameter 8.5×8.5=72.25 circular inches; divide it by 183.3, which is the number of circular inches in a square foot, and it gives .394 square foot for the area of the pump barrel, ×3.5 feet in length=1.379 cubic feet×18 strokes *per* minute=24.822 cubic feet of water raised per minute×60 minutes=1489 cubic feet of water *per* hour, raised by this pump. This quantity may be reduced to wine or beer gallons by multiplying the number of cubic feet by 1728 and dividing the product by the cubic inches in a gallon of the measure required. See page 113.

EXAMPLE IV.

There is a town, the inhabitants of which amount to 12000, and it is proposed to supply it with water from a river running through the low grounds 250 feet below the best situation for the reservoir.

It is required to know the power of an Engine capable of lifting a sufficient quantity of water, the daily supply being calculated at 10 Ale gallons to each individual; also, what size of pumps and pipes are requisite.

12000×10=120000 gallons per day required.

Engine is to work 12 hours, $\frac{120000}{12}$=10000 gallons per hour.

$\frac{10000}{60}$=166.6 gallons *per* minute.

The pump to have an effective stroke of 3¾ feet, and making 30 strokes per minute.

$\frac{166.6}{30}$=5.5533 or 5.6 gallons each stroke.

282 cubic inches in ale gallon×5.6=1579.2 cubic inches of water each stroke.

$\frac{1579.2}{45}$=35.1 inches area of pump.

3 feet 9 inches = 45 inches.

$\frac{35.1}{.7854}$=44.7 circular area, therefore $\sqrt{44.7}$=6.7 diameter of pump.

The pipes will require to be at least of the diameter of the pump; if they are a little more, the water will not require to flow so quickly through them, whereby less friction will take place.

The power of the Engine will be 166.6 gall. $\times 10\frac{1}{4}$ lb. the weight of a gallon ale measure of water $\times$ 250 feet=426925 momentum.

$\frac{426925}{32000}$=13.3, add $\frac{1}{5}$ =15.7 horse power, Boulton & Watts standard.

$\frac{426925}{27500}$=15.5 ——— =18.6 do. Desaguliers' do.

$\frac{426925}{22916}$=18.6 ——— =22.3 do. Smeatons' do.

The above Rules and observations will apply to raising water from mines, or deep wells. Some of the most remarkable works for raising great quantities of water from considerable depths are constructed in Cornwall in England. At some of the mines in that country, it is stated that the power of the steam engines employed principally for this purpose is nearly equal to that of 1000 horses. At the celebrated water works at Marli, which are now greatly decayed, there were formerly 14 water wheels estimated at 143 horse power.

TABLE

Of the quantity of water in weight and measure contained in Pipes of various lengths and sizes.

ONE INCH DIAMETER.

Feet High.	Quantity in cubic inches.	Weight in oz. Avoirdupois.	Gallons Wine Measure.
1	9.42	5.46	.0407
2	18.85	10.92	.0816
3	28.27	16.38	.1224
4	37.70	21.85	.1632
5	47.12	27.31	.2040
6	56.55	32.77	.2448
7	65.97	38.23	.2423
8	75.40	43.69	.3264
9	84.82	49.16	.3671
10	94.25	54.62	.4080
20	188.49	109.24	.8160
30	282.74	163.86	1 2240
40	376.99	218.47	1.6300
50	471.24	273.09	2.0400
60	565.49	327.71	2.4480
70	659.73	382.33	2.8560
80	753.98	436.95	3.2640
90	848.23	491.57	3.6700
100	942.48	546.19	4.0800
200	1.884.69	1.092.38	8.1600

The preceding table will often be found useful in facilitating various calculations relating to the raising of water and the quantity and weight of water contained in pipes of various diameters and lengths.

The table gives the contents of a pipe one inch diameter in *weight* and *measure*, which will serve as a standard for pipes of other diameters by applying to them the following Rule.

Multiply the number in the preceding Table, against any height, by the square of the diameter of the pipe, and the product will be the number of *Cubic inches*, *Avoirdupois ounces*, and *Wine gallons* of water that the given pipe will contain.

EXAMPLE.

How many Wine gallons of water is contained in a pipe 6 inches diameter and 60 feet high?

6×6=36, square of the diameter of the pipe×2.4480=88.1280 Wine gallons.

The wine gallon contains 231 cubic inches, and the new English measure called the Imperial gallon, contains 277. 274 cubic inches. To reduce the Wine to the Imperial Gallon it is only necessary to divide by 1.2; and for a like reduction of the Ale gallon to the Imperial gallon divide by 0.98324.

To this may be added the following simple Rule, which may be easily remembered, for finding the contents of a pipe of any given diameter and length.

Rule for finding the weight of water in a Pipe.

Square the diameter of the pipe in inches, and the product will be the *number of pounds* Avoirdupois of Water contained in every yard in length of the pipe.

EXAMPLE.

What quantity of water is contained in a Pipe 5 inches diameter and 252 feet perpendicular height.

5×5=25 square of the diameter=number of pounds of water×252 ÷3 feet in a yard,=2100 lbs. of water in the pipe.

TABLE

Of the heights of Jets of water with reservoirs of a given altitude.

Jets of water, or spouting fountains, are commonly introduced to ornament and refresh gardens and pleasure grounds. The ascent of a sparkling column of water into the air, its graceful curves in turning to descend, and the murmur of the broken drops on striking the basin in their fall have ever been considered as forming one of the most pleasing embellishments of the garden. Vast sums have been lavished, where natural advantages of elevated springs have not been attainable, in constructing engines to pump water to proper elevations to produce jets. The water works of Versailles, St. Cloud, Frescati and Peterhoff have been long celebrated both for the quantity of water discharged, and the heights of the spouting column. One of these I have seen at St. Cloud ascends to an altitude of nearly an hundred feet. The Jet at Peterhoff is stated to be nine inches in diameter and 60 feet high.

The velocity of a small jet of water, issuing in any direction from a reservoir, is nearly equal to the velocity that would be acquired by a body falling from the height of the surface of the reservoir to the orifice of discharge. A jet of water issuing from an orifice of a proper form, and directed upwards, rises almost to the height of the head of water in the reservoir. The resistance of the air and other causes combine to prevent the jet reaching quite to the height of the level of the reservoir.

The following Table shows the altitude of Jets produced by Reservoirs of a given altitude.

Height of Reservoir. Feet.	Height of Jet Feet.	Proper diameter of the Ajutage, or spouting pipe.	Diameter of the pipes of conduct.
5	4.91	$\frac{1}{4}$	$1\frac{3}{4}$
6	5.88	$\frac{1}{4}$	$1\frac{3}{4}$
7	6.84	$\frac{1}{4}$	$1\frac{3}{4}$
8	7.80	$\frac{3}{8}$	$1\frac{7}{8}$
9	8.74	$\frac{3}{8}$	$1\frac{7}{8}$
10	9.68	$\frac{3}{8}$	2
15	14.31	$\frac{5}{8}$	$2\frac{1}{2}$
20	18.82	$\frac{1}{2}$	$2\frac{1}{2}$
25	23.20	$\frac{1}{2}$	$2\frac{3}{4}$
30	27.48	$\frac{1}{2}$ to $\frac{3}{4}$	3 to $3\frac{1}{2}$
35	31.63	$\frac{3}{4}$	4
40	35.74	$\frac{3}{4}$	$4\frac{1}{2}$
45	39.75	$\frac{3}{4}$	5
50	43.65	$\frac{3}{4}$	$5\frac{1}{2}$
60	51.24	1 inch.	$5\frac{3}{4}$ to 6
80	65.64	$1\frac{1}{2}$	$6\frac{1}{2}$ to 7
100	79.12	$1\frac{3}{4}$ to $1\frac{1}{2}$	7 or 8 in.

PNEUMATICS.

The term *Pneumatics* is generally used to designate that branch of mechanical philosophy which treats of the compressible or elastic fluids, such as the air and gases, the properties of liquids, which are considered as nearly incompressible and inelastic, are described under the preceding titles of Hydrostatics and Hydraulics. Although the pressure and action of the aeriform fluids are governed by nearly

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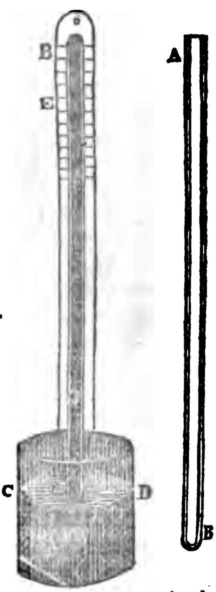
the same laws as those already stated in regard to watery fluids, yet there are circumstances attending the elasticity of the air, and its physical action upon all bodies and machines, which render the more particular consideration of its properties both interesting and useful. The air entirely surrounds us and is every where present, influencing and even controlling by its resistance and weight the operations of many of the most delicate as well as of the most powerful machines, from the striking of a clock to the movement of an atmospheric steam engine. A cannon ball of 3 lbs. weight when first discharged from the mouth of a cannon often moves at the rate of 1800 cubic feet per second. It encounters in this case a resistance from the air equal to a pressure ot 176 lbs. being more than 58 times its own weight.

The particles of air, although too minute and transparent to be seen, exhibit powerful evidences of their existence and materiality by the noise produced by their sudden contact with solid bodies, and the effects of their moving force in overthrowing trees and buildings, as observable in the hurricane and tempest. That the air has weight may not only be demonstrated, but even the exact number of grains that a cubic foot of it weighs may be readily ascertained. Take, for example, a glass bottle which will contain one cubic foot of air, and cement a brass stop cock to the mouth of it; then balance it very exactly in the scales of a delicate balance. By means of the stop cock apply the mouth of the bottle to an air pump, constructed and acting upon the principle of the common suction pump before described. After the air pump has been operated a sufficient time and all the air contained in the bottle has been pumped out or exhausted, a void space called a *vacuum* will remain within the cavity of the bottle. Let the stop cock be now closed to prevent the return of the air, and again place the bottle in the scale. It will be found that 523 grains must be taken out of the scale to produce an equipoise. Open the stop cock to admit the air and the scale containing the bottle will immediately preponderate, and the 523 grains must be again placed in the opposite scale to restore the equilibrium. It has been thus ascertained that a cubic foot of air at the temperature of about 50° of Fahrenheit weighs 523 grains, and a cubic foot of water at the same temperature having been found to weigh 1000 ounces avoirdupois, therefore 1000 oz $\div$523 grs. $=$ 840. Water appears then to be about 840 times heavier than air. Now it is manifest that the air surrounds and extends to great heights above us, as it sustains vapours or clouds at great elevations above the surface of the earth, and has been breathed upon the tops of mountains 3 or 4 miles high. If then air has weight like water, it must operate like water in pressing upon the surface of all bodies immersed in it. The fact of the pressure of the atmosphere, which includes the whole mass of air surrounding the globe, and extending, as is supposed, about 15 miles above its surface, may be exhibited by a simple experiment with a cylinder and a piston fitted to work air tight within it. For convenience of calculation suppose this piston to have a surface or area exactly equal to a square inch; and let the cylinder have a stop cock at the bottom of it. If this stop cock be shut and the operator attempt to thrust down the piston, the air beneath it in the cylinder having no opening through which it can escape, must receive the whole force of the pressure and will be found to yield before the piston allowing it to descend in proportion to the force applied upon it. Should the piston weigh 15 lbs. and an additional weight of 15 lbs. be added, making the pressure 30 lbs. the air will be compressed in bulk one half by doubling the pressure. On again doubling this pressure, making it 60 lbs. on the square inch the air will be compressed to $\frac{1}{4}$ of its original bulk, and may be further compressed in the same ratio to almost any practicable extent. Upon removing $\frac{1}{2}$ or $\frac{3}{4}$ of the weight or pressure the air will not remain passive in its compressed state, but will expand to double or treble its original volume. It appears therefore that the air after being compressed possesses a power of recovering or expanding to its original bulk; this property is termed its elasticity. The same law applies to steam, gases, and all vapours or aeriform fluids, the expansible power of which is illustrated by the table of Compressibility and Expansibility of air.

If the cylinder be filled with water or mercury instead of air, the utmost force or weight placed upon the piston would be insufficient to produce any perceptible descent of it. A pressure of 15 lbs. on each square inch of surface has been found to reduce water only $\frac{1}{21740}$th part,—a degree of compressibility so trifling that liquids are commonly considered for all practical purposes incompressible.

When the stop cock is open and the piston thrust down, the air will be entirely expelled before it, until the lower surface of the piston comes in as close contact with the bottom of the cylinder as with the sides of it. Should the operator now close the stop cock and attempt to raise the piston, he will find that a considerable force will be requisite to draw it up to the top of the cylinder. By attaching the piston to one end of a scale beam, and by placing weights upon the other end of it, he will find that a weight of about 15 lbs. or more exactly $14\frac{7}{10}$ lbs. will be required to lift a piston having an area or surface of precisely one square inch, besides the additional weight necessary to counterbalance the piston itself, and to overcome the friction of it upon the sides of the cylinder. If the piston when thus lifted to the top of the cylinder be detached and left at liberty, it will descend with the same force as if loaded with a weight of 15 lbs. on each square inch of its surface in addition to the weight of the piston itself. By opening the stop cock to allow the air to enter the cylinder beneath the piston, this effect will cease, as the air will thus have access to press against the under surface of the piston in the same manner as upon the upper surface of it, in which case the counter pressures neutralize each other, and the piston may be moved as freely upwards, as if in the open air. Suppose, in the above instance when the piston is lifted to the top of the cylinder, that the chamber be filled entirely with steam instead of air. Should the steam be in any way cooled or condensed, it would return to the state of water and occupy only $\frac{1}{1800}$th part of the space which the water filled when in the state of steam; (see page 69,) consequently if the chamber of the cylinder contained 1800 cubic inches of space occupied by the steam there would remain after the condensation of it only 1 cubic inch of water in the bottom of the cylinder, and the remaining 1799 inches would be void space or a *vacuum*. The same result would then occur as before stated, and the piston would be pressed down with the force equal to 15 lbs. on each square inch of surface of the top of the piston. This is the principle upon which the *low pressure* or atmospheric Steam Engine is put in motion, the steam serving merely to drive out or displace the air in the cylinder beneath the piston; after which the steam is condensed to form the vacuum. The immediate moving power is thus produced not by the steam itself, but by the atmosphere. (see page 144.) If the surface of the piston were enlarged to 1000 square inches, each square inch of its surface would be pressed upon by a force equal to 15 lbs. by which the same effect would be produced as if the top of the piston were loaded with a weight of 15000 lbs. Not only the piston but all parts of the sides of the cylinder in which there is a vacuum is pressed in with the force of 15 lbs. on the square inch. The sides of a thin glass bottle may thus be readily crushed by pumping out the air from it, or a cork may be driven into a bottle by the pressure of the air, if the bottle be filled with steam and suddenly corked up. The same experiment is frequently tried in relation to the sea water by sinking empty bottles to great depths therein. Indeed the analogy between the pressure of watery and aeriform fluids is so complete that this subject cannot be better illustrated than by supposing every object on the surface of the earth to be immersed to a certain distance below the surface of water. To produce a pressure of 15 lbs. on the square inch requires a column of water an inch square and 34 feet high. A column of mercury 1 inch square and only 30 inches high will also produce a pressure of 15 lbs. on its base of a square inch. Here then we have three fluids, one of them about 15 miles high, another 34 feet high, and a third only 30 inches high, which all produce an equal pressure. If there were no atmosphere at all a diver at the depth of 34 feet below the surface of the sea would sustain precisely the same pressure from the water as he sustains on emerging from the surface of it under the existing atmospheric pressure. 15 lbs. pressure on the square inch being about one ton on the square foot, and the body of a man of ordinary stature presenting a surface of 10 or 11 feet, a man consequently is subjected to a pressure of 10 or 11 tons weight, and if by means of a diving bell he were to descend 34 feet below the surface of the sea, he would sustain double the pressure, or 21 or 22 tons, and yet he would be sensible of no considerable pressure, the fluid particles contained within the body reacting equally in every direction against the external pressure. Although fishes have been taken at the depth of 2700 feet, where the pressure of the water amounts to nearly 80 atmospheres or 80 tons upon a square foot, yet a fish is not injured by such an immense weight, or sensibly impeded in his motions. The bones and vessels all contain air or various fluids capable of supporting any pressure, and the elasticity of such fluids within the pores or cells being equal to and counteracting the pressure from without, the action and reaction is in every direction equal, and not the thinnest membrane or blood vessel is injured.

Every sea and lake, and every square inch of the globe sustains the pressure of 15 lbs. on the inch, or 1 ton to the foot, and "the entire surface of the globe being estimated at 5575680000000000 feet, this number will express nearly the whole weight of the atmosphere in tons, a certain deduction being made for the space occupied by mountains and elevated regions.



Suppose the vessel C D to contain water, and the tube A B 35 or 36 feet in height, to be void of air, or to have a vacuum formed within it, and to have the open end A immersed in the water as represented by B. A. Now all parts of the surface of water in this vessel being pressed upon by the weight of the atmosphere except that part of it immediately beneath the vacuous space in the bore of the tube, and the pressure of the atmosphere being equal to that produced by a column of water 34 feet in height, it follows that the effective pressure upon the surface of the water in the vessel C D, is actually the same as if the water around the tube B A stood 34 feet high. In this case, it may readily be supposed that the water under the aperture of the inverted tube, exposed to no pressure and meeting no resistance to its motion, would ascend as high as the level of the external surrounding water, that is, 34 feet high. This is the principle of the ascent of fluids into a vacuous space as commonly understood by the term *suction*, the heights to which various fluids ascend, being as their respective weights, or as the heights of a column of such fluids an inch square required to weigh 15 pounds.

If a glass tube (as represented by A B in the last figure,) 33 or 34 inches long and closed at the end be filled with quicksilver, and be then carefully inverted by placing the finger upon the open end A, that it may be immersed in a vessel of quicksilver C D without spilling it or allowing any air to enter the tube, the quicksilver will settle down from 34 to 30 inches, or from B to E, until its weight is exactly counterbalanced by the pressure of the atmosphere, leaving the space above E void, or a vacuum. An instrument thus constructed is called a *Barometer*. The weight of the column of air extending from the level of the sea to the top of the atmosphere is counterbalanced by the column of mercury 30 inches high, in the same manner as if each fluid occupied opposite ends of a bended tube like the letter U, in which the respective altitudes will be inversely as the specific gravities of the two fluids. Accordingly as the specific gravity of the air, which is 0.00122 is to that of mercury, which is 13.6 : : so is the height of the column of mercury, 30 inches : to the height of the atmosphere, 333688 inches, or 27807 feet, or a little more than five miles, supposing the atmosphere to be as dense in the upper regions as near the earth. But the air being remarkably elastic the lower strata are compressed by the incumbent weight of the upper strata, so that the air becomes less dense continually as we ascend, and upon the summits of the highest mountains the air becomes so rare that birds with difficulty receive sufficient reaction from it to support them in flying. The air or atmosphere seems therefore to be merely collected immediately around the planets by gravitation, the intervening spaces between each heavenly body being filled with an air of the least conceivable density, one cubic inch of it it has been supposed, would fill a space larger than the globe if diffused in any part of the boundless space of the heavens where the air is no denser than it is at the distance of 300 miles from its surface. The space occupied by any given portion of air is reciprocally proportional to the pressure and to the temperature to which it is exposed. It will appear by reference to page 54, that the air becomes expanded $\frac{3}{8}$ths in volume by an increase of 180° of temperature. If a cubic foot of air weighs 523 grains at the temperature of 50°, and if there be $\frac{3}{8}$ths less air in a cubic foot when heated to 230° its specific gravity will be diminished $\frac{3}{8}$th. The mercury itself is dilated by heat, so that at different temperatures the same weight of mercury stands at different heights in the tube. For this reason thermometers are usually connected as appendages to barometers to indicate the temperature in order to correct barometrical observations. In common chamber barometers the heights of the columns are marked off $\frac{1}{10}$ or 0.01 of an inch, and in the best to $\frac{1}{500}$ of an inch.

The best time for making barometrical observations for the purpose of calculating heights, it is stated is during settled weather and at mid-day, and several observations are more likely to lead to accurate results than single observations. " By means of accurate registers of the barometers the difference of level of places the most remote from each other may be ascertained with a considerable degree of precision. It is found by numerous and careful observations in different parts of Europe, that the mean height of the barometer at the level of the ocean is 30.035, the temperature being 55° of Fahrenheit. The mean of three observations a day continued for 22 years at Cambridge, Massachusetts, gives the height of the barometer at the same temperature, 29,997. 30.035—20.997=.038 difference. The European observations having been made on a level with the surface of the sea this difference will show the elevation of the barometer at Cambridge above this level, by adopting the following rule which will answer without corrections for moderate elevations or hills of no very great height.

As 0.1 is to the difference in the barometric columns at the stations taken for the observations, so is 87 feet to the approximate difference of level required; thus

0.1 : .038 :: 87 : 33. 06, or 33 feet nearly, above the level of the sea. Now the actual elevation of the cistern of the barometer at Cambridge, as carefully ascertained by *levelling*, is found to be 31 feet. Thus under a pressure of 30 inches of mercury at the temperature of 50°, $\frac{1}{10}$, or 0.1 of an inch of mercury answers to 87 feet of atmosphere, and $\frac{1}{100}$ or 0.01 answers to 8.$\frac{7}{10}$ feet, and $\frac{1}{500}$ to 1.14 foot of atmosphere. Hence in a good mountain barometer, graduated to 500dths of an inch there will be a sensible difference in the pressure of the air arising from a change of altitude of less than 2 feet, or *of two thirds of the length of the instrument itself.*" On the tops of some of the highest mountains which have been ascended the barometer has stood at only 12 or 14 inches.

It is well known that frequent changes take place in the altitude of the mercury in the barometer when it remains stationary in a room. This effect is produced by the state of the atmosphere preceding or accompanying changes of weather. It was for this purpose that the barometer was first used, and is still frequently called the *weather glass.* The changes of weather being generally indicated by sudden variations in the height of the mercury rather than by the actual height of it, the points marked on the scale of barometers as "rainy, fair, or changeable," are not to be regarded. The following rules, it is stated, may in some degree be relied upon as corresponding generally to the concomitant changes in the barometer and the weather.

1. Generally, the rising of the mercury indicates the approach of fine weather, and the falling of it, that of foul weather.

2. In hot weather the fall indicates thunder. In winter the rise indicates frost, and in frost the fall indicates thaw, and the rise snow.

3. If fair or foul weather *immediately* follows the rise or fall, little of it is to be expected.

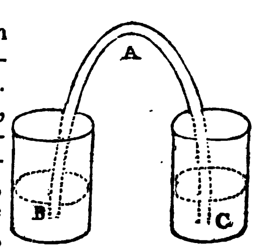
4. An unsettled state of mercury indicates changeable weather.

The variations in the height of the mercury does not exceed a range of 3 inches, the mercury being never lower than 28 nor above 31 inches. In order to render the minute variations of the height of the column of mercury more distinctly perceptible the top of the glass tube, at a height of about 28 inches above the level of the mercury in the cistern, is bent out of the vertical position in a sloping or diagonal direction, by which 1 inch perpendicular rise will make a movement of two or three inches in the surface of the mercury in nearly a horizontal direction, by which means a slight variation of only $\frac{1}{500}$ part of an inch is plainly indicated. There are various other kinds of barometers acting on the principles here described.

A barometer for common purposes may be constructed of a glass tube 33 or 34 inches long, with a bore $\frac{1}{4}$ or $\frac{1}{2}$ of an inch in diameter, closed at one end and open at the other. After being filled with quicksilver, the end of the tube may be placed in hot sand to expel all the air and moisture contained either in the cavity of the tube or in the mercury, which if left in the tube would fill the top with vapour and render the vacuum imperfect. The cistern in which the tube is inverted should be of considerable capacity in comparison with that of the tube, otherwise the mercury discharged from the tube by the fall of 2 inches might cause the mercury in the cistern to rise 1 or 2 inches, and on the contrary a rise of 2 inches in the tube might cause the surface of the mercury in the cistern also to fluctuate in the same ratio, whereby the scale upon the instrument might prove deceptive, and the true height of the column above the surface of the mercury in the cistern might not at all times be given.

The supply of oil in the common Argand lamp is regulated upon the principle of the pressure of the atmosphere. The reservoir of oil is formed like an inverted bottle, with the mouth immersed in a receiving vessel or tube of oil communicating with the wick of the lamp. As long as the surface of the oil in this receiving tube continues above the mouth of the reservoir, the oil will remain stationary in it, like the mercury in the barometer; but the instant the surface of the oil is caused to subside, by being absorbed by the wick in the process of combustion, the air has access beneath the inverted reservoir, and ascends into it in bubbles until it has displaced or allowed a sufficient quantity of the oil to flow down into the receiving tube to cause it to regain its former height above the mouth of the inverted reservoir, when the further discharge is checked until the oil becomes exhausted as before. It must be manifest that if there be any holes, or the least imperfection in the top of the reservoir to admit the air, the oil will descend freely at once without being regulated by the quantity actually consumed, and the lamp will in such case appear to leak or waste the oil. If the reservoir of oil be exposed in a room to the alternations of heat and cold, the consequent expansion and contraction of the volume of oil and air contained within it, will produce a similar waste or leakage. To prevent the oil from being thus expelled a small metallic slide or gate is made to slip over the orifice of discharge which answers to check the descent of the oil in all cases except when forcibly expelled by its expansion from heat. The Argand lamps as commonly constructed, are therefore frequently found to cause much inconvenience by soiling furniture with the leaking oil, an inconvenience which might be easily remedied by substituting a tight stop cock or valve in the place of the slide.

The Syphon.



The syphon is formed of a bended tube in which a fluid ascends upon the same principle that it rises in the tube of the barometer. If the air be exhausted from the tube A B C, having each end immersed in a vessel of water, the fluid will rise in it under the most favourable circumstances about 34 feet high, but in ordinary cases in practice not above 25 or 30 feet, owing to the presence of air, which renders the vacuum in this case somewhat imperfect. Should the surface of the fluid at C be lower than the surface of the fluid in

B, the column in the leg A C will be longer than in A B, and the longer column being consequently heaviest, will preponderate and descend from A to C, while the pressure of the atmosphere will force a fresh supply of fluid into the leg A B, which will thus continue to rise and pass over into the vessel C until the fluids in each vessel come to a level, when the current will cease to flow. Should the liquid in C be higher than that in B, the current would flow back to B until the fluids in each vessel are restored again to a level.

The Syphon is commonly used for conveniently drawing off liquors from casks or bottles without disturbing the sediment therein. It has been advantageously employed in Rhode Island in draining an extensive quarry of limestone by conveying the water over extensive ridges of rocks, thereby saving the expense of sinking deep channels through them. Long leaden pipes are arranged with the ends immersed in the water in the quarry, from whence they are laid over the tops of the rocks and banks intervening between the quarry and an adjacent valley. To put one of these long syphons in operation both ends are closed, and it is filled with water through a cock placed at the highest point or summit of the bend. The cock is then shut and the orifice at each end opened, when the current immediately commences flowing through the pipe over the top of the bank many feet above the level of the bottom of the quarry. At the top of the arch of the syphon as at A in the preceding figure, a tight metallic vessel formed like an inverted bottle should be connected by a stop cock at its junction with the syphon, and furnished also with a stop cock to pour in water when necessary. The fixed air usually contained in water will after a time accumulate in this syphon, and will stop its operation. The air will first enter this vessel, and displace the water contained within it, after which the communication of the vessel with the syphon may be cut off by shutting the cock. The air can be occasionally expelled from the air vessel, without interrupting the operation of the syphon, merely by filling it with water through the aperture or cock in the upper part of it; after which it may be regulated as before. By this syphon the labour of several horses at the pumps has been saved.

It sometimes happens that the arrangement of the fissures of rocks beneath the surface of a hill or mountain form tubes that produce natural syphons to convey the spring water from some internal cavern or receptacle of water to the vale below. In such cases, as in the instance of the artificial syphon above referred to, the water will commence and cease flowing from the hill side with great regularity as often as the internal reservoir becomes filled from the springs and exhausted by the drain of the syphon. *Intermitting* springs are thus formed.

The facility with which many insects and small animals traverse the smooth ceilings of rooms, and ascend the sides of blocks of polished marble, for a long time excited the surprise of the curious, until it was discovered that the feet of all these animals are provided with sets of muscles which by their contraction form hollows like the palm of the hand. The air is excluded by the pliable edges of their feet, which collapse in a circle around this hollow. At every step these animals are thus enabled to form a vacuum beneath their feet, which are thereby firmly attached to any solid object by the pressure of the atmosphere.

TABLE

Of the Compressibility and Elasticity of Air.

Bulk of uncompressed Air. Cubic feet.	Compression of the Air. lbs. on the square inch.	will sustain a column of Water. Feet high.	Space occupied by the compressed Air. Cubic Feet.	Elastic force or reaction of the Air. lbs. pressure on the Square Inch.
1	0	0	1	0
2	15	34	1	15
3	30	68	1	30
4	45	.102	1	45
5	60	.136	1	60
10	135	.306	1	135
20	285	.646	1	285
30	435	.986	1	435
40	585	1.326	1	585

It appears by the table of *Jets of water*, that spouting fluids rise nearly to the heights of their sources or heads of water. A pressure of 15 lbs. on the inch or of 1 atmosphere is equal to that of a column of water 34 feet high.

By the above Table it appears that a pressure of a certain number of pounds to the square inch is equal to a column of water of a given height, and by reference to a Table of Jets of Water at page 233, it further appears that the pressure produced by a column of water or reservoirs of various altitudes above the orifice of discharge, will cause water to spout up to heights proportionate to the pressure. With these data it will be easy to calculate the pressure required to be applied on the piston of a common fire engine to throw a stream of water to a given height, and also the height to which the stream will ascend with any given pressure upon the piston, making an allowance of at least ½ instead of ⅓ as directed at page 229, for the loss of power by the excessive friction of the water in passing with extreme rapidity through the valves and leather tube or hose.

EXAMPLE.

A fire engine having a piston 8 inches diameter throws a stream of water to the top of a belfry 65 feet high. What is the pressure or force applied to the piston?

By the Table of Jets it appears that a stream is made to spout up 65 feet high by the pressure produced by a column of water 80 feet high. The pressure of a column of water of the altitude of 80 feet, is equal to 2⅓ atmospheres or about 35 lbs. on each square inch of the piston. Add ½ to this pressure for the power lost in overcoming the friction of the water in passing through the valves and leather hose. 35+½=52½ lbs. upon each square inch. The area of the piston may be found by Problem IX, page 121. 8×8×.7854 ×52½=2638 lbs. answer.

This rule will be found to give a result that will fall short of the actual pressure, judging from a late experiment made with a Mill-Hydraulion, having a safety valve by which the actual pressure was indicated when the stream ascended to an elevation of about 65 feet against the spire of a cotton mill.

The quantity of water discharged in a stated time, when the length of each stroke and the number of them is given, may be found by Example 3, at page 230. For further observations on this subject see page 187.

By the best New-York Engines a stream ¾ of an inch diameter has been thrown 150 feet horizontally. If it be attempted to throw water beyond this distance, it becomes dissipated in spray. By enlarging the stream however, and increasing the power it may be thrown to a greater distance.

Velocity of the moving currents of Air, or Wind.

To find the velocity of the wind various instruments denominated Anemometers have been invented. The most simple method was employed by Coulomb in his experiments on wind mills, by which neither instruments, nor calculations were necessary. Two persons were placed on elevated ground at the distance of 150 feet or more from one another in the direction of the wind. The time in which a light feather was wafted from one station to the other was noted. The distance between the two stations being divided by the number of seconds gave the velocity of the wind per second.

Velocity of the Wind.		Perpendicular force on one square Foot in Avoirdupois Pounds.	Common Appelations of the forces of Winds.
Miles in 1 hour.	Feet in 1 second		
1	1.47	.005	Hardly perceptible.
2	2.93	.020	Just perceptible.
3	4.40	.044	
4	5.87	.079	Gentle pleasant Wind.
5	7.33	.123	
10	14.67	.492	Pleasant brisk gale.
15	22.00	1.107	
20	29.34	1.968	Very brisk.
25	36.67	3.075	
30	44.01	4.429	High wind.
35	51.34	6.027	
40	58.68	7.873	Very high.
45	66.01	9.963	
50	75.35	12.300	A storm or tempest.
60	88.02	17.715	A great storm.
80	117.36	31.490	A hurricane.
100	146.70	42.200	A hurricane that tears up trees and carries buildings &c. before it.

Wind Mills.

A great variety of mills have been invented to be moved by the power of the wind, the most common of which is constructed with four arms or sails. Mr. Smeaton states that the greatest effect is produced by the wind upon these sails, when they present an angle of 72 to 75 degrees from the axis or 15 to 18 degrees to the plane of their motion. Wind mills are principally used for grinding grain, the moving power being too irregular for most manufacturing purposes. In Holland, however, where there are no natural waterfalls, and where the scarcity of fuel renders the use of steam engines expensive, windmills are very generally used for almost all kinds of operations requiring power. In one small town, Saardam, there appear to be several hundred windmills, which when viewed from a distance above the green meadows seem to present as much canvass spread to the breeze as would be unfurled by a large fleet. The revolving motion of the countless sails successively rising and sinking, on a horizon as level as that of the ocean, presents an animating spectacle resembling the tossing undulation of snowy billows. Even the operation of sawing lumber is there performed by wind power; in one of these wind mills I counted 36 saws in operation, supplied by the vast rafts that descend the Rhine. The lower apartments of some of the wind mills used for grinding grain, are occupied by the families of the millers, and are models of neatness if not of mechanical skill.

By experiments of Luloss, of Leyden, one of the Dutch windmills employed to drain marshes was found capable of raising 1500 cubic feet of water 4 feet high in a minute with the current of wind moving at the rate of 30 feet per second. This gives a result of about 11½ horse power.

The sails of windmills are so constructed as to have different inclinations to the plane of their motion at different distances from the axis, greatest near the centre, and least near the extremities. This is called the *weathering* of the sails, as may be observed in the formation of the wings of a bird, and is done in order that the effect of the wind may be the same at different distances from the centre of motion.

From Smeaton's Experimental Enquiries, it appears that a windmill works to the greatest advantage when it is so constructed that the velocity of the sails is to their velocity when they go round without any load as 6.5 to 10 nearly; and also that the load, when the mill works in this manner, is to the load that will just keep it from moving as 8.5 to 10 nearly. This applies when the velocity of the wind continues the same. With different velocities of the wind the load or resistance that gives the maxium effect varies nearly as the square of the velocity of the wind. When the breeze is at the rate of 10 miles an hour, the load may be fourfold of what it may be when only 5 miles per hour; as $5\times5=25$, and $10\times10=100$, or 1 to 4.

The *effect itself* is nearly as the cube, the work performed being nearly in the above instances in the ratio of the cubes of 5, and 10, or as 125 to 1000. See Experimental Enquiry, p. 50 and 52.

Sound.

The air is the principle medium which serves to transmit sound. The organs of the ear are in contact with the air, which is also in contact with all surrounding bodies. A motion of these bodies cannot take place without producing also in the air a motion or undulation which extends in every direction in enlarging circles, like the undulations upon the tranquil surface of water, "when the small pebble stirs the peaceful lake." The vibration of the air produced by articulate sounds thus extend to the ear, and serve to transmit the wonderful interchange of thoughts and ideas. Solid and unelastic bodies are capable, like the air, of transmitting in a greater or less degree, vibrations which affect the organ of hearing. The sounds produced by striking two stones together under water may be distinctly heard under water and in the open air above it.

Sound flies through the calm air, or more properly the vibrations of the air extend as above stated with a regular velocity of 1130 feet *per* second, or about a mile in $4\frac{3}{4}$ seconds. Hence distances may be pretty nearly computed by counting the number of seconds which intervene between the time of seeing the glare of a flash of lightning, or of a cannon, and hearing the report.

EXAMPLE.

How far distant was the cloud from which the lightning issued, the thunder having been heard after counting 5 pulsations in the wrist allowing 75 pulsations in a healthy man per minute?

As 75 : 60 :: 5 : 4 seconds of time elapsed. $4\times1130=4520$ feet or nearly $\frac{7}{8}$ of a mile distant.

Sound is conveyed in tubes to much greater distances than in the open air, and with much greater velocity.

A cannon ball moves with a velocity $\frac{1}{2}$ greater than sound, consequently the ball will reach an object before the sound of the explosion. When a cannon is discharged the whole mass of the superadjacent atmosphere appears to be jarred or moved by the explosion; and as the sound of a cannon has been heard nearly 50 miles, the atmosphere over a circle of nearly 100 miles diameter may be supposed to have been affected more or less by the explosion. The elasticity and perfect fluidity of the air must appear wonderful indeed when it is considered that the weight of the mass thus actually moved, is calculated at a ton weight for every superficial foot of the earths' surface, or 43560 tons of air superincumbent upon every acre. An echo is produced by the reflection of sound like the rays of light from a mirror. The undulations of the fluid air appear to resemble still further those upon the surface of watery fluids, the waves of which as they extend from the disturbed point in the centre, in circles, continually enlarging, are repelled by solid obstacles, and rejected in faint counter ripples at angles corresponding with the angles of incidence.

ELEMENTS OF MACHINERY, AND THE CONTRIVANCES USED IN THE COMPOSITION OF MACHINES.

It is in the complex wheel work of Mill Gearing, and in all the countless varieties of motion and moving forces produced by the machinery employed in mills that the science of mechanics is remarkably displayed at the present day. Indeed, the interiour of a modern cotton mill exhibits a complete view of the practical application of all the Mechanical Powers, so admirably combined and cooperating in various ways to produce desired effects, that mere machines are made to operate with apparently as much self directed skill as is exhibited in the manual labour of intelligent beings. In the movements of the Steam Engine, power loom, Whitmore's card machine for cutting, bending, and inserting in the leather the wire teeth of cards, and of Wilkinsons' machine for making slaies, admirable mechanical ingenuity is displayed, the opérations of all these machines being complete in themselves, and requiring only the inspection of a workman or superintendant. The triumph of mechanical ingenuity, however, appears to be exhibited in the wheel work producing the surprising action of automaton figures, which have been made to resemble man in certain movements, whereby mere matter is made to appear to possess the attributes of mind; almost inducing the beholder to imagine that the modern mechanic, like Prometheus the great inventor of the arts of ancient times, had stolen the sacred fire from heaven to animate the works of his own hands.

It is believed that the general principles advanced in the preceding part of this treatise, cannot be more intelligibly illustrated than by describing the various modes in which they are practically applied in the arrangement of the Gearing of a manufactory, and in the contrivances used in the composition of machines to produce all the variety of movements and moving forces required in the processes of the useful arts.

Before proceeding to treat of the interior mechanism of the mill it may be proper to make a few observations upon the construction of the mill itself, and of the works connected with it. It often happens that many things are neglected, or are deemed of trivial importance in the original plan for the construction of new works upon unimproved water courses, which, as the works become subsequently enlarged, are frequent sources of regret when it is too late to alter or amend them. Having laid out and erected new works upon an unimproved mill site an opportunity has been afforded me of acquiring information upon this subject from actual experience, which has been not unfrequently impressed by disappointments and losses.

