TREATISE

ON

THE STEAM ENGINE.

BY

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IN COLUMBIA COLLEGE, NEW-YORK.

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PREFACE.

The second edition of the "Treatise on the Steam Engine," has been carefully revised, and many parts of it have been either re-written or much extended. Since the publication of the first edition, great improvements have taken place in the manner of using steam, and in two of its most important applications. The expansive action of steam, which was employed only in a few boats on the Hudson, has received a development in practice fully equal to what the author had anticipated, while the value of this mode action has been illustrated by the publication of its results in the pumping engines of Cornwall. The views of the author in respect to the defects of the existing theory of the motion of steam vessels have been confirmed, and new illustrations, derived from actual experiment, have been given in their proper place. The navigation of the ocean by steam, the practicability of which was denied by many, has been proved to be safe and certain. Finally, the use of steam in locomotion, which in 1830 was little more than in embryo, has been much extended and improved. The additions which have been made to the work have reference chiefly to these important subjects. For much valuable information in respect to steam navigation, acknowledgment is due to Mr. Haswell, the engineer of the U. S. Ship Fulton.

Although the imperfection of the theories of Robison and Tredgold has long been apparent, it has not been thought proper to abandon them altogether. It was, however, in contemplation to have attempted an exposition of a theory more consistent with true mechanical principles. This attempt has been rendered unnecessary by the successful investigations of Pambour, which are inserted in the form of an Appendix. It is still thought too early, in a work intended for practical men, to take this theory as the basis of our inference. The mode of proceeding in the former edition has in consequence not been altered.

Columbia College.
1st June, 1839.

PREFACE

TO THE FIRST EDITION.

The Treatise which is now submitted to the public does not pretend to the merit of originality. All that has been attempted is to exhibit in a succinct, and, as far as possible, popular form, the present state of our knowledge on the interesting subject of which it treats. From this the sole exceptions are the theories of the expansive action of the steam engine, and of steamboats. To the former has been added the consideration of the physical circumstances that were left out of view in the investigations of Watt and Robison; and the latter has been examined upon principles that, so far as the author is aware, although of frequent application in other branches of practical machines, have never been taken into account in this particular case.

Preparing the work for the American public, and as a substitute for treatises either too expensive or too rare to be of frequent occurrence, the author has not scrupled to avail himself of the labours of his European predecessors. The authors that have been most frequently consulted, are: Peclet, from whose *Traité de Chaleur* much valuable matter has been drawn; Farey and Tredgold; while the researches of Stuart have been of great service in the compilation of the historical parts.

The author has also derived much information from the friendly aid he has received in various ways from the most eminent manufacturers of the steam engine who were within his reach. To the West Point Foundry Association, to Mr. Allaire, and Mr. Sabbaton, of New-York, and to Messrs. Rush and Muhlenburg of Philadelphia, he takes this opportunity to return his acknowledgments for the liberal manner in which their practical knowledge has been laid open to him.

To Captain Bunker, of the steam-boat President, and to Mr. R. L. Stevens, he has also been under obligation for the facts in relation to steam-boats which he has adduced as the test of his theory.

From Dr. McNiven he has received important facts in relation to the preliminary experiments of Fulton at Paris, and the first trial of his boat on the Hudson, at both of which that gentleman had the good fortune to be present. Had not the work been extended beyond the size originally intended, this communication would have been inserted entire in the Appendix.

Should the present work be successful in extending the knowledge of the principles and mode of action of the most important of the instruments by which the power of man is extended; and particularly, should it have an influence of bringing into use those precautions and apparatus by which the risk to which human life is exposed, may be lessened, the object of the author will be fully accomplished.

Columbia College. }
New-York, 30th August. }

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CHAPTER I.

MECHANICAL AND PHYSICAL PRINCIPLES THAT ARE APPLICABLE TO THE CONSTRUCTION OF THE STEAM ENGINE.

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The material substances with which we are acquainted are either Solid or Fluid.

Fluids are again subdivided into two classes, those which are incompressible, and those which are elastic: the former are called Liquids, the latter Aëriform Fluids.

Elastic or aëriform fluids may either be capable of being readily condensed into the liquid form, and are then called vapours or steam; or can only be reduced to that form with great difficulty, resisting in some cases all the means, whether mechanical or physical, that have hitherto been applied for that purpose. The latter are styled gases, or permanently elastic bodies.

The last-named class may, however, when in chemical combination, assume both the liquid and solid form, and there are but few that have not, in recent experiments, been converted into liquids, by pressures of greater or less intensity. Still, however, although nearly the whole class are now known to be condensible, the distinction between vapours and gases may be here retained with propriety, inasmuch as there is a wide difference in the manner in which they are applied in practical mechanics.

2. Two great antagonist forces are concerned in determining in which of these mechanical states a body shall exist: these are, *Attraction* and *Heat*. To that species of attraction which takes place between the particles of one and the same body, whether it be simple or compound, in its chemical character, the name of Attraction of Aggregation has been given. When the intensity of the attractive forces, exerted mutually by the particles of a body, is greater than the action which heat exerts to separate them, the body will exist in the solid state; when the action of attraction and heat exactly balance each other, the body is a liquid; and when the repulsive force of heat predominates, the body passes into the state of an elastic fluid.

We know, however, of no perfect liquids; in them all there remains a greater or less preponderance of the attraction of aggregation. This is manifested by the tendency they have, when minutely divided, to form small globular masses, or drops. And hence the motion of their particles among each other meets with a slight resistance, which is said to be due to the viscidity of the fluid.

3. It may be considered as a general rule, that all bodies in nature are capable of existing, when properly influenced by heat, in either of the three mechanical forms. Thus, if we cannot, by mechanical or physical means, reduce the lighter gases to the solid form, still we find them assuming it in chemical combinations; while nearly all, even of the most refractory solids, have been melted and rendered volatile under the intense heat of the Galvanic Deflagrator, or of the Compound Blowpipe.

4. The general principles of mechanics apply equally to solid and fluid bodies, but are modified in their action by the peculiar nature of each. Solid bodies, having their particles firmly connected together, act as if all the matter they contain were collected in a single point. When the body presses merely by its own weight, or when the motion is rectilineal, this point is the Centre of Gravity, or of Inertia; if the body oscillates around a fixed point, it is the Centre of Oscillation or Percussion; and when it revolves around an axis, it is the Centre of Gyration. The properties of these points, along with the general principles of motion, and the causes that produce it, are of constant value in considering the structure of the steam-engine and its parts. And although these are to be found in all books on the theory of mechanics, it has been considered proper to recapitulate them in a succinct manner, in order that they may be referred to in the course of the work.

5. The cause which would tend to set a body in motion, whatever be its nature, is called a force.

A body moves in the direction of the force impressed, and with a quantity of motion equal to the intensity of the force.

A body set in motion by a force, and then abandoned to itself, would continue to move uniformly forwards in a straight line, were not its direction and the intensity of its motion to be changed by the action of other forces. Thus, near the surface of the earth, the friction of other bodies, and the resistance of the air, act continually to retard and finally destroy the motion of bodies, while the attraction of the earth constantly tends to change the direction of the motion, and bring the body back to the surface.

When a body is set in motion by a force which acts during the whole continuance of the motion, it will still describe a straight line, but the spaces described in equal times will gradually increase. If the force act with equal intensity upon the body, whether it be in rest or in motion, the motion is uniformly accelerated, and the force is said to be constant. All forces that act continually, whether constant or not, are called accelerating forces.

When more than one force acts upon a body at the same instant of time, the direction and intensity of the motion will depend upon the joint action, and we may imagine it to be the effect of a single force, whose direction and intensity correspond with the motion given to the body. Such a force, which, were the forces that really act withdrawn, would produce the same effect that they do, is called their Resultant; the forces that it would thus identically replace, are called the Components.

The resultant of two forces that act in the same straight line, and in the same direction, is equal to their sum; if in the same straight line, and in opposite directions, it is equal to their difference: generally, the resultant of any number of forces acting in the same straight line is equal to their algebraic sum, the difference of direction being denoted by the use of the positive and negative signs.

The resultant of two forces whose directions are inclined to each other, and which meet in a point, is represented in magnitude and direction by the diagonal of a parallelogram whose sides represent the direction and magnitude of the forces. The resultant of three forces is found, by taking, first, the resultant of two of them, and then combining this resultant with the third. The resultant of three forces thus found may be combined with a fourth, in order to find the resultant of four, and so on for any number of forces.

When in a machine a force acts obliquely, no more of the force is effective than that which would be a component of the force in the line of direct action; the other component is a loss of power, so far as the mechanical effect to be produced is concerned. It is, however, in general, worse than a mere loss of power; for the whole of the force decomposed in this last direction acts upon the machine itself, and generally to wear away or dislocate its parts.

Motions are capable of being resolved or decomposed in the same manner as forces, and the investigation may in this way be extended to the case of forces that continue to act during the whole duration of the body's motion.

A motion which grows out of the combination of two other oblique motions, is in the direction of the diagonal of the parallelogram whose two sides represent the magnitude and direction of the two forces, and the intensity of the motion is represented by the magnitude of the diagonal. When two oblique forces act, one of which abandons the body, and would thus produce an uniform motion, while the other continues to act during the whole duration, we conceive the motion to be divided into a great number of very small portions, during each of which the motion and direction remain constant: the body would then tend to go on in a straight line, at the end of each of the small intervals in which the small portions of the motion are performed, but is, during each of them, deflected into the diagonal of a parallelogram by the active force. In this way a polygon is formed, which, as the sides are inappreciably small, coincides with a curve. When, therefore, two motions oblique to each other are combined, one of which is uniform and the other accelerated, curvilinear motion is the consequence.

If two accelerating forces act, in which the rate of acceleration is the same, the motion is rectilineal; but if it be different, the motion is still curvilinear.

When two parallel forces act upon a body, the resultant divides the line that joins the points to which the forces are applied, into parts that are inversely proportioned to the intensity of the two forces, and the resultant is equal in magnitude to the sum of the forces. The resultant of three such forces is found by taking first the resultant of two of them, and combining it with the third; this may again be combined with a fourth, and so on to any number.

The resultant of any number of parallel forces continues of the same intensity, and passes through the same point, whatever be the direction of the forces; hence it is called the Centre of Parallel Forces. When the body is moving forward in a straight line, under the action of forces other than gravity, it is called the Centre of Inertia; when the body is acted upon by gravity, it is called the Centre of Gravity.

6. By gravity, or the attraction of gravitation, is meant that force, by virtue of which all bodies fall towards the earth in lines perpendicular to its surface. Although these directions

are neither absolutely parallel, nor the forces, at different parts of the earth, or different distances from its surface, equal; still the convergence of the lines is so small, and the variation so slow, that there is no impropriety in considering every particle of the body as acted upon by an equal and parallel force. The resultant of all these forces is the *Weight* of the body, and its place of action is the Centre of Gravity.

When the centre of gravity is supported, the body is supported also; when the centre of gravity is not supported, the body will fall until the centre of gravity reaches the lowest possible point. The supporting force may be applied to the centre of gravity, or it may act at a point vertically above, or vertically beneath that centre. In the first case the position of the body is indifferent, and it will remain at rest, however placed around the point of support; in the second case, the body, if once disturbed, will fall or move around the point of support, until this be vertically above the centre of gravity; in the third case, if the body be disturbed, it will oscillate until it return to rest in the position it originally held.

The centre of gravity of a straight line bisects it.

The centre of gravity of a cylinder, or of a spindle of symmetrical form, bisects the axis.

The centre of gravity of a circle corresponds with its centre, as does that of a sphere.

The centre of gravity of a triangle is in the line which joins its vertex to the point that bisects its base, and at the distance of two-thirds of this line from the vertex.

When the centre of gravity of a triangle is known, that of a quadrilateral figure may be determined by dividing it into two triangles, and finding their respective centres of gravity, whence the common centre may be determined, as it will divide the line that joins the two, into parts inversely proportioned to the size of the two triangles. The centre of gravity of a pentagon is found by dividing it into three triangles, and thus for any polygon whatsoever.

The centre of gravity of a triangular pyramid is in the line which joins the vertex of the pyramid to the centre of gravity of the base, and at a distance of three-fourths of this line from the vertex.

When the centre of gravity of a pyramid is determined, we have the means of finding that of any solid body bounded by plane surfaces, for it may be divided into triangular pyramids.

The centre of gravity of a solid cone is in the line which joins its vertex to the centre of its base, and at the distance of three-fourths of that line from the vertex. But the centre of gravity of the surface of a cone is at the distance of two-thirds of that line from the vertex.

The centres of gravity of an ellipsis and an ellipsoid of revolution correspond with their respective geometric centres.

When a body is attached to a fixed point and oscillates, the action is no longer such as would take place if the whole of the matter were collected in the centre of gravity; but the point, in which, if all the matter were collected, the action would be the same as actually takes place, is farther from the place of suspension; this point is called the *centre of oscillation.*

The centre of oscillation of a straight line is distant two-thirds of its length from the point of suspension.

The centre of oscillation of a triangle is at the distance of three-fourths of its height from the vertex.

The centre of oscillation of a cone, right angled at the vertex, is in the middle of the base.

The centre of percussion is that point in a striking body, at which the whole of the motion would be communicated to the body struck.

When the striking body moves round a fixed point, the centre of oscillation and centre of percussion are identical.

A body suspended from a fixed point, and oscillating under the action of gravity, is called a Pendulum.

The centre of Gyration is that point in a revolving body, in which, if all the matter were collected, the quantity of rotary motion would remain the same as before.

The centre of gyration of a straight line, moving around an axis passing through one of its extremities, is at a distance from that axis, which bears to the length of the line the ratio of one to the square root of three, $1 : \sqrt{3}$.

The distance of the centre of gyration of a circle or circular sector from its centre of rotation and curvature, is to the radius of the circle, as one to the square root of two, $1 : \sqrt{2}$.

The motions which we find in the parts of machines, and in the great natural agents that are employed to propel them, are either rectilineal or rotary. Rectilineal motion may be either continuous or reciprocating, and rotary motions may in like manner either go on continually, or the moving points may oscillate within certain limits, and thus reciprocate.

Among these four species of motion, taken by pairs, there are ten possible combinations, and these might therefore occur in the changes which a machine makes upon the original motion of the moving power, or which one part of a machine causes in the motion of another ; no more than eight of these combinations, however, are to be met with in practice.

a. A continuous rectilineal motion is sometimes converted into another continuous and rectilineal motion, in an opposite direction.

b. A continuous rectilineal motion is sometimes changed into a continuous rotary motion, or,

c. Into a reciprocating rotary motion.

d. A continuous circular motion is sometimes changed into an alternating rectilineal motion.

e. A continuous circular motion is sometimes changed into another continuous circular motion, in an opposite direction, or,

f. Into a reciprocating circular motion.

g. A reciprocating rectilineal motion is sometimes changed into a reciprocating circular motion.

h. A reciprocating circular motion is sometimes changed into another reciprocating motion in an opposite direction.

8. The particles of fluid bodies, having no, or at most an insensible, attraction of aggregation, act independently of each other. Hence, we cannot refer the motion of a fluid mass to either of the Centres of which we have spoken, but each particle moves freely under the forces that are impressed, whether

they act immediately upon it, or through the intervention of the adjacent particles.

Fluids thus transmit any force applied to one of their surfaces equally in all directions; and if a fluid be inclosed in a vessel, and a force act upon any portion of its surface, as by means of a piston perforating one of the sides of the vessel that contains it, the pressure upon every remaining portion of the vessel will be equal, upon an equal surface, to that acting upon the piston: thus, if the piston be a square inch, and be acted upon by a force equivalent to a pound, every square inch of the surface of the vessel will also have to sustain a pressure equivalent to a pound.

When a fluid is kept in equilibrio in an open vessel by extraneous forces, these forces must act perpendicularly to the uncovered surface of the fluid, and if the fluid be acted upon by gravity, its surface must therefore be horizontal, or perpendicular to the direction of gravity. In a small vessel, the surface is a horizontal plane, inasmuch as the forces may be considered as acting in parallel lines; but in large masses of gravitating fluids, as the ocean or great lakes, the surface becomes a curve parallel to the general figure of the earth.

Any line drawn upon such a surface, or parallel thereto, is called a level line, or more simply, a Level.

When a gravitating fluid is placed in a bent tube, or in vessels communicating at bottom, it rises in the two branches of the tube, or in the several vessels to the same level. And if a pipe be inserted in a close vessel, the pressure on the sides of it will be proportioned to their surface, and the height of the fluid in the pipe. If the fluid in the pipe be acted upon by some extrinsic force, the action will be transmitted to the sides of the vessel, and the whole pressure upon them will be as much greater than the pressure upon the fluid in the tube, as the surface of the vessel is greater than the area of the tube. This principle has been applied to the construction of an instrument, in which a small force, acting through the intervention of a liquid, is made capable of exerting an intense pressure. It is called the water-press pump, or, after the name of the inventor Bramah's press. The pressure of a gravitating fluid upon a horizontal base, is not proportioned, as in solid bodies, to the mass or weight of the fluid, but to the surface, and the height of the level surface of the fluid above the base. The measure of such pressure is the weight of a parallelopepid of the fluid, whose base is equal in area to the base of the vessel, and whose altitude is equal to the depth of the fluid. It is therefore the same, whatever be the capacity or shape of the vessel, provided the area ot the bottom and the depth of the fluid remain constant.

Upon surfaces that are not horizontal, the measure of the pressure of a gravitating fluid is the weight of a parallelopepid of the fluid, whose base is equal in area to the surface pressed, and whose altitude is equal to the depth of the centre of gravity of that surface beneath the level of the fluid.

Although the pressure upon a given surface depends upon the position of its centre of gravity, yet this is not the point to which the resultant of the hydrostatic pressure is applied. This last point is called the Centre of Pressure, and it coincides with the point which would be the centre of oscillation of the surface. Hence, in the calculations of the strength of the sides of vessels, or of walls to contain masses of fluids, the resultant of the resistances they oppose must pass through this point, and be at least equal to the hydrostatic pressure of the fluid.

When a body is placed in a fluid whose weight is less than that of an equal bulk of the fluid, it rises and floats at the surface, and as much of it is immersed as displaces a mass of the fluid whose weight is equal to its own.

In general, if any solid body be placed in a fluid, it will, if lighter, rise to the surface; if heavier, sink to the bottom; and the force with which it will rise or sink, will be equal to the difference between its own weight and the weight of an equal bulk of the fluid. Hence, a body immersed in a fluid loses as much of its weight as is equal to the weight of a mass of fluid of equal bulk.

Were the particles of fluids to move independently of each other, they would issue from an orifice in the bottom or side of a vessel that contains them, with the velocity a falling body would acquire in descending from the surface of the fluid to the level of the orifice, and the section of the stream would be equal to the area of the orifice, and of the same size everywhere. But in consequence of the mutual action of the particles, the stream, in passing through an orifice cut in a thin plate, does not continue of the same area with the orifice; it is at first contracted, and if the orifice be circular, the place of greatest contraction is at a distance from the vessel equal to the radius of its orifice; the shape of the jet is a truncated cone, whose greater base is equal to the area of the orifice, and whose least bears to it the proportion of 5 : 8. An opening in a thick-sided vessel discharges more, and pipes of different forms give greater or less increases to the above ratio. The quantity of fluid is measured by multiplying the velocity by the area of the less base of the truncated cone, which is called the *Vena Contracta.*

9. The comparative weight of equal bulks of different bodies is called their Density. We usually compare these by means of a conventional standard, whose density forms the unit in which the densities of the rest are estimated. Densities thus estimated are called the Specific Gravities of the bodies, and the body employed as the standard in most cases, is Water.

In estimating specific gravities, it is not merely necessary that the water be pure, but, as both the bodies are capable of assuming different densities at different temperatures, it is necessary to define the temperature at which the experiments shall be made. The best temperature for this purpose is, for reasons we shall hereafter state, from 38° to 40° of Fahrenheit's thermometer. To determine specific gravities, we make use of the principle that a body loses in water as much weight as is equivalent to the weight of an equal bulk of water. If, then, a body be weighed in air, and afterwards in water, the difference is the weight of an equal bulk of water; and as water is the unit, we have only to divide the weight in air by the loss of weight, and the quotient is the specific gravity.

The instrument by which specific gravities are thus determined, is called a hydrostatic balance. It differs from a common balance only in having a convenient apparatus added, by which the weight in water can be determined.

It sometimes becomes necessary to determine the specific gravity of bodies lighter than water. In this case the body, after being weighed in air, is attached to a body sufficiently heavy to cause it to sink, and whose weight in air, and weight in water are known. The dividend is, as before, the weight of the light body in air, the divisor is the difference between the loss of weight of the heavy body, and the loss of weight of the two united.

The Specific Gravities that are of most frequent use in the construction of steam engines, are as follows, viz.

Table of Specific Gravities.

Water at its maximum density,		1.000
Mercury,		13.568
Lead,		11.352
Copper,	Cast,	8.788
	Rolled,	8.878
Brass,	Cast,	8.396
	Rolled,	8.544
Iron,	Cast,	7.207
	Wrought,	7.788
Steel,	Hard,	7.816
	Soft,	7.833
Tin,		7.291
Zinc,		7.190
Sea Water,		1.026
Dry Oak,		0.932
Yellow Pine,		0.657
White Pine,		0.569

10. When two fluids of different densities press against each other in opposite branches of a bent tube, they will come to rest in their respective branches, at heights above the common level inversely proportioned to their respective densities.

Upon this last stated principle, we may determine the pressure of the mass of elastic fluid which surrounds our Earth, and which is called the Atmosphere. If a piston be fitted air tight, in a glass tube about three feet in length, and the lower end immersed in a vessel of mercury, the tube being held in a vertical position, and if the piston be drawn upwards, the mercury will follow the piston as it ascends in the tube, being forced up by the pressure of the atmosphere. When, however, the piston reaches a height of about thirty inches, the mercury will cease to follow, and an empty space will be left between its surface and the lower side of the piston.

In like manner, if a tube, closed at one end, be filled with mercury, and being closed by the finger, inverted, and the open end plunged in a basin of mercury, the mercury will remain suspended in the tube if its length be less than thirty inches; but if it be longer, and the tube be held vertically, the mercury will descend, flowing into the basin until its surface stand at a level of about thirty inches above the surface of the mercury in the basin.

This height of thirty inches is not constant, but varies in the same place, in consequence of changes which are constantly occurring in the pressure of the atmosphere; it also varies in different places, in consequence of their being at different elevations above the level of the sea, and bearing, in consequence, columns of air of varying depths; but at the level of the sea, the mean pressure is such as will support thirty inches of the mercury.

Now, according to the principle we have laid down, the pressure of this column of mercury upon a base of a square inch, will be equal to the weight of thirty cubic inches of mercury. This is almost exactly fifteen pounds, at which it is usual to estimate the pressure of the atmosphere upon every square inch of the surface of bodies subjected to it. This pressure, being that of a fluid, is equal in all directions; and hence is imperceptible to us, unless when it is taken off upon one part of a body, when that exerted on the opposite side becomes sensible. So far from tending to crush bodies placed in it, the atmosphere rather acts to support them, by bearing as much of their weight as is equal to the weight of an equal bulk of atmospheric air.

11. If the sealed tube be not entirely filled with mercury, a portion of air remains in it; when the finger is pressed on the open end and the tube inverted, the air rises to the closed end

of the tube; and when the apparatus is plunged in a basin of mercury, and the finger removed, the air within, being no longer compressed by the whole force of the atmosphere, will increase in bulk, and occupy a greater space than it originally filled, forcing out a part of the mercury.

It is a law which holds good in all elastic fluids, that they occupy spaces which are inversely as the pressures to which they are subjected, and their densities are in consequence in the direct ratio of the pressures. Hence the difference between the height of the mercury in the tube that contains air, and that to which it rises in one void of air, will be the measure of the density of the air thus contained, or of the pressure of any other elastic fluid separated by a column of mercury from the open atmosphere.

The experiment, with a tube containing mercury, and inverted in a basin of the same liquid, by which we measure the pressure of the atmosphere, was planned by Torricelli, and goes by his name. The apparatus, when attached to a support, and furnished with a scale on which the height of mercury in the tube can be measured, is called a Barometer. Of this there are several forms, and it is applicable to many important uses; of these, however, it is not our province to treat.

The same force which is capable of raising a column of mercury thirty inches in height, is capable of raising a column of water as much longer as the specific gravity of mercury is greater than that of water. This height is about thirty-four feet. Hence, if by any means a vacuum be made in a tube whose height is not greater than thirty-four feet, and its end be plunged in a mass of water, the fluid will rise and fill it. If the vacuum be imperfect, the water will still rise, but to a less height. Such is the principle upon which the common pump acts, where a piston, furnished with a valve opening upwards, and moving with reciprocating motion in a tube, also furnished with a valve opening upwards, exhausts a portion of air at each stroke, whose place is supplied by an equal quantity of water, until the water rises through the valve of the piston, and is lifted by it to the spout of the pump. Such also is the cause which supports a fluid in the branches of a syphon tube, whence it will flow with a force depending upon the difference in level, of the surface of the fluid in the vessel to which it is applied, and the open end of the syphon.

The Torricellian apparatus may not only be made the measure of the pressure of the atmosphere, and of the elasticity of gaseous matter contained in its tube, but may be applied to measure the pressure of any fluid immiscible with mercury, whether elastic or not. Neither is it necessary that its open end be immersed in a basin of mercury; but if it be turned up like an inverted syphon, the fluid whose pressure is to be measured, will act upon its open end, and the measure of the pressure will be a column of mercury whose altitude is the difference of the level of that fluid in the two branches of the tube.

If both ends of the bent tube be open, but, while the one communicates with the atmosphere, the other is acted upon by a fluid contained in a close vessel, the difference of the two levels of the mercury will now be the measure of the excess or defect of the pressure of the confined fluid, above or below the pressure of the atmosphere.

11. The great natural agent which, as we have said, acts in opposition to the attraction of aggregation, is Heat. Of its actual nature we know nothing, and it would be worse than useless to enter here into a consideration of the different hypotheses that have been framed in respect to it. It is, however, capable of acting upon our senses, producing the sensation of warmth, and of exercising influences of various natures upon all bodies. By means of these actions which determine its properties, it may be studied, and the laws of its action ascertained.

The first effect of heat of which we shall treat, is that of expanding the bodies submitted to its action. It is a general law, that all bodies increase in bulk when heated, and contract when cooled. But the manner and rate of their expansion and contraction differ, both with the mechanical and individual nature of the substances.

Of solids, each different species expands at a different rate;

but in all bodies of the same material the expansion is equal for equal increments of temperature.

In liquids, not only does each different liquid expand at a different rate, but the same liquid expands unequally for equal increments of heat at different temperatures. The expansion is least rapid when the temperature is not far from that at which the liquid congeals, and is most rapid as it approaches that at which the liquid boils.

In elastic fluids, whether gases or vapours, not only is the expansion of each uniform for equal changes of temperature, but the rate of expansion is identical in them all.

12. We apply this property of heat to the construction of instruments for measuring its intensity; such instruments are called Thermometers. They are now usually composed of a small tube, on the end of which a bulb is blown, and in which a portion of mercury is placed. The mercury is heated until it either fill the tube by its expansion, or, if the scale be intended to be long, with its vapour; the end is then closed by heat. When the mercury cools, it shrinks in the tube, and leaves the upper part free; and it will occupy a different space according to the temperature to which it is heated. To make such instruments capable of comparison with each other, it is necessary to adopt fixed points that may be easily obtained in all places. Of these, there must be at least two; and those which are now universally used, are what are usually called the Boiling and Freezing Points of water.

It is, as we shall see hereafter, a well-established fact, that the water which runs from melting ice is of the same temperature under all possible circumstances; and that the heat of boiling water under equal atmospheric pressure is also constant. In the latter case, therefore, it is necessary to define the pressure at which the experiment shall be made, and this has been established by usage at the mean pressure of the atmosphere at the level of the sea, or when the Barometer stands at 30 inches.

The scale which is usually employed upon thermometers in this country and in England, is that of Fahrenheit. This has the number 32 opposite to that point in the stem of the instrument where the mercury stands in melting ice; this is called the freezing point. Between this and the point at which the mercury stands in water boiling, when the barometer has a height of thirty inches, the space on the stem of the instrument is divided into 180 equal parts. Opposite to the temperature of boiling water therefore, the number 212°, equal to 180°+32°, is placed. The mark 0° is thirty-two divisions or degrees below the freezing point; and as mercury is capable of bearing, without congealing, even lower temperatures, and as they have actually been observed and may become the object of experiment, the scale is extended below this point as far as 40 equal divisions; these are also called degrees; but to distinguish them from those above 0°, and to enable such temperatures to be made use of in calculation, the numbers are arranged in inverted order, and distinguished by the negative sign.

To measure any temperatures that are not greater than that at which mercury boils, the scale is carried upwards, also by equal degrees, to about 600°. Mercury boils at 575°, and freezes at —40°; and thus the whole scale of Fahrenheit includes 615 equal divisions or degrees.

Mercury, like other fluids, is subject to the law of a diminished expansion near the point of its own congelation, and one increased near the temperature of its boiling; hence the equal divisions on the scale do not correspond exactly with equal increments of temperature. But, as the rate of expansion is very nearly uniform at all mean temperatures, at which by far the greater portion of philosophical inquiries are made, no practical error of any importance can arise from considering the degrees of the thermometric scale as corresponding to equal changes of heat.

13. Furnished with such a measure of heat, experiments may be made upon the expansion of the several classes of bodies. The results of such of these as are most important in reference to our subject are given in the following table, viz.

Lineal dilatation of some of the metals for each degree of Fahrenheit's thermometer, expressed in decimals of their length at the temperature of Melting Ice.

Copper, - - - - - -	0.0000096
Brass, - - - - - -	0.0000104
Wrought Iron, - - - -	0.0000068
Cast Iron, - - - -	0.0000061
Soft Steel, - - - - -	0.0000059
Tempered Steel, - - -	0.0000069
Lead, - - - - - -	0.0000158
Tin, - - - - - -	0.0000121

The cubical expansion of these bodies can be deduced from the above table, for it is a fact that is confirmed both by theory and experiment, that the fraction, which represents the expansion of any body in bulk, is just three times as great as that which represents its lineal expansion; the solid contents being taken as unity in the first case, and the length in the second.

The whole dilatation of Water between its freezing and boiling points, is - - - - - $\frac{1}{22}$

Of Alcohol, between the boiling and freezing points of water, - - - - - - - $\frac{1}{9}$

Of Mercury, - - - - - - - $\frac{1}{56}$

Within these limits the expansion of mercury is tolerably uniform; indeed, if contained in a glass tube, the joint effect of the expansibilities of the two bodies is to produce absolute uniformity, but water is not only liable to unequal rates of expansion at varying temperatures, but is also subject to a remarkable anomaly. When water is taken as it flows from melting ice, so far from expanding by the first application of heat, it contracts. This contraction continues until it reaches the temperature of 38°; from this point until it be heated to 40° its bulk undergoes no perceptible change; heated beyond 40°, it begins to expand, and continues to do so in an increasing ratio until it begins to boil. Hence water is at its maximum of density at a temperature of from 38° to 40°, and this being a physical state that can be defined independent of the thermometer, it is then best suited to be used as the unit in determining specific gravities.

The densities of water at various temperatures are as follows, viz.

32°	.99989	79°	.99682
34°	.99995	100°	.99299
39°	1.00000	122°	.99753
44°	.99995	142°	.98182
49°	.99978	162°	.97552
54°	.99952	182°	.96891
59°	.99916	202°	.96198
69°	.99814	212°	.95860

When water congeals, it suddenly expands, increasing in bulk one-ninth part of its former dimensions. By this sudden dilatation it becomes capable of producing the most powerful mechanical effects. Other substances also expand suddenly on passing from a fluid to a solid state; among these is cast iron, and this expansion is among the most important of the practical difficulties that attend the making of the parts of steam engines.

We have stated that all elastic fluids not only expand uniformly, but that the rate of expansion is the same in all. By the experiments of Dalton and of Guy Lussac, this dilatation is found to be 0.375 of the bulk between the temperatures of freezing and boiling water, or 0.00208 for every degree of Fahrenheit's thermometer.

14. When bodies are exposed to the action of heat, even when it is not sufficiently intense to produce any change in their mechanical state, they are found to be unequally affected in temperature by equal intensities of heat. Thus, for instance, the heat necessary to raise the temperature of a pound of water $3\frac{3}{10}$°, will be sufficient to heat an equal weight of mercury 100°. The heat thus absorbed by different bodies, in raising

equal weights an equal number of degrees is called their Specific heat. We know nothing of its absolute quantity, and are therefore compelled to express merely the ratio between the specific heats of the different substances, and this is usually done by taking the specific heat of water as unity.

Specific Heat of different bodies between the temperatures of Boiling and Freezing Water, according to Messrs. Petit and Dulong.

Water, - - - - - - -	1.0000
Mercury, - - - - - -	0.0330
Platina, - - - - - - -	0.0335
Copper, - - - - - - -	0.0940
Iron, - - - - - - - -	0.1098
Atmospheric Air, - - - -	0.2669
Hydrogen, - - - - - - -	3.2936
Oxygen, - - - - - -	0.2361
Steam, - - - - - - -	0.8470

All bodies, when compelled to change their volume, have their capacities for specific heat affected. When they are condensed their capacity is diminished; when they expand their capacity is increased. Hence, in the former case their temperature is elevated, in the latter it is lowered. In solid bodies that are not elastic, percussion and pressure heat them, and in some cases until they are red hot. The heat evolved at first is the greatest, and they finally, when the density becomes the greatest that the pressure can produce, cease to be further heated. In liquids the small increase of temperature that is caused by pressure, is exactly compensated when the pressure is removed. Gases and vapours are also affected in a similar manner; when they are condensed their temperature is raised, when they expand it is lowered. Steam is also subject to the same law, and thus when allowed to escape from a vessel in which it is generated under pressure, it rapidly assumes, in expanding, the temperature that belongs to steam generated under the lessened pressure to which it is now exposed.

15. When ice at a temperature below 32° is exposed to the action of heat, its temperature is readily raised to that degree; here the elevation of temperature suddenly ceases, the ice begins to melt, and no farther increase of temperature can be attained until the whole of the ice be melted. It is hence inferred that a portion of the heat applied, and which becomes insensible, is necessary to the constitution of the liquid, and resides in it in a state we call *Latent.*

In the same manner, the water proceeding from melting ice begins to shew an increasing temperature as soon as the whole of the ice is melted; the temperature continues to increase until it be raised to 212°, at this point the liquid begins to boil, or throw off steam rapidly, but the temperature of the water cannot be increased any longer. The steam that rises from the water has a similar temperature with the boiling liquid, and we infer from these two facts, that heat also passes into the latent state when it converts water into steam. When the steam returns to the state of water, and water passes into the state of ice, the heat that became latent in the previous change is again given out, and becomes sensible. To distinguish between sensible heat and that which is specific or latent, we employ, to designate the former, the term Temperature,—a word we have hitherto been compelled to make use of without explaining it.

The quantity of sensible heat which becomes latent on the liquefaction of ice is about 135° of Fahrenheit.

The quantity of sensible heat which becomes latent when water passes to the state of steam under the mean pressure of the atmosphere, is about 990°.

But water, as we shall see, is capable of forming vapour at all temperatures. It is found, that in every case the sum of the sensible and latent heat is a constant quantity, and is equal to about 1100°.

All other cases of liquefaction and evaporation are attended with similar phenomena of latent heat; and it is a general law, that whenever a body changes its mechanical state, its relations to temperature are also changed.

16. When the surface of a liquid is exposed, either at ordi-

nary temperatures, or submitted to the action of heat, the liquid is gradually dissipated. The same dissipation takes place in a greater degree when the pressure of the atmosphere is lessened or removed altogether. At some particular temperature, under the mean pressure of the atmosphere, liquids throw off vapours with great rapidity, and the process, which is attended with a violent agitation, is called ebullition. If the pressure be lessened, ebullition takes place at a lower temperature, until in the vacuum of an air-pump, water will boil below the heat of the blood. When the liquid is heated in a close vessel, it may be raised, under an increased pressure, to a temperature far above that at which it boils in the open air. The steam generated in all these cases has the same temperature as the liquid whence it flows, and contains, besides, heat in a latent state, according to the law we have just stated. The expansive force of steam, at various temperatures, is very different. At 212° it just exceeds the pressure of the atmosphere, and hence becomes capable of escaping from an open vessel in quantities just sufficient to carry off, in a latent state, all the heat that is communicated to the liquid, which, when it has once reached this temperature, does not grow warmer until the whole be evaporated. The general law of the tension or expansive force of aqueous vapour is, that while the heat increases in arithmetic progression, the expansive energy increases in a geometric ratio. It is usually stated that its pressure doubles for every 40° of Fahrenheit. A more exact measure of the tension of steam is deduced from the experiments of Dulong and Arago. Their results are comprized in the following table.

Table of the Elastic Force of Steam.

Temperature.	Pressure in Atmosphere.	Pressure per Sq. in. in lbs.	Temperature.	Pressure in Atmosphere.	Pressure per Sq. in. in lbs.
212°	1	15	380.6°	13	195
242	1½	22½	387	14	210
250.6	2	30	392.6	15	225
264	2½	37½	398.5	16	240
277.2	3	45	403.8	17	255
285.2	3½	52½	409	18	270
293.8	4	60	413.8	19	285
301	4½	67½	418.5	20	300
308	5	75	423	21	315
314.4	5½	82½	427.3	22	330
320.4	6	90	431.4	23	345
326.3	6½	97½	435.6	24	360
331.2	7	105	438.7	25	375
341.8	8	120	457.2	30	450
350.8	9	135	472.8	35	525
359	10	150	486.6	40	600
366.8	11	165	499.1	45	675
374	12	180	510.6	50	750

To find the force with which steam tends to burst the vessels in which it is generated or confined, 15lbs. must be deducted from the numbers in the third column of the above table, inasmuch as the pressure of the atmosphere acts in opposition to the elastic force of the steam.

The density and volume of steam at different temperatures may be ascertained by means of the following table, in which the density and volume of steam, estimated in relation to water, taken as the unit, are given for elastic forces estimated in atmospheres.

Table of the Density of Steam under Different Pressures.

Pressure in Atmospheres.	Density.	Volume.
1	0.00059	1696
2	0.00110	909
3	0.00160	625
4	0.00210	476
5	0.00258	387
6	0.00306	326
8	0.00399	250
10	0.00492	203
12	0.00581	172
14	0.00670	149
16	0.00760	131
18	0.00849	117
20	0.00937	106

The foregoing tables are only applicable to the case where water is heated in its liquid form, and when a portion of it remains to furnish matter to increase the density of the steam as its temperature rises. But when steam is heated out of contact with water, its tension increases only at the same rate as that of a gas. The latter case, however, rarely occurs in the use of steam for mechanical purposes.

When water holds saline substances in solution, the temperature at which it boils is raised in consequence of the attraction which exists between the liquid and the salt. It happens in some cases that the water of the ocean must be used in the generation of steam; the change which the salts it contains produces in its boiling temperature ought therefore to be known. Sea water is not of equal strength in all places, but no sensible error can arise from taking the experiments of Dr. Murray as the standard. He makes the density of sea water 1,029, and states, that in 10,000 parts there are contained:

Muriate of Soda,	- -	220
Sulphate of Soda,	- -	33
Muriate of Magnesia,	- -	42
Muriate of Lime,	- -	8
		303

or about $\frac{1}{33}$ pt. of the water. At this density the boiling point is 213.2.

When, however, a boiler is fed with sea water, the strength of the solution will continually increase, as no part of the salts will be carried off with the vapour, until saturation takes place. The boiling point will therefore be continually rising, as represented below.

	Salt in 10,000 pts. of water.	Boiling point.
Saturated,	3637 - -	226°
	3334 - -	224,9
	3030 - -	223,7
	2728 - -	222,5
	2425 - -	221,4
	2122 - -	220,2
	1818 - -	219,0
	1515 - -	217,9
	1212 - -	216,7
	909 - -	215,5
	606 - -	214,4
	303 - -	213,2

At these several degrees of solution, the vapour at the corresponding temperature has the same tension with that of pure water at 212°, or is equivalent to a single atmosphere. Starting from these several boiling points, the tension of the vapour will be increased exactly in the same ratio as that of pure water. Thus it may be stated approximately that the tension doubles for every elevation of 40° in the temperature; or, more exactly, the tension of the vapour of the solution at any given temperature may be obtained by deducting from that temperature the excess of the boiling point of the solution over 212°, and seeking the tension corresponding to the difference in the table on page 23.

When water, or any other liquid, is subjected to the action of heat in a close vessel, it rapidly attains its boiling temperature; the vapour thus thrown off adds to the pressure of the enclosed atmosphere, and retards the boiling. The temperature of the liquid will then rise beyond the temperature at which it boils in the open air, until it reach a limit which varies in each different liquid. At this last temperature, the whole mass of fluid is at once transformed into vapours of a great density, which fill the whole of the vase.

As the elastic force of the vapour, which is formed in a close vessel, increases with great rapidity with the elevation of temperature, it follows that the vessels in which liquids are thus enclosed to the action of heat, ought to be very strong, and capable of resisting a powerful pressure. But, whatever be their strength, if there were no limit to the temperature of the liquid, the time must arrive when the expansive force of the vapour would exceed the cohesion of the vessel, and burst it into pieces with great violence.

The means that may be resorted to, to limit the temperature of a liquid enclosed in a vessel, will be considered when the structure of the boilers is treated of.

We have just stated, that when a liquid was heated in a close vessel, the atmosphere of vapour formed within it would retard the ebullition until a certain period, when the whole liquid mass would assume the form of vapour. This remarkable fact was discovered by Cagniard de la Tour. His experiments give the following results. (1.) Ether is wholly converted into vapour in a close vessel, at the temperature of 302°, in a space less than twice its original bulk, and exerts an expansive force equal to 70 atmospheres. (2.) Sulphuret of Carbon is wholly converted into vapour at a temperature of 420°, and has an expansive force of 37 atmospheres. (3.) Alcohol and water have exhibited similar phenomena; the exact circumstances under which they change their state have not been observed, but it has been found that alcohol, becoming vapour of three times its liquid bulk, exerted a force of 119 atmospheres; and that water, at a temperature about that at which zinc melts, or 680°, expands at once into vapour of about four times its original bulk, exerting so great a force, that the experiment has been but seldom successful, in consequence of the breaking of the vessels in which it has been attempted to perform it.

17. Heat is conveyed in various manners: It may proceed directly from a heated body to those which surround it; it may

be conveyed through intervening bodies, or from one part of a body to another; and in fluids it is distributed throughout the whole mass, by the motion itself generates among their particles.

When a body, at any temperature whatsoever, is surrounded by air, or plunged in a fluid of a temperature lower than its own, it grows cooler, and finally assumes exactly the temperature of the medium in which it is placed. In all cases, a body hotter than those which surround it, gives out to them its excess of heat, until an equilibrium of temperature take place.

When a body is placed in a vacuum, it still gives out its heat to the bodies which exclude the air, and finally, but more rapidly than before, comes to the same temperature with them. It is thus evident that the heat possessed by a body, even when isolated in an empty space, passes through that space to the surrounding bodies. This heat, which is thrown off from every point of a heated body, is said to *Radiate.*

Heat radiates not only when the body is placed in vacuo, but when it is surrounded by air, by other gases, and by liquids. And it is sufficient for the present purpose to examine how the radiation is performed in air; for not only are the experiments more easy than in a vacuum, but it is in this medium that radiation takes place most frequently. Air may diminish the intensity of the radiating heat, but does not alter the laws which it follows.

Heat is thrown off by a heated body in right lined directions, as if it issued from the centre of a sphere in the direction of its radii. When thus radiating, it is capable of being reflected; and this reflection takes place in the same manner as that of light; that is to say, the angle of Reflection is equal to the angle of Incidence, and both are included in a plane perpendicular to the reflecting surface. Polished surfaces reflect heat best; and it has been found to be a general law, that the power both of absorbing and emitting heat from the surface of bodies, follows a common law, and is inversely proportioned to the power of reflection. The power of giving out heat is called that of radiating, and the experiments which have been made upon this property in bodies give the following proportional results.

Table of the Radiating Power of different Bodies.

Lamp Black, - - - - - -	100
Water, - - - - - - - -	100
Writing Paper, - - - - - -	98
Glass, - - - - - - - -	90
India Ink, - - - - - - -	88
Ice, - - - - - - - -	85
Mercury, - - - - - - -	20
Brilliant Lead, - - - - - -	19
Polished Iron, - - - - - -	15
Tin, Silver, Copper, - - - - -	12

Of all substances examined, lamp black and water radiate best, and polished metals worst. When a metal is scratched or tarnished, or when it is covered with a coat of water, of varnish, or even of woollen stuff, its power of radiation is increased.

The inverse relation which takes place between the powers of reflection and absorption might be almost inferred without the aid of experiment; for all the heat which falls upon a surface must be either reflected or absorbed; the less, therefore, that is reflected, the more ought to be absorbed. The relation between the properties of radiation and reflection is not so obvious, but experiment shows, that as the one increases the other diminishes.

18. When the temperature of a body differs from that of the surrounding medium, its mode of heating or cooling depends not only on its power of radiating, absorbing, and reflecting heat, but also upon the manner in which the heat it receives, or parts with, is distributed or withdrawn from its mass. No body permits radiating heat to penetrate to any great depth within its mass; in solid bodies, any farther heating is due to the radiation among their particles. This propagation of heat among the particles of bodies is called their conducting power. Different bodies possess this property in very different degrees: thus, a rod of glass may be safely held close to the place where it is in actual fusion, and a piece of charcoal to the place where

it is burning; while if a bar of iron be heated red hot at one end, the other is so much heated that it cannot be safely touched.

Gold and silver are the best of all conductors, and all the metals are good conductors; clay and pottery are much worse, and charcoal still more so. Straw, wool, cotton, down, and other substances of similar structure, are the worst conductors among solid bodies. This is, however, in a certain degree owing to the presence of air, which they confine in such a manner as to prevent its entering into circulation. Among the solid substances on which experiments have been made, the following relative powers of conducting heat have been observed.

Table of the Conducting Power of different bodies.

Gold, - - - - - - -	1000
Silver, - - - - - - -	973
Copper, - - - - - - -	898
Iron, - - - - - - -	374
Zinc, - - - - - - -	363
Tin, - - - - - - -	304
Lead, - - - - - - -	180
Marble, - - - - - - -	24
Porcelain, - - - - - - -	12
Fire Brick, - - - - - -	11

19. Liquids are, in general, worse conductors than any solid bodies. Their temperatures are, notwithstanding, rapidly raised by a proper application of heat. Thus, if a heated body be plunged in a liquid, the layers of the liquid immediately in contact with the body are heated; they expand, and become specifically lighter than those which surround them; they in consequence rise, and are replaced by others, which rise in their turn; and the motion continues until the solid and the whole mass of liquid assume a common temperature. When the vessel that contains a liquid is heated from beneath, a double set of currents is formed, the one of the warmed particles which rise, and the

other of cold, which descend to supply the place of the former. But if the heat be applied to the top of the fluid, no more than the upper surface is heated, and the rest retains its original temperature, or is warmed in a degree hardly perceptible.

20. Gases are affected in the same manner, but, being less dense, they carry off, by their motions, less heat than liquids do; and the radiation, which is hardly perceptible in a liquid body, becomes the most prominent cause of the cooling of a body exposed to the air.

The rate of the cooling of a body, surrounded by a fluid medium, depends, then, as well upon its power of radiation, as upon the abstraction of heat by the motion of the particles of the medium. The quantity of radiation decreases in a geometric ratio as the temperatures are lessened in arithmetic proportion, and it depends upon the character of the surface of the body. The rate of cooling by the contact of a fluid is, on the other hand, independent of the nature of the surface; but is most rapid from bodies which are themselves good conductors. Both the temperatures and the rate of cooling vary in a geometric ratio, but the common multiplier differs in the two progressions. In the temperatures it is 2, while in the rates of cooling it is 2.35.

The cooling property of gases may always be expressed in terms of some power of their pressure. The coefficient of the power is, in air 0.45, in hydrogen 0.315, in carbonic acid 0.517.

These laws are directly applicable to masses of fluid bodies, because heat or its diminution is propagated in them with extreme rapidity by means of their internal motion. In solid bodies the communication of heat is more slow: but in both, the laws both of heating and cooling are identical.

21. When a solid body is cooled, by being placed in a medium whose temperature remains constant, the outer part cools first, and the temperature increases from the surface to the centre; but this difference gradually becomes less and less, and the whole will finally reach an uniform heat equal to that of the surrounding medium.

When a solid body is placed in a medium of higher temperature than its own, the temperature will be at first greatest at the surface, and least in the centre ; but the heat will gradually penetrate, until the whole of the particles attain the heat of the surrounding mediums.

When the solid is only heated at some one point of its surface, the remainder will receive heat by virtue of the conducting power. But, as every point in the surface will radiate heat, it becomes obvious that a limit will be reached, when the quantity of heat lost by radiation will be exactly equal to that communicated to the body. Thus the temperature will become constant, but each different point will have that which will depend upon its distance from the point to which the heat is directly applied.

If a solid body be formed into a vessel, and contain a liquid, and if heat be applied beneath, the motion of the liquid will bring all the parts, with which it is in contact, to its own temperature, which the interior of the vessel will not surpass. The outside of the vessel will have a temperature greater than the liquid it contains; and this difference will depend upon the conducting power of the material of which the vessel is formed. If this material be a bad conductor, the difference may be considerable; but in metallic vessels, the difference will be hardly perceptible. If, on the other hand, the heat be applied above the surface of the liquid, the latter will no longer act to prevent this part of the vessel being heated as high as the substance that furnishes the heat is capable of doing. So also, if the heat be applied below the surface, but near it, little or none of the heat will descend through the solid sides of the vessel.

If, by any accident, a non-conducting substance be interposed between the vessel and the liquid, in this case also the vessel may acquire a heat greater than that of the liquid, and the heat will be distributed as if no liquid were present.

CHAPTER II.

COMBUSTION.

Definition of Combustion.—Oxygen.—Flame.—Atmospheric Air.—Currents of Air produced by Combustion.—Increase of Weight in the process of Combustion.—Temperature of Flame, and modes of burning of Solids, Gases, and Liquids.—Different species of Fuel.—Properties and Chemical Nature of Fuel.—Carbon and Hydrogen.—Comparative value of different kinds of Fuel.—Parts of Furnaces.—Ashpit.—Grate.—Body of the Furnace.—Flues.—Chimneys.—Damper.—Furnace Doors.

22. Of the various sources of heat, but one is of importance in its relation to our subject; this is, the chemical process which is called Combustion. The process, in its general and most extended sense, denotes the combination of bodies with a class of simple substances, that are thence called Supporters of Combustion; as applicable to our present object, it is restricted to their combinations with but one of them, namely, Oxygen.

23. Oxygen is an insipid, colourless, ponderable body, which we find existing in nature in a gaseous state, and which possesses the property of entering into combination with all well-known simple substances with a greater or less degree of energy. These combinations are all attended with the developement of a greater or less degree of heat, and the quantity of heat appears to be proportioned to the energy of the action by which the combination is effected.

24. It is a general law, that all bodies when intensely heated, become luminous. When this heat is produced by combination with oxygen, they are said to be ignited; and when the body heated by this chemical action is in a gaseous state, it forms what is called Flame.

25. Oxygen is one of the principal constituent parts of atmospheric air, of which it forms about one-fifth part, and it is from the atmosphere that the oxygen, which is the agent in the combustions that we apply to generate artificial heat, is derived. Although it is thus absorbed from the atmosphere in large quantities, by processes both natural and artificial, it does not suffer diminution in quantity, for there are several natural actions that are constantly restoring and replacing it. By a peculiar mechanical law that affects elastic bodies, they are uniformly distributed over the surface of the earth, each acting as if it were a distinct atmosphere; and hence the quantity of oxygen in the air is identical in all places and under all circumstances.

Not only is the quantity of heat developed by the combination of different bodies with oxygen extremely variable, but that at which they begin to combine is also very different. There are some that unite with it at the ordinary temperature of the atmosphere, while others require to be previously subjected to the most intense heat we have the means of producing; there are others again, with which it will only combine at the moment in which it is in the act of being separated from some of its other chemical combinations.

26. As the oxygen forms, in the process of combustion, a combination with the combustible body, it is obvious that a given quantity of atmospheric air must have its property of supporting combustion rapidly destroyed; and hence whenever the process is intended to be continued, it is necessary to supply fresh masses of air. The very process itself is, however, capable of creating currents in the atmosphere that will continue until a great part or the whole of the combustible has entered into combination; and we may, by a skilful application of mechanical principles, regulate and govern the supply of air thus

drawn towards the burning body. In some cases, however, where intense heat is desired, it becomes necessary to urge, over the surface, or through the mass of the combustible, currents of air by mechanical means. Apparatus for this purpose are called Blowing Machines, of which the common bellows is the most familiar instance.

The currents that we have spoken of are formed upon the principle, by which, as we stated in the last chapter, bodies are cooled when placed in fluids. The oxygen generally enters into combination with the greater portion of our common fuel without losing its gaseous form; and although more dense at a given temperature than it was before, it is generally so much heated as to become specifically lighter than the adjacent air, while the rest of the mass of air becomes equally heated, without undergoing any chemical change. Another of the combinations of oxygen with one of the constituents of our fuel is aqueous vapour, highly rarified by the heat of the combustion; these two substances, therefore, rise along with the part of the air that has not entered into combination; and the contiguous air rushes towards the burning body, in order to supply the place of the rising column. Chimneys or flues are usually adapted to carry up the heated air. The draught of these is rendered more intense, by permitting no air to enter them but what passes through the fuel; and the quantity that shall thus pass may be regulated, either by changing the magnitude of the opening by which the air enters the fire, or by varying the area of the flue. An apparatus intended to fulfil the former of these objects is called a Register, one to fulfil the latter, a Damper.

27. Although the density of oxygen is by no means great, still, as it is ponderable, it must in all cases increase the weight of the combustible. This, at first sight, appears contrary to ordinary experience, which perceives bodies wasting and diminishing under the process of combustion. This apparent anomaly grows out of the fact, that the products of the process are in many cases gaseous, and hence escape along with the current of air that passes through the burning body. Were we

to collect the whole of the products, we should find in them an increase of weight exactly equal to that of the oxygen which has been consumed.

28. Different bodies become luminous in the process of combustion at different temperatures, solids more early than gaseous bodies. None appear to become visible, even in a faint light, below a temperature of about 870° of Fahrenheit. The light is at first of a dull red colour; as the temperature augments, the light becomes more brilliant, and the body finally shines with an intense white light. Solid bodies may become luminous when heat is simply communicated to them, and without entering into combustion; but gases are never luminous, except while entering into combination. Liquids burn only by becoming volatile, and hence it is the aëriform matter that escapes, and not the liquid itself that becomes luminous.

When a combustible is solid, and so fixed as not to become volatile by the heat generated by its own combustion, it burns only at the surface, and the heat generated resides in the place where the combustion occurs, whence it is propagated to the surrounding bodies by radiation, or by their conducting power, except so much as is applied to heat the current of air that flows through the mass of burning fuel. But if the body be one that is capable of becoming gaseous at a temperature below that at which it ignites, the combustion takes place principally in the gaseous matter, extends into the column of rising air, and into the flue by which it is conveyed. The heat the vapours acquire in their combination with oxygen renders them luminous, and it is far more intense than that found where the fuel is itself situated. Solids may become volatile either by the physical process of evaporation, or by their constituents entering into new combinations, whose natural state is that of gas; flame is the product of their combination with oxygen in either case.

The brilliancy of a flame is no criterion of the intensity of its heat. The flame of the compound blowpipe, the most intense in heat of any that we can produce, is barely visible in the open day. Those flames are most brilliant in which a gas is concerned, that has a constituent capable of returning to the solid form during the process; this being capable of becoming more luminous at equal temperatures than gas, imparts this property to the flame of which it constitutes a part; such is the cause of the intense brilliancy of the flame of carburetted hydrogen, in the form of oil and coal gas, or of its purer state, olefient gas. Flame may be cooled until the gas ceases to be luminous, or to unite with oxygen. This is done by bringing into contact with it a metallic body, or other good conductor; in this case no fresh heat is generated in the current, which, therefore, no longer produces any new calorific effect.

Flame, as a general rule, is hollow; that is to say, the gaseous matter combines with oxygen only at its surface, except under particular circumstances: thus, the cone of a candle or gas-light is luminous only at its surface, but when an inflammable gas is intimately mixed with oxygen, the whole inflames suddenly and explodes, and when currents of air are propelled violently into the body of the flame, the heat is more intense, and less of the fuel escapes unconsumed than in cases of ordinary draught; the whole gaeous matter, too, may be consumed within a less space. This principle has been advantageously applied in this country to the boilers of several steam engines, where, as the space is limited, a more complete combustion within it is desirable. For this purpose a fan wheel has been used, and with great advantage. A similar plan has been more recently introduced in England, in the boiler of a locomotive engine, and is employed in the locomotive engines on the Baltimore and Ohio rail-road, in which anthracite is used as fuel.

The current of air which flows towards and through a mass of burning fuel, produces two effects, directly contrary to each other. While, on the one hand, the oxygen that is necessary for supporting the combustion, generates heat by entering into combination with the fuel; on the other, the residue of the atmospheric air, which constitutes four-fifths of the whole, carries off a part, greater or less, of the heat thus produced. The actual effect in heating depends upon the difference of these two effects, and is influenced by the relation between the mass of air and that of the combustible. When the area of the current of air is small when compared with the bulk of the combustible, as when it is directed through a tube of small diameter, the energy of the combustion is increased, and the flame is longer; on the contrary, when the same quantity of air enters by a larger orifice, the flame diminishes in bulk, and may even be extinguished by the second of the above-described actions.