The construction of the mill dam and trenches have already been treated of, as well as the important subject of ascertaining the sufficiency of the power of the stream for the purposes required. In locating a mill the general outlines should be fixed upon for the plan of the village, which in most situations in the United States is erected for the accommodation of the manufacturing population, forming a little colony around the waterfall which turns the mill wheel, in order that there may be as far as the nature of the situation will allow an agreeable arrangement of the cottages or dwelling houses. The roads or streets may in the first instance be regularly laid out, without much additional expense, and the buildings placed square with each other, and not diagonally as is observable in almost every manufacturing hamlet. The whole extent of the waterfall should be in the first instance located and improved as far as practicable, as water power is always valuable; and permanent bounds should be erected at the height of the ordinary level of the water in the mill pond to serve as landmarks of possession, should mills be afterwards erected in the same vicinity. Before fixing upon the immediate spot for sinking the wheel pit the earth around it should be carefully sounded by a pointed iron rod to ascertain if there be ledges of rocks which might obstruct the necessary excavations, as by changing the location only a few feet, obstructions of this sort may commonly be avoided; although it is desirable to place the foundations of a mill upon this solid basis, yet a little attention to this subject may save the subsequent expenditure of large sums, which are very frequently lost by the costly excavations in flinty rocks.

In laying out the ground plot for stone or brick mills the trenches should be staked out considerably larger than the intended size of the building to allow of the projection of one or two feet for the foundation stones, which on loose soils should extend considerably beyond the outer face of the main walls. If the lower courses of stone work intended for the foundations beneath the surface of the ground be 3 feet wider than the wall above it, then 2 feet of the projection should extend beyond the outer fronts of the walls and only one foot withinside of them. Walls of buildings have always a tendency to spring off or outwards, but are effectually prevented from falling inward by the floors. Even after the utmost caution has been bestowed in laying the foundations of a mill with large heavy stones, the walls should be secured to the ends of the beams by iron clamps, or screw bolts and plates, to prevent them from springing outwards. Walls sufficiently strong for warehouses have been found to yield at last to the constant tremour produced by the reciprocating motions of machinery, and the violent sudden thrusts occasioned by the irregular action of the teeth of wheels. Power looms, in particular, have a remarkable tendency to rack the walls of a mill if placed in an upper story, as the lathes of an hundred looms may at times have a simultaneous horizontal vibration back and forth. The proprietors of a considerable cotton manufactory in Rhode Island, who had arranged all their power looms in an upper apartment of their building, constructed of wood, found after a short time that the joints of the building were unable to withstand the movements of the looms, and the whole fabric was perceived to acquire a horizontal vibrating motion sufficient to cause water contained in a vessel to oscillate until a portion of it passed over the sides upon the floor. It is almost unnecessary to add that they were compelled to remove all their looms to a lower floor. In one of the finest weaving mills which I visited in Glasgow this difficulty appeared to be most effectually guarded against, by placing each power loom upon four small blocks of stone sunk in the ground floor to a level with the tiles. In this instance the building was only one story high, lighted from the roof by sky-lights to facilitate the operations of weaving the cotton yarn, which was as fine as No. 60. Mr Buchanan observes, that to obtain solidity and steadiness, a mill should not only be sufficiently *strong* and *stiff*, but sufficiently *heavy*, as the greater the mass the less in proportion will it be effected.

The arches above the floom and race of a mill, unless constructed near the centre of the building with each wing to serve as a buttress, are always inclined to yield to the weight pressing upon them, whereby one of the buttresses forming the end wall is commonly crowded off. The tremour of the walls affects the stones of the arch, the least yielding or opening of which allows the key stones to operate in an instant like so many wedges to prevent the span from recovering its former place, whereby the walls soon become seamed with unsightly cracks. It is better to form two small arches, or to support the centre by stone pillars than to form one arch of large span.

When the soil is composed of loose sand or clayey loam, the walls of the wheel pit should be founded upon piles, and in most cases it is common to extend the planked floor of the wheel pit sufficiently for the surrounding walls to be based upon it. Indeed it may be adopted as a general rule that it is true economy to construct all parts of the foundations of mills in the strongest and most solid manner.

The posts which support the beams in the centre of a mill should also rest upon a very solid mass of masonry, as the lines of shafts and other mill gearing are either attached or dependent upon them for being maintained in their proper situations. The settling of a pillar in the basement of a mill merely ½ of an inch will derange all the lines of horizontal shafts in every story above, whereby vast stress is thrown upon the couplings, and all the revolving wheels connected with such shafts immediately begin to wear irregularly, and to produce a clattering noise. If a block of hewn stone be used in any part of the structure, it should not be omitted here. Cast iron pillars or posts are generally used in England, and as they are cast hollow like water pipes they are not very expensive.

Great care is bestowed in laying the most solid foundations of hewn stone, to sustain the working parts of Steam Engines and water wheels in the best English mills. At the present prices of blocks of split granite in most parts of New England, the plummer blocks and other heavy fixtures for water wheels may be formed of granite at an expense which will not prove eventually much greater than if formed of timber, a material which in such situations is very liable to rapid decay. In setting up water wheels and steam engines, particular care should be bestowed in constructing the framing, which sustains the first impulse, or immediate action of the moving force, as independent of the walls and floors of the mill as possible, in order to avoid imparting to the whole building the tremour which is frequently so great as to be communicated in a very perceptible manner to the ground itself upon which the building rests.

Modes of transmitting a Force to a distance from a First Mover.

The most common mode of transmitting a moving force is by lines of revolving shafts. When a reciprocating motion, like that required for pumping, is necessary, a straight wooden shaft or spar is frequently substituted, which is made to operate by being thrust forth and drawn back alternately.

One of the most simple contrivances for transmitting great power to considerable distances is by means of the fluidity of water confined in pipes. If the water at one end of a long pipe be subjected to a pressure the force is immediately transmitted through the water to the other extremity of the pipe, as in the instance of the Hydrostatic Press page 179, through the tube I, whereby the power applied upon the arm of the lever D may be transmitted a mile or more to act with sufficient effect to lift a ship of war. A bridge over a canal intersecting the yard of one of the extensive Iron Foundries in Manchester, is thus speedily raised up in the air, to admit boats to pass beneath it, in the same manner as the plate B in the hydrostatic press, merely by connecting the forcing pump with the machinery of a steam engine. The pipes being laid under ground, the bridge in this case seems to rise from the earth by magical agency.

In raising coal from coal mines, it is frequently the practice to extend the bands, formed by sewing two or more ropes together side by side, to considerable distances across the field intervening between the shaft of the mine and the spot upon which the steam engine is located, in which case the rope band is supported upon rollers.

The shafts which serve to transmit the moving power from one part of a mill to a distant part of it should be so secured upon their bearings or pillows, as to be easily moved to restore them to their true situations when displaced by the settling or sagging of the beams to which they are affixed; as the teeth of the wheels revolving upon a long line of shafts all act irregularly the instant the centre of the shaft is deranged from its proper position, in which case not only the wheels but the couplings of the shafts are soon worn away and destroyed. The pillows or framing which supports a line of shafts must therefore be set up in such a manner that they may be moved at pleasure to accommodate any shifting or alteration that may from time to time become necessary in practice to preserve them in a straight line. Indeed every part of the mill gearing and of the machinery contained within the mill, should be put together in such a manner as to admit of being easily repaired or replaced with the least possible derangement to the other parts of the mechanism.

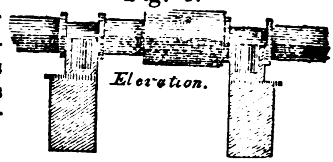
The strength of shafts to resist being twisted off by the force transmitted by them has been already treated of at page 38 and in the Table at page 39. By reference to this table it appears that for a shaft capable of transmitting a 4 horse power the journal oı neck which is usually the smallest and weakest part of the shaft, should not be less than 4 inches diameter when the shaft makes 25 revolutions per minute; but if the shaft be made to revolve 60 times per minute, then the journal or neck may be reduced to 3 inches diameter. The quantity of metal in the necks of the shafts in these instances being in the ratio of the squares of their diameters, $3\times3=9$, and $4\times4=16$; or as 9 to 16 ; therefore it requires only about half of the metal in a shaft to transmit a 10 horse power when the shaft revolves at the rate of 60 turns per minute as is required when it revolves a little less than 30 turns per minute. If the proprietor of a mill should find it necessary to transmit a 4 horse by means of one of his shafts just strong enough to transmit a 2 horse power when revolving 30 turns per minute, he has only to double the number of revolutions per minute and the same shaft will answer. By strict attention to this subject much unnecessary expense might often be saved in putting up the gearing of a mill by substituting light shafts with a quick motion in place of heavy shafts revolving slowly ; while at the same time the fixtures necessary to support shafts might also be reduced in weight in a corresponding ratio. It must, however, be borne in mind, that in practice it is not adviseable to reduce shafts to a very small size, as they thus become very liable to tremble and spring, especially if wheels and pullies be fixed upon them. Particular care is also necessary to adjust wheels very exactly upon shafts which revolve rapidly, or a discordant clatter will ensue.

In one of the finest cotton mills in Glasgow, belonging to Mr. Dunlap, this principle is adopted in the arrangement of the Gearing. In this instance it appears that a degree of taste may be displayed even in the construction of a cotton mill. The grounds around his establishment are decorated with shrubbery and flowers, the bright verdure and gay colours of which form an agreeable contrast with the tall dusky walls, while the long apartments of the interiour are filled with machinery preserved bright and in the neatest order, presenting to view long lines of machines and revolving shafts and wheels, which seem to be diminished in size as they are more remote in distant perspective. The steam engine being placed in a building distinct from the mill, the naked shaft is seen rapidly revolving in the open air between the walls of the two buildings. It excites surprise in a beholder on being informed that a shaft so small and apparently inadequate should be employed to impart motion to 21.000 mule spindles with all the necessary preparatory machinery for the manufacture of cotton yarn.

Couplings of Shafts.

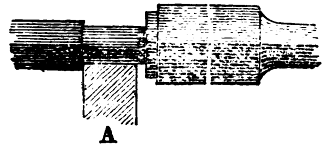
When it becomes necessary to transmit motion to a distance from the moving power, several distinct shafts are used, connected together by what are called couplings. Couplings are considered by Mr. Buchanan to be of two kinds, those having two bearings, and those having one bearing. The bearings of shafts are the parts which support their pivots, arbors or journals. A coupling is said to have double bearings when each of the ends of the shafts connected together rest upon their journals, as in Figure 1.

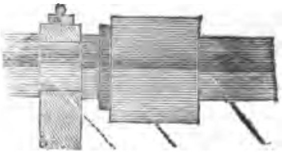
Fig. 1.



A coupling with single bearings is when the end of one shaft only rests upon its journal, while the coupling box supports the adjoining end of the other shaft, as represented in Fig. 2, where A is the bearing, B the coupling box, C the shaft supported at one end by the coupling box. D the journal or neck.

Figure 2.

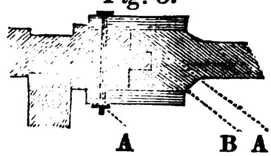




The coupling with one bearing is considered decidedly superiour to those with two bearings, as it is almost impracticable to arrange the axis of two shafts with such accuracy as to form a truly straight line; and even were this easily to be accomplished, yet the unequal wear of the journals, or the settling of the beams and floors of mills, would soon derange them. In some part of each revolution, in this case, one or other of the shafts must be lifted up, or be otherwise strained. For these reasons the coupling with double bearings, has been in a great measure abandoned for mill work in England in cases where it is required to transmit motion by long lines of shafts, and where the shafts are not exposed to much lateral pressure, arising from the action of cog wheels or belts and drums. The single bearing allows of a slight degree of flexibility in the coupling, and small deviations in the line of shafts are thus not so injurious. All couplings with two bearings are also attended with much friction.

Notwithstanding the above disadvantages of couplings with two bearings, if the shafts be intended to receive large wheels or drums upon them, two bearings are considered preferable. The coupling boxes are sometimes made square to receive the square ends of the shafts, and are sometimes bored out round to fit more exactly upon the turned ends of the shafts. In the latter case either pins or keys are inserted through the boxes or ends of the shafts to prevent their slipping round without communicating motion; or clutches are employed for the same purpose. Couplings with single bearings, if made and fitted with accuracy, are less expensive in the first instance, and occasion but little friction, and are consequently more durable. In most mills erected in the United States, sufficient care is not bestowed in constructing this kind of coupling to warrant their general use. It is almost impracticable to adjust the square coupling boxes, turned off from the foundry and trimmed with the chisel, to fit the square ends of the shafts with sufficient exactness. Coupling boxes are sometimes cast in two sides to allow of being rendered tight by bolts. These couplings become loose, when there is the least play, and the shafts acquire a hobbling irregular motion. When couplings are fitted to the ends of shafts, a steel pin like a dowel, should be inserted in the end of one of the shafts, to enter a hole drilled in the end of the adjoining shaft, to keep both the ends steady in their places while revolving; otherwise if there be the least wear in the boxes there will be a constant clatter at every revolution.

Fig. 3.



In Fig. 3, A A are the bolts passing through the shafts and coupling box, and B the dowel pin.

The most perfect couplings which I saw in use in Manchester were those with the boxes accurately bored out, and the ends of the shafts halved and turned exactly to fit the coupling box, which is secured to its place by a wedge or key.

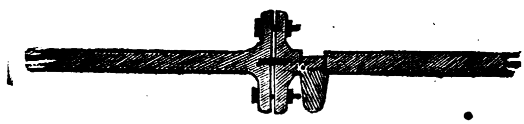
The durability of couplings increases nearly in the ratio of the parts of pressure or contact from the centre of motion. For this reason the ends of the shafts, where halved together, are enlarged to double the size of the shafts. By this plan of coupling, the box may be slipped over the shaft so that any one shaft may be taken down without disturbing the whole line of shafts connected with it.

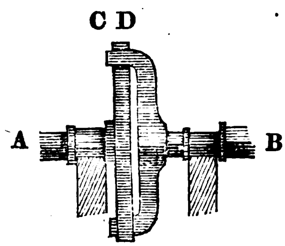
It is recommended by Mr. Buchanan to oil the coupling boxes as well as the other parts of machinery to diminish friction.

It has been considered in practice advantageous to employ a fly or balance wheel to relieve the coupling and to equalize motion at the extreme ends of long lines of shafts, where the work to be performed is irregular; such as arises from the strokes of a pump, and of the heavy hammers for milling cloth. The fly should be placed as near as possible to the machine, the movements of which it is intended to regulate.

It appears, then, that when it is intended merely to communicate motion through a line of shafts, couplings with single bearings are preferable; but if very large wheels and drums are to be fixed upon the shafts, to propel heavy machinery, it is adviseable to use double bearings; as the strain tends to loosen the boxes, and a little irregularity will cause the wheels that play into one another on the shafts, to change their axis or centre and to lose their regularity of motion. One of the principal advantages of a double bearing, is, that it admits of the removal of any shaft in a line of shafts without disturbing the remainder of them. In some of the best mills in the United States, the shafts are connected by circular plates or flanches cast upon the ends of each shaft, and bolted together by several bolts having a pin or dowel in the centre of the axis, as in the following sketch.

Fig. 3.





Clutches or Glands are frequently used as a convenient coupling for shafts with double bearings, where the resistance is uniform. It consists of two cross pieces C D, one fixed to the shaft A and the other to the shaft B. The cross piece D has its ends bended forward to lay hold of the cross piece C, which turns the shaft A.

Fig. 4.

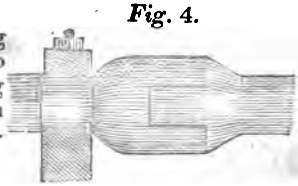


Figure 4 represents another coupling without a coupling box, each of the two shafts having projecting and receding quadrants adapted to each other. When these projections are small this is sometimes used for connecting upright shafts.

There are many other modes of connecting shafts by couplings, which are varied in form in various mills, almost every millwright having some favourite plan of his own.

Bearings and Steps for supporting revolving Shafts.

The bearings on which the journals of shafts rest and revolve are sometimes termed *pillows* or *brasses*, the latter metal being frequently used for this purpose.

As a general rule the bearings of shafts thould be made broad, as their durability is in proportion to their width or rubbing surface, while the friction is generally as the weight resting upon them.

The bearings which sustain upright or vertical shafts are formed with sockets to receive the end of the shaft, and are called *steps.* The bearings which form the horizontal support of vertical shafts to preserve them erect, against which the journals lean, are called *bushes.*

Various substances have been selected for these bearings, which are subject to great wear from friction. Gun metal formed of a composition of copper and tin, which is much harder and more durable than common brass composed of copper and zinc, is commonly used. Cast iron forms excellent pillows for the journals of shafts. Mr. Buchanan states that a water wheel in a cotton mill near Doune has run nearly 30 years on this metal without being perceptibly worn away. One of the best materials for the bearings of shafts, according to Mr. Tredgold, is paste board closely compacted in numerous folds by bolts, the edges being presented for wear. Pillows of boxwood and lignumvitae have been long in use, but have been found inferiour to beech, which is an excellent material for the steps of vertical shafts. When the weight of the revolving shaft is very light, lead, pewter, and zinc form good pillows or bushes to resist attrition. Cast steel, however, is generally admitted to be the best material both for the pillows and journals of shafts, and is now used in all machinery required to revolve with great rapidity, such as the arbors of cotton pickers, spindles, card cylinders, &c.

On the form of Pivots and Steps of vertical or upright Shafts.

Fig. 1.

A

The most usual form of the pivot or lower point of vertical shafts is that of an oval, leaving the pivot rather smaller upwards to prevent its binding in the step, as at the point A, in Figure 1.

The bearing or rubbing surface of the steps of pivots should not have a heavier weight of shafts to support than one ton upon a square inch, or the friction and wear will be increased to such a degree as to cause the steps and pivots to produce heat. To prevent this disagreeable and often dangerous effect, a flat termination is sometimes given to the end of the shaft, which is tipped with a piece of cast steel shaped as in Figure 2 and 3.

Fig. 2. *Fig.* 3.

Fig. 4.

The piece of steel has a small groove cut in it like the head of a screw for the purpose of feeding the oil, as in Figure 4.

Fig. 5.

Mr. Buchanan states that a better mode is to make the steel pivot cylindrical, and insert it into the foot of the shaft, as in Figure 5, forming the bottom of the steel pivot and step a very little convex, or interposing between the step and bottom of the pivot of the shaft, one or more thin pieces of steel made a little convex. The pieces of steel will partake of a small portion of the motion and will admit the oil freely to diminish the friction and heat.

The spindles of mill stones usually run in wooden bushes. Some millwrights prefer elm, and some cast iron, while others use a piece of greased rope to run the spindle in. If the spindle of the mill stone were made to run against the edges of multiplied folds of paste board strongly compressed by bolts, as recommended for other purposes, a most durable bush might be obtained.

Wheel Work.

The various kinds of *wheel work* employed to impart motion from revolving shafts are designated by the shape of their cogs or teeth.

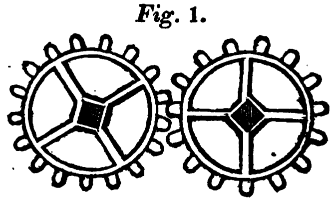
Cog-wheel is the general name for wheels having a number of cogs or teeth around their circumference. When these cogs are formed of the same material and of one piece with the body of the wheel, they are more properly called *teeth.*

A *Pinion* is a cog wheel of a small size, not having in general more than 12 teeth, which are sometimes called *leaves.* When, however, two wheels of different sizes work together, the smaller is commonly distinguished by the appellation of *pinion,* and the larger is called the *wheel.*

The terms, *Trundle, Lantern* and *Wallower,* are applied to designate a small wheel, formed like a cylindrical cage, having bars or staves instead of cogs. This kind of wheel was very generally used before the introduction of cast iron pinions.

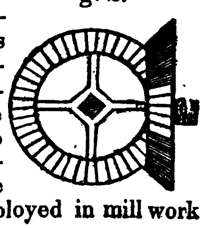
The wheel which acts as a mover is called the *driver,* and the one acted upon is called the *driven.*

Fig. 1.



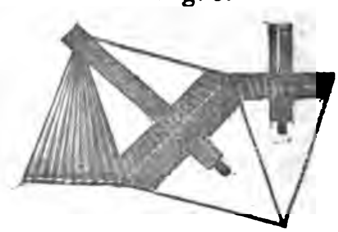
A *spur wheel* has its teeth perpendicular to the axis and in the direction of the arms, as in fig. 1. They are thus called from their resemblance to the rowel of a spur.

Fig. 2.



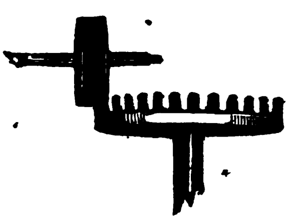
A *Bevelled Wheel* has its teeth sloped or bevelled to the point where the axis of the two shafts sustaining the bevelled wheels would meet if continued as in fig. 2. They are considered precisely as two cones rolling upon each other. The teeth may be considered as grooved in the cones to prevent their surfaces from slipping when resistance takes place. Bevelled wheels are more generally useful than any other kind of wheel employed in mill work

Fig. 3.



and machinery, as by means of them motion may be conveyed by shafts lying at any angle with the axis of the driving shaft, as in figure 3.

Fig. 4.



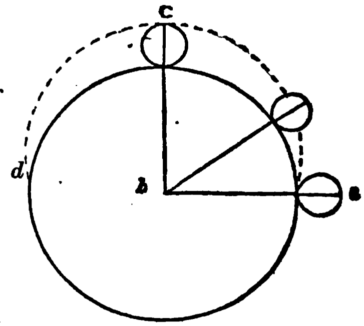
Crown Wheels, with wooden pins for cogs, were formerly employed instead of the present cast iron bevelled wheels. Cast iron has come into general use within about forty years, since which crown wheels are rarely to be seen, except perhaps in the silk mills, in which for some reason unknown to me the ancient plans of wheel work are still retained.

A pinion is sometimes made to work within side of a large wheel, the cogs of which all point towards the centre—the reverse of the common spur gear. This kind of wheel operates with little friction, and is often applied to the water wheel instead of the common bevel and spur gear. In this sort of gear it is generally found necessary to attach the cog wheel to the end of the shaft without a bearing upon each side. It should be the aim of the millwright in all practicable cases to avoid placing a wheel on the extreme end of a shaft, as the stress operates with lever power upon the journals or necks of the shafts. At the same time he should never if he can in any way avoid it, form three bearings to one shaft, unless a flexible light one, as it is almost beyond the skill of man to form and maintain three bearings upon one arbor in a perfectly straight line.

On the teeth of Wheels.

The shape of the teeth of wheels forms a subject of considerable importance in mill work, not only for ensuring their strength and durability, but also for preventing the great loss of power which is always wasted by the very friction which wears away and destroys the teeth. In making the teeth of wheels, therefore, one of the principal objects of consideration is to give them such a shape that the surface of one tooth may not *rub* or *scrape* against the surface of another, but that the friction may be obviated by giving to the faces of the teeth such a curve that when they come together and interlock they may roll upon each other, while at the same time the teeth at the commencement and termination of their mutual contact may suffer no jolt, but become engaged and disengaged with an equable motion.

To obtain these desirable results mathematicians have recommended various forms for the teeth of wheels. M De La Hire has proposed to shape the teeth outside of the pitch line with an *epicycloidal curve*. If a small circle, as *a*, having a point marked upon it, or a pin inserted at the point of contact with the large circle *b*, be made to roll over the circumference of the large circle from *a* to *c*, the pin will gradually rise from the circumference as it traverses over the surface, forming the curved line *a c d*, in its rise and descent. This curved line is called the *epicycloid*, and is recommended to be applied in forming the teeth to make them roll at their points of contact with each other in order to diminish the friction as much as possible.



The *Cycloid* is a curve described in a similar manner by a point in the circumference of a circle when rolling over a straight line. This is the curve which is given to the teeth of the *Rack*.

The compound curved line, called the *involute of a circle*, is particularly recommended as being preferable to the above mentioned plan for forming the acting faces of the teeth of wheels, to possess all the advantages attainable by the millwright. Teeth formed with this curve will act together with so little friction that the sliding action of a tooth 3 inches long on a wheel 10 feet diameter, does not amount to $\frac{1}{50}$ of an inch. By adopting this shape several teeth may be made to act, and react, at the same time on each wheel, whereby the pressure is divided among them, and is diminished in quantity upon each tooth ; and the chance of fracture and of wear by attrition is consequently diminished.

The *Involute* is a curve described by any point fixed in a string wrapped round the circumference of a circle when it is unwrapped or raised from the circle. The curved line thus described resembles the arc of a circle with a radius constantly increasing in length ; for as fast as the string is unwrapped from the circumference of the circle it becomes stretched straight and increases the length given off, or semi-diameter, for forming the sweep or curve.

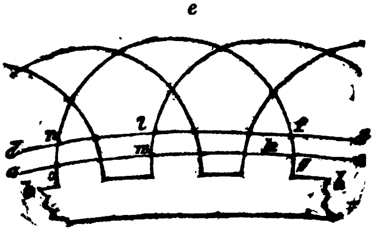
The above outlines give the most correct mathematical forms for the teeth of wheels, but it is found difficult to reduce these theories to practice; for which reason a more simple plan is generally adopted, whereby nearly the same results are obtained without the nicety of calculation required in the above instances. By supposing the teeth of wheels to be infinitely small, their action might be regarded as that of cylinders simply rolling upon or touching each other's surfaces. Thus by making them as small and as numerous as is consistent with strength, and to a certain extent to increase the breadth of the teeth for the purpose of obtaining the desired strength, millwrights are able to attain at once nearly all the advantages proposed in the preceding plans of *involute* and *epicycloidal* teeth. By doubling the breadth of the teeth, however, their strength is only doubled; but by doubling the thickness the strength is increased as the squares of the thickness, or in a fourfold ratio. A certain medium must therefore be observed between the breadth and thickness of the teeth, which is particularly treated of at page 42, (see Strength of Materials, and Table of the Pitch, Thickness, Breadth, and Strength of Wheels.)

The practice and observation of millwrights have enabled them to fix upon a method of forming the teeth of wheels which "answers nearly, if not fully as well in practice as the geometrical curves, which theory has pointed out to be the most proper. This they have effected by making the teeth of the modern wheels extremely small and numerous. In this case the time of action in each pair of teeth interlocked with each other is so transient, that the form of them becomes comparatively of slight importance. Millwrights now use the *arcs of circles* for the curves, which on small teeth so nearly approximate to the *epicycloidal* and *involute* curves, that the difference is of no consequence; and this method is the best, because it so easily gives the means of forming all the cogs exactly alike and precisely the same distance asunder, which by the application of any other curve than the circle, is not so easy."

When the teeth of two wheels interlock or indent with each other, it is manifest that the extreme points of the cogs cannot be considered as the acting rim of the circumference of cog wheels. Circles are drawn cutting the cogs intermediately between the roots and extreme tips at the place where they are indented together. These two circles, one described from the centre of each wheel, are the real moving circumferences of the two wheels, and are called the *pitch circle* or *pitch line* of the wheels as *a a*. The line drawn from the centre of one wheel to the centre of the other in contact with it, is called the *line of centres*.

Practical method of laying out or forming the teeth of wheels.

The cogs being fixed in the rim of the pattern wheel much larger than they are intended to be, the circle *a a* or *pitch line* is described around the face of the rough cogs. Another circle *b b* is described within the pitch circle for the bottom of the teeth, and a third *d d*, without it for the extremities. After these preparations the pitch circle is accurately divided into the number of parts or teeth, which it is intend-



ed to make upon the wheel : a pair of compasses are then opened out to the extent of one and a quarter of these divisions, and with this radius arcs or semi-circles are struck on each side of every division, from the pitch line *a a* to the outward circle *d d*. Thus the point of the compasses being set in the division *e* the curve *f g* on one side of a cog, and *n o* on one side of another cog, are described ; then the point of the compasses being set on the adjacent division *k*, the curve *l m* is described. This completes the curved portion of the cogs; and this being done all round completes every tooth : The remaining portion of the cog within the pitch circle *a*, is bounded by two straight lines drawn from the points *g* and *m* towards the centre; this being done also to the cogs all round, the wheel is set out, and the cogs after being dressed or cut down to the lines will be formed ready to work, every cog being of the same breadth ; and the space between every one and its neighbour, is exactly equal to the breadth, provided the compasses are opened to the extent of one division and a quarter as first described." The same rule applies to the teeth of bevelled wheels formed upon their developed pitch lines.

The best mathematical and practical plans are thus presented. Mathematicians and Millwrights seem to be somewhat at issue on this topic, the former complaining that the "Millwrights have their own nostrums, most of which are egregiously faulty, being little else indeed than instructions how to make teeth clear each other without sticking." On the other hand Mr. Buchanan, an excellent practical millwright, (see Tredgold's edition of Buchanan on mill work, to which the reader is referred for much valuable practical information on this subject) observes, that "the method of forming teeth by the arcs of circles will always enable a workman to execute short teeth nearer to the true form than any pattern tooth will enable him to do." "Pattern teeth," he further observes, "and compound curves, are things that may on some occasions be very useful, as where the teeth are long, and of considerable magnitude in respect to that of the wheel or pinion to which they belong. But in all ordinary forms of wheel work such operations must consume an immense quantity of valuable labour, to attain even the *same degree* of accuracy that is at once obtained by means of circular arcs" He also states that "it is the general opinion of those who are in the practice of constructing mill work, that teeth ought if possible never to begin to act before they reach the line of centres, as this mode of action is thought to occasion much unnecessary friction ; the friction of the receding teeth being less than that of the approaching teeth.

Much time and expense has been bestowed in some places in dressing the teeth of iron wheels with chisels and files, the teeth being cast large in the first instance to be reduced in this way to the proper shape. This method according to Mr. Tredgold, is now but seldom practised, the outer surface of the iron which is the hardest and smoothest for wearing, being destroyed by this operation, in addition to the disadvantage in point of economy of labour. The teeth of all wheels should however be carefully inspected, and if they are in the least irregular should be reduced by the file and chisel.

The following table gives the *Radii* or semidiameters of wheels of from 10 to 300 teeth, the *pitch being 2 inches*. The radius for any other pitch may be found by the following analogy. *As 2 inches is to the radius in the table, so is the new pitch to the new radius.*

No. of Teeth.	Radius in Inches.	No. of Teeth	Radius in Inches.	No. of Teeth	Radius in Inches.	No. of Teeth	Radius in Inches.	No. of Teeth.	Radius in Inches.
10	8,236	69	21.971	128	40,748	187	59,527	246	78,306
11	8,549	70	22,289	129	41.066	188	59,845	247	78,625
12	8,864	71	22,607	130	41,384	189	60,163	248	78,943
13	4,179	72	22,926	131	41,703	190	60.482	249	79,261
14	4,494	73	23.244	132	42,021	191	60,800	250	79,580
15	4,810	74	23,562	133	42,339	192	61,118	251	79,898
16	5.126	75	23 880	134	42,657	193	61,436	252	80,216
17	5,442	76	24,198	135	42,976	194	61,755	253	80,534
18	5,759	77	24.517	136	43,294	195	62,073	254	80,853
19	6,076	78	24,835	137	43,612	196	62,392	255	81,171
20	6,392	79	25,153	138	43,931	197	62,710	256	81,489
21	6,710	80	25,471	139	44,249	198	63,028	257	81,808
22	7.027	81	25,790	140	44,567	199	63,346	258	82,126
23	7,344	82	26,108	141	44,885	200	63,665	259	82,444
24	7,661	83	26,426	142	45,204	201	63,983	260	82,763
25	7,979	84	26,741	143	45,522	202	64,301	261	83,081
26	8,296	85	27,063	144	45,840	203	64,620	262	83,399
27	8,614	86	27.381	145	46,158	204	64,938	263	83,717
28	8,931	87	27,699	146	46,477	205	65,256	264	84,038
29	9,249	88	28,017	147	46,795	206	65,574	265	84,354
30	9,567	89	28,336	148	47,113	207	65.893	266	84,673
31	9,885	90	28 654	149	47,432	208	66,211	267	84,991
32	10,202	91	28,972	150	47,750	209	66,529	268	85,309
33	10,520	92	29.290	151	48,068	210	66,848	269	85,627
34	10,838	93	29.608	152	48,387	211	67,166	270	85,946
35	11,156	94	29,927	153	48,705	212	67,484	271	86,265
36	11,472	95	30,245	154	49,023	213	67,803	272	86.582
37	11,792	96	30,563	155	49,341	214	68,121	273	86,900
38	12,1 0	97	30,881	156	49,660	215	68,439	274	87,219
39	12,428	98	31,200	157	49,978	216	68,757	275	87,537
40	12.746	99	31.518	158	50,296	217	69,075	276	87,855
41	13,064	100	31,836	159	50,615	218	69,394	277	88,174
42	13,382	101	32,155	160	50,933	219	69,712	278	88,462
43	13,700	102	32,473	161	51,251	220	70,031	279	88,810
44	14,018	103	32,791	162	51,569	221	70,349	280	89,129
45	14,336	104	33,109	163	51,888	222	70,667	281	89,447
46	14,654	105	33,427	164	52,206	223	70,985	282	89,765
47	14,972	106	33,746	165	52,524	224	71,304	283	90,084
48	15,290	107	34,064	166	52,843	225	71,622	284	90,402
49	15,608	108	34.382	167	53,161	226	71,941	285	90,720
50	15,926	109	34,700	168	53,479	227	72,258	286	91,038
51	16,244	110	35,018	169	53,798	228	72,577	287	91,357
52	16,562	111	35,337	170	54,116	229	72,895	288	91,675
53	16,880	112	35,655	171	54,434	230	73,214	289	91,993
54	17,198	113	35,974	172	54,752	231	73,532	290	92,312
55	17,517	114	36,292	173	55,071	232	73,850	291	92,630
56	17,835	115	36,611	174	55,389	233	74,168	292	92,948
57	18,153	116	36,929	175	55,707	234	74,487	293	93,267
58	18,471	117	37,247	176	55,026	235	74,805	294	93,585
59	18,789	118	37,565	177	55,344	236	75,123	295	93,903
60	19.107	119	37,883	178	56,662	237	75,441	296	94,222
61	19,425	120	38,202	179	56,980	238	75,760	297	94,540
62	19,744	121	38,520	180	57,299	239	76,078	298	94,858
63	20,062	122	38,838	181	57,617	240	76,397	299	95,177
64	20,380	123	39,156	182	57,935	241	76,715	300	95,495
65	20,698	124	39,475	183	58,253	242	77,033		
66	21,016	125	39,793	184	58,572	243	77,351		
67	21,335	126	40,111	185	58,890	244	77,670		
68	21,653	127	40,429	186	59,209	245	77,988		

The preceding Table will often be found useful in setting out the teeth of cog wheels, and in making the patterns for cast iron wheels.

It is generally recommended, in calculating the number of teeth of two wheels playing into each other, to make one odd tooth, sometimes called by millwrights a *hunting cog*, that the same teeth may not constantly come together at every revolution or given number of revolutions. This was done originally with the intention of distributing the wear upon wooden cogs more equally, and to obviate any accidental differences in the hardness or solidity of this yielding material. In modern cast iron wheels the metal is of such uniform hardness that even in *match gearing*, composed of two wheels of the same size and number of teeth, each one of which must always engage the same tooth at every revolution, I have never observed any material difference in the wear of any one tooth; on the contrary it seems that if there be any original inequality in the surfaces or solidity of the teeth, they will sooner become adjusted to each other by their constantly returning mutual attrition at the irregular points of action, and for this very reason are commonly found to run more silently after being worn than almost any other kind of wheel work constructed with ordinary accuracy.

Of the size of Wheels and Pullies, and speed of Mill Gearing.

When it becomes necessary to increase the velocity of the revolving shafts of mill gearing it is commonly effected by employing a large wheel to act upon a small one, called the *pinion*. The greater the difference in the size of the wheel and pinion, the more rapidly and economically the requisite increase of speed may be obtained. It is indeed this very facility and apparent temptation to economy, which has introduced one of the most common defects observable in the gearing of mills in the United States, viz.: the use of wheels and pinions of small sizes or diameters. The tranverse strain arising from the oblique action of the teeth, particularly when somewhat worn, has a tendency to force the pinion from the wheel, and to make it bear harder on the journals, whereby a loss of power takes place from friction, and the pillows or bearings of the shafts often become heated. Mr. Buchanan states that "millwrights of experience have even found a great saving of power by altering corn mills, for example, from the old plan of using only one wheel and pinion (or *trundle*) to the method of bringing up the motion by means of more wheels and pinions of large diameters and finer pitches. The effect of the water power has often by these means been greatly increased, while the wear and tear has been much lessened, although the machinery thus altered became actually more complex."

When pinions are used to drive wheels Mr. Buchanan observes that the pinion should have not less than 8 or 9 teeth to work well; and if large wheels are used to drive small pinions, to increase speed, the pinion ought to have at least 11 or 12 teeth. It is adviseable rather to increase the size of the wheel than to diminish that of the pinion.

In general it is considered desirable to increase the velocity of mill gearing gradually, beginning with the first motion rather slow by wheels and pinions of large diameters. The gain or increase of motion should take place in the immediate vicinity of the steam engine or water wheel, where the shafts and wheels are always calculated to be large and strong to resist the stress upon them, which must take effect when great power is transmitted by a slow motion.

As before stated at page 137, the resistance arising from the friction of the iron axles or arbors of machines revolving on bearings of wood was found by Coulomb's experiments to be equal to about $\frac{1}{30}$ of the weight or pressure of the arbor, and "the *velocity* in these experiments did not appear to influence the *friction*, unless in the first instants of rest." Coulomb also found "that under the same pressure and with the same velocities the *friction is nearly the same* on *small* and *large* surfaces." By the experiments made in Manchester by Mr. Roberts upon the friction of wheels upon rail roads, which in part resembles that of wheels and pullies on their shafts, it appears that "goods might be conveyed on a rail road with very nearly the same expenditure of steam whether they were carried two miles or 20 miles per hour." The results of all these experiments seem to indicate that the resistance from friction to the motion of revolving shafts and wheels is in proportion to the weight or pressure upon their bearings rather than to their velocity.

In some of the cotton mills recently erected in Rhode-Island, the upright or vertical and horizontal shafts are all calculated to make 80 revolutions per minute. With this velocity of the upright shaft it must be necessary sometimes to reduce the motion communicated to the horizontal shafts, as the speed may occasionally be too quick for the machinery to be operated from them. For the ordinary operations of cotton and woollen mills a velocity of about 40 or at the utmost 60 revolutions per minute will be found sufficient for vertical shafts, and from 60 to 80 revolutions for the horizontal ones, according to the machinery which they are intended to propel.

After the velocity or speed is accelerated, lighter wheels serve to transmit an equal power to a distance from the first mover, as "the size of the wheels and shafts being the same, the stress is inversely as the velocity." Emerson, prop. 119. Rule 8. For example, if the circumference or pitch line of one pair of wheels be revolving at the rate of 8 feet in a second, and another pair of wheels in every respect acting under the same circumstances, be moving at the rate of 4 feet in a second, the stress on the latter will be double that on the former. It is therefore recommended to use wheels of large sizes, the teeth of which may be formed of less strength, to accomplish the same work, than when the wheels are small. By adopting this plan for the lighter parts of mill gearing, wooden cogs may be advantageously substituted to run upon iron teeth, whereby the increase of velocity will not produce the clattering noise commonly occasioned by the collision of the iron teeth of wheels when revolving with a quick motion, the din of which is sometimes inconceivably annoying to those who operate the machinery of a mill. The wooden cogs may be thus relieved of stress, in proportion to the augmentation of the velocity and diameters of the cast iron wheels into which they are inserted. In this case they will be found to answer exceedingly well, and to be very durable.

When wooden cogs and iron teeth operate together, the former should be inserted in the wheel and the latter should compose the pinion. When a very rapid motion of light machinery is required it is frequently the practice to cut the teeth of the spur wheels *spirally*, forming what is called *spiral gear*. Several teeth on each wheel are by this contrivance constantly engaged with each other, and the most rapid motion will be attended with but little noise. By a proper engine, spiral teeth may be cut with rapidity and great accuracy

When the circumference of two wheels revolve in contact with each other, it is manifest that unless their surfaces slip upon each other the number of revolutions they will perform respectively in a given time must be as their circumferences. Upon this principle the circumference of circular cisterns may be very exactly measured, for ascertaining the lengths of the hoops required for them, by means of a small wheel called the *perambulator*, having its circumference marked with a scale of feet and inches. Should the circumference of the perambulator be 3 feet, and in rolling around the circumference of the cistern it should make 6 revolutions, then $6\times3=18$ feet is the circumference of the cistern. In the same manner distances on level roads have been measured with tolerable accuracy by the revolutions of a carriage wheel $16\frac{1}{2}$ feet or 1 rod in circumference. Every revolution of the wheel in rolling over the road will give 1 rod, and if an index connected by wheel work with an endless screw upon the hub of the carriage wheel be fixed in sight of the driver, he can readily ascertain the distances traversed.

To calculate the Power and Velocity of the Wheel Work of Mill Gearing.

The shafts and wheels of mill gearing and machinery operate precisely like the wheel and axle, being merely modifications of the lever. Each separate wheel and axle being a lever, the effect of a succession of wheels and axles connected and operating together are the same as that of a series of levers, as explained at page 167. The arms of the wheels are the longer arms of the lever, and the short arm of the pinion wheel fixed upon the shaft is the shorter arm of the lever. Hence the condition of equlibrium is, that the power multiplied by the product of the radii or semidiameters of all the wheels is equal to the weight multiplied by the radii of all the axles; or the number of cogs or teeth being substituted for the lineal measure of the semi diameter of the wheels and pinions, the equilibrium will take place when the power multiplied by the product of the number of teeth in all the wheels is equal to the weight multiplied by the product of the number of teeth in all the pinions. Thus if 3 wheels be used of 100 teeth each and 3 pinions of 10 teeth each, then—

$$\frac{100\times 100\times 100=1000000}{10\times 10\times 10 = 1000}=1000 \text{ answer.}$$

That is the power will be 1000 fold, or 1 lb. suspended on the circumference of the first wheel will balance 1000 lbs. suspended on the axle of the last pinion.

The *velocity* of the circumference of a train of wheels and pinions may be found in the same manner ; as in the following

EXAMPLE.

What is the velocity of the circumference of the last wheel of a train when the train consists of 3 pinions of 10 teeth each, and 3 wheels of 100 teeth each, the first pinion moving 1000 feet per minute ?

$$\frac{1000\times 10\times 10\times 10=1.000000}{100\times 100\times 100=1.000000}=1 \text{ foot velocity per minute, ans.}$$

Hence it will appear that the power and weight will be in equilibrium when the power multiplied by the velocity of the power is equal to the weight multiplied by the velocity of the weight; a power of 1 lb. moving 100 feet per second will be in equilibrium with a weight of 100 lbs. moving 1 foot per second, as illustrated in explaining the laws of motion at page 153. These principles are often applicable in calculating both the power and the velocity of machinery, and should be impressed on the memory of the mechanic.

The following rules founded upon the above are here given, for facilitating the calculations of the dimensions of wheels and of drums and pullies upon the revolving shafts of the gearing and machinery of mills, to increase or diminish their velocity to a required extent.

It will be observed that in the following calculations the number of the teeth of wheels are taken for examples to illustrate the rules. Where Drums or Pullies are used, it is only necessary to substitute their diameters or circumference in inches (or tenths of an inch for greater exactness) in place of the number of teeth of wheels. The circumference and diameters of wheels of various sizes bear the same relative proportions to each other, as the number of teeth upon their circles, where the teeth are of uniform size.

The first mover or propelling wheel or pulley is called the *Driver.*

The wheel or pulley that is acted upon by the Driver is called the *Driven.*

The number of teeth and revolutions per minute of the Driver *being given, to find the number of teeth necessary in a* Driven *wheel to cause it to perform a required number of revolutions per minute.*

Rule 1. As the velocity required, is to the number of teeth (or diameter in inches) of the Driver :: so is the velocity of the Driver to the number of teeth (or diameter in inches) of the Driven.

EXAMPLE.

There is a shaft making 60 revolutions per minute, having upon it a wheel for a Driver with 38 teeth: what must be the number of teeth of the wheel upon a driven shaft (or the diameter of the pulley on a machine) to produce 100 revolutions per minute?

As 100 : 38 :: 60 : 22.8, or nearly 23 teeth, answer.

The number of teeth (or diameter of a pulley on a machine) and revolutions of the driven wheel, and the number of revolutions of the driving shaft, being ascertained, to find the number of teeth required for a wheel upon the driving shaft to produce the required velocity.

RULE 2. As the velocity of the Driver is to the number of teeth of the Driven, so is the velocity required to the answer.

EXAMPLE.

A machine has a wheel of 23 teeth, intended to be driven 100 revolutions per minute from a shaft making 60 revolutions per minute. What is the requisite number of teeth for a wheel to have, which is to act as a Driver from this shaft?

As 60 : 23 : : 100 ·· 38.5 teeth require forthe Driver. Answer.

When the number of teeth of two wheels of different diameters are given, and the number of revolutions per minute of the driver, to find the velocity of the Driven.

RULE 3. As the number of teeth in the Driven wheel is to the number of revolutions per minute of the Driver, so is the number of teeth in the Driver to the answer required.

EXAMPLE.

If a driver having 38 teeth and making 60 revolutions per minute act upon a driven wheel having 32 teeth, what number of revolutions per minute will the driven wheel make ?

As 32 : 60 : : 38 : : 71.25 revolutions per minute made by the driven wheel.

Train of Wheels.

It often occurs that a train of wheels or pullies becomes necessary for increasing or diminishing the velocity or number of revolutions of the shafts of machinery. Whenever this is the case the size of each wheel of the train should bear a regular proportion to that of the others. It may here be proper to repeat that a sudden increase of speed by using wheels and pullies of very disproportionate sizes being attended with great stress and friction, particularly when such wheels or pullies are of small diameters, should be studiously avoided in the construction of mill-gearing.

The following Rules have been given for calculating the proportion which the velocities of the wheels in a train should bear to each other, and the number of teeth to each wheel. These rules as well as the preceding are applicable to pullies, if their diameter in inches be substituted in place of the number of teeth.

Rule. *To find the proportion that the velocities of the wheels in a train should bear to one another to obtain a regularly increased speed.*

Subtract the less velocity from the greater, and divide the remainder by the number of one less than the wheels in the train; the quotient will give the mean number to show the average difference that should exist between each successive wheel of the train, rising in arithmetical progression from the least to the greatest velocity of the train of wheels.

In a train of wheels each except the first and last is supposed to be acted upon or driven upon one side, while it acts as a driver on the opposite side in contact with the succeeding wheel of the train. A second wheel or pulley may however be placed upon the same shaft to act as a driver, in which case the result will be the same, if the second wheel have the same size as the first.

EXAMPLE

What is the number of teeth in each of three wheels to produce 17 revolutions per minute, the Driver having 107 teeth and making 3 revolutions per minute ?

$$\frac{17-3=14}{3-1=2}=7$$ therefore 3.10.17 are the velocities of the 3 wheels.

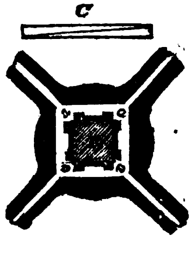
$$10 : 107 :: 3 : 32=\frac{107\times3}{10}=32$$ teeth in 2d wheel.

$$17 : 32 :: 10 : 19=\frac{32\times10}{17}=19$$ teeth in 3d wheel.

The above Rule is not founded upon any actual increase of velocity of the moving circumference of the wheels, but merely upon the increase in the number of their revolutions in the ratio of the diminution of their diameters.

Fixing Wheels upon Shafts of Mill Gearing.

One of the most perfect modes of fixing a wheel upon a shaft is to bore out the centre of it, to which the end of the shaft is fitted by turning in the usual way. To prevent the wheel from slipping around upon the shaft, binding screws may be made to pass through the hub. When the wheel is subjected to much stress keys are driven into a groove formed partly in the shaft and partly in the centre of the wheel ; or a hole may be drilled with one half of the bore perforated in the wheel and the other half in the shaft. If an iron or steel pin be fitted to this hole, the wheel cannot slip around upon the arbor of the shaft without entirely splitting the pin. When the shaft is square the centre of the wheel is also made square, and is fastened by wedges upon the shaft. Sixteen wedges are used as *a a a a* eight being driven on each side of the wheel; they are kept in their places by a shallow groove cut or cast in the wheel. The points of each pair of wedges are made to lap upon each other as at *c*, thus forming parallel surfaces from two tapering wedges. After placing the wheel upon the shaft a gauge is adjusted to four opposite points in the circle of the cogs, and by gently driving in a wedge on one side and loosening a wedge upon the other, the cogs at four opposite points in the wheel are at last brought just to graze the gauge as they revolve past it, provided the wheel is accurately adjusted. It is a very injudicious plan to drive numerous wedges in the middle of the axis as well as near the corners of shafts, as is commonly practised in the United States.



A *Ratchet Wheel* is a wheel fixed upon an axis and having teeth to receive a *ratch or pall*, which allows the wheel and axis to turn round in one direction, but prevents its revolving in the opposite direction by catching against the teeth. Ratchet wheels are generally used for preventing a weight raised by a machine from descending or recoiling should the application of the power be intermitted; but if the rachet wheel is acted upon by a moveable ratch, it is one of the most convenient modes of obtaining a circular motion from a reciprocating rectilinear motion.

Rag Wheels are formed with points or knobs to take hold of the links of chains, which are often used instead of belts and ropes when the movements are required to be sure and regular, and are exposed to great stress. By this precaution the chains are prevented from slipping around the circumference of the wheel, as ropes or belts will commonly do. When large chains with links of the usual form are to be wound around a cylinder or capstan, or are made to pass around a wheel, it is an excellent plan to form an iron groove to receive the vertical link. The chain may be then wound very regularly upon the cylinder, the side of every other link lying flat upon the barrel, and of the intermediate links, one half of each sinks into the groove, and the other projects above it. The links of a chain thus all retain their natural position when wound around the barrel, whereby their durability will be exceedingly promoted and a saving of friction will at the same time take place.

Rack Work. A straight bar with teeth or cogs arranged in a line upon one side of it is called the rack, which is usually employed as an elementary part of ma-

chinery in connexion with a pinion wheel, and is then denominated the *rack and pinion*. It is commonly used for imparting a rectilineal motion, backwards and forwards, to rods or beams of machines.

Wheels with Belts and Ropes. In the preceding examples of wheel work the force is transmitted by cogs, teeth, or cavities and protuberances on the surfaces of the wheels, which prevent the parts in contact from slipping or sliding without communicating motion. For light kind of machinery sufficient force may be transmitted by the mere *friction* of the surfaces of wheels without teeth, composed of rough woody fibres, or coated with buff leather or india rubber ; or still more conveniently by means of the friction of *belts* and *ropes* passing around pullies. This is one of the best as it is one of the most common modes of transmitting a moving force to all light machinery, in which a little slipping or yielding of the belt will not produce an injurious effect. In a large cotton mill in New-England, which I have had an opportunity of examining, belts are used almost to the entire exclusion of wheel work, and of lines of horizontal shafts. Although the machinery of this mill has been successfully operated in this way, yet the plan cannot be recommended either for economy or saving of friction. Leather belts it is well known are more or less affected by changes of weather, and it becomes necessary to create a tension adapted to operating the machinery under the most unfavourable state of the weather to ensure its effect at all times. In operating power looms it is a nice point to produce a uniform unfailing power to throw the shuttle with accuracy. This can be easily accomplished when only one belt intervenes between the pulley of the loom and the drum upon a shaft moved by cog wheels; if more than one belt intervenes, each having a tendency to slip or yield a little upon the drum, the accuracy of the shuttle movement is destroyed.

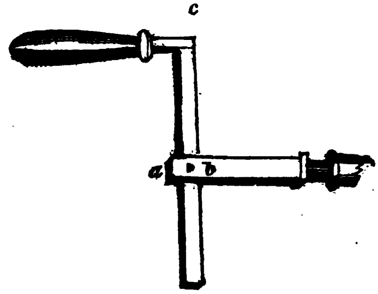
Ropes are more liable to slip upon a drum than belts, and in practice they are therefore always applied to grooves, in which they become jammed or bound fast as the tension increases. Irons formed like the letter Y may be conveniently driven into the wheels to receive and retain the rope.

Straps or belts, and ropes are more or less elastic, and have a tendency to slip upon the pullies encircled by them. A small allowance should be made for this by calculating the velocity of machines to be driven by belts and ropes somewhat greater than is actually required in practice.

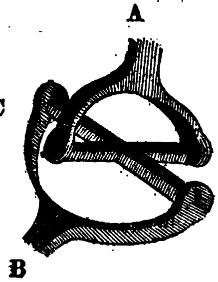
The *Crank* is too familiarly known to require a minute description. It is one of the simplest machines for conveying motion, and is found to be one of the most durable, because it operates upon the principle, well known to every intelligent mechanic, of bringing bodies connected with it to a state of motion or rest with a gradually increasing or diminishing velocity, thereby avoiding all the sudden shocks in overcoming the inertia of matter, which are so destructive even to the strongest machines. It is for this reason peculiarly well adapted to the operation of pumping, and of the vibrating motion of the piston and beams of steam engines, wherein heavy masses of matter are required to be alternately put in motion and brought to a state of rest. Wherever heavy reciprocating movements take place, the crank is deservedly a favourite elementary machine.

The *Sun and Planet Wheel* operates upon the same principle as the crank, but is considered inferior to it in respect to the action of the teeth of the wheels, which always allow of a little play and irregularity. It was adopted by Messrs. Boulton and Watt for producing a rotatory motion from their steam engines, after they found that the patent right for the application of the crank had been secured by a resident of Bristol.

It is sometimes convenient to have a *crank*, or a *winch*, which operates on the same principle as the crank, with a variable radius or length of lever, adapted to different purposes; either to produce a longer or shorter reciprocating stroke, or to give the advantage of lever power to turn the winch for raising weights, &c. This may be accomplished by making the arm *c d* to slide through a mortise in the shaft *a*, in which it may be rendered stationary wherever fixed by the binding screw at *b*. The arm *b c* may be thus lengthened or shortened at pleasure. A crank movement may be readily obtained from a revolving wheel, fixed upon the extreme end of a shaft, merely by inserting a pin in the outer side to receive a crank bar. The length of the stroke of a crank formed in this way may be easily regulated by placing the pin nearer to or farther from the centre.



The *Universal Joint* consists of two shafts A B, united by the two cross pieces C D, each end of which is connected with the semi-circle forming the ends of the shafts by a swivel pin or pivot. When the shaft B is turned it operates by means of the cross to turn the shaft A, the action of the cross on its pivots allowing the motion to be communicated, although the shafts are not in a right line with each other. This joint may be used when the inclination of the two shafts towards each other does not make a greater angle than 40º. When the angle is greater than this the *Double Universal Joint* may be employed. The latter joint is rarely used in



practice, as it is somewhat complicated. Bevelled wheels are commonly found more convenient and durable than the Universal Joint, which is seldom observable in machinery at the present day.

Ball and Socket. This simple contrivance, familiarly known as applied to the Surveyor's compass, serves as a sort of universal joint to allow of motion in various directions upon a fixed pivot. A piece of cork is inserted in the bottom of the socket, which is pressed by a screw against the ball in such a manner as to confine it stiffly to one place when required. There are very few cases in which this elementary mechanical contrivance is used.

Springs are very commonly used in machinery as a convenient reservoir of the power or moving force, which may thus be treasured up to react at any instant, and after any lapse of time, upon the desired point. The spring of a watch after being *wound up* may be made to react or uncoil itself in an instant, or during each instant of 24 hours ; or the force applied to wind up the spring may be retained by it for years, to operate after the hand that performed the office has mouldered to dust. A spring has no tendency to produce original action, but rather to act like the balance wheel, expending the force impressed upon it after the moving power has ceased, or is withdrawn.

ON THE METHODS OF DISENGAGING AND RE-ENGAGING MACHINERY.

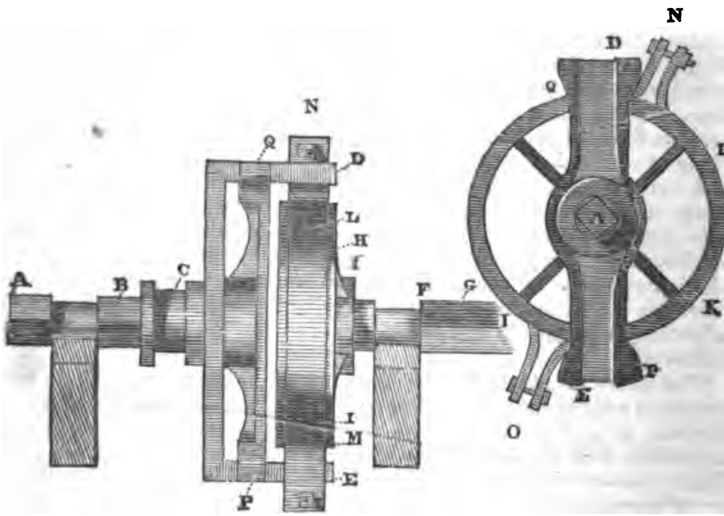
Almost every practical mechanic is well acquainted with the fact that when a heavy machine is suddenly put in motion by interlocking it with the swiftly revolving teeth of mill wheels, or with any other unyielding or unelastic part of the mill gearing, a shock or jar is produced which is very injurious, if not immediately destructive, to all the working parts of a machine; a blow like that of a hammer being the result of the resistance *or inertia* of the machine to the first impulse given it from the mill gearing. This is the case when the machines are put in motion by slipping the cogs of a wheel at rest into contact with the cogs of a wheel revolving with any considerable degree of velocity. From inattention to this subject an instance occurred within my knowledge in which one of the wheels of a heavy machine, thus brought into sudden contact with one of the wheels of the mill gearing, was stripped of several of the cogs the first time they were thrown into gear or interlocked, and after new wheels, with teeth of sufficient size to resist the shock, were substituted in place of those which had failed, the machine itself soon gave way, and became a mere wreck. When the moving force is thus applied to a machine, instead of receiving a gradually increasing motion, so favourable to the operations and durability of machinery, it is impelled into instantaneous motion. The *bayonet*, and the *cog wheel* upon a *moveable axis*, to be slipped into gear or out of gear by a lever, are modes of imparting motion of this description. When the prongs of the bayonet strike the cross piece upon the shaft of the machine intended to receive the impulse, or when the teeth of the wheel of the mill-gearing strike the teeth of the wheel to be put in motion by it, there is no elasticity or yielding power, but the machine has to sustain the shock, not only of the weight or momentum of the mill gearing, with which it may be in immediate contact, but also of all other distant parts of it, and of the momentum of the water wheel or steam engine itself. The whole mass of the wheel work and shafts of a mill are so closely connected as to move like one solid body, and thus their momentum, equal to that of several tons in rapid motion, is brought to bear at a blow upon the machine at rest. For slow movements, such as are required for boring and turning iron, or for light machinery like the turning-lathe, this mode of *engaging machinery* may be adopted without much disadvantage, not because the principle itself is favourable in these instances, but because the injurious effects of it are diminished by these particular circumstances under which the action takes place. Unless therefore the most urgent reasons require the adoption of this method of putting machines in motion, it should never be resorted to by the millwright.

The above disadvantages are avoided by employing the simple and excellent contrivance of the *fast and loose Pulley*. The elasticity of the belt, as well as the facility with which it slips on the surface of the pulley until the proper velocity is gradually imparted to the machine, renders this method the most perfect yet discovered for all cases of engaging machinery where the strength of the leather belts, and the nature of the work to be performed, will admit of their use. To put a machine in motion by the fast and loose pulley it is only necessary for the operator to guide the belt from the loose pulley, which as its name implies turns freely on the arbor of the shaft, to the fast pulley placed immediately by the side of it. It may be repeated here, that in forming pullies, the middle of the rim should be swelled a little, like the staves of a cask, as the belt inclines to that part of the pulley which is of the greatest diameter.

Instead of a loose pulley, a *single fast pulley* is frequently employed with a very slack belt slipping loosely around its circumference. A roller attached to the end of a lever is pressed down upon the loose belt to produce a tension by the pressure sufficient to prevent the belt from slipping freely around the pulley. By this contrivance the belt may be tightened or slackened upon the driving and driven pullies at pleasure, and the machine may be put in motion or stopped merely by placing a weight upon one end of the lever or by relieving it of such weight.

Friction Clutch.

When machines are to be operated which require more power than can be readily imparted by a leather belt, or are to be placed in situations exposed to moisture, where leather belts would soon decay, recourse may be had to the *Friction clutch.* This contrivance for engaging heavy machines is nearly as favourable as the fast and loose pulley, while at the same time it may be made to operate with greater certainty and effect, as the friction may be increased at pleasure to almost any degree, to prevent the hoop from slipping around the wheel, like the belts upon the circumference of pullies.



A B represents part of a shaft kept in motion by the mill; C D E a bayonet, which either slips on a square part of the shaft A B, or passes through the arms of a cross P Q (as represented in the figure) which cross is fastened to A B. F G is part of the shaft of the machine, to be connected with and driven by the shaft A B. Upon the shaft F G, an iron wheel or pulley H I K is fastened: this pulley has ledges to keep the screwed hoop L M N O steady and from slipping off. In setting on the machine, the hoop L M N O is carried round by the bayonet or clutch C D E, and the friction of the hoop on the grooved wheel H I K, brings it into motion in the same easy and gradual manner, that a belt does a machine driven by a pulley; the hoop will slip around the wheel several revolutions before the velocity of the shaft F G, and of the machine connected with it, is fully acquired. The hoop being formed in two semi-circles, united at N O, the friction may be increased at pleasure merely by tightening the screw bolts which connect them.

The Friction Clutch is constructed precisely like the *bayonet and clutch,* excepting that the prongs, instead of striking a fast cross piece, strike upon the ears of two semi-circles or half hoops of iron, united by two bolts, and embracing an iron cylinder or wheel, around which the hoop is intended to slip until the machine has gradually acquired the desired velocity. By a hoop of about a foot diameter and two inches breadth a friction may be produced nearly sufficient to transmit a one horse power.

The Friction clutch is in very common use in English mills for disengaging and re-engaging heavy machines, or such as require considerable power to operate them.

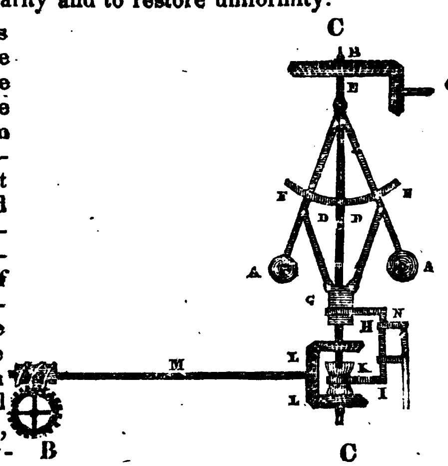
METHODS OF REGULATING THE MOTION OF MACHINERY.

There are few machines in which regularity of motion is not desirable, the perfection of their operations as well as their durability being thereby more or less affected. As the water rises and falls in the mill pond, or the steam is increased in quantity in the boiler of the steam engine by the occasional addition of fresh fuel, the moving power is subject to fluctuations, which affect the motion of every machine connected with or operated by the moving force. To obviate the irregularities of the action of these first moving forces, which are generally employed for most purposes requiring power in the useful arts, one of the most philosophical and beautiful inventions in mechanism has been applied with perfect success. The supply of water and steam, which are the first movers, is regulated by the *centrifugal force* of revolving balls. So perfect, indeed, is the operation of the *Governor*, by which name this invention is known, that all the machinery of a large mill is thereby made to move with an uniform velocity almost equal to that of the wheels of clock work. One of the unfailing laws of nature has been thus happily applied to produce uniformity of motion by proportioning the moving force to the resistance, and although the load or resistance may from time to time be greatly varied, the velocity will be constantly the same.

The *Governor* or *Mill-Regulator* produces the effect of equalizing the motion of the machinery by regulating the quantity of water or steam admitted to act upon the water wheel or steam engine. If the quantity of power admitted into action be always proportioned to the quantity of resistance, it is manifest that the resulting motion will always continue uniform. Two rods with heavy balls upon the end of each, resembling pendulums, as A A, are attached to an upright or vertical shaft C C by a joint at E. It is familiarly known that when balls thus suspended are made to turn round rapidly upon an axis CC as in the figure, they will cease to hang drooping by the side of the shaft, but will have a tendency to recede from the effects of their *centrifugal force*, and to become extended nearly horizontally. The weight of the heavy balls will prevent the arms of the levers from rising until they become quite horizontal. When the shaft C C revolves, the balls will continue to fly out, and cause the arms of the levers to be extended horizontally until their own weight counteracts their further rise, at which point they will remain suspended, and will continue to swing round without either rising or sinking, as long as the motion of the shaft C continues unchanged ; but the instant the velocity of the shaft C is altered, the centrifugal force of the balls connected with it, and partaking of its motion, will be sensibly affected. Thus the rising and collapsing of these balls will be a most delicate index of every change of velocity. To apply this principle in practice the shaft C C is kept constantly turning by a wheel connected with the main gearing of the mill by a shaft O. When the velocity of the mill gearing is exactly adjusted, it is so arranged that the balls shall become extended just far enough to lift up the moveable sliding collar H by the braces D D to a certain point on the shaft C C. This sliding collar is connected with machinery to act upon the gate of the water wheel, or a valve or door situated in the pipe which conveys the steam from the boiler to the cylinder of a steam engine.

Whenever the velocity of mill gearing is accelerated beyond the standard point, the sliding collar being drawn up by the braces operate in closing the gate or aperture to moderate the supply of water or steam ; and on the contrary when the velocity of the machinery is diminished below the standard point, as is frequently the case when different parts of the machinery are occasionally put in motion, the balls descend a little and press down the collar H, which operates instantly to open the aperture for the admission of a stronger current of steam or water to overcome the increased resistance. Thus the *mill regulator* seems like an active little sentinel on its post to watch over the movements of the machinery, and to count its revolutions, and whenever it exceeds or falls short by a single revolution in a minute its allotted number, it puts a train of machinery into instant action to correct the irregularity and to restore uniformity.

The sliding collar H is usually made to operate upon a vane or throttle valve to close the passage of the steam in a steam pipe by the immediate action of levers connected at one end with the valve and at the other with the sliding collar. The immediate centrifugal force of the balls would not however, be sufficient to lift the heavy water soaked gate of a water wheel; for which reason a train of wheel work, or an endless screw, as in the figure is employ-



ed, whereby this feeble centrifugal force is rendered adequate to producing the desired effect, by bringing into action the moving force inparted from the shaft O. A sliding collar K is fitted to the shaft C C in such a manner as to be carried around with it, but at the same time to be easily raised or depressed by the crooked rod N I whenever it is operated upon by the sliding collar H. This crooked rod serves merely to connect these two sliding collars, being forked at each extremity to embrace grooves in the collars H and K. In the collar K there are two notches, one fitted to a pin in the wheel above it, and the other to a similar pin in the wheel beneath it. These two wheels have round centres, and the shaft C C being also round allows these wheels to turn freely without partaking of its motion. The collar K, however, being fixed upon the shaft and revolving with it, alternately engages the upper or under wheel, by the notch and pin; whereby the lower wheel L will turn with the shaft C and put in motion the shaft M to close the gate, and when the motion is too much accelerated the reverse will take place, the collar K becoming disengaged from the lower wheel and engaged with the upper one, turning the shaft M in an opposite direction. The shaft M operating by means of a screw, (or by a train of wheel work) may readily be made to open or shut the gate of a large water wheel. When the velocity of the machinery is exactly at the standard point, the sliding collar K continues to turn with the vertical shaft without being lifted by the centrifugal force of the balls to engage the wheel above it, or depressed to engage the wheel below it ; during which time the shaft M and the gate of the water wheel will remain stationary, and all the machinery of the mill will continue to move with unvarying velocity. By means of this admirable contrivance the number of revolutions of the main wheels of a mill have varied so little each minute and hour during the day, that dial plates with minute and hour hands have in some instances been attached to a part of the mill gearing to serve instead of clocks to regulate the hours of labour.

The *Governor* may be applied very advantageously to regulate the velocity of wind mills by increasing the supply of grain to check the motion of the mill stones, or even by acting upon the sails by partially furling them.

It will commonly be found necessary when large powerful water wheels are employed to put in motion a small quantity of machinery, as is the case in new mills where a portion of the machinery only is ready for operation, to resort to some other expedient beside the governor to produce an uniform velocity, as the motion of the wheel is so instantaneously accelerated, when only half loaded, by disengaging a heavy machine, that the most inconvenient irregularity of motion will take place for a few moments until the governor gradually closes the gate. To remedy a difficulty of this sort it is only necessary to place a few planks across the race course below the water wheel to cause the water to flow back upon it two or three feet high. When the wheel is thus clogged, the same result is obtained as if it were loaded ; and the disengaging or re-engaging of a machine will have comparatively but little effect upon the velocity of the wheel.

When a very heavy machine requiring great power to operate it is to be occasionally connected with a water wheel, which is used at the same time to drive other machinery, such as power looms, requiring great regularity of motion, the quantity of water discharged upon the water wheel may at once be regulated by simply placing a moveable piece of plank or joist, with a bolt or pin through one end to serve as a pivot, immediately over the orifice or aperture of the gate. If a cord, attached to it and extended over pullies, be placed conveniently within the reach of the operator of the machine, whenever he is about to disengage or re-engage it with the mill gearing, he may regulate the supply of water. An independent gate or shuttle may thus be readily made at a very trifling expense, to be dropped or raised at pleasure for enlarging or closing the aperture for the discharge of the water precisely to the degree that may be required to operate any particular machine in the mill, while at the same time the general movements of the principal gate or shuttle will be in no respect impeded or altered. By means of this economical contrivance the heaviest pieces of machinery which are always placed near the water wheel, may be disengaged or re-engaged without producing a perceptible alteration in the velocity of the mill gearing.

The Governor is not of much practical use for regulating the desultory movements of a machine operating under an unequal load in different parts of its revolutions, such for example, as take place in the operation of pumping. The governor will exactly adapt the quantity of moving power to the aggregate work to be performed, but it cannot obviate the jolts produced by this want of uniformity in the resistance, the variations being too sudden to be within the control of the governor. For such cases the *balance* or *fly wheel* is employed.

If the number of revolutions of the *Governor*, or *Double Pendulum* as this contrivance is sometimes called, are intended to be the same, whatever may be the length of the arms, the balls will revolve in the same plane, and the distance of that plane from the point of suspension is equal to the length of a pendulum, the number of vibrations of which will be double the revolutions of the balls. For example: suppose the distance between the point of suspension and plane of revolution be 36 inches, the vibrations which a pendulum of 36 inches will make in a minute, (see pendulum, page 13) will be as follows :

The square root of the length of the pendulum, 36 inches, is=6.

$375 \div 6 = 62.5$ vibrations per minute, $\frac{1}{2}$ being taken is $= 31.25$ revolutions per minute should be made by the balls.

The Fly Wheel. The fly is usually constructed of a heavy mass of metal or wood, sometimes in the form of wheels with heavy rims, and sometimes with heavy arms or cross pieces revolving on an axis. The form is immaterial, except for convenience and ensuring strength of construction to withstand the vast centrifugal force, which has a tendency to tear them asunder while revolving with great velocity.

The principle by which the fly operates is merely that of equalizing irregular forces; it does not actually increase or produce power: —on the contrary whenever a fly is used it may be calculated that all the force necessary to turn it round, to overcome the resistance of the air and the friction upon the bearings, is positively lost. All the power applied to give velocity of motion to the fly, except what is consumed by friction and the resistance of the air, is free to act upon any solid body with which it may come in contact. Motion, like matter, when once created, appears incapable of being annihilated, except by being counterbalanced or neutralized by an equal quantity of motion in some other body moving in an opposite direction. Every body impinged upon by another solid body receives from it just as much motion as is lost by the impinging body.

The fly serves merely as a reservoir of motion or moving power, which is husbanded at one moment to be given out at a succeeding moment. This capability of receiving and imparting motion is common to all matter, whether moving forward in straight lines like a cannon ball, or revolving round an axis like the fly wheel, and is the principle upon which this contrivance operates so favourably in equalizing the motion of machines. It may be illustrated by the action of a horse in working a single suction pump. The impelling power in this case may be supposed to be uniformly exerted, but the resistance only takes place at intervals, when the piston is lifted with its load of water; during the return stroke the weight of the piston in descending has a favourable effect in relieving, and even in some cases assisting, the horse. To work this pump the horse must exert his force by jerks, for he will rush forward in his path when assisted by the weight of the descending piston; but will move slowly as he struggles to raise it again with the load of water resting upon it. If a fly be attached to this pump it will be constantly receiving accelerated motion during the descending stroke, which will be imparted again during the ascending stroke, and the weight of the column of water will be lifted not only by the energy of the prime mover, but by the moving force which has been accumulated in the fly wheel. In such cases the fly may actually enable the horse to perform nearly double the labour; as it in the first place relieves his breast of the irregular jolts proceeding from the unequal resistance, while it lends its assistance at the critical instant when the stress is greatest, bringing into instant action the force leisurely accumulated when the stress was least. Precisely the same effect results from the application of the fly to the steam engine, and to all other machines, whether the irregularities of their motion be owing to a varying resistance, or to an intermitting desultory first mover. During each intermission of the application of the impulse to the steam piston, making an interval of one or two seconds each stroke, during which the piston has no effect in turning the crank, the teeth of the wheels connected with the fly may be heard to catch in opposite directions, alternately, as the fly receives a fresh impulse or parts with it again to urge on all the machinery with nearly unabated speed. In steam boats the heavy paddle wheels operate like fly wheels, and are often relied upon as a substitute for them.

In the familiar operation of turning a winch for a grinding mill, and in turning a crank by his foot, a man can exert three or four times the power in many positions which he can in others, and by thus compounding the favourable with the unfavourable points for exertion, the aggregate power may be considerably increased. It is stated that "by this application of a fly to a winch a man may work all day in drawing up a weight of 40 lbs. whereas 30 lbs. would occasion to him greater labour in a day without the fly."

In the process of rolling iron, the Fly is used with remarkable advantage. Several seconds elapse, while the workmen are conveying the red hot bars of iron to the rollers, and are preparing to enter them. During all this interval the water wheel or steam engine has no work to perform, and is exerting its full force in increasing the velocity of the fly; and when the end of the bar is engaged, the operation is encountered with such an accumulation of force that the massy fly might in some cases possess sufficient momentum to perfect the process, and turn out the flattened bars, even if the power of the first mover were absolutely intermitted or cut off.

At the iron works on the Boston and Roxbury Mill dam, a fly about 12 feet diameter and weighing 15 tons is employed, situated upon the top of an upright shaft.* The rim of the fly is composed of a great number of bars of old sable iron welded to form distinct circles or hoops and afterwards firmly bolted together. By this mode of construction the rim is rendered exceedingly strong to withstand the centrifugal force, which produces a much greater stress than is commonly supposed by those who have never entered into calculations respecting it. A common stone for grinding table knives, only 44 inches in diameter, and making about 300 revolutions per minute exerts a centrifugal force equal to 23½ tons. (see page 162.) If the rim of a cast iron fly wheel be not cast in one entire piece, the segments should be most firmly united by bolts, and the ends still further connected by being dove-tailed.

Although the advantages resulting from the use of the fly arc so evident in many cases, the mechanic should not decide to use one without previously examining all practicable expedients to obtain the same advantages in other ways; as he must be aware that by employing a fly he will always have friction and the resistance of the air to contend against. In the instance of the single suction pump, the irregular resistance may be nearly equalised by giving the crank such a form that the piston of one pump may be always rising with its load of water; by which means a very material saving of power is produced, as also by giving to the current itself an uniform motion up-

*It may be observed that soap stone pulverized and mixed with oil or tallow forms the best anti-attrition compound to prevent the pivot of one of these massy fly wheels from destroying or cutting down the step which sustains it.

wards through the main pipe leading from the pit or well. By the single pump, the column of water drops back upon the valve at every return stroke, and must again be put in motion, by which operation a very considerable proportion of the power becomes uselessly wasted. The rotatory pump, when properly constructed, acts upon a principle which at once supersedes all these contrivances, as it both produces an uniform current, and renders all reciprocating motions unnecessary. Instead of using one heavy stamper or pounder, three or four may be used, raised successively with a uniform expenditure of force. A saw mill operates with great irregularity without a fly wheel, but the very cause itself of the irregularity, for many purposes has been obviated, by substituting *circular saws*, which revolve with a perfectly regular motion.

When a Fly is intended either to regulate the motion or to increase the effect of a machine, it should be placed as near as possible to the working point where the stress takes place. Machines which are to be frequently stopped and put in motion, if connected with fly wheels, sustain constant shocks which are often destructive to the machines, the operation of which they are intended to assist. The movements of the power loom, for example, are peculiarly irregular; but the machine is so frequently stopped to mend the broken threads in the process of weaving, that it will bear only a very light fly, which is attached in the English power looms to the fast pulley, being cast in one piece upon the arms of it. When steam engines are stopped instantaneously the moving force of the fly is also checked as suddenly, and excessive stress is produced upon the machinery; but the elasticity of the uncondensed steam reacting upon one side of the piston, and the vacuum upon the other, gradually brings the fly to a state of rest by yielding at first gently to it.