Although a body which continues solid during combustion burns only at the surface, the heat generated may be sufficiently intense to render the body luminous throughout; on the other hand, it is only at the surface that the currents of heated gas which constitute flame become luminous, but the solid matter conveyed by, or in the act of deposition from such a current, will be luminous, whether at the surface or not.

Such are the general principles of combustion, and such the nature of flame; they cannot be more fully developed, except by considering the peculiar nature and mode of burning of the several species of fuel in actual use.

29. Of the different species of fuel, those which are more commonly employed in generating steam are:

1. Pine Wood,
2. Hard Wood,
3. Bituminous Coal,
4. Anthracite Coal.

Each of these has its peculiar manner of burning; and hence the furnaces or fire-places in which they are used must differ in form and arrangement, as ought the flues and chimneys by which the current of air that passes through them is carried off.

30. The general properties of a good fuel are, that it should burn easily in atmospheric air, and that the heat generated by the combustion should be sufficient to keep it up until the whole is consumed. The heat is carried off from the fuel in three ways:

1. By the current of heated air.
2. By the direct radiation of its solid part; and,
3. By the radiation of the flame that issues, and the conduct-

ing power of the flues with which the flame comes into contact. In the application to the generation of steam, the first can be made but little use of, inasmuch as to cool this rising column of air would diminish its velocity, and thus lessen the draught of the chimney; but both the kinds of radiation, as well as the action of conductors on the flame, should be employed, and the vertical part of the chimney should not commence except at the distance from the mass of fuel at which the flame terminates. The simple combustibles which are found in the four different kinds of fuel which we have spoken of, are Carbon and Hydrogen; the coals contain sulphur, but it is not, generally speaking, in sufficient quantity to affect the manner of their combustion. There is also present a portion of oxygen.

31. Carbon is a substance which exists in a state nearly pure in common charcoal, and in the black deposit which is formed on the flues through which the column of air that has passed through burning fuel is carried.

In these forms it is a solid body of a deep black colour, insipid and inodorous; it is infusible by heat, and does not become volatile; but in most species of fuel it is, during combustion, divided into such small portions as to be readily carried off by the heated air, and is then deposited upon the flues, forming, with other condensed matter, Soot.

It combines with oxygen in two different proportions, forming carbonic oxide and carbonic acid. The former still retains the property of combining with oxygen, and, as it is gaseous, forms flame, which has a pale blue colour; the latter is incombustible, and extinguishes flame.

Hydrogen, in its pure form, exists in a gaseous state, and is the lightest of all known substances, having a density of no more than one fifteenth part of that of common atmospheric air. It combines with half its bulk, or eight times its weight of oxygen, when inflamed; and the compound that results is water, which, in consequence of the high heat generated by the combustion, is at first in a state of vapour. This combination is attended with the highest degree of heat we can obtain by any combustion whatsoever, as is manifest from the effects of the compound blowpipe, in which an united stream of oxygen and hydrogen, in the proportions that constitute water, are inflamed.

Hydrogen also unites with carbon, forming one well-known and universally admitted gaseous compound, Olefiant Gas. It is found also in the gaseous shape, containing a less proportion of carbon; but it was, until lately, in dispute whether any of the various gases of this character be definite compounds, or simply mechanical mixtures of olefiant gas with uncombined hydrogen. The former opinion has at last prevailed.

When a body, whether solid or liquid, which contains a combination of carbon and hydrogen, is exposed to a high heat, these gases are let loose and take fire; other compounds, of which these two substances constitute an important part, are also sometimes generated, but which are not combustible.

Thus, not only does a part of the fuel burn in the body of the furnace or fire-place, and its more volatile part separate, but new combinations take place there, a part of which are also inflammable, and burn in the chimney if a sufficient quantity of uncombined oxygen enter it along with them. These new inflammable products are carbonic oxide and the carburetted hydrogens.

32. Carbon, in burning, combines with no more than two and two-thirds of its weight of oxygen. In its combustion, one pound produces sufficient heat to increase the temperature of 13000 lbs. of water 1° Fahrenheit.

Hydrogen combines with eight times its weight of oxygen, and one pound of it, in burning, raises the heat of 42000 lbs. of water 1°.

Hence it is obvious, that of equal weights of fuel, that which contains most hydrogen ought in its combustion to produce the greatest quantity of heat. Such, in truth, is the case where the fuel is exposed, each kind under the most advantageous circumstances. And thus in steam engines pine wood is preferred to hard, and bituminous coal to anthracite. But as hydrogen, and the new compounds it forms, are easily separated in the form of gas, which also carries with it a dense smoke composed of minutely divided carbon, it is only when the whole smoke and gas can be consumed, that the species that abound in hydrogen manifest their full value.

In positions where the radiant heat of the fire-place can alone be made effective, or when the volatile matter either escapes unconsumed, or without being applied, those kinds of fuel which abound in carbon appear to be the most valuable. Thus, in the very careful and accurate experiments made by Marcus Bull, and published in the Transactions of the American Philosophical Society, the values of the different kinds of fuel appear to be almost exactly in the ratio of the quantity of carbon they contain. But, upon examination it will be found, that all the different substances were experimented upon in the same apparatus, and that one exactly suited to the most advangeous combustion of charcoal and anthracite. His experiments are therefore no more than a comparison, and, no doubt, a valuable one, of the effects produced by the direct radiation of that part of the fuel which remains solid, and furnish no criterion of the absolute heating powers of the substances when each is burnt in a furnace of the construction best suited to its own mode of combustion. Charcoal and anthracite lose little or nothing in the form of smoke, and the carbonic oxide that is generated is generally completely burnt: this is not the case with any other species of fuel, unless burnt in apparatus expressly constructed for consuming smoke. We have felt it our duty to state our objections to the experiments of Mr. Bull, as, in spite of these defects, they are the most valuable that we have it in our power to quote, especially as regards wood.

When the hard woods, after being well dried, are subjected to destructive distillation, the residuum of solid charcoal is no more than one-fifth part of the weight of the wood. About one-fourth part of the volatile matter is condensible into the liquid form, being water charged with an empyreumatic oil and acetic acid, a mixture that usually goes by the name of pyroligneous acid. Full one-half of the mass goes off in a permanently elastic form. As analysis shows no other substances present than the three we have stated, and as the oxygen is principally accounted for in the acid, these gaseous products are probably wholly inflammable. Pine wood furnishes little or no pyroligneous acid, and a less residue of charcoal; hence we may infer that when it is well dried, full three-fourths of the whole weight are capable of forming flame.

When wood is employed as a fuel, it ought to be as dry as possible. When recently cut, it always contains a considerable quantity of water; and as in burning it does not acquire heat enough to decompose that fluid, the water must be converted into steam, which requires a considerable quantity of heat. Wood does not part with the whole of its moisture by mere exposure to the air, but retains at least one-tenth part of its weight, unless artificial heat, at least as great as that of boiling water, be applied. Hence, when wood is to produce the greatest quantity of heat which it is capable of affording, it ought not merely to be seasoned, but dried by the direct application of heat. As usually employed, it has about 25 per cent. of water mechanically combined, the whole of the heat necessary for evaporating which, is lost.

Hard woods burn only at the surface; the heat there generated speedily causes the volatile matters of the whole mass to escape; such of them as are inflammable take fire, and form a flame. There soon remains nothing but a compact, dense mass of charcoal, which burns slowly and without flame.

Pine and other light woods burn with much more rapidity as they split under the action of heat, and are, besides, porous enough to permit the air to penetrate: much of the carbon too either assumes a new form of combination with the hydrogen, or is carried off in smoke; they therefore leave little or no charcoal, and give out flame during nearly their whole combustion.

The experiments of Count Rumford give the following results:

Species of wood.	lbs. of water heated 1° by 1 lb. of fuel.
Oak, seasoned, - - - -	4590
—— dried on a stove, - -	5940
Maple, dried on a stove, - -	6480
Fir, seasoned, - - -	5466
—— dried on a stove, - - -	7150

These are all too high for any practical purpose, as we rarely resort to artificial means of drying, and have but seldom the power of obtaining wood thoroughly seasoned. We therefore do not consider it safe to take at more than 4500 lbs. the quantity of water which 1 lb. of hard wood is capable of heating 1°, and 5000 for the quantity heated 1° by pine wood.

The more useful of Mr. Bull's experiments upon wood are as follows, viz:

Kind of Woods.	Weight of Cord.	Comp. value per Cord.
	lbs.	
Shell Bark Hickory,	4469	100
Pig-nut Hickory, -	4241	95
Red-heart Hickory, -	3705	81
White Oak, - - -	3821	81
Red Oak, - - - -	3254	69
Hard Maple, - -	2878	60
Jersey Pine, - - -	2137	54
Pitch Pine, - - -	1904	43
White Pine, - - -	1868	42

The difference in the modes in which bituminous and anthracite coal burn, is still more marked than between various kinds of wood. Those coals which contain much bitumen, (as Cannel coal,) burn much like pine wood, splitting and emitting an inflammable gas. Those which contain less, (as common Liverpool coal,) burn at first with flame, and then leave a mass of coke or charcoal, which burns without flame. Anthracite, on the other hand, has little or no flame, except what arises from the formation of a portion of carbonic oxide. All coals contain more or less water, but much heat is not lost in their combustion on this account. They do not burn, unless heated to a temperature at which water is decomposed, and in the flame that is formed, the two gases again combine and emit heat. On this account damp bituminous coal produces more flame than when it is dry; and although it does not appear to be of any use to moisten the anthracites, those varieties which lie below the level of water in the mine are more easily ignited, and give more flame than those which are found in dry situations. When bituminous coal is subjected to the destructive distillation, nearly two-thirds of its weight is left behind in the form of coke. This is principally composed of carbon; a part of the volatile matter, although condensible, is inflammable, and will join in generating flame; this, with the inflammable gases, amounts to about one-fourth of the weight of the coal, and the remainder, amounting to about $\frac{1}{12}$, is incombustible.

The best anthracites contain about 95 per cent. of inflammable matter, which is principally carbon. In burning them, however, a very considerable residue of carbon is always left, as the interior of the pieces into which they are broken cannot be inflamed, and the dust does not burn. This is not the case with bituminous coal, which may have every particle exposed to the contact of air, by stirring it during combustion, and of which the smallest fragments inflame. If we calculate the heating powers of the two species of coal from their chemical composition, they will be as follows:

Species of Coal.	Lbs. of water heated 1° by 1 lb. of fuel.
Average of bituminous coal, - -	13792
Anthracite, - - - - - -	12350
Coke, - - - - - - -	13000

In practice, however, a considerable quantity of heat is wasted, which the best experiments make about one-third, in the case of bituminous coal and coke, and the loss in anthracite from its less perfect combustion must be even greater.

The results thus reduced are, in the nearest round numbers,

	lbs.
For bituminous Coal, - - - -	9200
For Coke, - - - - - -	8600
For Anthracite, - - - - -	7800

but the latter is probably beyond the truth.

As a bushel of bituminous coal weighs from 80 to 84 pounds, and as the water which is used in feeding the boilers of steam engines has a temperature of 100°, the burning of a bushel of this coal is capable of converting 12 cubic feet of water into vapour; and the sum of the latent and sensible heat being a constant quantity, the result will be the same whether the boiler be employed to generate low or high steam.

The relative values of different fuels may be ascertained by applying them to the decomposition of litharge. It is known from experiment, that pure carbon will reduce to the metallic form 34 times, and hydrogen 103,7 times, their own weights of that oxide of lead. This differs but little from the relation in their heating powers which has already been stated. Taking these facts as the standard of comparison, we have the following for the results of the latest experiments which have been made on this subject:

Species of Fuel.	Pts. of Litharge reduced.	lbs. of water heated 1° by 1 lb. of fuel.
Oak seasoned, - - -	12,5	4790
Do. artificially dried, -	14,	5350
Nut Wood, - - -	13,7	5240
White Pine, - - -	13,7	5240
Yellow Pine, - - -	14,5	5550
Charcoal, - - -	25 to 32	
Turf, - - - -	8 to 15	
Charred Turf, - - -	17 to 26	
Lignite, - - - -	17 to 27	
Coal, Welsh, - - -	31,2	11,840
Newcastle, - -	30,9	11,815
Wigan, - - -	28,3	9820
Belgium, - - -	29	11,090
Durham, - -	31,6	12,080
Coke, good, - - -	28,5	9910
inferior, - -	22,2	7380
Anthracite, French, - -	29	11,090
Pennsylvania,	25	9560

33. The furnaces in which the fuel employed for generating steam is burnt, are composed of a chamber in which the com-

bustible is placed, a grate on which it is laid, an opening through which the air enters to the fuel, and an ashpit, into which the unconsumed portions fall. Furnaces usually receive the air from beneath and through the ashpit; but in some cases the air descends to the burning fuel, and passes downwards through the grate. In treating of these parts, we shall follow the air in its course, arranging them in the order in which it reaches them.

34. The Ashpit is generally a quadrangular chamber enclosed on three of its sides by walls, and open on the fourth, which is surmounted by a bar of iron, or an arch. Its section is usually of the same size as the grate, and its height depends upon the circumstances of its position. It ought, however, to have an opening to the free air as large as the area of the grate. In engines placed on the land, it has lately been a practice, which is attended with advantage, to have a few inches of water at the bottom of the ashpit; this is renewed by a small, but constant stream. The air that flows to the furnaces is thus kept cool, and enters them loaded with moisture, which increases the length of the flame. In some of the modern steamboats the boilers are placed upon the wheel guards, and the space below the grate is open to the water beneath. The combustion is found in these cases to be more intense. There can be no other general rules laid down for the construction of the ashpit, which will naturally assume its form from the figure and size of the furnace, and the position in which it is to be placed.

35. The grate is composed of parallel bars, usually of cast iron. They have frequently the form of a prism, whose section is an isosceles triangle, the base of which is uppermost. Their ends are rectangular, and wide enough to keep the triangular portions at a distance of half an inch. When long, they are made deeper in the middle, and gradually taper to their points of support. The size of the bars will depend upon their length, the weight of fuel they have to bear, and the shocks they are subject to in throwing it in and stirring it. The bars are

usually about half an inch apart, and the bars of the largest furnaces an inch and a half thick. The open space through which the air passes, is therefore no more than a fourth part of the aperture on which the grate rests, and the space is farther diminished by the lodgment of the fuel upon, and the ashes and cinders between them. The least space that ought to be left for the passage of air through the grate should be equal to the area of the chimney, and the area of the grate itself is consequently four times as great. This, however, being the minimum, and the fuel and cinders opposing a resistance, grates ought always to be larger than four times the area of the chimney. We shall hereafter give the princples on which dimensions of this last-named part of the apparatus depend. It is usual among practical engineers to give a foot of area of grate for every cubic foot of water evaporated in an hour when the fuel is coals, and double that space when the fuel is wood. This rule agrees with that deduced from theoretic considerations by the French and German engineers. In practice, however, with any free burning fuel, it is better to have a surface of grate beyond the absolute want, than one that may be too small. With anthracite, the case is probably different, as too large a column of air must diminish the intensity of the combustion. In the furnaces of Dr. Nott the bars are made extremely thin, and there is, in consequence, an obvious saving of heat. The open space is equal to that occupied by the bars.

36. Above the grate is situated the body of the furnace. Its horizontal section is determined by the size and shape of the grate, its depth will depend upon the nature of the fuel. It must, in the first place, be of sufficient depth to allow such a thickness of fuel as is best suited to its complete combustion; and in the second, there must be, above the fuel, a sufficient space for the flame to be fully formed before it enters into the flues.

It is very difficult to state exactly a rule for the depth of the fuel that lies upon the grate. The larger the masses in which the fuel is thrown in, the greater may be its depth. The depth may also be increased with an increase in the draught of the chimney. In all cases, fuel may be added until it appears to diminish the intensity of the combustion; for in this way the double advantage will be gained, of being compelled to feed less frequently, and the air that enters will be more completely applied to the support of the fire. On the other hand, the quantity of fuel thrown on at one time must not be sufficient to deaden the flame, as in this case a great proportion of it will escape in the form of smoke. Wood requires to be most frequently added, and anthracite coal endures the longest. It has been found that a depth of about four inches is most advantageous for bituminous coal; Anthracite will probably require at least double that depth, and wood will bear considerably more. In respect to the quantity of combustible, it is necessary that the furnace for burning wood should have at least twice the capacity of one for burning coal. A depth of from twelve to fifteen inches from the grate to the bottom of the boiler is sufficient for the most advantageous combustion of bituminous coal; while it has been found in practice, that if the depth of the furnace, in which wood is burnt, be less than three feet, the useful effect of the fuel is lessened.

When high steam is to be generated, the space may be made less, but it is in all cases disadvantageous to bring the boiler into contact with or too near to the fuel itself. The reason of these rules is obvious; for if the heat be withdrawn immediately from the fuel itself, rather than from the flame and the heated air that has passed through the furnace, the volatile matter and heated air will cool too speedily, the length of the flame will be lessened, and much of combustible will escape unconsumed; the draught of the chimney will also be diminished by the cooling of the air and the absence of flame.

In respect to furnaces placed within the boiler, they at first sight appear to be extremely advantageous, because, as the boiler itself forms their enclosure, no heat can be lost. But this advantage is not real, for the surface of the furnace being cooled down by the water to a temperature which in low pressure boilers does not much exceed 212°, and, even in the case of high pressure, is far beneath the heat of flame, the combustion will languish, the draught of the chimney will be diminished, and the flame will be of but little length. On the other hand, it is frequently necessary to employ furnaces thus situated, in order to economise room and lessen the weight; such is the case in steam-boats and locomotive engines. When such an arrangement becomes necessary, the inconveniences may be in some part obviated by lining the furnace with fire-brick, or other bad conductor of heat. The length of the flues may then be increased, and the whole gaseous matter converted into flame and applied usefully.

There are cases in which it is of advantage to burn the smoke that issues from furnaces. As, however, when the fire is properly managed, but little unconsumed matter will issue from a furnace of the ordinary construction, such plans are of very little value in making the heat produced by a given quantity of fuel greater. It is only, then, when the smoke which occasionally issues, when fresh fuel is added, is productive of inconvenience to the neighbourhood, that furnaces of the kind need be erected. In a general treatise, therefore, it is not considered necessary to enter into a detail of their construction.

When bituminous coal is used as a fuel, it may be supplied, in proportion to its consumption, by a self-acting apparatus, the invention of Brunton of Birmingham in England. This is said to lessen the expenditure of fuel rather more than one-third. In our country bituminous coal is not yet much employed, and in consequence, we have not thought it necessary to describe the apparatus. Those who wish to become acquainted with its structure, may consult Tredgold and Lardner.

37. From what has been already said, it will be obvious that the volatile parts of the fuel, and the heated air that has passed through it, are not to be permitted to enter at once into the chimney, but must be retained in contact with the boiler, at least until all the flame be made use of. The air and flame are therefore made to circulate in flues. These flues may be either beneath the boiler, upon its sides, or within it. Their length will depend upon the nature of the fuel; when it burns with much flame, they should be long; but if it give but little, a horizontal passage beneath the boiler, and of its whole length, will be

sufficient. Pine wood will therefore require the greatest length of flue, and anthracite coal the least.

The greater the periphery of the flue under a given area, the greater will be the quantity of heat it will give out, but at the same time the greater will be the friction of the heated air against its surface. Here again a difference in form may arise according to the nature of the fuel; the flues made use of, with combustibles that furnish the greatest quantity of flame, having the greatest practicable periphery, while those that burn with little or no flame should be square or circular. This, however, applies only to flues beneath the boiler or upon its sides; for when the flues pass through the boiler, considerations of safety will generally require their section to be circular.

Air being a bad conductor of heat, the bottom of a flue is less heated than its sides, and the latter much less than its top. Hence flues beneath the boiler are far more advantageous than those which surround it, and when a flue passes through a boiler, it ought, were there no other reason, to be entirely immersed in water.

The whole area of the flues must not be less than that of the chimney, otherwise the draught will be impeded; and, on the other hand, there is no advantage gained by making it greater.

38. When the flame is completely expended, no farther advantage is usually gained by making the current of air to circulate in contact with the boiler. A part of its heat might, no doubt, be withdrawn, but this will be done at the expense of the intensity of the combustion, unless it be practicable to make the chimney of very great height. The ascent of smoke in chimneys is due to the difference in the density of the heated air they contain, and of that of the open atmosphere. The force which propels the current is, therefore, the difference of weight of two columns, one of atmospheric air, the other of the heated and rarified air of the chimney, whose altitudes are equal, and the same as that of the chimney, and whose areas are equal to that of the aperture by which the heated air enters the chimney. When, therefore, it is possible to make the chimney high,

the air within it need not be as much rarified, in order to obtain an equal force of draught, and the flues may be permitted to circulate longer around the boiler. We conceive, however, that it may safely be taken as a general rule, that when the gas has been wholly inflamed, the heated air may be permitted to ascend. In furnaces for burning wood and bituminous coal, it frequently happens that the flame enters the vertical chimney, and that much heat is lost; while in those for burning anthracite, the flues are frequently so long as to diminish the draught of the chimney and the consequent intensity of the flame.

The ascent of the air in chimneys is due, as we have stated, to their height and the temperature of the ascending column of air. But the latter is the mean temperature of the air in the chimney, and not that at which it enters. The sides of the chimney absorb heat, and it is again withdrawn from them by radiation, and the cooling action of the air; and hence the velocity is rapidly diminished. Air, too, is subject to a considerable degree of friction in the chimney.

This last resistance is proportioned to the square of the velocity and the length of the chimney directly, and the diameter inversely.

The cooling of the air depends not only upon the quantity of surface exposed, but upon the nature of the material; and hence experiment alone can determine the effect which this has upon the velocity. We are aware that the greatest part of the heat that is thus lost is due to radiation. Now, of the materials usually employed in making the chimneys of steam engines, sheet iron, wrought iron, and brick, the first is the worst and the last the best radiator of heat. But the difference in this respect between the two first is but small, and as cast iron pipes must be thicker than those of wrought iron, the outer or radiating surface of the former will be the least heated. Hence it would be reasonable to conclude that chimneys of cast iron have the best draught, those of brick the worst. This has been found to coincide with actual experiment.

It has also been found that the friction of air in chimneys of different materials is not the same, that in brick being greatest, and in cast iron least.

It is extremely difficult to calculate the proper dimensions for a chimney, inasmuch as many of the elements are difficult to determine. Peclet has given a method founded upon strictly scientific principles, but it is altogether too complex for practice. The rule given by Tredgold, is—"*Multiply the number of cubic feet of water to be evaporated per hour by* 112, *and divide by the square root of the height of the chimney.*"

This may be taken as the minimum for chimneys of brick, and with bituminous coal for the fuel. The last-named author advises that the area of the chimney be made twice as much as is given by his rule. In chimneys of iron the area may be less, the fuel remaining the same; and they may be still futher lessened when the fuel is anthracite coal; on the other hand, the area of chimneys for burning wood should be greater than those for bituminous coal. The best form for the horizontal section of a chimney is that of a circle, for the friction is less in it than in any other figure, and in metal the cost of constructing it is also less. Of figures having circular sections, the best is the frustum of a cone, whose upper area is that which is given by the rule of Tredgold, and whose lower section has twice that area. If the chimney be cylindrical, a small truncated cone or conoid, placed upon its top, will make it act more advantageously.

39. As various circumstances will occur, in consequence of which it may be necessary to alter the intensity of the combustion, it is customary in most cases to place a Damper at the junction of the flues with the chimney. This is a plate of iron which slides in a groove, and may either wholly or partially close the aperture of the chimney. Its effect will be obvious from what has been stated of the draught of chimneys, which depends upon their height and the area of the space at which the smoke enters, as well as upon the difference of temperature of the external and internal air. In speaking of boilers, a method of making Dampers self-acting, so as to close or open the aperture of the chimney in exact proportion to the heat which is required, will be mentioned.

40. It remains to speak of the doors of furnaces. Those are usually rectangular, with hinges, and are fastened by latches. The material is generally cast iron, in some cases cast with a flaunch within, to support a lining of fire brick. The best of all would be a double door of iron, that when shut would enclose a stratum of air; but the inner shutter would be too liable to be destroyed by the fire.

When cleanness and neatness are desired, the whole front of the furnace is made of cast iron, with apertures for the doors and ashpit. In reverberatory furnaces, it is frequently usual to suspend the doors by a lever, to the opposite end of which is attached a counterpoise. Such an arrangement might probably be applied with advantage to the furnaces of steam engines.

The form, arrangement, and distribution of furnaces, flues, and chimneys, depend, in a great degree, upon those of the boiler. Instances of those that are found to answer best in practice, therefore, cannot be given until the structure of boilers has been examined.

CHAPTER III.

BOILERS.

Materials of which Boilers are constructed.—Figure of Boilers.—Strength and Thickness of Boilers.—Apparatus for showing the level of the water.—Feeding Apparatus.—Proof of Boilers.—Safety-Valves.—Air-Valves.—Steam Guages.—Self-regulating Damper.—Common Damper and Register.—Dangers arising from the fire-surface becoming bare of water.—Thermometer.—Plates of fusible metal.—Valves opening at the limit of temperature.—Deposits of solid matter, and modes of lessening and removing them.—Steam-pipes.—Generator of Perkins.

41. Water is converted into vapour, for the purpose of setting steam engines in action, in vessels that are called *Boilers.* These are always of metal, and three different materials are in use for their construction: Wrought Iron, Cast Iron, and Copper. Wrought iron and copper are rolled for this purpose into plates and sheets, which, after being bent to the proper form, are united by bolts, driven through holes punched around their edges, and riveted. When cast iron is used for boilers, they may either be of a single piece, or it may be cast in separate portions, which are united by screw bolts and nuts, passing through holes left or drilled in flaunches. Of the two first, copper is most easily worked, but it is far the most expensive material, and is therefore now used only in a few instances, where the others are, from the circumstances of the case, inadmissible. Copper is much less easily acted upon by oxygen than sheet iron, and does not decompose water at any

temperature; it acts less powerfully upon the saline deposits that occur when sea or other impure water is used; in addition, it is less liable, than either of the other materials, to split or crack on sudden changes of temperature.

Sheet iron is more tenacious than copper, but is liable to rapid oxidation, and has frequently invisible joints arising from the manner in which it is manufactured. Still, however, when the water used is tolerably pure, it is the best material, if we take into view the strength and comparative cheapness.

The tenacity of copper is diminished by heat, but that of wrought iron increases up to the highest temperature to which it will in any likelihood be exposed in a boiler.

The relative cost of boilers of the several materials may be estimated as follows: The comparative thicknesses of boilers to bear the same strain, are,

For Copper, - - -	3
For Sheet Iron, - -	2
For Cast Iron, - - -	12

The cost of them per lb. in New-York, is

Copper, - - -	34 cts.
Sheet Iron, - -	16 "
Cast Iron, - - -	6 "

Their respective densities according to the table §9.

Copper, - - -	8.878
Sheet Iron, - -	7.788
Cast Iron, - - -	7.207

The product of these three elements give their relative cost as follows:

Copper, - - - - -	906
Sheet Iron, - - - - - -	250
Cast Iron, - - - - -	522

Or, taking Sheet Iron as the unit:

Copper, - - - - - -	3.60
Sheet Iron, - - - -	1.00
Cast Iron, - - - - -	2.09

There is another point of view under which they ought to be examined, which is, the value of the material after the boiler has become unfit for service; and here copper might appear to have the advantage, as it will sell for a far higher proportionate price than either of the others; but still its depreciation in value, added to the interest on its cost, will be at least equal to the loss upon a boiler of wrought iron.

42. In determining the proper figure of Boilers, various circumstances appear at first sight as necessary to be taken into view. 1. The power to generate steam; 2. The action of their own weight to change their figure; 3. The pressure of the contained fluid; 4. The action of the steam to burst them. Upon a more close investigation, it will, however, appear, that none of these, except the last, is of any real importance.

The power of a boiler to generate steam depends upon the quantity of surface that is exposed to heat, and so long as this is the same, neither the figure of the boiler, nor the quantity of water it contains, have any effect upon its action.

Boilers are liable to bend by their own weight, but to give the top the figure of an arch, and to support the boiler well from beneath, obviates all difficulty on this score, except in boilers of the largest kind; and the most brittle of the three materials has in this respect an advantage over those which are more flexible. The pressure of the contained water also acts to change the shape of a boiler; as this force depends upon the product of the surface by the depth of the liquid, it increases with the height the liquid stands in the vessel, and with the developement of its sides; aud under equal depths, a vessel whose section is a circle will sustain the least pressure. Both of these actions may be rendered of little amount by distributing the water in several boilers instead of increasing the size of a single one.

Neither of these influences can be compared in their amount to the strain exerted by the steam which is generated within the boiler. This, too, varies in different species of engines. In some, as we shall see, the steam is condensed, and that flowing from the boiler acts against the partial vacuum which is thus formed. The steam in this case need not have an expansive force of more intensity than the pressure of the atmosphere, and it sometimes does not exceed that limit by more than a few inches of mercury ; such engines are called *Low Pressure.* There are, however, some condensing engines to which the names of Low Pressure is improperly applied, as means have been found to use, and condense steam of a tension of several atmospheres. Instead, therefore, of distinguishing engines as of high or low pressure, we shall speak of them as condensing, or high pressure, and with the former, steam of medium, or even high pressure, is frequently used. In other engines, which are called *High Pressure*, the steam employed never has an elastic force less than two atmospheres, more frequently reaches four or five, and sometimes is as great as ten. Boilers of the first description do not usually require materials of any great strength, nor is it necessary in them to seek for the form of greatest resistance. But in high pressure boilers, it is of the utmost importance, not only to use a material of sufficient tenacity, but to give them the figure which will be the least liable to yield under the great expansive force to which it is subjected.

That figure which has the greatest strength to resist such an expansive force, is one all of whose sections are circular. A sphere is the only solid which has this property, and it may be advantageously used upon a small scale. It, however, presents too small a surface, must have all its dimensions increased equally, and is not adapted to receive flues to retain the flame ; it is therefore never employed for the boilers of steam engines.

All the sections of a cylinder at right angles to its axis are also circular, it therefore presents the greatest resistance to forces acting against these sections ; its ends, however, if plane surfaces, are comparatively weak. In Europe, where such boilers are of recent introduction, the ends are made of the same material with the body of the cylinder, and are formed into the shape of a portion of a sphere. In this country, where they have been long in general use, the body of the boilers is made of sheet iron, and the ends are plane surfaces of cast iron, made thick enough to be of equal strength with the other material, and firmly bolted to it.

The same law that affects the strength of a vessel to bear an-internal expansive force, also regulates its resistance to a pressure from without. Hence, spherical and cylindric boilers resist collapse, from the condensation of the steam they contain, better than those of other figures; and hence also, when flues pass through boilers, they should be cylindrical.

From what has been said §30. in speaking of the action of fuel, it will be obvious that the heat penetrates into the boiler by radiation from the burning mass, or by the direct contact of the flame and hot air with its surface. The exterior face of the boiler first receives the heat, it is then propagated in the metal by its conducting power, and the latter heats the water in contact with its interior, by causing a motion among its particles. It is clear, then, that the quantity of water in the boiler has no influence on the quantity of steam which can be formed in a given time. All that is necessary is, that there should be enough to cover the whole metallic surface, to the outside of which the heat is applied. Hence the quantity of fuel consumed, the extent of the heated surface of the boiler, and the conducting power of the substance of which it is made, are the only elements that need enter into the calculation of the quantity of steam a given boiler will generate. It is better, too, to depend upon actual experiment for the effect, than to deduce it from any theoretic considerations. From a mean of several such experiments, it has been deduced that six feet of fire surface are sufficient to evaporate a cubic foot of water per hour. But as the flues will communicate less heat in proportion as they recede from the furnace, the sum of the surfaces of furnace and flues ought to be eight feet for each cubic foot of water to be evaporated per hour, for low steam, and for high steam, not exceeding five atmospheres, nine feet.

As the quantity of steam generated, depends, then, wholly upon the extent of the surface of the boiler which is exposed to heat, and as the saving of weight is in many cases advantageous, it has been proposed to use a combination of tubes for boilers, which will expose a much greater surface, in comparison with their internal capacity, than larger cylinders; for it is a mathematical law, that while the surfaces of cylinders of equal length increase as the diameters simply, their internal capacity increases with the squares of that dimension. A saving may also be made in the material of which the tubes are constructed, for the strength of a metallic tube to resist an effort to burst it, increases in the inverse ratio of its diameter. It has also been proposed to immerse such tubes wholly in the flame, and inject into them from time to time a certain quantity of water, to be converted almost instantly and wholly into steam.

The first of these plans has a speedy limit in practice, and the last is wholly inadmissible, as will appear from the following considerations.

1. The presence of a conducting body in the midst of the flame, will cool the gas of which it is composed, diminish the intensity of the combustion and the draught of the chimney.

2. When tubes are actually heated to the proper degree, and no longer act to cool the flame, the flues must be made short enough to permit the air to enter the chimney as soon as it is cooled down to the temperature of the tubes; otherwise, instead of heating them farther, it will tend to cool them.

In tubular boilers, also, the generation of steam will be at first extremely rapid, and will displace the water they contain; the quantity of steam generated will then diminish, and the metal being no longer cooled by contact with the liquid, will become red hot. Various inconveniences, which will be referred to hereafter, will arise in consequence.

3. The principal objection to the last plan is founded upon a remarkable experiment of Klaproth, which is as follows, viz. If a polished spoon of iron be taken and heated to a white heat, and a drop of water be let fall upon it, the drop divides at first into several smaller ones, which, however, speedily unite. This, if it be closely observed, will be seen to have acquired a rotary motion: it continually decreases in bulk, and finally explodes. A second, and a third drop exhibit the same phenomena, but the continuance of the drop upon the metal becomes less and less as the latter cools. One of the experiments gave the following results; and the others, although the absolute times of duration differed, all exhibited a similar law.

The first drop remained	40″
The second,	20″
The third,	6″
The fourth,	4″
The fifth,	2″
The sixth,	0″

This experiment of Klaproth has been confirmed by others of greater accuracy, made by a committee of the Franklin Institute. In these experiments it was found, that the evaporating power of iron increased up to the temperature of 334°; that the decrease in the evaporating power was so great above that limit, that the quantity of water which was evaporated at that temperature in 1″, required 15 seconds for its evaporation at 395°.

Perkins observed similar phenomena in the generator of his engine. This vessel being heated red hot, while empty, water was admitted. The elastic force of the vapour was at first but small, and increased rapidly as the temperature of the generator was diminished.

The explanation which has been given of this phenomenon is as follows, viz. when it occurs, the water is never in contact with the metal, or at least only at a single point, as is shown by the spherical figure of the drops, and their rotary motion; a stratum of steam intervenes, which, being a bad conductor, does not convey heat to the drop; and the expansion of the drop, out of contact with the metal, appears to be due to a repulsion which is exerted by incandescent bodies upon those which are colder. This last explanation is corroborated by another curious fact observed by Perkins. He adapted to his generator, by an aperture of one-eighth of an inch in diameter, a tube or adjutage of three feet in length and half an inch in diameter within; this tube was closed by a stop-cock, and the safety valve loaded with a weight of about 700 lbs. per square inch. The generator being heated red hot, the steam contained in it opened the safety valve; but, although the cock of the adjutage was opened, no steam escaped by it until the temperature was considerably lowered.

Thus it appears that the rapidity of the evaporation does not increase with the temperature of the vessel into which the water is introduced. It probably does so as long as the water is capable of moistening the metal, which it can only do before that becomes incandescent; but after the metal reaches a red heat, the rapidity of the evaporation decreases with every increment of heat.

Tubes, or other vessels, into which the water is injected and thus converted into steam, have this additional disadvantage: the deposits of solid matter that fall from almost all water when evaporated, and which are greater in proportion as the water is impure, become harder and more compact than when the boiler is kept full of water; they also adhere more forcibly to the metal, and are more liable to corrode it.

The objections which have been stated to tubular boilers do not apply to the use of tubes for conveying flame and heated air, from the furnace to the chimney. The latter method has now come into universal use in locomotive engines, and has been applied advantageously in steam-boats. It ought, however, to be observed, that they are generally placed too near each other, and that the space for water between them may thus be so far diminished as to render the boiler liable to the same objections as if it were itself tubular. This remark is more particularly applicable to the tubular flues which are situated near the bottom of the boiler.

A boiler has been used for some years in England in experiments on carriages intended to be moved by steam on common roads. This is the invention of Hancock. It is composed of a number of rectangular cases proceeding downwards from a common reservoir. These are sustained by bars of iron interposed between them, which divide the intervening spaces into rectangular flues. The whole is bolted together by rods, which traverse both the spaces which contain water, and the iron bars. Such a boiler will possess great strength, and will expose a great fire surface in proportion to its capacity. It is, however, obvious, that if the dimensions of the rectangular cases be too much diminished, the arrangement will be liable to the same difficulties which attend the use of tubular boilers.

It has been proposed in this country, and we have seen it practised in several cases, to adapt to the lower part of boilers, tubes communicating with them, and immersed in the flame. Such, too, was the form proposed by Woolf in England. Actual experiment has shown that such an addition has no real advantage, and when the tubes are constructed of cast iron, they run the risk of being broken by the sudden variations in temperature to which they are exposed. It may therefore be inferred as a general rule, that it is better to use cylindrical boilers of at least a foot in diameter, than tubes of small size, whether alone, or communicating with larger vessels.

43. We have stated that the most important force to which boilers, and particularly those containing high steam, are exposed, is the expansive energy of the steam itself. The action of this force upon the sides of a cylinder is proportioned to the elastic energy of the steam, and the radius of the cylinder ; and it is resisted by the cohesive force of the metal.

If the ends be a portion of a sphere whose radius is equal to the diameter of the cylinder ; then the strain upon any given surface is equal to that upon the sides.

When the ends, as is usual in this country, are plates of cast iron, their strength is investigated upon the principle of a beam, equally loaded throughout its length, and supported at the ends. The force that will break it, is proportioned to the square root of the pressure, multiplied by the square of the diameter.

The absolute weight which a cubic inch of the usual materials will bear without breaking, is, for

	lbs.
Bar Iron, - - - -	64000
Sheet Iron, - - - -	57000
Cast Iron, - - - -	19000
Sheet Copper, - - -	40000

It is not, however, sufficient that the boiler shall not break under the expansive force ; it must not even change its figure nor must the bolts, by which it is fastened, give. These materials are, in consequence, much nearer in value than their absolute strengths would show; for cast iron will bear 15300lbs. per cubic inch without changing its shape, and wrought iron no more than 17800lbs.

The change of figure that each will support without breaking, is also very different; in cast iron, the limits of expansion and fracture are very near to each other; sheet iron will stretch before breaking from $\frac{1}{\ }$ to $\frac{1}{20}$; while copper may be expanded $\frac{2}{5}$ths of its original dimensions. Another circumstance also must be taken into account, which is their respective liabilities to break by sudden changes of temperature; to this cast iron is very liable, sheet iron but little, and copper not at all. Taking all these circumstances into account, we have assumed as the numbers proper to represent the strength of these materials,

	lbs.
Sheet Iron, - - - -	9000
Copper, - - - -	6000
Cast Iron, - - - -	3000

The first being about half the strain that wrought iron bears without changing its figure; the other two bearing the nearest ratio to it in round numbers, that their respective strengths do.

It is also to be taken into view, that the tenacities first given, are estimated from experiments made upon the metals when cold, while it may occasionally happen that parts of the boiler reach a red heat. Now, it has been found from actual experiments that the tenacity of copper and cast iron may be diminished, by heating them red hot, to not more than a sixth-part of that which they possess at an ordinary temperature. The numbers last given are reduced from the first in even a greater ratio, and therefore are sufficiently small to make full allowances for this decrease of strength. On the other hand, it appears from experiments performed at the Franklin Institute, that the tenacity of wrought iron is increased by heat.

The usual rule for estimating the thickness of the plates of which cylindrical bodies are made, is as follows:

Multiply the Radius in inches by the pressure on each *square inch in lbs. and divide the product by the number assumed above as the strength of the material, the quotient is the thickness in inches.*

The rule for the ends is as follows:

If of the same material with the body of the cylinder, the ends, if hemispherical, need only be half as thick; if a portion of a sphere, whose radius is equal to the diameter of the cylinder, the two thicknesses are equal. If of any other radius, multiply half the radius in inches by the pressure in lbs. and divide by the cohesive force of the material.

If the ends be plates of cast iron,

Multiply the pressure on each square inch in lbs. by the square of the diameter in inches, and divide the product by twice the cohesive force of the material, the square root of the quotient is the thickness in inches.

Such are the rules which theoretic considerations would point out. We shall proceed to compare their results for a pressure of 100lbs. per square inch, with the practice of the best engineers of this country, in cylindric boilers of sheet iron with cast iron heads.

Diameter of Cylinder.	Thickness of Sheet Iron.		Thickness of Cast Iron Heads.	
	Calculated.	Used.	Calculated.	Used.
in.	in.	in.		in.
18	0.1000	0.1875		1.
24	0.1333	0.1875		1.25
30	0.1667	0.250		1.25
36	0.2000	0.250		1.50
42	0.2333	0.250		1.50

The labour of bending and shaping thick boiler plate is so great, and the imperfections of sheet iron increase so rapidly with its thickness, that, as a general rule, it may be stated that the diameter of cylindrical boilers, for high pressure steam, should not exceed 30 inches. There are, however, exceptions to this rule, in the cases of steamboats and locomotive engines where it is usual to carry the flues through the boiler.

When flues are thus situated, the same reason that leads to a preference of cylindrical boilers, would point out that the form of the flues should be of that figure. The same rules may be adopted for estimating their thickness. In all other cases it is better to increase the number of boilers, than to increase their diameter.

An increase in the number of boilers rather than an increase in the diameter of a single one, has this farther advantage, that the weight of water will be much less in the former than in the latter case. In increasing the diameter, the quantity of water, (the length of the cylinder remaining the same,) will increase with the square of the diameter, while the surface exposed to heat only increases as the diameter simply. A cylinder of twice the diameter will therefore carry twice as much water as two separate cylinders, while it has only the same capacity for generating steam. From what has been said, it may be inferred that sheet iron is the best material, and a cylinder the best shape for boilers in all usual cases. When sea water is used, copper is, however, the only one of the three materials that can be depended upon to resist the action of the saline deposit. In condensing engines, the cylindrical form has rarely been used, although it has advantages even in this case. But in Cornwall (England), in the engines employed in draining mines, cylindrical boilers containing cylindrical flues have taken the place of all others. The original boiler of Watt and Bolton had its vertical section constructed upon a rectangle, by describing a semicircular arc upon its upper side, forming a convex arch, and three less circular arcs within the remaining three sides, forming curves concave to the exterior. The lower arc is exposed to the fire, the two on the sides afford space for the return flues on the outside of the boiler. *See Pl. I., Fig.* 2.

This form of boiler is only to be found with engines of antient date, and has given birth to a variety of others. In the boilers intended for steam-boats the fire-place was formed by extending the boiler downwards so as to form three sides both of the furnace and ashpit, and the return flues were carried through the boiler. The fire surface was increased by mamillary projections, called teats; and finally, the direct flue was replaced by a great number of small tubes. This form, which has as yet been chiefly applied to locomotive engines, and the invention of which is disputed by France, England, and the United States, is the most advantageous of any yet attempted.

44. When boilers have been filled to the proper height with water, they will require a supply equivalent to the quantity of liquid that is carried off in the form of steam. This supply may be either admitted from time to time by the engineer when the water has fallen to a certain conventional level, or it may be introduced by a self-acting apparatus in such a manner as to keep the water at a constant height.

In the first case it is indispensable that the fireman or engineer should have it in his power, at any instant, to determine the height at which the water stands in the boiler; and although the apparatus for this purpose is not indispensable when the boiler is supplied by one that depends for its action upon the state of the water itself, it is so valuable a check upon the operation of the supply, that it should be adapted to all boilers.

The most usual and most ancient contrivance for this purpose, consists simply of two stop-cocks; each of these is attached to a short tube; one of them communicates with the boiler below the level at which it is wished to retain the water, the other enters it above that height. If the former of these be opened, and steam issue, water must be immediately supplied; if the latter give out water, the liquid stands too high. These tubes, in boilers where the steam has an elastic force little exceeding the pressure of the atmosphere, must be introduced horizontally into the sides of the boiler; but where high steam is used, they may rise vertically through its top, and be afterwards bent in a horizontal direction. Although two such stop-cocks are sufficient, a third is usually placed halfway between them. In their use, one precaution is necessary, namely, to leave them open long enough for the water which may have condensed in them to be blown out. *See Pl. I., Fig.* 5 *and* 6.

The best apparatus for ascertaining the level of water in a boiler, is a straight glass tube, open at both ends, which are placed in two cups that communicate by means of tubes with the interior of the boiler. To these cups the tube is cemented, and the water will stand in it at the same height that it does in the boiler. It was at one time supposed that this simple method could not be adapted either to high pressure boilers, or to those made of materials other than copper, but it has of late been successfully introduced in both cases.

Another mode, which, however, has rarely been used with steam engines, is to adapt a tube, made like the pipe of an organ, to the boiler, the lower end of which descends as far as the level, below which the water ought not to be permitted to fall. So soon as the water decends the least space below this point, steam will escape through the pipe, and give warning of the necessity for a supply by the sound it causes. In high pressure boilers, this tube cannot be applied in its simple form, as it would become of inconvenient length.

We have, however, seen more than one ingenious modification of this apparatus, in which the communication with the steam is effected by a valve that is intended to open when the water falls below its proper level, and to close after the supply has been introduced.

If a substance of convenient form, denser than water be taken, and be made to communicate with a lever on the outside of the boiler, by means of a wire passing through a stuffing box, it may be made just to float at the surface of the water by a counterpoising weight suspended from the opposite end of the lever. When the water falls, the floating substance will preponderate, and the lever will incline towards it; when the water is too high, the inclination will be in the opposite direction; and these deviations of the lever from the horizontal position, may be marked by an index at right angles to it, and affixed to its centre of motion.

In stationary engines, particularly those employed in manufacturing establishments, this method of indicating the position of water in the boiler has been successfully employed; but in steam-boats its use may not only lead to uncertainty, but be actually productive of danger. In the motion to which boilers are often subjected in the latter case, the water is continually shifting, and the whole boiler is sometimes filled with a foam composed of an intimate mixture of water and steam. The same remark applies to the case of locomotive engines, and it is by no means certain that any floating apparatus will act when the water foams.

45. The boiler may be supplied as often as appears necessary from the indications of either of these apparatus, by different means, that must vary according to the elastic force of the generated steam. If the steam have a force but little greater than an atmosphere, a simple tube, having a top shaped like a funnel, will answer the purpose. This must be inserted into the boiler through a steam-tight joint, until it nearly reaches the bottom, and it must be high enough to contain a column of water equivalent to the excess of the power of steam over the atmospheric pressure. The steam being of a constant elasticity, the water will stand in this tube at a constant height above the level of the water in the boiler, and if water be poured into it, an equal quantity must pass into the boiler. To adapt this to high pressure engines, a tube of inconvenient length would be necessary; recourse must therefore be had to other means.

The most simple of these is a spherical vessel, connected with the boiler from beneath by a tube and stop-cock, and closed at top by another stop-cock, surmounted by a funnel. The stop-cock is at first closed, and the sphere filled through the funnel and upper stop-cock; the upper stop-cock is then shut: and, when it is known that the boiler needs a supply, the lower stop-cock is opened, through which the water will now pass to the boiler. The alternate action of these stop-cocks, in the first instance, prevents the steam from escaping, and from interfering with the entrance of the water; and, in the second, permits the water to enter the boiler, while it is replaced by the entrance of steam into the spherical vessel. *See Pl. II., Fig.* 2. This apparatus is no longer applied to its original purpose, but under the name of a globe-cock is employed to introduce grease into the parts of high pressure engines.

The operation of such an apparatus may be facilitated by making two parallel passages through each of the cocks. One of these is in each made, when the stop-cock is open, to adapt itself to a tube, which reaches from each stop-cock nearly to the opposite side of the spherical vessel. When the upper stop-cock is opened, the water will enter through the tube, and the enclosed air or steam will escape at the other passage of the cock. When the lower stop-cock is opened, the water will rush through the naked opening, and steam rise to replace it through the tube.

A forcing pump may also be used to supply high pressure boilers, the pressure on the piston of which must be greater than the elastic force of the steam. A valve, by which the water the pump propels, may be made either to enter the boiler, or run to waste, at pleasure, will then supply the water that may be needed. This is the mode which is now universally used in all boilers which generate steam of a tension of more than one and a half atmospheres. *See Pl. IV., Fig.* 6.

In all cases, however, it would be better, if possible, that the feeding apparatus should be self-acting; or, to speak more properly, that it should be governed in its operation by the level at which the water stands in the boiler.

For boilers which generate steam not exceeding $1\frac{1}{2}$ atmospheres, the construction of such an apparatus is attended with but little difficulty; but as methods of applying it safely at higher tensions are now coming into almost general use, what we are about to say on this subject is fast becoming a matter of history, rather than one of practical utility. We shall therefore describe them for the purpose of exhibiting the ingenuity by which this part of the low pressure boiler was made to conform to the action of the engine, and not as applicable in the present state of our knowledge of the best mode of using steam.

The most obvious and simple of all, and it is equally applicable to high and low pressure boilers, is a ball floating on the surface of the water, and attached by an arm to a stop-cock upon the supply pipe. This stop-cock is opened when the ball falls, and shuts when it rises. It may be attached in a low pressure boiler to a pipe, of a length sufficient to bear a column of water equivalent to the excess of the force of the steam above an atmosphere; but in a high pressure engine it must be adapted to the pipe proceeding from a forcing pump.

This method is liable to the objection of being subject to get out of order, and of being out of sight and reach; it may, therefore, fail at the moment it is least expected.

The floating ball may be made to act, through the intervention of a lever and a rod, upon a conical valve in the feed-pipe.

A floating apparatus, similar to that which has already been mentioned for indicating the level of water in the boiler, may be made to regulate the supply of a low-pressure boiler. In the first place, the lever there described may have its centre of motion in the axis of a stop-cock to which it is attached. In the second place, a conical valve may be attached, by a rod, to the arm of the lever that carries the weight. Around this rod is a small reservoir of water, communicating with the boiler beneath by a pipe reaching nearly to the bottom. The conical valve is adapted to the junction of this pipe with the reservoir in such a manner as to open the communication when the float falls, and close it when the float rises. *See Pl.* II., *Fig.* 8.

For reasons which have already been mentioned, this method is not applicable to the boilers of steam-boat and locomotive engines.

In most cases engines do not require to be kept in constant action. Those employed in manufactories are always stopped at night, and generally while the workmen are at their meals. As the action must be kept up until the end of the working hours, a great loss of heat is caused by the sudden cessation of the motion of the engine at a moment when the steam has its full tension. This loss has been in a great degree prevented by a modification of this feeding apparatus invented by Hall of Glasgow. In this modification the float is double, one part lying at the level at which the steam is to be maintained while the engine is at work; the other within a few inches of the top of the boiler. The counterpoise is made up of two weights. These, when united, counterpoise the floats when the lower one is at the surface of the water in the boiler. On removing one of the weights, that which remains becomes a counterpoise to the double float when its upper part reaches the surface of the water. The water will, therefore, flow from the cistern of the feeding apparatus until the lower re-assumes its horizontal position. On the replacing this weight, the engine will work off the water which has been thus introduced before the feeding apparatus will begin to admit water.

By this arrangement, water is introduced at the temperature of condensation as soon as the engine is stopped, and the fire will be employed in bringing up to its working temperature during the interval of work. In the application of it to the engine of the Glasgow Water Works, a saving of nearly twenty-five per cent in the fuel consumed was obtained. The same method is, of course, applicable to ferries, and to passage boats which have occasion to stop at landings; and there would be no difficulty in graduating the water thus admitted to the intervals in the working of the engine.

In the great change which is taking place in the manner of working condensing engines by which high steam is advantageously employed, all these modes so ingeniously planned to regulate the supply of boilers, may be said to have become in a great degree obsolete. In particular, it may be questioned whether any apparatus governed by a float will be sure to work in a steam-boat, a locomotive, or even a fixed high pressure engine.

The supply of high pressure boilers, as has already been stated, is always effected by means of a forcing pump. *See Pl.* IV., *Fig.* 6.

This propels, by the action of the piston *a b*, a stream of water into a pipe furnished with two stop-cocks or valves, *c* and *d*, that act alternately; by one of these, *c*, water is admitted into the boiler, by the other, *d*, it is allowed to run to waste. These valves are usually left to the care of the engineer, as an apparatus to render them self-acting is necessarily complex. We, however, give a drawing of one, the invention of a Mr. Franklin, that has received the medal of the British Society of Arts. *See Pl.* II., *Fig.* 1.

All feeding apparatus should be sufficient to supply the boiler with considerably more water than it usually evaporates. Generally speaking, it is made to furnish five or six times as much, as it is far better that water should run to waste, than that there should be at any time a want of a full supply.

It will be obvious, that a self-acting feeding apparatus that will perform its duty when the engine is at rest, is still a desideratum for high pressure boilers. It is in the case of steam boats and locomotive engines that such an apparatus is almost indispensable, in order to place them wholly beyond the reach of danger, and to the want of it many fatal explosions are to be attributed. Many propositions have been recently made to supply this desideratum, but none have come into general use. In the absence of a self-acting apparatus, force pumps, to be worked by hand, are applied to the boilers of steam boats and to locomotive engines. They also serve to fill the boiler in the first instance.

46. A regular supply of water is not only necessary to keep up the flow of steam, but is of great importance to the safety of a boiler; we have therefore treated of it next in order to the material.

Whatever precautions may be taken in the choice and adjustment of the strength of the material, and in giving a regular supply of water, it is indispensable, before a boiler is made use of, that it should be proved. This is necessary, because the proof shows defects that would otherwise escape notice, particularly at the joints of the wrought metals, while in cast iron there are frequently cavities that are not seen upon the surface. These different defects might cause a boiler to burst with violence if it were to be subjected to the action of steam before proof had been performed in some other manner. This preliminary proof is best effected by means of the hydraulic press, or water pressure pump of Bramah, whose principle has been explained on page 9. This method is, however, still defective, inasmuch as it must be performed, if not with cold water, with that which is far below the heat to which parts of the boiler must be afterwards subjected.

It has been proposed to apply a pressure five or six times as great as the boiler is intended to bear. Nor is this too great a precaution, for the water proof is performed when cold, and we have seen that some metals are more tenacious when cold than when heated, and the proportion of six to one, at least, is necessary before this difference is obviated. If a boiler be not subjected to such a proof, it may be possible that when heated its limit of rupture may be reached before the safety valve opens.

The water proof having been performed, the boiler should next be subjected to a similar trial by steam, say of four or five atmospheres more than is usually to be generated in the boiler without causing its safety valves to act. In France, it is required by law, that all high pressure boilers be subjected to a proof five times as great as the boiler is intended to bear when in service. It is, however, to be considered that, when the boiler is to be used to generate high steam, such excessive strain would rather tend to increase the danger than to ensure safety; for if the strain to which the metal is exposed exceed the limit of its elasticity, is will be materially weakened, although it may not explode under the proof.

47. The next precaution to be taken is, that the boiler be furnished with safety valves. A safety valve is a conical or cylindrical stopper inserted into, or resting upon a seat of the same shape, and kept in its place by a weight equal to the most intense pressure that is intended to be exerted upon it by the vapour from within the boiler. When the steam acquires a force greater than this, the safety valve will open and permit the steam to escape; at all inferior temperatures it will remain shut. Three things must therefore be investigated in order to their preparation, viz: the size of the opening to which they are to be adapted, the load they are to bear, and the proper mode of placing them.

The openings must be large enough to permit all the vapour that can be formed to escape. This may be estimated at the conversion into steam of a cubic foot per hour from every eight or ten feet of fire and flue surface. But as the safety-valve will probably be most needed when the fire has been augmented beyond its proper quantity, it will be well to prepare for the escape of, at least, four times that quantity, say a cubic foot of water evaporated for every two feet of fire surface; this is the maximum of steam that can be formed under any ordinary circumstance.

The vapour will escape with a velocity that will depend upon its elastic force, but which increases much less rapidly than that does. We subjoin the velocities under different expansive forces.

Table of the Velocity of steam at different temperatures.

Expansive force.		Velocity per second.
$1\frac{1}{4}$	Atmospheres,	873
$1\frac{1}{2}$	do.	1145
$1\frac{3}{4}$	do.	1296
2	do.	1405
3	do.	1548
4	do.	1663
5	do.	1725
6	do.	1785
8	do.	1852
10	do.	1993
12	do.	2029
14	do.	2052
16	do.	2072
18	do.	2084
20	do.	2098

The quantity obtained, by multiplying these velocities by the area of the opening to which the valve is adapted, must be diminished by the constant fraction that represents the section of the *vena contracta* in fluids; this, in such an orifice, is about $\frac{3}{4}$ths or .75.

To determine the quantity then, that will issue by a given safety valve, three-fourths of its area must be multiplied by the velocity under the anticipated expansive force. When the quantity to be discharged per second is given, the reverse of the operation will give the proper area of the safety valve. The bulk of steam generated by the evaporation of any given quantity of water, may be found by multiplying the bulk of the water by the number representing the volume of steam of that temperature, on page 24.

It will not be attended with any inconvenience to make the safety valves of high pressure boilers as large as those used for steam of less elasticity, and this is the method which is adopted in practice.