In the process of coining, a fly is attached to the top of a screw, having the die fixed upon the lower end of it. The power thus collected in the fly by causing it to revolve is stated to be equal to a weight of 240,000 lbs. which is brought to exert this pressure with the mechanical advantage of the screw, whereby the die is made to descend upon one end of the screw with a slowly moving, but vast force, causing refractory metals to take impressions from the die like soft wax from a seal. So great becomes the accumulation of power that a force equal to 20 lbs. hung upon the circumference of a fly wheel 20 feet diameter and weighing only 4700 lbs. will accumulate a momentum in 37 seconds equal to that which a musket ball receives from a full charge of powder.

It was found difficult to employ horses for operating engines for driving piles until the fly was added to it, as the horses fell down at the instant that the weight was suddenly detached to descend upon the pile. Their force may be exerted in accelerating the motion of the fly, until directed again to act upon the weight.

The accumulation of power by the fly has been exemplified in the effects produced by the *sling*. When the thong which contains the stone is swung around the head of the slinger, the force of the hand is continually increasing its impulse, by causing it to describe a larger circle in an equal time than can be accomplished by the hand alone. If a leaden bullet be attached to the end of a piece of whalebone or rod, by taking the other end of the rod in the hand, sufficient velocity may easily be given to the ball to drive it through a board.

Fly wheels should be made of as large diameters as can be conveniently used, with as much of the weight in the rim and as little in the arms as is consistent with strength, while at the same time their motion should be rapid. By attention to these points less weight of metal will be required to produce equal results, and at the same time the friction upon the arbors will also be diminished.

A small fly with light thin vanes to act upon the air is sometimes used for regulating the striking of clocks, musical boxes, &c. The resistance of the air prevents a very rapid revolution of the vanes, and an uniformity of motion is soon attained. This contrivance, however, is attended with great loss of power, and is rarely used for heavy machinery.

Effective Powers of the Fly Wheel.

For all calculations relating to the force of a revolving Fly, its actual diameter is not taken, but the circle in which all its moving force is collected, called the *circle of Gyration*, the rule for calculating which are given at page 159 and 160. The weight of the arms and axis forming a part of the wheel brings this circle near to the centre and within the heavy rim of the wheel : but for most cases it will be sufficiently accurate to assume for the circle of gyration, or for the acting diameter of a fly of the usual proportion, the interiour of the rim where it is united with the arms. Supposing the fly to be 13 feet diameter, and the rim 6 inches deep, the operating diameter of this fly might be supposed to be 12 feet. If the fly be intended merely to receive and communicate motion, as employed for the purposes of equalising the velocity of machinery, its power may be estimated by its mass simply multiplied into its velocity ; for although a power exerted through a quadruple space is required to produce double the velocity, and this double velocity when once acquired is capable of imparting the same power undiminished except by friction and resistance of the air, yet an unelastic mass moving with a certain velocity will only reproduce the same velocity in the body upon which it acts. The force or momentum of a fly to produce action or mechanical effects is, however, a subject of much greater practical importance, than its power of reproducing a certain independent velocity of machinery. In all such cases the effective momentum is increased in the ratio of the *squares of the velocities*. The momentum accumulated in a fly seems to be capable of being the most intelligibly explained by comparing its force with that of an equal mass falling with the same velocity. Thus a fly wheel of 12 feet diameter, weighing 15 tons, and making 52 revolutions per minute, has its circumference moving with a velocity of 32 feet per second. 7 : 22 : : 12 : 37 feet circumference × 52 ÷ 60 = 32 feet velocity per second. This velocity would be acquired by a body falling in a vacuum 16 feet, as will appear by the Table page 12. If any solid body were interposed to receive the full impetus of this great momentum, the effects would be the same as those produced by a mass of 15 tons raised to a height of 16 feet and left to fall upon the body subjected to its action.

What momentum would be communicated to a Fly by a weight of 200 lbs. hung upon the circumference of the Fly, and allowed to descend freely by its gravity for 30 seconds, provided no force were lost by friction and resistance of the air?

The whole force of a weight of 200 lbs. falling freely during 30 seconds may in this case be supposed to be accumulated in the fly. The velocity acquired at the end of 30 seconds, would be at the rate of 966 feet per second. For further observations on this subject see *mechanical action and reaction* in pages 286 and 287.

UPON THE MECHANICAL ACTION OF MOVING BODIES, AND MECHANICAL RESISTANCE OR REACTION.

The effects produced by the action of mechanical force are found to differ more or less from those which are calculated upon in theory. When mechanical effects are theoretically estimated, the force is supposed to be transmitted by means of the machine to act regularly in mathematical points of time, whereas there are few cases in which the mechanical effect is not caused to vary greatly by the yielding of the machine or of the materials forming the subject of their action; and as the time of the immediate action is prolonged, the force for accomplishing many operations becomes diminished in intensity. This subject well merits the careful attention of those whose business it is to employ machinery calculated to overcome the resistance of refractory metals, and of other substances, by the accumulated momentum or force applied by sudden blows. It is only by considering the nature of the resistance to be overcome, that the mechanic can expect to know how to employ to the best advantage the power and machinery placed within his control. Sir Isaac Newton has taken no notice of these mechanical effects; but has confined himself rather to the subject of the motion of bodies, as ranging through boundless space, than to their mechanical action and reaction. He estimated the measure of the force of a body in motion by the standard of its power of communicating motion, considering the number of its particles, or its *mass*, when combined with, or multiplied by, its velocity, to represent the whole moving force of such body, as understood by the term momentum. It was, however, found that this mode of calculation, although it would apply to the measuring the velocity or motion reproduced, would not apply to measuring the mechanical effects produced, as for example, in driving piles and other similar operations; because by doubling the velocity the effects appeared always to be increased fourfold, or in the ratio of the *squares of the velocities*. This is evident when it is known that a body must fall four times the distance under the uniformly acting force of gravitation to produce double the velocity ; (see Table of Falling Bodies, page 12 ;) while the velocity of a body at the termination of a fall of 64 feet is at the rate of only double the velocity which it possesses at the termination of a fall of 16 feet, its mechanical effect is as the squares of the velocities. $32 \times 32 = 1024$; $64 \times 64 = 4096$; or as 4 to 1, as is proved readily by experiments. Hence has arisen a difference of opinion among philosophers in regard to calculating the forces of moving bodies, some of them agreeing with Sir Isaac Newton, and others adopting as a standard of calculation the *mechanical effects* produced by the impetus. "Early in the last century," it is stated, "philosophers carried on a controversy in relation to this subject, with a keenness which was not perfectly consistent with the dignity of true philosophy." Although this is in reality little more than a question about terms, yet in a short sketch of it the whole theory of the forces of moving bodies are explained in a manner which cannot but excite the interest of every intelligent mechanician, who feels a curiosity in investigating the very fundamental doctrines of the science which he professes. The whole argument appears to have been ingeniously illustrated by the following experiment stated in the words of Mr. Wollaston.

"Let a ball of clay, or any other soft and wholly unelastic substance, be suspended at rest, but free to move in any direction with the slightest impulse ; and let there be two pegs, similar and equal in every respect, inserted into its two opposite sides ; and let there be also two other bodies, A and B, of any magnitude, which are to each other in the proportion of two to one, suspended in such a position that when perfectly at rest, they shall be in contact with the extremities of the opposite pegs, without pressing on them. Now if these bodies were made to swing, with motions so adapted, that in falling from heights in the proportion of one to four, they might strike at the same instant against the pegs opposite to them, the ball of clay would not be moved from its place to either side ; nevertheless the peg impelled by the small body B, which has double the velocity, will be found to have penetrated twice as far as the peg impelled by A "

"One side, observing that the ball of clay remains unmoved, considers the proof undisputable, that the action of the body A, is equal to that of B, and that their forces are properly measured by their times of falling, or velocities multiplied into the masses. Their opponents think it equally proved, by the unequal depths to which the pegs have penetrated, that the causes of these effects are unequal," which they estimate by the "mass of the body in motion, and the square of its velocity jointly." The velocity of the large body being called 1, and that of the small body, double of this, or 2, then they estimate the measure of force to be as the square of these relative velocities, or as 1 × 1 = 1; and 2 × 2 = 4; or as 1 to 4. The body B being only of ½ the magnitude of the body A, and producing two-fold of the effect in driving in the pin, therefore its force, estimating by equal weights, is four fold of B.

The momentum of the two bodies A B, may be shown to be equal by referring to the table of Falling Bodies, page 12, and by supposing the larger body A to have fallen 16.1 feet and the smaller body B, four times this distance, or 64.4 feet. By the last column in the same Table it appears that although the relative spaces fallen through by two bodies be as 4 to 1, yet the actual velocity with which they will be moving respectively at the termination of their descents will only be at the rate of 64.4 feet and 32.2 feet per second, or as 2 to 1. The relative momentum of each is found by multiplying the masses into their respective velocities The mass A, being called 100 pounds moving at the rate of 32.2 feet per second, and the mass, B, 50 pounds moving at the rate of 64.4 feet per second, then

100×32=3200

50×64=3200. The momentum of each of these two falling bodies, although of different magnitudes, and descending through different spaces in different times, are thus shown to be exactly equal to each other, as proved by the experiment, the ball of clay remaining unmoved when receiving their simultaneous impulse.

Here then is a measure of equal forces, taking the quantity of motion destroyed in each of the balls as the standard, and yet the effects produced by these forces upon the pegs are apparently unequal. It is deemed of importance in this branch of science to examine this subject more particularly, and to trace these different effects to their true causes. The laws of nature will be found uniform in this case, as in all others, and will not admit of two rules for estimating the same force; for wherever, as has been observed, the demonstrations of science show a result different from that produced by nature, the error must be in the demonstration. Many errors frequently have been made in calculating the mechanical effects of moving forces from using two different rules for estimating them, viz: by considering the forces of bodies in motion to be in some cases simply as their velocities, and again in others under the same circumstances, as the squares of their velocities; or that a body moving with double the velocity of another has fourfold the force, and a body moving with three times the velocity of another will have nine times the force, and so on. In pursuing this investigation the mechanic will find the principles of motion and force, and of resistances with which he has daily to contend, brought fully under his consideration. The following explanations of the extremely different mechanical effects which are produced by bodies moving with different velocities, as in the experiment with the clay ball, are offered rather as suggestions than established opinions upon this subject.

Gravitation, Cohesion, and all other natural causes, which tend to obstruct the motion of bodies on the surface of the earth, by operating upon their component particles with *equal forces* in *equal times*, appear to be the principal sources of mechanical resistance. Gravitation, when operating as a mechanical resistance, will deprive a body projected upwards of equal portions of its velocity in equal times; or will destroy a certain velocity in an ascending body equal to that which it would produce in a falling body in the same time. In a body falling freely in a vacuum, for example, it will produce a certain additional acceleration of velocity of about 32 feet, uniformly, during each succeeding second of its descent Cohesion which draws together and unites the particles of matter in masses, forming one of the natural resistances which is the most frequently of all others to be overcome in practical mechanics, also exerts equal resistance in equal times against any force tending to separate the particles united by its agency. Whenever a moving body acts against any of these natural forces, re-acting in the nature of mechanical resistances, it must encounter from them *equal resistances in equal times*. The resistance of the cohesion of the particles of the ball of clay in the experiment being equal in equal times, the equal forces A B, will cause the respective pegs to continue penetrating during the same period of time without regard to their relative velocities during such time. If one of the pegs were caused to penetrate with a velocity 10 fold of that of the other, it would enter 10 times as far before having its motion exhausted by the attraction of cohesion of the particles of the clay.*

If by means of any contrivance, such as the springs of a travelling carriage for example, the time of the action of a moving force is prolonged, the cohesion of the particles of steel, forming the mechanical resistance, will counterbalance or sustain a proportionately greater force without being broken. A momentum equal to that of 1000 pounds may have its action so prolonged by means of springs, that instead of exhausting all its action in one moment of time, it might be diffused to ten moments, during each of which the stress would be only $\frac{1}{10}$ of 1000 pounds, and an elastic bar of steel possessing only $\frac{1}{10}$ of the absolute strength of an unelastic bar of the same material would in this case be found equally strong to resist or sustain the shock.†

* It should be observed here that there is always a twofold, or compound resistance, attending mechanical action as applied to overcoming the *Cohesion* of the particles of matter; for after the cohesive resistance is partially overcome, the force, as it continues to move forward, must necessarily in practice displace the dissevered particles in order to act upon succeeding ones. In this case a very considerable portion of its energy is spent merely in moving aside the particles. It is for this reason that the resistance to the motion of bodies in fluids, the cohesion of the particles of which offers the least possible resistance, is found to be very greatly increased with the increase of velocity; because the more swiftly a body moves in a fluid, the greater will be the number of particles to be displaced to make way for it; while at the same time the displaced particles will absorb additional power in proportion as they are struck with greater violence, and their motion is thereby rendered more rapid. In the science of Gunnery the resistance to motion is rendered still greater by the vacuum which is actually formed behind the ball, the air not being capable of closing around it, and rushing into its wake with the same rapidity with which it is displaced. The momentum of a ball measuring less than 1½ inch diameter is retarded or impeded from this cause alone with a constant force equal to 15 lbs. pressure against it.

† Springs produce therefore not only the effect of rendering travelling more agreeable but also of rendering the parts of a carriage supported by them less subject to stress from sudden jolts, and consequently more durable.

If on the contrary, the same mechanical force having its time of action uniformly prolonged by this spring to 10 moments of time, be made to act in one moment, by depriving the steel of its elasticity, the result would be the same as if the velocity of the force were increased 10 fold, by which the immediate action is made to take place in $\frac{1}{10}$ of the time. Thus one of the principal mechanical advantages resulting from increasing the velocity of a moving body appears to consist in condensing or abridging the time of its action.

In the experiment made with the Whirling Table (see Dr. Brewster's excellent edition of Ferguson's Mechanics, page 23,) if two balls of equal size, attached to strings of equal length, be made to revolve around an axis, having a pulley fixed in it for the string to pass over to operate upon weights, hung upon the other end of it for the purpose of demonstrating the centrifugal force possessed by each of the balls, and if the velocity of one of the balls be *double* that of the other, it will raise *four times the weight* hung upon the end of the cord. Here, again, a double centrifugal force is made to overcome a four fold power of gravity.

In this experiment by doubling the velocity of the revolving ball, its absolute centrifugal force is doubled, whereby it will be rendered capable of overcoming double the mechanical resistance of every kind in a given time; and by doubling the velocity with which the body moves and acts, it is caused to produce two equal impulses of the force, thus augmented or doubled, in the same time in which it exerted only one before. Two distinct mechanical effects appear to be produced by increasing the velocity of every moving body, viz: the momentum, or the *absolute* mechanical force with which the body moves, is increased in the same ratio with its velocity, whilst its *relative* force is increased and rendered more effective in overcoming all mechanical resistances, which oppose to it equal forces in equal times, in proportion as it is made to exert its action in a shorter time, or to repeat more impulses in the same time.

An illustration of both these results is presented in the familiar instance of a revolving shaft. If you double the cohesive force of the component particles of a revolving shaft, you at once double its absolute strength, as you doubled the absolute centrifugal force of the revolving ball in the first instance; and if at the same time you double the velocity of the revolving shaft, its *relative* strength will be again doubled thereby,—a fact well known in practice. The same shaft having its velocity doubled is thereby rendered capable of overcoming a two fold resistance in any given time. Thus by doubiing the absolute strength or cohesive force and velocity of a revolving shaft, it will be enabled to overcome a four fold resistance in a given time, as in the experiment made with revolving balls.

A similar result also takes place in spouting fluids. If one stream be made to issue from an orifice with double the velocity of another, it will ascend four times as high as the other; but no actual gain of power is available from this fact, which apparently indicates a four fold increase of resistance overcome, because if the same particles of fluid were allowed to descend again, they would each acquire the same velocity at the termination of their descent, as that with which they commenced their respective ascents. The mechanical resistance of gravitation to the ascent of bodies projected upwards produces only an equal degree of retardation of velocity in equal times. In the instance of spouting fluids, the flowing particles are put in motion by the gravitation of the mass of particles resting or pressing upon them, which have the same effect in throwing the particles upwards as if they rested upon one end of a lever, and an equal weight were to fall upon the opposite end of it from a height level with that of the surface of the water in the reservoir. By this rule, on referring to the table of Falling Bodies, it will appear that water will issue from an orifice under the pressure of a column of water 16 feet high, with a velocity of 32 feet per second, and under a head of 64 feet the velocity will only be doubled. A Jet of water issuing from an orifice at the rate of 64 feet per second will continue ascending with a motion regularly retarded by gravitation in a ratio equal to 32 feet during each second, and will therefore continue ascending during 2 seconds, at the expiration of which all its motion will be exhausted. During the first second of the ascent the average velocity, or space passed through, will be the mean between 64 and 32=48 feet per second; and during the last second, the velocity may be considered as commencing at the rate of 32 feet and terminating at 0, the mean velocity being only 16 feet. 48+16=64 feet will be the height to which the stream will ascend, while another similar stream projected with half of the velocity, will only ascend 16 feet high. All the gain of space passed through takes place the first second, during which the space traversed is thrice greater than that traversed by a body moving with half the velocity, the excess being two fold; which ratio of gain in overcoming the uniform resistance of gravitation is expressed by the figures 1, 3, 5, 7, &c. in the second column of the Table at page 12, showing that the spaces fallen through are increased progressively in a two fold ratio in every second, or twice 16 feet=32 feet. Although the spaces fallen through during each successive second appear to increase in so rapid a ratio, yet the average increase each second is actually but 32 feet. It appears, then, that the true measure of the power of gravitation is not the spaces passed through, but the specific velocity of 32 feet per second, created or destroyed in any moving body.

The resistance of gravitation to the ascent of bodies projected upwards being a uniformly retarding power, continually the same during one second, or any other given time, it follows that the greater the velocity of an ascending body, the less ratio will this uniformly retarding power bear to it during a given time. If the force of any moving body can be brought to act in half of a given time, by any contrivance, such for example as doubling the velocity with which it moves and acts, there will be but half the mechanical resistance or retarding power of gravitation opposed to it in half of such given time, Gravitation seems to produce its mechanical effects, in causing bodies to descend toward the centre of the earth, by operating upon them with continually repeated impulses, each of which is just equal to the weight of the mass, or rather constitutes the weight itself of the mass. The time in which each impulse is repeated must be in theory inconceivably short; but in practice a very perceptible time elapses before a body left to fall freely through the air will produce double the effects in overcoming the cohesion or strength of various materials, that it will produce merely by its pressure when resting as a dead weight. Forming an estimate from a number of experiments made upon the effects of gravitation in increasing the action of falling bodies in fracturing bars of various kinds of woods, and of iron and cast steel, the attraction of cohesion of the particles of which was assumed as a standard for comparing the forces, I found that when the materials subjected to the experiments would just sustain a certain weight carefully laid upon them, similar bars placed precisely in the same situations were pretty uniformly broken when one half of the same weight was dropped upon them from a height of $\frac{1}{5}$ to $\frac{1}{8}$ of an inch, according to the elasticity of the materials employed. Taking a small bar of cast steel, rendered as unelastic as possible, and supporting each end of it, and increasing carefully the weight suspended from the middle of it until the bar was broken, it appeared that when it would just support about 58 pounds, the instant before breaking, that 29 pounds lifted a little over one eighth of an inch, would break other bars made as nearly similar as possible in all respects, and placed in the same situation. When the weight fell from a less height than one eighth of an inch, the unavoidable elasticity of the materials employed rendered the effects of the moving force more nearly equivalent to the uniform pressure of a dead weight, by yielding and prolonging the time of action. Similar results attended the fracture of iron wire when broken longitudinally by suspending the weight at one end. The elasticity of the materials appeared to have a less comparative effect in diminishing the action of the falling weights in proportion as the weights were less, and were lifted higher to produce an equal momentum.

Supposing the force imparted by gravitation to falling bodies to be double that of their regular pressure as dead weights for every $\frac{1}{5}$ of an inch of space through which they fall, an estimate might be formed of the relative mechanical effects produced by the impetus or blow from any such body, compared with its uniform pressure as a dead weight; thus the hammer of a pile engine, weighing 500 lbs. and falling 10 feet, would produce mechanical effects equal to 600 fold the pressure of its own weight, or equal to the pressure of a dead weight of 300,000 lbs. $10 \times 12 \times 5 = 600$ fold $\times 500$ lbs. $= 300,000$ lbs. Where the action of the falling body is prolonged by the yielding elasticity of the materials subjected to the shock, the mechanical force will be less intense, and the mechanical effects will be diminished, as before observed, in a corresponding ratio. The action of the weight falling upon the head of the pile is only at its maximum when the pile actually ceases to penetrate further under its impulse, and when the yielding of the splintered top of the pile is the only cause of prolonging the time in which all the motion of the falling hammer is exhausted.

The calculations of the forces of moving bodies, by multiplying the weight by the velocity in feet or other lineal measures, serves only to show the comparative forces of such bodies, and not their actual moving force, as has been calculated by some writers.

A skilful engineer finds that it is not only necessary to attend to the calculation of a force or momentum sufficient to overcome a given resistance, but also to form an estimate of the *time of its immediate action* against the resistance to be overcome by it; otherwise he might have at his control a vast moving force, and yet the effects produced by it might be rendered very inconsiderable from a want of knowledge in applying it. A momentum equal to that of the globe itself might be retarded, and finally arrested, by a force no greater than that of an infant, if the time of action were to be sufficiently prolonged. The amount of the force itself is scarcely of more importance, in regard to mechanical effects produced, than the time and mode in which its action is applied. If the nature of the materials employed be such as to yield or give way at the instant of action, the time in which the force is imparted is thereby prolonged, and the intensity of its action is diminished in a corresponding ratio.

The impossibility of obtaining perfectly solid and unelastic materials, to operate with in practice, prevents the whole momentum accumulated in any moving body from being transmitted instantaneously, strictly speaking; and consequently mechanical action can never be produced so intense as calculated upon in theory. Hence arises the great difference so frequently observable in the mechanical effects produced by bodies moving with equal forces.

If two hammers, one formed of lead and the other of steel, having the same weight and velocity, descend upon a bar of iron, the former will produce but little impression compared with the latter, because, from the nature of the materials employed, the action of the one is gradually expended by means of its ductility, while that of the other is more instantaneous. Cast steel is one of the strongest of metals, a bar of which an inch square, capable according to Mr. Rennie, of suspending a weight of 134256 lbs. is easily broken by a blow of a small hammer. The particles of this metal are unyielding, and the mechanical action of the blow is exceedingly intense. If a bar of yielding lead of equal dimensions be substituted, it would sustain a much heavier blow without being severed, although it possesses only about $\frac{1}{73}$ part of the cohesive strength of cast steel; because the action is diffused or prolonged, and is rendered proportionately less intense.

In the process of coining the time of action is prolonged by the ductility of the metals, which, whilst receiving the pressure, enters and fills up the outlines of the superscription and figures formed in the cavity of the die, whereby the instantaneous pressure is not so great as is frequently calculated upon in this case.

If by means of any elasticity of the metal of shafts, or yielding in the couplings which unite them, and which intervene between a fly wheel and the point of its action, the momentum is not exerted instantaneously, the diminution of its mechanical effects will also be in the ratio of the prolongation of the time of action.

These facts are, indeed, familiarly known to the school boy, who in his sport throws himself from some bluff upon a bank of yielding sand. The diver who leaped from the precipice of 90 feet, at the falls of the Passaic, was a little longer than two seconds in descending through the air; but the force acquired by his descent was gradually imparted to the yielding fluid into which he plunged, which by prolonging the time of action gently arrested a momentum that would otherwise have proved instantaneously destructive. This principle is also familiarly known in practice to sailors, who use a bag filled with oakum, or other materials possessing a trifling degree of elasticity, which they interpose between the vessels' side and the pier head to prolong the time in which the moving force of a floating mass weighing several hundred tons is expended at the moment of contact. The least perceptible prolongation of the time, produced by the yielding of the materials substituted to transmit the shock, causes a remarkable diminution of the destructive effects resulting from the violence of the encounter.

The mechanical resistance, opposed by a body at rest to a body moving against it, before it receives motion from it, or the *inertia* of a mass of matter, as it is termed, appears to partake rather of a passive than of an active nature, being merely the state of contact necessary for the transmission of motion from one portion of matter to another. The force required to impart a certain motion to a body, being always a stated quantity, the time, in which one body receives motion from another, must depend entirely upon the intensity of the action, which takes place between them. The inertia of a body at rest does not therefore oppose a mechanical reaction or resistance, equal in equal times, like that of Gravitation and Cohesion, because it continues no longer than whilst the body at rest is imbibing the action of the force applied against it.

When the engineer finds it necessary to counteract or overcome the momentum of a moving body, he has to consider the most convenient methods by which he can prolong the time of its action, or of exhausting its motion against the body struck by it. Thus in some cases, where a force acts by sudden impulses or jerks, he will find that an elastic material, like a rope or cable, will sustain the stress, when an unelastic one, like an iron chain, possessing actually greater cohesive strength, might fail. On the other hand, when he desires to produce considerable mechanical effects by means of a small force, he has to consider the most favourable plan by which he can in a convenient time cause the action of the force to be exerted whilst moving through the greatest possible space. He may accomplish this by accumulating the force in a fly wheel, to operate at once with the sum of its moving force against the resistance to be overcome; or he may devise some plan by which the moving force at his command may be brought to bear against any portion of the resistance which it may be sufficient to overcome in *detail*. A small force continually applied to a fly wheel would soon accumulate sufficient momentum to break a cable in an instant; or the same force, if sufficient to break one strand of the cable, will accomplish the same result by breaking them all in succession, by prolonging the time of its action. By the former plan the engineer will have to procure the strongest machinery, capable of sustaining the shock of transmitting the accumulated action; while by the latter he may in many cases attain the same results by surprisingly light machinery. This last mode of overcoming great resistances, in the detail, is one of the most favourite expedients in mechanics, and should be adopted in all practicable cases, both for its simplicity and economy. The cohesive strength of the strongest beams of oak, and of bars of iron, is thus readily overcome in detail by the apparently trifling immediate action of a common saw, or file. This principle is also admirably illustrated in the operation of the cylindrical printing press. By causing a cylinder to roll over the types, and to press upon them successively, a slight pressure, prolonged in the time of its action for a few moments, will readily accomplish, *in detail*, by the aid of comparatively light machinery, the same work that requires a press constructed of massy materials, and with the most powerful mechanical combination of levers and screws, to accomplish at once by an instantaneous impression in the usual way.

MECHANISM FOR PRODUCING CHANGES OF MOTION.

In the construction of machinery the mechanic has commonly at his control a certain motion, such for instance as that of a revolving shaft or wheel, which he finds it necessary to convert into some other motion, for the purpose of accomplishing all the countless processes of the useful arts. There are few operations in practical mechanics of more frequent occurrence than the change of one of these motions into another, to produce the different *movements* observable in almost every machine. In the power loom, for example, in order to imitate the movements, that appear so simple when produced by the hands and feet of the weaver, which are all busily employed in the process of weaving, it is necessary to convert the continued circular motion, derived from the mill wheels, into the following varied motions, which must all take place in harmonious order during each stroke of the machine.

Rectilinear Motion, to carry the yarn forward to be woven.

Intermitted Rectilinear Motion, to throw the shuttle back and forth.

Alternate Parallel Rectilinear Motion, to raise or depress the heddles, to separate the yarn for the shuttle to pass through.

Intermitted Circular Motion, to unwind the yarn from the beam, and to wind up the cloth as fast as it is woven.

Reciprocating Circular Motion, to cause the lathe containing the reed or slaie and shuttle to swing back and forth.

All these apparently complicated movements are produced with wonderful regularity from a continued circular motion, by means of elementary machines of the most simple forms.

Although there are so many kinds or varieties of motion produced by a combination of mechanism, yet nearly all of them may be resolved into two simple motions, viz. *Rectilinear* and *Circular*. In the one case the motion of the body takes place in a *straight line*; and in the other it moves in *circles*, or parts of circles, around a common centre or axis. Water wheels and wind mills present familiar instances of first movers acting with a *circular* motion; while the piston of a steam engine, moving two and fro in the cylinder, presents an instance of *rectilinear* motion. Now as these machines are the great first movers commonly resorted to for operating machinery, it is manifest that there must be a variety of mechanical contrivances for modifying these motions in order to obtain at pleasure any desired movement from a rectilinear or circular one.

Rectilinear and *Circular* motion have been each divided into *continued* and *reciprocating*, as follows:

1. CONTINUED RECTILINEAR MOTION.
2. RECIPROCATING RECTILINEAR MOTION.
3. CONTINUED CIRCULAR MOTION.
4. RECIPROCATING CIRCULAR MOTION.

We shall take each of the above simple motions in succession, and show the most common modes by which other more complicated movements are produced from them, that the machinest having at command in constructing a machine a force acting with any one of these simple motions, may readily change them into such other motions as he may require for accomplishing the desired operations.

Of the *continued Rectilinear Motion*, strictly speaking, there are few or no examples; as it cannot take place unless in finite periods, or in infinite space. Even in the immeasurable fields of air, the heavenly bodies do not move in straight lines, but in circular orbits. The term *continued* rectilinear motion means, as here used, a rectilinear motion always in the same direction.

The *Reciprocating Rectilinear Motion* is observable in the movements of the piston of a steam engine in a straight line, in a range of limited extent.

The *Continued Circular Motion* is the most common and convenient of all motions employed in the useful arts, and is obtainable by wheel work of every kind.

A *Reciprocating Circular Motion* is exhibited in the instance of a pendulum, or of the end of a common pump handle, which are caused to vibrate in circular arcs.

CONTRIVANCES FOR CONVERTING A CONTINUED RECTILINEAR MOTION INTO VARIOUS OTHER KINDS OF MOTION.

When the first Mover has a Continued Rectilinear Motion, the following contrivances are employed to produce from it various other kinds of motion.

1. *To produce a continued rectilinear motion in a different direction.* For this purpose belts, ropes and chains are most commonly used, passing around fixed pulleys, or wheels. As the rope or chain is drawn over the wheel, it bends around its circumference to any degree required, and will communicate motion to any body connected with it. *See Fig.* 1.

A wedge entering between two solid bodies, one of them being fixed stationary, and the other moveable in slides or grooves, will produce this result, causing the moveable body to take the direction given to it by the guide or grooved slide. *Fig.* 2.

By adopting these slides or grooves, to serve as guides for directing the movement of a body, almost any oblique application of a moving force will produce a *continued rectilinear motion in a different direction*, provided the friction attending this contrivance be not objectionable. The principle itself is familiarly observable in the operation of a common door latch, or in the oblique action of the wind upon the sails of a ship; the water, being a yielding medium, serves as the slide or groove, through which the vessel glides with a continued rectilinear motion in a different direction.

2. *From a continued rectilinear motion to produce a reciprocating rectilinear motion.*

Wipers, or protuberances like the teeth of a saw, or of any other form best adapted to producing the desired motion, may be used. These wipers may be attached to an endless belt or chain, passing around two pullies, as in the figure; and as they pass beneath the body to be put in motion they operate like a succession of wedges, to force it up gradually, when the body may be suffered to fall by its own weight, or by the application of a spring, into the space between these moving wedges. *Fig.* 3.

An oval cog wheel with an axle fitted to rise and fall in a groove will produce a similar motion, if a moveable rack be made to pass under it. A friction wheel should be employed to support the belt or chain immediately beneath the point where the wipers act. *Fig.* 4.

3. *From a continued Rectilinear motion, to produce a continued circular motion.*

This may be readily accomplished by a rope or chain passing around a pulley, as when a bucket descends with a rectilinear motion into a well, a continued circular motion is given to the axle or barrel by the unwinding of the rope. *Fig.* 5.

The best and most commonly used contrivance for this purpose is the moveable rack, and the pinion revolving on its fixed axis. See page 267.

The chain interlocking with the points or indentations of the rag wheel will transmit this motion without slipping, where considerable stress takes place. When the resistance to be overcome is inconsiderable, a common leather belt may answer if pressed against the wheel or pulley, to be turned by it, by means of friction rollers. *Fig.* 7.

If a nut of a screw be made to advance along a screw having a coarse abrupt thread, it will cause the screw to turn with a continued and rapid circular motion, attended, however, with much friction. *Fig.* 8.

4. *A continued Rectilinear motion may be converted into a Reciprocating circular motion* by means of a chain, belt, or other contrivance, having pins or wipers so arranged as to catch upon one end of the arm of a lever, causing the opposite end of it to rise and fall, like a tilt hammer, in circular arcs. *Fig.* 9.

This result is also produced by a double Rack acting upon a double wheel as in figure 10. The intervals in the double rack, stripped of teeth, are opposite to the positions filled with teeth. As the double rack rises or falls, it will first engage the teeth upon one side of the wheel, and turn it partly round, when the blank on that side will instantly leave the teeth disengaged, and the teeth upon the opposite side of the rack will become engaged, and will turn the wheel back to its former place. This is repeated as long as the rack continues to rise or fall. It may be observed, however, that these contrivances operate with considerable stress if the teeth are allowed to become engaged and disengaged suddenly, and, if the action be violent, the teeth or mechanism will commonly in a short time begin to fail.

One of the most beautiful contrivances for converting a continued rectilinear motion into a reciprocating circular motion is that of the common clock weight and pendulum. The rectilinear descent of the weight operates upon the double lever connected with the pendulum rod, and without abruptly checking the vibrations produces an easy reciprocating circular motion of the pendulum, attended with but little friction.

TO PRODUCE VARIOUS MOVEMENTS FROM A FIRST MOVER HAVING A RECIPROCATING RECTILINEAR MOTION, OR MOVING BACK AND FORTH IN A STRAIGHT LINE IN A RANGE LIMITED BETWEEN TWO POINTS.

1. *To convert a reciprocating rectilinear motion into a continued rectilinear motion.*

This result may be readily attained by means of a pall or ratch and moveable rack. When the moving body is drawn back the ratch follows dropping into each indenture between the teeth of the rack, as it passes over them. When, however, the moving body in reciprocating its stroke is forced back again, the ratch catches in the teeth of the rack, and drives it forward before it. This operation, on being repeated, causes the moveable rack to advance at every stroke through a space equal to the length of the stroke performed by the moving body. *See Fig.* 11.

If the ratch be caused to operate upon a ratchet wheel fixed upon a shaft with a pinion wheel connected with it, the direction as well as the velocity of the motion may be varied at pleasure, by applying the driven rack to any part of the circumference of the wheel, and by varying the size of the pinion wheel. This is the usual plan adopted in saw mills, to cause the carriage supporting the log to pass forward to the saw. *Fig.* 12.

If the direction, however, be not in the same plane with that of the first mover, the motion must be communicated to a second shaft by bevelled wheels.

2. *To convert a reciprocating rectilinear motion in one direction into a reciprocating rectilinear motion in other directions.*

This may be effected by a moveable rack acting upon a pinion, some part of the circumferenee of which is made to act upon a second moveable rack. If the direction of the motion is to be produced in different planes, bevelled wheels may be used to transmit the motion from one shaft to another, the pinion upon the last shaft being made to act upon the rack. If the velocities are to be increased or diminished two or more pinion wheels of different diameters, or sectors of wheels, may be used upon the same shaft; the relative magnitude of the wheels must be proportional to the velocities required. Belts and ropes are the simplest and the most commonly employed contrivances for this purpose, as they are not only capable of producing motion in the direction of the same plane as that of the first mover, but in any other plane or direction, merely by passing the the belts or ropes around pulleys arranged to give the desired direction. If the friction of the belts and ropes be inadequate to communicating the motion, rag wheels and chains may be used. *Fig.* 13.

3. *To convert a reciprocating rectilinear motion into a continued circular one.*

This is one of the most useful changes of motion produced by machinery. The first rude attempts to convert the reciprocating rectilinear motion of the piston of a steam engine into a *continued circular* motion, for turning machinery, were made by attaching a great pump to the end of the beam, moved by the piston, for the purpose of pumping up water into a basin or reservoir, from whence it was discharged upon a common water wheel, to which the descending stream imparted a *continued circular motion* applicable to manufacturing purposes. It was soon discovered that the common crank would produce the same result by fixing a fly wheel upon the end of the crank shaft, in order to cause the crank to continue turning during the moments when the piston of the steam engine comes to a state of rest, and ceases to act upon it whilst changing the direction of its motion. When the crank is on a straight line with the piston rod, the latter can have no effect in urging it to turn round, but merely presses the crank against its pivots or centres. In this case the crank is said to be on its centre, and the steam engine cannot be put in motion, to renew its stroke, unless the crank is turned past this position by some force applied to it. The force accumulated in the fly wheel, at this critical moment, lends its aid to move around the crank, until the piston can again act upon it; and thus a continued circular motion is produced. In steamboats the heavy paddle wheels serve instead of the fly to produce this result. *Fig.* 14.

For the reasons given when treating of the *Crank* at page 268, it is decidedly the best plan invented for converting a direct into a circular motion, and should be employed in all practicable cases.

A simple plan is adopted by sailors at sea, for imparting to a spindle a continued circular motion for spinning coarse hempen yarns, by means of a reciprocating rectilinear motion. A small circular piece of wood is fixed upon a spindle to operate as a fly wheel, and a cord is passed around the spindle, the ends being held in each hand. By producing a tension of the cord when drawn in one direction it is caused to bind upon the spindle, and to turn it rapidly round; and when the cord is drawn back, to return or reciprocate the stroke, it is slackened so loose that it slips freely around the spindle, without retarding the motion communicated to it in the first instance, which motion is kept up by the light fly wheel, until a fresh impulse can be imparted to it; whereby the spindle is caused to twist the hempen yarn with considerable regularity. *Fig.* 15.

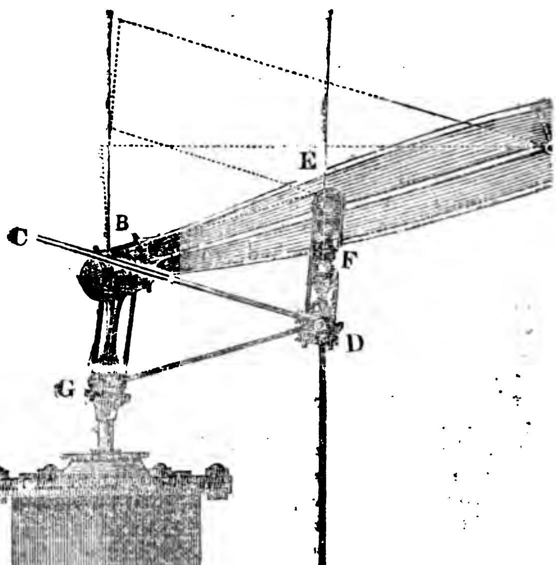
It is sometimes necessary to ascertain the number of strokes made by machinery in various operations. This may be done very per fectly by causing a ratch, as in fig. 16, at every stroke to catch the tooth of a wheel, projecting above the level of the slide upon which it traverses, and to turn it sufficiently to bring up a fresh tooth above the slide to receive the action of the succeeding stroke. When the range of the number of reciprocating strokes to be counted exceeds the number of teeth which can be conveniently formed on a wheel, a pin may be inserted in the side of the wheel, which at each entire revolution will engage one tooth of another wheel, and will turn it forward one cog or tooth; or an endless screw upon the axle of this wheel will have the same effect to turn it forward one cog for each entire revolution. If an index or hand be connected with the axles of these wheels, traversing around the circumference of the dial plate of a clock face, the number of strokes performed by any machine in a given time may be readily ascertained. This contrivance is frequently resorted to for measuring. the length of yarns in machinery for spinning wool, in order to give precisely the same degree of twist to the threads, and to ascertain the length of thread spun, each unit indicated on the clock face being equal to the length of thread drawn out at every operation.