The weight, with which the upper surface of a safety valve is to be loaded, should be equal to the pressure which the vapour, at the maximum temperature for which the boiler is calculated, is capable of exerting upon the lower side of the safety valve. When this expansive force of the steam, at the given temperature, is estimated in atmospheres, one atmosphere, or 15lbs. per square inch, is to be deducted from the estimate, inasmuch as the escape of the steam is opposed by the pressure of the atmosphere itself, which therefore acts as a part of the weight with which the safety valve is loaded. Therefore, to find the weight:

The area of the safety valve in square inches must be multiplied by 15 *times the number of atmospheres to which the expansive force of steam at the given temperature is equivalent, less one : the product is the weight in pounds.*

The weight in most cases acts upon a lever of the second kind, by the intervention of which the pressure is increased. As the foregoing rule gives the pressure that ought to act upon the safety valve, the weight that is suspended from the lever must be diminished, in the ratio by which the whole length of the lever exceeds the distance between the fulcrum of the lever and the safety valve.

The number of atmospheres, to which the expansive force of steam, at different temperatures, is equal, may be found by the table upon page 23.

There is a curious phenomenon which occurs when steam issues from a safety valve, or other orifice; the temperature of the vapour just without the opening, is lower, the higher the tension of the steam is within the boiler. Thus steam issuing from a boiler, the water within which is at 212°, scalds the hand; while if it had a tension of several atmospheres, the heat would be easily borne without injury. This phenomenon, which at first sight appears almost paradoxical, grows out of the rapid dilatation of dense steam, and the consequent increase of its capacity for specific heat. The greater the tension, and consequent density of the steam, the greater will be the diminution of temperature.

This explanation would teach us that the size of safety valves, as calculated from the table on p. 24, is less than they ought to be in practice, and no inconvenience can arise from making them of such size as will allow the escape of low steam; for the weight will close the valve as soon as the tension of the steam is sufficiently diminished.

Safety valves, generally speaking, are of the figure of a frustum of a solid cone, ground to fit a hollow frustum of an equal hollow cone. They may, as has been stated, be pressed down by a weight, acting directly, or through the intervention of a lever. In the former case the weight may either hang from the valve within the cylinder, or be fastened to its exterior surface. A valve of this description furnishes a constant pressure, and ought to be adapted to the highest temperature the boiler is intended to bear. If it act by means of a lever, the pressure of the weight, when at the extremity of the lever, ought to be equal in its action to the same maximum tension; but, by making it act nearer to the fulcrum, its action may be made equivalent to the expansive force of steam of lower temperatures. The latter is, therefore, best adapted to the case where the action of the boiler is left to the discretion of the fireman; while those where the weight acts directly, may be enclosed and kept beyond his reach.

On Plate I. are to be seen several varieties of the safety valve. Fig. 10, is a conical valve, whose weight is suspended beneath it, and hangs within the boiler. Fig. 11, is one, also conical, whose weight lies above it, and without the boiler. Fig. 12, is another of the same shape, and bearing a weight upon it, which is enclosed in a cylinder in such a way that it may be shut up beyond the reach of the workmen. Fig. 13, is a cylindrical safety valve, working in a pipe and pressed down by a spring; when the pressure of the steam overcomes the elasticity of the spring, the lateral openings in the pipe are uncovered in succession, and the space for the escape of steam increases with its tension. A safety valve, pressed down by a lever bearing a weight, is represented upon *Pl. II.* at *Fig. 7.*

The best mode of regulating the length of the arms of the lever to each other, is to make them in the ratio which the surface of the valve bears to the unit of superficial measure. Thus, if the surface of the valve be five square inches, the arms of the lever should be in the ratio of 5 : 1. The advantage of this method is, that the weight which is applied to the lever is the exact measure of the pressure on each square inch of the valve.

In locomotive engines, a suspended weight is liable to an oscillating motion, which varies its pressure upon the valve, and may cause it to be continually opening and shutting. For this reason, instead of a weight, a spring has been substituted. This, being made upon the principle of the common spring weighing machine, may give any required pressure on the lever of the safety valve beneath a given limit. The tension of the spring is adjusted by means of a screw, which draws out the spring until its index marks upon a scale the weight for which the tension is intended to be a substitute.

In all boilers there ought always to be two valves, one of which is left to the care of the fireman or engineer, the other fitted to the intended maximum pressure of the contained steam, and closed up. Very serious accidents have frequently occurred from leaving safety valves wholly to the control of a workman, or even of the captains of steam vessels, who may feel a temptation to increase the pressure of steam beyond what the boiler is capable of bearing. The proper situation of the safety valve is upon the top of the boiler: and when there are two, one should be at each end; that left to the discretion of the workmen at the end next the fire, so as to be within their reach; that which is beyond their control, at the farther extremity. When the aperture by which the boiler is entered for the purpose of cleansing it, is situated on the top, the safety valve is often placed in its cover.

In consequence of a remarkable fact that has recently been observed, much doubt has existed as to the certainty of the action of a safety valve. When air is strongly compressed in a vessel or pipe, and issues thence by an orifice in a plane surface, if a plate or disk be presented to the orifice by one of its plane surfaces, so far from being driven away, it will be retained at a very small distance from the orifice. In this case the air escapes in the form of the surface of a very obtuse angled cone around the edges of the disk, leaving a conical vacuum beneath; and in consequence of the well-known fact that there is a lateral communication of motion from a current of fluid to neighbouring portions of the same or other fluids, the air above the plate moves towards it in order to join the stream; the vacuum beneath, and current from above, united, retain the disk at a constant, but small distance, from the plane in which the orifice is pierced. It has been found that the escape of steam is attended with similar phenomena. Still, however, in conical safety valves, if thin, there is no reason to apprehend any danger from this source. In those of the usual form, the increased resistance growing out of this cause, will not exceed one-twentieth of an atmosphere, or three-fourths of a pound upon each square inch. But were the valve to have the form of a frustum of a cone, whose height is great in proportion to the aperture, the resistance might become enormous; and, in the case of some experiments that were made in reference to this subject, it amounted to upwards of thirty atmospheres. Here, then, we have a strong reason in confirmation of the propriety of the usual practice of making the safety valves of high pressure boilers of the size of those of condensing engines.

However carefully a safety valve may have been constructed, it may, notwithstanding, cease to act, in consequence of rust, which will fix it to its seat. This is much more likely to happen when it has been long shut, but may occur even to valves in frequent action. Still, however, to open the valve from time to time is the best preventative; for a safety valve that has remained closed for a week, no longer deserves the name.

Large boilers of but little strength, as employed for generating low steam, are sometimes exposed to a danger of an opposite nature. When the fire is extinguished, the steam within will be condensed and a partial vacuum formed, the external atmosphere will now act, and may cause the boiler to collapse. It has been proposed to remedy this defect by an air valve. A conical valve opening inwards, and kept in its place either by a counterpoise or a weak spring; if either of these be little more powerful than the weight of the valve itself, they will keep it in its seat so long as the tension of the steam within exceeds that of the atmosphere; but when the latter becomes the most powerful, the valve will open and admit air.

We have stated, that when the space intended to be occupied by water becomes narrow, it may be wholly displaced by steam. In such case danger will arise from the burning of the metal, and from the heating of the steam after it is generated. To meet this danger, an ingenious person of the name of Douglas has proposed to place in the bottom of boilers a valve opening inwards; and he asserts that he has seen it in action even when the boiler contained steam of 4 or 5 atmospheres. We do not pretend to vouch for the fact, which appears contrary to mechanical laws; but that it should be true, is not more extraordinary than many of the cases of violent explosion.

49. Lest the safety valve or valves should by some accident become fixed to their seat, it is important that there should be some means of determining, at any moment, the elastic force of the steam within the boiler. Apparatus for this purpose are called Steam Guages. The simplest form of these is a bent tube, the two branches of which are parallel; one of these branches is open to the air, the other is bent in such a manner as to be adapted to an opening in a part of the boiler above the level of the water it contains, or to the steam pipe, and is soldered or sealed to it in such a manner that steam cannot escape by the joint; this tube, if empty, would permit steam to escape through it, but mercury is poured in to fill the bend, and rise some inches in each branch of the tube. When the expansive force of the contained steam is just equal to an atmosphere, the mercury will stand at equal heights in each branch of the tube; when the pressure increases, the level of the mercury, in the branch nearest the boiler, will be depressed, and that in the open branch raised; the sum of the two equal changes of level will be the measure, in inches of mercury, of the expansive force. As the changes of level in the two branches are equal, it is sufficient to measure that of the outer tube alone; this is done by a scale on the side, if the tube be of glass; but if of iron,

by placing in it an iron rod, which floats upon the mercury; and which just reaches the top of the tube when the two columns of that fluid are of equal height. The tube or rod might be graduated by division into half inches, each of which would correspond to a difference in the two levels of a whole inch, the thirtieth part of an atmosphere, or half a pound upon each square inch of surface, over and above one atmosphere. Were the guage to be graduated to inches, each inch would correspond to one pound of internal pressure against the weight with which the safety valve is loaded; and this is the mode of graduation most usually employed in this country. A guage of this form is represented on *Pl. I., Fig.* 7. By adding to the length of both branches of the tube, making it of a strong material, and increasing the quantity of mercury, this guage may be fitted for steam of any elastic force, but it might in that case become inconvenient to observe its indication by means of a graduated rod. In such cases a float of iron may rest on the surface of the mercury in the open branch, and be attached, by a cord passing over a pulley, to a counterpoise; the ascent and descent of which, along a graduated scale, would mark the difference of level upon the same principle as the rod.

A straight tube, inserted nearly to the bottom of a close cistern, which communicates at top with the steam of the boiler, and which contains a mass of mercury, will also answer this purpose. If the surface of the cistern be large in proportion to to the area of the tube, the change of level within it may be neglected, and the height of the mercury in the tube measured in inches. *See Plate I., Fig.* 8.

The steam guage may be made to act as an additional safety valve. In this case its height must not exceed that which will measure, in a column of mercury, the maximum pressure the boiler is intended to bear; and the top must be widened into the form of a funnel, sufficiently large to contain all the mercury with which the tube is supplied. Such an apparatus, with the arrangement of float and counterpoise sliding in a scale, is represented *Pl. I., Fig.* 8.

A guage for a high pressure boiler may be made by immersing the lower end of a glass tube in a basin of mercury; the upper end of the tube is closed, and it contains atmospheric air. The basin of mercury is enclosed in a case communicating with the boiler. The steam, acting on the surface of the mercury, will force it up the tube and compress the air, and the space that it occupies, being according to the law stated on p. 14, inversely as the pressure, will show the tension of the steam. Such a guage is represented at *Fig.* 8, *on Pl. I.*

50. Should the fire be more intense than is consistent with a regular supply of steam of the required temperature and pressure, an apparatus has been contrived to moderate its action, by the very increase in elastic force which it communicates to the steam. This is called the self-acting or self-regulating damper. Hitherto they have only been applied to boilers containing steam of so small an elasticity as to be capable of being supplied with water by an open feed-pipe, as described § 45.

The water stands in this pipe at a height above that in the boiler, which depends on the difference between the elastic force of the steam and the pressure of the atmosphere. A plate of iron, sliding in a vertical groove at the throat of the chimney, is attached to a float resting on the surface of the water in the feed-pipe by a cord passing over pullies; when the float rises by an increased action of the steam, raising the water in the feed-pipe, the damper will descend, and when the float descends, the damper will be raised. It will, in the former case, lessen, and in the latter, increase the aperture of the chimney, and the draught will vary with the size of the aperture, as has already been stated. Such an apparatus is represented as attached to the boiler, *Fig.* 1, *Pl. I. n* is the float, *o* the pully. The use of a self-acting damper is liable to the same difficulties as that of a self-acting feeding apparatus. It is hence scarcely or never used, except the steam is of very moderate tension.

51. In addition to a self-regulating damper, there should be another, to be worked by hand as occasion may require; and in order to place the fuel completely under the control of the fireman, the passage by which air is admitted to the ashpit ought also to be capable of being opened and shut at pleasure.

Doors and valves for this purpose should therefore be provided, and the apparatus is called a Register. Such dampers are placed in the chimneys of almost all our steam-boats, and temporary doors to the ashpit are made of plates of sheet iron.

52. There are dangers, however, to which boilers are exposed, against which safety valves and self-acting dampers present no security, and of which steam guages give no notice. As a general rule, it is no doubt true that the temperature and tension of vapour bear a constant relation to each other; but it may so happen that steam, after being generated, is raised to a high temperature without exerting a proportionate expansive force. Thus, if a portion of a boiler should acquire a heat greater than the water contained in the other parts, as it may do when not covered with water, the steam will receive an excess of heat without acquiring a proportionate elasticity. In experiments made by Mr. Perkins, steam was heated to a temperature at which, if of a corresponding density, it ought to have exerted a force of 56000 lbs. per square inch, but which did not exert a pressure of more than 150 lbs. The reason is obvious, for it was enclosed in a separate vessel, and its quantity remaining constant, it did not increase in density. Had, however, a small additional quantity of water, heated under pressure to a high temperature, been injected, it might be inferred, that the steam would have acquired the density necessary to enable it to exert the force corresponding to its temperature. Perkins also established the truth of this inference by actual experiment. Water was heated in one of his generators, the safety valve of which was loaded with a weight of 60 atmospheres, to a temperature of upwards of 900°; a receiver was prepared, void of both air and steam, and heated to upwards of 1800°; a small quantity of water was then made to pass from the generator to the receiver; this was instantly converted into steam, whose heat was sufficient to inflame the hemp that coated the tube, at a distance of 10 feet from the generator; its temperature was therefore estimated at not less than 1400°. In spite of this high temperature at which the steam was formed, its pressure did not exceed five atmospheres. But by injecting

more water, although the temperature was lessened, the elastic force was gradually increased to 100 atmospheres. In phenomena of this description we may find the cause of many explosions that cannot be explained on any other principle.

If we suppose that the supply of water is impeded, neglected, or checked altogether, the level of that in the boiler must descend, and parts exposed to the action of the fire may become dry; such parts may then be heated far beyond the temperature of the water beneath; and the vapour may be rendered by them sufficiently hot to make other parts of the boiler luminous. If, by any cause, the water from beneath be brought into contact with the vapour and heated surfaces of the boiler, it will be instantly converted into steam of great expansive force, and in quantities for which the usual safety valves are not sufficient to provide an escape. An explosion must therefore ensue.

The water may be brought into contact with these heated parts of the boiler, or with the hot vapour, by the very means that in other cases would be applied to diminish the danger. Thus, if the safety or throttle valve should be opened, the water, which was before boiling quietly, will suddenly rise with violent ebullition, or if the feeding apparatus begin again to act, the level of the water will be raised. In both cases, a contact will take place with the red hot surfaces, and with the intensely heated steam.

There are also other cases in which the space usually occupied by water, and even the whole boiler, becomes filled with a foaming mixture of steam and water. The circumstances are similar to those of a pot boiling over. In such cases the metal of the boiler and flues may be heated to incandescence, for such a mixture is a bad conductor of heat. Here again the injection of water into the boiler, or the opening of the valves, may be attended with danger.

Water also, as has been stated (§16,) if heated to 680°, tends to assume the gaseous form, and then exerts a pressure which no vessel, constructed as boilers usually are, is capable of resisting. It is also within the limit of possibility that in iron boilers an explosive mixture may be generated. The metal, when red hot, will decompose the steam, and hydrogen will be liberated. If by any means oxygen can be introduced, the same heat will cause it to explode; but oxygen cannot enter until the tension within the boilers become less than an atmosphere.

These have been admitted to be the only causes of the explosion of boilers, whether of low or high pressure. When boilers give way under the force of steam alone, dangerous consequences appear to have rarely happened. We have ourselves been twice in steam-boats, working with steam of not less than an atmosphere and a half, when the boiler has given way; and in neither case was the accident known to the passengers, except by stopping of the machinery.

The wrought iron boiler of a high pressure engine, working with steam of the tension of six atmospheres, gave way some years since in a manufacturing establishment in the city of New-York, and the only bad effect was the extinction of the fire by the efflux of water.

At Paris, the lower part of a boiler of cast iron, working with steam of the same force, gave way, and no other bad consequences followed.

In nearly all the cases where fatal accidents have occurred, the explosion appears to have been due to other causes than the mere expansive force of the steam that would be formed when the boiler is in proper order and supplied with water. There are, however, a few instances where the escape of large quantities of steam into close cabins, or its partial decomposition in passing through the fire, have produced, suffocation. Neither can it be doubted that a boiler of equal or nearly equal strength throughout may give way with explosion under the action of steam gradually and steadily increasing in temperature.

In the fatal accidents of the Chief Justice Marshall and Helen McGregor, the explosions took place after delay at stopping places, and followed almost instantly the opening of the throttle valve to set the engine again in motion. In the former, where the main internal flue gave way, the safety valve was either open, or had just been closed; one of the persons on board remarked a peculiar shrillness in the sound of the escaping steam, that can only be ascribed to its being intensely heated, without having a corresponding density ; another observed that it had a violet hue, which may perhaps be explained by supposing it to have been heated until it would have been luminous by night. In opposition to the opinion that the water had fallen too low and left the flues bare, it was stated by the captain that the guage cocks had been tried, but on examining the boiler it was found that they were situated on the side of the boiler nearest the landing; and it is well-known that on such occasions the influx of passengers to that side is often so great as to change the level of the boat so much as to render the guage cocks, when so situated, useless.

It is also possible that the fireman, who was by no means skilful, may have mistaken water of condensation in the tube for that coming from the boiler. This last mistake is one that ought to be carefully guarded against, by leaving the cock open several seconds.

Of the intense heat that steam sometimes attains, even without causing explosion, the following instance may be cited: the packing of the piston of a steam-boat, working with steam of a tension no greater than an atmosphere and a half, burst into flame on opening the cylinder at least half an hour after the fire had been extinguished. Here it is evident that any mixture of heated water with this steam might have caused explosion.

Even the injection of water into an empty space, whose temperature is not below 680°, may cause explosion, by its being wholly and suddenly converted into steam of great density and expansive force.

The committee of the Franklin Institute have, in their report of a series of interesting and valuable experiments made by them, thrown some doubt upon the explanation given by Perkins of the cause of the explosion of boilers. We do not, however, consider their experiments as absolute proofs of the inaccuracy of his positions. We may remark, that in their experiments the density of the steam was never increased even to an approximation to what would have been consistent with the saturation of the space at its final temperature. Thus, in one of their experiments, the tension of the steam obtained by the injection of water upon the heated sides of a vessel was 12 atmospheres, while the temperature was that of steam which, if saturated, would have exerted a force of $27\frac{1}{2}$ atmospheres. Cold water was also used and injected, while in practice the water, which would be most likely to be mixed with steam heated after it had been generated, would be that rising in foam from the lower part of the same boiler.

If the committee of the Franklin Institute have left us in doubt as to the accuracy of Perkins' explanation, they have raised none as to the certainty of danger when portions of the metal of boilers become intensely heated. In addition to the causes assigned by him, they have shown that the tenacity of copper decreases as it is heated, even from low temperatures; and that, although that of iron increases with the temperature up to a limit which is above that at which steam is usually employed, it decreases rapidly at temperatures above that limit, and at a red heat is no more than one-sixth of what it is when cold.

Boilers, when the fire is made within, or when the return flues pass through them, are obviously far more subject to accidents arising from this cause than those heated from without; low pressure boilers are as liable to them as high; and it is confidently believed that very many explosions are to be attributed to this cause, against which the usual safety apparatus furnishes no protection. To pay the greatest attention to keeping the feeding apparatus in order, and to have the means of ascertaining at every moment the height of the water in the boiler, are the surest means of defence; but as the first of these may fail, and does not act in many boilers after the engine is stopped; and as the second depends upon the faithfulness of the engineer, or may also be clogged, and cease to give true indications; other means have been proposed.

53. The first of these is a thermometer, inserted through a collar into the part of the boiler occupied by the steam, and which will therefore indicate its temperature. It must be made to mark the higher temperatures only, and may be graduated by a standard instrument, in a bath of hot oil. This is, how-

ever, but a fragile instrument, and may also be neglected by the workmen.

54. Another method, which promises to be effectual in many cases, is to form a part of the boiler of a plate of metal fusible at a comparatively low temperature. Such is an alloy of bismuth, lead, and tin, by varying the proportions of which a considerable difference in fusibility may be attained. They ought to be of such a mixture as not to melt until heated beyond the temperature assumed as the limit of the heat to which it is ever desired to raise the steam, but fusible at one considerably below that at which the boiler becomes red hot. From 20° to 40° above the maximum heat the steam is meant to attain, will be well suited to the purpose; for they will then melt before any part of the boiler can become red hot. These plates must be adapted to the upper part of the boiler, and be of course in contact with the steam; they are inserted at the end of tubes fitted steam-tight to the boiler. As they are apt to soften long before they melt, they ought to be covered by a diaphragm of wire gauze. When thus protected, they have been found not to give way until they actually melt. As different parts of the boiler may acquire different temperatures, two such plates will be needed upon its outer surface, at the two ends; they ought to be as near to the body of the boiler as possible. When flues pass through the boiler, we conceive that it would be a proper precaution to furnish them also with plates of this description, but in this case the metal might be less fusible, and lead unalloyed would suffice. It has been objected to plates of fusible metal, that when they give way, the engine becomes useless; and that in steam-boats in particular, danger may arise from the proposed means of safety. But this objection has been fully obviated by an invention of Professor Bache of the University of Pennsylvania. In this, the tube in which the fusible plate is inserted, is prolonged above it far enough to allow the application of a safety valve, which may therefore be adapted, and close the opening, until a new fusible plate can be procured. It has, however, been found easy to protect the fusible

plates from the heat within the boiler, and they are thus rendered nugatory.

When fusible plates are not used, and when from a thermometer, or from other appearances, there is reason to apprehend that the water has fallen too low in the boiler, and that the temperature of parts of it have been raised to a dangerous degree of heat, the only means of safety are, to check the draught of the chimney by the damper, to lessen or extinguish the fire as soon as possible, or even to procure rapid cooling by pouring water on the outer surface of the boiler. The safety valve may then be opened; and, after the cooling is complete, the boiler filled up by a hand force pump. A damper kept open by the action of the engine, and closing the instant it stops, would have a good effect, and might be easily adapted to a centrifugal apparatus.

55. It has been proposed, as a mode of securing safety in cases of great increases of temperature in the upper part of the boiler, to provide safety valves that would open at the limit of temperature beyond which danger might ensue. A safety valve of the usual form, but loaded with a great weight, and placed upon a tube containing a cylinder of metal, will answer this object: let the metallic cylinder be supported from beneath, and of such a length that the dilatation by heat shall bring it in contact with the safety valve at the required temperature; any further increase of temperature will open the safety valve, and permit the escape of steam; its action is certain, for the expansive force of the metals when heated, is capable of overcoming the most powerful resistances: but it is rather to be used as an indicator of the necessity of moderating the fire, and putting the feeding apparatus in order, than as affording perfect security from explosion.

It is difficult to point out methods that are of themselves entirely to be relied upon to prevent explosions. However perfectly a boiler may be constructed or furnished with safety apparatus, it will still depend much upon the carefulness and intelligence of the persons entrusted with its management. One thing, however, appears certain, although contrary to general belief, that as the most usual causes of explosion affect low pressure boilers equally with those which generate high steam, the latter are not more subject to accident than the former. There are precautions, however, which, if resorted to, may diminish the risk of such accidents in a very great degree; so far, indeed, that without the greatest carelessness, they cannot occur. These may, perhaps, be recapitulated to advantage.

1. Cylindrical boilers, without any return flue, either without or within, are safer than any others.

2. Internal flues should be avoided wherever it is possible, and especially the chimney, or vertical flue, should never be permitted to pass through the boiler. But if internal flues must be used, and they cannot be avoided in steam boats and locomotive engines, the plan of diminishing them to mere tubes is the best, and care must be taken that the spaces between them are not too small.

3. Every boiler should be furnished, in addition to the usual safety valve, with one not under the control of the fireman.

4. All boilers should be furnished with guage cocks, or other apparatus, to show the level of the water, and these should be so placed in steam boats, that no error in their indication can take place when the vessel heels or rolls.

5. Plates of fusible metal should be provided, of a composition melting so far above the usual temperature of the water and vapour, that they will not open on any ordinary occasion, but will give way before they attain a temperature that can be dangerous; and these should have the addition proposed by Professor Bache.

6. A thermometer may be introduced into the boiler, whose indications may be seen from without.

7. Self-acting feeding apparatus should be adapted to the boiler, by which water will enter, and keep the fluid within at a constant level; and this should depend upon the waste of water, and not on the action of the engine. It unluckily happens that no such apparatus has yet been introduced into use which is adapted to high pressure engines, nor indeed for any where the tension of the steam exceeds 1 $\frac{1}{4}$ atmospheres. Neither are they always applied even to low pressure engines; and in those

intended for steam boats, they would be worse than useless, from the uncertainty of their action.'

8. The chimney should be provided with a damper by which the draught of the flues may be suddenly checked, and doors should, if possible, be placed upon the ashpit. A damper that would close as soon as the engine ceased to move, would be of great service in lessening the liability to explosion, and this does not appear to be difficult of attainment.

9. The proof of the boiler should be conducted with the greatest care, first with water, at a pressure five or six times as great as the boiler is intended to carry, and afterwards with steam of more than the highest possible tension. The water proof should be repeated from time to time, and every part carefully examined to ascertain that all the safety apparatus is in working order. In high pressure boilers, the force pump with which they are fitted is well adapted for giving the water-proof.

Few or none of these precautions are usual in our American steam boats: the boilers, even if cylinders, have both internal flues and furnaces, and the vertical chimney frequently rises in the boiler; there is never more than one safety valve; plates of fusible metal are unknown; the feeding apparatus is merely a forcing pump, which is turned on or thrown off at the pleasure of the engineer, and which does not act at all at the time the engine is not in motion; but a very few steam boats have dampers upon their flues; in fine, the proof is wholly a matter between the maker and proprietor, and for its proper performance the public have no guarantee. Thus, of all the precautions that have been proposed in order to insure indemnity from explosion, but two are in use among our steam boats; namely, the safety valve and the guage cocks; the former being still subject to the caprice of the persons employed, and the latter having an uncertainty in their indications, both when the boat inclines to either side, and when they contain, as they most frequently will do, water of condensation. They are also of no value when the water in the boiler foams.

The means which are used are not certain to insure safety, even where the care of the officers of the vessel, and of the persons employed about the engine, is unremitting, and directed by the utmost intelligence ; hence dangerous accidents occur without giving rise to blame, and thus diminish a proper feeling of responsibility. On the other hand, were the list of precautions that we have given, to be completed by a self-acting feeding apparatus, independent of the action of the engine, for a high pressure boiler, we conceive that no accident could possibly happen where they are employed, except through carelessness, inattention, or fool-hardiness.

Should it appear that the feeding apparatus does not act to supply as much water as is evaporated, the damper should be closed, and the boiler might even be cooled by the gentle application of water from without ; but it will always be a sure source of danger to inject water in abundance, or even to open the safety valve suddenly, after the water has once fallen below its proper level, and before it is ascertained that neither the temperature of the steam within, or of the sides of the boiler, are such as to cause a sudden conversion of the water that comes into contact with them into steam.

55. In connexion with this subject, we have to mention and condemn an addition which is often made to the boilers employed in our American steam boats. In consequence of the space which can be allowed for the boiler being limited, it has been found that the flame often passes into the chimney, and even issues from its upper opening. As much heat would be thus lost, it has been attempted to apply it to the steam, in its passage from the boiler to the engine, by enclosing the chimney in a cylindrical case called a steam-chimney, through which the steam must pass. This method is, however, the least advantageous mode of applying heat, for the steam, heated out of contact with water, is not rendered more elastic than air would be under similar circumstances, and has its energy far less increased than if the same heat was applied to the water in the boiler. On the other hand, dangers similar to those of which we have just spoken, occur ; and if the risk of the heated steam being mixed with water is less than if it were in the boiler, another source of accident is to be found in the rapid

oxidation of the iron of the chimney, thus heated in contact with steam. This part of the chimney will, therefore, require frequent repairs, and if they be omitted, may give way with violent explosion. To this cause the explosion of the steam boat William Gibbons, in the spring of 1836, is to be ascribed. It may therefore be stated, that the necessity for the use of a steam chimney is a proof of bad calculation in the plan of the boiler, and that the heat which it is intended to save by this means, may be much better applied.

56. There is another species of danger which arises from the deposit of solid substances. Almost every kind of water that is used for boilers, contains more or less earthy and saline matter. The constant evaporation is replaced by new supplies of the same impure water, and the soluble portion or mechanical impurity is consequently accumulating. The soluble parts become greater in quantity than the contained water can hold in solution, and these are deposited, along with those that are merely suspended. Crusts thus form on the lower part of the boiler, and the surface covered by them, being no longer in contact with the water, may be heated red hot, and may be corroded in consequence of the property that some of these salts have, of being decomposed by the metals at a red heat. The boiler will become weak in these places, and be liable to burst. It hence becomes necessary to cleanse the boilers frequently; for this purpose, as well as for examining the interior, an opening is made in the boiler, large enough to admit a man. This has a cover, which, when the boiler is in use, is fastened down by screw bolts and nuts, and is packed in such a manner as to be steam-tight. This opening is called the Man-hole.

These deposits become frequent and copious when sea-water is used, and it has be found necessary, in consequence, to cleanse the boilers of steam boats that navigate salt water at least once a week. So soon as the boiler has received successive supplies of salt water, amounting together to nine times its own capacity, a crust of a double sulphate of line and soda will begin to collect. A farther evaporation will cause the deposit of salt, and finally of the chloride of magnesia.

When the water is fresh, and the deposit principally consists of sulphate of lime, as is the case with hard pump waters, vegetable feculæ will suspend the impurities. To furnish this, potatoes may be thrown into the boiler, in the proportion of half the weight of bituminous coal that is consumed per hour. This quantity of that root once added, furnishes starch enough to keep the earthy matter suspended by the water for a long space of time, and it has not been found necessary to cleanse boilers, when this addition is used, oftener than once a month. It is not known whether the same method will be effectual in preventing the saline deposits of sea water.

The necessity of cleansing and scraping boilers in which sea water is used, may be in a great degree prevented by blowing off a part of the water from time to time. This method is, however, attended with a great waste of heat and consequent consumption of fuel. We shall have occasion to cite an improvement in the engine, by which it is ensured that the boiler shall be fed with distilled water; and by the adoption of this improvement, all the dangers and inconveniences of which we have spoken may be obviated.

57. It merely remains that we should speak of the pipes by which the steam is conveyed from the boiler to the engine. The size of these will depend on the quantity of steam the boiler is intended to furnish, the resistance the pipe itself opposes to the passage of the steam, and the loss of heat.

Steam issues into a space containing atmospheric air with the velocities given in the table on p. 73. The velocities with which it rushes into a vacuum are as follows, viz.

Table of the Velocities with which Steam flows into a Vacuum.

Force of Steam.		Velocity per second.
1	Atmosphere,	1908
2	do.	1977
3	do.	2006
4	do.	2022
5	do.	2038
10	do.	2098
15	do.	2121
20	do.	2141

It will be seen from this table, that the velocity of effluent steam increases very slowly with increase of temperature. This grows out of the fact that the density of vapour increases under ordinary circumstances nearly as fast as its elastic force. Did both follow the same law, the velocity would not increase at all; but the weight of steam expended by a given orifice, increases rapidly, for the density of hot steam is much greater, and the weight that passes out is in the compound ratio of the density and the velocity.

The table on page 73 gives the velocity for high pressure engines, for they, as we shall see hereafter, are resisted by the pressure of the atmosphere. The table just given contains the velocities for condensing engines. Both of these, however, require a correction for the friction, and the loss of motion by cooling; but for these it is impossible to give any general rule. A method that has been found to succeed in practice is, to make the orifice, or nozzle, by which the pipe communicates with the engine, such as would be calculated from the velocities of the tables, and to make the rest of the pipe larger. The greater the distance the steam has to pass, the larger should be the pipe. To prevent the loss of heat growing out of the increased surface, the metal might be kept bright, in which state it will be a bad radiator of heat; but this method is not applicable in practice. The steam pipes are, therefore, often covered with a bad conductor of heat.

The principles for calculating the area of the orifice by which such pipes communicate with the engine, and the surfaces of safety valves, are therefore identical; we shall, in order to render them more intelligible, reduce them to the form of a Rule.

To find the area of the passage by which steam shall reach the engine from the boiler in which it is generated:

Divide the quantity of water in cubic inches evaporated per hour, by 3600, (*the number of seconds in an hour,*) *multiply the quotient by the volume of steam of the given temperature, from the table on page* 24: *This will give the number of cubic inches of steam that must pass per second. Divide this by the velocity per second, taken in the cases of high steam pipes, from the table on page* 73, *and in the case of low steam pipes from the table on page* 93. *The quotient is three-fourths of the required area, whence the diameter of the circular section can be obtained in the usual manner.*

Cylindrical boilers, placed in a vertical position, and having internal fireplaces and flues, have been much used in the United States. In our first edition we noticed one planned by Col. Miller of Charleston, S. C.; but of this we have seen but a single instance, and it has not come into use. The most familiar case of this sort is in the locomotive engines of the Baltimore and Ohio Rail-road. We deem it due to justice to state, that Mr. John Stevens, of Hoboken, communicated to us, some years since, a plan of a boiler on similar principles, that we do not doubt would have been equally efficacious.

In the use of anthracite coal, blowing engines to excite the combustion have been found advantageous. Such engines have also been applied to other kinds of fuel. In locomotive engines, the steam, after it has completed its action, is permitted to escape into the chimney, and by forcing out the air in its rapid expansion, acts to cause a more intense draught, and is thus superior to the best blowing engines.

58. Besides boilers of the various kinds we have mentioned, Mr. Perkins proposed one upon very different principles, which, for the sake of distinction, is called a Generator. It is a strong vessel, completely filled with water, which is heated to a very high temperature, and prevented from being converted

into steam by the strength of the vessel and the pressure upon its safety valve. A small quantity of water is flashed in from a forcing pump, which causes the escape of an equal quantity, that is instantly converted into steam of high temperature and consequent elasticity. As it is our intention to confine ourselves to forms that have actually come into general use, and as the generator of Perkins is still a subject of experiment, it does not enter into our views to describe it more particularly.

For the same reason that we do not dwell upon the generator of Perkins, we shall pass, with a slight notice, the boiler invented by Bennett of Ithaca, N. Y. In this the fuel is placed in a tight chamber furnished with two valves. Through one of these air is forced in by a blowing engine. The other opens into the boiler. Air will, therefore, accumulate in the fire-place until, by the joint effect of heat and compression, it assumes a tension even greater than that of the steam. It will then make its way into the boiler, and join the steam in its action on the engine. In experiments made with this apparatus, it appeared to produce a greater effect with a given quantity of fuel than any other boiler. Difficulties of a practical character have hitherto prevented its being brought into use.

On Plate I. will be seen various forms of boilers.

Fig. 1 and 2, are a longitudinal section and front elevation of the low pressure boiler of Watt, together with its furnace.

a a a a, body of the boiler.

b, furnace, with its grate, *c*, ashpit.

d d d, flues.

e, man hole, for entering the boiler to cleanse it.

f, steam pipe, *g*, steam guage of the form shewn on a larger scale at Fig. 7.

h, safety valve of the form shewn at Fig. 12.

i, float of the feeding apparatus.

k k, lever of the feeding apparatus, *l*, valve of the feeding apparatus.

m, supply cistern fed by the hot water pump of the engine, below this is the tube that conveys the water to the boiler, and which contains the float *n* of the self-acting damper.

o o, pullies of the self-acting damper *p*.

q, feed pipe.

r r, guage cocks. It has been already mentioned that this form is now but rarely used, and, with its apparatus, is rather a matter of history than a model to be copied in the existing state of the steam engine.

Fig. 3, is a transverse section of a cylindrical boiler, the same letters are employed to designate such of the parts as are represented. When used for low steam, all the parts represented in the preceding figures may be applied with equal facility to it. The faint circle within shews how the return flues might be made to pass through this boiler.

Fig. 4, is a cylindrical boiler, with internal furnace and flues.

On Pl. VII. may be seen an outside view of a low pressure boiler for a steam boat; this has an interior furnace and flues.

On Pl. VIII. is a plan and section of an English steam boat boiler.

On Pl. VI. are end views of a pair of cylindrical boilers for a high pressure engine.

Perhaps the most perfect form which has yet been given to boilers, is that now adopted almost universally in locomotive engines, and which we have more than once referred to. The body of the boiler is cylindric. One of its ends rises no higher than the level of the water in the boiler, and forms the back of a furnace, in which by the prolongation of the plates of the boiler, the fuel is surrounded by water, except towards the ashpit. The flame and heated air are conveyed through the boiler in a number of pipes. In fixed engines, they are so much more costly than those of the form of a simple cylinder, as to be inapplicable; but wherever it is important to save both room and weight, they are to be preferred to all others. They are, therefore, not only in general use upon rail-roads, but have been much employed in American steam boats.

An outside view of a locomotive boiler may be seen on Plate IX.

Having thus explained the structure of the boiler, and of the various accessories with which it may be furnished in order to render its action more regular and safe, we shall next proceed to treat of the action of steam as a mover of machinery, and of the different forms of engine that are at present in use.

CHAPTER IV.

GENERAL VIEW OF THE DOUBLE-ACTING CONDENSING ENGINE.

Of Prime Movers in general.—Principles of the action of Machines.—Modes of applying Steam as a prime mover.—Application of Steam to the Double-Acting Condensing Engine.—Modes of removing Water of Condensation and Vapour.—Modes of changing the reciprocating Rectilineal Motion of the Piston Rod into a reciprocating circular motion.—Method of changing the reciprocating circular motion into a continuous one.—Mode of regulating the varying motion of the Engine, and making it produce one with uniform velocity.—Other methods of obtaining a rotary motion.—Effect of the joint action of two Engines.—Water used to produce condensation.—Water that has been employed in condensation applied to feed the boiler.—Manner of ascertaining the state of the Vacuum formed by condensation.—Mode of regulating the supply of Steam.—Accumulation of Steam in the boiler, and mode of preventing it.—Double-acting condensing Engine considered as self-acting.—Packing and Cements.—Estimate of the power of the double-acting Condensing Engine.—Estimate of the quantity of water evaporated for each unit of force.—Estimate of the supply of water for the boiler.

59. The agents which we employ for the production of mechanical effects through the intervention of machines, may be divided into three classes.

1. The muscular force of man and living animals;

2. The force of gravity producing the descent of heavy bodies, whether solid or fluid;

3. Heat, applied either to change the volume of bodies that do not change their mechanical state during its action, or to convert bodies into elastic fluids, acting with a powerful expansive force.

To the second of these classes we refer the force of running water, descending in channels to find the lowest accessible level; to the third, the currents of the atmosphere or wind, the more powerful agency of inflamed gunpowder, and of liquids converted into steam.

60. Machines are instruments by which we change the direction or intensity of the moving force. They can all be reduced to six simple forms, called Mechanic powers, and these again to two still more simple modifications. In their action there is but one principle involved, which is as follows: *The product of the moving force, estimated in some conventional unit, into the space through which the point to which this force is applied, is, in all cases, equal to the sum of the products of all the resistances into the spaces described by their respective points of application.*

This principle has two distinct cases; in the first, the machine is at rest, or in equilibrio, under the action of the power and the resistances. In this case the points of application must be supposed to move, and the space employed in the calculation is that through which they would move without altering the conditions of equilibrium. The principle is, in this case, called that of Virtual Velocities. In the second case the machine moves with uniform velocity under the action of the opposing forces, and is said to have attained a state of permanent working, or to be in dynamical equilibrium.

A machine passes from the state of rest, in consequence of the conditions of equilibrium being violated, and of the moving power acquiring, in consequence, a preponderance over the resistances. It leaves the state of rest gradually, and therefore moves at first with accelerated velocity, the conditions of equilibrium, so long as this acceleration is going on, no longer hold good; and there is one case in which the acceleration might continue as long as the motion. This is when the moving force is capable of acting with equal intensity upon a body at rest and upon a body in motion. Of the three classes of forces we have mentioned, gravity is the only one that thus acts, and it is limited by the check which the motion meets, in consequence of the body acted upon reaching the solid mass of the earth, the resistance of which speedily brings it to rest. But, even in the case of this force, the bodies which are propelled by it meet with resistances, that may finally render their motion uniform. Thus a stream of water, although propelled by the force of gravitation, moves in a pipe or channel of constant section with uniform velocity. In all other cases the action of the moving force does not depend upon the velocity with which the body in which it resides moves, or has a tendency to move, but upon the difference between this and the velocity of the machine to which it is applied. Hence, when the point of application is at rest, the force acts upon it with the whole intensity it is capable of exerting; but when this point has a velocity equal to that of the body through which the force acts, the former no longer receives any impulse from the latter. As the motion grows out of the superiority of the moving force, and as the action of this force diminishes with every increase of the velocity of the point to which it is applied, equilibrium between its action and that of the resistances must again take place, and if they both act upon a machine, it will assume a state of permanent working.

We have used the term resistance; for the machine must not only do the work for which it is constructed, but must also overcome retarding forces that exist in the very nature of materials and workmanship, or which grow out of extrinsic causes. Friction is the retarding force from which no material is free, and which no perfection of workmanship can wholly remove; the more important of extrinsic forces is the resistance of the fluids, in which machines may be placed, and which in most cases is that of the air of the atmosphere.

We measure the mechanical action of a force not merely by the weight it is capable of raising, but by the space through which it raises that weight in given time. Hence, as the products of the moving and resisting forces, into the respective spaces through which their points of application pass, are equal either in the states of ordinary or dynamical equilibrium, the measure of these forces is also equal; and even were there neither friction nor resistance from the air, the utmost work a moving force is capable of performing, is no more than its own measure. Thus nothing is gained by any machine, if considered abstractly, while the whole amount of friction and the resistance of the air is absolute loss.

In practice, however, machines are of very great value, in spite of this actual waste of moving power: we are enabled by them to accommodate the direction of the motion of the agent employed to that of the work to be performed; we can render a power that has a fixed and determinate velocity, capable of doing work with any other given velocity; we can apply a natural agent, whose intensity is determinate and invariable, to overcome a resistance of far greater intensity, although at the expense of a loss of velocity; and we can in either, or all of these cases, bring to the aid of the power of man the action of the great natural agents, water, wind, and steam. Thus, then, the exertion that man must apply, when furnished with proper machines to enable him to make use of these great agents, may frequently become wholly intellectual, and he will no longer have need of his mere physical energies; or at any rate, a single man will be able to direct the action of a power to perform a work, for which the united strength of thousands would be insufficient.

It is in the application of steam to machinery, that this triumph of human mind over matter and the elements is most remarkable.

61. Steam may be applied as a moving power in four different modes:

1. It may act against a space, wholly or partially void; in this case, if proceeding from a water of the temperature of 212°, it exerts a force equivalent to the difference between the pres-

sure of the atmosphere and the tension of the matter contained in the space against which it acts; or, if heated to a higher degree in a close vessel, with a force corresponding to the increased temperature, according to the law stated on page 24.

2. It may be admitted, at a high temperature, into a space greater than it is capable of filling at the density that corresponds to its heat, and act against a space void of air by its expansive force.

3. It may, if proceeding from water heated to a high degree, in a close vessel, be able not merely to overcome the resistance of the atmosphere, but to exert, in addition, a great mechanical force.

Or, 4. It may cause motion by its re-action.

In the two first cases it is necessary to have the means to form and keep up a vacuum. The mode universally employed for this purpose consists in taking advantage of the condensation of steam itself into a liquid form. By the table upon page 24 it appears that the volume of steam at the temperature of 212° is 1696 times as great as that of the water whence it is generated; hence, its complete condensation would leave but $\frac{1}{1696}$ of the space it previously occupied, filled with any material substance. Such complete condensation is indeed impossible, for reasons we shall hereafter refer to; but it is yet obvious that a vacuum of a considerable degree of perfection may be thus attained.

The condensation of steam is effected by withdrawing its latent heat. This is done in the steam engine by the application of cold water, that may either be applied to the surface of the vessels which contain it, or actually brought into contact with the steam itself. In the method now universally adopted into practice, the vessel is not only kept cool by immersion in a cistern of water, but a jet of cold water is constantly flowing into it.

62. Let a piston be fitted steam tight to a cylinder, closed at each end, and let the space both above and below it be filled with steam; if the steam beneath the piston be suddenly condensed, and fresh steam be permitted to flow into the upper part, the piston will be depressed to the bottom of the cylinder

by the whole energy of the steam, as given in the table on page 24; if, so soon as the piston has reached this lowest position, steam be admitted beneath it, and the steam resting upon the upper side be suddenly condensed, the piston will now be forced upwards with a force equal to that by which it was caused to descend; after reaching the top, the piston may again be forced down, and this alternating action may be kept up as long as steam can be supplied on the one hand, and the means of condensing it found upon the other.

If now a rod be passed through a collar in one of the lids of the cylinder, and fastened at one of the ends to the piston, this rod may be made the means of conveying the force which the steam exerts upon the piston, both in its ascent and descent, either directly, or through the intervention of other bodies, to some point at which it may be made to perform some regular work, or overcome some resistance.

63. If the steam be condensed within the cylinder, there will be a great loss of heat, and consequent increase in the expense of supplying the moving power. Whether this condensation be effected by affusion of water upon the outer surface of the cylinder, or by the injection of a stream into its interior, the temperature of the enclosed space and of the sides of the vessel will be lowered, and the heat the steam has communicated to them, wholly or partially withdrawn. When the motion of the piston is to be reversed, and steam begins to enter on the side on which it was before condensed, it must again heat the piston and the adjacent parts of the cylinder up to its own temperature; this it does by parting with its latent heat, and it is consequently condensed: the steam flowing from the boiler, therefore, exerts no mechanical action until the heat, before abstracted, is again replaced; as the piston moves, fresh portions of cooled surface are exposed, and fresh quantities of steam must be expended in heating them. Such is the effect produced by the alternate heating and cooling of the parts, that it has been found, by actual experiment, that at least five times as much steam is expended upon them as is necessary simply to fill the cylinder.

Hence, it is obvious that the steam ought to be condensed in a separate vessel, having a communication alternately with the upper and lower sides of the piston.

64. Water is capable of forming vapour at all temperatures whatsoever. Its tendency to rise is, however, impeded by pressure, and thus it does not boil in an open vessel where the rising of steam is impeded by the resistance of the atmosphere, until it reaches the temperature of 212°. But with each diminution of pressure, the boiling temperature becomes lower, until, in the vacuum of an air pump, it boils at 90° : Hence, so soon as a portion of the steam is condensed, fresh vapour will be rapidly formed at a lower temperature, and although the expansive force of this diminishes in a geometric ratio, yet it is still capable of opposing a resistance to the motion of the piston. This resistance is such that it has been found by experience that the vapour of water of 212°, whose expansive force is equivalent to a pressure of 15lbs. on every square inch, had never acted upon the piston with a mean force of more than 10lbs. until means were applied to remove or obviate this resistance.

It may be removed, or at least very much lessened, by taking care to keep up a vacuum in the separate condenser. Two modes present themselves for doing this : the engine may be placed at least 34 feet above the level of a cistern of water, and the condenser may be made to communicate with it by a pipe. As that height is the maximum distance to which the pressure of the atmosphere can raise a column of water, the water of condensation and the condensed steam will flow into the pipe, and as much will pass out at its lower end ; the water being supported at a constant level by this pressure. It, however, happens so rarely that a proper situation can be found to carry this plan into effect, that it has never been applied to practice, and has ceased even to be thought of by those concerned in the construction of steam engines.

A pump has therefore been resorted to, in order to keep up a vacuum in the condenser, by carrying off the water of condensation, and the vapour that may remain, or be again generated. This pump is called the Air Pump. It may be, with the condenser, immersed in a cistern of cold water, and a jet of that fluid may play through an aperture into the condenser. In this manner a greater cooling surface is brought into contact with the steam, and the condensation is effected more rapidly than could be done by simply cooling the surface of the condenser. The water that thus enters is regulated to the working of the engine by a valve called the Injection Cock. In some cases, however, as in steam boats, a cold water cistern cannot be employed. The modifications which the structure of boat engines has undergone, will be described hereafter.

65. The alternating rectilineal motion of the piston in the Cylinder of the engine, can of course be only directly applied, to perform a work with the same species of motion and with equal velocity. Thus, by passing the piston-rod through the bottom of the Cylinder, it might be made to work a pump, or by laying it in a horizontal position, to drive a horizontal blowing machine. But the cases where this direct application is possible are very few and unimportant, and they have never been introduced into practice. Even where a motion of the same kind, and with equal velocity, is required, it is the more usual custom to carry the motion of the piston-rod to the place where the work is to be performed, through the intervention of a Balance or Lever beam, resting upon pivots.

This beam, having the axis that passes through these pivots fixed, its ends move in circular arcs with reciprocating motion. Now, as the motion of the piston-rod, although reciprocating, is rectilinear, it becomes necessary to make the connexion between the piston-rod and the beam of such a nature as will permit the one of these motions to be accommodated to the other.

The simplest, and it might almost be said, the most obvious plan, is to affix a bar to the end of the piston-rod, at right angles to its direction, and make the ends of this bar describe straight lines, by adapting them to straight guides of iron ; the end of the piston-rod being thus kept to its rectilineal course, the end of the beam is attached to it by a bar, which has a motion upon cylindrical gudgeons, affixed both to the piston-rod and the beam. Through this bar the force that impels the rod in its ascent and descent, is conveyed to the beam, and the gudgeons allow the bar to change its position in such a way that one end may always move in a straight line, and the opposite one in an arc of a circle.

We have said that this method would seem the most obvious; it is not, however, the earliest, and has only been used in the United States, where it has entirely surperseded the earlier method we are about to describe. This method is called the Parallel Motion. A bar similar to that we have described connects the piston-rod to the end of the beam, but the former has no guides; a parallelogram is then formed of this rod, of a part of the lever-beam, and of two bars equal and parallel to them; the two gudgeons we have mentioned are situated at two of the angles of this parallelogram, and at the other angles the connexion between the pieces that form the sides is also effected by gudgeons or pivots, which are called Centres. This parallelogram has therefore sides of a constant magnitude, but the angles are capable of variation in size by the motion of the sides upon the centres which connect them. The centre at the angle diagonally opposite to that where the end of the beam is joined to the bar which connects it to the piston-rod, is attached by a bar to an immovable pivot in the frame of the instrument, or in an adjoining wall. By this last connexion, the point at this last-named angle, will, when the beam oscillates, describe a circle around the centre of the fixed pivot.

The points at the two angles of the parallelogram which are situated at the end of and upon the beam, will also describe circular arcs, whose convexity is opposed to that of the arc described by the point attached to the fixed pivot. When the radii of these three different arcs bear a proper relation to each other, the remaining angular point of the parallelogram will describe a straight line. Its path is, in truth, a portion of a curve of contrary flexure, but within the limits of the oscillations of the beam, it does not differ sensibly from a straight line. But as it is not really and truly a straight line, this method, however ingenious, is both less perfect in theory and more complex in practice than the other. The side of the parallelogram opposite to that which is a part of the working beam, is called the Parallel Bar; the remaining two sides are called Straps; the bar which connects the lower angle of the parallelogram, to which the piston-rod is not fastened, with a fixed pivot, is called the Radius Bar.

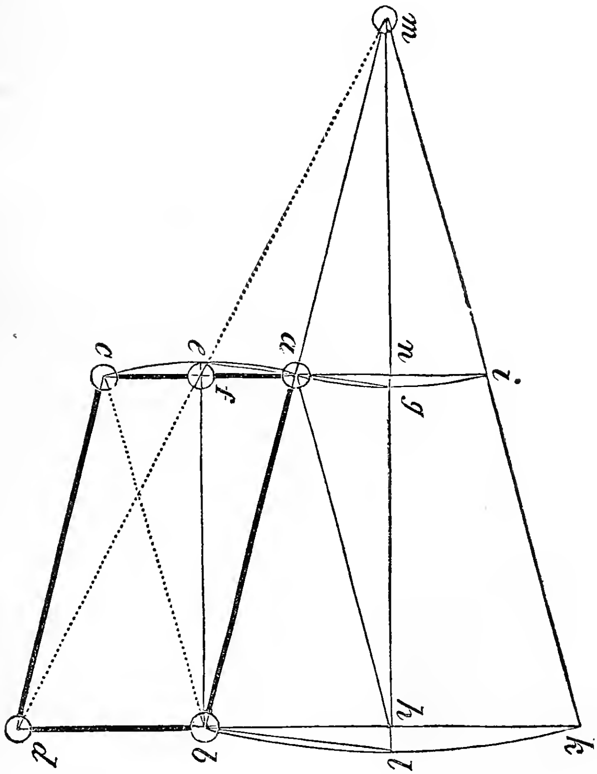
We have spoken of the bars, that, with a part of the beam, make up the parallel motion, as single. So far as their theory is concerned, this is sufficient, but for the sake of a proper adjustment of the pivots, the straps are made double.

In the pair of straps nearest the fulcrum of the lever beam, there is another parallel motion, which is applied to work the air pump. This consists in adapting a pivot, to the two straps to which the pump-rod is attached, by a circular socket, in such a way that the direction of the rod is not changed by the motion of the pivot; this pivot, thus placed between two points which describe circular arcs convex towards opposite directions, may be so adjusted in its distance from each respectively, as constantly to describe a straight line. The principle of these parallel motions will be understood by reference to the following description and figure.

m b is a part of the lever beam in its lowest position, *m* being the centre on which it vibrates; to the points *a* and *b* are attached the straps *a f c* and *b d*, and to these the parallel bar *c d*; the axis of the radius bar is in a line passing through *b*, and its other end is attached to the point *c*. The four angles *a*, *b*, *c*, *d* are formed by pivots so as to have a free motion, and the radius bar has pivots both at *b* and *c*. Thus the points *a* and *b* will, when the beam moves, describe the circular arcs *a g i*, and *b l k*, while the point *c* will describe the circular arc *c e a*, whose convexity is opposite to the two former arcs; and they will compel the point *d* to describe the straight line *d b h*. In this figure the line *a b* is half the length of one arm of the lever beam, and the radius bar is equal to the same line, but there may be other proportions; all that is necessary, is that the radius bar shall be equal in length, between its centres, to the distance between the points *m* and *a*.

The second parallel motion is formed by placing a pivot *f*, at the point where the line *m d* cuts the side *a c* of the parallel-

PARALLEL MOTION.



ogram, this point will then be compelled to describe the straight line *f a n*.

For the parallel motion has recently been substituted the following arrangement, to which we have already referred as still simpler. To the end of the piston-rod is attached a bar, or cross head, at right angles to it, the ends of this are placed between parallel vertical guides, situated in the plane passing through the line *d b h*. The cross beam is turned, at two places, into the form of pivots, to which the straps that unite the piston-rod to the working beam are applied. This method has several advantages over the parallel motion. It is much more easy of construction, and requires no geometric skill in the workmen. It is less costly. It, in addition, will permit the beam to describe an arc of greater amplitude, and thus the space occupied by the engine may be diminished.

66. The end of the beam, opposite to that which is attached to the piston-rod, has also a reciprocating circular motion, rising as the other end falls, and falling as it rises. This species of motion is hardly adapted to be applied directly to any usual species of work. In most of the important applications of the steam engine, the required motion is circular and continuous. It hence becomes necessary to convert the reciprocating motion of the working end of the beam into the last-named variety of motion. This change is effected by the intervention of the Connecting Rod or shackle bar, and the Crank.

The connecting rod is a bar of iron attached to the working end of the lever beam by a cylindrical pivot, and a circular socket, in which it has a free motion. The crank is an arm or radius of iron, having a pivot at each end, one of these is fixed in a horizontal position to a socket in a solid support, and the arm has a free motion around the axis of this pivot; the pivot at the other end projects from the arm, and is inserted in a socket on the lower end of the connecting rod. The length of the crank between the axes of the two pivots is equal to half the space passed through by the piston in the Cylinder, or what is called the length of the stroke. It is at least so when the arms of the beam are of equal lengths, as is most usually the case; and when they are not, this distance has the same ratio to half the length of stroke as the arms of the beam, to which the connecting rod and piston are respectively attached, have to each other. The working end of the beam, rising and falling in a circular arc, under the impulse conveyed from the Cylinder through the parallel motion, will act upon the crank through the intervention of the connecting rod; the moveable end of the crank will describe, under this influence, a semicircle during the time that the beam either rises or descends: this semicircle may be directed to either side of the vertical line passing through the axis of the crank; and a slight force applied to it in a proper direction, at its highest or lowest positions, will cause it to describe a complete circle.

This apparatus may be better understood by reference to *Fig.* 5, on *Pl. IV*, where *A* represents the end of the lever beam, *b* the part of the connecting rod, which is forked at the end, and embraces the beam; *c*, the connecting rod represented in its highest position; *d*, the pivot on the crank to which the connecting rod is attached; *E*, the arm of the crank of which *f* is the centre; *g*, *h*, *i*, *k*, represent four other positions of the crank.

67. The force that renders the rotary motion of the crank continuous, is derived from the fly-wheel, which also fulfils another most important purpose.