3 *To a convert reciprocating rectilinear motion into a reciprocating circular one.*

The most beautiful mode of converting a reciprocating rectilinear motion into a reciprocating circular one is by the contrivance called the *parallel motion*, which was first applied by Mr. Watt to his steam engines. By this invention, and by that of the mill governor, he has conferred inestimable benefits in the useful arts, in addition to his other more imposing and splendid inventions in relation to the steam engine. The piston rod of a steam engine, in order to prevent the escape and waste of the steam and unequal wear and friction, must be preserved in a straight line during its ascent and descent through the circular hole formed for it in the top of the cylinder. It is evident, then, that it would not answer to connect the piston rod directly with the beam, which, as it moves in circular arcs upon the centre A, would bend the piston rod at every stroke. A rod C D plays on a fixed centre C, and the end D moves in a circular arc like the end of the beam. The end D of the rod C D, and the point E of the beam are connected by a rod, which moves on joints at D and E. The point F, midway between the two points D and E, which moves in circular arcs, is found to move upwards and downwards in a straight line, and therefore a piston rod attached to the point F will ascend and descend with the beam in a *straight line*.

At the point D is attached a bar C D; and to that is connected the bar G B, so united together by moveable joints, that the four sides of the figure B G D E shall be parallel to each other respectively. The point G moves in a straight line, similar and parallel to that described by F, but as much longer than it, as B A is longer than E A.

To the point F, the piston of the air pump of the steam engine is usually attached, and the main piston rod of the great cylinder is connected to the point G.



The length of the several rods or bars forming this *parallel motion* is commonly proportioned as follows:

E is the middle point between A B. C D is made equal to E A. The length of the bars B G and E D may be varied a little, as convenient. In the practical construction of steam engines the following rules are given for proportioning the parts of the parallel motion.

"The radius and parallel bars are of the same dimensions; their length being generally $\frac{1}{4}$ of the length of the beam between the two glands, or one half of the distance between the fulcrum and gland. Both pairs of straps are the same length between the centres, which is generally three inches less than the half of the length of stroke."

Before the invention of the parallel motion, the end of the beam was formed with an *arched head*, or with a segment of a circle, the working part of the circumference of which, being always perpendicular to the rack or chain moving the piston rod, caused it alternately to ascend and descend in a vertical straight line. The common beer pump is usually constructed with a contrivance of this kind, the handle being attached to a segment of a cog wheel for moving the rack connected with the forcing piston, which acts in the barrel of the pump with a reciprocating rectilinear motion. [*Fig.* 19.]

A very simple and useful contrivance has been employed in the United States, as a substitute for the arched head and parallel motion, to connect the piston rod with the end of the beam of the Steam Engine. A bar is fixed on the head of the piston rod, at right angles to it, and to the end of the beam. The ends of this cross bar slide in grooves or guides formed in two parallel and vertical bars of iron, which cause the upper end of the piston rod to move in a straight line, preserving it from being bent over to either side. The end of the working beam is connected with the cross bar by a stiff rod of iron, having joints where it is united with each to accommodate the constantly varying changes in the respective positions of the working beam and cross-bar.

The following simple plan may be adopted for converting a reciprocating rectilinear motion into a reciprocating circular one, by using ropes or chains. A B is a lever turning on the centre C, E is a half wheel turning with it, to which, at the extremities D F, the ends of a rope or chain are attached, which are then passed around rollers or sheaves G H. A reciprocating rectilinear motion in any point I, will produce a reciprocating circular motion in the ends of the arms A B, and *vice versa*. [*See Fig.* 21]

[*Fig.* 22.] If the nut of a screw as at A, be made to move upwards and downwards upon a screw with very coarse threads, it will impart to the screw a reciprocating circular motion. By forming upon any cylinder a single thread or a projection like that of the thread of a screw, or by cutting a spiral groove in such cylinder, and by adopting thereto a guide, the cylinder will acquire a reciprocating circular motion when it is pushed forward and drawn back in a straight line. By this contrivance, the cutters are caused to channel out the spiral grooves in the manufacture of the rifle barrel.

A common bow used by watch makers for drilling holes, is one of the simplest instances of the conversion of a reciprocating rectilinear motion into a reciprocating circular one. The bow string is rolled around a small wheel or pulley, carrying the awl or piercer, and an alternate rectilinear motion of the bow string causes the small wheel around which it is wound, to turn the drill alternately in different directions.

[*Fig.* 23] Another contrivance, also frequently used for drilling holes, is operated by two strings A C, A D, attached to a moveable cross piece C D, and to the top of the spindle A B, having a small fly wheel E fixed upon it. By turning the spindle the string is twisted around it and the cross piece, slipping freely upon it, and serving as a collar to sustain it erect in its place, is raised towards the top at A. If the cross piece be now pressed down, it will cause the strings to unwind, and will impart to the spindle a circular motion. The momentum of the small fly will continue to urge round the spindle until it winds up the strings in an opposite direction, and raises the cross piece vertically to its former position, when the operation may be repeated. Thus the reciprocating rectilinear motion of the cross piece C D will produce a reciprocating circular motion of the spindle, into the point of which at B, the drill may be fixed.

CONTRIVANCES FOR PRODUCING VARIOUS KINDS OF MOTION FROM A FIRST MOVER HAVING A CONTINUED CIRCULAR MOTION.

1. *To convert a Continued Circular Motion into a Continued Rectilinear Motion.*

The rack and pinion, described at page 267, is the most obvious and frequently employed contrivance for this purpose, the pinion having a continued circular motion, and the rack upon which it acts having a continued rectilinear motion.

[*Fig.* 25] The winch applied to turn an axle or barrel for winding up a belt or rope, as in raising a bucket from a well, is a well known contrivance for this purpose.

[*Fig.* 26] The endless screw acting on the teeth of a rack, will also produce a continued rectilinear motion of the rack upon which it acts; or if the rack be fixed stationary and the screw itself be moveable, the latter will acquire a rectilinear motion.

A common screw on being turned advances endwise with a continued rectilinear motion. As every revolution, or part of a revolution of the screw causes it to advance a certain distance, the rectilinear motion derived from it has been applied to measuring small distances with wonderful accuracy.

[*Fig.* 27] When it is required to exert very great power from a first mover having a circular motion without employing blocks and tackle, and other expensive machinery, the simplest and most effective contrivance is a rope and axle of different diameters, in the form of a windlass, with a *compound barrel*, consisting of two cylinders C D connected upon the same axis. The rope D E C is coiled around the extremity of the cylinder D, and after passing around the pulley E, attached by the hook F to the body receiving a rectilinear motion from it, it is coiled around the larger cylinder C. Levers or a crank or cog wheel may be applied to B to turn this *compound barrel.* The rope is so arranged that when the barrel is turned, it is unwound at D, and at the same time is wound up at C. Let it be supposed that the circumference of the part of the barrel C is 21 inches, while that of the part D is 20 inches. It is evident that when the compound barrel is turned once round, 21 inches of rope will be gathered upon the cylinder C, and 20 inches will be uncoiled from D. The quantity of rope wound up exceeds the quantity unwound in the ratio of 21 to 20, or making an excess of only 1 inch of rope wound up by one turn of the barrel. The rope D E C being doubled around the pulley at E, the body attached to the hook will be moved only ½ of an inch by one turn of the barrel. By the common capstan of the same circumference as C, the body at F would be raised ½ of 21 inches, or 10½ inches by one turn of the barrel. It being the *golden rule* in mechanics to compute the power of any engine by dividing the velocity of the impelled point by the velocity of the working point; the power of the improved capstan will be found to be to that of a common one, as 10½ to ½, or as 21 to 1; or as powerful as blocks with a 21 fold tackle. The great friction which takes place where tackle and blocks are used, destroys about ⅓ of the power; whereas by this simple contrivance very little power is thus wasted, and the gain instead of being 21 fold will be nearer 26 fold, in practice. If it be desired to double the power of this machine, it is only necessary to cover the cylinder D with laths of wood, so that the difference between the two cylinders C D of the compound barrel may be half as great as before. The power of this capstan increases in proportion as the difference between the sizes of the two cylinders decreases; and by making the two cylinders very nearly of an equal size, the power of it may be almost infinitely increased. Any mechanic, with the materials within his control, can readily construct one of these simple *capstans*, which he will find as effective as a capstan of the common kind with all the expensive apparatus of double blocks, and other tackle connected with it.

2. *To convert a Continued Circular Motion, into a Reciprocating Rectilinear Motion.*

[*Fig.* 28] The crank is most commonly used to produce a reciprocating motion from a circular one. The *crank motion* is obtainable not only from the crank itself, but from any common wheel revolving upon the end of a shaft, and having a pin fixed in the side of it near its circumference, to which a moveable crank bar is attached. The body to be put in motion is directed in a rectilinear course by proper guides or grooved slides, as in fig. 28. As the wheel revolves the beam C D is evidently pressed upwards and drawn downwards, alternately, with a reciprocating retilinear motion.

[*Fig.* 29] A wheel having a shaft fixed through it at a point on one side near its circumference, instead of its centre, termed an *eccentric wheel*, will also produce this effect. The rim of the eccentric wheel is usually grooved out to receive an iron hoop or clasp, which being well oiled, allows the circumference of the eccentric wheel to turn freely around within it. By connecting a moveable bar with this hoop, it will be alternately crowded from the centre of the shaft, and drawn back towards it at each revolution. One of the principal advantages attending this contrivance is, that it does not impair the strength of a shaft, like the bended crank, and may be placed at pleasure upon any part of a shaft, as convenience may require. The eccentric wheel may be commonly observed on the main shafts of steam engines, where it is used for producing a reciprocating motion for opening and shutting the valves. It is also sometimes used for working pumps; but the slipping of the hoop around the grooved circumference of the eccentric wheel is attended with great friction, where the stress is considerable, and consequently operates with a greater loss of power than where the crank is employed.

[*Fig.* 30] The *Camb* is a wheel, or portion of a wheel, operating like an eccentric wheel. The motion, however, produced by a Camb, instead of being uniformly increased and diminished in velocity during one entire revolution of the shaft upon which it is fixed, may be varied at pleasure, or even intermitted. This contrivance is so generally employed in machinery, that a sketch of its operation, and of the mode of forming a camb to produce the desired movements, will here be given.

The *Camb* and *Wiper* are very useful elementary machines, operating upon the the principle of a wedge applied by one of its faces to a revolving wheel, which by being turned upon its axis gradually raises or separates the weight from the centre of the wheel. A is the wheel or cylinder, and B E H the wedge wound around it, which thus applied is called the *Wiper*, or eccentric piece. By the revolutions of the wheel A, the points B C D E, are successively brought under the arm M, which is provided with a friction roller. Each of the points *b c d e*, being made respectively at the same distance from the centre A as the points B C D E, the arm M and the hammer W, must consequently be raised to corresponding heights as these parts of the *Camb* slide under it.

It is of considerable importance to give a proper form to Cambs, by which peculiar motions are to be imparted, or heavy hammers or pounders are to be raised, for pounding ore or for other purposes, in order that the weight may be raised with uniform velocity.

The *Wiper* may be very readily set out mechanically with a pair of compasses, so as to produce any desired increase and diminution in the velocity in the following manner.

Let A be a wheel moved by any sufficient power to raise the pin or arm M from *o* to *e*, in the same time that the wheel moves round one-fourth of its circumference from O to E, where the wiper may be supposed to terminate abruptly in the line E A, to allow the weight W to fall suddenly. It is required to fix upon the rim of the wheel A, a wing, O B C D E H, which shall raise the weight uniformly with a regular motion. The wiper being intended to extend around one fourth of the wheel from O to H, divide this portion of it into any number of equal parts, the more the better, by lines of indefinite length, extending from the centre A, beyond B C D E. Then setting one point of the compass upon A, and extending the other to *b*, on the line A *e*, make A B equal to A *b*, A C, equal to A *c*, A D equal to A *d*, and A E equal to A *e*. Through the points O, B, C, D, E, draw the curve O B C D E, which will be the proper form for the wiper.

The motion produced by this wiper must be uniform, as it is evident merely from inspection that when the wheel turns regularly and the point B comes to *b*, the arm M will be raised from O to *b*, and so continually when each equal portion of the circle A C, A D, A E arrives at O, the arm M will be raised by equal degrees to *c*, *d*, *e*.

Let it be now required to form a *Camb*, which by one revolution of the wheel A shall raise a weight uniformly for the first ¼ of the revolution, and then allow it to descend uniformly during one half of a revolution, and then to remain at rest during the remainder of the revolution.

By the preceding sketch the weight is made to ascend uniformly to *e*; to cause its descent to be uniform while the wheel is revolving from E to I, divide the semicircle E I into any number of equal parts as before, the more the better, and then setting one point of the compass on the centre A, extend the other to *d*, and make A F equal to A *d*, and make the other lines similarly proportional to A *c*, and A *b*. After the point E comes under the arm M, it is manifest for the reasons before stated, that it will uniformly descend until it arrives at I, that is, during ½ of the revolution of the wheel; and during the remaining ¼ of its revolution from I to O, the arm M will rest stationary upon the circumference of the wheel, being neither raised or depressed by it. Thus if it be desired to produce an accelerated, retarded, or intermitting motion, it may be readily accomplished by dividing the line O *e* according to the proposed acceleration or retardation, and forming the curve as above described.

There are many other modes given for forming *Wipers* and *Cambs*; but the preceding from its simplicity and accuracy will be found to answer for most cases in practice.*

[*Fig.* 31] Wipers, which operate, as before observed, like a succession of wedges attached to a revolving wheel, may be placed either upon the circumference or side of a wheel as most convenient. If the reciprocating rectilinear motion be required to be slow, a less number of wipers will be necessary. A B is a wheel turned by a winch, or otherwise, having wipers arranged in the one case on its circumference, and in others on its side, like the teeth of a crown-wheel. The form of the wipers may however be adapted to the particular circumstances of the case for which they may be used. A rod C D plays in guides E F, having one end preserved in contact with the teeth of wipers, either by its own weight, or by the action of a spring. Every wiper as it passes the end of the rod crowds it off like a wedge, but as soon as the end of the rod has passed over the top of each tooth, it falls or is forced back into the indenture between them. In one end of a rod similar to C D, a needle has been inserted by which the holes are perforated in the

* At the West Point Foundry eccentric Cambs are employed to move the pistons of the Blast Cylinders.

leather for receiving the wires in the process of making cards. If all the teeth on the wheel A B were reduced to one, the surface of the wheel would be an inclined plane, and the reciprocating motion of the rod would take place only once during each revolution of the wheel.

[*Fig.* 32] A B represents a wheel turned by a handle H or by a belt. A projecting pin is inserted in the side of the wheel at C, which is fitted to move freely in the rectilineal groove or slit cut in a cross piece D E attached to the ascending and descending rod *a b*, supported by the guides *m n*. When the wheel is turned, the pin at C, moves in the groove from D to E, and from E to D alternately. When acting upon the lower side of the groove or slit in the cross piece D E, it depresses it together with the beam *a b*, to which it is attached. After the pin has descended to the lowest point of its circuit upon the wheel, it begins to ascend, and to act upon the upper side of the groove, lifting with it the cross piece and beam *a b*, thus imparting to it a *reciprocating rectilinear motion.*

In this case the ascent and descent of the beam *a b*, is at first very slow, and during the middle of its descent very rapid. This irregularity may be remedied, and the velocity of the ascent and descent may be rendered perfectly uniform throughout, by giving the groove or slit in the cross piece a proper form, as in the figure, where the groove D E, instead of being rectilineal, is formed into two similar curves.

If the pin at C cause the beam *a b* to move through a space exactly equal to what it moved through when it described the first or quarter of the circle, then the curved sides of the grove or slit must cross one another at S like the figure ∞ . If it be required that the beam *a b* move through a less space in the second than in the first quarter of the circle, then the form of the curves must be that in the figure, where the two branches are seperated at S; but if it is required that the beam should be moved through a greater space, then the curves will cross one another at two points, thus 

[*Fig.* 34] If a pinion wheel having teeth only on one half of its circumference be connected with a vertical rack, it will continue to raise the rack during one half of each revolution, when it will disengage itself, and the rack with the stamper or other machinery attached to it will fall by its own weight during the remaining half of its revolution, when the blank side of the wheel, stripped of teeth, is presented to it. Thus the stamper will be alternately lifted and dropped during each revolution of the wheel.

[*Fig.* 35] The reciprocating rectilinear motion takes place in this case from the action of the pinion, and the weight or gravity of the rack and stamper connected with it, which causes it to rise and fall. By forming a double rack, the pinion wheel itself may be made to impart both these movements to the stamper or beam. A pinion P, having teeth on nearly one half its circumference, is placed within a double rack, A B C D. After the small pinion wheel turning from right to left, has raised the double rack by acting upon the side B D, the blank portion of the wheel, divested of teeth, disengages the rack upon that side, while the pinion, continuing to turn, engages the teeth upon the other side of the rack, and presses it downwards. The double rack and such moveable objects as may be connected with it will thus acquire a reciprocating rectilinear motion.

If the length of the reciprocating stroke required be inconsiderable, a single tooth or wiper, fixed upon the pinion wheel P, and striking a pin on each side of the rack, will produce the same effect.

[*Fig.* 36.] Another contrivance is shown in figure 36, where A B is a double rack with circular ends, driven by a pinion P, which is calculated to move freely in a groove or slit *m n*, cut in the cross piece C D; when the pinion P comes to the end, the projecting piece *a* meets the spring S, and the pinion P, will descend in its groove, and carry back the other side of the rack: the reciprocating rectilineal motion of the rack will thus be kept up continually.

[*Fig.* 37.] A very philosophical but rarely employed contrivance for this purpose is shown in figure 37. The wheel A B, having teeth on the concave surface of its rim, is so fixed that it cannot revolve. Another wheel C of exactly half the diameter of the concave wheel A B, is fitted to work within it by means of the crank D C. As the crank is turned the small wheel is made to traverse or roll over the teeth on the inner side of the rim of the fixed concave wheel, the centre C of the smaller wheel describing a circle round the centre of the larger one. Any point fixed in any part of the circumference of the wheel C, will move in a *straight line* across the wheel A B in one revolution, and will return along the same diameter the next revolution, producing in this way a very remarkable reciprocating rectilinear motion across the concave wheel. This result is susceptible of mathematical demonstration.

[*Fig.* 38.] It is frequently necessary to impart to a cylinder, whilst turning on its axis, a reciprocating rectilinear motion, as for example in emery cylinders for grinding steel blades, in order to obviate any accidental irregularities upon the surfaces of the cylinders, and to ensure accuracy in the operation. A reciprocating motion may be given to any such cylinders by fixing them upon their arbors in such a manner as to allow of their slipping freely in a longitudinal direction, or endwise upon the boxes or bearings upon which they rest, when connected by levers or otherwise with the *spiral cylinder* A B. Upon the circumference of this cylinder a thread or groove is formed like that of a screw. This thread or groove after being extended from one end of the cylinder to the other is reversed, winding back again in an opposite direction and intersecting the threads formed in the first instance, until it joins the thread at which it commenced, forming a zigzag upon the circumference of the cylinder resembling the figure ∞ A guide is adapted to this spiral groove or channel, being made to turn in such a manner as to follow the windings of it back and forth upon the cylinder. The groove or thread being well oiled, when the cylinder is turned it is obvious that the same result must take place as if a common screw were turned under the same circumstances;—either the guide or pin C must be caused to move in the bar D, or the cylinder A B itself must receive a logitudinal motion on its bearings. This reciprocating rectilinear motion may be communicated either from the guide C, or cylinder A B, as most convenient.

[Fig. 39] If it be required to produce one or more vibrations of the rod A B or of the cylinder C D, it may be effected upon the same principle, merely by adapting the point at A, to the groove in the circumference A D. In this case either the rod A B, or the cylinder C D, or both, may receive a reciprocating rectilinear motion.

A pinion wheel having a continued circular motion, and working into the teeth of an oval or of an eccentric cog wheel, will cause the axles of such wheels to rise and fall, or to have a reciprocating rectilinear motion in a slit or groove adapted to receive them, as in the figure.

3 *To convert a Continued Circular Motion in one direction into a continued Circular Motion in various other directions.*

[Fig. 40] To produce a circular motion in the *same direction*, it is only necessary to use a belt, rope, or chain, passing around two wheels or pullies.

[Fig. 41] If 3 wheels be used, acting upon one another by teeth or friction, the last wheel will have a motion in the same direction as the first. The intermediate wheel, serving in this case merely to transmit the change of motion, is called a *stud* wheel. There is an evident convenience in using belts where two shafts are at a considerable distance from each other, in which case several of these intermediate wheels would be necessary if employed instead of belts.

[Fig. 42] A continued circular motion in the same direction is produced when a small wheel acts upon the teeth arranged upon the interiour circumference of the rim of a larger wheel, called a concave toothed wheel.

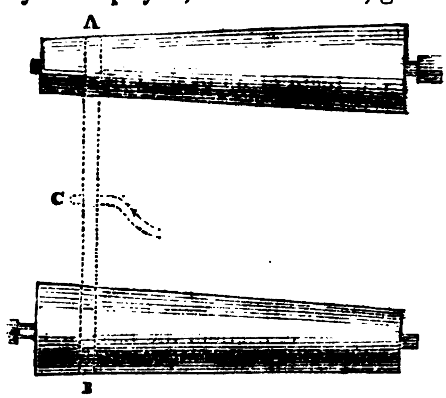
[Fig. 43] To produce a circular motion in an *opposite direction*, a common toothed wheel may be employed, or if belts and ropes are used, this effect may be produced by crossing them between the two wheels.

To communicate a continued circular motion to a shaft placed at almost any angle with the moving or driving shaft, bevelled or crown wheels may be employed, as in figure 2 and 3, page 256. Hooke's Universal Joint, see page 269, will produce nearly a similar change of motion.

[Fig. 45] An endless screw, working into a toothed wheel, will convert a continued circular motion in one direction into a continued circular motion at right angles with the plane of its direction. In figure 26, the axis of the wheel is represented as parallel to the horizon; but it is evident that to whatever part of the circumference of the toothed wheel the screw is connected, provided the axis of the wheel be perpendicular to the axis of the screw, the circular motion may be transferred from it at any angle inclined to the horizon.

[*Fig.* 46] By half crossing the belt, as in figure 46, rotation round an axis may be transferred to an axis at right angles to it. This contrivance is often adopted for turning spindles, which are placed vertically in a straight line or row at A, and are driven from a long horizontal drum at B.

To convert a uniform circular motion into a constantly varying circular motion, Alternate Cones may be employed; one of which A, gives motion to the other, B. The belt serving to communicate the motion is gradually moved along from one end of the cone to the other by the belt guide C, to which motion is imparted from some part of the machinery. When this belt is moved toward the large end of the cone A, it at the same time is moved from the large end of the other cone B. The diameter of the driving cone decreases beneath the belt in the same ratio as that of the driven cone increases; and *vice versa*. The number of revolutions of the driven cone may be thus regularly diminished or increased at pleasure.



[*Fig.* 48] Another contrivance, for increasing and diminishing at pleasure the velocity of a body revolving with a continued circular motion, is shewn in figure 48. AB is a smooth circular plate fitted upon the end of the revolving shaft C. Upon the end of the shaft E, is fixed another circular plate or wheel D with its edge pressed against the side of the circular plate A B, which turns the wheel D by means of the friction created by the pressure. If the parts in contact are covered with buff leather or with India rubber, the mechanical effect of the friction will be greatly increased. To the shaft E a longitudinal motion is imparted by the machinery, causing the wheel D to ascend and descend between the centre of the wheel A B, and the top of it, A. It is evident that as the small wheel D approaches the centre of the large wheel it will be turned by it a less number of times than when it traverses upon the extreme part of the circumference of it; and in proportion as it is made to approach or recede from this centre it will have a varying circular motion.

To transmit a uniform action from one revolving body to another, when the moving power itself acts with a regularly diminishing or increasing force.

[*Fig.* 49] An example of this is exhibited in the construction of a watch, the main spring of which as it is uncoiled gradually becomes less powerful, until it ceases to act. The watch spring, consisting of a thin ribbon of tempered steel, is inclosed in the barrel A, through the centre of which is inserted a stationary axle or post, around which it is capable of turning freely. One end of the spring, at C, is fastened to the moveable barrel, and the other end D, to the fixed axle. The tendency of the spring to recoil cannot turn the fixed axle within the barrel, but causes the barrel to turn about the fixed axle. A chain is wound round the barrel A, having one end fastened to the conical cylinder B, called the *fusee.* When the watch is wound up, the key is applied to the axis of the fusee at E, and the chain is drawn off the barrel A, causing it to turn upon its axle. The spring contained within the barrel is thus stretched to its utmost intensity. As soon as the key is removed from the fusee, the tendency of the spring to recoil operates upon the barrel A, which is connected with the fusee at the highest part of the conical figure. The resistance of the wheel work of the watch takes place against a small toothed wheel fixed upon the fusee. At the very commencement when the force of the spring is strongest, it acts with the least leverage power upon the fusee, the chain being at this time at the top of it; but as the chain is gradually drawn off the fusee upon the barrel A, the spring as gradually operates more feebly. The increased size, however, of the base of the cone of the fusee causes this diminishing force to have an equal mechanical efficacy or leverage power in turning the fusee and the wheel work or other resistance connected with it. Thus by giving a proper tapering form to a cone these two opposite effects may be made to counterbalance each other, and a uniform action may be produced by a body revolving with a constantly diminishing or increasing force.

When long and heavy chains or ropes are lowered into the shafts of deep mines, the additional weight of the rope or chain is added to that of the descending buckets; and in raising the buckets again, the power required is constantly diminishing in proportion as the weight of the rope or chain suspended is diminished. By rendering the barrel upon which the rope is wound slightly conical or tapering, this inequality will be compensated.

To convert a Continued Circular Motion in one direction into an Intermitting Reversed Circular Motion.

[*Fig.* 50] This operation is frequently required in practical mechanics, where cloth for example is to be wound back and forth from one roller to another, or where the sluice or gate of a water wheel requires to be alternately opened and closed by the *Governor* to regulate the supply of water. Upon the shaft A B, having a continued circular motion in one direction, is fixed the clutch g g which is fitted to slide freely endwise towards A or B; but is caused to revolve with the shaft by fillets or projections from the axle fitted to grooves in the centre of the clutch. The two wheels O P, having their centres bored out smooth, are fixed upon a rounded part of the shaft, in such a manner, that when the shaft turns, the wheels remain loose and are not carried round with it. The wheel C is fastened upon another shaft, having its teeth engaged with those of both the wheels O P. If it be required to cause the wheel C to turn in one direction, the wheel O is thrown into gear by the arm of the lever *f e*, which operates upon the clutch *g*, forcing it into the hollows between the arms or in the face of the wheel O; and the same is done in an opposite direction to reverse the motion of the wheel C, by causing the wheel P to act upon the opposite side of C. As represented in the figure both of the wheels O P are *out of gear*, or disengaged of the clutch *g*, and the wheel C is consequently at rest, as well as the two wheels O P. The clutch only engages one of the two wheels at the same time, the disengaged wheel being then turned freely by the wheel C upon the axle of the shaft A B, in a contrary direction to that in which the shaft A B is turning.

If the reversed motion is to be communicated to the shaft A B from the continued circular motion of the wheel C, it is only necessary to thrust the clutch alternately toward the respective wheels O, or P, to cause the shaft A B to turn first in one direction, and then in a contrary direction. By a little ingenuity in the construction of a machine, the end of the lever *f e* may be operated upon by some part of the mechanism to produce this change of motion without requiring the personal attendance of the operator.

It may be observed here, that in most cases in which cloth is to be subjected to the repeated action of any process wherein this invention is used, the same result is attained more perfectly by connecting the two ends of the piece of cloth together, and by causing the endless webb thus formed to traverse around rollers. Each portion of the fabric is in this manner brought successively forward to undergo in turn the desired operation.

[*Fig.* 51.] A continued circular motion in one direction is converted into a compound circular motion in an opposite direction, by the contrivance shown in fig. 51. If A be supposed to be a toothed wheel engaged with the smaller wheels 1 2 3 4, it is manifest that by causing it to revolve, each of the small wheels will be turned by it at the same instant. If the wheel A were to be fixed stationary upon a table, and the circular plate B C, to which the small wheels are attached upon spindles passing through it, be made to revolve, carrying these small wheels with it, it is equally manifest that each wheel would be caused to turn rapidly on its axis, their teeth being engaged with those of the stationary wheel B. The spindles thus inserted in these small wheels have been employed to twist the yarns for making cords, while the revolution of the plate containing these bobbins and spindles at the same time *lays* the strands in the most regular manner, as in the process of the manufacture of ropes. A machine constructed upon this plan presents to view when in ope-

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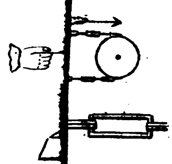

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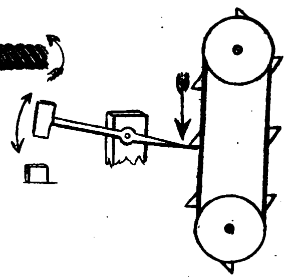

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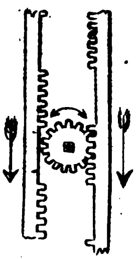

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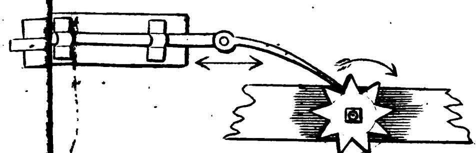

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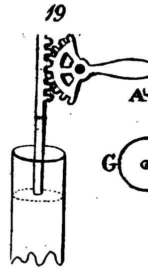

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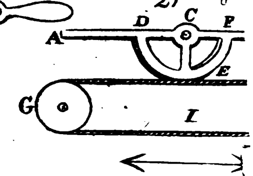

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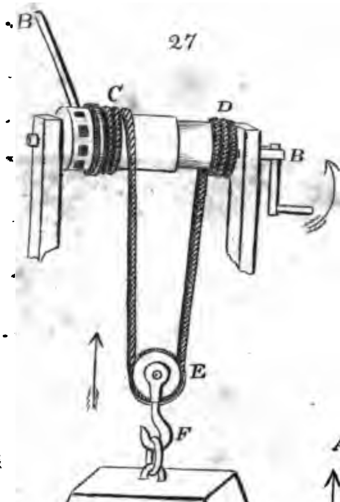

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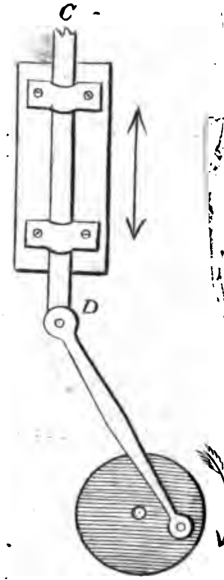

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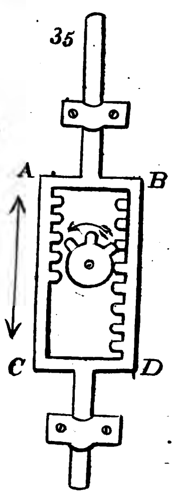

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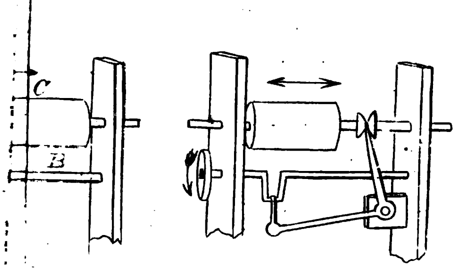

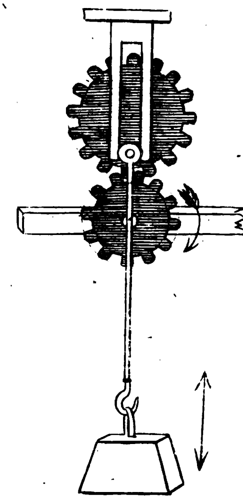

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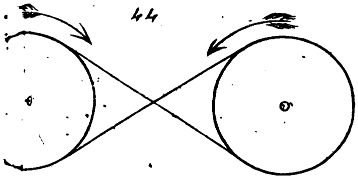

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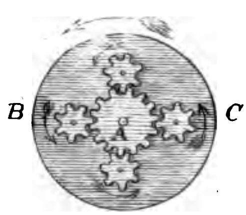

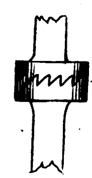

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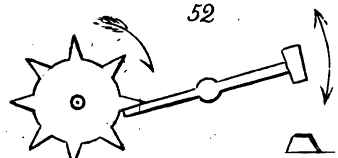

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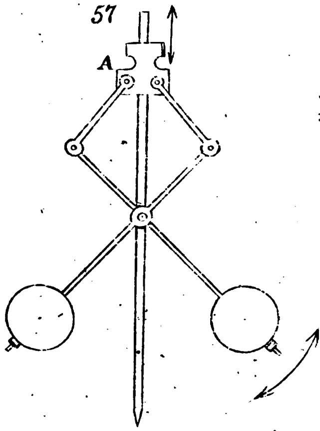

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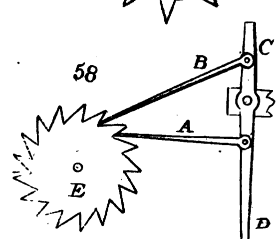

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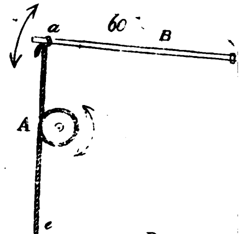

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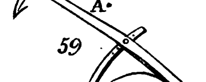


tation an amusing spectacle, apparently resembling the circling movements of a cotillion among the whirling bobbins.

4. *To convert a continued circular motion into a reciprocating circular motion.*

[*Fig.* 52.] A common forge or trip hammer, lifted by wipers fixed in a revolving shaft, and falling again by its own gravity, is one of the most familiar instances of the conversion of a continued circular into a reciprocating circular motion; the hammer as it rises and falls describing circular arcs.

The crank connected by a bar or rod with the end of a working beam will also produce this effect; the end of the rod connected with the crank moving with a continued circular motion round the axis of the crank, while the other end, connected with the beam, moves alternately in a circular arc.

In *figure* 53 is shown another contrivance for this purpose. *A* is a crown wheel fixed upon the end of a shaft, and stripped of teeth on one side. C D are two spur wheels upon the same shaft E F. The wheel A being turned constantly in the same direction, the teeth upon one side no sooner quit the wheel C than they become engaged with those of the wheel D; and the shaft E F is thus caused to turn first in one direction, and then back in the opposite direction, and a reciprocating circular motion is produced.

Any of the preceding contrivances, which will produce a *reciprocating rectilinear motion*, will also produce a *reciprocating circular* one, by applying them to any part of a machine having a motion about a fixed centre or axis like a pendulum or working beam.

[*Fig.* 54.] In the process of weaving, various contrivances have been resorted to for swinging the lathe with a motion resembling that produced by a hand weaver, who allows the lathe to rest for an instant to give time for the shutttle to traverse from one end of it to the other. In weaving narrow cloth this is not so important as in broad cloth weaving, in which operatation the shuttle has to traverse about 12 feet across the cloth at every stroke. Having made various experiments upon this subject, I have found that the *oval and eccentric wheel*, working together, produces a regularly accelerated and retarded motion best adapted for this purpose. In fig. 54 A is the oval wheel operating as the *driver*, B is the eccentric wheel *driven* by it. By the rules laid down, when treating of the Camb at page 301 the proper proportions may be given to cause these apparently irregular wheels to operate as harmoniously together, as if made perfectly circular. The eccentric wheel makes two revolutions for one of the oval. The crank, to cause the lathe to perform its vibrations, is attached to the end of the shaft forming the axis of the eccentric wheel B. The oval wheel in the situation represented in the figure is imparting to the eccentric wheel its greatest velocity. When the eccentric wheel has performed a half revolution, the lathe is drawn back and remains nearly stationary whilst the shuttle is passing across the loom, the blow to beat in the weft is then suddenly made, and the lathe is as suddenly drawn back again where it dwells for a few moments before it repeats the stroke.

TO PRODUCE VARIOUS KINDS OF MOTION FROM A FIRST MOVER HAVING A RECIPROCATING CIRCULAR MOTION.

1 *To convert a Reciprocating Circular Motion into a Continued Rectilinear Motion.*

This effect is produced by most of the preceding contrivances for converting a reciprocating rectilinear motion into a continued rectilinear motion.

[*Fig.* 55] The *Lever of Lagaroust* is one of the most ingenious contrivances for producing this result. A B are the two arms of a lever working on the centre C. The double rack receives a rectilinear motion from a guide in the longitudinal groove C D. Two bars furnished with hooks lay hold of the teeth of the rack alternately, as each end of the lever is depressed, lifting the rack at each stroke, and imparting to it a continued rectilinear motion.

2. *To convert a Reciprocating Circular Motion into a Reciprocating Rectilinear Motion.*

This may be effected by most of the contrivances which will convert a reciprocating rectilinear motion into a reciprocating circular one.

The movement of the pump handle in circular arcs is one of the most familiar examples of this result, the pump rod being guided by the pump barrel in a rectilinear direction. A joint or hinge is necessary both at the junction of the piston rod with the arm of the lever and with the piston, to accommodate the varying circular motion of the arm of the lever.

[*Fig.* 56] The pistons of air pumps are generally moved by a pinion and rack. The pinion A is turned by a crank B with a reciprocating circular motion, and the pistons attached to the end of the moveable racks *c c*, are alterately raised and depressed by the pinion, as it is first turned in one direction, and then in a contrary direction.

The reciprocating circular motion of the arms of the levers in figure 21, will produce a reciprocoting rectilinear motion of the rope or chain at I.

[*Fig.* 57] If a succession of levers united like pairs of scissors, as in figure 57, sometimes called *lazy scissors*, have a reciprocating circular motion, such as takes place when scissors are opened and closed, the end A will have a reciprocating rectilinear motion.

3 *To convert a Reciprocating Circular Motion into a Continued Circular Motion.*

This may be readily accomplished by connecting with the end of any working beam a moveable ratch to operate upon a rachet wheel.

[*Fig.* 58] Another similar contrivance is a lever C D with two ratches A B operating upon the same rachet wheel E. By imparting to the lever a reciprocating circular motion, when the end C approaches the ratchet wheel, the ratch B presses against the wheel and urges it round its centre; at the same time the ratch A is drawn from the wheel and falls upon the next succeeding tooth of it. The ratch B being in turn moved from the wheel and the ratch A moved towards it, the latter operates upon the wheel, while the former in its turn is falling to the succeeding tooth, and thus the motion is continued.