No motion can well be imagined more irregular than that of the piston of a steam Cylinder. When it is in contact with either end of the Cylinder, the entrance of the steam gradually impels it from a state of rest, until it acquires a maximum of velocity, whose magnitude depends upon the relation between the supply of steam and the work to be performed. When it reaches the opposite end of the cylinder it again comes to rest, more or less suddenly, according to the manner in which the steam is supplied and cut off. A motion in the opposite direction next succeeds, gradually increasing at first, and again ceasing when the piston reaches the opposite limit of its motion. It will be thus seen that not only is the direction of the motion alternating, but that its velocity is continually varying, and that at two instants there is no motion whatever. Now, in very many applications of steam, it is not only necessary that the action be continuous and circular, but that its rate should be uniform. To effect these two objects, advantage is taken of the nature of matter, which has not the power either of setting itself in motion, or bringing itself to rest; hence, when a mass is once set in motion, it will have a tendency to move forward continually, and with uniform velocity; this it will tend to do, although the force that set it in motion cease to act; and if its motion be resisted, the moving mass will communicate motion to the bodies which oppose it. The part of a machine in which this principle is called into action, is called a Fly-Wheel. It is usually a heavy circular ring, attached, by radiating arms, to the axis of a part of the machine that has a rapid motion. In steam engines it is fixed to the axis of the crank. The fly-wheel, like every other part of a machine, opposes a resistance to the moving power, and requires a certain expenditure of force to set it in motion; but when once it is set in motion, it requires but small accessions of force, and these may be exerted at intervals, to keep it moving with the greatest mean velocity which the moving power, acting through the intervention of the machine, is capable of communicating. If the power be variable, and therefore have a tendency to cause irregularity in the motion of the machine, the fly-wheel resists acceleration, on the one hand, because it cannot suddenly acquire a new velocity; but will oppose any increase with a force equivalent to the product of its mass into the difference between the velocity it has when the acceleration begins to act, and that which the accelerating force is capable of giving; on the other hand, as its motion cannot be suddenly checked when the force is either lessened or ceases to act, it therefore goes on, with a velocity decreasing only in consequence of the resistances it meets. In parting with its motion, it will communicate as much to the bodies which resist it, and will thus keep up the velocity of the machinery driven by the engine, and render that of the engine itself regular until the acceleration again commences. Hence, in the varying action of the piston of a steam engine, the fly-wheel moderates the speed when it has a tendency to become greatest, receiving then an accession of force; this it distributes again among the parts of the machine that are in motion, when the speed of the piston lessens, or actually becomes nought, which happens when it reaches its highest and lowest points. If the mass and velocity of the fly-wheel be made great, this tendency to uniformity will become absolute, and it will go on with uniform velocity, under the constant variation of the motion originally received from the prime mover, giving to the machinery driven by the steam engine a regular and constant velocity. This tendency of the fly-wheel to go forward with continuous rotary motion, accelerated at first until it reach a mean between the maximum and minimum velocity which the piston is capable of communicating to it, through the intervention of the parallel motion of the working beam and the crank, is attained by its passing through a single semicircle, or by performing no more than half a revolution; hence, when the piston reaches its upper or lower position, and the steam ceases for an instant to act, the fly-wheel carries the crank forward beyond the vertical line; the new impulse derived from the steam when it acts on the opposite side of the piston, is exerted to compel the crank to move forward in the opposite half of the circle it before described, and therefore with continuous rotary motion.

The form and mode of action of the crank has a very beneficial influence, in permitting the uniform motion of the fly to be attained without exerting any injurious action upon the engine itself. The force of the crank is always applied to the fly-wheel, in the direction of a tangent to the circle the crank itself describes; the force of the steam acts upon the crank in the direction of the connecting rod. When the force of the steam is nothing, in consequence of the piston being in the act of changing the direction of its motion, these two lines are at right angles to each other; the crank may therefore be carried forward by the fly-wheel, without being interrupted by the absolute cessation and subsequent change in the direction of the motion of the piston. But when the steam is exerting its maximum force upon the piston, these two lines nearly coincide, and the crank receives the whole force of the steam. Among all the modes, therefore, by which a variable and alternating motion is converted into one that is continuous, none is more advantageous than the crank, and few as much so. One, which will be mentioned in the history of the Steam Engine, has equally good properties in this respect, and we know of no other.

Persons ignorant of the principles of mechanics are in the habit of considering and declaring that much power is lost when motion is conveyed through the intervention of a crank. This idea appears to have been originally founded upon what occurs when a man works by means of a winch, an apparatus similar to a crank, and acting upon the same principles. Here a power which, when constantly and directly exerted, is capable of balancing a pressure of 70lbs., is not capable of overcoming a resistance of more than 25lbs. This, however, arises from the force itself actually falling, during one part of the revolution of a winch, as low as the last-named limit; and hence the revolution cannot be completed if the constant resistance exceed that amount. The power of a man depends not only upon his muscular force, but upon the manner and direction in which that muscular force is exerted; and in some parts of the motion of a winch, this manner is extremely unfavourable. The crank or winch still acts upon the resistance, with the whole force the man applies to it, but this is less at some parts of the revolution that it is in others. In the steam engine, a similar variation in the intensity of the prime mover occurs, and it is greater in amount; but while a man is as much, and even more fatigued in applying his force in the unfavourable positions of the winch, the varying motion of the piston of the steam cylinder corresponds almost exactly with a variation in the expenditure of steam.

As a general principle in mechanics, no force can be lost; it may be applied to resistances which do not enter into the estimate of the work performed; for instance, to overcome the friction of the machine; or it may, by improper or disadvantageous direction, be wasted upon the machine itself, whose parts it thus tends to tear asunder or wear away. This last circumstance does occur in the action of a steam engine, such as we have described it, but the crank is not the only part which is liable to this objection. The rod or strap, which forms a part of the parallel motion, does not always act in the direction of a tangent to the arc described by the end of the working beam, with which it is connected. Hence, it at times expends a part of the force of the engine upon the beam, tending to draw it from its place. A similar obliquity occurs where the connecting rod is attached to the opposite end of the beam, and a similar waste of power. In the crank, the connecting rod acts upon it at all angles with its tangent, from 0° to 90°; and hence a part of the force is wasted to draw the axle of the crank from its seat. Were the force of the steam constantly exerted upon a connecting rod three times as long as the stroke of the engine, the power thus wasted would bear to the whole power of the steam the proportion of 0.225 to 1, but as the steam actually ceases to exert any force at the upper and lower points of the crank's revolution, here no loss can occur, and the waste cannot exceed the ratio of 0.139 to one, or about one-seventh part; while, if, as usually happens, the pressure of the steam first gradually increases, and then again diminishes, the real waste need not exceed one-tenth part of the force of the engine. A longer connecting rod causes the power to act more directly, and its waste to be consequently less.

This waste is less than the friction of the engine, and still less than the increase the friction would acquire in any of the methods that have yet been proposed, of making the steam act directly upon a body so disposed as to be capable of acquiring a rotary motion, instead of applying it to a piston working with alternate strokes in a cylinder. We are therefore disposed to think that most of the plans which have been hitherto proposed of constructing rotary engines, have been a sheer waste of ingenuity.

68. The method we have described, of converting the alternating motion of the piston-rod into a continuous rotary one, through the intervention of a parallel motion, a working beam, a connecting rod, and a crank, is not universal. The change is sometimes effected more immediately by affixing the connecting

rod to a cross-head on the end of the piston-rod, which is then made to work between guides. When the Cylinder is vertical, the connecting rod and crank are usually double, the former descending on each side of the Cylinder. We have seen more than one plan, in which the Cylinder itself was suspended upon trunnions, permitting it to have a vibratory motion. In this last form the connecting rod may be dispensed with, and the piston-rod acts immediately upon the crank. The steam is admitted to the Cylinder through the trunnions. Such was the condensing engine of French, placed in a boat on the Hudson river in 1808, and such is the high pressure engine constructed recently by an ingenious workman in the employ of the West Point Foundry; and which, since the first edition was published, has been used both in stationary and locomotive engines constructed at the Novelty Works, New-York. This mode of suspension is, however, only suited to small engines, where the Cylinder has but little weight. When the beam is suppressed, there results a very considerable saving of room, and there are occasions where this is very important. An engine which has no beam, will occupy a space whose length is less than half that taken up by one that has. In many of the American steam boats, and particularly in most of those constructed under the direction of Fulton, the engine has this form. In the Western States, it is usual not only to suppress the beam, but to lay the cylinder in a horizontal position. This last method has many advantages, among which may be mentioned as the principal, that a vessel is far less injured by a force acting in the direction of its length, than by one exerted vertically; and that the engine may be laid entirely under deck without interfering with any of its more valuable properties.

On the other hand, the suppression of the working beam has this disadvantage, that the obliquity of the action of the piston upon the connecting rod is greater than occurs when the parallel motion and beam are used; and that the loss growing out of this obliquity is greatest in proportion to the power when the latter is a maximum; hence, the waste, compared with the mean power, is greater than in the other case. This, however, does not apply to Cylinders hanging upon trunnions, for, in them, the power is applied directly when at its maximum of intensity.

69. In some few cases the motion communicated to the fly-wheel is rendered more uniform by using two complete engines, whose cranks are adapted to the same axle, but are situated in planes at right angles to each other. When the piston of one of these Cylinders has reached the top or bottom, that of the other will be in the middle of its stroke. One of them will, therefore, be acting at its maximum of force when the other ceases to act altogether. This plan is far preferable in effect to that of a single engine of the same nominal power, but it is more expensive, as a single engine of twice the force of each of them costs considerably less than the two. In many of the best locomotive engines this method has been successfully used; but when two engines are applied to a boat, it has been found that it was difficult to keep them at the same rate of working; hence each is now usually applied to a separate shaft, and moves only one of the wheels. In the British steamers, however, the two engines act at right angles to each other upon the same axle.

A fly-wheel is not always an indispensable part of an engine, for there may be some of the machinery which is driven, that will act as a regulator in its stead. Thus, in steam-boats where the wheels have a rapid motion, and in rail-way carriages, no fly-wheel need be employed.

70. The condensation of the steam is effected in the Condenser, both by keeping it constantly cool, and by admitting a jet of cold water into that vessel. To accomplish these objects, it is wholly immersed in a cistern supplied with cold water; and a stream constantly spouts through an aperture in the side of the condenser, to which a stop-cock is adapted; the quantity of this stream is regulated by the greater or less aperture which the stop-cock affords for the passage of the water. Steam at 212°, is capable, as may be inferred from what has been stated on page 21, of heating six times its weight of water to the same temperature, and the united bulk is seven. The temperature of condensation is usually 100°, and to cool seven measures of

water of 212° to 100°, will require about sixteen measures of water, which, added to the six employed in condensation, is twenty-two. That is to say, twenty-two times the bulk of water evaporated by the boiler, is the least quantity that will suffice for the proper condensation of steam, and cooling the condensed water. There must, besides, be a supply to prevent the water of the cistern from growing warm; and it has hence been usual to make the cold water pump capable of supplying a pint of water for every cubic inch evaporated from the boiler.

71. In order to save a part of the heat, the condensed steam and water of condensation are delivered by the air pump into a vessel called the Hot Water Cistern, whence the water is raised, by the Hot Water Pump, to the feeding apparatus of the boiler. These two pumps are worked by rods, attached to the working beam, when the engine has one; in other cases these rods, with the rod of the air pump, are attached to a bar or beam, one end of which is adapted to the piston-rod, and rises and falls with it; the other is fastened to a fixed centre upon which it oscillates.

72. The power of a condensing engine depends upon the state of the vacuum that is kept up in the condenser, as well as upon the pressure of the steam flowing from the boiler; hence it is important to be able to know whether the rarefaction produced by the condensation of the steam, and the action of the air pump, be more or less perfect. This knowledge is attained by the Vacuum Guage. A glass tube, open at both ends, has its lower extremity immersed in a basin of mercury, the other end communicates by a pipe with the interior of the condenser. When the steam is condensed in that vessel, the pressure of the atmosphere forces the mercury to rise in the tube to a height which is the measure of the exhaustion; the difference between the height of this column and the height at which the mercury stands in a barometer, is the measure of the force which acts in opposition to the pressure of the steam upon the piston of the engine. This must, therefore, be deducted, in estimating the actual performance of the engine, from the

indications of the steam-guage after an atmosphere has been added to the latter. An apparatus called the Indicator, in which a spiral spring is alternately opposed to the steam and the vacuum, has been proposed as a substitute for both the Steam and Vacuum Guages ; but it has not yet come into general use.

It is, however, the only apparatus by which a true estimate can be obtained of the force actually employed in a steam engine, and, when compared with the steam and vacuum guages, would illustrate that part of the theory which is yet deficient, namely, the determination of the pressure which is exerted by steam of a given tension upon a piston moving with a given velocity.

73. The action of the fly, in producing regularity of motion, reaches only to the inequalities that take place in the motion of the piston during a single stroke. Should the flow of steam increase, the mean motion of the fly-wheel will be accelerated, and, should the flow be diminished, the fly-wheel will be uniformly retarded. Neither does it control any change in the motion of the machinery, driven by the steam, unless that change be periodic. But it frequently happens that the quantity of steam supplied by the boiler, fluctuates. Some regulator is therefore necessary, whenever work is to be done with regularity, which shall control the prime mover itself. For this purpose a Governor is adapted to the steam engine. This is also required in cases where the quantity of work to be performed is fluctuating, as is the case in many branches of manufactures, where a part of the machinery may be suddenly stopped, or may be as suddenly connected with the engine. The governor is an apparatus that is sometimes called a Conical Pendulum. Two heavy balls are suspended by bars to the opposite sides of a vertical axis. This axis is set in motion by the engine ; as it turns, the balls of the governor acquire a centrifugal force, which may be sufficient to overcome their weight, and cause them to diverge and fly off, performing in their course a larger circle than before. As the balls fly off, they act, through the intervention of a system of levers, upon a valve that is situated in the steam pipe. This, which is called the Throttle-valve, has the form of a circular disk of metal, exactly filling

up the pipe when placed across it. It turns upon pivots placed at the opposite ends of one of its diameters, and may thus either present its edge to the steam that passes along the pipe, in which case it hardly resists its course; or may assume any intermediate position until it close the pipe altogether. When the balls of the governor revolve with so little velocity that the centrifugal force cannot overcome their weight, the levers place the throttle valve in the position that presents its edge to the steam; when the velocity becomes great enough to throw out the balls to their utmost limit, this valve is thrown across the pipe, and shuts the passage completely; with intermediate positions of the valves, the passage is more or less open, according to the rotary velocity of the governor.

The governor is driven, by a strap that passes over a drum on the axis of the crank, or by wheels and pinions, deriving their motion from the same part of the engine. This apparatus is of no use in navigation or locomotion, but is indispensable in engines used for manufacturing purposes.

74. When the throttle valve acts under the influence of the governor to lessen the efflux of steam from the boiler, the elastic fluid will accumulate in that vessel, and its density and elasticity will increase along with its temperature. In this event it will act upon the float which counterpoises the self-regulating damper, and the latter will descend and lessen the draught of the chimney. A diminution in the expenditure of steam thus acts to diminish the intensity of the fire by which it is generated, while, if it accumulate too suddenly, the safety valve affords it a vent.

It is, however, to be remarked, that such floats are inadmissible, except when the tension of steam does not much exceed a single atmosphere; and that self-regulating dampers are never used in steam-boats or locomotive engines.

The valves, by which steam is admitted into the upper and lower parts of the cylinder alternately, and by which the communication with the boiler is opened and closed, are worked by machinery attached to the engine. Rack work upon the rod of the air-pump was originally used for this purpose, but it is now more usual to adapt an Eccentric to the axle of the crank. The eccentric is a circular plate of metal, which has an opening within it that just fits a part of the axle of the crank. This opening is placed in a position eccentric to the plate itself, and hence the apparatus derives its name. The eccentric plate is attached to the axle of the crank, and revolves with it. A circular ring fits upon the eccentric, but leaves the latter a free motion within it; any given point in this ring will, therefore, have its distance from the axis of the crank changed within certain limits; this change is conveyed to a bent lever which works the valves, through the intervention of an open frame-work of the figure of an isosceles triangle, whose two equal sides are tangents to the circular ring that encloses the eccentric plate.

75. The Double-Acting Condensing Steam Engine, then, is in a great measure self-acting. In truth, when applied to perform work with an uniform velocity, little is left to be done, except to supply the fire with fuel, and to observe the indications of the guages from time to time. Even the supply of fuel has been regulated by machinery driven by the engine, in such a way that it need not be fed for several hours. It is therefore not to be wondered that the condensing steam engine, worked by steam of a tension little exceeding an atmosphere, was considered for a time, and is still considered by many, as the most perfect of all human inventions. We shall, however, have occasion to describe another method of working the condensing engine, by which its efficient power has been more than quadrupled. It unluckily happens that much of the beautiful and ingenious apparatus which, in their application to the engine or the boiler, tend to render the former self-acting, are rendered useless in the new mode of working.

76. The pistons of the Cylinder and air-pump, and the openings in the covers of those parts of the engine through which they move, are rendered steam tight by packing. The substance formerly solely employed for this purpose was hemp, in the form of plaited bands, and it is coated with grease. The joints of the several parts are closed by plaited hemp, or felt, coated with white

lead ground in oil, or where one part is made to fit into another, by an iron cement, composed of iron filings, or gun borings, muriate of ammonia, and flour of sulphur; the proportions are sixteen parts by weight of the first, two parts of the second, and one of the third substance. The joints are, generally speaking, formed by flaunches cast upon the pieces, in which holes are drilled; through the latter are passed screw bolts, that are fastened by nuts.

The power of machines is estimated in terms of some conventional force, taken as the unit. Steam engines having been originally introduced as a substitute for the action of horses, it became the practice to compare the force of an engine with the strength of a number of horses. The unit, which is employed in the estimate, is, therefore, a horse-power; and we speak of engines as being of the power of a certain number of horses. As the strength of horses is very various, this is still a vague method, and it becomes necessary that the estimate of the work a horse is capable of performing, should also be agreed upon. Different engineers have at different times made use of different values; but the modes of estimating the horse-power resolve themselves into the expression of the number of avoirdupois pounds raised one foot high in a minute.

Desagnliers estimates this number at 27,500lbs., and Smeaton 22,916lbs. Watt supposes that a horse is able to raise 32,000lbs.; but in calculating the power of the engines of Watt and Bolton, the estimate has been taken as high as 44,000lbs.

The force which acts is the pressure of the steam, and as much pressure as is indicated by the steam guage is supposed to act upon the piston; this, multiplied by the velocity of the piston, gives the whole power of the steam; but before the steam that issues from the boiler can reach the piston, it is retarded by the friction of the pipes, and loses by cooling a part of the expansive force indicated by the steam-guage; its action is next diminished by the cooling it undergoes in the Cylinder itself; and before the power is transmitted to the working point of the engine, it must overcome the friction of the piston, open and shut the valves, force the steam into the condenser, and work the air-pump and the hot and cold water pumps. It has, next, to overcome the friction of the axles of the lever-beam, parallel motion, and crank; and the piston is besides resisted by the uncondensed steam remaining in the condenser. Of the last, the vacuum guage furnishes a measure; but of all the rest nothing is known perfectly, except by comparing the work actually performed with the original force of the steam.

We have further to remark, what appears to have been neglected by all former writers, that the actual tension of the steam is not the measure of its pressure upon the piston when in motion. It will be obvious that the whole of such a force can only be exerted upon a body at rest, and that when the velocity of a body is as great as that with which the steam can follow it, all pressure ceases. It might be a mathematical investigation of no little theoretic interest to determine at what velocity within these limits a maximum effect is produced, and what will be the pressures of steam of a given tension upon a piston moving with given velocities. It does not, however, seem probable that at the present moment such an investigation would be attended with any valuable practical result.

It has been deduced from observation upon the working of engines, that more than 40 per cent. of the original power of the steam is lost from these several causes; hence the indication of the steam-guage must be diminished in that ratio at least, before it is employed in the calculation of the force of the engine.

In this country it has been usual to estimate the horse power at 33,000lbs., raised one foot per minute, and the mean pressure of the steam, in a condensing engine, at 10lbs. per square inch. We hence have the following rule:

Multiply the area of the piston in square inches by 10, *and by the velocity of the piston in feet per minute; divide the continued product of these three quantities by* 33,000, *the quotient of the estimated force of the engine in horse power.*

The rule of Brunton gives 44,000lbs. for the divisor, and that of Tredgold reduces the mean pressure to 9,10 pounds per square inch, which would correspond to a divisor of nearly 36,000 when the pressure is assumed at 10lbs. The tension of the steam is supposed to be five inches of mercury, marked by $2\frac{1}{2}$ inches in the mercurial guage; and equivalent to a pressure of $2\frac{1}{2}$lbs. more than an atmosphere, or $17\frac{1}{2}$lbs. per square inch. The safety valve is loaded with a weight of three pounds per square inch, which, with the aid of the atmosphere, will retain steam whose expansive force is not greater than 18lbs. per inch.

77. The quantity of water to be evaporated in order to do the work of a horse in a double-acting condensing engine regulated as we have just stated, may be estimated as follows, viz:

A cubic foot of water, evaporated under the ordinary pressure of the atmosphere, occupies a space 1696 times as great as it did before; but the space it occupies under a pressure of $17\frac{1}{2}$ pounds is, if we abstract from the expansion by temperature, less in the ratio of 15 to $17\frac{1}{2}$; for elastic fluids occupy spaces inversely proportioned to the pressures by which they are confined, (see p. 14); hence the space occupied by steam having an expansive force of $17\frac{1}{2}$lbs. is 1454 times the original bulk of the steam.

A cubic foot of water, therefore, occupies a space, in the form of such steam, of 1454 cubic feet; and the effective pressure, as we have before stated, is 10lbs. per square inch, or 1440lbs. per square foot; the power of a cubic foot of water is, therefore, to lift 1440×1454 or 2,093760lbs. through the space of a foot. If this be divided by 33,000, which is the conventional weight to be lifted by a horse power per minute, it will give the number of minutes in which, if a cubic foot of water be evaporated, it will keep up this conventional unit of force. The quotient is 63, or three minutes more than an hour. It is therefore usual to allow the evaporation of a cubic foot of water per hour to be equal, in the engine under consideration, to a horse power: and as it is well to be always certain of a supply of steam, boilers are made to furnish more units of steam than the engine is estimated at; the waste of heat in small boilers being greater in proportion than in large ones, this excess is a constant quantity, the boiler being calculated to produce steam equivalent to two horse power more than the estimated force of the engine. We have seen that a surface of boiler in contact with flame and hot air of 8 square feet (see p. 57) is equal to the conversion of this quantity of water into steam.

78. The feeding apparatus of the boiler, which is, in this form of engine, composed of a pump that raises the water of condensation from the hot water cistern to a cistern at the top of the feed pipe, must therefore supply at least one cubic foot per hour for each horse power at which the force of the engine is estimated; or $\frac{1}{1454}$ part by bulk of the capacity of the cylinder, at each stroke of its piston. As, however, it is better to have an excess than a defect of water, the hot water pump usually raises at each stroke $\frac{1}{900}$th part of capacity of the cylinder.

Such are the general principles of action of one form of the condensing engine, which, to distinguish it from others in which the same operation is employed to form a vacuum, is called the Double-Acting Engine, to which epithet is also added the name of the inventor, Watt. We are now prepared to enter into a more particular view of its several parts, the use and operation of which would have been unintelligible, had we not previously investigated their uses, and the relation in which they stand to each other.

CHAPTER V.

DESCRIPTION OF THE DOUBLE-ACTING CONDENSING ENGINE.

Usual form of Double-Acting Condensing Engine.—Steam-pipe.—Jacket.—Side Pipes.—Side Valve.—Puppet Valve.—Balance Valve.—Cylinder.—Cylinder Lid.—Cylinder Bottom.—Piston.—Woolf's Piston.—Metallic Packing.—Condenser.—Air Pump.—Delivering Door.—Air Pump Bucket.—Hot Water Cistern and Pump.—Cold Water Cistern.—Injection Cock.—Water of Condensation.—Cold Water Pump.—Parallel Motion.—Lever Beam.—Pump Rods.—Connecting Rod.—Crank.—Fly Wheel.—Tumbling Shaft.—Eccentric.—Double Eccentric.—Adjustment of Eccentric.—Governor.—Throttle Valve.—Other forms of Double-Acting Condensing Engine.—Mode of setting these Engines in motion.

79. Having in the last chapter explained the general principles of action of the Double Condensing Engine, we shall now proceed to describe the several parts more particularly, and in reference to a plate, on which they are figured in connexion with each other. *See. Pl. III.* As the condensing engine, in its most complete form, and adapted for general purposes, is in more general and frequent use in Great Britain than in this country, an engine constructed by Messrs. Murray, Fenton & Wood, of Leeds, has been chosen for the illustration of this part of our subject

Fig. I. is an external elevation of this engine. Fig. II. a section. Fig. III. a horizontal plan. Fig. IV. a view of the lower part of the apparatus from the opposite side. The same letters apply to the same parts in these four several figures.

In the engine before us, the steam reaches a part of the steam-pipe marked *s*, whence it flows into a space formed around the Cylinder by a cylindrical case called the Jacket. The use of this is to keep the Cylinder itself at an uniform temperature. All engines have not this additional part, and in this country in particular we never recollect to have seen it used. For it, a simple casing of wood is frequently substituted, which, being a bad conducter, has been supposed to be well adapted to preserve the heat of the cylinder.

From what has been said in respect to the mode in which heat is carried off under certain circumstances, it will appear that both Jacket and wooden casing are liable to objections. In the air, but little heat is carried off in consequence of the conducting power of the surface, and by far the greatest part of the loss is due to radiation. Now, of the metals, the rough blackened surface of cast iron is among the best radiators, and wood stands high in the general order of radiating power; and hence, in the first case, the steam will be cooled before it reaches its place of action; and in the second, the temperature of the Cylinder will be more affected than if it had not been cased. The principles we have discussed would point out as a sure method of retaining the heat, to enclose the Cylinder in an air-tight cylindrical case of some bright metal, with a thin body of air between them. The confined air will convey but little heat to the casing, and that which is conveyed will radiate very slowly.

80. In the engine before us, the steam passes from the jacket to the side-pipes, marked *a a*, through the opening marked *b*. The form and arrangement of these pipes depends upon the structure of the valves; in this engine the valves are of that description called the Slide-Valve. This was originally invented by Murray, of Leeds, but was compressed by him within a shorter space; the valve before us, which occupies the whole side-pipe, is an improvement of Watt's.

81. The side-pipe has the general figure of a half cylinder,

the plane face of which is turned towards the Cylinder of the engine, and is terminated at top by a square box. The steam enters this pipe by a channel *b*, that communicates with the jacket. In engines that have no jacket, the steam-pipe usually enters the side-pipe from behind it, about the middle of its height.

Within this pipe is placed another, which exactly fills it at the upper and lower extremity, but which is made less in the middle, so that the steam, on entering the side-pipe, fills up the space between the two pipes. The inner pipe is moveable, and attached to a rod that passes through an air-tight collar in the square box, of which we have spoken, and by which it is drawn up and pushed down alternately, under the action of a mechanism that will be hereafter described.

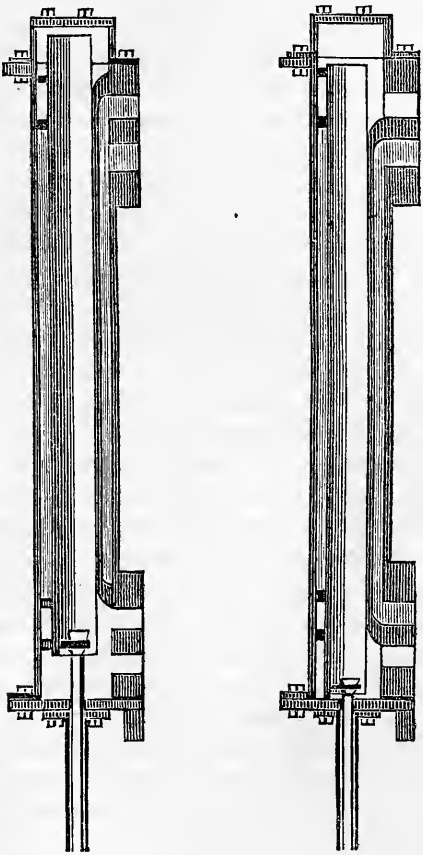
Between the Cylinder and the outer pipe are two channels, whose section is rectangular. One of these forms a communication with the upper, the other with the lower part of the Cylinder.

The length of the inner pipe is so adjusted that when that part, at one of its extremities, which just fills up the outer pipe, is opposite to the corresponding rectangular passage, the other rectangular passage shall be opposite to the space that we have described as left between the middle part of the inner and the outer pipe. Hence, steam will flow into the Cylinder from this space. In the plane surface of the part of the inner pipe that is applied to the first-named rectangular passage, there is a corresponding rectangular opening, by which the steam, from the adjacent side of the piston, will pass into the inner pipe, and thence by a passage marked *o* into the condenser *n*. In the position in which the engine is represented in the figure, the steam is flowing into the lower part of the Cylinder, and beneath the piston, while it is passing out at the opposite end, and through the inner pipe to the condenser.

The inner pipe has a similar rectangular opening at its opposite extremity; when, by the action of the engine, the inner pipe changes its position, this opening adapts itself to the adjacent rectangular passage; while the other communicates with the space between the two pipes, and thus the direction of the steam and the motion of the piston are reversed.

It will therefore be seen that there is a constant communication between the space contained between the two pipes and the boiler, while the inner pipe has a constant communication with the condenser. A change in the position of the inner pipe brings the openings of the Cylinder alternately into communication with the boiler, and condenser.

It is obvious that this species of valve requires very perfect workmanship; the plane surfaces of the outer and inner pipe must be ground in the most careful and exact manner, and the



circular surfaces, where they come in contact, at the upper and lower extremities, must also be accurately fitted.

The structure and use of this species of valve will be better understood by reference to the figures on the preceding page, in which it is represented in two different positions. In order to give more variety, we have taken a form different from that of the engine in *Pl. III.* in which the spindle enters the side-pipe from above, while in the figure, the spindle is applied beneath.

This valve, being as long as the Cylinder, has been called the Long Slide-valve, in order to distinguish it from one acting upon the same principle, but which does not occupy so great a space, and which is called the Short Slide-valve. *Pl. I. Fig.* 6, represents a section of a cylinder, and side-pipes adapted for the occupation of a valve of the latter description; and we shall describe it more fully hereafter, in treating of the kind of engine to which it is most frequently adapted.

The valve which is most frequently used in modern English engines is also of the sliding form, but is divided into two parts, the one corresponding to the upper, the other to the lower end of the cylinder. The slides are connected by a rod. This form is called the double D valve, and is placed, like the puppet valve we are about to describe, between two side-pipes, one of which communicates with the boiler, the other with the condenser.

Sliding valves have the advantage, which is in many cases important, of opening gradually, and thus causing no sudden shock when the motion of the engine is changed; and by a proper adjustment of the distances between the openings of the inner pipe, and of the apparatus by which it is driven, it may be made to cut off the steam before the motion of the piston is completed, and thus again render the change less sudden. On the other hand, the accuracy of workmanship it requires may not be always attainable, and its repair cannot be effected in situations remote from well-organized workshops. It is also to be stated, that when impure water is used, it has been found to wear rapidly and unequally; and thus, after having been introduced in many of our steam-boats, it was laid aside, and another and more ancient species of valve restored. Of this we shall proceed to give a description.

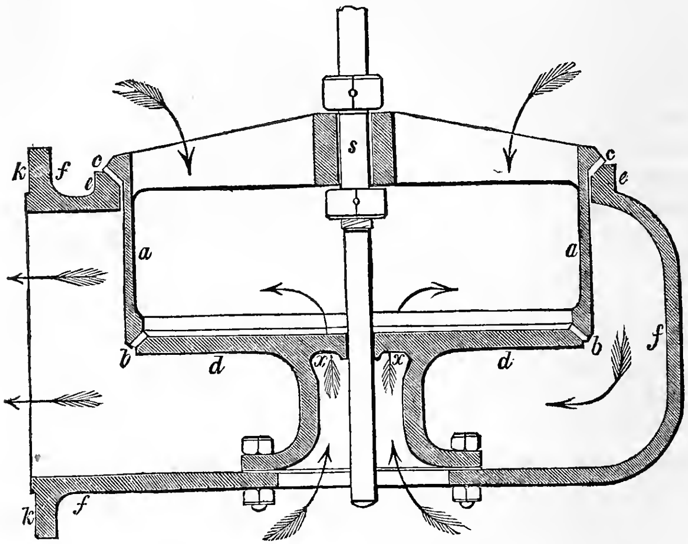
82. This species of valve, usually called the puppet valve, is represented on *Pl. II, Fig.* 3.

The side pipes are two in number, of which that marked A, is continually receiving steam from the boiler, through the steam pipe E, while that marked B is constantly conveying it to the condenser. These pipes are united by being both inserted at each end into the same cylindrical case, or box, of which there are consequently two, at C and D. These are called *Steam Chests*, and each of them is divided into three spaces by two diaphragms, having each an opening of the form of a truncated cone, whose least base is lowermost. These appertures are called nozzles, and are the seats of the valves; to these nozzles, four solid frusta of cones, *a*, *b*, *c*, *d*, are accurately ground, and form the valves; from the space between the two diaphragms in each box, is an opening that allows the steam to pass to and from the cylinder.

It will be obvious, that when the two upper valves, *a* and *c*, in each box, are raised, steam must flow from the boiler into the Cylinder, and when the two lower of each set, *b* and *d*, are raised, it must flow from the cylinder to the condenser. Hence, it is necessary that they should reciprocate, the valves *a* and *d* opening when the valves *b* and *c* close, and *vice versa*. Hence, the two valves, *a* and *d*, are united, and made to open and shut at the same time; as are the two valves *b* and *c*. It will be perceived by the drawing, that each valve has a cylindrical spindle or stem attached to it, and the four nozzles are in the same vertical line. The spindles of the two steam valves, *a* and *c*, are hollow, and admit the spindles of the two condensing valves, *b* and *d*, to pass through them. The purpose of this will be explained hereafter. In more ancient forms of the engine, the spindles were replaced by a short rack, into the teeth of which the teeth of a circular segment caught. The use of this form will also be stated hereafter.

In some engines, the steam and condensing valves of each pair are placed obliquely, instead of being in the same vertical line. In this case each spindle is solid and has its separate steam-tight collar.

The most perfect form of valve is that of Trevithick. The slide valve, if tight, is attended with great friction, and the puppet valve is kept in its seat by a pressure of steam, which, on each square inch of its surface, is equal to that on a similar area of the piston of the engine, and this resistance is estimated at more than the friction of a slide valve. The valve of Trevithick has the



form of a cylinder, on the upper end of which, at *c c*, is a conical ring, and a hollow cone is turned at *b b*, on its inner and lower surface. The first of these conical surfaces rests in a hollow frustum *e e*, the second upon a solid frustum *d d*. It will therefore be seen that the resistance to the opening of the valve, is the pressure on a surface equal to the difference between the areas of the conical surfaces, *c c* and *b b*, instead of that upon a circle whose diameter is *c c*. The arrows show the directions in which the steam flows.

The side pipes sometimes have, for the sake of ornament, the form of pillars, the entablature being extended above to cover the space left vacant by the side pipes.

The old rule for the side of these nozzles was, to make their least diameter one-fifth, at least, of the diameter of the Cylinder; but one-fourth of that diameter is now a more usual dimension. The passages into the boiler must have an equal area, as must the passages of the slide valve that has just been described.

83. The Cylinder of a steam engine has the figure which is denoted by its name; and, in order to avoid ambiguity, it has been and will always be distinguished by beginning it with a capital, in order to prevent its being confounded with such other parts as have also a cylindrical form. It is represented in the figures on *Plate III*, by the letter *b*.

This vessel is, in all large engines, made of cast iron, cast with a core, and reamed out to the proper size. This operation requires great care, and should be done in a mill liable to no agitation, for much of the value of the engine will depend upon the interior being as truly a mathematical cylinder as the nature of materials will admit. Near the upper end of the Cylinder is cast a rectangular piece, in which is the passage *h*; and at both ends are cast flaunches, to admit the fastening of its lid and bottom, by means of screw-bolts and nuts. In the engine on the plate, the lid is screwed to a flaunch on the jacket, and the flaunch of the Cylinder secured to the jacket by packing.

84. The lid of the Cylinder is a circular plate, whose diameter is equal to that of the flaunch to which it is adapted. On its lower side, it is turned, so that a circular projection fits the inside of the Cylinder, barely leaving room for the packing. In the middle is an opening to admit the passage of the piston-rod, and around this opening, on the upper side of the lid, is cast a cylindrical stuffing-box, to receive the packing, by which the rod is made to work steam-tight. In small engines the upper part of this stuffing-box is cut into the form of a female screw, to receive the screw that compresses the packing, and the head of the former is turned into the form of a cup, to contain oil. In larger engines the oil cup is connected with the lower part of the stuffing-box by screw-bolts and nuts.

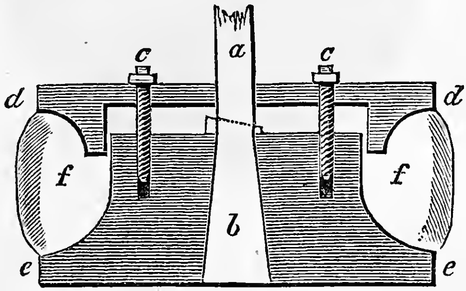
85. The bottom plate of the Cylinder is of the same diameter with the top, and has a similar projection turned upon it, to fit the Cylinder. The lower steam passage passes through it, and is cast in one piece with it. In the engine before us, the flaunches of the Cylinder and the jacket are united to the bottom by the same set of screw-bolts and nuts.

The length of the Cylinder must be as much more than the length of the stroke of the piston as is equal to the thickness of the latter, and, in addition, a small space to prevent the piston from striking. In the engine on *Plate III*, the diameter of the Cylinder is equal to half the length of the piston's stroke. This proportion is not a constant one, but is that sanctioned by the general practice of Watt. In the English steam-boats where the engine is placed beneath the deck, the stroke is necessarily short, and power is gained by increasing the diameter of the Cylinder.

We shall have occasion, in speaking of steam-boats, to treat of the proper length of stroke for engines intended to propel them. In those which are applied to manufactures, the proportion stated above is perhaps the best.

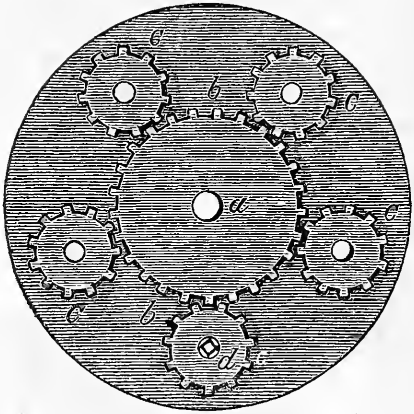
86. The piston is still usually composed of two pieces of circular section, that are just so much smaller than the internal section of the Cylinder, as to move in it freely without touching. The lower piece is firmly attached to the piston-rod, by making the lower end of this rod of the shape of a truncated cone, of which the lesser base is uppermost, and of the same size with the rod. A key is passed through the rod just above the piston, and unites them firmly.

The two pieces of which the piston is composed are connected by screws, and have a semicircular groove cut, as it were, out of their united mass, forming a ring completely around them. This open ring is occupied by the packing. The packing is usually formed of hemp, moistened by an oleaginous substance. This packing is compressed, and made to apply itself closely to the sides to the Cylinder, by the screws which unite the two pieces of which the piston is composed. As the packing wears, the screws are turned, and thus the packing, being again compressed, is forced out, and again applies itself to the cylinder. This arrangement may be better understood by the following figure, which represents a section of the Piston: *a* is the Piston-rod terminating in the truncated cone *b*; *c c* screws to unite the two parts of the piston, *d d* and *e e*; *f f* section of the packing.



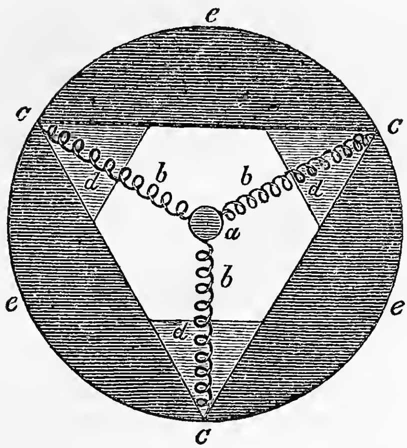
87. An ingenious mode of tightening the packing without taking off the lid of the cylinder, was invented by Woolf. The head of each of the screws is cut into the form of a toothed pinion, and the teeth of all these work in a wheel, having a free motion around the piston-rod. It is, therefore, evident that if one of the pinions be turned, not only will the screws attached to it be made to act, but all the others will be equally driven forward. One of the screws has a square head, which can be reached by a key passed through an opening in the lid of the Cylinder, and which is usually closed by an air-tight cap; it may thus be turned, by removing the cap, and all the others will be turned equally by the wheel and pinions.

In the figure annexed *a* is the piston rod, *b b* the wheel fitted loose upon it, *c*, *c*, *c*, *c*, *c*, pinions forming the heads of the screws that compress the packing, *d* square head formed upon one of the screws, by adapting a key to which, the wheel *b b* is turned, through the intervention of the pinion to whose screw the key is applied; the wheel *b b* turns the remaining pinions, and with them the compressing screws.



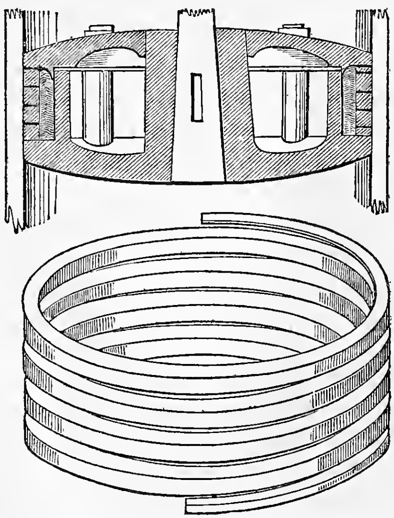
88. Metallic packing appears likely to supersede all others, and has already done so in many instances. The earliest attempt at a substitute of metal for hemp was made by Cartwright. Two rings of metal, accurately ground to fit the cylinder, are interposed between the upper and lower parts of the piston. Each of these rings is cut into three parts, and they are placed upon each other in such a manner that the joints of the one ring fall half way between the joints of the other, in the same manner as the break-joint of masonry. Three springs are made to act upon each of these rings, one at each joint, and thus to press the two adjacent pieces outwards. In this manner the springs carry the rings outwards, to replace any diminution by wear, and the breaking of the joints prevents any escape of steam through the apertures that are thus made in either of the rings.

The annexed figure shows this arrangement, where *a* is the piston-rod, *b*, *b*, *b* springs that press against the joints *c*, *c*, *c* of one of the rings, which is here represented as formed by inscribing an equilateral triangle in a circle, *d*, *d*, *d* are parts of the three pieces that form the second ring, whose joints fall at the points *e*, *e*, *e*, against which springs similar to *b*, *b*, *b* press.



In applying a metallic piston, accuracy in the boring is absolutely essential, nor can they be introduced except when this part of the workmanship is of the best description.

Another form of metallic packing, which is represented beneath, has been used in locomotive engines. It is composed of



a screw-formed ring, compressed between the plates of the piston. The several convolutions of the screw are united by solder, until they are turned down to the proper dimensions. The solder is then melted off.

The most perfect form of metallic packing is one in which the elastic force of the steam itself is used as the spring. The piston in this case is a single cylindric plate of cast iron. Two flat rings are turned out off its curved surface, leaving three flaunches. The upper and lower flaunches are pierced by a number of small holes, by which the steam tends to pass into the flat rings. These rings are occupied by a double compound ring of bell-metal, the pieces of which are so arranged as to break joint, and thus prevent the steam from passing them and the inner surface of the Cylinder. This packing has the great advantage that its friction is exactly proportioned to the tension of the steam by which the engine is worked; while in all other methods, if the packing is compressed sufficiently to be tight at the highest tension to which it is subjected, the friction is enormous at lower tensions.

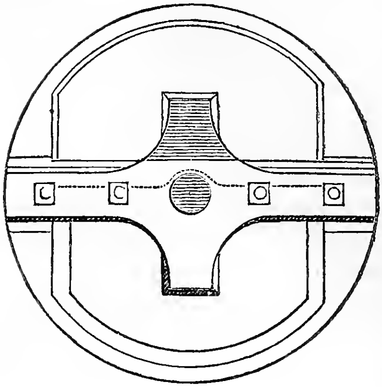
89. The Condenser is a vessel of a cylindric form. It is represented in Fig. 2, Pl. III. by *n*. Through the top passes the pipe *o*, which conveys the steam from the valves of the engine. On the side is an aperture, to which is adapted the valve *r*, called the Injection-cock, the use of which is to admit a constant jet of cold water to condense the steam. The capacity of the condenser, when the engine works with steam of the pressure of 17½lbs. per inch, is usually one-eighth part of the capacity of the Cylinder. Its several dimensions are therefore each one-half of the corresponding measure of the cylinder. But when steam of greater tension is used, the size has been increased to half the capacity of the cylinder, and both have equal diameters.

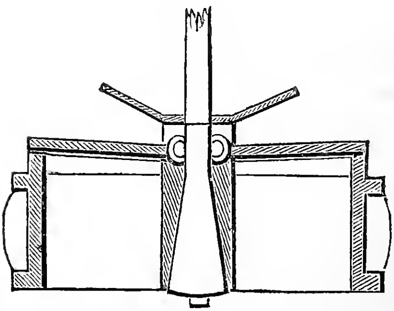
The state of the vacuum in the condenser is ascertained by means of a vacuum guage. This is represented *Pl. I. Fig.* 14. *a a* is an open vessel of mercury, *b b* a glass tube immersed at one end in the mercury, and communicating at the other with the condenser through the tube *e*. As the vacuum is formed in the condenser, the presure of the external air will force the mercury up the tube *b b*, and the difference between the height to which it rises, and that at which the mercury of the barometer stands at the time, marks the resistance the gaseous matter, that cannot be withdrawn from the condenser, offers to the descent of the piston.

The Condenser communicates with the Air-Pump by a horizontal passage of a rectangular shape. In this passage is siuated the Foot-valve *t*. This has usually the form of a shutter hanging by a hinge on its upper side, in a position slightly inclined from the vertical, and closing by its own weight. The valve is fitted to its seat by grinding or filing. The condenser and air-pump are screwed down to a common base called the bed-plate.

90. The Air-pump *q* is also a cylindrical vessel, almost identical in figure with the Cylinder. In the engine before us it has half the lineal dimensions of the cylinder, and consequently one-eighth of the capacity, or one just equal to that of the condenser. The lid of the air-pump is similar to that of the Cylinder, permitting the passage of the rod through a stuffing-box.

91. The piston of the air-pump is packed in the same manner as that of the cylinder, but, unlike it, is not solid. It contains a valve, which is usually of that form called the butterfly valve. In this shape, the Piston-Rod is attached to a bar extending across the piston in the direction of one of its diameters; to this are adapted by hinges, in such a manner as to open upwards, two shutters that fill up the rest of the circular opening of the piston. These shutters, therefore, rise and fall together like wings, whence their name. The piston and its valves are usually called the Bucket of the Air-pump. From the dimensions we have stated above, it will be obvious that the stroke of the Bucket is just half that of the Piston of the Cylinder. A plan and section of an air-pump bucket are represented on the following page.





92. On the side of the Air-pump, and near its top, is cast a rectangular passage, which is closed by a valve *v*, similar in form and structure to the foot-valve, and which is called the Delivering-door or Clack-valve.

93. Upon the rise of bucket of the Air-pump, the water of condensation is discharged by the delivering-door into a rectangular vessel of iron *w*, called the Hot-water Cistern. The Hot-water Pump, by which the water of condensation, or at least as much of it as is necessary for the supply, is carried to the boiler, is represented at *x*. It is a common pump, composed of a barrel and two valves. The water converted into steam is, as we have seen on page 116, $\frac{1}{1454}$th part of the capacity of the

Cylinder for each stroke of the piston; the pump is made to furnish a greater quantity, or $\frac{1}{900}$th part, in order that there may be no risk of a defect in the supply.

As the water of condensation is much greater in quantity than this, being twenty-two times as much in weight as the steam that is employed, a large portion of the water must run to waste, which it does by a waste-pipe.

The calculation of the size of the hot-water pump may be made as follows, viz.

Divide the cubic contents of the cylinder in inches by 900, *and this quotient by the length of the stroke of the pump, the quotient will be the area in square inches, whence by the usual geometric rule the area of the valves may be calculated.*

The stroke of the hot-water pump in the engine on Pl. III. is one-third of that of the cylinder.

94. The condenser and air-pump are immersed in a cistern of water, called the cold-water cistern. In some engines this is a basin in the ground, lined with masonry, laid in cement. In steam-boats it is omitted altogether, and its want supplied by increasing the size of the condenser. In other engines again, it forms a cast-iron trough or basin, on the sides of which the whole of the apparatus is supported. In the engine represented on Pl. III. this is the case, as will be obvious from the several views in which it is represented, *a a* being this trough. An engine thus supported, and which may therefore be placed upon any solid basis, entirely independent of walls or buildings, is called a portable engine, even when of the largest dimensions.

95. From the cold-water cistern, a pipe passes into the condenser. The use of this is to admit a jet of water, to condense the steam with greater rapidity, by bringing it in contact with a greater surface. The extremity of this pipe is sometimes covered by a nozzle, pierced with holes like that of a watering-pot. The quantity of injection water is regulated by a valve called the Injection-cock, which is to be seen in Fig. 2.

96. As the injection-cock is constantly drawing water from this cistern, and as the water it contains is constantly abstracting heat from the condenser and air-pump, it requires a contant and regular supply, as well to keep it at a proper temperature, as to renew what is actually expended. For this purpose the cold-water pump *y* is provided. It, like the hot-water pump, is a common pump, communicating with a reservoir of fresh water. We have, upon page 116, stated the quantity of water that is needed to keep the water in this cistern at the proper temperature, whence the area may readily be calculated when the length of the stroke is known. The length of the stroke of the cold-water pump, in the engine before us, is the same as that of the air-pump, or half that of the Cylinder.

Hall's condenser, which has recently been introduced, is composed of a series of tubes immersed in the cold water cistern. The condensation is effected by the steam coming in contact with the cold surfaces of the tubes, instead of being caused principally by injected water. The tubes are freed from the condensed steam by an air-pump of the same size and structure as that we have described, and this is of sufficient power to diminish the tension of the remaining vapour below that which is due to the temperature of condensation. The vacuum guage, consequently, which in the common condenser does not rise above 26 inches, has been maintained for days together in Hall's Condenser at 29,5.

In the engines to which Hall's Condenser has hitherto been adapted, steam of a tension little greater than a single atmosphere has been used. The air-pump has, therefore, sufficient power to pump the condensed water directly into the boiler. This it would not be able to do without much expenditure of the force of the engine, were steam of 2 or 3 atmospheres used, as is frequently the case in our American condensing engines. But their ordinary force-pump working in a hot cistern, would answer the purpose. In the use of this condenser the exact quantity of water which has passed through the engine in the form of steam is returned to the boiler at each stroke of the pump, and being obtained by the condensation of vapour, has the purity of distilled water. If, therefore, a boiler be filled at first with pure water, no inconvenience can possibly arise from the accumulation of solid matter. Nay, even sea-water may be used without its becoming more injurious than at first. As there will be a waste arising from the escape of steam through the safety valves, a small distilling apparatus is added to the ordinary boilers; so that no other water than what is obtained by condensation need be admitted into the boiler. It is obvious that this condenser is not only convenient, and capable of adding to the power of a given engine, but must be conducive to the safety of boilers in which there can be no deficiency of water as long as the engine remains in action.

97. The theory and use of the Parallel Motion, 1, 2, 3, 4, has already been explained—see pages 116, 117. The rule for one of its most usual forms is as follows, viz: The parallel bar is half the length of one arm of the working beam, or one-fourth of the distance between the two glands. The radius-bar is of the same length with the parallel-bar. The two pairs of straps are, of course, equal in length, and are usually three inches less between their centres than the length of the half stroke of the piston-rod.

The centre, to which the air-pump is attached, is in the inner pair of straps, at the point where a line drawn from the fulcrum of the lever beam, to the upper end of the piston-rod, cuts the inner strap. *See page* 106.

98. The length of the lever-beam, in Watt's engines, is usually one and a half times the length of the stroke of the piston-rod. The beam is usually cast in one piece. The centres of the parallel motion, pump rods, and connecting rod are turned out of rods of steel, and passed through the beam. In many modern engines the lever beam is a trussed frame of cast-iron, bound by a band of wrought-iron, and this is a most important improvement in the structure of the engine.

99. The air-pump rod *u* being attached to the inner pair of straps, is at a distance, from the centre of motion of the lever-baem, of one-fourth of the length of the latter.

The rod of the cold-water pump is attached to the lever-beam, at an equal distance from the fulcrum on the opposite side.

The rod of the hot-water pump is at a distance, from the fulcrum, of one-sixth of the length of the working-beam.

The length of the connecting rod between the centres, in Watt's engines, is twice the length of the stroke of the piston. In most American engines it is three times that length; and less is lost by obliquity of action in the latter case.

100. The arm of the crank z, is half the length of the stroke of the piston in all cases where the arms of the lever-beam are of equal length.

101. The radius of the Fly-Wheel may be various, according to the uses to which it is applied; the motion for driving machinery ought to be taken off at a distance from its centre, equal to that of its centre of gyration. *See page* 7. In the engine on Pl. III., the fly-wheel has a radius equal to twice the whole length of the cylinder. The weight is calculated by the following rule:

Multiply the number of horse's powers of the engine by 2000, *and divide by the square of the velocity of the circumference of the wheel per second, the quotient is the weight in* cwts.

The velocity of the circumference is readily found when the radius is given, for the crank has a velocity as much greater than that of the piston-rod as the circumference of a circle is greater than its diameter; and the circumference of the fly-wheel has a velocity as much greater than the crank as the radius of the former is greater than that of the latter.

In the first form of Watt's engines, the valves were opened and shut by apparatus of the same description with that which had been used in the more ancient forms. Tappets were attached to the rod of the air-pump, which, during the ascent and descent of the rod, acted upon levers with counterpoising weights. These levers were thus made to give a reciprocating motion to toothed segments, that acted upon racks attached to the valves, and thus opened and shut them. We shall return to this manner of working valves in the history of the engine.

When conical valves are used, a spindle is attached to each, and the nozzles are immediately beneath each other. Thus the two spindles of each pair of valves are in the same vertical line; the upper spindle in each pair is hollow, and the spindle of the lower valve passes through it. The weight of the valves is usually sufficient to close them, and keep them shut; if not, they are loaded until they shut themselves. In order to open them, the following arrangement is employed:—The spindles of the two valves, that are to act simultaneously, as, for instance, the steam valve of the upper pair and the condensing valve of the lower, are united by lifting rods, which have consequently the forms of three sides of a rectangle. These rods are pressed upwards at a particular part of the motion of the engine by pieces projecting from a horizontal shaft that has an oscillating motion. These projecting pieces or arms lie in the same plane, and on opposite sides of the shaft; so that when one of them acts upon the rod that moves one pair of valves, and presses them upwards, the other ceases to act, and permits the other two to fall into their seats by their own weight. The return of this oscillating shaft permits the first pair of valves to shut, and causes the other piece, or cam, to act upon the two that were before shut.

102. This oscillating shaft is called the Tumbling Shaft. It receives its motion by means of a small crank that is attached to it, and moves upon it as an axis. This crank is connected with the axle of the fly-wheel by an apparatus called the Eccentric. This is represented in Figs. 1 and 2, on Pl. III., and is shown separately in Fig. 4.

A circular plate *b* has an opening of a circular shape cast in it, but having an eccentric position in respect to it. This last circle just fits the shaft of the fly-wheel, and is wedged firmly to it, so that the latter carries the circular plate *b* around with it in its revolutions.

To the circular plate is fitted a circular ring *c*, within which it can turn, and which, therefore, need not receive any motion from it, but what arises from the eccentricity of the revolution of the plate. To this ring are attached two bars *d*, *e*, forming the sides of an isosceles triangle. These are united by frame-work. These bars terminate in a single piece, in the direction of a perpendicular to the base of a triangle, and which has a handle *f* turned upon its extremity. The use of this handle is to lift the eccentric from its place, when it is wished to stop the engine, and return it again, when the engine is to be set in motion. A notch of a semicircular figure is cut in the eccentric, which drops upon a pivot, turned upon the crank of the tumling shaft *g*.

It will be obvious, that while the axis of the fly-wheel is carried around, and with it the circular plate, the end of the triangular frame will have an oscillating motion communicated to it, which the free motion of the ring *c*, will allow to be converted into a reciprocating circular motion in the crank of the tumbling shaft; it will thus give the latter a motion suited to the opening of the valves, by means of the two arms that have been described.

The engine upon the plate (Pl. III.) has, as has been described, a slide valve. This is set in motion in a manner different from the puppet valves.

An arm, *h*, projects from each end of the tumbling shaft, and both are in one plane at right angles to its crank, *g*, *f*. To these arms are attached two light lifting rods, that rise above the side-pipe where they are united by a cross head. To the middle of this is attached the rod that moves the slide, and thus the latter is both raised and depressed by the action of the eccentric, while as we have seen, the puppet valves are raised only, and return to their seats by their own weight.

103. When an engine is used for purposes that occasionally require its motion to be reversed, two eccentrics may be employed, that adapt themselves to cranks situated at the opposite ends of tumbling-shaft, in planes at right angles to each other. Only one of these eccentrics is used at a time; when it is necessary to reverse the motion of the engine, the piston is stopped at

half-stroke, or in the position represented in Figs. 1 and 2, on Pl. III. The eccentrics are then exchanged; that before in use being raised, and the notch of the other dropped upon its crank. When the steam again flows, the piston will return in a direction opposite to that in which it was proceeding when stopped. Another method that has been used in some English steam-boats, consists in cutting two notches opposite to each other in the rod of the eccentric; the rectangular cranks of the tumbling-shaft are at the same end of the shaft; the eccentric lies between them, and may be made to apply itself to either at pleasure. This arrangement has also been so modified as to be placed within the control of the helmsman of a steam-boat. The necessity of communicating with the engineer by conventional signals is thus avoided.