[*Fig.* 59] A very convenient instrument for rolling over heavy logs or pieces of timber, is shown in figure 59. A C is a lever having a moveable hook with a sharp point B; by lifting the end of the lever A, the point of the hook B being first driven into the wood, a circular motion of the log or piece of timber may readily be produced.

[*Fig.* 60] One of the old turning lathes operated by treadles or pedals, once in common use, is represented in figure 60; *a b c* is a cord fixed at *a*, to the spring B, and after passing around the cylindrical wheel A, it is fixed at *c* to the pedal D. The reciprocating circular motion, imparted by the foot to the end of the pedal *c*, is thus communicated to the wheel A.

[*Fig.* 61] The most common and useful contrivance for this purpose is the crank assisted by the fly wheel. The end of the working beam of a steam engine has a reciprocating circular motion, and when connected by a rod with the crank will impart to it a continued circular motion, as in figure 61.

4 *To convert a Reciprocating Circular Motion in one direction, into a Reciprocating Circular Motion in other directions.*

This simple change of motion may be produced by means of bended levers, cog wheels, belts and chains, and by various other contrivances, which the circumstances of each particular case will commonly suggest.

All of the preceding contrivances are of the most simple and elementary kinds generally used in practice for producing these changes of motion in machinery. There are various other methods of producing all these changes of motion by employing a combination of mechanism of a more complicated nature. Of such contrivances, which partake rather of the character of *real machines* than of elementary ones, a description will not here be attempted.

STEAM ENGINE.

There is probably not an individual, among the number of those by whom the steam boats are daily crowded, who does not feel an interest in comprehending the principles which govern the movements of the mechanism by which he is carried forward as it were triumphantly over the waves against adverse tides and winds. The importance of the Steam Engine, not only as it affects those engaged in the practical details of its operations and construction, but as the great efficient servant of civilized man, ministering in various ways to his daily wants and luxuries, and transporting him with the velocity of an untiring race horse to remote distances, renders the history of its first invention and subsequent improvements generally attractive.*

The knowledge of the expansive elastic force of steam in rushing from a close vessel of boiling water appears to have been known in the earliest ages; but the project of employing the force of steam to operate upon machines was first published in the year 1683 by the Marquis of Worcester. No steam machine or engine appears however to have been successfully put in operation until Captain Savery constructed one, for which he obtained a patent about the year 1700.

It is stated by Savery that his attention was accidentally turned toward this subject from the following circumstance. Having drunk a flask of Florence at a tavern, he called for a basin of water to wash his hands, and flung the empty flask into the fire. A small quantity of wine which remained in the flask began to boil, and the steam issued from its mouth. It occurred to him to try what effect would be produced by inverting the flask, and plunging its mouth into cold water. Putting on a thick glove to defend his hand from the heat, he made the experiment; when to his surprise the water rushed upwards through the neck of the flask and filled it. Here then was a discovery of an easy mode of driving out the atmospheric air from a hollow vessel by means of steam, and of causing water to ascend into the vacuous space resulting from its subsequent condensation. Supposing any such tight vessel of the capacity of 1800 cubic inches to have the air thus expelled from it, and to be filled with steam; by cooling the vessel the steam will be condensed in drops upon the side, which trickling down will form exactly one cubic inch of water in the bottom of the vessel, leaving 1799 inches of space entirely void of air, thus creating a *vacuum* (see *Steam*, page 69.) To extract the same quantity of air from any hollow vessel by manual labour, a very considerable

* The Tables and practical Rules herewith given for the construction of the different parts of the Steam Engine are collected from the works of the best writers upon this subject. From the last edition of "Practical Mechanics" by Robert Brunton, (to which the reader is referred) much useful information upon this and other subjects has been selected.

An account of the nature and properties of *Steam*, and of the economical production and employment of it in the useful Arts has been already given at pages 66 to 75.

exertion of strength is necessarily applied to work the air pump employed for this purpose. Although steam appears to rise so freely from the surface of boiling water, and to occupy the interiour of the vessel with so much facility, expelling the atmospheric air, yet in reality as great a force is thus silently and imperceptibly exerted by the agency of heated water, as must be exerted to extract the same air by the air pump. If a common pump barrel, instead of being exhausted of air by the laborious method of a piston or *sucker*, were to be exhausted of air by first filling it with steam and by afterwards condensing this steam, the atmospheric pressure, as explained at page 237, would force the water of the well, into which the open end of the pump might be immersed, to ascend into the pump barrel, and into any steam chamber connected with it placed not higher than 34 feet above the surface of the water, upon the same principle which causes the ascent of water in the common pump.

Pursuing this plan, Savery constructed the first *Steam Engine* by forming a steam chamber or vessel, with a pipe leading down from it and terminating in the water of a well. Having filled the chamber and pipe with steam, he caused a stream of cold water to gush upon them to cool them suddenly for the purpose of condensing the steam contained within them. He thus carried into effect the principle suggested to him by immersing the mouth of the inverted bottle filled with steam in the basin of water. By contriving suitable stop cocks he drew off the water thus raised, and again filled his steam vessel and pipe as before to repeat the operation. By this *Vacuum* Engine, Savery was able to raise the water by the most careful experiments nearly 34 feet high; but when he put the engine into actual operation, owing to the unavoidable defects of the machinery, and the imperfect vacuum created, he could in practice only raise the water about 26 feet high. A succession of lifts was therefore necessary to raise the water from one station to another 26 feet above it. This apparatus became thus so complicated for draining deep mines that it was rarely employed.

In order to concentrate the force of the steam engine to raise the water at once from the bottom of a mine or well of greater depth than 26 feet, Newcomen contrived to condense the steam in a cylinder beneath a moveable piston. By filling the cavity of a cylinder with steam when the piston was raised to the top of it, and by producing a vacuum by causing a jet of cold water to spout amidst the steam, the piston was immediately forced downwards by the *atmospheric pressure* with a force equal to a weight of about 15 lbs. or more exactly $14\frac{7}{10}$ lbs. on each square inch of its surface (*see atmospheric pressure*, page 235.) Upon a piston of only one foot area, or exposing a surface of 144 square inches, this pressure is equal to about one ton. By enlarging its diameter it is obvious that the power of this engine is capable of being increased to almost any required extent, as upon a cylinder of 60 inches diameter the atmospheric pressure exceeds 42,000 lbs. He connected the piston, upon which the pressure was made to take effect, by a chain to one end of a beam supported in the middle upon a pivot called the *working beam*, the other end of the beam being connected with the pump rod in the well. When the condensation took place the steam piston was drawn down by *suction* (as it was once termed) with a force proportionate to the number of square inches contained in its surface, or in other words to its size, and the opposite end of the working beam was at the same time elevated with an equal force, diminished only by friction. The piston or sucker of the great pump connected with the end of the beam was thus lifted with its load of water, which was raised at once from the bottom of the mine, the size of the piston of the steam engine being made larger, or that of the pump being made smaller, in proportion to the depth of the mine to be drained. After the piston had arrived at the bottom of the cylinder and had terminated its working stroke, the steam was again admitted beneath it, and the weight of the pump rods more than counterbalancing that of the piston, preponderated, in its descent elevating the opposite end of the beam, and causing the steam piston connected with it to rise again to the top of the cylinder, when the operation was repeated as before.

The valves for regulating the admission of the steam upon the piston were originally opened and shut by the hand of an attendant. A boy entrusted with the management of a set of these valves, to save himself the unremitted attention and labour which was necessary to manage them, ingeniously contrived by means of strings tied to the levers of the valves and connected with the beam of the engine, to cause the valves to be opened and shut exactly at the proper time by the movements of the beam. The operation of the valves was now performed more perfectly than before, and the machine was made to attend itself.

The vast elastic force of steam to burst from strong boilers, when confined in them, was about this time more fully demonstrated by Papin in a course of experiments which he made for the purpose of dissolving or melting horn and bones in water. He found that he could not raise the heat of water above a certain point of temperature unless it were confined in a strong close vessel, which he termed a *Digester*, in allusion to the object for which it was employed. Apprehending danger from confining the steam without some mode of ascertaining the pressure exerted by it against the internal surface of his digester, he formed in the top of it an aperture, with a plug or moveable piece of metal fitted to it. This plug being an inch square and loaded with a certain weight, would indicate, by being lifted out of its place, that the pressure of the steam against the bottom of it, and of course against every square inch of the interiour surface of the boiler, exceeded the weight imposed upon the top of it. He placed upon this plug of one square inch area a weight as heavy as he deemed his boiler would with safety sustain pressure on each square inch exposed to the action of the steam; hence originated the *Safety Valve*.

The Steam Engine continued to be used on the plan introduced by

Newcomen for above half a century, until Mr. Watt in 1763 applied himself to improving it. The account of the improvements of the Steam Engine made by Messrs. Boulton and Watt forms the history of this machine, since it has continued to be employed at the present day with only some trivial improvements, in nearly the same state in which they left it.

Mr. Watt a native of Greenock, near Glasgow, having his attentention accidentally directed to the construction of steam engines, from the circumstance of his having had a model of one of these machines belonging to the university of the latter city put into his hands to be repaired, turned his particular study to devising some plan of employing the steam with less waste by condensation. The steam being condensed, as before observed, immediately beneath the piston in the cylinder, in order to create a perfect vacuum it was necessary to inject sufficient water into the cylinder to reduce the heat of the whole mass of metal of which it was composed below 100°; otherwise the steam mixed with the condensing jet formed a quantity of hot water in the bottom of the cylinder, which would *boil* again at the temperature of 100° whenever the vacuum was formed, or when relieved of the atmospheric pressure, as explained in treating of the *Boiling Point* at page 63. It there appears that water will boil in a *vacuum* when the heat of it is so moderate as to be barely perceptible on applying the hand to the side of the vessel containing it, and that warm water contained in a flask exhausted of air will commence boiling on being plunged into cold water. The steam formed in this case soon fills the cylinder again and counteracts the descent of the piston. When on the one hand he attempted to make a more perfect vacuum by cooling the cylinder below the temperature of 100°, he found that the quantity of steam condensed and wasted in again heating the cylinder from 100° to 212°, to which point it was necessary to heat the whole cylinder before the ascent of the piston took place, was equal to filling the capacity of the cylinder *three times full*. When on the other hand he attempted to avoid this great waste of steam by only partially cooling the cylinder, by using the jet of condensing water sparingly, the vapour remaining imperfectly condensed, and the fresh supply of vapour arising from the hot water counteracted the atmospheric pressure and robbed the engine of its power.

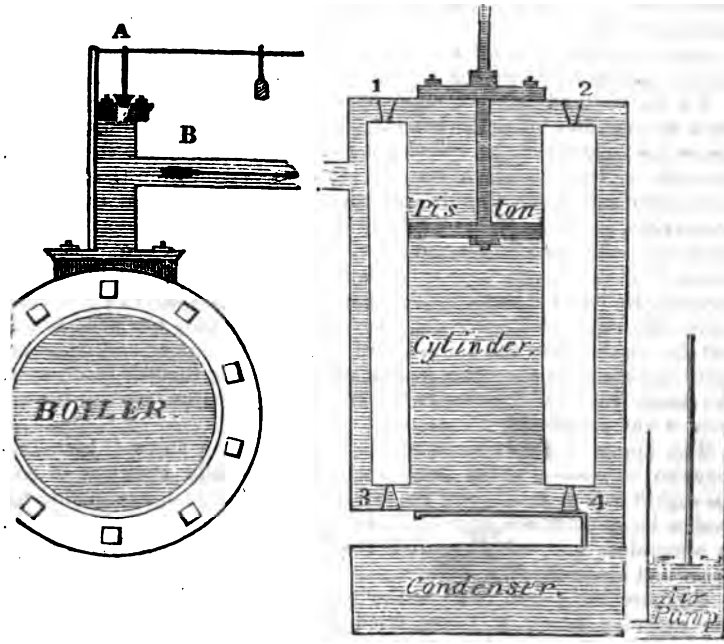
To prevent this loss he first had recourse to a cylinder composed of wood, which soon became too rough for use. Some other experiments of a similar nature having failed of answering his expectations, he at last hit upon the most important improvement of effecting the condensation in a separate vessel, since called the *Condenser*, which is connected only by a steam pipe with the chamber of the Cylinder. By this alteration in the mode of condensing the steam, a saving was at once made of one half of the quantity of fuel. This condensing vessel he kept cold by immersing it in a cistern into which a stream of water was constantly discharged from a *cold-water pump*, worked also by the beam of the engine. To cause the condensation of the steam to take place more suddenly, he found it necessary to allow a jet of cold water to gush into the condenser amidst the steam. One of the principal difficulties that presented itself in the execution of this plan was to get rid of the condensing water and condensed steam, which collected in the bottom of the condenser, together with a small quantity of air, which all water contains in a greater or less quantity and gives out in boiling. This last difficulty he overcame by employing an *Air Pump*, to draw out both the air and water or other fluids which might be collected in the condenser. It is related by Mr. Watt that some of these most interesting inventions were the results of experiments made with a simple apparatus formed of apothecaries' phials.

The top of the cylinder of his engine remaining open, exposed to the air, and the upper surface of the piston being kept covered with a thin sheet of water to preserve it air tight whilst ascending and descending, the steam was unnecessarily condensed from this cause, as it was before by the injection of the cold water. This was remedied by filling a groove formed in the circumference of the piston with hemp saturated with tallow, called the *packing*, as generally practised at the present time, although various contrivances formed of metallic rings have been since tried as a substitute without satisfactory success.

Mr. Watt further closed the top of the cylinder with a cover, and caused the piston rod to work through a hole in it, rendered steam tight by means of a collar *stuffed* also with hemp saturated with tallow. The steam was by this contrivance admitted above the piston as well as below it, acting alternately upon its upper and under surface, while the vacuum was in like manner alternately formed above and below the piston. This completed the last great improvement necessary for deriving the full advantage of the power available from the employment of steam; for whilst the steam is actually exerting its elastic force against the piston to *drive it before it*, the vacuum formed by the condensation of the steam, increases the effect, *drawing or sucking the piston*. The machine with this improvement was called the *Double Acting Steam Engine*, to distinguish it from the single acting engine before described. The chain which was used to connect the end of the beam with the piston in the single acting engine was now necessarily laid aside, as its flexibility would prevent the transmission of the upward stroke to the end of the beam, and a stiff inflexible iron rod, called the *piston rod*, was substituted. Here a difficulty again occurred to preserve this rod from being bent out of a straight line, in which it was necessary to cause it to move through the aperture in the cover of the cylinder, by the circular movement of the end of the beam This difficulty was removed by the persevering genius of Watt, who invented the *Parallel Motion*, described at page 296, for converting the reciprocating rectilinear motion of the piston rod into the reciprocating circular one of the end of the working beam.

The Steam Engine was now completed in all its principal working parts, as used at the present day. In the following simple sketch, introduced for the purpose of explaining the principles upon which the steam engine operates, the different parts are exhibited with a view rather to render the functions performed by each, distinct and intelligible to the reader, than to show the arrangement of the parts as usually combined in the practical construction of the machine.

After understanding the principles upon which the steam operates, the reader will be able readily to distinguish the location of each part in its proper position in any working engine.



In the diagram, A is the *safety valve*, capable of being lifted up from the aperture into which it is pressed down by the weight, which is placed on the end of a lever. When the pressure exerted against the bottom of the plug exceeds that exerted by the weight imposed upon the top of it, it is lifted and leaves the aperture open for the steam to escape to relieve the boiler.

The pipe B conveys the steam from the boiler through the valves or cocks 1 and 3 to the top and bottom of the Cylinder, upon both sides of the piston. The valves or cocks 2 and 4 serve to open and shut the passages communicating with the *Condenser*. To keep the *condensor* sufficiently cold to condense the steam, it is immersed in a cistern into which cold water is constantly discharged from a pump also operated by the steam engine. In the bottom or side of the condenser a small tube is inserted, through which a jet of cold water enters and is scattered amongst the steam in spray from the end of the pipe, which is perforated with numerous holes for this purpose, like the rose of a watering pot. The steam after being condensed into water is drawn out of the condenser by the air pump, together with the air which always arises from the water when first boiled, and enters the condenser mingled with the steam. The piston of the air pump is connected with the working beam and operates upon the same principle as the common suction pump. When it is thrust down the water and air beneath it is prevented from retreating back to the condenser by the valve at C, which opening outwards from the condenser allows of the free exit of any fluid; but closes against any fluid pressing to re-enter it.

To understand the principle upon which the steam operates, it must be remembered that when the piston is at the top of the cylinder, the steam below it in the cylinder is to be drawn off by the condenser, through the valve 4, and at the same time the steam from the boiler is to be admitted above the piston from the valve 1. When the piston has arrived at the bottom of the cylinder, the steam above is drawn off to the condenser by opening the valve 2, and the steam from the boiler is at the same time to be admitted to rush below the piston through the valve 3 to force it upward again. The valves 1 and 3 are called the *upper and lower steam valves*, because they are used to admit the steam from the boiler; and 2 and 4, the *upper and lower exhausting valves*, as the effect produced by opening them is to draw off the steam from the cylinder to the condenser, thus exhausting the air from it and producing a vacuum.

The upper steam valve 1, and lower exhausting valve 4, being always to be opened at the same instant, are usually attached to one moveable rod or lever, and the other two valves 2, 4, are moved together by another rod or lever. By this arrangement the operation is simplified, and only two rods require to be alternately moved to open and close the four valves.

Suppose the piston to be at the top of the cylinder, the portion of the cylinder below it being filled with the steam which has just pressed it upwards. Let the upper steam valve 1, and the lower exhausting 4 be opened, and let the two valves, 2 and 3, be at the same instant closed. The steam contained within the lower part of the cylinder, will immediately rush through the valve 4 into the condenser, and a vacuum will be produced below the piston. By the simultaneous opening of the valve 1 a supply of steam is admitted from the boiler to rush into the top of the cylinder, and to press down the piston, which will descend under this united impulse. The piston having descended to the bottom of the cylinder, the valves 1 and 4 are closed, and 2 and 3 are opened, the latter of which admits a fresh supply of steam to rush into the lower part of the cylinder to act against the bottom of the piston, whilst the former opens the passage for the escape of the steam into the condenser, where it is condensed by the cold into drops of water, which trickle to the bottom of the condensing vessel, and are drawn out by the air pump together with the atmospheric air, should there be any in the condenser.

Supposing the piston to present an area of one superficial foot, or 144 square inches to the action of the steam, and the elastic force of the steam to be just sufficient to lift the safety valve when loaded with a weight of 6 pounds to the square inch, the following calculation will show the force or power with which the piston will descend. The pressure on each square inch = 6 lbs. being multiplied by the number of square inches of the piston exposed to this pressure, will show the elastic force exerted by the steam against the piston to be $144 \times 6 = 864$ lbs. The piston being also acted upon by means of the vacuum with a force or atmospheric pressure of nearly 15 lbs. on the square inch, $144 \times 15 = 2160$ lbs. $+$ 864 lbs. $=$ 3024 lbs. total pressure, which operates in giving motion to a piston of one square foot surface in the same manner as if a weight of an equal number of pounds were loaded upon it to cause it to descend.

From the preceding sketch the mode in which the steam acts upon the piston is shown. In order however to render the machinery for opening and closing the valves as compact and convenient as possible, many different plans have been adopted by engineers. In the view given in the frontispiece is exhibited one of the most approved and common plans of arranging the valves, and the air pump, cold water pump, and injection pump to supply the boiler with water.

There are usually five *rods* attached to the great working beam, which is thus the medium of transmitting motion to all parts of the mechanism, viz.

1st, The *Piston Rod B of the great Cylinder*, A, is attached to the end of the Beam, to which it gives motion, and is the first mover of all the working parts of the steam engine.

2d, The *Piston Rod D* is connected with the Beam at the point F of the parallel motion to work the Air Pump E, for the purpose of exhausting from the condenser G any air that may enter it with the steam, and to pump out also the water produced by the condensation of the steam.

3d, The *Piston Rod H of the Injection Pump*, which draws the condensed hot water from the reservoir of the condensing apparatus I, and forces it by a small pipe back into the boiler.

4th. The *Piston Rod of the cold water Pump* J, which raises the water from some well or reservoir to discharge it upon the condensing apparatus G E to keep it cold.

5th, Lastly, the *Connecting Rod* K, which connects the other end of the working beam with the crank L, to impart the continued circular motion to the machinery.

These piston rods are attached to the working beam at a sufficient distance from its centre to produce the required length of stroke to be given to the several pistons. The cylinder of the air pump is commonly half the length of the steam cylinder, and its piston rod is attached to the beam at the point exactly in the middle between the end of the beam and the centre or fulcrum.

The great Cylinder is formed of one piece of cast iron moulded hollow and bored out with the greatest accuracy to admit the piston to play steam tight within it. The piston is formed in two parts, the upper half being moveable and capable of being made to approach or recede from the lower half by means of screw bolts. Around the circumference of the piston a rope of loosely braided hemp is wound, to make it fit the cavity of the cylinder. By turning the nuts upon the screw bolts, the fillet of hemp is caused by the approach of the two plates together to bulge out between them against the internal sides of the cylinder, to which the piston may by this contrivance be caused to fit very closely to prevent the passage of the steam past it, and as it becomes worn away it is only necessary to turn the nuts to cause this *packing* to bulge out still more. The aperture in the top of the cylinder through which the piston rod works is in like manner provided with a *stuffing* of hemp, which is capable of being compressed by bolts. This contrivance for pressing the hemp against the piston rod for forming a steam tight joint is called *a stuffing box.*

The parallel motion C F has already been described at page 297. The operation of the fly wheel to convert a reciprocating motion into a continued circular one has also been described at page 277.

The steam is conveyed from the boiler by the pipe M, to the cylinder A, into which it enters through the valves 1, 3, as represented in the plate forming the frontispiece, passing off by the valves 2 and 4 into the condensing vessel G, which is kept immersed in cold water. To render the condensation more rapid and perfect, a small jet of cold water is kept playing into the condenser through the tube N. The steam condensed into water is pumped out, together with the air which may accidentally force its way through the joints into the vacuum within it, or which as is most commonly the case, may enter the condensing vessel together with the steam, all water in its natural state containing more or less *fixed air* or gas. The piston rod of the air pump works through an air tight collar or *stuffing box*, and as it descends, the air and water pass through a valve in the piston and gain its upper surface. When the piston is lifted, the condensed water and air are both forced through the valve into the reservoir or *hot well* I, from whence the small forcing pump H draws the hot water, and injects it back again into the boiler to keep it supplied with water.

The valves 1 2 3 4, as in the figure before described, are lifted in pairs alternately, two valves being opened and two closed at the same instant.

These sets of valves are usually contained in hollow cast iron pipes attached to the top and bottom of the cylinder, called *valve boxes;* each of which have a communication by means of pipes with the boiler to receive the steam, and with the condenser to discharge it.

As represented in the plate forming the frontispiece to the volume, 1 is the upper steam valve, which admits the steam above the piston; and 2 is the upper exhausting valve, which when opened allows the steam to escape into the condenser, where it resumes its natural fluid state of water. The lower steam valve 3 admits the steam beneath the piston and the valve 4 allows it to escape into the condenser.

In order to put this steam engine into operation the engineer first examines the crank, which if vertical, as represented in the plate, cannot be turned by the connecting rod, however powerful the engine may be, the whole force being in this position exerted merely to lift up the shaft and fly wheel from the pillows or bearings. In this case, it is necessary by manual strength to turn the fly wheel, or if in a steam boat, the paddle wheel, until the crank is *past the centre.* The engineer then opens all the valves and allows the steam to enter above and beneath the piston, in which case the pressure being equal upon both its upper and under surface, it receives no impulse or motion from it. The steam finds its way finally into the condenser, from which it expels before it through the valves of the air pump, or a small valve constructed for this purpose, all the atmospheric air which it may happen to contain, and which if not thus driven out would render the vacuum produced by the condensation of the steam imperfect. After the temperature of the cold cylinder and pipes is sufficiently raised, to effect which will require the condensation of a considerable quantity of steam within them,* the engineer again regards the position of the crank in order to cause the engine to turn the machinery connected with it in the proper direction, as for example in steamboats, to cause the paddle wheels to be *turned forward* or *turned back.* If it be required to cause the piston of the engine to make the first stroke by ascending to the top of the cylinder, the upper steam valve 1 and exhausting valve 4 are closed at the same instant,(being attached to the same moveable bar.) The communication between the boiler and the top of the piston is thus cut off, and between the bottom of the piston and the condenser. The lower steam valve 3 and upper exhausting valve 2, also attached to one rod, are suffered to remain open and the jet of cold water is allowed to play into the condenser to form the vacuum. The elastic pressure of the steam will now be exerted against the bottom of the piston to urge it upwards, while at the same time the steam above it will be drawn off into the condenser, and a vacuum will be formed there, and the whole energy of the machine will be thus brought into action.

To ascertain the height of the water in the boiler, which should be kept two thirds filled to prevent the injurious action of the fire, by which it becomes heated red hot when the water is boiled away, two or three cocks are commonly inserted in the side or end of the boiler at different heights, the highest a little above the proper level of the water, and the lowest at the level below which the water should not

* It is stated in the examination of James Brown, before the Committee of the House of Commons on the subject of *Steam Packets,* (see Partington on Steam Engines, page 285) that "the water sometimes collects from the gradual condensation of the steam to the depth of 18 inches upon the top of the piston, and if the engine is started suddenly without its being cleared away, it has no time to get through the thoroughfares. The consequence is that it is jammed between the top of the piston and the under side of the cylinder cover, and risks the breakage of some part; the water not being compressible something must give way"

be suffered to boil away. The intermediate cock may be placed nearly midway between the others to show the average height of the water. When the water is boiled away to such a depth that its surface is below the level of either of the cocks, steam instead of water will issue when they are opened by the engineer to ascertain the state of the water in the boiler.

A body floating on the surface of the water in the boiler, and having liberty to rise and fall with it, has been often employed to operate by means of a wire upon a lever to turn a cock for the admission of a fresh supply of water. In this case the pressure of the head of water to force it into the boiler must be greater than that of the steam to escape from it; otherwise a puff of steam will issue from the orifice instead of the water entering it. The forcing pump, as at H, is for this reason found more certain of operation, and preferable.

The Steam Engine as originally constructed by Watt was used merely to pump water, as it had previously been employed for above fifty years, no invention or plan having at that time been advantageously applied to convert the reciprocating circular motion of the end of the working beam into a regular circular motion, so desirable for moving machinery for manufacturing purposes.* Mr. Watt was anticipated in his plan of employing the crank, now in general use, by Mr. Washbrough, of Bristol, to whom is ascribed the first application of the *fly wheel* to regulate the motion of the steam engine.

Without the aid of the fly wheel to equalise the movements of his engine, Mr. Watt found that each stroke of the piston was made with a velocity continually increasing from the commencement to the

* Before the Crank was introduced, a circular motion was in some instances obtained for manufacturing purposes by drawing the water, raised by the great pump of the engine, upon a common water wheel. At the works of Messrs. Boulton and Watt at Soho, near Birmingham, the superintendent shewed me the old steam engine originally constructed for pumping water from a small pond on the borders of a park, discharging it into a reservoir or mill pond. The water thus raised by the steam engine into the mill pond was made to turn a water wheel constructed in the usual manner, thus converting the reciprocating rectilinear motion of the piston into a continued circular motion for turning machinery. This engine appears to have been preserved as a monument of the ancient state of the machine, and serves to exhibit by way of contrast the important improvements made by the original proprietors of these works. In connexion with these useful improvements of one of the most splendid machines produced by the ingenuity of man, the names of Boulton and Watt will be associated, and perpetuated in every region of the world. To Watt belonged the rare felicity of acquiring both wealth and fame from his inventions; and whilst enjoying the rich pecuniary rewards of his genius and industry, he experienced the still higher reward of being classed among the benefactors of mankind. "The Steam Engine," observes a late writer, "by his admirable contrivances has become a thing stupendous alike for its force and flexibility, for the prodigious power which it can exert, and the ease, and precision, and ductility with which it can be varied, distributed and applied. The trunk of an elephant that can pick up a pin, or rend an oak, is nothing to it. It can engrave a seal and crush masses of obdurate metal like wax before it; draw out, without breaking, a thread as fine as gossamer, and lift a ship of war like a bauble in the air. It can embroider muslin, and forge anchors; cut steel into ribands, and impel loaded vessels against the fury of the winds and waves. It is our improved Steam Engine that has fought the battles of Europe, and exalted and sustained through the late tremendous contest the political greatness of our land. It has armed the feeble hand of man, in short, with a power, to which no limits can be assigned; completed the dominion of mind over the most refractory qualities of matter; aud laid a sure foundation for those miracles of mechanic power, which are to reward the labours of after generations."

termination of the stroke, when it frequently became so rapid under the full accelerating pressure that there was danger of injury to the machinery. To prevent this, and to render the descent more uniform throughout, he caused the part of the machinery which operated to open and close the steam valves to be so altered as to admit the steam to press upon the piston during only one half of its descent, allowing the steam to expand and act upon the piston with a constantly diminishing pressure through the remainder of its descent. This decreasing force of the steam was found in practice to be about sufficient to impel the piston with a uniform unaccelerated velocity. An advantage was also found to attend this contrivance of still greater importance than merely regulating the motion of the piston; for instead of consuming a whole cylinder full of steam at each stroke, only one half of a cylinder full was necessary. Supposing the elastic pressure of the steam against the piston to be 2000 pounds throughout the whole length of the stroke, by closing the valve to prevent the admission of more steam into the cylinder after the piston has completed one half of its stroke, leaving the remainder of the stroke to be accomplished by the expansion of the steam already contained in the upper half of the cylinder, the average pressure will be as follows, according to a calculation made by Dr. Rees.

At the beginning, the power of descent will be	2000 lbs.
At one fourth, the power will be	2000
At one half, the power will still be	2000
At three fourths of the descent the power will be diminished to	$1333\frac{1}{3}$
because the steam must occupy $\frac{1}{4}$ of the length of the cylinder, in addition to that half of the cylinder which it occupied before the expansion began; therefore the space is as 3 to 2, and the pressure being inversely as the spaces, will be $\frac{2}{3}$ of 2000, or $1333\frac{1}{3}$	
At the bottom the pressure will be	1000
because the steam is expanded to occupy twice the space it filled before.	
	$8333\frac{1}{3} \div 5 = 1666\frac{2}{3}$ lbs.

average pressure of the steam through the whole descent of the piston.

By this calculation it appears that one half of a given volume of steam will produce five sixths of the effective pressure, and an equal atmospheric pressure arising from its subsequent condensation, that will be produced by double the quantity of steam when allowed to act upon the piston through the whole length of its stroke. The important saving of power is also thus made by preventing the steam from expending its full force on the crank when it has nearly arrived on its *centre*, whilst the actual quantity of steam required to be condensed is diminished, and the vacuum is more speedily and perfectly obtained. It is somewhat remarkable that until of late few low pressure steam engines in the United States have been constructed to operate upon this principle, which was considered as one of the most important improvements effected by the genius of Watt.

To carry this plan more completely into effect, steam engines have been constructed by Hornblower and Wolf with two distinct cylinders and pistons, the first for receiving the immediate elastic pressure of the steam, and the second for allowing it to expand to the utmost for producing a vacuum and obtaining the force of the atmospheric pressure; in effect combining together, as one machine, the high and low pressure engine.

Mr. Woolf, it is stated at page 74, found from a variety of experiments, that a certain quantity of steam, compressed in a boiler with a weight upon the safety valve of 5, 6, 7 or more pounds on every square inch, may be allowed to expand itself to an equal number of times its own volume, when it will be still capable of filling the cylinder in which the expansion takes place, and will have the same temperature as that of the steam before it began to expand. The most economical mode of employing this principle, it is stated, consists in the application of *high pressure* steam first to a small piston as in common high pressure engines, and after it has acted upon this piston, instead of allowing the steam to escape into the open air where it is dissipated and wasted, it is made to pass into a second cylinder of much larger dimensions, where it is caused to operate upon the same principle as the *low pressure* engine, by condensation and the atmospheric pressure. When the engine is set to work, steam of a high temperature is admitted from the boiler to act by its elastic force upon one side of the smaller piston, while the steam which has already acted upon the other side of it is let off into the larger cylinder, where it is condensed and acts upon the piston in the same manner as in the common low pressure engine of Boulton and Watt, before described. Steam engines constructed upon this plan by Mr. Woolf have been in operation at some of the mines in Cornwall for pumping water, where they have been compared with the engines constructed upon the plan of Boulton and Watt, and monthly statements of the quantity of water raised from the mines by each have been published. According to Messrs. Lear's Report, by one of Woolf's engines having the larger cylinder 53 inches diameter and the smaller cylinder of about $\frac{1}{5}$ of the capacity of the larger one, with the length of stroke 9 feet, the quantity of work performed was on an average of several months equal to about 50 millions of pounds lifted 1 foot high for every bushel of coals consumed; whilst the average work performed during the same period by other engines did not much exceed half of this amount. From this statement there appears to be a remarkable saving of fuel from the use of Woolf's steam engine for pumping water.

Notwithstanding these favourable reports, owing probably to the more complicated structure of the machinery and the necessity of applying extraordinary heat to maintain a proper temperature of the small cylinder, Woolf's engines are not very generally introduced into use. The form of the boilers adopted by Mr. Woolf has undoubtedly contributed greatly to give his engines superiority over all others for economy of fuel. He employs iron tubes arranged horizontally, to give a waving course to the blaze, and to cause it to impinge against the iron tubes successively as it is impelled towards the vent of the chimney by the current of air rushing through the grates of the furnace.

It will not here be attempted to give a sketch of all the various plans which have been suggested for improving the construction of steam engines, since the original improvements of Watt. Some of these plans possess the merit of great ingenuity; but after all the expense which has been bestowed in experiments upon this subject, and, as has been observed by Dr. Rees, " after various kinds of *parallel motions* have been tried,—cylinders have been placed horizontally and inverted;—made of long and of short proportions with large air pumps and small ones; and for the minor parts, such as the valves and the machinery for actuating them, scarcely two following engines have been made alike for many years, until by a vast deal of experience the methods now employed became settled into established forms;—but few of them are superiour to the original of Mr. Watt. Respecting parallel motions, and the proportions of the parts, no methods have been found so good as the original engine. And we accordingly find that all the most established and experienced manufacturers make engines which are not altered in any great feature from Mr. Watt's original engine with a beam and parallel motion acting on a simple crank."

The mode adopted by Messrs. Boulton and Watt for receiving their remuneration was alike remarkable for its ingenuity and liberality. They required only ⅓ *of the saving of coals* effected by their improved engine compared with the best steam engines before in use, leaving the benefit of the remaining ⅔ to the several proprietors. Having ascertained by accurate experiments the quantity of coals on an average consumed by their engines to produce a given number of working strokes, and that their engines required about ¼ of the coals consumed by the old engines to produce the same effect; it only remained to devise some plan to count the number of strokes made by their engines in any given time to form an estimate of the total amount of coals saved, and of the amount due them for their third part. The number of strokes he contrived to ascertain by causing the working beam to operate upon a ratchet wheel, turning it sufficiently at every successive vibration to bring forward a succeeding tooth of the wheel. The number of vibrations made by the beam was thus accurately ascertained by the number of teeth or cogs of the ratchet wheel acted upon by it. One wheel being insufficient to contain a suitable number of teeth to give the result of the strokes made by the engine, unless counted very frequently, he employed a train of small wheel work, fixing upon the axis of the last wheel a moveable hand, traversing a graduated dial plate like that of a clock face, as explained at page 295 and figure 16. This apparatus called the *counter* was locked up, secured by two different keys to prevent deception, one of the keys being kept by the proprietors of the engine, and the other by the agent of Messrs. Boulton and Watt; who went round periodically to open the counters in the presence of the party having the other key to determine the number of vibrations made by the working beam during his absence in order to calculate the quantity of coal consumed, and the consequent saving made of the same. The extent of their profits may be judged from the saving in the expense of coals required for three engines in Cornwall, the proprietors of which agreed to compound for the *third* due for the use of the patent by paying about twelve thousand dollars per year. The total amount of the value of fuel saved by these three engines, therefore, must have been about thirty-six thousand dollars per annum.

It is stated that the patentees expended a sum nearly equal to a quarter of a million of dollars in perfecting their improvements before they received any considerable returns.

The steam engine it appears was first employed in North America about the year 1760, and two engines were erected in New-England before the revolutionary war. At the beginning of the present century no more than four engines of any importance were at work on the whole continent of America. One of the earliest Steam Engines constructed in the United States was erected upon Newcomen's plan at the Hope Furnace in Rhode-Island, where it was used for raising water from the shaft of a pit sunk for obtaining iron ore.

High Pressure Steam Engines.

Steam Engines having a condensing apparatus attached to them to condense the steam for the purpose of forming a *vacuum*, and obtaining thereby the moving force produced by the pressure of the atmosphere, (as explained at page 236) are commonly termed *low pressure*, or *atmospheric* engines. The main dependence for obtaining the moving power in engines of this kind being the formation of a yacuum, it is rare that steam is employed of greater elastic force or pressure than 5 or 6 lbs. on the square inch.* In the *High Pressure* engine the condensing apparatus, consisting of the condensing vessel, cold water pump and air pump, is dispensed with, and the steam after acting upon the piston is allowed to escape in puffs into the open air, where it is dissipated and lost. It is evident that unless this description of steam engine be operated with a much higher pressure of steam than 5 or 6 lbs. on the inch, it would be less powerful than the low pressure engine, which combines this advantage of the elastic pressure of the steam with the still greater advantage of the atmospheric pressure, equal to nearly 15 lbs. more. In fact,

* Some of the best American Steamboats with engines on the low pressure plan operate with 10 or 12 lbs. pressure to the inch, cutting off the steam at $\frac{1}{2}$ or $\frac{2}{3}$ of the stroke.

high pressure engines are commonly operated in England with a pressure of steam of from 50 to 80 lbs. on the square inch, and in the United States very commonly with nearly 150 lbs. on each square inch of the safety valve.*

Although the moving power available from the condensation of the steam is permitted to be lost in the high pressure engine, yet in practice it is found to possess many desirable advantages to compensate for this loss. Being divested of the expensive and heavy condensing apparatus, it is thereby rendered not only a cheap but comparatively light and portable machine, well adapted from the latter circumstance for *locomotive* purposes or for moving carriages on rail roads, or vessels on navigable waters. Some of the comparative advantages in respect to economy of fuel, arising from the use of high pressure steam, have been mentioned when treating upon the sub-

* The boiler of the steamboat Ætna was burst near the city of New-York, in the year 1824, by a pressure probably much greater than 200 lbs. on the inch, or by a stress of above 28800 lbs. against each square foot of the plates of iron of which the boilers were constructed. Having performed a passage in the steamboat Ætna the day before this calamity occurred, by which the lives of a considerable number of the passengers were instantaneously destroyed, I was induced to enter into conversation with the engineer upon the subject of the steam with which he was operating, by observing the remarkable effects produced by it when the valves were opened on starting from the wharf. The action of the steam when first allowed to rush from the boiler upon the piston appeared to be exceedingly violent, causing the whole fabric of the boat to tremble in every joint as if struck by a cannon shot. After the accident the boat floated like a wreck upon the water, as completely shattered as if a magazine of gunpowder had been exploded within it. The boilers formed of thick plates of malleable iron, appeared to have first given way upon the under side, where weakened by exposure to the fire. The steam being discharged into the furnace beneath the boilers, the reaction caused the boilers to recoil, throwing them out of their places, and breaking away all the iron fastenings by which they were secured, and throwing fragments of the metal with irresistible force through the wheel house and in other directions. The bottom of the steamboat immediately beneath the boilers appeared to be entirely cleared of every fixture and swept clean even of the very ashes collected between the timbers. The boiler of a high pressure engine which was burst several years since at Pittsburgh was caused to rise in a similar manner by the reaction of the steam from the brick work of the furnace beneath it, which thus served like a mortar to project the boiler, weighing several tons, upwards through the roof of the building to a height of above 100 feet into the open air.

Although the stress sustained by the boilers of the high pressure engines so greatly exceeds that to which the low pressure engines are subjected, yet they are constructed proportionately stronger, and with due care are not much more dangerous. The common fault is that engineers, in their blind zeal to cause these machines to achieve some remarkable performance, impose upon them a stress greater than originally calculated for them to bear with safety; or they carelessly suffer the water to become nearly exhausted, and the boilers to become heated red hot above the water line. In the latter case when the injection pump is put into operation a very great supply of steam is rapidly produced by the contact of the water with the red hot metal, which in this softened state is subjected to a stress that takes place too suddenly to be effectually relieved by the safety valve. From either of these causes the low pressure engines are quite as liable to be burst as high pressure ones; and there are instances of accidents of this nature happening to each. A fine new copper boiler of a low pressure engine was burst, two or three years since, at Jersey City opposite the city of New-York. The explosion, however, of the latter description of boilers is not usually attended with consequences so disastrous as when the boilers of high pressure engines explode. Having had opportunities of examining the broken remains of boilers of both kinds of engines after being burst by steam, I observed that the sheets of copper and iron of the low pressure boilers appeared merely to be torn in various directions from the weak point which first yielded, being apparently rent like cloth. Pieces of the high pressure boilers, on the contrary, were entirely severed and driven off in fragments with the force of an exploded bomb. In the rupture of the low pressure boilers the principal danger appears to result from the steam and scalding water discharged from the rents formed in the sheets of metal.

ject of *steam* at page 74. Where there is not a sufficiently abundant supply of water for the purpose of condensing the steam of a low pressure engine, a high pressure one may be used; as it requires only water enough to keep the boiler replenished.

High pressure steam was early used for mechanical purposes by means of the *Elopile*. The blast of steam discharged from a small pipe, mingling with the air through which it passes, forces a strong current upon the ignited coals and thus renders the fire more intense.

Small floats fixed upon a light wheel and interposed before the orifice of discharge, to receive the impetus of the rushing current of steam, were found by Brancas to produce a rapid rotatory motion.*

Leopold, it is stated, about the year 1720, combined the condensing or vacuum engine of Newcomen with the high pressure principle of the Marquis of Worcester, and produced the *first high pressure* engine worked by a cylinder and piston. Messrs. Trevithick and Vivian constructed at a subsequent period a portable high pressure engine remarkable for its peculiar lightness. Oliver Evans, who is called by a late European writer, the Trevithick of America, has taken the lead in introducing high pressure engines into use on this side of the Atlantic. His engines are constructed to work with a load of 120 lbs. to the inch, and to cut off the admission of the steam upon the piston when it has performed from ¼ to ⅓ of its stroke. Many of the steamboats which ascend the Mississippi, and the other great rivers of the western states, have steam engines operating upon this plan.

It was ascertained by Papin, as before stated, that by confining water in close strong vessels, it is practicable to raise the temperature of it to almost any required extent, limited only by the strength of the boiler to resist its expansible force. Were it possible to confine water in a vessel heated red hot, the water within it would acquire the same heat, and would then possess a temperature sufficiently high to convert the whole of it instantaneously into steam of the common temperature of 212°, if in this state it could be poured out of the boiler into an open vessel. Mr. Perkins has attempted to carry this principle into effect by making a small boiler of copper, 3 inches thick and of the capacity of about eight gallons, capable of resisting an internal pressure of 4000 lbs. on the square inch. Instead of allowing the steam to rise freely from the water, as takes place in common engines, he fixed in the passage of the pipe conducting from his small boiler to the engine, a safety valve loaded with about 500 lbs. on the inch, and kept the boiler completely filled with water. In

* This simple plan was adopted as a substitute for the Kitchen Jacks once in common use, and a patent was obtained for this application of it in the United States. Sufficient steam was generated in a boiler, of about the size of a tea kettle, to turn the spit. The success of the invention was flattering to the patentee for a short time, until one of his boilers burst with a loud explosion, destroying divers parts of the culinary apparatus, and scalding the cook. The report of the disaster spreading rapidly, threw the whole fraternity into consternation, who afterwards regarded the invention itself as "death in the pot," and refused with one accord to co-operate at the same fireside with so dangerous a helpmate.

this manner he was able to heat the water to four or five hundred degrees of the common thermometer. When the boiler had attained this temperature a small quantity of water was forced into it by means of the forcing pump, whereby an equal quantity was forced out through the safety valve, lifting it with its weight of 500 lbs. on the inch. Immediately after escaping through the valve the water expanded (or *flashed* as Mr. Perkins terms it) into steam of an enormous pressure, which he made to act upon the piston in the ordinary manner. Mr. Perkins has displayed much ingenuity in the plan and construction of his boiler or *generator*, and in the mode of operating with it; but his improvements seem to be noticed rather for the mechanical ingenuity displayed in them, than for any successful result that has attended them. To heat the water sufficiently hot to *flash* into steam would require a temperature of nearly 1200° of heat, being double the heat actually employed by Mr. Perkins. The subject of cooling steam and returning it in this state to the boiler has already been treated of at page 73, (*see elastic pressure of steam.*) There is no difficulty attending the use of steam of the extremely great elastic force employed by Mr. Perkins; but the great difficulty appears to be in generating it in the small boilers employed by him as fast as required for use. When I saw Mr. Perkins' high pressure engine in operation in London in 1825, in addition to the generator there appears to be a number of small tubes arranged in the furnace to aid the generator in furnishing steam; and even with this aid the engine appeared to operate feebly, its movements being very sensibly retarded by throwing into gear a common turning lathe. Although two years had elapsed from the date of his patent, yet I could not ascertain that a single engine upon his plan was in operation in England, except in his own machine shop.

A moveable cylinder has been used to allow of the more immediate action of the piston rod upon the crank without the intervention of the beam or cross bar and slide. One end of the cylinder is secured by trunnions resembling those of a mortar or cannon, while the other end of the cylinder is permitted to follow the motion of the crank to which it is connected by the piston rod. The principal objection urged against this plan is the risk of bending the piston rod and the unequal wear of the piston.

Rotative Steam Engine.

The great loss of power resulting from the reciprocating movement of the piston of the common steam engines, in the operation of which it is necessary alternately to put in motion and bring to a state of rest the mass of inert matter contained in the working beam, piston rod, &c. has rendered it very desirable to apply the steam directly to turn a wheel, as water is applied to turn a water wheel, in order to produce at once a continued circular motion without the intervention of the beam, crank, and fly wheel. Numerous plans have been devised for accomplishing this object by causing the steam to act in various ways upon the moveable floats of wheels revolving in a tight drum or case. The circular motion has been readily obtained, but the experiments have all failed, principally from the difficulty of causing the floats to revolve steam tight without essentially impairing the operation of the machine by friction.

Should a rotative steam engine require even a greater comparative expense of fuel than the reciprocating engine, it might notwithstanding be preferable, on account of its peculiar lightness, and the simplicity of its operation, to all other steam engines for moving carriages upon rail roads and for other locomotive purposes.

At the coal mines in Rhode-Island, a small rotative steam engine has been in operation for pumping water. The steam is caused to operate upon twenty or thirty small wheels fixed upon a vertical axle, and inclosed in a steam tight drum or case. Each wheel is separated from the one below it by an intervening plate of metal. These plates are pierced with small holes in a diagonal or sloping direction to guide the current of steam as it descends from one steam chamber to another, acting by its impetus in rushing through these small holes against notches formed beneath them in the sides of the revolving wheels. This principle of the application of steam is similar to that already described as first employed by Brancas to turn a single wheel by discharging the jets of steam against the floats. A much greater power is obtainable from the impetus of the steam in this engine than any one would suppose, judging from the weight or momentum of the steam which impinges against the notches of the wheels. This power is principally attributable to the wonderful velocity with which under a considerable pressure steam moves, causing these steam wheels to make a great number of revolutions in a second. In proportion as the velocity of motion becomes reduced by a train of wheels and pinions, the power becomes increased. A wheel revolving with feeble power at the rate of two or three thousand turns per minute is capable of producing a very effective leverage impulse in turning the last of a train of wheels with a velocity of only 60 or 80 revolutions per minute.

In some of the English Steamboats instead of employing a single engine of great power two smaller engines of equal aggregate power are employed, both acting upon cranks upon the same shaft, so arranged that when one engine is exerting its full force in turning it the other is changing its direction, and the result of their joint action is a force nearly constant. In steamboats which are destined to navigate boisterous seas or bays, two steam engines are generally preferred to one of equal aggregate power on account of the chances of accidents. One of the finest American steamboats has actually made a regular trip with the aid of only one engine, whilst the other one was out of order.

It is calculated that in English steam navigation the weight of engine, coals and water for ordinary passages averages about 1½ tons to the horse power.

Portable Steam Engines.

Portable Steam Engines are frequently employed in pumping water for draining foundations, and for accomplishing various other operations of a temporary nature, for which the labour of a number of horses is ordinarily required. This description of engine is so constructed as to be very light and at the same time powerful, and moveable with facility from plaee to place, wherever required for use. The furnace is formed within the boiler itself, and consequently no expense is necessary for setting them in brick work. In whatever situation they are located they are ready for operation as soon as the steam pipe is connected with the cylinder, and the machine rendered firm on its base.*

Proportions of the parts of Steam Engines.

Boilers. The boilers of English Steam Engines are of various forms. They are frequently constructed of the form termed " wagon shaped," or with flat bottoms and round tops proportioned as follows : Width 1. Depth 1.1. Length 2.5. They are also constructed with flues for the fire to pass through them, and with the furnaces also within them. The latter description of boilers are peculiarly well adapted for steamboats, as the water is made to surround the furnace and to intercept the heat, which might otherwise endanger the wood work of the vessel.

Most of the high pressure steam boilers in the United States are cylindrical, formed of plates of iron ⅜ of an inch thick. When one cylinder is not sufficient to supply the requisite quantity of steam, two or more cylinders about thirty inches diameter and twenty or thirty feet long are employed, connected together by steam pipes. The strength of these iron boilers is greatly increased by the cylindrical form given to them, and by their diminished diameters. A

* In Paris, where taste and fashion seem to extend their influence even to mechanical contrivances, I have sometimes stopped to view small engines of less than one horse power in full operation at the windows of shops where freshly ground chocolate is vended. To insure the freshness of the quality of their favourite beverage the customers of such shops are enabled to enjoy the satisfaction of having the cocoa ground and prepared under their personal inspection, whenever their zeal in the science of Gastronomy prompts them to be thus particular. Some of these small portable steam engines are truly beautiful specimens of mechanism, being constructed of polished steel and brass and decorated with ornamental pillars and capitals of these metals, which appear tremulously glittering in the sunbeams at every stroke of the machine, the whole apparatus being doubly reflected by the surrounding mirrors. The movements of one of these little steam engines, thus exhibited, appear magical, usually serving to attract and amuse a crowd of spectators who stop for a few moments to gaze at them as they pass.

Beautiful little models of steam engines of about a " mouse power" are made by the mathematical instrument makers of London with boilers complete, weighing only a few pounds. These small portable steam engines are used by lecturers to illustrate the principles of this branch of science.

riband of iron an inch wide forming the circumference of a boiler of 30 inches in diameter evidently exposes a less surface to the pressure of the steam than a similar riband of iron forming the circumference of a larger boiler. The strength of the best iron (see strength of materials, page 26) being capable of sustaining a stress, tending to break it by pulling it asunder endwise, equal to that produced by a weight of about 800 lbs. for every eighth of an inch of its sectional area or square measure, the strength of a riband of iron ⅜ of an inch thick and 1 inch broad may be found as follows.

$8\times3=24\times800$ lbs.$=19200$ lbs. required actually to break the ring of iron ⅜ of an inch thick and 1 inch wide, if made of the best iron and free from flaws. Oliver Evans calculates the stress produced by the steam upon a similar ring or section of a cylindrical boiler to be *as its diameter multiplied into the lbs. pressure on each square inch.* A boiler of 30 inches diameter, having a pressure of 200 lbs. on the square inch would by this mode of calculation be $=30\times200=6000$ lbs. stress produced by the steam to break the iron which is only about ⅓ of its ultimate strength. This riband of iron forming a circular ring of the boiler, is at the same time subjected to a transverse stress produced by the pressure of the steam against the cast iron ends of the cylinder. To calculate this stress, find the area or number of square inches of surface of the end of the boiler by Rule 2, Problem IX, (page 121) and multiply the number of square inches area by the pressure against each square inch. The pressure of steam of 200 lbs to the inch against the head of a boiler 30 inches diameter will thus be found to be 141400 pounds ($30\times30\times.7854=707$ inches area$\times200$ lbs. pressure$=141.400$ lbs.) By Problem VII. the circumference of a cylinder 30 inches in diameter is found to be 94 inches. 141400 being divided by 94 gives 1500 lbs. stress to draw asunder in a lateral direction the fibres of iron contained in each inch of the circumference of the boiler. This stress tending to destroy the lateral cohesion of the fibres, instead of breaking them by drawing them endwise, operates probably as severely upon the strength of the best iron as the stress of 6000 lbs. taking effect longitudinally, the chances of flaws in this direction rendering the tenacity of the metal much less certain. It is indeed the chance of some flaw or imperfection on the sheets of iron which must render the calculations of the strength of high pressure boilers at best very uncertain. The strength of a boiler should be actually tested by experiment with a forcing pump. (*See methods of proving the strength of vessels, pipes, &c. by the pressure of water, page* 186.) Care should however be taken in fixing upon the standard for proving the boiler. If the proof be too severe the very precaution to insure safety may be the means of weakening and causing the subsequent destruction of the boiler; but it is safest to prove a boiler with a pressure much greater than that at which it is intended to operate it. As in the case of the strength of the wood used in carpentry, not above ¼ of the stress required actually to break the metal should be assigned as a permanent load in practice.

One of the safest kinds of high pressure boilers has been invented by Mr. Babcock of Rhode-Island, and used for the purpose of steam navigation. Several strong iron tubes are inclosed in the brick work of a furnace, and are kept nearly at a red heat therein. The steam is generated by injecting the water into these empty heated tubes by means of a small forcing pump, a sufficient quantity being forced in at each stroke of the pump to form the necessary quantity of steam consumed at every stroke of the engine. Whilst the tube partially cooled by the injection is regaining its heat, the water is successively injected into the other heated tubes arranged in the furnace, until in turn the tube first used is again employed. The steam being thus formed only in very small quantities, and consumed at each stroke as fast as it is formed, should any of the tubes be burst the destructive effects must be very circumscribed; and consequently the risk of danger must be equally diminished. One of the principal disadvantages of this boiler arises from the very circumstance that contributes to safety,—a scanty supply of steam.

Mr. Wadsworth of Rhode-Island has also constructed very safe and convenient high pressure engines with boilers formed of a great number of strongly rivited iron tubes about 5 inches diameter, and 5 or 6 feet long, connected at one end with a strong wrought iron chest or trunk serving as a reservoir for the water and steam. The tubes are arranged in alternate layers in the brickwork of the furnace, in a manner the most favourable for intercepting and receiving the heat. Metallic valves are fixed at the junction of each tube with the reservoir to prevent, by being instantly closed, the escape of the water or steam from the reservoir should any one of the tubes be burst, or otherwise accidentally fail. In no other form of boiler, occupying the same space, is there an equal extent of surface exposed to the action of the fire. These tubular boilers if made of considerable length might answer for operating small engines with anthracite coal.

When boilers are to be used for steam navigation upon salt water they are often constructed of copper to resist the corroding qualities of the strong brine, which becomes concentrated within them after a short time. Iron boilers, it is stated by an English writer, will not last more than 4 or 5 years if used with sea water. To prevent the concretion of the salt in masses upon the bottom and sides of them, it is recommended to use mashed *potatoes*, in quantity about one per cent. of the weight of the salt water. Iron boilers used with fresh water are very durable. Boilers of this description about 25 feet long and 30 inches in diameter, have been in constant use at a bleachery in Providence more than fourteen years, for the greater part of the time without intermission by night and day, without requiring material repairs, and are still in use. The fuel consumed under them was pine wood.

Boilers are provided with a safety valve to prevent the force of the steam from bursting them, and with a *vacuum valve* to prevent their being crushed in by the atmospheric pressure should the steam contained above the boiling water be condensed. (*See vacuum valve, page* 68.)

Messrs. Boulton and Watt in constructing these boilers allow 25 cubic feet of space for each horse power. Other English engineers allow 5 feet of surface of boiling water, the fuel being coals.

Furnace. In the arrangement of the grates and form of the furnace a great variety of plans are adopted. The principal object in all is to bring the current of air in contact with the burning fuel to render the combustion perfect, and then with the boiler to impart to it the heat generated by the combustion of the fuel. Whenever thick black smoke arises from the chimney top it is an evidence that the furnace is either badly formed, or that the fireman is wasting the fuel by crowding too much at once into the furnace.* Brunton's circular revolving fire grates turned by the machinery of the engine, and supplied uniformly with coals by means of a hopper (*see page* 90) has been found to succeed well in England in producing a regular fire without smoke. One of these revolving grates lately constructed beneath a steam boiler in Providence appears to have failed of answering the purpose for which it was intended from the difficulty of keeping the grate clear of cinders, by which they became so much clogged as to materially impede combustion.

As a general rule it should always be observed that grates of all kinds of furnaces should be placed sufficiently high above the bottom of the ash pit to prevent the heat, ascending from the coals and embers which fall beneath them, from causing them to become warped out of shape. If grates be made thin and deep, and be placed out of the reach of the heat ascending from the embers beneath, the glowing fire above will rarely injure or destroy them.

Working beam. The length of stroke being 1, the length of beam to the centre will be 2, the length of crank .5 and the length of connecting rod 3. In order to sustain the great stress that takes place upon this beam, it is necessary to make it very strong. To obtain the requisite strength it is commonly formed of a great mass of metal weighing, it is stated, for an engine having a cylinder 52 inches diameter about 3½ tons. This mass must be put in motion in half a second, and receive a velocity of about 3 feet per second, it must then be brought to a state of rest, again into motion and again to rest, to complete one entire revolution of the crank. This consumes much power, to save which and at the same time to ensure the necessary degree of strength some of the latest American steamboats are provided with Working Beams to their engines formed of wrought

* The same result takes place on a small scale in trimming a lamp. If the wick be lifted too high more oil is furnished than can be combined with the draught of air, and the unconsumed portion of the oil rises in the state of a fine charcoal, and when collected forms *lamp black*. In domestic economy it is not however so much the waste which takes place in this case, that is objectionable, as the pernicious effects of the floating particles of soot with which the air of an apartment soon becomes loaded. It appears by the report of a coroners' inquest holden in Massachusetts upon the body of a man found lifeless in an apartment of an hotel, that he was actually deprived of life or suffocated by the smoke arising from lamps left burning when he retired to bed.

iron, rendered light by open work arranged with due regard to the direction of the stress. In the operation of large steam engines the loss of nearly a one-horse power may be averted in this way.

Length of stroke. The stroke of an engine is equal to one revolution of the crank shaft, but when stating the length of stroke the length of the cylinder only is given; that is, an engine with a three feet stroke has its cylinder 3 feet long, besides an allowance for the thickness of the piston.

"The following table shows the length of stroke, (or length of cylinder,) and the number of feet the piston travels in a minute, according to the number of strokes the engine makes when working at maximum.

Length of stroke.	Number of strokes.	Feet per minute.
2	43	172
3	32	192
4	25	200
5	21	210
6	19	228
7	17	238
8	15	240
9	14	250

Valves. The diameter of the valves of Nozles ought to be fully one fifth of the diameter of the Cylinder.*

Air Pump. The capacity of the air pump should be equal to one fourth of the capacity of the Cylinder.

Condenser. The condenser is generally made equal in capacity to the air pump; but when convenient it ought to be more, for when large there is a greater space of vacuum, and the steam is sooner condensed.

Cold Water Pump. The capacity of the cold water pump must depend on the temperature of the water. When the water is at the common temperature each horse power requires from 5 to 7½ gallons per minute, the latter quantity being preferable where water can be conveniently obtained. Taking this quantity as the standard the size of the pump is easily found by the following rule, viz. Multiply the number of horse power by 7½ gallons and divide by the number of strokes per minute. This will give the quantity of water to be raised at each stroke of the pump. Multiply this quantity by 231 (the number of cubic inches in a gallon) and divide by the length of effective stroke of the pump and the quotient will be the area, or number of superficial square inches contained in the surface of the piston.†

* For high pressure steam engines the *Four Way Cock* is frequently used, which as its name implies serves instead of the four valves usually employed.

† Before selecting a spot for erecting a steam engine it is a most important consideration to make thorough examination for the purpose of ascertaining if the requisite supply of water can be obtained for the boiler and condenser, a failure in this respect being as prejudicial as a drought to a water mill. It is common in many places in England, where the supply of water is not abundant, to form reservoirs, 50 or 100 feet square and 4 or 5 feet deep, to receive the hot water from the condensing apparatus. In this small pool the

Hot Water Pump. The quantity of water raised at each stroke ought to be equal in bulk to the 900th part of the capacity of the cylinder.

Fly Wheel. The use of the fly wheel has already been described. The Rule for finding its weight, is,—Multiply the number of horses' power of the engine by 2000, and divide by the square of the velocity of the circumference of the wheel per second, the quotient will be the weight in cwts.

EXAMPLE.

Required the weight of a Fly Wheel proper for an engine of 20 horse power; the fly to be 18 feet diameter and making 22 revolutions per minute?

18 feet diameter=56 feet circumference $\times$22 revolutions per minute=1232 feet motion per minute$\div$60=$20\frac{1}{2}$ feet motion per second; then $20\frac{1}{2}^2=420\frac{1}{4}$, the divisor.

20 horse power$\times$2000=40 000 dividend.

40 000$\div 420\frac{1}{4}$=90.4 cwt. weight of wheel.

The *Parallel Motion* and *Governor* have been described.

Modes of calculating the power of Steam Engines.

When Boulton and Watt first introduced their steam engines into use horses were very generally employed in the various works or manufactories not operated by water power. The proprietor of any of these works after determining to substitute a steam engine in place of horses could only state the number of horses which he had been in the habit of employing, and specify in his orders that he required a steam engine possessing a power equal to that of a certain number of these animals. To comply with these orders Messrs. Boulton and Watt were therefore under the necessity of first ascertaining the power of a horse, and then assigning a certain equivalent standard of power to their machines. The most ready mode of trying the strength of a horse appeared to be the raising of heavy weights over a pulley. By experiments with the strong horses employed in the London Breweries they estimated the power of a horse sufficient to raise 32000 or 33000 lbs. 1 foot high in a minute, or a weight of

water is allowed to remain exposed to the open air until it becomes sufficiently cool to be again used in the condensing apparatus. One of these reservoirs of warm water in Leeds appeared to be remarkably stocked with fish of various kinds. They were probably furnished with an abundance of food from the oil and tallow used for the packings of the steam engine, mingled with the condensing water and discharged with it. The warm water remaining on the surface of the pond the fish occupied the lower part, from whence I saw one or two bushels of fish taken out at one draught of a seine.

It is also necessary to consider the situation of the springs calculated to be depended upon for furnishing water, as they may be so located as to be cut off or exhausted by some neighbouring proprietor. An instance occurred in Leeds, in which the proprietors of two extensive manufactories, in their competition for obtaining water, continued to bore to a depth of two or three hundred feet to regain the water from each other.

150 lbs. by a rope passing over a pulley, the horse travelling at the ordinary pace of 2½ miles per hour, or 220 feet per minute.*

In assuming the extreme power of the strongest horses as a standard, they never disappointed the purchasers of their engines by furnishing them with machines of inadequate force for accomplishing the labour of the number of horses to which they were warranted to be equal. This gave rise to the mode of estimating the effective force of Steam Engines by the *Horse Power.* Other Engineers, as before stated at page 146, found that ordinary horses could only raise a weight of about 100 lbs. over a pulley when travelling at the rate of 2½ miles an hour or 220 feet per minute and working 8 hours per day. The actual force exerted in this case was found to be equal to 22000 lbs. raised one foot high in a minute. Another engineer fixed upon still another standard, estimating the horse power at 27500 lbs. raised one foot high in a minute. By means of so many different standards for estimating the horse power, much confusion and irregularity has been introduced, and purchasers of steam engines are frequently perplexed in their calculations, particularly when it is stated that the steam from the boiler is to be made to act with a considerable elastic pressure on the square inch more than that of the atmosphere. The horse-power as applied to steam engines being merely a conventional standard for estimating the moving force of the machine, it appears to be of little importance whether it represents the average force exerted by a common horse or not; but it is of great importance that one standard or mode of calculation should be exclusively adopted, otherwise most vexatious disappointments and losses must frequently ensue. Judging of the value of these costly machines by this standard, purchasers are liable frequently to be deceived in the prices they pay for them, as well as in the quantity of work performed by them. The different modes of calculating the Horse power will therefore be given.

The standard of the horse power of a steam engine being taken at a force sufficient to lift 33000 lbs. 1 foot high in a minute, it is manifest that a much greater force must be applied to put the steam engine in motion. The machine itself consumes about ½ of the estimated moving force that acts upon it merely to keep it in motion, and only the remaining ½ is disposable, or available in raising 33000 lbs. one foot high in a minute. The calculation of the theoretical pressure upon the piston is sufficiently simple, bnt the difficulty consists in making proper allowance for the quantity of moving force consumed by the machine itself, in order to ascertain the amount that will be left free and at the disposal of the engineer. Although the atmospheric pressure upon the the piston is estimated at about 15 lbs. on each square inch, yet so imperfect is the vacuum usually formed by

* 528 cubic feet of water, weighing 62½ lbs. each, equal to 33000 lbs, raised 1 foot high also represents a horse power.

The power of an ordinary man has been found by a great number of accurate experiments to be equal to raising 1 cubic foot of water one foot high per second, or 60 cubic feet weighing 3750 lbs. 1 foot high per minute.

the condensation of steam in the condenser, that the actual pressure is found to be only 11 or 12 lbs. on the inch in practice. The power consumed in moving the great Air-Pump, and in overcoming the inertia of the masses of metal forming the Working Beam, Piston Rods, &c. absorbs about one half of the whole moving force applied upon the Piston. Even in the calculation of the effective power of the common Water Wheel, which is a machine of the simplest kind, operating in the most simple manner, with a continued circular motion, ⅓ of the moving force of the weight of water applied in the buckets is considered as lost, without the possibility of rendering it in practice available for turning machinery.* Were the loss of power by friction and otherwise always uniformly and proportionately the same in amount in engines of all sizes, one general rule might be applied to calculate their effective horse power. But it is found that the friction and loss of power is comparatively much greater in small steam engines than in those of large dimensions, the difference of waste being one fifth greater in small engines than in large ones. For this reason the estimate of the effective power of steam engines should be made by means of a Scale or Table, rather than by any general Rule of calculation, wherein no distinction is made in computing their power.

The general rule given in Brunton's compendium of Mechanics is probably the most correct for calculating the effective power of the low pressure engine under 50 horse power. This Rule, with two others, one from Dr. Brewster's edition of Ferguson's Mechanics, and the other from Nicholson's Operative Mechanic, will here be stated, that the reader may have a view of the various modes given by different writers for calculating the effective power of a steam engine, as well as the various standards of *Horse Power* adopted by them.

The immediate moving force of the steam being applied against the surface of the Piston, pressing upon it, as has been before stated, with a certain force on each square inch, it must be evident that the greater the number of square inches contained in the surface or area of the piston the greater will be total amount of pressure upon it. If the piston thus acted upon be attached to one end of a beam balanced on its centre, and the weight to be raised be hung upon the other end of it, if the piston descend 5 feet it must elevate the opposite end of the beam 5 feet, together with the load hung upon it. This is the simplest expression of the power of a steam engine, showing that the power is in the compound ratio of the area of the piston and length of stroke, or the distance it travels in a minute.

Brunton's Rule for calculating the power of Steam Engines. Multiply the area of the Piston by the effective pressure = 10 lbs. the product is the weight the Engine can raise—Multiply this weight by the number of feet the piston travels in one minute, which will give the momentum or weight which the engine can lift one foot high

* The best water wheel cannot be made to raise by a common pump a greater quantity than ⅓ of the water that operates upon it, to the level from which it falls.

per minute; divide this momentum by 44,000 and the quotient will be the number of horse power to which the engine is equal.

EXAMPLE.

What is the power of an engine, the piston (or cylinder, to which it is fitted closely) being 24 inches in diameter, and the stroke 5 feet, making 20 double or 40 single strokes per minute?*

24×24×.7854=452 square inches of surface of the piston exposed to the pressure of steam. This number of inches being multiplied by 10 pounds, the estimated pressure on each square inch, the quotient will show the total pressure upon the piston, 452×10=4520 lbs. The piston making 40 strokes per minute of 5 feet each moves 200 feet per minute. The piston therefore moving with this velocity and impelled by a pressure equal to 4520 lbs. represents theoretically an equal weight lifted 200 feet high, or 4520×200=904000 lbs. raised 1 foot high in a minute. This momentum being divided by 44000 gives the Horse Power according to Brunton's estimate =904000÷44000=20$\frac{24}{44}$; or about 20½ *horse-power* is the effective power of this steam engine.

Dr. Brewster multiplies the area of the piston=452 square inches by 12 lbs. pressure upon every square inch (instead of 10 lbs. as by Brunton's Rule) and divides the momentum by 33000 (instead of 44000 as in the preceding Example.

This calculation gives the following result: 452 square inches, area of a piston 24 inches diameter, × 12 × 200 = 1,084,800 momentum ÷33000=32⅞ *horse-power* according to Dr. Brewster.

Nicholson gives the following mode of calculation. "It has been generally set down among engineers, that nearly one half of the power of steam must be deducted from the disposable force; therefore suppose an engine of 24 inch piston, the area of which will be 452 square inches, has a perfect vacuum as indicated by the barometer of the condenser, and the weight of the atmosphere, denoted by the weather-barometer, be about 15 lbs. and the steam gauge on the boiler stands at about 2 inches, which is an indication of about 2 lbs. pressure on the square inch, we may estimate that there is 17 lbs. pressure per square inch upon the piston. Therefore 17×452= 7684 lbs. on the piston, *half* of which being deducted for allowance for friction, leaves a disposable force of 3842 lbs. moving through the distance at the same rate in which the piston moves; which force being divided by Messrs. Boulton and Watt's estimate of a horse-power, will give the nominal power of such engine. In high pressure engines, where the steam is not condensed, what is indicated by the steam gauge of the boiler only must be estimated as the pressure acting upon the piston." 3842 lbs. effective pressure × 200 feet the distance travelled by the piston per minute=768400 momentum ÷33000=23¼ horse power, very nearly, as estimated by Nicholson.

Taking the same data for calculation it thus appears that very dif-

*The Piston being circular, to find the number of square inches contained in its area, multiply the square of its diameter in inches by the decimal number .7854 (see Rule 2, page 121.

...rent results are given of the estimate of the effective power of a steam engine.

A low pressure steam engine with a 24 inch piston moving at the rate of 200 feet per minute is rated

According to Brunton		at	20½	horse-power.
	Dr. Brewster	"	32⅞	"
	Nicholson	"	23¼	"
According to the following table		"	20	"

When there is such a discrepancy among the best writers, it is not surprising that there should also be a great chance of disagreement on this subject between those who purchase steam engines and those who manufacture them. By adopting the lowest standard and mode of calculation an engine of much smaller dimensions and inferiour value may be substituted in place of the one required. The following Table of Dr. Rees' will show that the effective power of steam engines is not increased in a regular ratio with the increase of size of the cylinders, although the pressure on each square inch may be the same. "Experience and custom has established that certain sizes of cylinders will be equal to a certain number of horses' power."

" The steam in the boiler is supposed to be kept within the limits of from 2 to 4 lbs. pressure on each square inch more than the atmospheric; in this case the cylinders of the diameters marked in the Table will have very nearly the powers assigned to them."

It should be particularly observed that this Table designates steam Engines to be of a certain horse-power when working with steam averaging about 3 lbs. pressure on each square inch in addition to the atmospheric pressure. If a steam engine with a cylinder of the same dimensions as expressed in the table work with a greater pressure than 3 lbs. on the inch, this additional pressure goes to increase the working power of the engine, and one of somewhat smaller dimensions or of lower standard power will answer. In this case to calculate the additional horse power ⅝ of the excess of pressure over 3 lbs. to the inch may be added to the effective power of the engine. Thus if a 20 horse power engine be operated with 6 lbs. pressure of steam instead of 3 lbs. the excess will be 3 lbs. Multiply the area of the piston by 3 and this product by the velocity per minute of the piston, and divide the product by 33000, the quotient will be nearly the additional power of the engine. If the steam be cut off when the piston has performed only ¼ or ½ its stroke allowance must be made, as per page 323.

It is usual, Dr. Rees observes, with engine makers to calculate the velocity of the pistons of engines at 220 feet per minute; but we have rarely found them to come up to this in practice, and have therefore calculated them at less." If the velocity of the steam piston be found to be greater or less than in the table, the effective pressure upon each square inch of the piston must be diminished or increased in proportion, or else the power, of the engine will be different although the cylinder remain the same.

A TABLE of the Dimensions of Mr. Watt's Steam-Engines, shewing their different Powers, either to raise Water by Pumps, or to turn Machinery by Cranks and Fly Wheels.

Nominal Horse Power.	Dimensions of the Piston.			Effective Pressure or Load on the Piston.		Velocity of the motion with which the load is raised.			Mechanical effect expressed by the weight which can be raised in a Minute to a height of one foot.		Consumption of coals in an hour, in pounds weight.
Of double acting Steam Engine.	Diameter in Inches.	Area in square inches.	Number of square inches for each Horse-Power.	Pressure on each square inch in Pounds.	Load on the Piston in Pounds	Length of the stroke in feet	Number of strokes per minute	Velocity of the piston per minute in feet.	Cubic feet of water.	Pounds Avoirdupois.	By each Horse power.
1	6.0	28	28.0	7,	199	1⅔	50	166⅔	528	33,000	20,7
2	8.3	54	27.4	7,2	392	2	42	168	1,056	66,000	15,6
4	11.6	106	26.5	7,3	777	2½	34	170	2,112	132,000	13,8
6	13.9	152	25.4	7,0	1070	3	31	185	3,168	198,000	12,2
8	15.9	199	24.9	6,9	1389	3½	27	190	4,224	264,000	10,5
10	17.7	245	24.5	7,	1718	4	24	192	5,280	330,000	10,0
12	19.2	288	24.0	7,1	2062	4	24	192	6,336	396,000	9,8
14	20.6	332	23.7	7,1	2357	4½	22	196	7,390	462,000	9,0
16	21.75	373	23.3	7,1	2666	4½	22	198	8,448	528,000	8,7
18	23,0	412	22.9	7,2	3000	4½	22	198	9,504	594,000	8,5
20	24.0	452	22.6	7,3	3300	5	20	200	10,560	660,000	8,3
24	26.1	532	22.2	7,4	3960	5½	18	200	12,672	792,000	7,8
30	28.7	645	21.5	7.6	4897	6	17	204	15,840	999,000	7,2
34	30.3	721	21.2	7,49	5500	6	17	204	17,952	1,122,000	7,0
40	32.6	832	20,8	7,6	6346	6½	16	208	21,120	1,320,000	6,7
44	34.	906	20.6	7,7	6980	6½	16	208	23,232	1,452,000	6,5
50	36.	1020	20.4	7,7	7857	7	15	210	26,400	1,650,000	6,2
60	39.2	1206	20.1	7,8	9428	7½	14	210	31,680	1,980,000	5,9
70	42.	1386	19.9	8,0	11,106	8	13	208	36,960	2,310,000	5,8
80	45.	1590	19.8	8,0	12,692	8	13	208	42,240	2,604,000	5,6
90	47.5	1773	19.7	8,2	14,558	8½	12	204	47,520	2,970,000	5,6
100	50.	1963	19.6	8,2	16,176	8½	12	204	52,800	3,300,000	5,5
120	54.7	2340	19.5	8,5	20,000	9	11	198	63,360	3,960,000	5,5
140	59.	2734	19.4	8,6	23,503	9	10¾	197	73,920	4,620,000	5,5
151	61.	2922	19.3	8,6	25,424	9,6	10½	196	79,728	4,983,000	5,5
172	65.	3318	19.2	8,8	29,258	9,6	9¾	194	90,816	5,676,000	5,5
189	68.	3682	19.2	8,9	32,484	10	9½	192	99,729	6,237,000	5,5
200	70.	3848	19.2	8,9	34,555	10	9½	191	105,600	6,600,000	5,5

"This Table is formed from observation of a great number of engines of different powers, and making the intermediate sizes to correspond to the same law of increase. Thus, a 20 horse power-engine is always made with a cylinder of 24 inches diameter, which is allowing 22.6 square inches of the piston's surface for each horse power; but larger engines have a less allowance: an eighty horse power engine has 19.8 square inches to each horse power, and small engines have a much greater allowance, a ten-horse power engine having 24½, and a one-horse 28 square inches. This difference is to compensate for the numerous disadvantages which attends these small machines.

The differences in the length of stroke do not affect the calculations of Powers, because if the length of the stroke is altered the number *per* minute is also changed, and the distance travelled by the piston remains about the same.

"The allowance for fuel in this table is as small as it will ever be found to be in actual practice: the consumption of fuel is not in direct proportion to the power of the engine, because small engines lose more heat and have more friction in proportion than large ones, and the reciprocations of the strokes are more frequent. Scarcely any engines will do with less fuel when they are working with their full load, and many engines will require more. We have taken the effect of the twenty-horse power engine at twenty millions of pounds of water per minute, raised one foot with each bushel of coals weighing 84 lbs; this makes the consumption of such an engine very nearly two bushels *per* hour; an eight horse power requires one bushel. The performance of the engine of 100 horse-power is taken at 30 millions, and all the intermediate sizes by a regular law of increase. Engines will be constantly found which are of the dimensions marked in our Table, and are called so many horse power, although they are working with either a greater or less power than the Table expresses; in such cases the allowance of fuel must be altered in proportion."