104. It will be obvious that the time at which the valves open and shut may be determined by the position of the eccentric upon the shaft of the fly-wheel. This may be done, by this apparatus, far better than it can be by tappets upon the rod of the air-pump, or, as they are usually called, a plug-frame, This determination is of no small importance to the working of an engine. Should the piston be impelled by the steam to the very end of its stroke, a violent blow will take place between it and the head or bottom of the Cylinder; while, on the other hand, if the steam-valves be opened too soon, a part of it will be expended in diminishing the action of the steam on the opposite side of the piston. In both cases power will be wasted, and the lost power will be exerted to injure the apparatus. In putting up an engine, the position of the eccentric is determined by actual trial, and the eccentric is left in the position where it is found to tend most to the equable and regular working of the engine.

105. A band passing over a drum on the axis of the fly-wheel turns a second drum, which is upon the axis of a bevel wheel. This bevel wheel gives a motion to another, that carries upon its axis the Governor. This arrangement is represented upon the plate, but could not be distinguished by letters.

This governor, as has been stated, is a conical pendulum. The weights revolve in the same plane, which is raised by their centrifugal force when the velocity increases, and falls as the velocity of rotation diminishes. The theory of this instrument shows that its revolutions are half the number that would be performed by a pendulum, the length of which is equal to the distance of the plane in which the centres of the balls revolve, from the point where the bars, by which they are suspended, cross each other. Thus, then, if the least and greatest number of the revolutions that it is intended that the fly-wheel shall perform, in a given time, be known, it will be easy to calculate the length of the conical pendulum.

106. The rods that bear the balls of the governor are united by pivots to two others, also connected by pivots, and sliding at their point of union upon the axis of the governor. The parallelogram that is thus formed, is sometimes above the joint whence the balls hang, as in the horizontal engine on *Plate VI*, and sometimes below it, as in the high pressure engine on *Plate V*, or the separate figure of the governor on *Plate IV*, *Fig.* 2. In either case it gives motion to a lever, which acts at its opposite end upon a rod that moves the handle or lever of the throttle valve. This system of levers is so arranged that the throttle valve is opened to its utmost limit, when the balls of the governor are in their lowest position, and is wholly closed, when they have been thrown out to their greatest extent by the centrifugal force. In the first case, therefore, all the steam that is generated, flows to the engine; in the last, it is wholly cut off.

107. The form of double-acting condensing engine which we have thus described, is that which is most commonly used in manufactures, particularly in Europe. It cannot, however, fail to have been remarked that it contains, at least, one part by no means necessary to its action: this is, the lever beam. The engine, as we shall see hereafter, was originally applied to the single action of pumping water, and in this the pump-rod, or brake, was conceived to be essential; this, when made with

equal arms, became the lever beam. Successive advances towards perfection in the structure were made, as improvements on the original plan, and not as original inventions. It has thus happened that an unnecessary and cumbrous part of the apparatus has been perpetuated. A far more simple form of the engine, and which is in many cases preferable, is that which was used by Fulton in his steam-boats, and of which one is represented on *Plate VII.* It will be at once seen by inspection, that in this engine the beam is suppressed, together with the parallel motion. As a substitute for these parts, a cross-head A is adapted to the upper extremity of the piston-rod, B; this works between vertical guides, *a*, *a*; it is connected to the two cranks, *c*, *c*, by the two connecting rods, *b b*, *b b*, and to these is joined, in the case before us, the axis of the water wheels, D D; the axis of the fly-wheel might in like manner be turned by these cranks, were it intended to apply the engine to general purposes.

The pumps are worked by a beam, E E, far lighter than it need be in the other form of the engine, and but half the length. It is forked at the end nearest the cylinder, which it thus embraces, and is connected with the cross-head A of the piston-rod B, by the connecting rods, *d d*.

The peculiarities in this engine, which adapt it to a steam-boat, will be described in another place.

108. When a steam-engine is to be set in motion, the boiler must first be filled with water by hand, the fire lighted, and the steam raised to the proper tension. The steam and side-pipes, the Cylinder, condenser, and air-pump, will be full of air, and the whole will be cold. The air must be extracted, and the engine heated up to the temperature corresponding to the tension of the steam, before it can be set to work. This is done by what is technically called blowing through the engine. All the valves are opened simultaneously by hand, and steam is thus introduced to all the parts. As steam is lighter than air, it will force the air from the cylinder towards the condenser. Hence the air is sometimes allowed to escape by a valve contrived for the purpose; this is usually adapted to the con-

denser, by means of a pipe forming an elbow, and bent vertically upwards. This pipe is closed by a conical valve opening upwards. So long as air remains in the condenser, and is compressd by the steam from above, it is capable of making its way through this valve. The completion of the operation is shown by its being followed by steam, which, when this valve is situated beneath the level of the water in the cold water cistern, is known by a slight crackling noise. It is, however, more usual in this country to suppress the valve on the side of the condenser, or *snifting-valve ;* in this case the air makes its way through the air-pump, and is discharged at the clack-valve. When the steam thus shows itself, the injection cock is opened, a condensation of the steam in the condenser takes place almost instantly, and the pressure of the steam from the boiler becomes in a short time sufficient to put the engine in motion. The eccentric is now applied to the crank of the tumbling shaft, and the engine becomes self-acting.

In engines with slide valves, a simultaneous communication cannot be made between the boiler and the two sides of the piston. An additional valve is therefore provided, making a communication between the lower end of the side pipe and the boiler. This is called the Blow-valve. It is opened by hand, and closed as soon as the engine is ready to work. This valve is to be seen on Pl. III.

To set a large engine in action has hitherto been a very laborious operation, whether the slide or puppet valve be used. This difficulty was noticed by Trevithick, who contrived a double-seated valve, which required much less labour to work it. The most perfect construction of this kind is that brought into use by Mr. Adam Hall of New-York. In this the valves are so nicely balanced that a single man is able to blow through the most powerful engine.

CHAPTER VI.

GENERAL VIEW OF CONDENSING ENGINES ACTING EXPANSIVELY, OF HIGH-PRESSURE, SINGLE-ACTING, AND ATMOSPHERIC ENGINES, PARTICULAR DESCRIPTION OF HIGH PRESSURE ENGINES.

Regulation of steam by the valves of Condensing Engines. —Expansive force of steam, supposing the temperature to remain constant.—Expansive force of steam of a given tension, and in a given engine, on the same hypothesis.—Expansive action of steam of a given tension and constant temperature, when the friction and resistance is taken into view.—Expansive action at increasing tensions, and with temperatures varying according to the law of specific heat. —Effects of steam acting expansively, as usually employed.—Action of high pressure steam when not condensed.—Cases in which high pressure engines are useful.—Reconsideration of the precautions to be used in boilers generating high steam.—General view of the high pressure engine, its steam pipes, side pipes, and valves.—Calculation of the power of high pressure engines, their working beam, parallel motion, throttle-valve, governor, and forcing pump. —General view of the single-acting condensing atmospheric engines.—Particular description of a high pressure engine, with a beam, and of long and short slide valves.—Particular description of a horizontal high pressure engine.—Description of a rotary engine.

109. To set the Double Condensing Engine into motion, two of its valves must be opened. One of these admits steam

from the boiler, to act upon one side of the piston, while the other lets the steam from the opposite side pass into the condenser. These two valves are united so as to open and shut together, as are the two which, alternating with them, give motion to the piston in the opposite direction. These valves require a certain space of time to open to their full extent, and thus the motion of the piston in the first instance, and the change at each successive alternation, are effected gradually. So also the valves are permitted to close before the engine has reached the limits of its stroke, and thus the shock the engine would sustain, and the consequent loss of power, are in some measure obviated.

This may, obviously, be effected still more certainly, by cutting off the steam at an earlier period of the motion of the piston, while the communication with the condenser is still left open.

110. When the steam is cut off, it does not lose its whole power, nor does it lessen suddenly in force; for, being elastic, and acting against a partial vacuum in the condenser, it will expand, until it either fill the Cylinder, or until the friction and the resistance of the partial vacuum in the condenser, become equivalent to its own expansive force. Watt, to whom we owe the double-condensing engine, was the first to remark that advantage might be taken of this to increase the effect of a given quantity of steam. Thus, if the Cylinder be but partially filled, and the steam then cut off, it will still act expansively, and all the force that it continues to exert is so much gained. Were the decrease of the temperature, arising from the change in the relation of the steam to specific heat, left out of view, the force of the expanding steam would decrease in a geometric progression, and might be calculated by means of tables of hyperbolic logarithms.

Calculated in this way, the power of a given quantity of steam would be increased in the ratios given on next page.

Cylinder filled.	Power of Steam.
Wholly	1.
One-half	1.69
One-third	2.10
One-fourth	2.39
One-fifth	2.61
One-sixth	2.79
One-seventh	2.95
One-eighth	3.08

111. The advantages of using the steam expansively would, therefore, according to this hypothesis, be very remarkable; but to obtain them would require an entire remodelling of the engine and the alteration of its proportions. To use the same quantity of steam, it would be necessary that the steam pipes, the nozzles, and the Cylinder itself, should all be increased in the ratio which the part of the Cylinder filled bears to the whole. If these remain unchanged, the consumption of steam, (supposing the temperature to remain constant,) would be lessened in the same ratio inverted, and the force with which the steam would act upon the piston, would have the following ratio:

Cylinder filled.	Force.	Steam expended.
Wholly	1.00	1
One-half	0.84	$\frac{1}{2}$
One-third	0.70	$\frac{1}{3}$
One-fourth	0.57	$\frac{1}{4}$
One-fifth	0.52	$\frac{1}{5}$
One-sixth	0.46	$\frac{1}{6}$
One-seventh	0.42	$\frac{1}{7}$
One-eighth	0.39	$\frac{1}{8}$

These calculations are, as has been stated, made upon the hypothesis, that the temperature continues invariable, which is far from being the case; for steam, like all other substances, has its capacity for specific heat increased during its expansion, and its temperature and consequent elasticity are diminished.

112. It must next be taken into view, that the absolute power of the steam is not all exerted; for steam, as has been seen, acting with an expansive force of 17½ lbs. per square inch, is only capable of overcoming a resistance equivalent to 10lbs. Hence, in an engine working at low pressure, the advantage gained by making it act expansively, would cease if the steam were cut off earlier than that at half the stroke, for at $\frac{58}{100}$ the resistances would be equal to the expansive force, even if the temperature remained constant, which, as we have seen, it does not. The motion might, indeed, be kept up for a time by the flywheel; but even then, without taking into view the irregularities that would ensue, the effective action would diminish most rapidly, as will appear from the following calculated results:

Cylinder filled with steam of 17 1-2lbs.	Mean effective Force.
Wholly	1.00
One-half	0.72
One-third	0.48
One-fourth	0.26
One-fifth	0.17
One-sixth	0.06
One-seventh	0.00

We therefore conceive ourselves warranted in the conclusion, that when an engine acts expansively, the steam should never be permitted to expand itself to more than twice the bulk it occupies under the atmospheric pressure.

Working at low pressure, in order to produce an equal effect, the engine should be nearly one-half larger in its capacity, and the expense of fuel would be three-fourths of what it would be if the steam were employed in the usual manner. Unless, therefore, in cases where fuel is extremely scarce, there is probably no real advantage to be gained in making low pressure steam act expansively.

113. There is another point of view in which the expansive action of steam may be investigated, for the steam may be used at an increased pressure. If it have an expansive force of an

atmosphere and a half, it would, if cut off at one-third of the stroke, expand, in filling the Cylinder, to the assumed limit of pressure, of half an atmosphere. The original effective force, after allowing for resistance, would be 15lbs. per square inch, and the mean action would be two-thirds of that amount, or 10lbs. per inch during the whole stroke. Hence the engine would now work up to its nominal power.

Steam, under a pressure of $1\frac{1}{2}$ atmospheres, has, if we leave out of view the temperature, a density one and a half times as great as under atmospheric pressure simply; hence, to fill one-third of the Cylinder would require the evaporation of as much water as would fill half the cylinder with steam of 212°. An engine, therefore, acting expansively with steam of the elasticity of $1\frac{1}{2}$ atmospheres, would, on this hypothesis, do the same work as when acting in the common manner, and consume but half the quantity of fuel. For, as the sum of the latent and sensible heat is the same, both in high and low steam, the quantity of water converted into steam is the same, whatever be its temperature.

Let us next suppose the steam to have an elastic force equal to two atmospheres. It might, on the same hypothesis, expand to four times its original bulk before its elasticity became less than half an atmosphere. Hence it might be cut off at one-fourth of the stroke.

Its original effective force, after deducting the constant resistance, will be $22\frac{1}{2}$ lbs. per square inch, and it will act with a mean force of $\frac{57}{100}$ of that amount, or upwards of $12\frac{1}{2}$lbs. Hence the engine will, under such circumstances, work with one-fourth more than the power at which it would be estimated according to the common rule.

The steam would in this case also fill half the cylinder before it reached the density of steam of 212°, and hence the quantity of water used, and fuel expended, would be the same as in the former. And, in all cases where the limit of the expansion of the steam is an elasticity equal to half an atmosphere, the quantity of water evaporated and fuel expended would be constant. But the effective power would go on increasing with the elasticity of the steam, according to the following table:

Relative power of the same engine acting in the ordinary manner, or expansively. The temperature being supposed not to vary on expansion.

Steam in Atmospheres.	Cylinder filled.	Fuel Expended.	Effective Force.
$1\frac{1}{6}$	wholly	1	10
$1\frac{1}{2}$	$\frac{1}{3}$	0.5	10
2	$\frac{1}{4}$	0.5	$12\frac{1}{2}$
$2\frac{1}{2}$	$\frac{1}{5}$	0.5	$15\frac{1}{2}$
3	$\frac{1}{6}$	0.5	18
$3\frac{1}{2}$	$\frac{1}{7}$	0.5	19
4	$\frac{1}{8}$	0.5	20

114. In order to cut off the steam, a valve of the figure of a throttle valve is placed in the steam pipe. A weight, or strong spring closes it and keeps it shut, except when the one is lifted, or the other forced back, by the action of the engine. This is usually performed by placing two teeth or cams, of proper form and size, upon the axis of the crank. A plan of this kind may be seen on *Pl. IV. Fig.* 4. where *c* is the axis of the crank, *a* and *b* two cams, or teeth, that act upon the spring *g d*, which is connected with the handle *c f* of the expansion valve, by the rod *d e*. *F* is a portion of the steam pipe.

A very ingenious and simple mode of working a cut-off valve has been invented by Perkins, and applied to his expensive engine. He places an additional eccentric upon the shaft of his fly-wheel, to this is attached a jointed rod directed by guides. The end of this rod acts upon the lever of the valve, and by the adjustment of the length of the rod it may be made to act for a longer or shorter time. When the rod ceases to press the valve, a strong spring applied to it causes it to close.

An addition has been made to the short slide valve, by which the steam may be cut off at any part of the stroke of the engine.

A valve of the usual form is surrounded by a frame composed of two plates, each of sufficient surface to cover the steam passages. These plates are united by bars, which are pressed down by two strong springs.

The eccentric is made to act upon a rod passing through a collar in an axle. To this collar it is adjusted by a screw in such a manner that the two arms of the rod may be made at pleasure to have different relations to each other. The space through which the eccentric moves one end of the rod being constant, the opposite end may be made to pass through different spaces according to the position of the point in the rod, which is made by the screw the axis of motion. It will therefore be easily seen that the valve may in its motion be either made to strike the frame or not, at pleasure. In the latter case the steam will not be cut off, and by varying the motion in the former case, it may be cut off at any required point in the motion of the piston.

115. The estimate that has been given of the powers of steam acting expansively, is, as has been seen, formed upon the hypothesis that it expands to bulks that are inversely as the pressures. This is not the case, in consequence of the change of temperature that the very act of expansion produces. Thus, the steam of a tension equivalent to half an atmosphere, has a temperature of 180° and a density of 0.00032; while, with a tension of 2, 3, and 4 atmospheres, it has the following densities:

2 Atmospheres	- - - - -	0,00111
3 do.	- - - - -	0.00160
4 do.	- - - - -	0.00210
Steam of		
2 Amospheres	expanding to 4 times its bulk, has a density of - - -	0.00028
3 do.	to 6 times its bulk, - -	0.00027
4 do.	to 8 times its bulk, - -	0.00026

In a vessel which would neither give nor abstract heat, the tension and temperatures would be diminished, in the three several cases, in the ratios of $\frac{32}{28}$ or $\frac{8}{7}$, $\frac{32}{27}$, and $\frac{32}{26}$ or $\frac{16}{13}$. But in an expansive engine, the cylinder may be readily kept up to the temperature of the steam before it begins to expand, and the steam in expanding will derive heat from it. The method, which is occasionlly adopted in a low pressure engine, of enclosing the cylinder in an outer case, called a jacket, will be far more beneficial in an engine acting expansively, and the diminution in tension, arising from diminished density, will be counteracted by increased heat. This, however, will be attended with a loss of heat in the surrounding steam, and will require the capacity of the boiler to be increased in proportion. It is, therefore, to be taken into view, that the comparison of engines acting expansively, as given on page 154, is not absolutely true; but that, in order to make it so, the fire surface of the boiler should be increased $\frac{1}{8}$th at the pressure of two atmospheres, and $\frac{1}{5}$th at the pressure of four, and the safety valve loaded with additional weight in the same proportion. The expenditure of fuel will also be increased in the same degree. The advantages derived from making engines act expansively are still great, notwithstanding this increase in the expenditure of fuel; for an engine receiving steam of the tension of 4.$\frac{4}{5}$ atmospheres, cut off at $\frac{1}{8}$th of the stroke, will do twice as much work as one receiving low steam, with but six-tenths of the fuel it expends. If we correct our previous calculations upon these principles, the results will be as follows, which will give the actual effect which may be produced by the same engine, acting at low pressure or expansively, with different loads on the safety valve.

Relative powers of the same engine acting at low pressure or expansively, the change in the relations of the expanding steam to temperature being taken into account.

Load on the Safety Valve.	Cylinder filled.	Fuel Expended.	Effective Force.
3lbs.	wholly	1	10
10lbs.	$\frac{1}{3}$	0.55	10
19lbs.	$\frac{1}{4}$	0.56	12$\frac{1}{2}$
27lbs.	$\frac{1}{5}$	0.57	15$\frac{1}{2}$
36lbs.	$\frac{1}{6}$	0.58	18
46lbs.	$\frac{1}{7}$	0.59	19
57lbs.	$\frac{1}{8}$	0.60	20

This table is, however, far from exhibiting the whole advantage of which the method of cutting off the steam before it has filled the cylinder is capable. It will be easily seen that our calculations would be only adapted to the case of a diminution in the fire surface of the boiler, and that in practice a different course would be pursued;—the same quantity of water would still continue to be evaporated, and the same amount of fuel expended, unless the whole system were changed. Let us then suppose that with a given engine and boiler, the steam is cut off at different portions of the stroke. If cut off at half stroke, the density of the steam will be doubled; and if at one third, tripled, and so on. The tension of the steam will be increased even in a higher ratio, for steam of two atmospheres has a density of no more than 0.00110, while twice the density of steam of the tension of a single atmosphere is 0.00118. The usual pressure in the condensing engine also exceeds an atmosphere by one-sixth, and the tension obtained by cutting off will be a multiple of this instead of one of a single atmosphere. We shall, however, neglect this in our view of the comparative effects of an engine working expansively, with steam of different tensions.

Relative powers of an engine using the same quantity of fuel, and acting expansively at different tensions.

Force in Atmospheres.	Cylinder filled.	Effective force.
$1\frac{1}{6}$	wholly	10
2	$\frac{1}{2}$	10.75
3	$\frac{1}{3}$	27.5
4	$\frac{1}{4}$	35.6
5	$\frac{1}{5}$	43.5
6	$\frac{1}{6}$	51.

It will therefore appear that, without any change in the general distribution and plan of an engine, provided the boiler be strong enough to bear the increased force of the steam, its power may be readily increased five-fold. This will be done without using steam of a temperature higher than is frequently employed in engines of a different structure.

It is more usual to cut off the steam at half stroke, and to depend, for an increase of force, upon an increased capacity of the boiler to generate steam. This method is, however, disadvantageous, as it will require an alteration in the boiler, other than an increase of its strength; and will, besides, demand a more powerful apparatus, and larger supply of cold water for keeping up the vacuum of the condenser. Nor does it give results near as satisfactory as the mode to which we have just referred, if the expenditure of fuel be taken into account, as will be perceived from the following table:

Relative force of steam used expansively in a cylinder of constant dimensions, and always cut off at half-stroke.

Force in atmospheres.	Fuel expended.	Effective force.	Force with the same fuel.
2	1	18.75	18.75
3	$1\frac{1}{2}$	32	21.67
4	2	45	22.5
5	$2\frac{1}{2}$	58	23
6	3	72	24

116. It may therefore be inferred, that the best mode of using the double acting condensing-engine, is to make it of the usual form and dimensions, and give it a boiler of sufficient strength, with a fire surface of the usual extent; but to cut off the steam at as early a period of the stroke as may be considered safe. This method has been brought to the test of actual experiment in the pumping engines employed in the mines of Cornwall, and by its use, the power of an engine of a certain nominal horse power has been increased five-fold.

The method of cutting off at half-stroke has been more especially used in the steam-boats of this country, and the tension of the steam has been raised by increasing the fire surface of the boiler. The last object has been effected by a variety of artifices. It may, however, be fairly inferred, that the method of cutting off at such part of the stroke as corresponds to the desired increase in the tension of the steam is much preferable.

High as our estimate of the advantages of using steam expansively may appear, it is, notwithstanding, far less than those of

Watt and Woolf. The former hazarded the opinion that steam of 4lbs. was capable of expanding itself to 4 times its bulk, and still retaining the tension of an atmosphere. Woolf seized this expression as the basis of his calculations, and inferred that steam of 5, 6, 7, 8, &c. lbs, was capable of expanding as many times as the unit of measure of the safety valve was loaded with pounds. These views are wholly erroneous, and are contrary to the physical and mechanical properties of steam.

Our own reduced estimates are more to be relied upon, and offer sufficient inducements for the employ of the expansive action of steam.

Our calculations in respect to the increase of power gained by expansive action have reference, as will be at once seen, to a constant velocity in the working point of the engine. It may, however, happen that the resistance is constant, or increases with the velocity only; and that the increase in the power arising from expansive action, is applied to an increase in the velocity. Analogous advantages will be gained in this case, which is that of steam navigation.

116 *b*. It will easily be seen, from what has been stated in relation to the expansive action of steam in the condensing engine, and from what we shall in relation to the increase obtained in the force by using steam of great elastic force in the high pressure engine, that a given engine may be made to work far beyond its nominal power. The horse power is, in either case, estimated from the area of the piston, the height and velocity of its stroke, and the pressure taken at the amount which has hitherto been most frequently used. Thus, in the condensing engine, the pressure is usually estimated, after the resistances are allowed for, at 10lbs. per square inch; and in high pressure engines, at 40lbs.

In the former engines, by increasing the tension of the steam in the boiler, and cutting it off in such a manner as to allow it to act by its expansive force, we have seen that the force given by the combustion of a given quantity of fuel, may be increased more than three-fold, and the action of a given engine doubled. A still greater effect may be produced, by using steam of higher tension than such as, in its expansion, will diminish to the limit we have assumed in Chap. VI. In addition, then, to the estimate in horse powers, which has now become of no other use than a mode of describing the size of an engine, in contracts between the maker and purchaser, it has become customary to compare the work of engines with each other, by a mode of estimate which is called their *Duty*. The mode in which the duty of a steam engine is estimated is in the numbers of pounds which can be raised 1 foot high by the combustion of a single bushel of coals. We have seen that this quantity of coal is capable of evaporating 12 cubic feet of water, and therefore of keeping an engine of twelve horse power in action for an hour. It ought, therefore, according to the estimate we have just made, raise to a height of 1 foot

$$24000 \times 60 \times 12 = 17{,}280000 \text{lbs.}$$

or upwards of seventeen millions of pounds. Watt and Boulton constructed an engine, whose duty reached as high as 19 millions; and it was said that their own engine at Soho, did work equivalent to a duty of 21,600000lbs.; but, on an examination, in legal form, of all the engines they had put up in Cornwall, two years before the expiration of their patent, it was found that the average duty was no more than 17 millions, or in strict conformity with our estimate. Many of these engines acted expansively; and one performed a duty of 27 millions, in spite of which the average fell to the limit we have stated. The expiration of Watts' patent left engineers free to make such improvments as experience or science might suggest. The expansive action of steam was the improvement which was principally relied upon; and, in order to obtain from it the greatest practicable advantage, for the old boilers of Watt, such as are figured on Pl. I. were gradually substituted cylindric boilers capable of bearing steam of great tension. In this way the force of the steam has been gradually raised from little more than a single atmosphere to 10, and an intelligent Cornish engineer states that he has seen it raised as high as 20 or 30 atmospheres. In this way the average duty has been regularly on the increase, being in 1833, 19½ millions; in 1814, 20½ millions; in 1815, the same; in 1816, nearly 23 millions; in 1817, 26½ millions; in 1818, 25½ millions; in 1819, 26¼ millions; in 1820, 28¾ millions; in 1825, 32 millions; in 1828, 37 millions; in 1829 41 millions; in 1830, $43\frac{1}{3}$ millions. During this time, single engines have performed far more than the average, and in the year 1835, one has reached a duty of 94 millions.

117. When steam of high pressure is used to propel engines, it is frequently made to act without the aid of a condenser, and consequently in opposition to the whole pressure of an atmosphere.

The engine, in this case, becomes much more simple, inasmuch as the condenser and air-pump may be dispensed with, as well as the cold and hot water pumps; but for the latter is substituted a forcing pump to feed the boiler, and in most cases a common pump will be needed, to raise the supply. The cold water cistern, and the water for condensation are no longer necessary, and thus a very great weight may be saved, which in some cases is of great importance.

In estimating the resistances which the action of the steam meets with, it is to be considered, that the imperfection of the vacuum of a condensing engine merges in the pressure of the atmosphere, in one where the steam is not condensed; and that thus the resistances, which, in the former, were estimated at $7\frac{1}{2}$lbs. per square inch, may be diminished, as well as by the power required to work the air and cold-water pumps. The resistances, other than the pressure of the atmosphere, need not therefore be taken at more than 5lbs. per square inch, which, added to the pressure of the atmosphere, makes a constant resistance to the action of the steam, in a high pressure engine of 20lbs. per square inch. Hence, steam of an expansive force of two atmospheres will work in a given cylinder with the same force that steam of $17\frac{1}{2}$lbs. would work in a condensing engine. But steam under a pressure of two atmospheres has rather less than two-thirds of the density of steam of $17\frac{1}{2}$lbs. per inch; and hence it would require more than $1\frac{1}{2}$ times as much water to be evaporated in order to fill the cylinder, and $1\frac{1}{2}$ times as much fuel. In this case, therefore, there would be a loss of 50 per cent. in using a high pressure engine.

If the steam had a pressure of $2\frac{1}{2}$ atmospheres, its effective force would be $17\frac{1}{2}$lbs. per square inch, or would bear, to that in a low pressure condensing engine, the ratio of 7 to 4. But, to fill the Cylinder with steam of corresponding density, would require nearly twice as much fuel.

At a pressure of three atmospheres the effective power of the steam becomes 25lbs. per square inch, or bears to that of a low pressure engine the ratio of 5 : 2. To fill the cylinder with steam of this density, requires fuel in about the same ratio; and hence, at this limit, the power of high and low pressure engines, consuming the same quantity of fuel, becomes nearly equal.

With four atmospheres of steam, the effective pressure becomes 40lbs., the consumption of fuel is about three to one; and here the high pressure engine has an advantage in the ratio of four to three.

At five atmospheres, the effective pressure is 55lbs. per inch, the ratio of water evaporated or fuel consumed as $3\frac{3}{4}$ths to 1. Arranging these and similar calculations in a table, we have as follows:

Effect of High Pressure Steam to work Engines.

Pressure in Atmospheres.	Fuel in the same Engine.	Force in the same Engine.	Force with the same Fuel.
2	$1\frac{1}{2}$	1	0.75
$2\frac{1}{2}$	2	1.75	0.875
3	$2\frac{1}{2}$	2.5	1.000
4	3	4	1.333
5	$3\frac{3}{4}$	5.5	1.46
6	$4\frac{1}{2}$	7	1.55
10	7	13	1.86
20	14	28	2.00
30	20	43	2.15
40	26	58	2.23

118. It thus appears that the useful effect of high pressure engines increases far more slowly than the increase of the elastic force of the steam. This arises from the fact, that the density of steam increases nearly as fast as the pressure under which it

is generated. Did both increase in the same ratio, there would be nothing gained by the use of high steam. A high pressure engine is, therefore, far inferior in power to one in which the steam acts expansively, and is subsequently condensed; as will appear from a comparison of the preceding table with that on page 154.

There are, however, cases in which the high pressure engine is preferable to any other. Thus, when water is scarce, the high pressure engine dispenses with the use of that employed in condensing the steam, which, as we have seen, is 22 times as great as that which is evaporated from the boiler. The weight of the air-pump and condenser, of the cold and hot water cisterns, as well as of the water they contain, are all saved. Hence, where locomotion is important, as where steam is employed to propel carriages upon railways, high pressure engines can alone be used. These engines are also much simpler in their construction, being composed of fewer parts; and they occupy far less room than condensing engines, whether the latter act expansively or not.

Advantages similar to those obtained in the condensing engine may be obtained by permitting the steam to act expansively in the high pressure engine. The obstacle to be surmounted in this case, is the danger which may be feared, from increasing the tension of the steam to so a high degree as would be necessary to obtain important results.

119. Whether an engine be constructed to receive the most important advantages from the expansion of the steam, or be a simple high pressure engine, in which the steam, after it has caused the piston to perform its motion, is permitted to escape into the open air, the boiler must be so constructed as to contain and generate steam of high elastic force. Common high pressure engines work usually with steam of from five to six atmospheres, and there is no doubt that expansive engines might be constructed in such a manner as to be worked advantageously with a little less than five atmospheres. The load of the safety valve is at this latter limit 57lbs., while to contain steam of six atmospheres, requires a load of 75lbs. per square

inch. It remains to inquire, how far it may be consistent with safety to employ steam of such expansive force? The principles on which the strength of boilers depends, have been fully illustrated in Chapter III. From what has there been stated, it will appear that the cylinder is the best form for boilers, and that a boiler of this shape, and of small diameter, may be made to resist the regular pressure of far more than six atmospheres; that by diminishing the diameter of the cylinder the strength is increased in the inverse ratio of the squares of the diameters; and that by a reduction in this dimension, any required strength may be obtained. The application of the Hydrostatic press furnishes a proof, in the first instance, of the cohesive force of the material and the joints, to resist any given pressure; and the proof may be finally completed by subjecting the boiler to the action of steam of more elastic force than it is ever likely to be compelled to bear in practice. The steam-guage will enable the engineer to know that the pressure is kept below the desired limit, and the safety valve opens as soon as that limit is reached. In case of a deficiency in the supply of water, or obstruction in the feeding apparatus, a thermometer will show the increased heat that is the consequence, and plates of fusible metal will melt as soon as a safe limit of heat is passed. A self-acting feeding apparatus will generally furnish a regular supply, for the failure of which the last-mentioned apparatus affords a safeguard. Registers and dampers will allow the fire to be moderated, and almost extinguished, whenever it becomes necessary. Next, the tendency of solid matter to collect and be deposited on the bottom of the boiler, may be lessened by mixing vegetable feculæ with the water; but careful cleansing will be required, at proper intervals, to obviate all danger from this cause. If an engine must be in constant operation, it ought never to have less than two boilers, one of which can be employed while the other is under repair; and in all cases of constant employment, there should be one boiler more than is necessary to supply the engine. If the work be of such a nature, that the persons employed about the engine may have a temptation to increase the force of the steam beyond the proper degree, there should be two safety valves, one of which should be beyond their control.

No one of these precautions should be omitted when high steam is used, unless they are impossible from circumstances. In locomotive engines, and in steam-boats, spare boilers cannot be introduced; the necessity for them, may, however, be done away, by prescribing stated periods of inactivity, when the boilers may be cleansed.

With proper precautions, we do not hesitate to say that boilers in which steam is generated of no greater tension than is necessary for giving the condensing engine its full power by expansive action, may be rendered as little liable to accident as low pressure boilers; and, indeed, the more common cause of explosion, namely, the exposure of the metallic flues, or the sides of boilers, to the fire, when not covered with water, is as likely to affect low pressure boilers as high. Of the two fatal explosions that have occurred in the harbour of New-York, one was a copper boiler containing low, the other an iron one containing high steam. But although, with proper precautions, high pressure boilers may be rendered as little liable to burst as those planned for generating low steam; the explosions of the former, when they do take place, are more likely to produce dangerous consequences than the latter. We have ourselves been in two instances in steam-boats when low pressure boilers have given way, and the fact was only known by the stopping of the engine. This will always be the case when they give way under the ordinary pressure of the steam, for, supposing the safety valve to be loaded with 3lbs. per inch, the escape of no more than a fifth part of the steam will restore the equilibrium between the outer and inner sides of the boiler. Even if the boiler burst at the limit of its proof, the quantity of steam that can escape is little more than the half of that it contains in it.

In boilers containing steam of four or five atmospheres, a rent will allow the steam to expand itself to four or five times its original bulk, even when it takes place under ordinary circumstances; while if it occur at the limit of the proof, in consequence of the safety valve ceasing to act, the steam may have a tendency to expand itself to ten or twelve times its original bulk, and even in the former case the explosion may be dangerous. In a low pressure engine, then, any dangerous explosion that can occur, grows out of the subsidence of the water below its proper level, and the very weakness of its material is a cause of safety. While in a high pressure boiler, the same risk is incurred, and, in addition, a giving way, even under the usual state of the steam, may sometimes be dangerous.

A boiler, however, that has been properly proved, and is examined at regular stated periods, cannot well burst, except by the clogging of its safety valve, or by the uncovering of its sides and flues. The former accident may be considered as hardly within the limit of possibility, if the guages of the engine are in order, and the engineer attentive to his duty ; and as both species of boiler are equally liable to the latter, we conceive that it may be considered as certain that no more risk is now incurred by using high pressure steam than by using low.

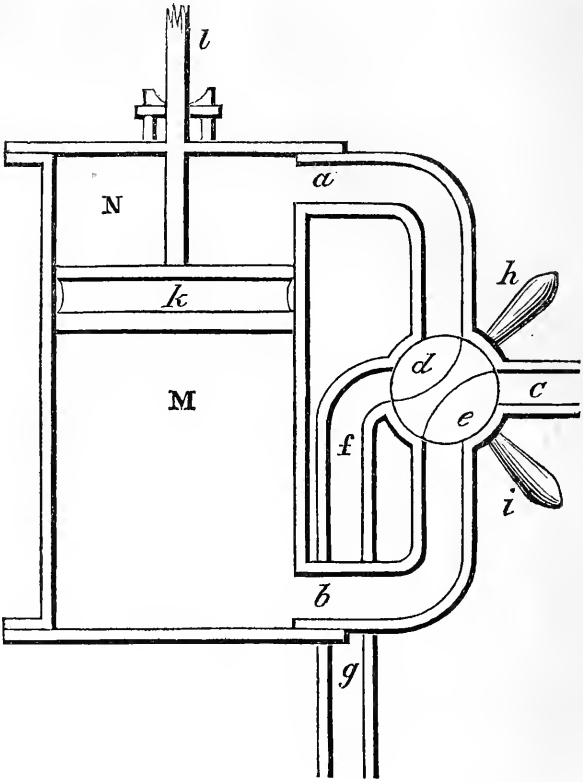
In expressing this opinion, it may be repeated that proper safety apparatus must be applied to the high pressure boiler, and that in steam-boats and locomotive engines there should be an additional safety valve, beyond the control of any person on board the former, or entrusted with the management of the latter. Moreover, the practice which is said to prevail on the Mississippi, of using steam of 10, 15, or even 25 atmospheres, is to be reprobated.

120. Such being our views of the possibility of using high steam with safety, cylindrical boilers, generating high steam, are rapidly superseding all others. They are applied in most cases to condensing engines acting expansively ; but where saving of weight or of room, and even of original cost, is an object ; in locomotive carriages ; in boats navigating shallow rivers ; and wherever water is scarce : high pressure engines will be employed. Being less complex, they will also be preferred wherever good workmen to perform the repairs, or intelligent engineers, are not to be obtained. Upon the land, such boilers should be simple cylinders, having the fire-place and flue beneath them. But in steam-boats and locomotive engines, internal furnaces and flues are indispensable.

121. The parts of a high pressure engine are the following:

A steam-pipe through which the steam passes from the boiler; the area of this is calculated upon the principles laid down on page 89.

Side pipes connected at one extremity with the steam-pipe, and at the other with the open air. In these are situated the valves which admit steam alternately to the opposite sides of the piston, or permit its escape. The original form of the valve was a cock with two passages and four openings, proposed at first by Leupold, and adopted both by Trevithick and Evans. This valve is represented on the next page. *M N* is the cylinder of the engine; *a b* the side-pipe, in the middle of which is a conical socket, to which is adapted a frustum of a cone, with two passages *d e*, and consequently four openings; *c* is the steam pipe, and *f g* the exhaust-pipe, or in a condensing engine the communication with the condenser; *h* is the lever by which the valve is turned through a quadrant at each stroke of the piston; and *i* is the other position of the lever. The steam, in the position of the valve that is represented on the drawing, flows from the pipe *c* through the passage *e* into the lower part of the side pipe *b*, and thence enters beneath the piston; while the steam above the piston flows out at *a* through the passage *d* into the pipe *f g*; in the other position of the valve, the motion of the steam is obviously reversed.



For this, in almost all high pressure engines, has been substituted a short slide valve, which has been found by experience to be more advantageous. This valve is worked by an Eccentric placed upon the axis of the crank; a convenient mode of doing this is represented upon *Pl. IV.* at *Fig.* 3, where,

A is the axis of the crank;
B the circular plate, *a a a a* triangular frame;
b rod and adjusting screw;
c handle, *d* arm of tumbling shaft;
e axis of tumbling shaft;
f f spindle of slide valve;

g g steam chest;

H steam pipe;

I eduction, or exhaust pipe;

k k bottom of cylinder, on which is cast a piece *l l* containing one of the steam passages.

A plan and section of this valve are represented on *Pl. II. Fig.* 5, and will be described hereafter.

The Cylinder resembles in form that of a condensing engine, fitted with a piston, and piston-rod passing steam-tight, through the cover of the engine.

122. The power of the engine is calculated by taking the continued product of: the effective pressure of the steam per square inch in lbs., the area of the piston, the length of stroke in feet, and the number of strokes per minute; which product divided by 33000 gives the number of horse powers. The effective pressure of the steam is 20lbs. less than its absolute expansive force, or 5lbs. less per inch than the load of the safety valve. It is, however, usually calculated at two-thirds of the pressure of the steam, which is the true amount when the steam is equivalent to 4 atmospheres, or the safety valve is loaded with 45lbs. per square inch.

123. The action of the piston may be conveyed to the working points of the engine in the same manner as in the condensing engine. All, therefore, that has been said on pages 104, *et seq.*, is applicable here. So also, when the machinery requires regulation, a fly-wheel is adapted to the crank, and where the work must be performed at a constant velocity, a Governor, acting upon a throttle-valve, is adapted.

A parallel motion for a high pressure engine is represented on *Pl. IV. Fig.* 1. In this,

c d represents the lever-beam;

b the piston-rod;

c and *d* the pivots or centres of the parallel motion;

e the pivot to which the piston rod is attached;

g g a part of a fixed frame that bears the pivot *h* of the radius bar;

c e and *d f* are the straps;
h f the radius bar;
e f the parallel bar.

The governor of a high pressure engine is represented on the same plate at *Fig.* 2; *a* and *b* are the two bevel wheels;

c d the axis of the governor;

e e spherical weights, suspended by rods from joints on a fixed collar *f*;

g is a collar sliding on the axis *c d*, by the motion of the bars *g h*, *g h*;

i i is a circular arc forming a loop at each end, in which the bars *f h*, *f h* play;

g h k is a lever moving on the pivot *k*;

l l a connecting rod that unites the end *l* of the lever to the handle or lever of the throttle valve.

124. The forcing pump that feeds the boiler, and the lift-pump that supplies the water which the former injects, are worked by rods from the lever beam, when the engine has one. In other cases, motions are taken off from the piston-rod in such a way as to answer the same purpose.

125. The high pressure engine is thus fitted to subserve all the objects that can be fulfilled by the double-acting condensing engine. There are, however, engines which are not suited to produce more than a reciprocating action, and which were of older date, although of less value, being applicable to but few purposes. Such is the single-acting condensing engine. In this engine, the lever-beam is loaded with a weight, at the end opposite to that to which the piston is attached, and the latter rests, when the engine is not in action, at the top of the Cylinder. The Cylinder and steam passages are then filled with steam; a communication is now opened, from the lower side of the piston, with the condenser, and the pressure of the steam on the upper side forces the piston down to the bottom of the Cylinder; the steam and condensing valves are next closed, and the third valve, which forms a communication between the opposite sides of the piston, is opened; there being now no

resistance to the motion of the piston, other than the friction, the weight at the opposite end of the beam again preponderates, and the piston is drawn back to its pristine position, the steam flowing through the open valve and steam pipe from the upper to the lower side of the piston.

In this engine the steam acts only during the downward stroke of the piston, and during its return no force is exerted upon the piston. The effort is, therefore, directed to raise a weight, which may, in its descent, perform a work of such nature as is suited to this peculiar species of alternating motion. The raising of water, by a forcing pump, is the most usual purpose to which such an engine is applied.

A parallel motion is unnecessary in this engine, and the piston-rod is connected with the beam by a chain, that applies itself to a circular arc on the end of the beam. The pump-rod, loaded with a weight, is attached in a similar manner to the opposite end of the beam.

The air-pump, the cold and hot water pumps, are attached to rods worked by the beam.

The power of this engine being exerted during one motion of the piston only, is obviously no more than half of that of a double-acting condensing engine of the same dimensions. It is, besides, applicable to but very few purposes: and as these very purposes may be accomplished by a double-acting condensing engine of half the size, this form has gradually fallen into disuse. It was, however, at one time much in use for draining the water of mines, and raising that fluid for the supply of cities; and it has not wholly gone out of use for the former purpose, in its application to which its powers have been increased by making the steam act expansively.

126. At a still earlier period in the history of the Steam Engine, an engine was employed, in which the air of the atmosphere acting upon the piston was the prime mover. The vacuum on the lower side of the piston is caused by a condensation, effected in the cylinder itself. This engine is, for the reasons mentioned on page 102, far inferior to those in which a separate condenser is employed. It is also inferior in effect to

an engine in which steam is the moving power, for the latter is always made to act with a force a little superior to simple atmospheric pressure.

127. The form of engine last mentioned is now obsolete, and the preceding one nearly so. The expansive engine does not differ in form from the double-acting condensing engine: we shall therefore restrict ourselves to the description of the high pressure engine, and leave the detail of the others until we treat of the history of the invention.

On Pl. V. is represented a high pressure engine of 30 horse power, manufactured by the West Point Foundry Association.

A is the cylinder, the stroke of whose piston is about three and a half times the diameter. It stands upon a rectangular vessel I, through which the waste steam passes, heating water that is raised to it by a lift pump, not represented in the plate.

The piston-rod *b*, is seen only in the end view, and is hidden in the other by the sides C C, in which its cross-head moves. This rod is attached to a lever-beam D, by straps *a a*, whose length from centre to centre is half the stroke of the piston-rod.

D is the lever-beam, the length of each of whose arms is rather more than three times as much as the stroke of the engine.

E the Connecting-rod or Shackle-bar.

F the Crank.

G G, the Fly-wheel.

H, a reservoir of water, through which the waste steam passes by a pipe, until it finally escapes by the tube *r r*.

f f, is the eccentric, which moves the tumbling shaft *k*, to which is attached, by connecting rods, a cross-head *l*, which gives motion to the slide valve contained in the side pipe B.

g g, is an endless chain passing over drums, one on the axis of the crank, the other on that of the vertical bevel-wheel.

h, are two bevel-wheels that give motion to the axis of the governor K.

While the balls of the governor diverge, they raise one end of the lever *i*, the opposite end is pressed down and closes the throttle valve, situated at *c*, in the steam-pipe.

d is the rod of the forcing pump that conveys water from the reservoir H, to the boiler.

A section of the Cylinder of this engine, and of its slide valve, is represented on *Pl. II. Fig.* 4.

f, lower passage for the steam.

e, upper passage for do.

h l, openings in the sliding pipe, adapting themselves alternately to the passages *e* and *f*.

g, third opening in the steam pipe, represented as applying itself to the eduction passage *m*.

m, eduction passage to which the openings *l* and *g* apply themselves alternately.

i, *i*, interior of the side pipe, in which the slide is worked by the spindle.

k, spindle, connected by rods with the eccentric.

Another slide valve for a high pressure engine is represented in its connexion with the Cylinder at *Fig.* 5, on the same plate.

a, *b*, *c*, *d*, is a rectangular bar of cast-iron, called the steam-chest; it is constantly receiving steam from the boiler. The lower side of this has three openings, represented at *g*, *c*, *f*, in the ground plan.

Within the steam-chest, is a septum *g*, being a cup, or trough of a rectangular shape, whose open face is downwards, and is ground to apply itself closely to the lower plate of the steam-chest, against which it is firmly pressed by the steam.

This septum is of such a size as to cover two of the openings of the plate, and to exclude the third. Hence, one or other of the lateral openings always communicates with the middle opening, through the septum, while the remaining one receives steam from the steam-chest. This septum is drawn backwards and forwards by the spindle *h*, which is worked by an eccentric.

The central opening *c*, corresponds to the eduction pipe by which steam escapes; the other two communicate, one with the upper part of the Cylinder, the other with the lower, and in the varying positions of the sliding septum, steam is alternately admitted from the steam-chest, and allowed to escape by the eduction pipe through these apertures.

A Horizontal high pressure Engine, manufactured by the West Point Foundry, is shewn on Pl. VI., together with its two cylindrical boilers.

A, ashpit.

B, *B*, furnace doors.

C, *C*, boilers.

D, cylinder.

E, piston-rod.

F, connecting rod.

G, *G*, *G*, fly wheel.

H, governor.

I, reservoir of cold water.

K, forcing pump.

L, cistern of water to be heated by waste steam.

a, pipe forming communication between the water in the two boilers.

b, *b*, *b*, steam pipe.

c, safety valve.

d, lever and weight of safety valve.

e, pipe for waste steam from safety valve.

f, pipe for waste steam after it has passed the valves and been used in the cylinders.

g, steam chest containing slide valve.

h, pipe by which the cold water is conveyed to the reservoir *I*.

i, pipe by which water passes from the reservoir to the cold water cistern.

k, continuation of pipe *f*.

l, *l*, *l*, parallel motion for vertical forcing pump.

n, *n*, *n*, eccentric.

o, tumbling shaft.

A section of the cylinder of this engine, with its side pipe, is to be found on Pl. II. Fig. 6th.

It has been objected to the horizontal form of Steam Engines, that the packing wears unequally, being first abraded on the lower side of the piston, and that the Cylinder itself must finally be worn into an elliptical shape. With proper precautions in the use, however, no practical difficulty need arise. Engines of this form have advantage, in various cases, that will hereafter be enumerated, particularly in their application to steamboats.

High pressure engines are also occasionally constructed without the lever beam; the form and distribution of the parts resemble, in this case, the condensing engine figured on Pl. VII.

In consequence of the loss arising in the conversion of the reciprocating rectilinear motion of the piston of the usual forms of steam engines into one which is circular, by means of the crank, a loss which is supposed by many persons to be much greater than it really is, it has been frequently attempted to obtain a rotary motion directly. For this purpose a very great number of engines have been planned, and many of them have been constructed and actually tested. In four of them have the views of the projectors been realized; nay, it might at one time have been safely stated that all attempts at the construction of a rotary engine had resulted in failure. From this general censure might perhaps be excepted the engine of James. Still, its action has not been found to be as efficient as that of the more usual forms of engine, using the same quantity of fuel. At the present moment, however, (1836,) an engine in which a rotary motion is produced by the reaction of steam, is in the course of experiment, and there is great reason to hope that it will be successful. It has been tried in several instances with such results as to make it certain that as great a power can be obtained from it in many cases by a given quantity of fuel than in any other mode in which steam has been applied. Practical difficulties exist in applying it to all the various objects for which the steam engine is used, particularly when it may be necessary to change the direction of the motion. This engine is the invention of — Avery, of Syracuse, N. Y.

CHAPTER VII.

EARLY HISTORY OF THE STEAM ENGINE.

Introduction.—Statue of Memnon.—Hero of Alexandria.—Eolipyle.—Anthemius and Zeno.—Cardan.—Mathesius.—Baptista de Porta.—De Causs.—Brancas.—Wilkins and Kircher.—Marquis of Worcester.—Hautefeuille.—Papin's first plan.—Savary.—Papin's Engine for the Elector of Hesse.—Newcomen and Cawley.—Potter's Scoggan.—Beighton's Hand-Gear.—Smeaton.—Leupold.

128. The description of the steam engine, given in the previous chapters, has been limited to the three more important varieties: the double-acting condensing engine impelled by low steam; the double engine acting expansively; the high pressure engine. These alone are in general actual use, and the consideration of their theory is all that is directly valuable to the maker or user of steam engines. The various other forms that the engine has assumed, in its progress from rude beginnings to its present improved state, the several projects that have been brought forward and successively abandoned, may be best treated of in the historical form. In this manner also, may the relative merit of the inventors and improvers be best set forth.

The steam engine, as it is the most powerful agent by which the power of man has been extended, so also has it employed the labour, ingenuity, and talent of more individuals than any other human invention.

To give the true history of the steam engine, as indeed of most of the discoveries which have conferred important benefits on mankind, would be, in fact, to enter into the annals of nearly all the arts and sciences. Instruments have been frequently contrived, and principles stated, for which the world was not at the time prepared. Centuries sometimes elapse before the period arrives at which the wants of society call for their application, or the intelligence of the age can appreciate their merit. Then some more fortunate genius recalls the forgotten plan from oblivion, or, unconcious of the labours of his predecessors, derives from his own resources, inventions, not perhaps more meritorious than theirs in the abstract, but suited to the condition and wants of his cotemporaries. To the last then is the world really indebted, and to him is the gratitude due. His predecessors may have even gone beyond him in actual progress, his cotemporaries may have been upon the eve of the same discovery, and may have been so far advanced, that a few years, months, or even days, would have placed them by his side. But the good fortune, and it may perhaps be little more, of him who first reaches the useful result, must eclipse the merit of all others. Priority in the application of an invention to practical purposes, if associated with originality, or even with the calling up of forgotten projects, that were impracticable or useless at the moment of their first conception, is the point on which a claim to high distinction in the annals of the useful arts must depend.

In the history of the steam engine then, a few names stand prominent, in consequence of the immediate advantages to the world with which their labours were followed. Savary, who first successfully substituted steam for the labour of animals; Newcomen, who first succeeded in applying it to move a solid body, through whose intervention the work might be performed; Watt, who called in physical science, to discover and remedy the defects of his predecessors, and made the steam-engine an instrument of universal application; Fulton, who performed the first successful voyage by the impulse of steam; and Evans and Trevithick, who cotemporaneously gave to the engine such a form as suited it for locomotion on land, and ascertained that such locomotion was practicable.

It is necessary, before we enter into the history, to particularize these authors of the great steps the steam engine has made, in principle or in application; for the more minute our inquiries become, the more will the real and vastly superior merit of these parties seem to descend to the level of others, whose ingenuity either formed the basis of the strides made by those we have named; who had previously nearly reached the same results; or were on the very eve of attaining them. Thus Savary and Newcomen, united, did but little more than the Marquis of Worcester had done before them, but had not applied to purposes of real utility; Watt found a competitor in the person of Gainsborough; and but a few weeks would have placed Stevens on the very eminence where Fulton now stands.

The fitness of the time at which these several inventors succeeded in their projects, if it be rather to be ascribed to good fortune than to pre-eminent merit, tends still more than any other cause to separate them from their competitors. Had the mines of Cornwall been still wrought near the surface, Savary or Newcomen would hardly have found a vent for their engines. Had the manufactures of England been wanting in labour-saving machinery, the double-acting engine of Watt would have been suited to no useful application; a very few years earlier than the voyage of Fulton, the Hudson could not have furnished trade or travel to support a steam-boat, and the Mississippi was in possession of dispersed hordes of savages.

But if good fortune in the circumstances of the time, or in the success of the enterprize, were to be arguments against the honours that history assigns, we should sink its greatest names to the level of the most obscure, and those who have changed the face of the earth, to those who prepared, by gradual steps, the means by which the changes were effected. In the history of a mechanical invention too, it may frequently appear, on a cursory examination, that those who, by unsuccessful, although ingenious efforts, actually retarded the progress of discovery, are as meritorious as those who convinced the world of the value and practical merit of their inventions. So soon, however, as success is attained, jealousy calls up all analogous projects, however far from being adapted to the times at which they were proposed, or which some simple but undiscovered step prevented from being introduced into practice, and ranges them on an equal level with, or even exalts them beyond, those to whom the world owes the perfected invention.

Conflicting national pride too comes in aid of individual jealousy, and the writers of one nation often claim for their own vain and inefficient projectors the honours due to the successful enterprize of a foreigner.

If success be a title to honour in general history, it ought to be still more so in mechanical inventions. They require, to bring them into use, an union of practical and theoretic attainments, the want of either of which may render them abortive. Few projectors are thus doubly qualified, at the commencement of their career; and few or none have been successful, until by long and costly experience, they have added practice to theoretic knowledge, or have, by laborious study, brought science to the aid of mere mechanical skill.

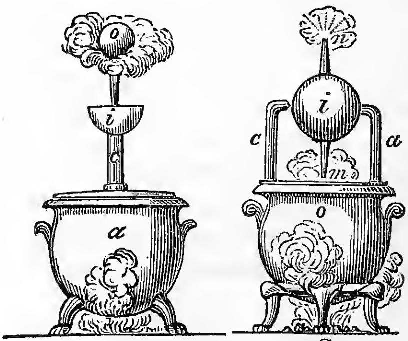
That steam is capable of exerting a mechanical force must have been obvious from the most remote antiquity, for we have no reason to believe that man was ever ignorant of the use of fire. But to apply steam to any useful purpose is an idea comparatively recent. Still, however, the remotest antiquity that can be reached by profane history, has been quoted as affording an instance of the employment of steam, if not for a useful purpose, at least for one that produced no unimportant effect at the time, and excited the curiosity of mankind for centuries.

129. The elder Hero of Alexandria, who lived about 130 years before the Christian era, is the first author who gives any account of the application of the vapour of water. We are unable to quote his work in the original, but are indebted for a notice of it to the beautiful little treatise of Stuart, to which we, once for all, acknowledge our obligations.* In this work it is stated that Hero expressly ascribes the sounds produced by the statue of Memnon to steam generated in the pedestal, and

* *Historical and Descriptive Anecdotes of Steam-Engines, and of their Inventors and Improvements*, by Robert Stuart, *Civil Engineer*.—London, 1829.

issuing from its mouth. Now, by the researches of Champollion, who is the highest authority on this point, the Memnon of the Greeks is identified with Amenophis II., a prince of the 17th Egyptian dynasty, who reigned at Thebes 1600 years before Christ. Here, then, we have an application of steam, if the surmise of Hero be true, before the date of the Exodus of the Israelites. We must, however, express our opinion, that this is rather an ingenious explanation of the philosopher himself of the mode in which he could have effected the same object, than an account of what was really performed by the Egyptian priests.

130. Hero constructed or described more than one instrument, entitled to the epithet of steam engine. Two of them, of which one would have answered to raise water and the other would have produced a rotary motion, are figured below.



B C

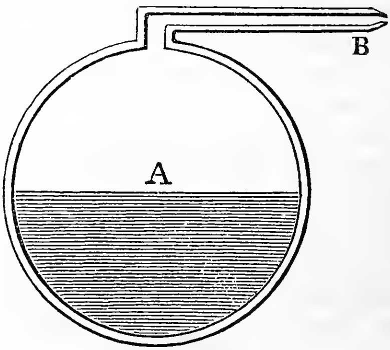
In the figure marked B, *a* is a vessel in which water is boiled; the pipe *c* proceeds nearly to its bottom; the steam will therefore accumulate in the upper part of the vessel, and force the water in a jet through the pipe *c*. A fountain may thus be formed, on which may be supported the ball *o*.

In the figure marked C, *o* is a similar vessel; two pipes, *a* and *c*, proceed from it; these are bent towards each other, and serve as pivots to the sphere *i*, in which there are openings corresponding to those in the pipes *a* and *c*. From points in the sphere diametrically opposite to each other, proceed the pipes *m* and *n*, which are bent towards the end at right angles, and directed to opposite sides of the apparatus. The steam generated in the vessel *o* passes through the pipes *a* and *c*, into the sphere *i*, and thence into the pipes *m* and *n*, issuing from which in opposite directions, it, by its reaction, gives a rotary motion to the sphere.

Hero does not give the slighest hint that his invention was capable of any useful application, nor does he appear to have imagined that he was in possession of an instrument that was in future ages to produce such important results.

The Greek philosophers, however, seem rarely to have attended to the practical value of their investigations; it was sufficient for them to discover and to astonish; and even when they mention arts and instruments that seem to have been actually introduced, they avoid contemptuously all notice of their uses in the arts. "The ancient philosophers," says an ingenious author, "esteemed it an essential part of learning to conceal their knowledge from the uninitiated; and a consequence of their opinion that its dignity was lessened by its being shared with common minds, was their considering the introduction of mechanical subjects into the regions of philosophy, as a degradation of its noble profession, insomuch that those very authors among them, who were the most eminent for their own inventions, and were willing by their own practice to manifest unto the world these artificial wonders, were, notwithstanding, so infected by this blind superstition, as not to leave any thing in writing concerning the grounds and matters of these operations; by which means it is that posterity hath unhappily lost, not only the benefit of these particular discoveries, but also the proficiency of these arts in general. For when once learned men did forbid the reducing them to vulgar use and vulgar experiment, others did thereupon refuse those studies as being but empty and idle speculations; and the divine Plato would rather choose to deprive mankind of those useful and excellent inventions than expose the profession to the ignorant vulgar." We are luckily fallen upon happier times. The student and the proficient in science no longer shut themselves up from the busy world, or hide their acquisitions like mysteries from the public; but their whole endeavour is to bring their learning into such a form as may calculate it for the most wide dissemination, and enable it to produce the most extensive usefulness.

132. The Eolipyle, however, was an instrument well known to the ancients. It was applied by them to but one single object, that of exciting the energy of combustion. It is mentioned by Vitruvius, Lib. I. *Cap.* VI., as an illustration of the causes of the winds. It was supposed that the blast actually proceeded from the Eolipyle, but as steam would not support combustion, we must look to some other cause for its effects in this respect. We find it in the lateral communication of motion that takes place among fluids, by which a current of air is made to follow the course of the steam that issues from the neck of the Eolipyle. We give a figure of this instrument.



It is composed of a globe or other hollow vessel A, to which a pipe B, is adapted. If a portion of water be introduced, and the vessel placed over a fire, steam will be generated, and issue forcibly from the narrow aperture. If it be mounted on wheels, it will recoil by the reaction of the escaping vapour; and a rotary motion may be produced, by two pipes, but in opposite directions, as in the machine of Hero.

133. A knowledge of some of the properties of steam seems

to have been retained during the flourishing periods, and even to the decline, of the Roman empire. In the reign of Justinian a dispute occurred between Anthemius, the Architect of that Emperor, and the Orator Zeno, which shows this fact. Yet the knowledge was here applied to mere purposes of private malice, while it might, by the exercise of no greater ingenuity, have produced important and useful consequences. From this period until the revival of learning, we find no record of any use of steam, either for useful or entertaining purposes.

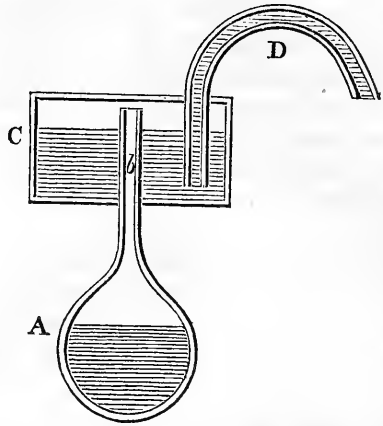
134. Cardan is the earliest modern author in whom we detect any hint of a knowledge of the mechanical properties of steam. This extraordinary man, who united all the learning of his age to even more than all its superstition, appears to have known, not only the expansive force of steam, but the fact that a vacuum could be produced by its condensation ; a fact so important in the action of the steam engine. Among his proposals is one for the use of the current of rarified air in a chimney, to produce a rotary motion. He, first of the moderns, gives a description of the Eolipyle. The work which contains the former of these plans is dated 1571.*

135. A German of the name of Mathesius, in 1571, to borrow the words of Stuart, "displayed almost as much ingenuity in contriving to introduce so untoward a subject into a sermon as a description of an apparatus, answering to a steam engine, as would be required to invent the machine itself, and which he gives as an illustration of what mighty efforts could be produced by the volcanic force of a little imprisoned vapour."

136. The researches of modern writers, among whom we may note with the highest praise him that we have just mentioned, has disclosed various persons, who seem to have had ideas more or less just of the mechanical power of steam. The only one that we consider worthy of notice is Baptista Porta, a Neapolitan, who lived towards the close of the sixteenth centu-

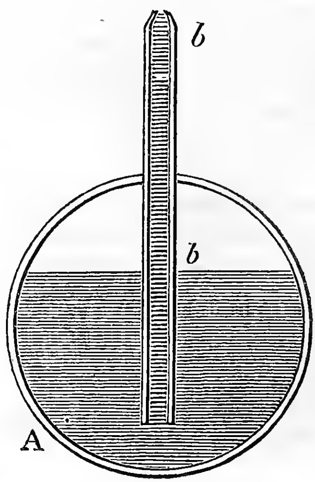
* Stuart's Historical Anecdotes of the Steam Engine, page 19.

ry. His machine, which is the germ of several that have been noted as original, is figured below.



Water is boiled in a vessel A, placed upon a furnace. The steam rises through the pipe *b* into the upper part of the box or vessel C, the lower part of which is filled with water. The pressure of the steam on the surface of the water forces it up the rising pipe D.

137. Next in the order of time is De Causs. Among various engines contrived by him is the following:



A spherical vessel A has a pipe *b b* inserted, until it nearly reaches its lower part. The vessel is partly filled with water, which is boiled, and the steam accumulating in the upper part, forces the water up the pipe. Here it will be observed that the heated water is itself raised, and the powers and utility of the engine are evidently far less than those of the machine of Porta.

138. The first person who seems to have had an idea that the power of steam was capable of being applied to any other useful purpose than that of raising water, was Brancas, an Italian, who proposed to direct the blast issuing from an Eolipyle upon the leaves of a wheel, which, being set in motion by its impetus, might serve to move machinery. This method is unluckily imperfect and wasteful, yet the attempt is deserving the highest praise, inasmuch as he is the only person, who, in the infancy of these investigations, entertained any hope of realizing the vast benefits that steam has since conferred upon the world. Had steam been confined in its action to the single object of raising water, it might have been of notable use in a few cases; but its great and important value, as a prime-mover, has been only realized since methods of applying it, to any species of work whatsoever, have been discovered.

139. This plan of Brancas was repeated by Bishop Wilkins; and Kircher proposed to apply two Eolipyles to concur in the same effect. The last-named author also proposed an engine similar in principle to that of Porta.

140. Of all those who attempted to apply steam to useful purposes, without being successful in introducing his engine into general practice, the Marquis of Worcester fills the greatest space. He has been claimed by English authors as the first who made any experiments of importance upon steam; and it has been asserted that the next of their countrymen, who undertook the investigation, did no more than copy, without acknowledgment, the plans of Worcester. Even the first truly successful form the steam engine assumed has been shown to be

consistent, in many respects, with the description of one of the engines of this nobleman.

It is yet a disputed point, what was actually the form of the engine of Worcester. His description is at best vague, and is without any figure; various authors have exercised their ingenuity in framing plans of a machine that should be consistent with the expressions of his work. We do not consider it important to do so, but shall content ourselves with quoting his own words. They are to be found in a little treatise, entitled "*A century of the names and scantlings of such inventions, as at present I can call to mind to have tried and perfected, which, my former notes being lost, I have at the instance of a powerful friend endeavoured, now in the year* 1655, *to set down in such a way as may sufficiently instruct one to put the whole of them into practice.*" This work was originally printed in London in 1663, and has been six times reprinted; the reprint of 1813 has been consulted for the following, being the 68th Proposition.

"An admirable and most forcible way to drive up water by fire, not drawing or sucking it upwards, for that must be, as a philosopher calleth it, *infra spheram activitatis*, which is but at such distance, but this way hath no bounder, if the vessels be strong enough; for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three quarters full, stopping and screwing up the broken end, as also the touch-hole, and making a constant fire under it; within twenty-four hours it burst, and made a great crack; so that, having found a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, have seen the water to run like a constant fountain forty feet high; one vessel of water, rarified by fire, driveth up forty of cold water; and a man that attends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with water, and so successively."

Vague as this description is, it would still be possible to construct an engine that would perform a similar work by the expansive force of steam. It would be very inferior to modern engines, but would yet be effectual.

It has generally been imagined that this is the sole reference to steam in the *Century*. But two others certainly correspond so closely to the character of our modern high pressure engines, that it may not be amiss to quote them also. They are the ninety-eighth and hundredth propositions of his work.

"An engine so contrived that working *primum mobile* backward or forward, upward or downward, circularly or contrariwise, to and fro, upright or downright, yet the pretended operation continueth and advanceth, none of the motions above mentioned hindering, much less stopping the other; but unanimously agreeing, they all augment and contribute strength to the intended work and operation; and therefore I call this a *semi-omnipotent engine*, and do intend that a model thereof be buried with me."

"How to make one pound weight to raise an hundred as high as one pound falleth, and yet the hundred pound descending, doth what nothing less than one hundred pounds can effect. Upon so important a help as these two last-mentioned inventions, a waterwork is, by many years' experience and labour, so advantageously by me contrived, that a child's force bringeth up an hundred feet high, an incredible quantity of water, even two feet diameter, so naturally that the work will not be heard into the next room; and with so great ease and geometrical symmetry, though it work day and night from one year's end to the other, it will not require forty shillings reparation to the whole engine, nor hinder one day's work; and I may boldly call it the most stupendous work in the whole world; and not only with little charge to drain all sorts of mines, and furnish cities with water, though never so high seated, as well as to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with water enough for their private occasions; but likewise supplying rivers with sufficient water to maintain and make them portable from town to town, and for bettering of lands all the way it runs. With many more advantageous and yet greater effects of profits, admiration, and consequence; so that, deservedly, I deem this invention to crown my labours, to reward my expenses, and make my thoughts acquiesce in the way of further inventions."

In the first of these steam obviously meets the description of his *primum mobile*, for in whatever direction it proceeds, it is still capable of exerting the same mechanical force. The single pound raising one hundred, in the second, meets the conditions under which the piston of a steam engine acts, for its weight bears even a less proportion to the power of the engine.

The following is an extract from a manuscript left by the Marquis of Worcester.

"By this I can make a vessel of as great burthen as the river can bear to go against the stream.

* * * * * * * * * *

"And this engine is applicable to any vessel or boat whatsoever, without being therefore made on purpose; and worketh these effects. It roweth, it draweth, it driveth, (if need be) to pass London Bridge, against the stream at low water."

It is to be remarked, that Worcester claims, on his title-page, the merit of having actually completed, and used all the inventions he describes in the work: in support of this assertion various evidence has recently been adduced.

He employed a mechanic for thirty-five years, under his directions, in the manufacture of models; and many of his projects that appear, in his manner of announcing them, absolutely impossible, have been unexpectedly realized by modern inventions.

That the steam engine of Worcester was no vague conception, but was actually put into operation, a recent discovery has settled, upon testimony the most convincing. The Grand Duke of Tuscany, Cosmo de Medicis, travelled in England in 1656. His manuscript account of his journey remained unpublished until 1818, when a translation was made and printed. The following is an extract from this translation:

"His highness, that he might not lose the day uselessly, went again after dinner to the other side of the city, extending his excursions as far as Vauxhall, beyond the palace of the Archbishop of Canterbury, to see an hydraulic machine, invented by my Lord Somerset, Marquis of Worcester. It raises water more than forty geometrical feet by the power of one man only; and in a very short space of time will draw up four vessels of water, through a tube or channel not more than a span in width."

Here, then, is a description of an engine in actual operation, and corresponding in terms with that referred to in the century of inventions.

141. In the several projects of which we have hitherto spoken, the expansive power of steam was used alone. It was made to act directly upon the surface of water to raise it; or, issuing from the orifice of an Eolipyle, set a wheel in motion; or again, issuing from two tubes attached to an Eolipyle, caused that instrument to revolve upon an axis, by the reaction of the vapour. In each of these ways the use of high steam is essential to success, and this upon a large scale is attended with danger, particularly in the low state of mechanic arts, and before the various contrivances we have mentioned in chapter III. were invented.

The action of steam of a force no more than equal to the pressure of the atmosphere, against a vacuum formed by its own condensation, is a far more safe, and, as we have seen, more useful application of its energy. The researches of Stuart seem to show that this was first proposed by a Frenchman of the name of Hautefeuille. He, in the year 1678,* published a work, in which he intimates that the alternate generation and condensation of the vapour of alcohol might be applied, without waste, to the production of mechanical effects. We have, however, no proof that this project ever went farther than the mere proposal. It is, notwithstanding, to be considered as one far beyond the knowledge of that age, of the nature and properties of steam.

142. Sir Samuel Morland, who was cotemporary, appears, from the very words he employs, to have been merely an imitator of the Marquis of Worcester, and therefore claims no notice among those who aided in the progress of the steam-engine.

* Stuart's "Anecdotes."

143. In 1680, the year previous to that in which Sir S. Morland visited France, Dr. Denys Papin, a French Protestant, invented the safety valve, which has since been of such important service in the construction of the steam engine. It was first employed by him in an apparatus called the digester. This apparatus is a boiler, within which water is retained under pressure, in order that it may be heated beyond the temperature at which it boils in the open air. The original object was to extract the gelatinous matter from bones, in order to apply its solution as food. To prevent any risk of danger, a conical aperture was left in the lid of the vessel, and to this was adapted a conical stopper, pressed by a weight suspended at the end of a lever. It was, in short, identical with the most usual form of safety valves at the present day.

Although he thus employed water at a high temperature, and had discovered one of the methods that are still in use, of rendering the boiler safe, still it was long before he attempted to apply the power of steam. The motion of a piston in a cylinder was suggested by him, as a method of adapting the expansive force of an elastic fluid to produce mechanical effects. In this apparatus he at first proposed to employ air rarified by heat; he next attempted to exhaust the space beneath the piston, and make use of the pressure of the atmosphere; and finally, to raise the piston by the inflammation of gunpowder. In a letter to Count Zinzendorf, however, he proposes to use steam for the same purposes. In the Leipzig Transactions, also, for the year 1690, he repeats the proposition, and explains the principle upon which he founds the application of this substance, both to raise a piston, and to produce a vacuum by its condensation. There is, however, no evidence that a separate boiler ever entered into his views, without which it would have been impossible to make any useful application of his principle.

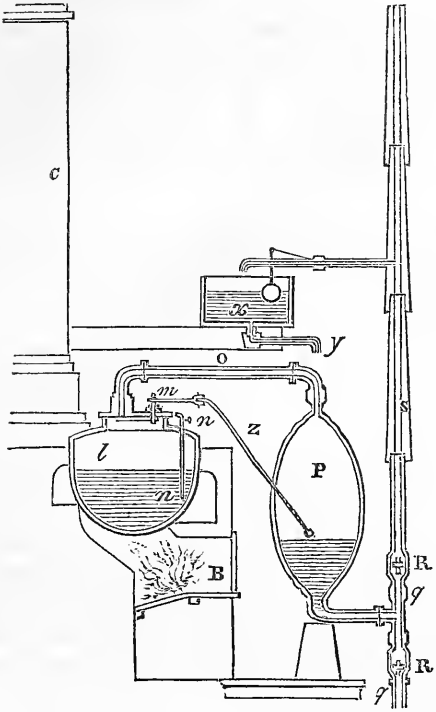
Nothing, then, had been actually effected by Papin in this earlier stage of his researches, and he did not extend them farther until steam had actually been successfully employed in raising water; if we can indeed say that he ever was successful in pointing out a mode in which it could be rendered of practical value.

144. The history of steam, applied to purposes of acknowledged utility, commences then with Savary. It has been much debated whether this person were in reality an inventor, or had merely the judgment to perceive an opening for the introduction and adaption of previous discoveries. His own statement is, however, clear, distinct, and worthy of credit. Having been, in the early part of his life, employed in the mines of Cornwall, he was aware of the vast expenditure incurred in keeping them free of water; and an accidental observation appeared to point out to him a simple and easy mode, in which a substitute could be found for the expensive labour of animals. Being at a tavern in London, he threw upon the fire a Florence flask containing a small quantity of wine; he observed the wine to boil, and a cloud of vapour to issue from the neck, while the interior remained transparent. Struck with the appearance, he seized the flask and inverted the neck in a basin of water; after a short time he found the flask filled with liquid, in consequence of the condensation of the steam forming a vacuum, into which the water was raised by the pressure of the atmosphere.

The very form and arrangement of his apparatus is a proof of the truth of his story, for it is no more than a flask-shaped vessel of iron, in which a vacuum is formed by the condensation of steam. This part of its principle had not before been acted upon, nor even thought of, except in the suggestion of Hautefeuille, which we have before spoken of. The action of the vessel is in this respect identical in principle with that of the common pump. He did not, however, limit his views to this single action, but proceeded to add to it the action of the forcing-pump. For this purpose, so soon as the flask was filled with water, steam proceeding from the boiler, of a high temperature and corresponding tension, was admitted into the flask, after the communication with the water beneath was closed, which, acting on the surface of the water contained in the vessel, forced it up a lateral pipe. As it was impossible to obtain a perfect vacuum by the condensation of the steam, the first part of the action of Savary's engine was limited to the height of 25 feet; the second part has no limit, but in the tension of the steam, and the strength of the materials, of which the vessel and the rising-pipe were composed. This however, was, from the imperfect state of materials and workmanship, limited to less than 70 feet; so that the two different actions of the engine, working in succession, raised the water to little more than 90 feet. Even at this comparatively small limit, the danger attending the use of this engine became excessive, while the height, to which it was capable of raising water, was entirely too small for the purpose of draining mines. Several different engines, placed at different levels, would have remedied the last defect, but the cost of attendance would have been enhanced in proportion. Such defects were obvious; there were, however, others which could not be accounted for until the doctrine of latent heat was discovered, and which we shall return to on a subsequent page.

The cause which affects the action of high pressure engines, and prevents them from working with the power that might, at first sight, have been anticipated, is also to be found in operation in this engine. The force required to raise water from sixty-five to seventy feet, is equivalent to steam of a tension of not less than three atmospheres; now, as the density of steam increases nearly as rapidly as its tension, it is obvious that to obtain this in quantity sufficient to fill the vessel, would require the evaporation of nearly three times as much water as would fill it, were the tension no more than a single atmosphere. Hence, in fact, little is gained by the second part of the action of this engine; for water may be raised, with an equal expenditure of fuel, nearly as high by condensation, in vessels placed at different levels, as it is by direct pressure of any intensity, however great.

We have placed on the opposite page a section of the engine of Savary, which in its complete form was double, one vessel receiving the water in consequence of the condensation of the steam, while from the other it was forced up by direct pressure; these vessels alternated with each other in their operation.



l is the boiler in which the steam is generated.

O, steam pipe, by which steam is conveyed to the vessel P.

q q, pipe communicating with a reservoir beneath; through this pipe the water is raised to the vessel P, where the steam is condensed by the pressure of the atmosphere.

S, rising-pipe through which water is forced when the steam flows from the boiler through a valve on the steam-pipe O, which is manœuvred by the lever *z m*.

R R, valves opening alternately.

x, reservoir to supply water of condensation; it receives water from the rising-pipe S, through a pipe governed by a float and stop-cock.

y, pipe through which the cold water falls on the outside of the vessel P.

n, gauge-cock to show the height of water in the boiler.

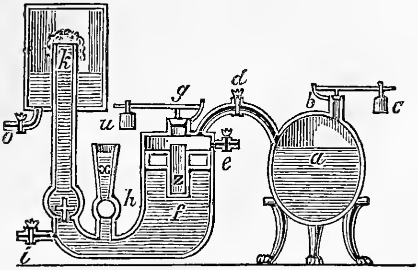
We have stated the more obvious defects of Savary's engine, as well as one which is not usually quoted. There is, however, another of far greater importance, but which rests upon a physical principle, entirely unknown at the period in which he lived. This grows out of the necessity of filling the vessel alternately, with steam of high tension, and water of a low temperature.

When the steam is first admitted into the vessel, it will be condensed against its sides and upon the surface of the water; nor will it begin to act mechanically until both be heated to the temperature of 212°. Its full effect will not take place until both are heated to such a degree as will maintain the steam at a temperature, and consequent tension, appropriate to the height of the place of discharge. As the water is forced out of the vessel, fresh cold surfaces are exposed, and must be heated in their turn; and when the vacuum is to be formed, the outside of the vessel is cooled by the affusion of water, while the inside is farther cooled by the rise of water from the reservoir beneath. In these different ways it has been found, by experiments carefully conducted, that $\frac{11}{12}$ths of the steam is condensed without acting at all, and that, of course, a similar proportion of fuel is wasted.

The engine of Savary, therefore, is confined to a single object, namely, that of raising water; and even this, for the reasons we have stated, it does to great disadvantage. Still, however, the introduction of this engine was not only important as a step to the construction of more perfect ones, but it was of itself of some value when compared with the methods for raising water that were at that period in use.

145. An apparatus which, at first sight, bears a strong similarity to Savary's, was constructed by Papin, for the Elector of Hesse, in 1707. It differs in having a piston, working in the vessel into which the steam is alternately admitted and condensed, and makes no important use of the pressure of the atmosphere. It appears that, even with the aid of the celebrated Leibnitz, he had been unable to bring his cylinder engine to perfection, and had abandoned his researches until again stimulated by the success of Savary.

We give a figure of this last engine of Papin.



a is the boiler, furnished with a safety valve *b*, pressed down by a weight *c*, suspended from a lever. Water is introduced into the boiler through this valve. *f* is the forcing vessel, having an aperture at the top closed by the valve *g*. A piston is placed in this vessel, having a socket into which a cylinder of iron *z*, heated red hot, is introduced to keep up the temperature of the steam; water is admitted into the forcing vessel through the funnel *x*, and valve *h*. The rising pipe *k* enters an air vessel. The action of the steam in the forcing vessel raises the water into the air vessel, whence, by the pressure of the condensed air, it runs in a continual stream; when the piston has descended to the bottom of the vessel *f*, the valve *d* is closed, and no more steam flows over; the valves *e* and *g* are opened; through the former, the steam that has been used escapes, and through the latter the forcing vessel is again filled.

146. The time had now arrived in which the world was to derive essential advantages from the employment of steam as a moving power. Even Savary's engine, although more valuable than any other we have hitherto spoken of, had obvious defects, which prevented its coming into general use. These obvious defects were remedied by the engine of Newcomen and Cawley, their patent for which issued in 1705. Departing from the idea entertained by all former inventors, except in the abortive proposition of Papin, of making the steam act directly to raise water, either by pressing upon its surface or by forming a vacuum on its condensation, Newcomen and Cawley sought the

means of working the brake of a forcing pump. With this view, the pump-rod being loaded with a weight sufficient to bring it to rest in its lowest position, the brake or lever of the pump was made with equal arms, and resting on a pivot in the middle of its length.

The pump-rod being thus loaded, and attached in this manner to one end of the beam, a piston, of size considerably larger than that of the pump, was attached to the other, and made to fit a Cylinder, at the upper end of which it rested, under the preponderating weight of the pump-rod and its load. The Cylinder had in its bottom a valve opening upwards, by which steam could be at pleasure admitted or cut off. To the side of the Cylinder and near its bottom was attached a horizontal pipe, bent upward at the open end: in this was placed a valve opening to the air, which is called the snifting valve. Steam of the temperature of 212° being admitted into the Cylinder, would, from its levity, rise to the upper part of that vessel, displace the air previously contained therein, which flows out through the latter valve, making a sound which has given this valve its name. If the steam that thus enters the Cylinder have its communication with the boiler closed, it may readily be condensed, and a partial vacuum formed, beneath the piston. The pressure of the atmosphere will now act, and force the piston downwards to the bottom of the Cylinder; the opposite end of the lever-beam will be raised, and with it the pump-rod, and the weight with which it is loaded. If the communication with the boiler be again opened, the pressure on the opposite sides of the piston will again become equal, and the preponderating weight of the pump-rod will cause it to descend, and draw up the piston to its primitive position. A second condensation will cause the piston again to descend, and the process may thus be kept up so long as the boiler continues to supply steam.

The condensation in the Cylinder was at first produced by cooling the outside, by the affusion of cold water; and, when the action was required to be rapid, by placing the cylinder in an external cylindrical space. A hole having been accidentally made near the bottom of the Cylinder, the water spouted into it, and the condensation was found to be much more rapid.

This was then imitated, by adapting a pipe to the Cylinder, through which a jet was made to flow as often as it was necessary to condense the steam. This pipe and injection apparatus, were governed by a stop cock or valve placed upon it. Thus there were two valves necessary to the action of this engine, and these were to act alternately, the one opening as the other closed, and vice versa.

147. In the original form of the engine these were worked by hand, a boy being placed within reach of the levers that opened and shut them, to perform that operation as often as necessary. This employment being excessively irksome, one of the persons was not slow to perceive that it might be performed, even better than it could be by any personal attention, by the alternating motion of the lever beam itself. This important step towards the perfection of the engine was made by a boy of the name of Potter, and was immediately adapted to all the engines of Newcomen and Cawley.

It will be at once obvious, that the steam in this engine was employed solely to form a vacuum by its condensation, and that the pressure of the atmosphere was the efficient agent. Hence, as Savary's patent comprized the use of steam for this purpose, he was associated in the profits of Newcomen and Cawley.

As this was the sole use that was made of the steam, it was unnecessary to generate it of a tension greater than that of the atmosphere; hence its use became perfectly safe, while the height to which it was capable of raising water was as great as could be effected by a forcing pump worked by any agent whatsoever. This engine, therefore, far exceeded that of Savary, both in its ease of application and its power.

On the other hand, the principal physical defects, noted as affecting Savary's engine, were still inherent in Newcomen's, and its mechanical execution became far more difficult. So great, indeed, was the latter difficulty, in the then imperfect state of the arts, that it was found impossible to keep the piston tight, except by covering its surface with a mass of water, whose presence still further enhanced the physical imperfections.

The steam being condensed within the Cylinder, the whole was cooled down at each stroke to the temperature of condensation; while the part of the Cylinder above the piston in its lowest position, was still further cooled by the mass of water employed to render it tight. On the re-admission of the steam, the whole was again to be heated up to the boiling point; thus the waste of fuel was quite as great as in the engine of Savary.

Another imperfection grew out of the partial nature of the vacuum that it was possible to produce in the cylinder. Water which boils under the ordinary mean pressure of the atmosphere at 212°, rises into vapour at all temperatures whatsoever, and boils at lower temperatures under diminished pressure. Hence, so soon as the piston began to descend, the action of atmospheric pressure was lessened by the generation of fresh steam, and although this was in its turn condensed, its place would be occupied by new steam of a lower temperature, and a resistance would be opposed to the descent of the piston.

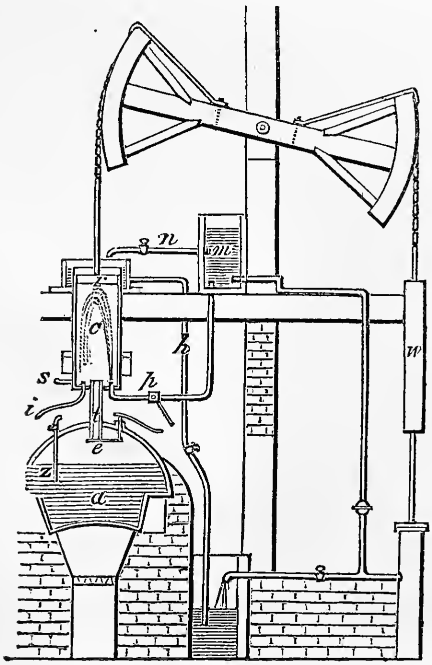
In consequence of this retarding force, it was found in practice impossible to make the pressure of the atmosphere, which is, at a mean, 15lbs. per square inch, act upon the piston with a mean force of more than 7½lbs., and from this, in estimating the action of the machine, the friction, and other retarding forces, are to be deducted. This engine, therefore, consumed about twelve times as much fuel as would have generated steam sufficient to fill the Cylinder, and worked with but half the force the moving agent was capable of exerting.

The rectilineal motion of the pump and piston rods was, in this engine, accommodated to the circular motion of the ends of the lever-beam, in a very simple and ingenious manner. The ends of the beam were made in the form of arcs of circles, and the rods were suspended from them by chains, attached to the highest point of each arc. Thus, as the active pressure of each of these, in the performance of its share of the work was vertically downwards, it was always applied directly to the beam, the two rods being respectively always in the direction of tangents to the circular arcs formed upon the working beam.

148. The valve apparatus of Potter, called by him the Scog-

gan, was, in 1718, superseded by a more perfect arrangement invented by Beighton. A frame or bar was attached by a chain, working also over a circular arc, to the lever beam; projecting pieces or pins, forming a rack, were attached to the frame; the valves were moved by quadrants cut into teeth, and acting upon a rack connected with the spindle of the valve; to each of these quadrants was attached a lever, which was pressed by the pins upon the frame through a circular arc, until it passed the line of motion of the frame, and was disengaged; from this position, the lever was made instantly to return to its original place, by the action of a weight. These levers being also furnished with handles, to enable the valves to be open and shut by hand, the apparatus was called the *Hand Gear*, the frame and pins, the *Plug Frame*. This mode of working the valves continued to be used up to the beginning of the present century, with but little improvement; nor has it yet fallen wholly into disuse.

The engine of Newcomen is exhibited in the annexed draw-



ing, by which its mode of action and the uses of its several parts may be better understood.

a is the boiler.

t, the steam pipe.

e, the steam valve.

c, the Cylinder, into which the injection water is seen playing through the valve and pipe *p*.

r, the piston.

s, the snifting valve.

m, a reservoir of water, whence the injection pipe is supplied and water flows, through the pipe *n*, to keep the piston tight.

The injection water is discharged through the pipe *i*, and the excess of that floating on the piston by the pipe *h*.

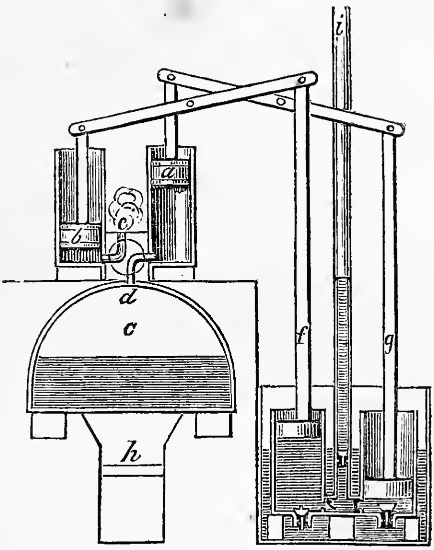
w is the weight attached to the pump-rod, by the action of which the piston is returned to its highest position.

The lever beam and pump are too obvious to need description.

149. The engine of Newcomen and Cawley was improved in its mechanical structure by Smeaton, and derived additional force from the general improvement of the mechanic arts. Smeaton also formed tables of the dimensions of the several parts. With these improvements it is still occasionally used, particularly in places where fuel is cheap and abundant; where its small cost, and its safety, are considered as more than counterbalancing the great waste of fuel with which it is attended.

150. In 1718, a German engineer, of the name of Leupold, published a work containing a description of two engines, the merit of which he ascribes to Papin. They are, however, rather to be considered as ingenious applications of his own, of the principle of that inventor, aided by the knowledge of what had been effected by Savary and Newcomen. In one of these the steam was made to act alternately upon the surface of water in two vessels, and it is so similar in every thing, but the form and position of its parts, to the engine of Savary, that we do not conceive it necessary to describe it minutely. The second is a high pressure engine with pistons, and is extremely ingenious,

besides being remarkable as the first in which steam of high tension was made to act upon a piston. The first of these is liable to all the objections that we stated in speaking of Savary's engine. The second is far better, and even preferable in many respects to the engine of Newcomen. It is, besides, applicable to the production of a continuous rotary motion, and is therefore the first that could have been applied to general purposes in the arts. Of this last engine we have in consequence given a figure.



Steam is generated in the boiler *c*, and flows thence through the pipe *d*; it is represented as passing through one of the passages in a four-way cock, beneath the piston *a*, while the steam which had filled the other cylinder is escaping into the air through the passage *e*. The piston *a* works a lever and the pump-rod *g*, while *b* works another lever and the pump-rod *f*.

h is the fire-place.

The two pumps force water alternately into the rising pipe *i*.

Did the levers act upon cranks situated upon the same axis, a continuous rotary motion might be produced.

Steam in this case is the moving power, and is not condensed as in the engine of Savary. It, therefore, is constantly retarded by the pressure of an atmosphere, and must have a tension of at least two atmospheres in order to work to advantage.

The history of the steam engine is thus brought down, from the most remote period at which the power of that agent was first suspected, until it assumed a definite form, and became capable of useful application. Hitherto, however, but one species of work came directly within its scope. In the succeeding chapter we shall find its physical defects remedied or removed, and its application finally made universal to every species of manufacturing industry.

CHAPTER VIII.

CONCLUSION OF THE HISTORY OF THE STEAM ENGINE.

Power and Defects of Newcomen's Engine.—Birth and Education of Watt.—Professor Robison.—Watt's first experiment.—Professor Anderson.—Watt's second experiment.—Inferences.—Separate Condenser.—Steam applied as the moving power.—Packing.—Jacket and Air-pump.—Working Model.—Dr. Roebuck.—Experimental Engine.—Watt's first patent.—Gainsborough's claim.—Boring apparatus.—Form of Watt's first Engine.—Saving of Fuel.—Projects for rotary motion.—Fiztgerald, Stewart, and Clarke.—Double-acting Engine of Watt.—Washborough and Pickard.—Crank.—Sun and Planet Wheel. Other Inventions and Improvements of Watt.—Hornblower.—Watt's patent extended.—Governor.—Introduction of steam into various mechanic arts.—Expiration of Watt's patent.—Cartwright and Sadler.—Murray, Maudslay, and Fulton.—Woolfe.—Oliver Evans.—Trevithick and Vivian.—Rotary Engines.—Conclusion.

151. In the preceding chapter the prominent defects of the engine of Newcomen and Cawley have been pointed out. In spite of these, it had been found of immense value in practice, in raising water for the supply of cities, and more particularly in draining mines. So great, indeed, had been the advantages derived from it in these cases, that hopes had been from time to time entertained that this engine might be rendered efficient in performing work of other descriptions; and it had even been thought of as the prime means of propelling boats. That the energy of the prime mover was adequate to any of these pur-

poses was certain, but mechanical difficulties opposed its application. Even had these been overcome, the engine was liable to physical imperfections, which had not at this period been suspected, far more formidable than those which are merely mechanical. The latter, we now know, are so great in amount, as to have prevented the atmospheric engine from competing with almost any other prime mover, except in a few particular cases. These objections, whether physical or mechanical, might have been gradually removed; the former by the general progress of the arts, the latter by the discoveries in physical sciences with which the close of the last century teemed. The steam engine, however, was not destined to wait for the slow changes which follow the application of purely theoretic principles to practical purposes. A single individual was found, who, by his own researches and unaided efforts, reached the law of the relations of steam to heat, which was, about the same time, discovered in its more general form by Dr. Black. This illustrious individual was James Watt.

152. Watt was the son of respectable, but poor parents. His grandfather exercised the profession of a schoolmaster, his father that of a merchant in Greenock, in Scotland. Having received the elements of a liberal education, which the excellent school system of Scotland places within the reach of all, Watt, at the early age of sixteen, became the apprentice of a maker of optical instruments in the city of Glasgow. Two years afterwards he removed to London, and obtained employment from a maker of mathematical and philosophical instruments. In this employment, his health became affected, and he was compelled to return to his native district.

In undertaking business on his own account, he would have preferred Glasgow, as offering far greater prospects of success than Greenock, and hence became anxious to settle in the former place. To this plan, however, obstacles presented themselves, in the form of the laws of the corporation, by which the exercise of a trade was restricted to those entitled to the privileges of a burgess, to which Watt had no claim. From this state of difficulty he was fortunately relieved by the interposition of the professors of the University. This institution possessed, as a remnant of ancient privileges, the right of claiming immunity from the corporate restrictions, and Watt was furnished by them with apartments within the college buildings, in which he pursued his trade.

153. His attention was first called to the subject of steam by Professor Robison, then a student of the University of Glasgow, at a date as early as the year 1759; but their researches were attended with no important advances.

154. In 1761, Watt made experiments with an apparatus resembling the engine of Leupold; but becoming aware of the danger attending the use of high steam on a large scale, he ceased from any farther pursuit in that direction.

155. In 1764 he was employed by Professor Anderson, then holding the chair of mechanical philosophy in that institution, to repair a working model of Newcomen's engine. The obvious waste of steam that he found to attend the action of this model, and the great quantity of injection water it required, struck him as facts unaccounted for by any previous scientific reason. Suspecting that the first defect might arise from an erroneous estimate of the comparative densities of steam and water, he, by a few simple experiments, endeavoured to ascertain the true relation, and found that water in becoming steam expands itself, under ordinary pressures, to 17 or 1800 times the bulk it had previously occupied. This is not far from the truth, as we now know from more accurate experiments, and corresponded with the estimate of Smeaton. At this density for steam, his experiments shewed that six times as much steam, as was simply sufficient to fill the Cylinder, was expended at each stroke of the piston. He at once attributed this increased expenditure to the cooling of the Cylinder. The great quantity of injection water next engaged his attention, and the high heat the Cylinder retained in spite of the large quantity admitted. By adapting a bent tube to a common teakettle, and immersing the end of the tube in a vessel of cold wa-

ter, he passed steam from the kettle into the cold water, by which the steam was condensed. The temperature of the water was increased by the heat of the condensed steam; and by inquiring into the gain of weight which had taken place when the water reached the boiling point, he inferred that it required six times the weight of the steam simply to effect its condensation, without lowering its temperature, or, that 1800 measures of steam were capable of heating six measures of water to their own temperature, although the 1800 measures are derived from no more than one measure of water. Thus he reached experimentally one of the most important facts of the doctrine of latent heat, a doctrine which had been that very year taught in the same institution, for the first time, by Dr. Black. On communicating the result of his observation to that distinguished chemist, he received from him an explanation of that doctrine, which furnished the confirmation and rationale of the phenomenon he had observed.

His experiments also shewed him that the pressure of steam increased nearly in geometric progression, while its temperature was raised in arithmetic. The decrease of tension at lower temperatures follows a similar law; and hence the pressure of the atmosphere on the piston never acted with a force greater than eight pounds per square inch.

156. Thus, then, the cause of the imperfections of Newcomen's engine became apparent at one and the same time, by the aid of actual experiment, and by the application of the general theory of Black. But it was far less easy to point out the remedy for these defects than to discover the cause. It was evident, that to obtain all the power the steam was capable of exerting, the Cylinder should not be colder than the steam which entered it; while, on the other hand, the condensed steam should not raise the injection water above the temperature of 100° at the very outside, while a lower temperature would be preferable. The mode which he adopted, of meeting these two requisites, is as simple as it is ingenious; yet it was not attained without great study and reflection on his part.

157. It was not until a year after his performance of the experiments we have spoken of, that it occurred to him that if a communication were opened between the Cylinder of the steam engine, and another vessel exhausted of air, the steam would rush suddenly into the empty vessel ; and that, provided the latter were kept cool by being immersed in water, or by injection, the steam would continue to flow until the whole were condensed.

158. With this idea he appears to have entertained, at the same time, the intention of using steam itself as the moving power instead of atmospheric pressure, and his experiments on its elasticity had shown him that a small increase in its temperature would probably give a very considerable addition of power. To effect the latter part of his plan, it would be necessary to make the piston-rod work air-tight, through a lid or cover adapted to the cylinder. A modification of the common air-pump had an arrangement that served as a model of the latter method, the barrel being covered by a lid, having at its centre a collar of leathers, by which the passage for the pump-rod was rendered air-tight.

159. It next became obvious that the piston could not be rendered tight in this case by keeping a mass of water floating upon its surface, for this liquid would have been speedily evaporated, and would have wasted much heat. Hence, more perfect workmanship would be required, and the packing must be moistened with a liquid that did not boil, except at a temperature higher than that to which the steam was ever raised. Oil is a liquid of this description ; but tallow, which becomes fluid at a temperature below that of ordinary steam, is still better. It is said that he originally proposed a packing of leather, but as this substance chars and cranks at a comparatively low temperature, it is unfit for the purpose, and bands of hemp were employed in its stead.

160. To keep the cylinder from losing heat too rapidly, he conceived the idea of enclosing it in the *Jacket.*

Two methods occurred to him of keeping up a vacuum in the condenser. The first was that of adapting a pipe thirty-four feet in length, plunging at its lower end into a reservoir of water; the second, that of exhausting the vessel by a pump. The former being applicable in but few cases, he chose the latter for general use; and we have, indeed, no instance of the first being applied in practice.

161. These views were submitted to the test of experiment, first in an apparatus of small size, and finally in a working model, whose Cylinder was nine inches in diameter. The results were as satisfactory as his most sanguine expectations could have anticipated, and convinced him that he had discovered the means by which all the physical defects of the ancient engines could be remedied; the steam no longer wasted by admission into a cylinder cooled by injection; and a vacuum far more perfect obtained, than had ever been before reached.

The expense of constructing a steam engine, and the difficulty of inducing capitalists to embark in an untried scheme, seems to have deterred him from bringing it forward; and he devoted himself, for upwards of three years more, to pursuits far beneath the powers of his mind.

162. It is, even at the present day, rare to find in men wholly devoted to business pursuits that acquaintance with physical principles which will enable them to judge of the merits of an improvement in the arts that rests wholly on those principles. And such was the invention of Watt, which differed, as far as superficial examination could reach, from the engine of Newcomen, only in the addition of a cumbrous appendage, of which the light of physical science alone could exhibit the appropriate use, and manifest all the importance. For information of that description it was in vain to seek among the traders of Glasgow at that early period, and Watt wisely determined to keep his discovery to himself until he could meet with a person qualified to appreciate its merits. Such a coadjutor he at last found in the celebrated Dr. Roebuck, a person to whom

Great Britain is under great obligations as the founder of the Carron works, in which the manufacture and application of cast iron was brought to that degree of perfection, which has added so much to the wealth of that country.

Educated in the most liberal manner, and for a learned profession, he became an adept in all the chemical and physical sciences of the day, and had applied his knowledge to the establishment of a chemical manufacture whence he was deriving enormous profits. These he undertook to apply to mining for coal and iron at Kinneil, and to the establishment of the celebrated manufactory of iron, of which we have spoken.

163. His scientific intelligence at once appreciated the whole merit of Watt's improvement, and he gladly furnished the funds for constructing an experimental engine, which was tried in the drawing of water from one of the mines at Kinneil. This engine worked as well as had been anticipated, and Watt was furnished by Roebuck with the means of securing his invention from piracy, in the form of a patent.

In return for his advances, Roebuck became joint proprietor of the patent, and from his capital and influence, Watt had reason to hope for the speedy introduction of his invention into general use. But Roebuck had embarked in schemes beyond the reach of his finances, and of these, one, so far from being profitable, was ruinous to his fortune. The Carron works indeed flourished, but the mining speculation made no returns ; and so far from being able to assist Watt any further, he was himself compelled to abandon, not only his least promising scheme, but also that which was going on successfully, and thus to leave to others to profit by the fruits of his intelligence and enterprize. In the wreck of his affairs, his share of Watt's patent passed into the hands of his friend Bolton of Birmingham. This skilful and enterprising merchant was not only well qualified to appreciate the merit of Watt's invention, but possessed the capital, by the aid of which alone it could be brought into successful operation.

164. The first patent of Watt is dated in March, 1769, and

when an application was made to Parliament for its extension, opposition was made, on the plea that the most important part of his invention, the separate condenser, had been invented at a period at least as early as the date of the patent, by a person of the name of Gainsborough. This claim was, however, set aside in consequence of clear and decided proof that Watt's method was not only original with him, but earlier in date.

165. It does not appear that any other of the methods by which Watt had rendered his engine so superior to all former ones, had occurred to Gainsborough or any other person. Still we have no reason to doubt that Gainsborough had actually, and by investigations of his own, reached the plan of a separate condenser; and we cannot but believe that the study of the doctrine of latent heat might have led others, at a date not much later, to a similar discovery. That the improvements in physical science had rendered the world ripe for the introduction of Watt's invention, need be no diminution of his great merit; for, if not the only one who thought of the remedies we have mentioned above, he was undoubtedly the first, and prior by several years to any other person. Nor is it merely by priority of invention that Watt is to be distinguished; there was a finish and completeness about every plan that emanated from his mind, which suited it at once for practical usefulness.

This, indeed, was a peculiar trait of the genius of Watt; invention was with him so much a habit, that he rarely examined any project without suggesting improvements; while caution, almost amounting to timidity, led him to keep back from the world his own discoveries until he felt assured of their success. This excess of caution would probably have retarded, if not wholly prevented his success, had he not been fortunate in his connexion with a partner, who possessed the boldest spirit of mercantile enterprize, united to the most consummate judgment and prudence. In this point of view we may consider the world as being almost as much indebted to the intelligence and business ability of Bolton as to the genius of Watt.

English writers have spoken of Watt as illiterate and deficient in education. If he is to be judged by the standard of classical knowledge, to which alone the name of learning is given in that country, the assertion might be true. But we should rather be inclined to cite him as an instance of an education exactly directed to the purpose of rendering him useful in the important career to which he was called. The public schools of Scotland, if the mere pedantry of classical knowledge be neglected, give that species of instruction which extends the power of using the vernacular tongue for all business and practical purposes; Watt, besides, became a good practical geometer, and his early pursuits compelled him to be acquainted with all the physical science that was then known. When to this was added practical skill in mechanical operations, we cannot but think that Watt had derived from education that knowledge which was exactly suited to render him eminent.

166. We have stated that the engine of Watt dispensed with the use of water for the purpose of keeping the piston tight, and that a greater degree of accuracy was in consequence required in the workmanship. The Cylinders of steam engines are cast hollow, by means of a core that fills up a part of the mould. They are then reamed out, and brought to the proper size by means of a borer, or tool affixed to a revolving axis. Great improvements in the boring of Cylinders were introduced by Smeaton at the Carron works, but the method was not, at the date of Watt's patent, so perfect, as to give the interior a form wholly independent of the original shape of the cavity. But Watt had the advantage of receiving, just as he was about establishing a manufacture of steam engines at Bolton's works of Soho, near Birmingham, a new method of boring. This was the invention of Mr. John Wilkinson, a proprietor of iron works, at Birsham, near Chester. Watt immediately availed himself of this improvement, and was, by means of it, enabled to furnish Cylinders of a perfection of workmanship that had previously been despaired of. In a Cylinder of fifty inches diameter, constructed by him at an early date, the greatest error was less than the sixteenth part of an inch. This perfection of workmanship was almost essential to the introduction of steam into general use, as a prime-mover of machinery; for, although the process

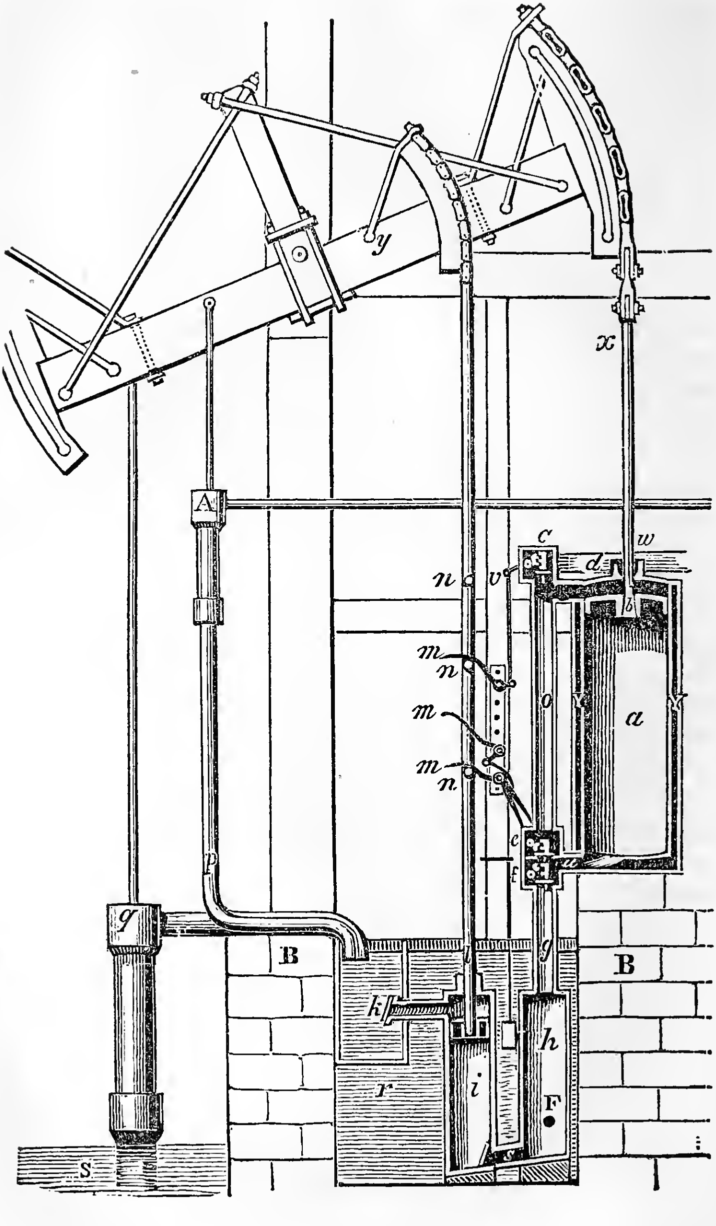
of raising water had been, and might still have been, effected with advantage by Cylinders of less accuracy, the durability of the engine would, even in this very limited application of its powers, have been lessened, while the delicate operations it now performs would have been impracticable. This method of boring was still further improved, until a six foot Cylinder could be bored, with no error greater than the fortieth part of an inch.

167. In the first engine of Watt, the piston was attached by chains to the lever beam, from the opposite end of which the pump-rod, loaded with a weight, hung. The primitive position of the instrument is therefore the same as in that of Newcomen, namely, the pump-rod preponderates, and holds the piston in its highest attainable position. The engine has three valves, by one of which steam is admitted beneath the piston into the Cylinder, where it displaces the air, and fills its cavity wholly. So soon as the Cylinder is thus filled with steam, this valve is shut, and the remaining two are opened ; through one of these the steam passes into the condenser, which acts to convert the steam into water, partly in consequence of the coldness of its sides kept constantly immersed in a cistern of water, and partly by the aid of a jet of injection water ; through the other valve, steam flows from the boiler and presses down the piston, thus causing a motion at the opposite end of the beam, and raising the pump-rod. The piston having reached its lowest position, these two valves are closed. It thus becomes necessary that the piston should be again raised to its original position by the weight attached to the pump-rod. This might have been done by allowing the steam situated above the piston to escape into the air, and permitting steam to flow into the lower part of the Cylinder. The pressure on both sides of the piston being thus nearly equalized, the weight would have preponderated and raised the piston. But in this case a Cylinder full of steam would be condensed at each descent of the piston, and another allowed to escape, without effect, at each ascent. The waste of the last-mentioned quantity of steam was thus obviated by Watt ; a pipe was adapted to the side of the Cylinder ; in this the two

steam valves were placed so that the communication, from the lower of these valves with the boiler, could only be effected by opening the upper one. Hence, in first filling the Cylinder, both of these valves must be opened at once; in all other cases they act alternately. The upper valve was placed above the passage by which steam enters into the upper end of the Cylinder, and thus only the lower steam valve intervened between the steam acting on the piston from above, and that rushing into the condenser from below. The piston having reached its lowest position, the steam and condensing valves are shut, and the valve in the side pipe is opened; a communication is thus made between the steam above the piston, and the part of the cylinder beneath it, the weight of the pump-rod then acting upon the piston, will meet no other opposition than the friction of the piston itself, and the resistance which the steam experiences in passing through a pipe; the weight will therefore preponderate, the piston will be drawn up, and the steam will circulate from the upper side of the piston through the side pipe, and fill the space beneath the piston.

The upper valve alone is a steam-valve, except when the engine is to be set in motion; at which time the second valve is opened with it, and admits steam to the lower part of the cylinder. In all other cases the latter is merely a valve of communication, and may be called the equilibrium valve. The third valve may be called the condensing valve.

This arrangement may be better understood by the inspection of the following figure, and the uses of the parts will be understood by reference to the description of the double-acting engine.



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a, Cylinder.
b, Piston represented in its primitive position.
c, Steam-valve.
d, Steam-pipe.
e, Equilibrium-valve.
f, Condensing-valve.
g, Pipe leading to condenser.
h, Condenser.
i, Air-pump.
k, Hot-water cistern.
l, Air-pump rod.
m, *m*, *m*, Hand Gear.
n, *n*, *n*, Tappets of the Plug-frame.
o, Side-pipe.
p, Hot-water pump,
q, Cold-water pump.
r, Cold-water cistern.
s, Foot-valve.
w, *x*, Piston-rod, working in a stuffing-box at *w*.
y, Working-beam.

168. Still further to diminish the loss of heat, Watt pumped back the water of condensation into the boiler; by these several improvements so great a saving of fuel was obtained, that the patentees asked no other remuneration for the use of the invention, except one-third part of the value of this saving. In a single mine in Cornwall, where three of their engines were employed, this compensation was commuted for £8000 sterling per annum.

The valves still continued to be opened and shut by an apparatus similar to the plug-frame and hand-gear of Beighton, but improved, and rendered more easy in its action; the former became a part of the rod of the pump by which the vacuum of the condenser was maintained. The pump and piston-rods were still suspended by chains from circular arcs forming parts of the lever-beams, and the air-pump rod was suspended in the same manner; the latter, therefore, required a weight to return it downwards, after it had been raised by the beam.

The condenser and pump underwent various modifications before Watt was satisfied with their action, and finally assumed the form described in treating of the double-acting engine.

169. Previous to the time of Watt, there had been but little demand for steam, as a moving power, for any other purpose than that of raising water; and for several years after his first researches, the state of the manufactures of England was not such as to require powers beyond what could be obtained from natural waterfalls or the action of the wind. Savary had, indeed, proposed to make the water raised by his apparatus fall upon an over-shot wheel, and thus to apply the power of steam to any manufacturing purpose whatever. Similar projects had been entertained in relation to the engine of Newcomen. Neither of these, however, could have been applied to any advantage, in consequence of the great cost of fuel they must have occasioned, particularly as the effective power of a wheel is considerably less than the absolute mechanical force of the water employed.

The several projects of steam-boats that we shall hereafter speak of, necessarily required rotary motions; but these were all imperfect and abortive. Leupold's engine alone, had the two pistons been applied to cranks situated upon the same axis, could have produced a rotary motion; but the inventor does not appear to have been aware of the value of this part of his own invention, or at least did not consider this application of it of importance.

170. In 1757, a person of the name of Fitzgerald attempted to take off a rotary motion from the piston of Newcomen's engine by means of ratchet-wheels, that could be forced forwards during the descent of the piston, but would remain fixed during its ascent. The continuity of the motion was to be kept up by a fly-wheel. This was too imperfect a method to be succesful, and had no result. A similar project was entertained by persons of the names of Stewart and Clarke, who attempted to apply it to sugar mills in Jamaica; but this, like the other, was abandoned as impracticable or useless. Still later, at a colliery

in England, a drum for raising coal had been worked by an atmospheric engine, but even this rude apparatus was but imperfectly driven. Hence it was left for Watt to fit the steam engine for general use, as well as to improve it in its application to the sole purpose in which its energies had been successful before his day.

171. The first step towards making the steam engine capable of producing a continuous motion in machinery, was to make the piston work during its ascent as well as its descent; for both in the atmospheric engine, and the first engine of Watt, the moving power is exerted only to press down the piston, which is afterwards returned to its original position by the action of a counterpoise.

Watt, whose caution was equal to his genius, proceeded in his inventions by slow and gradual steps. His first engine hardly varied from Newcomen's in external form, and was, in truth, rather a great and all-important improvement upon that imperfect apparatus, than an invention absolutely original. In the same manner his double-acting engine was obtained by a slight and simple alteration of his former one. It was required that the piston should be forced upwards as well as downwards by the steam; he effected this by adding one additional valve to the three employed in his single-acting engine. The equilibrium valve of the single engine became a steam valve, instead of serving as a mere communication between the opposite sides of the piston, and the valve that was added was one forming a communication between the condenser and the upper part of the cylinder. Hence it was necessary that the steam-pipe should extend to the lower pair of valves, and the condensing pipe to the upper; the side pipe was thus doubled. The improved hand gear of Beighton was still retained, to open and shut the valves.

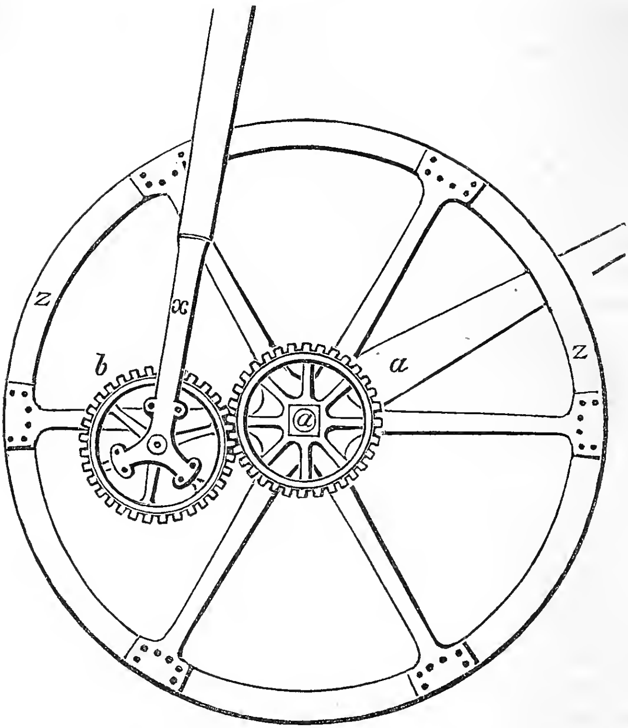
The mode of operation of this engine has already been fully explained, it is therefore unnecessary to repeat it here. But it did not at first assume the perfect form in which it has been represented in chapter IV. The steps by which Watt proceeded were as follows. The rectilineal motion of the piston-rod having been rendered capable of exerting an equal force, both during its ascent and descent, a connexion with the beams by chains was no longer sufficient; for although they would be efficient in drawing the beam downwards, their flexibility would not admit of their forcing it upwards. It hence became necessary that their connexion should be made of a rigid material, and yet in such a manner as to permit the rectilineal motion of the one to accommodate itself to the circular motion of the other. True to his general system of slow and cautious improvement, Watt attempted at first no violent alteration. The circular end of the lever beam was merely cut into teeth, or rather had a toothed segment bolted to it, and for the chain a rack was substituted, which caught into the teeth of the segment. Thus the stroke of the piston became effective, both during its ascent and descent. It will be obvious, however, that this is a rude and imperfect method, and he speedily contrived a better in the shape of the parallel motion:

172. About the time that Watt undertook to adapt his principle to general purposes, an engineer of the name of Washborough attempted to attain a similar end, by means of the atmospheric engine. His plan was very similar to Fitzgerald's, and was improved by Pickard. Engines of their joint construction came into use in Gloucestershire, and at the block manufactory of Mr. Taylor at Southampton. The first actual application of the crank to the steam engine seems to have been due to Pickard.