To calculate the *actual working power* of low pressure engines, recourse must be had to the *Barometer Gauge*, operating upon the principle of the common Barometer and connected with the condensing vessel, to show the state of the vacuum formed beneath the piston, and consequently the atmospheric pressure, whilst the *Steam Gauge* indicates the actual elastic pressure of the steam upon the piston.* The effective pressure being multiplied into the velocity

* The Steam Gauge consists of an inverted Syphon, one leg of which is connected with the steam pipe while the other is open to the atmosphere. When this inverted Syphon is formed of an iron tube, the mercury not being apparent within it, there is inserted in the open end of the tube a light stick which is buoyed up on the surface of the quicksilver, and rising and falling with it, serves as a floating index. The difference of level of the mercury in the two legs indicates the pressure of the steam. When the mercury rises 1 inch in one leg it is caused to subside 1 inch in the other, making the difference of level 2 inches; and 2 inches of mercury being equal to 1 lb. pressure, each inch of rise of the index shows an increase of pressure of 1 lb. on the inch. It is the duty of the fireman frequently to look at this steam gauge, as it serves as his moniter, informing him by the subsiding of the quicksilver that the steam slackens and that more fuel is required.

in feet per minute of the piston, and divided as before stated by any of the preceding standards of horse power, will give the actual working power of the engine.

To calculate the power of high pressure engines it is usual to multiply the area of the piston in square inches by the elastic pressure of the steam upon each square inch as indicated by a steam gauge or the weight on a safety valve, and this total pressure by the distance in feet per minute traversed by the piston, one half of this sum being deducted as an allowance for waste of power by friction,* &c. and the remainder being divided by 33000, the standard of a horse-power, the quotient will be the power of the engine.

This rule applies very well to steam engines of 80 or 100 horse power or of larger dimensions, but for computing the effective power of small high pressure engines it will give a result much too high, for the reasons before stated in regard to the comparative increased friction and loss of power attending the operation of small engines. It appears that for high pressure engines under ten horse power, the divisor should be 44000 instead of 33000, to assign to these engines their true standard of horse power compared with the low pressure engines in the preceding table.

70 superficial feet of a steam boiler left exposed to the open air at a temperature of 32° or the freezing point will occasion a loss, it is stated, of ½ of a bushel of coals for every 12 hours, more than if properly covered with non-conducting substances.

In the experiments for calculating the horse-power the force exerted by the horse was found to be available only for about 8 hours each day, the remaining hours being necessary for his repose to recruit his exhausted vigour. A steam engine, it is obvious, requires no rest but at long intervals for repairs, and moves with unrelaxed and unwearied action throughout the twenty-four hours, and is thus capable of accomplishing as much labour as three relays of horses, or thrice the number of horses at which the engine may be rated.

To find the power required to lift a weight at any velocity, multiply the weight in lbs. by the velocity in feet per minute, and divide by the *horse-power;* the quotient will be the number of horse-power required.

It appears by Mr. Smeaton's experiments that a pair of milling stocks composed of four falling hammers, used for fulling cloth in the manufacture of woollens, requires about 1½ horse power to operate them regularly.

According to Fenwick's experiments the power required to prepare properly one ton of old rope per week for the purpose of making paper is equal to that required to raise a weight of 300 lbs. with a

* By an experiment made with a large new high pressure steam engine in Rhode-Island, it appeared that when the throttle valve was thrown open and the machinery of the mill disconnected with the engine, it required 25 lbs. to the inch on the safety valve to cause the steam engine to make its regular number of working strokes, and to maintain its proper speed. Without having its friction at all increased by being loaded, it thus required about 17 horse-power, equal to ¼ of the whole estimated power of this engine, to move the beam, piston and fly wheel.

velocity of 390 feet per minute; (about 3½ horse-power.) and for preparing in like manner two tons of the same materials per week requires a power sufficient to raise 300 lbs. with a velocity of 525 feet per minute, (about 5 horse power) the mill working from 10 to 12 hours per day.

Cement for rendering Joints steam-tight.

The following receipt forms a strong and durable cement for joining the flanches of iron cylinders of steam engines, or hydraulic machines.

Mix boiled linseed oil, litharge, red and white lead together to a proper consistence, always using the larger proportion of white lead. This composition may be applied to a piece of flannel and fitted to the joint. Cisterns built of large square stones and put together with this cement will never leak.

A more powerful cement for withstanding the action of steam is composed in the proportions of 2 ounces of sal ammoniac, and 4 ounces of flour of sulphur made into a stiff paste with a little water. When the cement is wanted for use, dissolve a portion of the paste in water rendered slightly acid, and add a quantity of iron turnings or filings sifted or pounded to render the particles of uniform size. This mixture put into the interstices of iron work will in a short time become as hard as stone.

Calculation of the power required to operate Cotton Mills.

The following experiment upon the quantity of water required to operate the machinery of cotton mills, was made under the direction of Samuel Greene, Esq. of Pawtucket, R. I. and may probably be relied on as being very nearly correct. The mill gearing and water wheel with which the experiment was made were not constructed in the most perfect manner, for which reason Mr. Greene supposes that the effective power of the water was somewhat diminished, by being necessarily expended in overcoming the augmented friction.

A cotton mill in Pawtucket contains 800 spindles, (about half of them throstle and half mule spindles) with preparation and looms sufficient to weave the yarn, which is spun to the fineness of about 18 hanks to the pound. When all the machinery is in operation at a regular speed it was necessary that the aperture of the gate should be opened 4 inches wide, the length of it being 5½ feet, and the middle of the aperture being one foot below the level of the water in the floom. The whole descent or fall of water was 12 feet.

The following calculation shows the quantity of water which runs through this gate upon the water wheel and also its effective force in *horse-power.*

$5\frac{1}{2}$ feet=66 inches×4=264÷144=1.83 foot area of the aperture of the gate. Under a head of 1 foot (see Table, page 193) the theoretical velocity is 8 feet per second. To reduce the theoretical velocity to the true velocity an allowance must be made for resistance arising from the friction of the water in crowding through the opening. Where there are side walls to conduct the water to the aperture, multiply the theoretical velocity, 8 feet per second, by the proper decimal number .860, as directed in the Table at page 194, which gives 6.88 feet for the true velocity of the water per second through the aperture.

The area of the aperture 1.83×6.88=12.5904 feet, or in round numbers $12\frac{6}{10}$ cubic feet of water actually discharged *per* second with a fall of 12 feet to operate this Cotton Mill.

To calculate this effective force in *horse power*, multiply the number of lbs. of water which descend in a minute by the effective fall, computing only one half of the *head;* allow $\frac{1}{3}$ for loss by friction and otherwise, and divide the remainder by 33000 for the answer.

12.6 cubic feet per second ×60=756 cubic feet per minute×$62\frac{1}{2}$ lbs. the weight of each cubic foot of water,=47250 lbs. × $11\frac{1}{2}$ feet effective fall,=543375 momentum. Allow $\frac{1}{3}$ for loss by friction, &c. and divide the remainder, 362250 by 33000=11 horse power, very nearly, required to operate the machinery of this Cotton Mill; being at the rate of $13\frac{3}{4}$ horse power for a cotton mill of 1000 spindles with all the looms and other necessary machinery.

About 5 cubic feet of water per second discharged upon a wheel with a fall of 30 feet may be considered as accomplishing about a maximum effect when it operates with proper velocity 1000 spindles for making the usual proportion of throstle twist and mule weft, of about No. 30, together with the looms for weaving the same. This result is equal to that produced by about $11\frac{1}{2}$ horse power.

The allowance of head and fall being nearly the same for delivering water upon water wheels of all dimensions, and for clearing them of water at the bottom, it is evident that with a high fall of water and high wheels the waste of power will be proportionately much less than with low ones. This loss absorbs a large proportion of the power of small wheels, and for this reason, as in calculating the power of large and small steam engines, a rule which will answer for calculating correctly the power of a water wheel of a medium diameter will over estimate the power of a smaller wheel, and will underrate that of a larger one. A fall of 12 feet will in practice be found to be equal to only about $\frac{1}{3}$ of the fall of 30 feet in respect to effective power.

UPON THE RELATIVE ADVANTAGES POSSESSED BY ENGLAND, FRANCE AND THE UNITED STATES OF AMERICA, AS MANUFACTURING NATIONS.

The following Table will give a comparative view of some of the most important advantages possessed by three of the principal manufacturing nations of the earth to manufacture at the cheapest rates. The price of labour forms the most important particular; but the superior skill of the labourers, and the improved machinery employed by them must be taken into consideration, as well as the facilities of obtaining water or steam power. In respect to water power, the United States possess eminent advantages over most other countries. France abounds in fine mill streams; but in some of the principal manufacturing districts of that country steam engines are from necessity frequently employed for operating machinery. In England the water power, although of inconsiderable amount compared to the steam power in use there, is highly improved wherever available in the manufacturing districts. It is probably attributable to the abundance and cheapness of water power, that the manufacturers of the United States are enabled to compete successfully with England and France in the production of such fabrics as require the application of a considerable moving force, notwithstanding the lower rates of labour in these two countries. With the several relative advantages possessed by England and by the United States, the rivalship between the two countries in manufactures is probably destined to continue long, and to be intensely interesting to the destinies of thousands of industrious artisans, when the manufacturers of the United States shall more generally extend their competition to supplying the markets of various foreign countries with some of the products of industry now furnished from England. Already has the competition been commenced, and successfully maintained by the Americans in supplying the markets of South America with coarse cottons, and with many other manufactured articles. Even the Hindoo labouring at his loom for a few cents per day, and subsisting upon a handful of rice for his daily fare, has been compelled to yield to the superiour skill and machinery of the American Manufacturers, whose fabrics have already been transported for sale to the distant markets of Calcutta and Canton.

This Table will also give an idea of the relative comforts which the labourers in these several countries can enjoy as the fruits of their toil. In England the price of bread, as of almost every other article necessary for their support, is raised so high by excessive taxation, as to sweep away one fourth of their earnings. In France much less, and in the United States, comparatively little, is exacted from the labourer by taxes upon the necessaries of life. For this reason a labourer in the United States, although he should receive only the same nominal amount of wages, possesses an advantage of more than twenty-five *per* cent. over a fellow labourer in England, from the circumstance of the comparative cheapness of almost every article which he requires for his own use or for that of his family.

COMPARATIVE TABLE of the average price of Labour in England, France and the United States of America.*

	ENGLAND.		FRANCE.		UNITED STATES.
	s. d.	d. c.	francs.	cts.	dls. cts.
A common day labourer earns per day	3.0 stg.=	74	about 2.	37 to 40	about 1.00
A Carpenter	4.0 "	97	" 3 to 4.	55 " 75	" 1.45
A Mason	4.6 "	1.10	" 3½ to 4½	60 " 80	" 1.62
A Farm-Labourer (*per* month and found)	27.0 "	6.50	"	400 " 600	" 8.00 to 10.00
A Servant maid (*per* week and found)	2.9 "	.67	"	"	" 1.00 to 1.50
Best Machine Makers, Forgers, &c. *per* day	8.0 "	1.94	"	"	" 1.50 to 1.75
Ordinary " " "	4.6 "	1.10	" 5.	" 92	" 1.25 to 1.42
Common Mule Spinners in Cotton Mills	4.2 "	1.02	"	80 " 90	" 1.08 to 1.40
" " Woollen Mills	3.10"	.94	"	40 " 50	" 1.08
Weavers on hand looms	3.0 "	.74	"	37 " 50	" .90
Boys 10 or 12 years of age do. *per* week	5.6 "	1.30	"	85 " 100	" 1.50
Women in Cotton Mills *per* week, average	8.0 "	1.96	"	148 " 200	" 2.00 to 3.00
Do. Woollen Mills " "	8.0 "	1.96	"	" 150	" 2.50
In Holland a day labourer earns about 35 cents					
" Carpenters and Masons " 60 "					
" Ship Carpenters " 80 "					N. York Pittsburgh.
Average price of Wheat *per* bushel in 1827	7.4 "	1.79	"	" 117	96 cts. 49 cts.
" price of good coals for steam engines *per* ton.	9.0 †	2.20	" ‡	600 " 700	7.00 " 106 "

*This Table was formed with great care from the result of personal inquiries made in the most important Maufacturing Districts of England and France, and the prices are taken at an average, as nearly as practicable. Since the year 1825, at which period these notes were taken, there have been considerable fluctuations in the price of labour in England, resulting probably in a general depreciation of wages. The value of the Spanish dollar is estimated at about 4 shillings 1½ penny Stg. when the exchange between England and the United States is 10 per cent in favour of the former country, making the shilling sterling about 24⅓ cents. The Spanish dollar is not a current circulating coin in England, and has no standard value in that country; but is bought and sold as bullion. By a Statute Law of the U. States the Spanish dollar was made a standard coin for the currency of the country, and was arbitrarily rated at the value of 4s. 6d. stg. for the purpose of assessing the duties upon all articles imported from England, and paying a certain impost upon the first cost. By thus underrating the value of the sterling currency, the American duties on English Manufactures are in effect reduced about 10 *per* cent.

† In Manchester ‡ Near Louviers and Paris

From a view of the preceding Table it appears that the average wages of persons engaged in manufacturing operations are nearly 20 *per* cent cheaper in France than in England, and about 18 or 20 per cent cheaper in England than in the United States. Nothwithstanding the difference in the prices paid for the same descriptions of labour in France and in England, judging from the observations which I have had opportunities of making, it would appear that the superiour skill of the English operatives, and the improved machinery generally employed by them yield so much greater products as nearly to equalize the difference in the cost of labour; and the two countries may be therefore considered as possessing nearly equal facilities for manufacturing cheaply, so far as labour is concerned. For instance, one man with the aid of two girls and a boy I have seen operating with the greatest apparent ease about seven hundred mule spindles in England; whilst in the same month I have seen in Lille, in France, two Frenchmen exerting their utmost force to turn by their manual labour the crank of a single mule of only two hundred spindles, with a boy to assist in piecing the threads. Very many of the French mills are operated by horses, which may be frequently observed traversing in their monotonous circle beneath the vaulted arches of old gothic cathedrals and monasteries, which have been converted into manufactories. The clustered pillars and sculptured stone work of these venerable structures form a strange contrast with the bright colours of the painted machinery, the perpetual din of which scarcely allows the spectator to muse upon the change that has taken place since the period when the silence that reigned within these walls was only broken by the chant of the matin and vesper anthem. Although the machinery of the French mills is generally put in motion by water or steam power, and the most improved English machines are introduced into them, yet there is a most apparent difference in the manufacturing enterprize of the inhabitants of the two countries. In the best cotton mills near Rouen and Paris, intelligent English mechanics are generally to be found aiding or directing the operations. In those branches of business in which the taste of the artist contributes to the value as much as his skill, the French appear to excel their English neighbours. This is particularly observable in the articles of jewelry exhibited at the glittering shop windows of the Palais Royal, and also in various branches of the silk manufacture.

In respect to general information the French and Flemish mechanics appear to be deficient, their enterprize and industry having been for many years paralized and interrupted by the continental wars of Europe. Since the arts of peace have gained the attention of the governments of Europe, and been sustained by them with fostering care, the mechanical arts have made more rapid advances. There still exists a languid indifference and want of information in relation to the progress of improvements made in other countries.*

* On my way from Brussels to Haerlem to view the national exhibition of the manufactures of Belgium, holden under the auspices of the king and honoured by his presiding at

To the effects of a republican form of government existing in the United States it may be attributed (if the writer be not blinded by a partiality for the free institutions of his country) that a spirit of commercial enterprize and of manufacturing industry prevails, unequalled in any other country. There is in the United States no ennobled order of men, and lofty pride of ancestry, to render the manufacturer or merchant half ashamed of his profession; and no burthensome system of taxation to depress the mechanic, and to circumscribe his scanty means to gaining a mere subsistence. From the habits of early life and the diffusion of knowledge by means of free schools, there exists generally among the mechanics of New-England a vivacity in inquiring into the first principles of the Science to which they are practically devoted. They thus frequently acquire a theoretical knowledge of the processes of the useful arts, which the English labourers may commonly be found to possess after a long apprenticeship and life of patient toil. For this reason the American mechanic appears generally more prone to invent new plans and machines than to operate upon old ones in the most perfect manner. The English mechanic on the contrary, confining his attention simply to the immediate performance of the process of art to which he is habituated from early youth, acquires wonderful dexterity and skill. One of these labourers was pointed out to me by the proprietor of an English manufactory as having occupied for nearly thirty years the same spot by the side of his machine, or rather machines—the materials of brass and steel of a succession of them having failed and worn out under his inspection. The constant tread of his feet during this

the distribution of the prizes, having accidentally fallen into company in a diligence with a Flemish artist on his way to the same place with some of his new machines, our conversation turned upon the subject of steam navigation, then lately introduced into that country. He inquired if there were any steamboats in America, and was surprized on being informed that they had been in successful operation there nearly twenty years. I took occasion to describe to him several American inventions, among others the machine for cutting and heading nails, which are completely finished and fall from the engine as fast as one can count them. The machine for making weavers reeds or slaies seemed to strike his attention as a wonderful invention, whereby the mechanism is made to draw in the flattened wire from a reel, to insert it between the side pieces, to cut it off at the proper length, and finally to bind each dent firmly in its place with tarred twine, accomplishing the whole operation without the assistance of the attendant, in a more perfect manner than can be performed by the most skillful hand. Although he possessed a good share of intelligence, the complicated operations of these machines, performing processes which he supposed could only be brought about by manual dexterity, appeared to him incomprehensible. But when I proceeded to describe Blanchard's lathe in which gun stocks and shoe lasts are turued exactly to a pattern, his belief seemed somewhat wavering, and on continuing to give him a description of Whitmore's celebrated Card Machine, which draws off the card wire from the reel, cuts it off at a proper length for the teeth, bends it into the form of a staple, punctures the holes in the leather, and inserts the staples of wire into the punctures, and finally crooks the teeth to the desired form—performing all these operations with regularity without the assistance of the human hand to guide or direct it, the credulity of my travelling companion in the diligence would extend no farther, and he evidently began to doubt all the statements I had been making to him, manifesting at the same time some little feeling of irritation at what he appeared to consider an attempt to impose upon him such marvellous accounts. Uttering an emphatic humph! he threw himself back into the corner of the diligence, and declined further conversation during the remainder of our ride upon the subject of mechanics and of the improvements made in Flemish manufactures.

long period had channelled furrows in the very floors, and every motion of his body appeared almost as mechanical as if he had become a machine himself. Without information on any other branch of business, such a man, when thrown out of his accustomed employment by the vicissitudes which must at times attend the affairs of a manufacturing as well as of a commercial people, is usually left helpless and destitute, unable to turn his hand to other avocations. If a New-England man does not succeed in one branch of business he may commonly be found readily essaying some other; even sometimes officiating in the profession of the law or of medicine, after commencing his career with the labours of the plane or anvil. It is undoubtedly true that in very many instances this versatility is attended with a profitless result, as in the present state of the arts and sciences a long period of assiduous labour is required to attain skill and experience in any branch of business. Although many valuable and ingenious inventions in the useful arts have originated in the United States, from which the old* as well as the new world have derived vast benefits, yet it cannot be denied that an incalculable loss of labour and expense in useless experiments has been the result to most of those who have been allured by the delusive search for new inventions and patent rights to deviate from the beaten path. These gropings in the dark for mechanical improvements can in no way be so successfully prevented as by opening the eyes of the mechanic, and causing him to view and examine his schemes more perfectly by the light of science. Some of the extensive manufacturers of Leeds, with a most commendable liberality, have formed small circulating libraries for the use of the persons engaged in their establishments, thus furnishing them with the means of becoming both more intelligent and virtuous. For this purpose numerous mechanics' libraries have also been instituted throughout England, and the scholars and statesmen of that great and powerful country, with a philanthopy for which " ages yet unborn shall call them blessed," have lent the sanction of their names and the vigorous support of their talents for the general diffusion of Useful Knowledge. This has been effected, too, on terms so completely within the means of almost every labourer, that it can scarcely be said of the Mechanics of the present day, in the words of Gray,

> " That knowledge to their eyes her ample page,
> Rich with the spoils of time did ne'er unroll."

England possesses a decided superiority over France and most of the United States in the abundance of coal, and in the consequent advantages afforded by steam power. Notwithstanding, however, the abundance of coal found in England, and the very general use of the Steam Engine, water power is highly valued in all the manu-

* Of late years England has received more benefits from adopting improvements in the useful arts from the United States than she has imparted, and the respectful attention of the inhabitants of that country " illustrious in arts and arms," is now bestowed on the inventive genius of Americans.

facturing districts, and mills are erected on streams, which in many instances are sufficient to turn the water wheels, and operate the machinery attached to them, during only a part of the year.* Among the mountains of Scotland, however, I have noticed numerous fine mill streams which remained unimproved. In Manchester, where coals are as cheap as in most of the manufacturing districts of England, the total cost of steam power, including all charges, amounts to about 20*l. per* year for each horse power, or at the current value of the Spanish dollar, to very near one hundred dollars *per* annum, as Mr. J. Dyer of Manchester stated to me. The opportunities of obtaining information on this subject possessed by this enterprizing American, from a long residence in Manchester, and from being engaged in an extensive branch of manufactures there, has probably enabled him to ascertain this fact with accuracy. The fuel forming the principal part of the expense of operating steam engines, by calculating the cost of coals in England and the United States a comparative estimate may be formed of the expenses attending the operation of a steam engine in each of the two countries with a tolerable degree of correctness. In the manufacturing districts of France near Rouen, where the most extensive cotton and woollen mills are located, the coals used are brought principally from the mines at Charleroi, and are nearly as dear as in the United States. The coals exported from England to the United States are of a superior quality to those ordinarily consumed for manufacturing purposes, and sell at an advanced price in Liverpool of nearly four shillings per ton, or from fourteen to fifteen shillings sterling per ton. Virginia Coal is about equal in quality to the common English coal for the purpose of operating steam engines, and costs on the seaboard of the Northern and Eastern States three times as much as the coals used in Manchester for steam engines. The daily wages of a fireman and good engineer is nearly as high in England as in the United States. The actual expense necessary for operating a steam engine in England, all other things being equal, may therefore be estimated at rather more than two fifths of what it is on the sea board of the Middle and Eastern States, when coals are used for fuel; while at Pittsburgh, on the contrary, from the wonderful abundance of coal, steam power is actually available at about $\frac{3}{4}$ of the expense required in England. Pine wood seems to be preferred in the United States as fuel for steamboats, from producing a ready and intense heat without being attended with disagreeable sulphureous vapours during combustion.

* At the Stanley Mills in the West of England, there are five large cast iron water wheels. On entering the basement story of this fine mill, which was with much politeness shown to me by one of the proprietors, the wheels appeared in sight, with the iron shafts and gearing for gaining motion, revolving in a spacious apartment beneath massy beams and arches of cast iron, moulded into tasteful forms and designs. My surprise was greatly excited on being informed that with all these water wheels, a deficiency of water rendered it necessary to keep a steam engine in operation during 3 or 4 months of the year. An engine of 40 horse power was actually in operation at that moment lending its aid in turning the machinery by means of a long revolving shaft, leading from the engine house through the wall of the mill, and connected with the mill gearing near the water wheels.

In respect to the construction of machinery, all the latest and most approved machines of every description used in England have been introduced and are now in actual operation in the best mills in the United States; and some of the New-England manufacturing establishments have already begun to rival those of old England in magnitude. A single manufacturing company have now in operation twenty thousand cotton spindles with all the machinery and looms to convert the yarn into finished cloth, and have erected a mill capable of receiving ten thousand spindles more, together with the necessary number of looms. The same company have also sufficient machinery in operation to manufacture daily about 300 yards of fine broadcloth.

The manufacturing operations in the United States are all carried on in little hamlets, which often appear to spring up in the bosom of some forest, gathered around the water fall that serves to turn the mill wheel. These villages are scattered over a vast extent of country, from Indiana to the Atlantic, and from Maine to North Carolina, instead of being collected together, as they are in England, in great manufacturing districts. A stranger, therefore, in travelling through the United States, can form but an imperfect estimate of the extent of manufacturing operations carried on therein. He sees no vast manufacturing towns in which the labouring classes are collected together, forming the crowded population, which is always favourable in commercial as well as manufacturing cities to the increase of immorality and vice, by screening the vicious from the marked ignominy that is usually visited so heavily upon the guilty in the narrow circle of a small community or country village.*

Some of the cotton mills in New-England are constructed in a style surpassing in appearance the English mills, the apartments being spacious and lofty and the shafts of the mill gearing and machinery turned and polished. The modern English mills are built with a more strict adherence to the " beauty of utility," no more expense being bestowed in the superfluous ornament of these great workshops, or of the machinery contained within them, than is consistent with economy, and the due adaptation of the moving parts of the machines, to ensure their harmonious operation and durability.

In 1807, it was estimated that there were only 4000 spindles in operation for spinning cotton in the United States. In this year there are probably more than a million of spindles, with a sufficient number of power looms to weave the yarn produced from them.

It is in the orderly system and economy of arrangement in the de-

*In the town of Providence, which has been termed the Manchester of America, from having been the centre of the most extensive manufacturing operations, there was in 1826, only one cotton mill of less than a thousand spindles, whilst several hundred thousand were in operation on the mill streams in the country adjacent. A cotton mill, intended for operating 7 or 8 thousand mule spindles with the preparation and looms, was erected in 1827, as an experiment of the practicability of employing *Steam Power*. Anthracite coal from the Schuylkill is successfully used in the furnace of the Steam Engine of this cotton Mill.

partments of labour that the English excel all other nations, as well as in the vast capitals employed in the various branches of industry. To the silent operation of the spindle may be traced this great wealth, accumulated whilst England was enjoying the benefit of an advanced state of Mechanical Science, by means of which one man was enabled to accomplish as much labour as was performed in other countries by an hundred. Every foreign country was thus rendered tributary to her, and the wealth of the world was poured into her coffers. Reposing in the wealth thus acquired, with the advantage of a low rate of interest, and with mills already built and filled with machinery that has redeemed its cost, England possesses great facilities for maintaining a vigorous competition with all her manufacturing rivals, who on starting in the contest must make new investments and sink an equal capital in buildings and machinery. Of the amount of this fixed capital in England some estimate may be formed from a sketch of one of the Manchester cotton mills, which I was permitted to visit by the politeness of the proprietor Mr. Murray, who conducted me through the various departments of his works. His mill is built of brick in the form of a hollow square, and contains *ninety thousand* mule spindles. On entering the gateway at which a porter is always in attendance, you advance into an open area or yard enclosed on all sides by the mill walls towering to the height of eight stories. In the centre of this interior square you behold a navigable sheet of water bordered by a quay, by the side of which you view the canal boats discharging loads of coal at the very furnace doors of the steam engines, or receiving the bales of yarn to be transported to different parts of the country. A tunnel is formed beneath the mill to connect this basin with one of the principal canals that traverses a considerable part of England, thus affording every possible facility for transporting the raw materials to the very centre of the works, and for shipping the manufactured goods in return to any part of the kingdom. In the very preparation of the sea island cotton, before it enters the machinery, there appeared to be fifty or sixty persons at work in one apartment, beating it with sticks in order to open it for more perfect examination. As the doors of the long apartments containing the machinery are thrown open, the countless wheels revolving upon extended lines of shafts; ranges of machines apparently of regularly diminished sizes as they are more remote from the eye in distant perspective, and all the numerous work people moving to and fro at their tasks—appear at a glance before you, almost producing the bewildering sensations which are sometimes excited by the strange visions of a dream. Threads as fine as those of the filmy web of the spider are here drawn out upon the machines with the utmost ease and regularity. The labour of three persons at a mule of three hundred spindles is required for a whole week merely to spin four pounds of Sea Island cotton into yarn of 300 hanks to the pound.* These works, in which nearly thirteen

* A very respectable manufacturer in Manchester stated to me that a single pound of Sea Island cotton, wrought into Lace, had been sold for 54 guineas (about $270.) a sin-

hundred persons are employed, belong to an individual who commenced business as a mule spinner, and by his enterprise and industry has accumulated the capital here invested in buildings and machinery, which truly rival in extent and importance many national works. Separated from this mill by a narrow street is another cotton mill of nearly equal magnitude.

From the concentration of each branch of manufacture in particular districts in England very considerable advantages are obtained, all the allianced operations of business and subordinate manufactures, which are usually found to spring up and flourish together, being thus brought within the range of a convenient neighbourhood. Superior economy in furnishing the necessary machines and excellence in the fabrics produced from them is thus ensured. In Manchester and in the adjacent villages are located the principal cotton mills. The traveller, after leaving Manchester and crossing the range of hills upon the borders of Yorkshire, quits entirely the Cotton Manufacturing district, and enters the district in which the manufacture of wool exclusively occupies the attention of the population, scarcely a solitary cotton mill being there to be found.

In both France and England females are more generally enured to hard labour than in the United States. In the manufactures of iron carried on in Birmingham and Sheffield, females participate even in the labours of the anvil. To many of the cottages in the villages adjacent to these towns, a small forge forms no uncommon appendage, at which the inmates may be seen at work during the intervals of their household employments, shaping the glowing metal and completing many of the articles of iron which are sold at such moderate prices in the United States. A gentleman long resident in Sheffield stated to me that he had seen a grandmother and her two grand-daughters busily engaged at the same forge; and in these districts I have had opportunities of observing young girls dexterously wielding the file and hammer among wreaths of smoke, with their fair complexions and ruddy cheeks tinged by the soot of the smithy. In France females perform the most arduous labours of the workshop, and toil during the heat of the day exposed to an ardent sun whilst performing the various operations of husbandry in the open field. They often appear as brown as the sun burnt peasant, and nearly as muscular. They are even frequently to be seen loading the carts from the manure heaps (which commonly find favour by the cottage door side,) and turning the furrows with ploughs drawn by cows as well as by horses and oxen. In some parts of Holland the women labour in the capacity of porters, carrying upon their backs burthens so heavy as to excite the compassion of a spec-

gle bale of cotton manufactured at this rate would produce sufficient to purchase a whole cargo of the raw material.

According to Mr. Huskisson, although England does not raise a single pound of cotton, she manufactured in the year 1824, no less than the value of about two hundred and seventy-nine millions of dollars. In the same year fifty millions of yards of cotton goods were exported to the United States.

tator unused to such sights. The French labourer appears not to have an idea of the term "comfortable," as understood in England and the United States, and bestows less consideration in providing the numerous small articles of household furniture which contribute so much to the domestic enjoyment of the poor man's fireside; but he will take his hasty meal any how and any where, making up by the gaiety of social intercourse, what is wanting in substantial good cheer. An industrious New-England mechanic commonly appears to take pleasure in his business; but the French mechanic is rather inclined to make a business of his pleasures. The former is disposed to labour to provide not only for the present but the future welfare of himself and family; the latter seems with stoical philosophy to be content in securing sufficient to supply his present wants, after which he is ready to devote his leisure moments to recreation, leaving his children after his death to depend on their own exertions for success—the legacy left him by his own parents. The work people of the French mills do not all dwell in the villages collected around the manufactories, as is usual in the United States, but in many instances travel considerable distances to their daily labour, carrying their provisions for the day with them, and returning in the evening to their homes. In pleasant weather I have seen them seated upon the grass beneath some shady tree in the vicinity of a mill, partaking of their humble fare, which as it lay spread open upon their white napkins appeared to consist mostly of sallads and bread. The cottages occupied by the farm labourers upon the estates of wealthy landholders in England are fitted up with much neatness, and present to the eye of the traveller a cheerful aspect, many of them having little flower gardens planted in front of the doors, and creeping vines clustering with flowers around the windows, apparently bespeaking the comfortable circumstances of the inmates, and a leisure to attend to some of the little luxuries of life, after providing a supply of its necessaries.

Whatever may be the competition that is destined to take place in manufacturing industry between the inhabitants of the Old and New World, there need be little jealousy that the latter will soon become entirely independent of the skill and industry of the former. The various products of the ingenuity of British and French artists are perfected with a skill so constantly improving and so well adapted to meet the ever changing wants of American purchasers, that these purchasers are too often tempted to extend their contracts beyond the bounds prescribed by prudence. Of this fact, the great amount of losses sustained by English manufacturers from American bankruptcies furnishes ample proof. If the American hesitates in purchasing the fine cloths and cutlery of England or the silks of France, it is not because he has no inclination to become possessed of such articles, but because those countries *will not receive the products of his labour in exchange for them.* Although the introduction of the manufacture of coarse cottons into the United States may appear to have curtailed the importation of similar foreign fabrics precisely to the same value or amount, yet upon examination it will be found that the ability of a new and very considerable class of people, composed of the body of manufacturers in the United States, having a taste for costly foreign fabrics are enabled by means of their business to purchase them, and to procure all the countless articles of foreign production which from being habitually used are become classed among the necessaries of life. The female, who before the introduction of cotton machinery into the United States was accustomed to spin with the single wheel to clothe herself and family in the plainest homespun of household manufacture, was enabled to consume only a trifling amount of foreign products. By the aid of the present improved machinery, with an equal application of industry the same person is enabled to purchase the silks of France, the straw bonnet of Italy, and the tempting products of English looms. The result has been rather a change of articles imported into the United States, than a diminution of the value of them. It was observed by Pitt in his speech in the British parliament upon the subject of taxing the American Colonies, that "they yielded all their savings to your emolument." The same observation is still applicable to the Independent States of America, their coin being now more effectually drained by English industry than it ever was by any system of English taxation.

Table of the Velocity for Boring and Turning Cast Iron.

BORING.		TURNING.	
Inches diameter.	Revolutions of Bar per minute.	Inches diameter.	Revolutions of Shaft per minute
1	25,	1	50,
2	12,5	2	25,
3	8,33	3	16,67
4	6,25	4	12,50
5	5,	5	10,
6	4,16	6	8,33
7	3,57	7	7,15
8	3,125	8	6,25
9	2,77	9	5,55
10	2,5	10	5,
15	1,66	15	3,33
20	1,25	20	2,50
25	1,	25	2,
30	0,833	30	1,667
35	0,714	35	1,430
40	0,625	40	1,250
45	0,56	45	1,12
50	0,5	50	1,
60	0,417	60	0,834
70	0,358	70	0,716
80	0,313	80	0,626
90	0,278	90	0,556
100	0,25	100	0,50

For Boring Cast Iron the proper velocity for the *surface bored* has been found to be 78.54 feet per minute. A velocity greater than this not only takes out the temper of the cutters by producing great heat, but also causes the metal to expand, when if the machine stops for a short time a mark is left from the contraction of the metal.

If hand tools are employed in turning, the velocity may be considerably increased.

The progression of the cutters may be 1-16th of an inch for the first cut, and for the last 1-24th.

Table of the Properties of Bodies.

TABLE OF THE PROPERTIES OF VARIOUS BODIES OR PORTIONS OF MATTER.

BODIES.	Specific Gravity compared with rain water,	Weight of a cubic foot.	Melts at Degrees of heat.	Cohesive strength of a square inch pulled in the direction of their lengths.	Will bear on a square inch without danger of being crushed by pressure	Crushed by a weight on the square inch.	Transverse strength of pieces of Timber supported at each end and loaded in the middle. Length 2 feet and 1 inch square.
WOODS.		lbs.	lbs.	lbs.	lbs.	lbs.	
American Yellow Pine	0.46	26,7		7500	400	1606*	829
Ash	0.75	47,5		17000	1000	3540	314
Beech	0.696	45,3		11500	600	2360	
Elm	0.544	34,		7000	321	1284	265
White Fir	0.67	29,3		11000	500	1928	212
Mahogany	.56	35,		8000			255
Oak	.83	52,		12000	1000	3960	482
METALS.						Probably	Transverse strength of Bars, 2 feet .6in long, 1 in. square
Cast Steel	7.85	490,6		134256	50000	200000	
Cast Iron	7.24	453	20577 °	19488	45000	166272	1086
Cast Brass	8. 0	500	3807 °	18000			
Cast Zinc	7.02	439,25	648	33000			
Cast Tin	7.29	455,7	442	4736		8832	
Copper	9.	562	2548	33792		117888	
Iron, Russian	7.78	486		59000			
English Iron	7.60	475		55000			
Lead	11.32	708	594 °	1600			
STONES, &c.							
Brick	2.000	125		275	200	808	
Chalk	2.315	144,7			100	500	
Clay	2.	125,					
Granite	2.602	166			2000	8288	
White Marble	2.706	169		1811	1500	6060	
Welsh Slate	2.752	172		12800			
Free Stone	2.	125		500	900	3700	
Gravel	1.749	109					

* These results are given by Mr. Rennie. There is a considerable variation in the estimates made by various experimentalists, which may be attributed to the difference in the quality of the materials employed and the modes in which the experiments were made.

INDEX.

ERRATA.

The reader will please to make the following corrections with his pencil,

Page 13, in the tenth line from the top for *height*, read *velocity*.
" 13, eleventh line from the top, for *sixteenth* read *fourth*.
" 14, eighth line from the top for 14.16 read 4.16.
" 15, fourteenth line from the top, for *filled with water* read *collapsed*.
" 17, thirteenth line from bottom, for *hart* read *heart*.
" 24, eleventh line from the bottom, for *our* read *four*.
" 24, bottom line for *square* read *cube*.
" 37, eleventh line from bottom, for 421.1.875, read 421. 1875,
" 46, sixteenth line from bottom for, *fluids* read *gases*.
" 46, seventeenth line from do. for *seperated* read *separated*.
" 67, twenty fourth line from top, for *flanges* read *flanches*.
" 85, twenty-ninth from bottom for *or* read *nor*.
" 86, seventh from top, for *or*, read *nor*.
" 102, second line from top, for *supercede*, read *supersede*.
" 111, twenty third line from top, for 40 *feet* read 50 *feet*.
" 111, twenty-fourth line from top for 50 *feet* read 40 *feet*.
" 127, seventh line from bottom for *Fnustvm*, read *Frustum*.
" 137, sixteenth line from top for *brass* read *wooden*.
" 143, fifteenth from bottom, for *lesser* read *less*.
" 154, sixth line from bottom erase *such*.
" 156, second line from top, for *when bodies are drawn* read *when a body is drawn*.
" 163, sixteenth line, for *circular a route* read *circular route*.
" 166, for *the wheel and the axle*, read *the wheel and axle*.
" 184, ninth line from top, for *cubic feet* read *cubic inch*.
" 198, last line, for 16 *feet* read 1 *foot*.
" 205, seventeenth line from bottom for *action* read *acting*.
" 227, for *Archimede's Screw* read *Archimedes' Screw*.
" 234, tenth from top, for 1800 *cubic feet* read 1800 feet.
" 242, erase decimal points in the third column of Table.
" 246, sixth line from bottom for *have* read *has*
" 248, tenth line from top for *effected*, read *affecled*.
" 279, fifth line from the top for *ratatory* read *rotative*.
" 280, ninth line from bottom, for *much greater* read *much less*.
" 314, first line insert a comma after *pivot*.
" 324, fourteenth line from bottom for Messrs. *Lears*, read Messrs. *Leans*.
" 202, tenth line from bottom, for *Canpoy* read *Canopy*.