173. Watt however, at an earlier date, conceived the idea of making two single-acting cylinders act upon cranks situated upon the same axis, and thus produce a continuous rotary motion. In the attention which the introduction of his engine into use for raising water required, this idea was suffered to remain unimproved until he had completed the plan of making the engine double-acting, and of communicating the motion of its piston to the beam, by the rack and toothed segment. To apply the motion thus obtained to general purposes, it became necessary to convert the reciprocating motion of the beam into

one continuous and rotary. That a crank was the most simple and obvious means of performing this has already been shown, and Watt recurred at once to the idea we have stated above, as having suggested itself to him, except that in the double-acting engine but one crank would be necessary. Various simple and familiar instruments have rotary motions, that are produced by this instrument. Among these may be mentioned, as of most frequent occurrence, the Potter's wheel; the turning lathe; and a variety of the spinning-wheel, then in constant use, although now nearly obsolete. The friends of Watt assert that his views were communicated by a workman, who passed from his employ to that of Pickard; but there is no reason why both may have not fallen upon the same simple and obvious plan of producing the same kind of motion. Be this as it may, Pickard took out a patent for the application of the crank to produce a rotary motion in the Steam Engine, and Watt, satisfied that his own ingenuity could provide a substitute, did not attempt to contest it, but left it as an obstacle in the way of his other competitors.

174. To produce the effect that the crank was intended to perform, he adapted to his engines an apparatus called by him the sun-planet wheel. This is represented on the following page.



x, Connecting Rod.

$z\ z$, Fly-wheel.

a, Wheel fixed upon the axis of the fly-wheel.

b, Wheel revolving upon a pivot at the extremity of the connecting-rod.

The wheels a and b, having equal radii, whose sum is equal to the length of the stroke of the engine, the teeth of the wheel b will apply themselves to those of the wheel a, during the whole motion of the engine. The wheel b will turn the wheel a around, and cause the axis of the wheel, to which the latter is attached, to revolve.

It will be obvious that the axis of the fixed wheel must revolve twice as fast when driven in this manner as it does when propelled by means of a crank; there are, in consequence, cases where it may be better suited to the required work than the crank; such was the case in the earlier adaptations of Watt's engine to manufacturing purposes. When, however, in his subsequent engines, a crank furnished a better and more suitable speed, he did not hesitate to employ it, confident in the priority of his own claim to its application.

175. We have thus seen Watt taking up the engine in a very imperfect state, gradually perfecting it in its application to its ancient purpose, and finally rendering it universal in its uses. He also made many accessory improvements, by which its use was rendered more easy and certain. Of these we may particularize the steam-guage, the barometer guage for the vacuum of the condenser, the self-acting feeding apparatus, the self-regulating damper, and the form of boiler which is yet most generally employed with double-acting condensing engines.

Under his directions the hand-gear of Beighton was first improved, and finally superseded by the eccentric, and the long slide valve was introduced. The eccentric and slide valve were claimed also by Murray of Leeds; but although he may, perhaps, be entitled to the merits of a separate discovery, Watt was successful in showing the priority of his own claim to them.

After the parallel motion was added to the engine, the beam still continued to be of wood, as was the connecting rod. Subsequent steps led to the substitution of the more inflexible material cast-iron, and the pivots of the parallel motion, instead of being, as before, placed beneath the beam, were now cast upon it, and turned down to the proper size and shape. Frames and pillars of iron to support the beam were gradually substituted for the floors of buildings and walls, that were at first used; brass boxes forming the sockets for all the circular motions were introduced; and the external beauty of the machinery improved by perfection of finish, that added equally to the power and durability of the engine. It was in 1778 that Watt made the piston act during both its motions, and he did not cease, to the very end of his life, to extend its usefulness and improve its structure.

No valuable addition to the condensing engine was made except by himself, or under his direction, if we leave out those of

Murray, which we have mentioned, and to which Watt was able to substantiate an earlier and more authentic claim.

176. The application of steam acting expansively is also due to Watt. One of his single engines employed it in this manner at Soho as early as 1776; and he used it also in his double-acting engines almost from their first construction. We have seen, in another place, that he did not reap all the advantages of which this method is capable, nor was he permitted to hold it, as an invention of his own, without contest. Two brothers of the name of Hornblower, in 1782 took out a patent for the use of the same principle, but by means of two Cylinders. In the first of these the steam acts by its tension, and produces an effect equal to that which it does in the high pressure engine. On escaping from this it enters a second and larger Cylinder, in which it expands, and from the opposite side of whose piston the steam flows alternately to the condenser. Thus, then, the resistance which the atmosphere opposes to high steam, is removed, and the effect of its expansion brought into play. As the separate condenser interfered with the patent right of Watt, this plan could not be brought into use, nor was it desirable that it should; for an engine of equal power on this construction is more costly than that of Watt, and it is difficult to make the two Cylinders employed, one containing high the other expansive steam, act in such harmony, that one of them shall not be retarded by the other.

177. Five years of Watt's patent had run out before he had fairly introduced his single engine into use. He therefore made application, in 1775, for an extension of the usual period, and the application was, after much opposition, granted. Thus, by a noble effort of national generosity the profits of his discovery were secured to him for a term of years sufficient to remunerate him for his labours and sacrifices. The patent-right thus extended became the object of a series of attacks, leading to judicial investigation; but in spite of the interested and continual opposition, the patent was in every case maintained.

It is, indeed, highly to the credit of the institutions of Great

Britain that this long contest should, in all its points, have been constantly decided in favour of him to whom the world, after an interval that has deadened all partial feeling, assigns unanimously the merit of discovery. Such an honourable result, we fear, could hardly have been attained in our own country, in which the most carefully guarded patent-rights are proverbially insecure, and those inventions which have added most to the national wealth, have been those that have been of least pecuniary value to the inventors.

A conical pendulum had been applied to mills of various descriptions before the time of Watt. The suggestion of the valuable use to which it might be applied in the steam engine, is said to be due to a Mr. Clarke of Manchester; we do not, however, know whether he ever applied it in practice. It was, whether as an original invention of his own or not, speedily adopted by Watt, and adapted to all his engines where regularity of motion is needed.

178. The patent for Watt's double-acting engine is dated in 1782, and in the same year one was erected at the Bradley Iron Works on this principle. It had the toothed segment on the lever beam, and a rack attached to the piston-rod. Since that period the improved engine has been introduced to a very great extent in the manufacture of iron; for impelling the blowing apparatus in blast furnaces, and for rolling, hammering, and slitting wrought iron.

The patent for the parallel motion was issued in 1784, and in that year the Albion Flour Mills were erected in London.

Two of Watt's double-acting engines, of 50 horse power each, were applied to drive twenty run of mill stones; the establishment was conducted with great profit until the year 1791, when the building, with all the machinery and stock, was consumed by fire. It was suspected at the time to be the work of an incendiary, instigated by those who, by the aid of other prime movers, were unable to compete with the improved agency of steam. The experiment, however, was so far successful, as to satisfy all that the engine might be advantageously adapted to almost every species of manufacturing industry.

In 1785 the first cotton mill moved by steam was erected by Messrs. Robinson and Papplewick, in Nottinghamshire. In 1788, a coining apparatus for copper was erected at Soho, and driven by a steam engine; the machinery there applied has been imitated at the Royal Mint of Great Britain and the Imperial Mint at St. Petersburgh, and all were set in motion by double-acting engines on Watt's construction.

In 1793, cotton was first spun at Glasgow by steam. In the year 1793, it was introduced into the woollen, worsted, and flax manufactures; and in 1797 was employed at Sheffield for grinding cutlery.

179. In the year 1800, the extended term of Watt's patent expired. Up to this time the introduction of his engine into use had been slow. This has been ascribed to the prejudice entertained against the monopoly, but probably is in some measure due to the fact that the arts did not keep up with the rapid improvement of the steam engine. At this date the steam engines in London did not exceed 650 horse powers; in Manchester, 450 were in use; and about 300 at Leeds; while upon our own continent but four engines of any importance were to be found, two of them at Philadelphia and one at New-York, all employed for raising water.

180. During the continuance of Watt's patent, various plans were proposed, which were rendered abortive in consequence of his being in possession of the sole right of using the only plan by which low pressure engines could be rendered efficient, the separate condenser. Hence, with the exception of Hornblower, against whom Watt and Bolton obtained a verdict, there are no important names to be mentioned, except those of Cartwright and Sadler; these two engines are chiefly remarkable for the suppression of the lever-beam.

Watt, as we have already stated, proceeded in his improvements slowly and gradually, and they were all applied to the form in which he found the engine existing. Hence the beam, a heavy and cumbrous appendage, formed a constant part of all his engines, as it had done of the original pumping engine of

Newcomen. The parallel motion, the connecting-rod, the sun and planet wheel, the rods of his air, cold, and hot water pumps, were all adapted to this part of the ancient apparatus; and from the use made of it in working the latter, it appeared to be almost indispensable. In Cartwright's engine the beam was suppressed altogether, and with it the separate pumps. A cross-head was placed upon the piston-rod, bearing two short connecting rods, that turned the cranks of two wheels of equal diameter catching into each other, and a pinion attached to the axis of the crank was driven by one of them. As this engine did not work as well as the double-acting engine of Watt, it merits no further notice at this stage of the history; although, had it appeared before the improvements of Watt, it would have been of great value. Cartwright is, however, to be mentioned with high praise as the inventor of the metallic packing for pistons, which, as has been stated on a former page, promises to supersede all others.

Sadler's engine was a single-acting engine, differing from Watt's principally in the position of the equilibrium valve, which was situated in the piston itself. A wheel was fixed to an axis passing at right angles through the top of the piston-rod; this worked between guides, and on the opposite end of the axis was placed the connecting-rod that turned the crank of the fly-wheel. The rod of the air-pump was worked by a short lever, the centre of whose motion was at the end, instead of the middle, as in the ancient beam, and which, having no other work to do but that of pumping, was much lighter than the latter.

From the date of the expiration of Watt's patent, the use of the double-acting condensing engine has been extended in a rapidly increasing ratio, insomuch that far more engines are now made at Soho, in spite of the ardent competition of various manufacturers, than were ordered while Watt was possessed of the sole right of making engines, as well as using his principle.

181. The improvements made in the condensing engine since that period have principally consisted in the finish and perfection of the parts, and in this Murray of Leeds has been most distinguished, his engines having a beauty of proportion and

accuracy of workmanship exceeding most others. In England, the beam has been continued in almost all cases except in the engine of Maudslay, while in this country it has, in many instances, been laid aside. The first engines constructed in America for Fulton's steam-boats have the form represented in Pl. VII., which is superior to that of either Sadler or Maudslay. Where the beam is retained, the parallel motion has been superseded, in several American engines, by a simple slide to guide the connecting strap. The adaptation of this to the lever beam is the invention of Mr. R. L. Stevens, whose name we shall have occasion to quote hereafter as a successful constructor of steam-boats.

The eccentric and slide valve belong to this last period of the history of the double-acting engine, but their invention has been already referred to.

182. The use of the expansion of steam has been stated to have originated with Watt, and we have mentioned the attempt of Hornblower to adapt the same principle to an engine composed of two Cylinders. This, which was defeated in consequence of its interfering with Watt's patent, was revived in 1804 by Woolfe, with a boiler for generating high steam. This engine has been found to work to great advantage; but for reasons mentioned in speaking of Hornblower's engine, it will be obvious that steam of equal tension would act to still greater advantage in an engine composed of but a single Cylinder. This last method has received great extension in several American engines, and in the pumping engines of Cornwall.

It has been seen that the plans proposed during the term of Watt's patent were either such direct infringements as to be prohibited by legal proceedings, or wholly inferior in utility to his inventions. The very year, however, that saw his patent expire, also saw the introduction into use of two engines, that, had they been brought into perfection before, might have competed with that of Watt upon equal terms. For the history of one of these we are compelled to go back almost to the date of Watt's earlier discoveries.

183. Oliver Evans, well known in this country as an excel-

lent mill-wright, and as the inventor of the labour-saving machinery in grist mills, entertained the idea of the possibility of propelling wagons by the action of high steam as early as 1772. Soon after, he ascertained, by experiment upon a small scale, the practicability of so doing; and in 1786 applied to the State of Pennsylvania, which (under the old Confederation) had not parted with this attribute of sovereignty, for an exclusive privilege. It is well to remark that his engine was from the first intended to be double-acting, and that even the last-mentioned date is but little later than the construction of the engines for the Albion mills, whose principle was long kept secret by Watt. His applications, both for private and public patronage, were treated as the reveries of insanity, and it was not until 1801 that success in his profession enabled him to raise the funds for erecting an experimental engine. This was first applied to grind gypsum, and afterwards used in sawing marble. It was publicly exhibited in Philadelphia in that year.

In 1804 he was employed by the corporation of Philadelphia to construct a dredging machine to be worked by steam; with this he made successful experiments, both on locomotion and navigation by steam, that will be mentioned in their proper place. Not the least of the improvements of Evans lies in the form of his boilers, which he was the first to make in the form of a cylinder; a form that we have already shown to be preferable to any other yet proposed. His first experiments were made with a gun barrel, and he steadily adhered to that form in his subsequent operations.

The engine of Evans retained the lever beam of Newcomen, and has been copied in this respect in many American engines, of which the beautiful one figured on Pl. V., is a specimen. In others, the arrangement in Pl. VII. has been adopted, and others again are horizontal, as represented on Pl. VI. The latter form has hitherto been principally used on the Mississippi and its branches. The high pressure engine came more early into general use in the United States than it did in Europe, and long experience has rendered its proportions better understood in our country than they are in England. It is with us the favourite form, except in the steam-boats of the Atlantic coast. In these, a fear of the greater danger, with which it was thought to be attended, has prevented its introduction. It seems, however, to be now almost conceded, that, with proper precautions, boilers generating high steam may be rendered as safe as any others; and hence the conclusion has been drawn that high steam, acting expansively, as it is the most powerful application of steam, will, wherever circumstances will admit, supersede all other methods.

184. The year 1801 also witnessed the construction of the high pressure engine of Trevithick and Vivian. The boiler in this case was a Cylinder of cast iron; the fire was made within it, and hence it is less safe than the boiler of Evans. The Cylinder was immersed in the boiler, in order to retain the heat of the steam. In the first engines it was attempted to condense the steam; but this is always attended with disadvantage, unless when the steam has had an opportunity of cooling itself by expansion. The fly-wheel, connecting rod, and crank were above the Cylinder, and no parallel motion or beam was needed. In the application of the engine to locomotion, a plan of connecting rods like those on Pl. VII. was finally adopted, but, so far as we can learn, only one connecting rod was used at first, even in this case, as in the engines of Sadler and Maudslay.

Such is the history of the engines that are now in actual use, or have served as steps to the present state of the art. Another class remains to be mentioned.

185. Watt had included in his first patent a method of producing a rotary motion by the direct action of steam, but had with sound judgment abandoned it in favour of a double-acting Cylinder engine. In spite of this virtual acknowledgment of the inferiority of this principle, innumerable projects have since been entertained of rotary engines. The result of these experiments may be summed up in a few words. The advantage to be derived is, in fact, of but little moment, while the mechanical difficulties that lie in the way are such as have hitherto prevented any engine having a rotary motion, produced by the direct action of steam, from coming into general use.

Among the various rotary engines which have been proposed, we may mention one by the Hon. R. Sherman of Connecticut, which was exhibited recently in New-York, and which performed well.

That which is exhibited in the annexed draught, has been

Fig. 1.

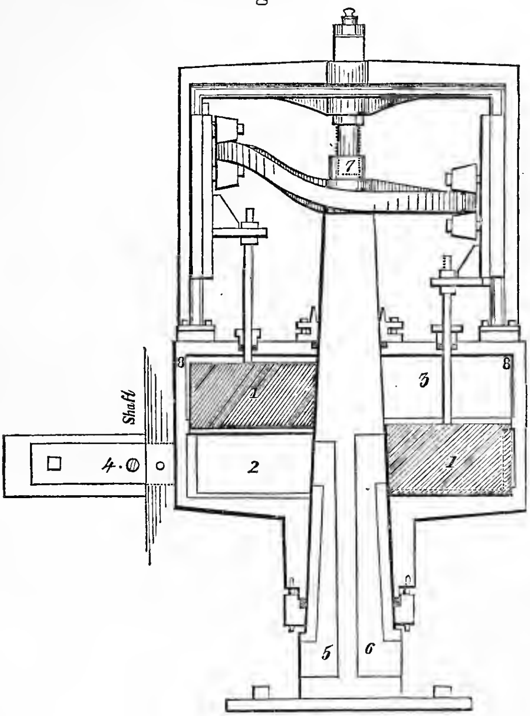
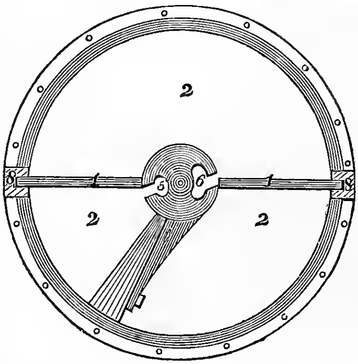


Fig. 2.



for several years in actual use in the western part of the state of New-York, and has been employed to propel a boat on the Morris Canal. In this engine the gates marked 1 and 1 receive the pressure of the steam which enters through the passage 5, and is discharged at 6. These passages are so situated that one of the gates will be always receiving the pressure, and during its action the other gate is lifted over a partition or diaphragm by means of a curved wheel 7, which runs between friction rollers. Of this engine Fig. 1. is a section, and Fig. 2. a plan.

The principle of reaction, which has been attempted in Barker's mill, where water produces a rotary motion by issuing from holes placed near the ends of a moveable arc, has also been proposed as a mode of using steam. We have described an instance of this kind in the engine of Avery.

The Cylinders of engines have occasionally been suspended on trunnions; in this case the piston-rod may be applied directly to the crank. The earliest of these was one constructed by French in 1808, in a steam-boat in the Harbour of New-York, a model of which of the same date is among the apparatus of Columbia College.

186. In the brief sketch we have thus given of the History of the Steam Engine, many ingenious contrivances and inventions have been passed over. These have been omitted for want of space, and because few of them, however ingenious, have had any prominent effect in introducing the steam engine into more general use. The different forms of boilers that have been proposed, or even actually used, would occupy no small room. The object of our essay is, however, accomplished when the engine has been traced, from its first rude beginning to those forms in which it is found in most common use, and when we have noticed those different inventions that have tended to facilitate its progress, or by which it has been fitted the better to subserve the purposes for which it was invented. The most important step is undoubtedly that made by Watt, and it is remarkable in the history of the arts, not more from the immense value that it has had in its practical application, than for being the result of scientific research and the study of physical principles, by the most elegant and accurate processes of induction.

CHAPTER IX.

APPLICATIONS OF THE STEAM ENGINE.

General view of the applications of the Steam Engine.—Raising water.—Grinding corn.—Cotton Spinning.—Navigation.—Bossut's laws of the impact of fluids.—Principles of the action of Paddles.—Juan's laws of the action of fluids on solids moving in them.—Maximum speed of vessels.—Power required to propel paddles.—Relation between the power and the surface of the Paddles.—Laws of the motion of Steam-boats.—Theory of paddle wheels.—Comparison between theory and observation.—Practical Rules.—Suggestions for the improvement of Steam Navigation.—Steam-boat engines.—History of Steam Navigation.—Navigation of the Ocean by Steam.—Rules for Boilers of Steam-boats.—Application of Steam to Locomotion.—History of the Steam carriage.—Conclusion.

187. THE steam engine is now applied to almost every species of manufacturing industry, and as a substitute for the labour of men and animals in almost every art, and in many of the other cases in which they were formerly employed. In its earliest forms it was used to raise water, and still in its more perfect shapes fulfils the same object; it performs almost every variety of manufacturing manipulation; propels vessels through the water; and drags carriages upon railways, and even upon common roads.

188. In raising water, pumps may be adapted to the beam of the engine, and the useful effect may be safely taken, at the raising of 24000lbs, one foot high per minute, for every horse

power of the engine, estimated in the manner that has been pointed out.

In pumping by the steam engine, it would appear from experience that the stroke of the pump-rod should not exceed eight feet. The number of cubic feet of water which a pump will deliver per minute, may be found by multiplying together half the velocity of the pump-rod, the square of the diameter of the barrel, and the constant fraction 0.00518. The velocity at which the maximum work is performed, and which is to be used in the foregoing calculation, is found by multiplying the square root of the length of stroke by the constant number 98. The proper velocity for a pump of 8 feet stroke is therefore about 270 feet per minute, and as the pump-rod is suspended from the end of a lever of equal arms, the velocity of the piston of the engine is the same.

The friction of the pumps is estimated as equal to a column of water whose height is the sum of $1\frac{1}{2}$ feet for each separate pump or lift, and of $\frac{1}{20}$th of the whole height to which the water is to be raised. These quantities must be added, therefore, to the height, in order to obtain the efficient resistance. Calling this H; the number of cubic feet of water to be raised per minute, W; the pressure of the steam on each circular inch p; and assuming the velocity of the piston to be 180ft: D, the diameter of the cylinder of the steam engine is found by the formula,

$$D=\sqrt{\left(\frac{H\times W\times 0.7332}{p}\right)}$$

The diameter of the barrel of the pump may be found by the formula,*

$$d=\sqrt{3.15W}$$

These rules are independent of the conventional estimate of horse power, and are therefore well adapted to practical application.

The estimate of the quantity raised per horse power, which has been given above, has been far exceeded in practice by the expansive action of steam. The duty of the pumping engines in Cornwall has been raised in this way from an average of 17

* Grier's Dictionary.

millions of pounds for each bushel of coals to one of $43\frac{1}{2}$ millions, and one engine has raised more than 90 millions.

189. In Grist mills, it is estimated that the power of five horses is necessary for every run of stones, and for performing the work necessary to supply them, moving the whole of the usual labour-saving machinery. In applying the engine to this purpose, rotary motions of the proper velocity are taken off from the axis of the crank by systems of wheels and pinions.

The dimensions of engines to perform this description of work are given in the following table :*

Bushels Ground per hour.	Diameter of Cylinder in inches.	Bushels Ground per hour.	Diameter of Cylinder in inches.
4	12.5	26	29
6	14.6	28	29.8
8	16.75	30	31.1
10	18.5	32	32
12	20.2	34	33.3
14	21.75	36	34.2
16	23.25	38	35.2
18	24.75	40	36
20	26.25	42	37.3
22	27.25	44	38
24	28.1	48	39.5

The engine is supposed to be double-acting, condensing, and using steam without expansion. By employing the expansive action of the steam, an increase in the quantity of work which may be performed will be obtained, in ratios which may be inferred from our previous investigation of that method of action.

190. In manufacturing machinery, the motions are taken off in the same manner. It would be tedious, nay impossible, to recite every particular case of this sort; we shall therefore limit ourselves to the spinning of cotton. In this branch of manufacture, it is estimated that each horse power will drive 200 thros-

* Grier's Dictionary.

tle spindles, or 1000 mule spindles, and perform all the work of preparing the cotton for them.

Those subjects which appear to require more full illustration in this work, are the propulsion of vessels, and the motion of carriages upon rail-roads.

191. Vessels in which steam is used as the moving power, are generally propelled by the action of paddle wheels. These receive a continuous rotary motion from the steam engine, and the paddles tend to impel the vessel in consequence of the resistance which opposes their passage through the water. This method, which is the most simple and perhaps the most obvious, has in practice been found preferable to any other which has yet been proposed. In order to give motion to a paddle-wheel, it is only necessary that it should be fastened to the axle of the crank of any of the usual forms of engine. The wheel will thus be caused to perform a complete revolution in the same time that the piston takes to perform a stroke, estimating under that term its whole motion, from the time it leaves either extremity of the cylinder, until it return again to the place whence it set out.

The force which the wheels exert in propelling the vessel depends upon: the velocity with which they strike and move through the water; the immersed area of the paddle; and the fluid resistance of the water. The velocity of the vessel will depend upon the force with which the wheel tends to impel it on the one hand, and the resistance the water opposes to its progressive motion on the other.

To determine the velocity a given engine will give to a vessel, and the conditions under which a maximum effect may be produced, is evidently a problem of great complexity. It does not appear yet to have been solved in a satisfactory manner, nor does it seem to be within the strict limits of analysis, in consequence of the great number of circumstances which must be taken into account. It is, however, possible, by reference to scientific principles, and comparing their results with the facts observed in practice, to form rules which may be of value in the construction of steam vessels.

The action of a paddle-wheel upon the water must be governed nearly, if not exactly, by the laws which fluids follow in impinging upon solid bodies. These may be stated as follows:

1. With equal surfaces equally inclined to the fluid, the resistances are nearly proportioned to the squares of the velocities;

2. With equal velocities, and equal inclinations of the surfaces to the fluid, the resistances are proportioned to the areas of the surfaces;

3. With equal velocities and equal surfaces, the resistances are nearly proportioned to the squares of the angles of inclination, until the angle of incidence diminish to 50°; beyond this, the resistance decreases more rapidly.

4. The measure of the action of a fluid upon a plane surface, to which it acts at right angles, is equal to the weight of a column of the fluid whose height is that whence a heavy body must fall to acquire the velocity, and whose base is the area of the surface on which the fluid acts.

5. As the resistance increases in the ratio of the squares of the velocities, there must be a maximum beyond which a given force cannot propel a plane surface through a fluid.

6. This maximum velocity being given, the maximum of effect will be produced by a paddle-wheel when it moves through the water with one third of that maximum velocity.

192. Experiments appear to be wholly wanting by which the maximum velocity of a plane surface, moving through a fluid, can be determined. It, however, happens that this may be deduced from observation of the rate at which the wheels of steam vessels move; for there is in most cases a very considerable excess of power, and hence the relative velocity of the wheel necessarily becomes that at which the work is most efficiently done, and is therefore one third of the maximum velocity with which the paddle might be impelled had it no work to perform. This relative velocity of the circumference of the paddle-wheel has been found in American steam vessels to be not far from $6\frac{1}{2}$ feet per second.

The maximum velocity of a paddle-wheel when it has no work to perform, might therefore be taken at 19½ feet per second, or 13.2 English miles per hour.

Were the laws of the resistance of fluids to boilers moving through them identical with those of impact, it might be inferred that the last-named velocity is also that of the maximum speed of steam vessels. If we were to take this as the limit, it might be inferred that the proper velocity to be given by the engine to the circumference of a paddle-wheel should be 26 feet per second in order to give to the vessel a velocity of 13.2 English miles per hour, and retain for the wheel a relative velocity or rate of motion through the water of 6½ feet per second.

Although this is by no means true, and although there are now many instances in which boats have been driven at a higher velocity than 13.2 miles per hour. We shall rest at this point for the present.

193. The greatest speed of vessels, and consequently the maximum velocity of paddle-wheels, may be examined, either by the aid of theory, or ascertained by actual experiment. For the theoretic investigation we may have recourse to the principles of Don George Juan.

It is stated by this author, that the resistance which opposes the motion of bodies moving in fluids, may be divided into three parts:—

1. A resistance growing out of the disturbance of the conditions of equilibrium, and arising from the friction of the fluid. This is a constant force.

2. The fluid resistance proper, which varies with the square of the velocities. This has so small a co-efficient, that it is insensible at small velocities, but increasing with their squares, it speedily becomes the most important, and the first bears then so small a relation to it, that at mean velocities this need alone be taken into view.

3. The wave raised in front of the moving body, and a want of support from behind, growing out of the space which the body leaves unfilled behind it when the velocity becomes

great. The mere resistance, growing out of these causes, increases with the fourth power of the velocities, but, in addition, the weight of the body must be raised upon an inclined plane, and hence will arise a limit beyond which the velocity of a vessel cannot be carried.

At small and mean velocities, this species of resistance is wholly insensible, but it finally becomes, in consquence of its rapid increase, the most important of the three. It is when this occurs that we would fix the limit of the speed that can be advantageously given to a vessel, or with which a paddle can be impelled.

194. The exact limit of speed at which the wave raised in front of a vessel becomes an insuperable obstacle to an increase of velocity, depends upon circumstances for which no theory can account. In our former edition we ventured to place this limit at 12 nautical miles per hour, and this was the greatest speed which had been reached in American steam-boats. In all which then existed, a prodigious wave was raised in front at rapid motions. This important resistance led our naval architects to modify the figure of the prows, and they have thus proceeded by successive steps, until, in the case of the steam-boat New-York, no perceptible wave is formed. It appears, therefore, almost impossible in the present state of our knowledge to limit the speed which may be attained by steamboats.

The experiments of Juan were made at velocities less than the least which are now given to steam-boats, and there is good reason to believe that his theory ceases to be true at the higher velocities. The result of the practice upon the Hudson seems to prove, that at velocities exceeding 10 nautical miles per hour, the resistance, so far from varying with the squares of the velocity, becomes almost constant. This at least is certain : every increase in the rotary velocity of the paddle-wheel, has been attended with an equal increase in the progressive velocity of the vessel. The expenditure of steam is, however, in a greater ratio than the velocity ; but this is easily accounted for when it is considered that, in order that it exert a given pressure on a piston in more rapid motion, it must have a greater tension in the boiler.

Experiments have been made on a large scale upon the motion of boats on the Firth and Clyde, and on the Monkland Canal in Scotland, by Mr. McNeill. His conclusions as are follows:

1. In a wide and deep canal the resistance was observed to increase with the velocity, but not in any uniform ratio.

2. In a shallow and narrow canal the resistance had a limit at a certain velocity, and thereafter decreased with an increase of the velocity.

3. That the resistance bore a relation to the inclination of the keel.

4. That the boat rises in rapid motion, being in some cases, on an average, four inches less immersed in the water than when at rest. This rise was greatest at the bow, and least at the stern.

Mr. Russell, who had observed similar facts, comes to the conclusion that at a velocity of 43.8 miles per hour the vessel would no longer be immersed, but would skim along the surface. This corresponds with what is observed in the ricochet of cannon balls, which occurs only so long as they retain considerable velocities.

195. To determine the power required to propel a paddle-wheel through the water with a given velocity, we must consider that the measure of force depends not only on the resistance overcome, but the velocity with which it is conquered. Hence it would appear that the resistance estimated as being equal to the weight of a column of water whose base is the area of the paddle, and whose height is that whence a heavy body must fall to acquire the velocity, is to be multiplied by the velocity per minute, and the product divided by the weight raised by the unit of power in the same space of time.

The height due to a given velocity is found by dividing the square of the velocity per second by the constant number 64.

The unit of power is 32,000lbs. raised one foot high, but this is probably reduced in the machine itself, as we have heretofore seen, to 24,000lbs. Hence we would have the following rule :

Multiply together the cube of the relative velocity, the number of seconds in a minute, the weight of a cubic foot of water in $62\frac{1}{2}$lbs., and the area of the paddle in feet, divide the product by the constant number 24,000 multiplied by the constant number 64, the quotient is the horse power.

This rule, however, is obtained by neglecting very many of the circumstances which ought to be taken into account, and must therefore be very wide of the truth. It is also difficult to determine the mean relative velocity, for this varies at every possible inclination of the paddle. A very beautiful investigation is given in one of the appendices to the new edition of "Tredgold on the Steam Engine," by Mr. Morway. In this, all the circumstances seem to be taken into account, and the results of the theories correspond very closely with observation in British steamers. We fear that this elegant investigation gives formulæ altogether too complex for the use of practical men. We shall, in consequence, prefer to deduce rules from experience.

The other rules, which have been deduced from theory, are as follows :

In the same vessel, and with a constant relation between the area of the paddle-wheels and the transverse section of the vessel, the velocities are as the cube roots of the powers of the engines.

The relation between the velocity of the wheels and of the vessel is constant so long as the ratio between their surfaces remains the same.

It is obvious that this last rule cannot be correct, if it be true, as we have inferred, and shall hereafter show by a comparison of various observations, that the relative velocity of the circumference of paddle-wheels is a constant quantity.

196. If we apply the rule for the area of paddle-wheels to the case of a paddle-wheel working at a maximum, or with a relative velocity for its vertical paddle of 6.5 feet per second, we shall find that each horse power of the engine should be capable of impelling a paddle of half a square foot. But a paddle does

not act during the time of its immersion in the water with equal intensity; and although no loss of power might arise from this cause, the obliquity of its action applies a part of the force to resistances that do not assist in propelling the vessel. Thus, on entering the water, a part of the force is applied to lift the wheel from its axis, and on quitting the water to press it down. In addition, a quantity of water is raised upon the paddle, a part of whose weight acts in direct opposition to the moving power. The loss growing out of these causes can only be investigated experimentally. We shall attempt this from a comparison of the circumstances of the steam-boats North-America and President. The former navigates the Hudson River, and is remarkable for a speed that has hitherto never been equalled by any other steam vessel; the latter plying between New-York and Providence, it has been found, in her construction, necessary to preserve stability as well as to obtain speed, and if her velocity be less than that of the former, she still combines the two qualities of speed and safety in a degree superior to any vessel we are acquainted with.

The particulars necessary for our purpose in relation to the President, are as follows, viz :

Breadth of beam, ...	32 ft. 6 in.
Draught of water, ...	9 ft.
Diameter of Water-wheels, . .	22 ft.
Length of bucket, ...	10 ft.
Depth of do.	3 ft. 6 in.

She has two engines of the following dimensions :

Diameter of Cylinder, ...	4 ft.
Length of Stroke, ...	7 ft.

Number of double strokes or complete revolutions of paddle-wheel per minute, 21. When but one engine works, the number of revolutions of the single wheel on which it acts are reduced to $17\frac{1}{2}$.

The average passages to Providence have been performed, when both engines acted, in $15\frac{1}{2}$ hours; when but one was used, in $19\frac{1}{2}$.

The distance between New-York and Providence is usually estimated at 210 miles; carefully measured, however, upon a map, it is found to amount to no more than 160 nautical, or 184.3 English miles. From these data, the average velocity of the boat through the water is very nearly 12 miles per hour, or 17.6 feet per second ; the average relative velocity of the wheel 6.5 feet per second, when both wheels and engines were in motion ; the average velocity of the boat when but one engine worked, becomes 9.45 miles per hour, or 13.86 feet per second ; the relative velocity of the wheel 6.3 feet per second.

The wheels, therefore, move with a relative velocity almost identical with that which our hypothesis has assumed to correspond to a maximum effect. But the actual effect is far beneath the rule we have laid down. Estimated from a comparison with other condensing engines, those of the President would have each a nominal power of about 110 horses, which, in consequence of the rapidity of their action, is increased to about double ; but by the rules on page 121, the power of each of the engines is that of 160 horses. As each paddle has a surface of no more than 35 square feet, each horse power drives no more than 0.22 feet of paddle, or less than one-fourth of a square foot. And it would appear, from comparing the relative velocities in these two cases, as if, in this vessel, the proper ratio between the moving power and the paddle had been attained.

The North-America has the following dimensions :

Breadth of beam, - - - - - -	30 ft.
Draught of water, - - - - - -	5 ft.
Diameter of Water-wheel, - - -	21 ft.
Length of bucket, - - - - -	13 ft.
Depth of do. - - - - - -	2 ft. 6 in.

She has two engines of the following dimensions :

Diameter of Cylinder, - - - -	$44\frac{1}{2}$ in.
Length of Stroke, - - - - -	8 ft.
Double Strokes per minute, 24.	

The estimate of her speed furnished by her owners, is 19.8 feet per second. The relative velocity of the wheel is 6.6 feet per second, exceeding our theoretic limit one-tenth of a foot. The relation between the velocities of the boat and the wheel is as 3 to 4.

The power of each of the engines, estimated by the rule on page 121, is 186 horses, the area of each paddle $32\frac{1}{2}$; and hence each horse power propels no more than 16 hundredth parts of a square foot through the water.

The velocity of the wheel is, however, greater than that of the President in the ratio of 6.3 : 6.6, or of 21 to 22; which makes the comparison more favourable than would at first appear, to the North-America. For, conceiving the wheel of the former to work to the greatest possible advantage, each horse power would, at the increased relative velocity the latter has, propel no more than one-fifth of a square foot of paddle.

The powers of the engines of both boats, as estimated by us, far exceed what would usually be ascribed to them from a mere consideration of their dimensions. Those of the President being of the size of condensing engines usually estimated at 110 horse powers; those of the North-America, at 98 horse powers. This difference arises from the great speed with which they are driven; it being usual to give no more velocity to the piston of a condensing engine than about 200 feet per minute, while that of the North-America has 384 feet, and that of the President 336 feet.

The near coincidence of the actual performance of these boats with our theory, except in one respect, is a tolerable warrant for its accuracy. The point in which this difference occurs, is the area of paddle that can be driven by each horse power of engine. The rule on page 239 would make this force equivalent to move half a square foot with the velocity of 6.5 feet per second; while in the case of the President, the actual performance, reduced to that velocity, is no more than one-fifth of a square foot; while in the case of the North-America it falls as low as one-sixth. The disturbing causes that effect this variation from the theory are obvious, and have been explained, but it is not easy to reduce them to calculation.

In the new class of vessels which has come into use in the neighborhood of New-York similar results have been obtained, as will appear from the following facts:

Steam-boat Cleopatra.

Diameter of wheel, - - - -	23 ft.
Length of bucket, - - - -	$11\frac{1}{2}$ ft.
Breadth of do. - - - - -	$2\frac{2}{3}$ ft.
Revolutions per minute, - - -	24
Velocity of wheel per second, - -	28.8 ft.
——— of vessel, - - - - -	22.6
Relative velocity of wheel, - - -	6.2

Steam-boat Lexington.

Diameter of wheel, - - - -	24 ft.
Length of bucket, - - - -	11 ft.
Breadth of do. - - - - -	$2\frac{2}{3}$ ft.
Revolutions per minute, - - -	23
Velocity of wheel per second, - -	28.8 ft.
——— of vessel, - - - -	22.5 ft.
Relative velocity of wheel, - - -	6.3 ft.

Steam-boat Massachusetts.

Diameter of wheel, - - - -	22 ft.
Length of bucket, - - - -	10 ft.
Breadth of do, - - - - -	$2\frac{1}{3}$ ft.
Revolutions per minute, - - -	26
Velocity of vessel per second, - -	19.95 ft.
——— of wheel, - - - -	26.25 ft.
Relative velocity of wheel, - - -	6.3 ft.

The same general fact, that the velocity of a paddle-wheel through the water is a constant quantity in a wheel of given diameter and dip, and does not vary in different wheels materially from 6.3 ft. per second, has been observed in the high pressure steam-boats which navigate the Mississippi and its branches by Professor Locke.

197. We have seen that, according to the usual theory, the resistance sustained by a body moving in a fluid is proportioned to the square of its velocity and the area of its section.

The moving force, necessary to give a vessel a given velocity, should therefore, as has also been stated, be equal to this resistance multiplied by the velocity, or proportioned to the cube of the velocity; and in similar vessels the resistance is proportioned to the square of one of the homologous dimensions.

Thus, to obtain double the velocity in a given vessel, and with given wheels, it might appear eight times the force should be employed, and so on.

But, as the space passed over in a given time is proportioned to the velocity, the actual expenditure of power, in performing a given distance, is proportioned to the squares of the velocities.

These laws would be true only when the weight of the engine is considered as constant, but as this increases in a greater ratio than the power, it would make the acquisition of great velocities still less advantageous.

If, however, we have recourse to facts instead of theory, we find that the resistance never increases in the cases which occur in practice, in a ratio as great as the square of the velocity; and it appears probable, that at the higher velocities it becomes almost constant. Supposing the resistance to vary with the velocity simply, we obtain the following rules, which are more consistent with experience:

(1). *To obtain double the velocity in a given vessel, we must employ an engine of 4 times the power.*

(2). *To obtain an equal velocity in similar vessels of different dimensions, we must employ engines varying in force with the areas of their transverse sections, or with the squares of their homologous lineal dimensions; or, to express the same fact in another manner, with the squares of the cube roots of their respective tonnages.*

(3). *The actual expenditure of power in passing through a distance with different velocities is as the velocities.*

An obvious advantage will be gained by increasing the size of the vessels, for the resistances vary as the square of similar dimensions, while the tonnage increases with their cubes.

It has been imagined by some, that the motion of steam-boats was different in a current from what it is in still water. This, however, cannot be the case, unless it be so rapid that the slope becomes an important element, forming an inclined plane up which the weight is to be lifted. This conclusion is obvious from the following considerations. When a vessel is in a current, and the propelling force ceases to act, she speedily acquires the velocity of the fluid, and is relatively at rest in respect to it. If the propelling force be steam applied to wheels, and they be set in motion, the action upon the fluid is precisely the same as if no current existed, and hence the velocity through the water will be the same as when the fluid is at rest. Thus, then, the velocity, in respect to the shore, will be the sum or difference of the velocity the vessel would have in still water, and that of the stream. The case is, of course, widely different when the force is applied by chains, or other connexion, with a fixed point upon the shore.

198. The next consideration in respect to paddle-wheels is their diameter. This is determined by means of the velocity that it is intended to give the circumference, compared with the velocity of the piston; the wheel being attached to the crank will make half a revolution for each stroke of the piston. Hence, in this mode of gearing the wheels, great velocities can only be attained by a proportionate increase of the diameters. This is attended with several practical inconveniences, first in a great increase of the weight, and secondly in raising the height of the centre of gravity. The action of a paddle depends, as has been shown, upon its relative velocity, but when the paddles of a wheel act in succession, the water will follow in the wake of the first which acts; and the second may, if it succeed at too short an interval, impinge upon water that is already in motion. For this cause, the paddles upon the wheels should not be more numerous than is just sufficient to keep up a continuous action. The proper arrangement, for this reason, is such, that when one paddle is vertical, the preceding one shall be just issuing from, and the succeeding one just entering the water.

When paddle-wheels impinge against the water in an oblique direction, they sustain a sudden shock, when the interval is as great as we have pointed out; the reaction of this sudden resistance upon the engine is injurious, and it checks and destroys the accumulation of power which the water-wheel might otherwise attain, and distribute, upon the principle of the fly-wheel. Hence in the early steamboats, fly-wheels driven with greater velocity than the paddle-wheels, were found of great value; and even in the rapidly moving boats of the present day, where the velocity and weight of the paddle-wheels enable them to answer the purpose of a fly-wheel, these shocks are not without an injurious effect.

Various methods have been proposed to remedy this defect.

In some English steam-boats, the paddles have been placed obliquely upon the circumference of the wheel, but still perpendicular to a plane tangent to it; their inclination to the vertical plane, therefore, remains the same as in the usual form, but they enter the water by an angle, instead of striking with one side, and hence do not experience the shock of which we have spoken.

There is, however, a defect which more than compensates any advantage to be derived from this arrangement. The wheels act in directions inclined to the plane of the vessel's keel, and thus a part of their power is exerted to press the vessel in a lateral direction; and although the two wheels mutually neutralize this part of each other's action, the whole of the force exerted in this direction is wasted.

A better arrangement has been introduced into his steamboats by Mr. R. L. Stevens. The wheel is triple, and may be described, by supposing a common paddle-wheel to be sawn into three parts, in planes perpendicular to its axis. Each of the two additional wheels, that are thus formed, is then moved back, until their paddles divide the interval of the paddles on the original wheel into three equal parts.

In this form, the shock of each paddle is diminished to one-third of what it is in the usual shape of the wheel; they are separated by less intervals of time, and hence approach more nearly to a constant resistance; while each paddle, following in the wake of those belonging to its own system, strikes upon water that has been but little disturbed.

Believing this oblique action to be a great defect, many attempts have been made to construct wheels in such manner that their paddles might dip and rise from the water in a vertical position. The first attempt of this sort was made twenty years since by a civil engineer of the name of Busby, who applied his wheel to one of the Jersey City ferry-boats. When in action it was found inferior in power of propulsion to the common paddle-wheel, and is, of course, still more so to that of Stevens. Within a few years several attempts of the same kind have been made in England; but after impartial investigation by Barlow, it seems to be conclusively proved, that, except when there may be a great variation in the dip of the paddles, they are inferior to the common wheel.

Still more recently, a paddle to which the name of cycloidal is given, has been introduced in England. The form of this may be conceived by imagining the paddles of a common wheel to be sawn each into three parts by cuts parallel to the axis of the wheel, and that two of the parts are each moved backwards one third of the distance between two contiguous paddles. This method, however is not original, for it was tried some years since on the Hudson, and after a fair trial, abandoned. It is unquestionably inferior to the wheel of Stevens in river navigation, but possesses advantages similar to those with vertical paddles in navigations when the dip of the paddle may be subject to variation. This variation often occurs in the navigation of the ocean, as the stock of the fuel must be great at setting out, and will be exhausted before the passage is completed. It cannot, however, be questioned that, should it be found practicable to reef the paddles of Stevens's wheel in such manner that their dip may be constant while the draught of water of the vessel changes, this method would be superior for the navigation of the ocean to any other.

The objection usually made to the common paddle-wheel, and, in consequence, to Stevens's, is, that there is a loss of power arising from the oblique action. This loss, it has been shown by Barlow, is more than compensated by the increase in the relative velocity of the paddle when in its oblique position. It thus happens, that with a given expenditure of steam the wheel with vertical paddles revolves more rapidly than the common wheel, but at the same time gives a less progressive motion to the vessel.

Another loss in the application of the power, arises, as we have seen, from the water that is lifted by the paddles as they pass out of the water. But the loss is not equal to the whole weight lifted, for this water will already have acquired a velocity of rotation that will diminish the pressure on the paddle, and as the paddle is oblique, the actual pressure may be resolved into two forces, one of which retards the motion of the wheel, and is lost, while the other acts horizontally to propel the vessel. This loss will, of course, be least in large wheels, if the immersion of the bucket be constant. The larger the wheel, the less will be the weight of the water lifted.

The paddle is not immersed wholly in the water, except when nearly in its vertical position. Hence it does not exert a constant force to propel the vessel, but as the expenditure of power from the engine will follow the law of the area, no loss arises from this cause. But the inclination of the paddle is, besides, constantly varying; and while the water opposes a resistance perpendicular to the surface of the paddle, depending upon the area immersed and the square of the velocity; only that part of this resistance, which, when decomposed, is parallel to the surface of the water, acts to propel the vessel, the rest is wasted upon the vessel, whose weight is alternately lifted and forced downwards.

A steam vessel is set in motion with a velocity that gradually increases until it becomes uniform. At this time the resistance of the water to the motion of the wheels exactly balances the progressive motion of the vessel. Hence, if we knew the relation between the laws by which the resistance to plane surfaces, and to those of the figure of a vessel, are governed, we might determine the proportion which ought to exist between the area of the paddle and that of the midship frame of the vessel. Experiments by the Society of Arts in London appear to show, that when a solid of small size is fashioned into the figure of a vessel, the resistance was not more than $\frac{1}{7}$th of that which opposes a plane surface. Other observations make the resistance to good models vary from $\frac{1}{8}$th to $\frac{1}{10}$th.

But observation on a large scale gives far more favourable results. In the case we have above quoted of the steam-boat President, the resistance to the tranverse section of the vessel is no more than $\frac{1}{20}$th part of that incurred by the wheels when both engines act; while, when but one acts, it falls as low as $\frac{1}{26}$th. In the North-America, it appears to be no more than $\frac{1}{22}$d. This inference has recently been confirmed by a series of experiments recorded in the Transactions of the Royal Society by P. W. Barlow. In eleven boats the resistance varied from $\frac{1}{10}$th to $\frac{1}{24}$th, and was at a mean $\frac{1}{17}$. In the great improvements which experience has suggested in the figure of our more modern boats, and in the false prows which have been adapted to our older vessels, the resistance has been diminished still further; and we need no longer hesitate to allow a higher limit than even $\frac{1}{27}$. The improvements have with sound judgment been directed to the object of preventing the formation of the wave, and thus to get rid of the most important retarding cause altogether; this has in some instances been almost completely attained. In the steam frigate Fulton, the ratio of these resistances has been reduced below $\frac{1}{45}$.

The table, therefore, which was given in our first edition, may be considered as obsolete. No possible danger, then, can arise, in assuming that in a vessel of a good model, the resistance to the progressive motion falls as low as $\frac{1}{27}$th part of that which acts upon the paddles. If, then, we assume for the relation between the absolute velocities of the boat, and the wheel, when working to the greatest advantage, the proportion already stated of 3 : 4; the most advantageous size of the paddles will be such that the area of each should be one-sixth of that of the midship frame of the vessel, or the sum of those which act at a time, on both wheels, one-third of that quantity. If the engine be so constructed as to give the paddle-wheel a rotary velocity of 26 feet per second, the boat will acquire a velocity of 13.2 miles per hour.

Besides the paddle-wheel, various other plans for propelling vessels by steam have been suggested. Some of these will be referred to in the history of Steam Navigation. In addition to these, it has been proposed to drag vessels by means of a chain resting on the bottom of a canal. This method is to be preferred in this case, inasmuch as the wave which is raised by the wheels is destructive to the banks of the canal. This proposal has recently been carried into effect with success on a Ferry in England.

In long canals, the expense of a continuous chain is objectionable; but it has recently been discovered that the friction of a chain on the bottom of a canal is sufficient to propel a vessel. A very ingenious arrangement for this purpose, in which an endless chain, of which a part lies on the bed of the canal, and is set in motion by a steam engine in the vessel, has been contrived by Mr. Leavenworth of New-York.

199. Our practical rules may now be summed up and recapitulated, as follows, viz:

1. The relative velocity of the circumference of the wheel appears to be, in all cases, about six and a half feet per second.

2. Each horse power of engine, calculated according to the rules on page 121, will drive a paddle of the area of one-fifth part of a square foot with this velocity.

3. The maximum absolute velocity of a paddle, to give the greatest velocity a boat has usually attained, is 26 feet per second; but there are recent instances where as much as 29½ feet per second has been reached; and if the wave can be avoided, it would be unsafe, without a better theory of the motion of bodies in fluids than has yet been investigated, to name a limit which new improvements may not exceed.

4. In a vessel of good model, these velocities may certainly be attained, when the relation between the area of the midship frame of the vessel, and that of the paddles of both wheels, is as three to one; and they have been attained when the relation has been as small as 10 : 1.

200. We cannot quit this subject without suggesting some views, which it is hoped may still further improve steam navigation. It has been seen that if the power of the engine be calculated according to the usual rule, each horse power ought to propel a surface of paddle equal to half a square foot; while in the two instances which we have cited the performances have

been no more than .16 and .22 ft. In the one case, therefore, at least two thirds, and in the other more than one half the force estimated appears to be useless. It is obvious that this arises from the great velocity with which the piston of the engine is driven, in order to acquire the great velocities now usual in navigation. The whole tension of the steam acts as a pressure on the piston, only when that is at rest, and with every increase of velocity the pressure must be diminished. Experience derived from the action of engines employed in manufactures and pumping, would seem to show, that the maximum performance of a condensing engine takes place, when the velocity of the piston is from 250 to 280 ft. per minute. It is now usual to drive those of steam-boats at rates between 400 and 600 ft. per minute. If the former numbers express one-third of the velocity which the piston would assume had it no work to perform, the defect in the performance of the engines of the North-America and President is almost exactly consistent with theory. On the other hand, it is absolutely necessary that the rotary velocity of the circumference of the paddle-wheel should not be less than 26 feet per second, if the vessel is to move with the velocity which is now demanded. It would therefore appear, that a great saving of steam must accrue from such a disposition of the engine, as would allow its piston to move with no greater velocity than 280 feet per minute, and should, notwithstanding, give one of 26 feet per second to the wheel. Two modes suggest themselves at once for accomplishing this object, namely, to increase the number of revolutions of the wheel by gearing, or to substitute for the crank the original contrivance of Watt, the Sun and Planet wheel. There is, however, an objection to the use of toothed wheels in steam-boats which is not unfounded, and if this be as positive as is usually thought, these methods are not likely to come into practical use. There remains, however, another, which we have not seen suggested, namely, to make the arms of the lever beam of unequal lengths. In this way an engine of comparatively short stroke, and whose piston would in consequence move with a proportionally less velocity, would give the necessary speed to the paddle-wheel, while the crank would still be applied at a favourable distance from the axis.

The increase which has been given to the speed of the paddle-wheel is partly gained by an increase in the velocity of the piston, and partly by enlarging the diameter of the wheel itself. Adopting the method just suggested, the number of strokes of the piston might be increased, and the diameter of the wheel diminished.

A similar advantage would be gained by the use of the Sun and Planet wheel.

In steam vessels intended for the navigation of the ocean, the British nation has as yet been more successful than ourselves. They have, however, failed in giving them any thing like the velocity which we are in the habit of using. It would seem to be easy to give the American rate of motion to steam vessels, without impairing the good and sea-worthy qualities of the British steamers. In this event the mast and sails which they yet find of use, would be no more than a useless incumbrance, as our vessels outstrip even brisk gales of wind, and would, in consequence, find it always acting in opposition to them. More particularly is the bowsprit objectionable. The motion of a steam vessel, in her pitching is not, like that of an ordinary vessel, derived from the motion of the waves alone, but is, in addition, influenced by the action of the engine. It therefore will be often struck by the waves in a high sea, and it is not wonderful that several accidents have already happened to this spar, in the few voyages that have been made between New-York and Great Britain. Not only is the bowsprit an incumbrance, and exposed to danger, but it is wholly unnecessary, even if it be admitted that steam vessels must be equipped with sails. The length of steam vessels is so great, that by lessening the after-sail, all the functions of the jib will be fulfilled by stay-sails spread between the cutwater and the foremast.

If the speed of steam vessels on the ocean be increased to the American rate, sails may still be necessary in order to provide for accidents to the engine, or to spare the expenditure of fuel. It will not, however, be necessary to make any other provision for spreading them, than to step the lower masts, and reeve their standing rigging; the topmasts and top-gallant masts, with the yards, should be stowed away, and only sent aloft when the necessity for spreading sail arises. To one acquainted with the manner in which steam is used in our river steam-boats, and in which it may doubtless be applied on the ocean, the heavy masts, yards, and sails, with which the British steamers are incumbered, are not less offensive, than are the structures which we pile on the decks of our vessels, to the nautical eye.

In the steam vessels for ocean navigation, the timbers ought to be carried up to the level of the upper deck, the whole planked in, and strengthened by ceiling plank. Instead of the partial coverings of cabins and wheel-houses, the whole should be closed in by a spar deck extending from stem to stern, and, if possible, flush.

The great relative length which must be given to steam vessels, renders them more liable to the usual tendency to the change of figure called hogging than other ships. They, in consequence, require to be proportionably stronger. This increase of strength is usually sought, by increasing the number and the scantling of the timbers. We conceive that this is wrong in principle, inasmuch as the weight of the vessel is the cause of the change of figure, and to increase it in adding to the strength of the material, may in the end render the evil which is to be conquered greater. We should, in consequence, prefer to diminish the scantling, and even lessen the number of timbers, taking care that each shall constitute a frame; and would propose to meet the tendency to change of figure by laying the ceiling plank diagonally, and by a system of lattice-work planking, reaching from the keelson to the main-deck. In addition, a series of iron stays, extending from the stem to the stern-post, over the lower mast-heads, might be employed.

The several frames ought to be united by bolts or rods of iron extending through three continguous timbers, and in such number, that every timber should be connected on each side with the second in distance from it.

The engines employed should be of the character to which the name of portable is given; that is to say, the whole of the parts which compose each of them should be united in a frame of iron. In this way the engine will act upon itself, and not upon the vessel. A horizontal engine is also to be preferred when it can be used, as a vessel is much less racked by its motion than by one whose cylinder is vertical.

The boilers should be of such a form as carry the least weight of water in proportion to their fire surface which is consistent with safety. For this reason, those with tubular flues are to be preferred. The only fuel which can be employed is coal, for the weight and bulk of wood would be an insuperable objection to its use on long voyages. Of the different kinds of coal, the bituminous, under equal weights, gives the greatest quantity of heat, but generates so much smoke as to render the vessel uncomfortable for passengers. It is therefore probable that the mode of burning anthracite coal in boilers, with tubular flues, like those used in locomotive engines, and in which the ignition is promoted by a blowing engine, will be preferred.

None of the vessels, which have yet been constructed for navigating the ocean, appear to us to be worthy of being cited as models to be copied. The English steamers are objectionable from the excessive and useless weight of their engines, and the great space they occupy; and from the great size, and the weakness of their boilers. The steam frigate Fulton can hardly be considered as intended for ocean navigation. The Natchez, which runs as a packet between New-York and New Orleans, appears to unite a greater number of advantages than any other vessel, but has not sufficient tonnage to unable her to carry fuel for crossing the ocean.

201. The steam engine, such as has been described in Chapter V., requires several modifications to suit it for the purpose of propelling boats. When placed in the middle of the vessel, that form represented in Pl. VII., in which the great working-beam is suppressed, and two connecting-rods adapted to the piston by a cross-head, is often used. But when two engines are employed, the beam must be retained. The cold-water cistern would load the vessel with an enormous weight, and hence the condenser is not immersed in water; the hot-water cistern is, generally speaking, set upon the top of the air-

pump ; and the delivering-door is a conical valve surrounding the air-pump rod. Water for condensation is supplied by a standing-pipe, passing through the bottom of the boat and rising above the level of the external mass of fluid ; the injection-cock is below this level, and the water is forced into the condenser, by virtue of the difference of level. The waste hot water passes out by a similar pipe. These pipes are called standing pipes, and they are represented on Pl. VII., at *h h* and *l* ; *h h* being the pipe adapted to the condenser, which it supplies through the injection-cock *i*, and *l* being the pipe through which the waste hot water is discharged from the cistern on the top of the air-pump *H*. A hand force-pump *K*, is employed to fill the boiler at first, and it is afterwards supplied by a force-pump *I*. The hand pump may also be employed to keep up the water in the boiler, when the engine is not in action.

The condenser is increased to half, and the air-pump to one-third of the capacity of the cylinder.

These standing pipes are exposed to danger, and the openings through which they pass are of such size that the slightest accident, or even overloading, may be followed by the sinking of the vessel. It has, in consequence, been proposed to adapt valves to these openings, which might be shut in case of an accident happening to the steam pipe, or of the vessel being loaded beyond her proper depth. Valves for this purpose have been invented in England by Kingston, and in this country by Mr. Haswell, the engineer of the U. S. Steam frigate Fulton.

Another very important modification consists in the size of the valves and steam-pipes. It has already been seen, that in some cases, when steam acts expansively, the area of the nozzle should be increased; but in steam-boats the great velocity required for the wheels being usually gained, not by gearing, but by increasing the velocity of the piston, this can only be attained by affording a passage for an increased flow of steam. This method of increasing the speed has this advantage, that velocity is gained without increasing the weight of the engine, by merely adding to the fire surface of the boiler.

In the steam-boats on the Hudson, not only has the velocity of the piston been increased by increasing the number of strokes, but by adding, at the same time, to the length of the cylinder. And, although it is obvious that in this way the pressure of steam of a given tension in the boiler, upon the piston, must be lessened, an equal area of paddle-wheel is driven. This we ascribe, in opposition to a high authority, to the fact that the crank of the engine acts in a more favourable point in the wheel. It would appear to us, that the true position of the extremity of the crank would be in the circle described by the centre of resistance of the paddle, and that it is only when applied to this circle, that all the force of the steam is applied to propel the vessel. Now, as it would be impossible to give the area of the crank so great a length as this, the nearer it approaches to it, the better. Hence, the method used in the American steam-boats has not only been successful in practice, but is founded upon true mechanical principles.

The great length which is given to the cylinders of American engines, and the supposed necessity of placing their bed plates so high that the axle of the wheels may lie below them, is attended with the disadvantage of impairing the stability of the vessel. Now, although a vessel ought not to be too stiff, because in that case the motion of rolling is violent, it seems probable that in our vessels there is not that degree of stability which is necessary for perfect safety. We have, therefore, to mention with approbation a very ingenious form of engine planned by Mr. Lighthall. In this, the cylinder lies in a horizontal position near the keelson of the vessel, and has the long stroke of the American boat engines. The motion of the piston is communicated to the wheels by straps working in guides, a lever beam, connecting-rod, and crank. The form is therefore similar to that of the engine on Pl. III. provided it were laid upon its side. The manner in which Mr. Lighthall has provided for the working of the pumps and valves of his engine is simple and sufficient. By means of this form of engine, all the advantages to be derived from length of stroke are secured, without any of the defects of the usual methods.

The general form of the engine on Pl. III. is now more used in steam-boats in the U. S. than that on Pl. VII. The stroke of the piston, and the length of the connecting-rod and crank, being greater in proportion to the height of the lever beam than in the first of these engines. The lever beam is not, as in Pl. III., a solid mass of cast iron, but is an open frame of that material surrounded by a strap of wrought-iron.

202. The application of steam to the propulsion of vessels appears to have been among the very first ideas that suggested themselves to the inventors or improvers of the engine. Worcester, in the quotation that we have made from the "Century of Inventions," speaks of the capacity of his invention for rowing. Savary proposed to make the water raised by his engine turn a water-wheel within a vessel, which should carry paddle-wheels acting on the outside; and Watt, as we are well assured by a personal auditor, stated in conversation, that, had he not been prevented by the pressure of other business, he would have attempted the invention of the steam-boat. Newcomen alone gave, as far as we can learn, no intimation of any such design; and this we are rather to take as an evidence of his correct appreciation of the powers of his engine, than as arising from any want of ingenuity. In truth, before the time of Watt, no modification under which steam was applied to useful purposes would have been able to propel vessels successfully. Even with all his improvements, the fuel is a great load, and its carriage no small difficulty; but, before he lessened its consumption so materially, it would have been hardly possible for a vessel to carry enough of combustible matter, except for very short voyages.

Previous in date to all these persons, recent discoveries have brought to light an ancient record in which we have the description of a vessel propelled by steam in a manner that obtained the suffrages of the witnesses.

Blasco de Garay, an officer in the service of the Emperor Charles V., made, at Barcelona, in the year 1543, an experiment on a vessel, which he forced through the water by apparatus, of which a large kettle, filled with boiling water, was a conspicuous part. If this be true, and we have no reason to doubt the authenticity of the records, De Garay was not only the first projector of the steam-boat, but among the first who conceived the idea of applying a steam engine to useful purposes. He was, however, too far in advance of the spirit of his age to be able to introduce his invention into practice, and even the recollection of his experiment had been lost, until the record was accidentally detected among the ancient archives of the province of Catalonia. This experiment was, therefore, without any direct practical result; neither did it produce any effect in facilitating the researches of subsequent inquirers, and may therefore be considered rather as a matter of curious antiquarian research, than as deservedly filling any space in the history of the steam-boat.

English authors have also raked up from oblivion a patent granted in the year 1736, to a person of the name of Jonathan Hulls. He, however, never made even an acting model of his invention, and the prime-mover itself was at the time in a state far too imperfect to have permitted its being successfully used in the manner proposed by Hulls. So far, then, from classing this among ingenious and profitable improvements, we should rather be inclined to rank it among those which, from their obvious impracticability, merit the oblivion into which they instantly fall.

The paddle-wheel, it has been stated, is the only apparatus that, when worked by steam, has been found completely successful in propelling vessels. The use of this for such a purpose, but set in motion by other prime-movers, is of remote antiquity, and was from time to time again brought forward, used for a season, and again abandoned.

Among these attempts may be mentioned a boat constructed on the Thames by Prince Rupert, whose action was witnessed by Papin, by Savary, and probably by Worcester. So far as regards the antiquity of the method, Stuart quotes manuscripts from the library of the King of France, from which he states it was ascertained, that during one of the Punic wars, a Roman army was transported to Sicily upon vessels moved by wheels worked by oxen. The use of a water-wheel, in a manner the reverse of that in which it was employed to propel machinery, is almost too obvious to be entitled to the character of invention; it was therefore only necessary that the necessity for their use should exist, and their introduction would have followed as a matter of course.

It was, however, long questionable whether they could be used to advantage when attached to a steam engine, and in the earlier experiments, the blame appeared to fall upon them, rather than upon the imperfections of the engine, or the unskilful and unartist-like manner in which they, and the rest of the apparatus, were adapted to the vessels.

We have stated that Watt's engine was the first possessed of sufficient powers to be used to advantage in vessels. This is not merely an inference from what can be observed in the practice of the present age, but was, in 1753, made a matter of mathematical proof by Bornouilli, in a memoir which gained a prize offered by the French Academy of Sciences. He, however, expresses his opinion too broadly, applying his inference rather to the power of steam itself, than the mode in which it was then commonly applied.

Still there were some who, not aware of the defects of the prime-mover, continued to seek for the means of applying it to vessels. Among these may be named Genevois and the Comte d'Auxiron. The former, whose attempt dates as early as 1759, is chiefly remarkable for the peculiarity of his apparatus, which resembled in principle the feet of aquatic birds, opening when moving through the water in one direction, and closing on its return. The latter made an experiment in 1774, but his boat moved so slowly and irregularly, that the parties at whose expense the trial was made, at once abandoned all hopes of success.

In 1775 the elder Perrier, afterwards so celebrated as the introducer of the manufacture of steam engines into France, made a similar attempt, which was equally unsuccessful. But, not discouraged, and ascribing his failure to the use of paddle-wheels, he applied himself for some years afterwards to the search for other substitutes for oars. It does not appear, however, that he made any valuable discovery.

The Marquis de Jouffroy continued the pursuit of the same object. His first attempts were made in 1778, at Baume les Dames, and in 1781 he built upon the Saone a steam-vessel

150 feet in length and 15 in breadth. In 1783 his experiment became the subject of a report made to the French Academy of Sciences, by Borda and Perrier. The report is said to have been favourable.

We have seen that the double-acting engine of Watt was not made public before 1781, and that it was not until 1784 that it received those improvements by which it was fitted to keep up a continuous and regular rotary motion. No previous engine having the necessary properties, we feel warranted in rejecting all attempts prior to the former date as premature, in attempting to perform that to which the means in the possession of the projectors were inadequate.

We are to look to our own country, not only for the first successful steam-boat, but for the very earliest researches into the subject, after the improvement of the engine by Watt had rendered success attainable. The very nature and circumstances of the United States appeared to call for means of conveyance different from those which are employed in other countries. Our whole coast is lined by bays and rivers, by the aid of which a safe parallel navigation, might, at small expense, be extended from one extremity of the Union to the other; but which, land-locked, and protected from the winds, is at some seasons tedious to the ordinary methods. Still more recently, the Mississippi and its innumerable branches have become the seat of flourishing settlements, separated from the Atlantic coast by ridges of barren mountains, and almost inaccessible from the Gulf of Mexico by either sails or oars, in consequence of the rapidity of the stream. Our population, with the wants and curiosity of the highest civilization, is still scattered over so vast a region, as to demand rapid means of communication and great foreign importations. These wants could not have been satisfied, nor this active curiosity gratified, by any means yet discovered, except the steam-boat. The earlier projectors appear, however, rather to have reference to the prospective state of our country than to circumstances which existed at the moment of their attempts. Hence we shall find that they sought in foreign countries the encouragement, the wealth of their native land was inadequate to afford.

Rumsey and Fitch were cotemporaneous in their researches. Both attempted to construct steam-boats as early as the year 1783, and modes of both their contrivances were exhibited in 1784 to General Washington. Rumsey's was the first in date of exhibition, but Fitch was first enabled to try his plan upon a scale of sufficient magnitude; for, in 1785, he succeeded in moving a boat upon the Delaware, while Rumsey had not a boat in motion upon the Potomac before 1786.

Fitch's apparatus was a system of paddles; Rumsey at first used a pump, which drew in water at the bow and forced it out at the stern of his boat. The latter afterwards employed poles, set in motion by cranks on the axis of the fly-wheel of his engine, which were intended to be pressed against the bottom of the river. About the date of these experiments Fitch sent drawings of his apparatus to Watt and Bolton, for the purpose of obtaining an English patent; and in 1789 Rumsey visited England upon the same errand. The former was not successful in obtaining patronage; but the latter, by the aid of some enterprising individuals, procured the means to build a vessel on the Thames, which, however, was not set in motion until after his death, in 1793.

Fitch's boat was propelled through the water at the rate of four miles per hour. We may now reasonably doubt whether paddles would have answered the purpose upon a large scale, for more than one experiment on this principle has since been tried, and without success. The method of Rumsey is more obviously defective, and we need not wonder that it was followed by no valuable results.

Next in order of time to Fitch and Rumsey, we find Miller, of Dalswinton in Scotland. This ingenious gentleman had, as early as 1787, turned his attention to substitutes for the common oar, and had planned a triple vessel propelled by wheels. Finding that wheels could not be made to revolve with sufficient rapidity by men working upon a crank, the idea of applying a steam engine was suggested by one of his friends, and an engineer of the name of Symington employed by him to put the idea into practice. The vessel was double, being an experimental pleasure-boat on the lake in his grounds at Dalswinton.

The trial was so satisfactory, that Miller was induced to build a vessel sixty feet in length. This was also double, and it is asserted that it was moved by its engines along the Forth and Clyde canal at the rate of seven miles per hour. The boat, the wheels, and the engine, were, however, so badly proportioned to each other, that the paddles were continually breaking, and the vessel suffered so much by the strain of the machinery as to be in danger of sinking, and Miller found it unsafe to venture into any navigation of greater depth than the canal. The apparatus was therefore removed and laid up, and here the experiments of Miller ceased. He himself appears evidently to have considered this experiment an absolute failure, and ascribed the blame to the engineer. We have to remark that the double boat used by Miller, was a form ill suited to the purpose; in the ferry boats of that structure, introduced by Fulton into this country, the resistance growing out of the dead water included between the two hulls, has been found such, that they have been gradually abandoned, and single vessels substituted.

John Stevens, of Hoboken, commenced his experiments on steam navigation in 1791. Possessed of a patrimonial fortune, and well versed in science, he was at the time wanting in the practical mechanical skill that was necessary to success; he was hence compelled, at first, to employ men of far less talent than himself, but who had been educated as practical machinists. His first engineer turned out an incorrigible sot; his second became consumptive, and died before the experiment was completed. Stevens then resolved to depend upon his own resources, and built a workshop on his own estate, where he employed workmen under his own superintendence. In this shop he brought up his son, Robert L. Stevens, as a practical engineer, to whom many important improvements in steam navigation, and the most perfect boats that have hitherto been constructed, are due.

During these experiments, Stevens invented the first tubular boiler; and his first attempts were made with a rotary engine, for which, however, he speedily substituted one of Watt's. With various forms of vessels, and different modifications of propelling apparatus, he impelled boats at the rate of five or six miles per hour. They were, in truth, more perfect than any of his predecessors', but did not satisfy his own high-raised hopes and sanguine expectations. These experiments were conducted at intervals up to the year 1807, and much diminished his fortune. We must, however, pass from the detail of them, and the notice of the parties who became concerned with him, in order to speak of what was doing in Europe in the meantime.

The Earl of Stanhope, in 1793, revived the project of Genevois, for an apparatus similar to the feet of a duck. It was placed, in 1795, in a boat furnished with a powerful engine. He was, however, unable to obtain a velocity greater than three miles per hour. While engaged in these experiments, he received a letter from Fulton, who proposed the use of paddle-wheels; and it is probable that his neglect to listen to this suggestion caused a delay in the introduction of the steam-boat of at least twelve years; for we cannot doubt that the ingenuity of Fulton, backed by the capital and influence of Lord Stanhope, would have been as successful then as it was on a subsequent occasion.

In the year 1797 Chancellor Livingston, of the state of New-York, built a steam-boat on the Hudson River. He was associated in this enterprize with a person of the name of Nisbett, a native of England. Brunel, since distinguished for the block machinery, and as engineer of the London Tunnel, acted as their engineer. In the full confidence of success, Livingston applied to the legislature of the state of New-York for an exclusive privilege, which was granted, on condition that he should, within a year, produce a vessel impelled by steam at the rate of three miles per hour. This they were unable to effect, and the project was dropped for the moment.

In the year 1800 Livingston and Stevens united their efforts, and were aided by Mr. Nicholas Roosevelt. Their apparatus was a system of paddles resembling a horizontal chain pump, and set in motion by an engine of Watt's construction. We now know that such a plan, if inferior to the paddle-wheel, might answer the purpose; it, however, failed in consequence of the weakness of the vessel, which, changing its figure, dislocated the parts of the engine. One of the workmen in their employ suggested the use of the paddle-wheel in preference, but, as Stevens candidly states, their minds were not prepared to expect success from so simple a method.

Their joint proceedings were interrupted by the appointment of Chancellor Livingston to represent the American government in France, but neither he nor Stevens were yet discouraged; the latter continued to pursue his experiments at Hoboken, while the former carried to Europe high-raised expectations of success.

It has been stated that Symington was employed by Miller of Dalswinton as his engineer; we have now to record an attempt made by him under the patronage of Lord Dundas of Kerse. Miller's views appear to have been directed to the navigation of estuaries and rivers, if not to that of the sea itself. Symington, on the present occasion, limited himself to the drawing of boats upon a canal. The experiment was made upon the Forth and Clyde canal, but the boats were drawn at the rate of no more than three and a half miles per hour, which did not answer the expectations of his patron, and the attempt was abandoned. During this attempt, Symington asserts that he was visited by Fulton, who stated to him the great value such an invention would have in America, and by his account, took full and ample notes. In the attempt he thus makes to claim for himself the merit of Fulton's subsequent success, he is defeated by the clear and conclusive evidence that Fulton exhibited in a court of law, of his having submitted a plan analogous to that afterwards carried into effect, to Lord Stanhope, in 1795, six years prior to the experiment of Symington. That Fulton, whose thoughts had continued to dwell upon steam navigation, and who saw with prophetic eye, the vast space for this development afforded by the Mississippi and its branches, should have visited all the places where steam-boats were to be seen, was natural; but a comparison of the draught of Symington's boat, which is still extant, with the boats constructed by Fulton, furnishes conclusive evidence that the latter borrowed no valuable ideas from the former.

In the same year, 1801, Evans made, at Philadelphia, an experiment of a most remarkable character. Being employed by the Corporation of that city to construct a dredging machine, he built both the vessel and the engine at his works, a mile and a half from the water. The whole, weighing 42,000 lbs., was mounted upon wheels, to which motion was given by the engine, and thus conveyed to the river. A wheel was then fixed to the stern of the vessel, and being again set in motion by the engine, she was conveyed to her destined position. Evans, however, appears long to have abandoned the hopes of exciting his countrymen to enter into his projects of locomotion, and content with his steady business as a millwright, and the proof he had thus given of the soundness of his ancient projects, pursued the matter no farther.

We have thus completed the review of those attempts at navigation by steam which were abortive, either from absolute deficiency, or from their not fulfilling the expectations of the parties interested. It is now our more gratifying task to record instances of complete success. Livingston, who, as we have stated, carried with him to France a sanguine belief that steam navigation was practicable, met Fulton at Paris. They were immediately drawn to each other by similarity of views, and the latter undertook to make those investigations which the avocations of the other prevented him from doing. It occurred to Fulton that the first step towards success was to investigate fully the capabilities of different apparatus for propulsion. These preliminary experiments were made at Plombieres, and led to the conviction that of all methods hitherto proposed, the paddle-wheel possessed the greatest advantages. He next planned a mode of attaching wheels to the engine of Watt, ingenious in itself, but complicated, and which he afterwards simplified extremely.

Up to this time the relation of the force of the engine to the velocity of the wheels and the resistance of the water to the motion of the vessel, had never been made a matter of preliminary calculation. Aware, however, that upon a proper combination of these elements all positive hopes of success must depend, he had recourse to the recorded experiments of the Society of Arts, and limiting his proposed speed to four miles per hour, planned his machinery and boat in conformity. The experimental vessel was then constructed at Paris, and being launched upon the Seine, performed its task in exact conformity to his anticipations. It was then, as afterwards, remarkable, that by a sound view of theoretic principles, the single boats of Fulton always possessed the speed which he predicted at the moment of planning them. This was not the case when he attempted double vessels, in consequence of his leaving out of view that important resistance which was mentioned in speaking of Miller's vessel.

This preliminary experiment was performed in 1803. While Fulton was engaged in preparing for it, a person of the name of Des Blancs, who was possessed of a patent for apparatus for steam navigation, endeavoured to interrupt it as an infringement on his rights. Fulton, however, communicated to him his preliminary experiments, in which he had found paddle-wheels superior to the chain of floats proposed by Des Blancs, and the opposition ceased. The trial on the Seine having proved successful, it was resolved to take immediate measures to have a boat of large size constructed in the United States; but as at that time the work-shops in America were incapable of furnishing a steam engine, it became necessary to order one from Watt and Bolton. This was done, and Fulton proceeded to England to superintend its construction. In the meantime Livingston was sufficiently fortunate to obtain a renewal of the exclusive grant from the state of New-York.

We here remark an anachronism in the work of Stuart. Symington's own narrative, as given by that author, seems to place the interview with Fulton in 1801. Stuart, in a subsequent place, refers it to the date of this visit of Fulton's to England. We have previously stated it as happening at the former date upon Symington's authority, as this is alone consistent with the expression of astonishment that he records. For this could hardly have been uttered subsequent to the trial made upon the Seine. Each of the dates, however, causes a dilemma. If he saw Symington's boat in 1801, he returned to France with his previous impression in favour of paddle-wheels very much weakened; if not until 1804, he had already performed more than Symington.

In like manner the claim of Henry Bell, so pertinaciously maintained by British authors, falls to the ground. Bell claims the merit of having furnished Fulton with the plan of his successful steam-boat on the ground of his having furnished plans and drawings, which he heard, *two years* afterwards from Fulton, were likely to answer this end. On receiving this letter, he states that "he was led to consider the folly of sending his opinions on these matters to other countries, and not putting them into practice in his own." Now, as Bell did not build his first boat until 1812, we cannot place the date of Fulton's second letter earlier than his return to America in 1806, and that it was written from America Bell's expressions render evident. Fulton, therefore, could have derived no benefit from his advice, for his experiment in France was in 1803, and the engine of Watt and Bolton, which was first used on the Hudson, must have been ordered at least a year before the alleged date of Bell's communications. Neither can we reconcile his claims with the statement made by his friends, that he was several years in bringing his plans to perfection, and his boat was, after all, very inferior to those constructed by Fulton several years earlier. The anxiety of the British public to transfer the honours of Fulton to Bell, is manifest from a report of a Committee of Parliament, where it is stated that Bell came to this country to construct boats for Fulton, while it is now admitted that he never was on this side of the Atlantic. We apprehend, however, that the correspondence with Bell took place on a different occasion. When Fulton planned his ferry-boats for the East River (New-York), he proposed to make them double; he therefore naturally desired to know something of Miller's vessel which he had never seen, and, by Bell's own statement, the request of Fulton for information was limited to that single object. Bell asserts that he furnished, in addition, views and plans of his own, but long before this time Fulton's boats were in successful operation, and many competitors had already appeared, not only in those places where an exclusive grant existed, but even within the waters of the state of New-York.

The engine ordered from Watt and Bolton reached New-York towards the close of the year 1806, and the vessel built to receive it was set in motion in the summer of 1807. The success that attended it is well known.

In the mean time Livingston's former associate, the elder Stevens, had persevered in his attempts to construct steam-boats. In his enterprize he now received the aid of his son, and his prospects of success had become so flattering, that he refused to renew his partnership with Livingston, and resolved to trust to his own exertions. Fulton's boat, however, was first ready, and secured the grant of the exclusive privilege of the State of New-York. The Stevens's were but a few days later in moving a boat with the required velocity, and as their experiments were conducted separately, have an equal right to the honours of invention with Fulton. Being shut out of the waters of the State of New-York by the monopoly of Livingston and Fulton, Stevens conceived the bold design of conveying his boat to the Delaware by sea, and this boat, which was so near reaping the honour of first success, was the first to navigate the ocean by the power of steam.

From that time until the death of Fulton, the steam-boats of the Atlantic coast were gradually improved until their speed amounted to eight or nine miles per hour, a velocity that Fulton conceived to be the greatest that could be given to a steam-boat. To this inference he was probably led by the observation of the increased resistance growing out of the wave raised in their front. His three earlier boats, the Clermont, the Car of Neptune, and the Paragon, were flat bottomed, their bows forming acute curved wedges, the several horizontal sections of which were similar. His last boats had keels, but they were introduced for no other purpose than to increase their strength. In the boats constructed by his successors after his death, a nearer approach was made to the usual figure of a ship, but the waves still formed an important obstacle. In the mean time the younger Stevens was steadily engaged in improving steam navigation, each successive boat constructed under his direction possessing better properties than the former. The view he took of the subject was different from that of Fulton; believing that the great size of the wave was owing to defective form, he instituted experiments, both on a large and small scale, to determine the figure in which this obstacle is of least magnitude. On the setting aside of the exclusive grant of the State of New-York to Livingston and Fulton, he prepared a boat for navigation of the Hudson, which performed its voyage at the rate of 13 and a half English miles per hour.

Steam-boats were not introduced into Great Britain until 1812, five years later than the successful voyage of Fulton. Bell, whose name has already been mentioned, built the first upon the river Clyde at Glasgow. In March, 1816, the first steam-boat crossed the British Channel from Brighton to Havre. Since that period their use has been much extended and their structure improved; but, until lately, no European steam-boat had attained a speed of more than 9 miles per hour.

In 1815 steam-boats, previously constructed by Fulton for the purpose, commenced to run as packets between New-York and Providence, Rhode Island, a part of which passage is performed in the open sea. One of these vessels had been intended to make a voyage to Russia, but the greatness of the expense deterred the proprietors from undertaking it. This voyage was performed in 1817 by the Savannah, and in 1818 a steam-ship plied from New-York to New-Orleans as a packet, touching at Charleston and the Havana.

In 1815 also, a steam-boat made a passage from Glasgow to London, under the direction of Mr. George Dodd; but it was not until 1820 that steam-packets were established between Holyhead and Dublin. In 1825 a passage was made, by the steam-ship Enterprize, from London to Calcutta. All doubts, therefore, in respect to the practicability of navigating the ocean by steam might have been considered as settled. In point of economy, however, it can never compete with sails, and hence probably can only be used to advantage for conveying passengers, or for purposes of war.

In the steam-boats of the Ohio and Mississippi, high-pressure engines are now in the most general use. The boilers are usually cylindrical, with internal flues; and the favourite position of the cylinder is horizontal, resembling the engine on Pl. IV. Many of them, however, have conical valves, which are necessarily placed in vertical boxes; this has demanded a novel arrangement of the steam and eduction pipes, and of the apparatus for working the valves.

In France, Steam navigation has been of even more recent introduction than in England. Five years, as we have seen, elapsed from the time of Fulton's successful voyage until Bell navigated the Clyde, four more passed before a boat, built in England, crossed the Channel, and proceeded up the Seine to Paris.

As steam navigation took its rise on the Hudson, so the steam-boats navigating that river have uniformly been before all others in point of speed. The passage to Albany does not at present (1839) average more than 10 hours, which is at the rate of nearly fifteen miles per hour. It is stated by Mr. Redfield, that the maximum velocities are 16 miles per hour, that 15 miles per hour is no unusual rate, and 14 may be considered as an ordinary performance on the Hudson river. The first boats which approached to this degree of speed were constructed under the direction of R. L. Stevens. Others, however, speedily followed; and the attainment of such velocities, which European writers even at the present moment declare to be impossible, is due to the competition which has existed upon the Hudson.

The speed of which we speak, has been obtained by increasing the length of the stroke of the piston, the area of the steam-pipes and valves, the diameters of the wheels, and by changes in the form of the vessels, to which false prows have been adapted as experiments, until the figure of least resistance seems in some cases to have been reached. In some of the newer vessels the model has reached such a degree of perfection that no wave is raised at the bow, and no depression caused at the stern of the vessel. Above all, the expansive action of the steam has been employed, by means of which a given engine can be driven with greater velocity, and at a diminished cost.

Others have approached this same speed so nearly, that the difference of passage has not been many minutes in the distance of nearly 150 miles. In a passage made by the author, on the Hudson, in 1829, the wheels of the New-Philadelphia averaged 25½ revolutions per minute; and the piston moved with a velocity of 405 feet per minute, being 21 feet more than has been stated on a former page as the velocity of those of the North-America. Since that time the velocities of the pistons of steam-boats have been still further increased, and have in some cases amounted to as much as 600 ft. per minute.

204. The first attempt to navigate the ocean by steam was made, as we have seen, by John Stevens of Hoboken, in the year 1809, when he sent a vessel, originally constructed for a ferry-boat, from New-York to Philadelphia, around the capes of the Delaware.

In the summer of 1815, the first steam vessel built on the Clyde by Bell made a passage from Glasgow to Liverpool, and during the autumn of the same year several other vessels, also built on the Clyde, were sent to different parts of England. During the equinoctial storm of 1816 one of these crossed from Brighton to Havre, in a gale which the cutter packets employed at that time on the station were unable to weather.

The practicability and safety of navigating the stormy seas which surround the British Islands being thus demonstrated, the British Government was not long in undertaking to establish lines of packets for the conveyance of its mails. The first line was established between Holyhead and Dublin, and has been in successful operation for twenty years. It is said that they have rarely failed in sailing at the appointed time, and have met with few or no accidents.

Before the death of Fulton, he had planned a vessel which was intended to be used on the Baltic. This vessel was in a state of forwardness at time of his death. Circumstances prevented his successors from sending this vessel on her destined voyage, but she was placed as a packet between New-York and Newport, R. I. in which passage the open sea is navigated for a short distance. The very voyage contemplated by Fulton was effected in 1818 by a vessel built in New-York, called the Savannah. The Savannah made her passage from New-York to Liverpool, partly by steam and partly by the aid of sails, in 26 days. From Liverpool this vessel proceeded around Scotland to the Baltic, and up that sea to St. Petersburgh. In returning thence she touched at Arendahl in Norway, and, without making any other intermediate port, reached New-York in 25 days.

During the year 1819, a vessel rigged as a ship, but furnished also with a steam engine, was built at New-York, for the purpose of plying as a packet between that port and Charleston, Cuba, and New-Orleans. So far as safety and speed were concerned, the experiment was successful; but after several passages it was found that the number of passengers was not sufficient to defray the expense, and the scheme was abandoned. The vessel was of such excellent model and construction, that she was purchased by the Brazilian government for a cruizer, and was as late as 1838 still in existence in that service. Before this, however, the engine was taken out, and no other mode of propulsion employed except her sails. This vessel was constructed under the direction of Mr. Jasper Lynch, who had acquired his knowledge of the use of the steam-engine from Fulton. The experiment, although a failure in point of profit, was worthy of the most complete success. The vessel had admirable properties both as a sea-boat and a sailer, and the speed was not less than that which the best English steamers have reached up to the present time. Nothing was wanting except a sufficient tonnage to have enabled this vessel to cross the Atlantic in a time as short as that employed by the Great Western and Liverpool.

The regularity and safety with which the passages between Holy-Head and Dublin were performed, established the fact of the superior safety of steamers in stormy and dangerous seas. Lines of packets were, in consequence, speedily established between different points of the British Islands, and from Great Britain to the continent. Communications by steam have long existed to Hamburgh, Rotterdam, Antwerp, Calais, and Havre; and there are numerous steam packets plying between different ports of England and Ireland. The most important line is that between London and Leith, in which the largest steam vessels built before those intended for the navy or for crossing the Atlantic, were employed.

The British Government has gradually extended its lines of communication to Lisbon, Gibraltar, Malta, and Corfu. It has had it also in contemplation to extend them to Syria, in order to reach the Euphrates by land, and thence to establish steam-packets to Bombay. A company has also been formed for building steamers to proceed to India by the way of the Cape of Good Hope.

The first voyage to India by steam was performed in 1825, by the Enterprize. This vessel took her departure from Falmouth, and was 47 days between the Cape of Good Hope and Calcutta. As in the passage of the Savannah, the voyage was performed by the alternate aid of wind and steam.

In spite of these experiments, of greater or less promise, it was seriously maintained by no mean authority, as late as August 1838, that the passage of the ocean, as a regular business by steam vessels, was impracticable. The most that could be hoped, as was alleged, would be to pass from the most western ports of Europe to the Azores or Newfoundland, and then take in a fresh supply of fuel.

In the face of these discouraging predictions, the direct passage from a port in Great Britain to New-York was made almost simultaneously by two steamers before the end of the year in which the argument was held. Of these vessels, one (the Great Western) had been built for the express purpose, and had a tonnage adequate to the great probable consumption of fuel; the other (the Sirius) was of the very class which had furnished the basis of the opinion; and yet the fuel which could be carried was not entirely exhausted. It is therefore established beyond all possibility of doubt, that steam vessels, if they have the capacity of 12 to 1400 tons, may perform the direct passage from England to New-York by steam alone. It would also appear that no difficulty need exist in combining the sea-worthy qualities of the English steamers with the rapid motion of the American steam-boats; and this may be effected, along with a considerable saving in fuel, and a great reduction of the weight of engine, boiler, and water. With such reductions the carriage of many tons of cargo, as well as of passengers, will become possible, and the profits of the speculation will be placed upon a secure basis.

The form of the engines and boilers of the British steamers which have crossed the Atlantic, does not materially vary from that given in Pl. VIII. The required increase of power has been given by enlarging the diameter of the cylinders beyond the proportion which is there exhibited; and the extent of iron frame-work in which the engine is supported and kept together, has been enlarged. The proportions of the cylinder, and the manner in which two working beams are suspended from the piston rods in each engine, have been adopted with a view to ensure the stability of the vessel by placing the weight as low as possible. So long as the masts and sails of steamers approach in weight and extent to those of ordinary vessels, this is no unwise precaution; but as we firmly believe that sails might be dispensed with, this reason will no longer exist. The weight of these beams in particular is much greater than is admitted in American engines of equal power, where, instead of solid masses of cast-iron, a light frame-work of that material, surrounded by a strap of wrought iron, has been substituted, with a positive gain of strength.

The boilers of the English vessels are of a form which is very weak, the flues are of great size, and the quantity of water is much greater in relation to the fire surface than is admitted in the American practice. While, therefore, we have to admire the sagacious views with which a sufficient capital to build such noble vessels has been contributed, and contrast it with the limited scale on which the navigation of the ocean has been attempted in this country, we believe that great improvements remain to be made, by the introduction of the methods which we have cited as having contributed to give the great speed, which has been attained in the river boats of the United States. This is nearly one half more than has yet been reached in Europe, and with it there can be no doubt that the passage may be accomplished in 12 days.

205. The subject of the explosion of steam boilers has recently attracted a great share of public attention. A vast number of facts, and a great variety of written opinions, have been collected by the Secretary of the Treasury, and published by order of Congress. Among these papers we may quote, for the infor-

mation of our readers, one by Mr. Redfield of New-York. This gentleman adopts a different view of the subject from that given by us in Chap. II. Still the results at which he arrives are in strict conformity with those derived from the other theory, and are therefore to be implicitly relied on.

"If high-pressure engines must continue to be used, (of which I see not the utility or necessity,) the working pressure *should never* exceed fifty pounds to the square inch; and this may be easily effected by increasing the size and stroke of the working cylinders and piston. The forms of the boilers should be cylindrical, and their diameters from 36 to 42 inches, supported by their centres as well as at their terminations. Flues, if of a size affording but one or two in each boiler, are always dangerous; they displace too much water, and also obstruct the proper cleaning. Flues, however, are not to be dispensed with, but their number ought to be increased and their size diminished. An upper tier of four flues, and a lower tier of two, (the latter somewhat larger than the former,) are not too many for boilers of 42 inches in diameter; or 44 to 48 inches, if low pressure. These smaller flues, if properly arranged, will greatly facilitate the cleaning, and displace but little water; but their length should not usually exceed ten or twelve feet, as they abstract heat very rapidly. They will be better if made perfectly smooth on their inner surface, from a single long sheet of iron, lighter than the shell; and are not often liable to leaks or accidents. The outer shell should never be less in thickness than a full quarter of an inch; and a thickness much exceeding this, it is well known, cannot be used with advantage.

"In condensing engines which work expansively, called low-pressure, when working with ordinary speed, the pressure of the steam should usually range between one and one and a half atmospheres above the boiling point. But on emergencies the pressure may be increased to two atmospheres. *The boilers should have a range of strength falling but little short of those used for high pressure.* They may be constructed in the common wagon top form, provided that they are properly braced in their flat sides and arches, and have as many as four or six flue-arches for a boiler of eight or ten feet in width. The returning flues should be cylindrical, and of smaller diameter. The water-sides, water-bottoms, bridge-walls, and other flat surfaces, should, however, be brace-bolted at intervals of six inches; and the arches, shell, and all other portions, secured in a proportionate manner. If a *steam-chimney* is used, even of the circular form, it should be brace-bolted at smaller intervals than any part of the flat surfaces which are covered by water."

206. Steam is also employed to move carriages upon the land. For this purpose, the wheels of the carriage are set in motion by the engine, in the same manner that the paddle-wheels of a steam-boat are caused to turn; the friction which they experience upon their track causes them to move forward, unless they meet a resistance to their progressive motion equal to this friction. The experiments of Coulomb and Vince show that, under the circumstances in which wheels act, the friction of their circumference will depend upon the weight with which they are loaded, and the nature of the rubbing surface, but not in the least upon the velocity. The tire of wheels is made of iron, and steam-carriages usually run upon tracks, also of iron, forming what is styled a rail-road. Rail-roads are parallel bars of iron, laid either level, or with a gentle and uniform slope; and steam has, as yet, only been usefully applied to locomotion upon roads of this character. The reasons why they should be superior in this respect to a common road are obvious. The resistance is not only regular and uniform, but equal upon every wheel; while on a common road there is a constant variation in slope, and in the nature of the surface; and besides, obstacles are frequently met that affect but one of the wheels, and thus tend to turn the carriage to one side. There is thus a want of continuity in the motion of the carriage, a lateral sliding friction of the wheels upon the road, and one arising from penetration into the materials of which the road is made. In addition, the friction of the wheel upon the shoulder of the axle and on the linch pin, is of great amount on a common road. In spite of these difficulties, some tolerably successful experiments have been performed with steam-carriages upon common roads.

The case, however, that is most usual as well as most advantageous, is motion upon rail-roads. Here the friction is that of iron against iron. We cannot anticipate that the wheels will be prevented from sliding upon a rail-road by the maximum friction that takes place between two pieces of iron in experiments; dust, moisture, and other circumstances interfere to lessen the adhesion. It cannot, therefore, be safely taken at more than $\frac{1}{6}$th part of the weight. If there be a force applied, sufficient to cause the wheels of a carriage to turn around, it will continue to go forward until the resistance becomes equal to $\frac{1}{6}$th of the weight of the carriage. The carriage is, therefore, under the same circumstances as if it were drawn forward by a cord capable of bearing a strain of $\frac{1}{6}$th part of its weight.

The resistances to the progressive motion are the friction upon the axis of the wheels, and the disturbances growing out of lateral shocks. The friction of steel axles upon brass boxes, well coated with oil, is $\frac{1}{40}$th part of the weight; and the force applied to overcome it has its intensity increased in the ratio of the radius of the crank to the radius of the axle. As the radius of the crank of an engine of a given power cannot be increased without diminishing the area of the piston or its own velocity, there is no gain of force by simply varying the proportions of its engine. On the other hand, as with an equal number of revolutions, points will move faster on the circumference of a larger wheel than they will on a smaller one, and the progressive motion will depend on the velocity of the circumference, there is a constant and regular gain in velocity, by increasing the diameter of the wheels. This, however, has its limit in practice, for, by increasing the diameter of the wheels, the centre of gravity is raised, and the machine becomes unstable.

According to the best experiments and observations, the friction of carriages upon rail-roads has been in some cases diminished to $\frac{1}{600}$th; and may be safely taken as not more than $\frac{1}{20}$th. A locomotive carriage, therefore, all of whose wheels are driven by the engine, may move forward if it drag behind it any weight less than thirty-two times its own.

It might, at first sight, appear that, as the friction which causes the carriage to go forward increases with its weight, heavy carriages and engines were the best for locomotion; but the resistances increase also with the weight, and thus all weights, not absolutely essential to the structure of the engine, are disadvantageous. Hence, for locomotion, no other engine but that of high pressure can be admitted; for condensing engines of equal power are not only heavier in themselves, but require a quantity of cold water for condensation, that would, of itself, furnish a load for the engine. So also the boiler and the load of water, should be the smallest that is consistent with the generation of the necessary quantity of steam.

The workmanship of the carriages used on rail-ways has been regularly improved for several years past, and probably has not attained perfection. The want of perfection in the workmanship, and perhaps the absolute impossibility which exists of making all the wheels of equal diameter, has led to the practice, in rapid motions, of giving no more than one pair of wheels a motion from the engine. This pair bears little more than half the weight, and hence the propulsive power is apparently less than if all the wheels were driven. This loss, however, is not real; for the sliding of wheels, not absolutely equal in diameter, will consume more power than is apparently lost.

On the other hand, in slow motions, and in the ascent of inclined planes, heavy engines, of which all the wheels are driven by the engine, are employed.

A vast improvement has taken place in the performance of locomotive engines since the publication of our first edition. At that time we did not venture to state the actual draught of a locomotive at more than seven times its own weight. We are now enabled to rate it as high as thirty-two times as much as rests on the driving wheels. With an engine of the weight of 8 tons, the load has been as great as 175 tons, or more than 40 times the weight which rests on the active wheels; and the velocity with this load is $12\frac{1}{2}$ miles per hour. In doubling the load, the velocity is diminished to $\frac{1}{8}$th, while in a given distance the expenditure of fuel is diminished one half.

An engine constructed by H. R. Dunham & Co. of New-York for the Harlæm Rail Road weighed 20,400 lbs. or about 9 tons; the boiler being full of water, and the engine in working order. Of this weight 10,680 lbs. bore on the driving wheels. The load drawn was 105 tons upon 35 cars, whose weight is not given. The road was not level, and the slopes were from 25 to 30 feet per mile.

A locomotive engine is propelled in all cases by steam of high pressure. This mode of employing steam is rendered necessary by the great quantity of water required in condensation, which would of itself furnish a large part of the load which can be drawn. The cylinder of the engine has been usually placed horizontally, or but little inclined. Some of those on the Baltimore and Ohio Rail Road have been placed vertically. Two cylinders are generally used, acting upon cranks on the axle of the same pair of wheels, at right angles to each other. In this way one piston is at its maximum action while the crank of the other is passing the centres, and greater regularity of motion is ensured. When the other wheels are to be set in motion, they are united with the first pair by means of connecting rods. We have already stated in what cases all the wheels are to be driven, and when no more than one pair.

In the former case no more than four wheels are used. In the latter case, after trying curricle engines, those with six wheels have been found most serviceable. The English engineers place the driving wheels, which are of greater diameter than the remaining four, between the other two pairs. In the American engines the driving wheels are at one end of the carriage, and the four others are united in the same frame on which the opposite end bears. Engines of this form, of great perfection of workmanship, have been constructed by various artists, of whom the most celebrated are Baldwin and Norris. We have obtained, as an illustration of this part of the subject, a draught of a locomotive by Dunham of New-York. This is represented on Pl. IX., and is a specimen of the form now considered as most advantageous. An engine with six wheels was first planned in the year 1826 for the Mohawk and Hudson Rail Road, by Mr. J. B. Jervis.

In order to compare the action of steam upon rail-roads, with its performance in propelling boats, we have the following principles: —

Friction opposes a resistance which has a constant measure at all velocities; but the measure of the power required to overcome it, will depend both on the resistance and the velocity. Hence the powers of engines, by which different velocities are obtained in the same carriage, are proportioned to the velocities. But as the time for passing over a given space is inversely as the velocity with which the distance is performed, a given distance should be performed, with a constant load, at any velocity whatever, with a constant expenditure of fuel.

If the same locomotive engine have its velocity increased by lessening the loads it drags or diminishing the friction, by both of which methods a limited change in velocity may be attained, the expenditure of steam has been found to increase in a higher ratio than the velocities. This arises from the fact, to which we have more than once referred, that the action of steam of a given tension on the piston of an engine is diminished, when the velocity is increased. Were it not so, the expenditure of steam should be in this case proportioned to the velocities.

It is therefore obvious, that when speed is the sole object in view, locomotion on land soon becomes more advantageous than steam navigation, for the power in the latter case increases, according to the received theory, as the cubes of the velocities; and the expenditures of fuel as the square. Even if the view which we have presented as more consistent with the facts, be true, the power must be increased as the squares, and the expenditure of fuel with the first power of the velocities. On the other hand, friction on rail-roads has not yet been so much diminished as to enable them to compete either with steam or canal navigation, in the conveyance of heavy loads at small velocities. The friends of rail-roads have anticipated that they will soon be enabled to lessen the friction so much as to place them, in all respects, on a par with either of the other species of transportation. It would, however, appear, both from theory and experience, that unless when a saving of time is the principal object, the application of steam to navigation is more advantageous than to the rail-road.

207. Evans, as has been already mentioned, was the first

who entertained rational hopes of being able to move carriages by steam, for we must reject the views of Robison and Watt as wholly impracticable; and indeed the impossibility of using the condensing engine was ascertained and admitted by Watt. Evans not only was the first to entertain correct views, but was also the first to submit them to practice, in the removal of his dredging machine, which has been before referred to in the present chapter.

In 1802 Trevithick and Vivian took out a patent for the application of their engine to propel carriages upon rail-roads. In 1804 they published a description of a carriage intended for common roads, but it was not until 1806 that an actual experiment was made. This was performed upon the Merthr Tydvil Rail-Road, in Wales. The performance of the apparatus was, however, far less than might have been anticipated from its power, and this was ascribed to a want of sufficient adhesion of the wheels to the rail. We recollect having heard this failure ascribed to the circumstance that but one of the wheels was set in motion by the engine; but all the authorities that we have consulted seem to agree, that all the four wheels were made to revolve.

The failure, which, had the first statement been true, is at once to be accounted for, becomes difficult to explain if these authorities state the real circumstances.

A difficulty, however, in the use did occur, and being ascribed to the cause that has been mentioned, a person of the name of Blenkinsop undertook to obviate it. For this purpose he laid a rack, or rail cut into teeth, between the other two rails, along the whole extent of road: into this a pinion, set in motion by the engine, caught. This method was found effectual at slow velocities, and was used from the year 1801, in which it was invented, nearly up to the present time, at Middleton Colliery, near Leeds in England. It will not admit of great velocities, but is applicable to the rising of ascents far more steep than can be overcome by the mere adhesion of the wheels to the road.

In 1812, Messrs. W. & E. Chapman obtained a patent in England for a locomotive engine, the power of which was applied by means of a chain fixed at the two ends, and passing over an axle upon the carriage that was caused to revolve by the engine.

In 1813 Mr. Brunton, of Batterly Iron Works, proposed a plan for locomotion by steam, in which he employed a system of levers, resembling, in their action, the bones of the human leg.

In 1815, Dodd and Stephenson, of Killingworth, in England, returned to the original principle of adhesion, and were completely successful, showing that on rail-roads, absolutely or nearly level, the friction was sufficient to produce progressive motion in all cases except when the rails were covered with snow. Their engine had six wheels, two of which were moved by the engine, and the others connected with them by an endless chain passing over drums.

Locomotive engines have received, since that time, continual improvements. Two cylinders have been used, each acting upon a pair of wheels. The next step was to use two cylinders acting at right angles to each other upon the same pair of wheels, and to move the others by connecting rods.

In these several improvements, the weight of the engine and its parts were gradually increased to an excessive amount. The centre of gravity was also raised so high as to render the carriages unstable. In consequence of this, a search has more recently taken place for engines and carriages of small weight. This has been successful in a remarkable degree, in locomotive engines exhibited upon the Manchester and Liverpool Rail-Roads. The details of these experiments are to be found in the Mechanics' Magazine for November and December, 1829, and in the Quarterly Review for March, 1830, to which we refer our readers.

The Baltimore and Ohio Rail-Road was projected, and some parts of it finished, as early as the Manchester and Liverpool. It also became the seat of a number of experiments, and these have been continued upon it, and on other more recent rail-roads, until such a degree of perfection has been reached in the structure of locomotive engines in the United States, that they have been made an article of export.

208. In concluding this work, a few reflections on the importance of the subject may not be irrelevant. The steam engine has been described in its most usual and most perfect forms; in the historical sketch, it has been traced from the earliest notices of the knowledge of the mechanical power of steam, down to the present time, when it occupies so important a space among the productions of human skill. Feeble and imperfect in its first beginnings, and limited, for nearly a century after its introduction, to a single, and by no means important object, it became in the hands of Watt an instrument of universal application. It is now equally subservient to those purposes which require the greatest delicacy of manipulation, and those which demand the most intense exertions of power. Its introduction and gradual improvement have required inventive talents of the highest order, and the exertions of genius the most sublime; in its uses we see developed and realized, not only the brilliant conceptions of poetry, but the wildest fables of romance; it has already changed the state of the world, and altered the relations of civilized society; and in its farther progress it seems to promise to perform even more inportant services, and to fulfil yet higher destinies.

APPENDIX.

ANALYSIS OF A NEW THEORY

OF

THE STEAM ENGINE.

BY

THE CH. G. DE PAMBOUR.

The following analysis of a new theory of the Steam Engine, made by its author, from the full exposition which he has laid before the French Institute, will be found to possess much interest. Before it was received, the second edition had been prepared for the press; and, even had it been judged expedient, it would have been too late to adopt it as the basis of practical rules. It may, however, be stated, that however fully we concur in the views of the Chev. de Pambour, it would have been premature to adopt it until it had received a more general sanction; and that its assumption might have for a time unfitted our own work for the use of practical men. It is therefore annexed as an Appendix, for the purpose of giving it circulation, and preparing the public mind for its reception in the place of that of Robinson, which has hitherto formed the basis of all treatises on the Steam Engine, and from which, although aware of its defects, we have not ventured to deviate.

PART I.

PROOFS OF THE INEXACTITUDE OF THE ORDINARY METHODS, AND EXPOSITION OF THE ONE PROPOSED.

§ 1. *Mode of calculation hitherto in use.*—All the problems in the application of steam-engines merge into these three—

The velocity of the motion being given, to find the load the engine will move at that velocity.

The load being given, to find the velocity at which the engine will move that load ;

And, the load and the velocity being given, to find the vaporization necessary, and consequently the area of heating surface requisite for the boiler, in order that the given load be set in motion at the given velocity.

The problem, which consists in determining the useful effect to be expected from an engine of which the number of strokes of the piston per minute is counted, that is, whose velocity is known, evidently amounts to determining the effective load corresponding to that velocity ; for that load being once known, by multiplying it by the velocity we have the useful effect required.

According to the mode of calculation hitherto admitted, when it is wanted to know the useful effect an engine will produce at a given velocity, or, in other words, the effective load that it will set in motion at that velocity, the area of the cylinder is multiplied by the velocity of the piston, and that product by the pressure of steam in the boiler ; this gives, in the first place, what is called the theoretical effect of the engine. Then, as experience has shown that steam-engines can never completely produce this theoretical effect, it is reduced in a certain proportion, indicated by a constant number, which is the result of a comparison between the theoretical and practical effects of some engines previously put to trial ; and thus is obtained the number which is regarded as the practical effect of the engine, or the work it really ought to execute.

A mode perfectly similar is followed, for determining the vaporization which an engine ought to produce in order to produce a desired effect ; that is to say, for resolving the third of the problems which we have presented above. As to the second of these problems, that which consists in determining the velocity the engine will assume under a given load, no solution of it has been proposed in this way, and we shall expose, farther on, some fruitless essays that have been made to resolve it in another way.

As in the above-mentioned calculation no account is taken of friction, nor of some other circumstances which appear likely to diminish the power of the engine, the difference observed between the theoretical and the practical result excites no surprise, and is readily attributed to the circumstances neglected in the calculation.

§ 2. *First objection against this method of calculation.*—This mode of calculation is liable to many objections, but for the sake of brevity we limit ourselves to the following:—

The coefficient adopted to represent the ratio of the practical effects to the theoretical, varies from $\frac{1}{3}$ to $\frac{2}{3}$, according to the various systems of steam-engines; that is to say, that from $\frac{2}{3}$ to $\frac{1}{3}$ of the power exerted by the machine is considered to be absorbed by friction and divers losses. Not that this friction and these losses have been measured and found to be so much, but merely because the calculation that had been made, and which might have been inexact in principle, wanted so much of coinciding with experience.

Now it is easy to demonstrate that the friction and losses which take place in a steam-engine can never amount to $\frac{2}{3}$, nor to $\frac{1}{3}$ of the total force it developes. It will suffice to cast an eye on the explanation attempted, on this point, by Tredgold, who follows this method in his Treatise on Steam-Engines.* He says (art. 367,) that, for high pressure engines, a deduction of $\frac{4}{10}$ must be made from the *total* pressure of the steam, which amounts to a deduction of $\frac{5}{10}$ on the ordinary *effective* pressure of such engines; and to justify this deduction, which, however, is still not enough to harmonize the theoretical and practical results in many circumstances, he is obliged to estimate the friction of the piston, with the losses or waste, at $\frac{2}{10}$ of the power, and the force requisite for opening the valves and overcoming the friction of the parts of machine, at $\frac{6}{100}$ of that power. Reflecting that these numbers express fractions of the gross power of the engine, we must readily be convinced that they cannot be correct; for, in supposing the engine had a useful effect of 100 horses,

* The author here refers to the first edition of 'Tredgold on the Steam-Engine:' in the new edition just published, the algebraic parts are transformed by the editor into easy practical rules, accompanied by examples familiarly explained for the working engineer.

which, from the reduction or coefficient employed, supposes a gross effect of 200 horses, 12 would be necessary to move the machinery, 40 to draw the piston, &c. ! The exaggeration is evident.

Besides, in applying this evaluation of the friction to a locomotive engine, which is also a high pressure steam-engine, and supposing it to have 2 cylinders of 12 inches diameter, and to work at 75 lbs. total pressure, which amounts to 60 lbs. effective pressure, per square inch, we find that from the preceding estimate, the force necessary to draw the piston would be 5650 lbs., whereas our own experiments on the locomotive engine, the *Atlas*, which is of these dimensions, and works at that pressure, demonstrate that the force necessary to move, not only the two pistons, but all the rest of the machinery, including the waste, &c., is but 48 lbs. applied to the wheel, or 283lbs. applied on the piston.

It is then impossible to admit, that in steam-engines the friction and losses can absorb the half, nor the third, much less the $\frac{2}{3}$ of the total power developed ; and yet there do occur cases wherein, to reconcile the practical effects with the theoretical ones thus calculated, it would be necessary to reduce the latter to the fourth part, and even to less ; and, what is more, it often happens that the same engine which in one case requires a reduction of $\frac{3}{4}$, will not in other cases need a reduction of more than about $\frac{1}{6}$. This is observed in calculating the effects of locomotive engines at very great velocities, and afterwards at very small ones.

There is no doubt, then, that the difference observed between the theoretical effect of an engine and the work which it really performs, does not arise from so considerable a part of the applied force being absorbed by friction and losses, but rather from the error of calculating in this manner the theoretical effect of the machine. In effect, this calculation supposes that the motive force, that is, the pressure of the steam *against the piston or in the cylinder*, is the same as the pressure of the steam in the boiler; whereas we shall presently see, that the pressure in the cylinder may be sometimes equal to that of the boiler, sometimes not the half nor even the third of it, and that it depends on the resistance overcome by the engine.

§ 3. *Formulæ proposed by divers authors to determine the velocity of the piston under a given load, and proofs of their inexactitude.*— We have said that this problem was not resolved by the foregoing method. The following are the attempts made to that end by another way. Tredgold, in his Treatise on Steam-Engines (art. 127

and following), undertakes to calculate the velocity of the piston from considerations deduced from the velocity of the flowing of a gas, supposed under a pressure equal to that of the boiler, into a gas supposed at the pressure of the resistance. He concludes from thence, that the velocity of the piston would be expressed by this formula,

$$V = 6 \cdot 5 \sqrt{h},$$

in which V is the velocity in feet per second, and h stands for the difference between the heights of two homogeneous columns of vapour, one representing the pressure in the boiler, the other that of the resistance. But it is easily seen that this calculation supposes the boiler filled with an inexhaustible quantity of vapour, since the effluent gas is supposed to rush into the other with all the velocity it is susceptible of acquiring, in consequence of the difference of pressure. Now, such an effect cannot be produced, unless the boiler be capable of supplying the expenditure, however enormous it might be. This amounts, consequently, to supposing that the production of steam in the boiler is unlimited. But, in reality, this is far from being the case. It is evident that the velocity of the piston will soon be limited by the quantity of steam producible by the boiler in a minute. If that production suffice to fill the cylinder 200 times in a minute, there will be 200 strokes of the piston per minute; if it suffice to fill it 300 times, there will be 300 strokes. It is then the vaporization of the boiler which must regulate the velocity, and no calculation which shall exclude that element can possibly lead to the true result; consequently the preceding formula cannot be exact.

This is why, in applying this formula to the case of an ordinary locomotive engine of the Liverpool Railway with a train of 100 tons, the velocity the engine ought to assume is found to be 734 feet per second, instead of twenty miles an hour, or five feet per second, which is its real velocity.

Again, in his Treatise on Railways (page 83), Tredgold proposes the following formula, without in any way founding it on reasoning or on fact:

$$V = 240 \frac{\sqrt{l\,P}}{W},$$

in which V is the velocity of the piston in feet per minute, l the stroke of the piston, P the effective pressure of the steam in the boiler, and W the resistance of the load. But as this formula makes no mention either of the diameter of the cylinder, or of the quantity of steam supplied by the boiler in a minute, it clearly cannot give the velocity sought; for if it could, the velocity of an engine would be the same with a cylinder of one foot diameter as with a cylinder of four feet, which expends sixteen times as much steam. The area of heating surface, or the vaporization of the boiler, would be equally indifferent: an engine would not move quicker with a boiler vaporizing a cubic foot of water per minute, than with one that should vaporize but $\frac{1}{4}$ or $\frac{1}{20}$. Hence this formula is without basis.

Wood, in his Treatise on Railways (page 351), proposes the following formula also, without discussion,

$$V = 4 \frac{\sqrt{l\,P}}{W},$$

where V is the velocity of the piston in feet per minute, l the length of stroke of the piston, W the resistance of the load, and P the surplus of the pressure in the boiler, over and above what is necessary to balance the load W. This formula being liable to the same objections as the preceding, is also demonstrated inadmissible *a priori.*

Consequently, of the three fundamental problems of the calculation of steam-engines, two have received inaccurate solutions by means of the coefficients, and the third, as we have just seen, has received no solution at all.

§ 4. *Succinct exposition of the proposed theory.*—After having made known the present state of science, with regard to the theory and estimation of the effective power of steam-engines, it remains to exhibit the theory we apply to them ourselves.

It is well known, that in every machine, when the effort of the motive power becomes superior to the resistance, a slow motion is created, which quickens by degrees till the machine has attained a certain velocity, beyond which it does not go, the motive power being incapable of producing greater velocity with the mass it has to move. Once this point attained, which requires but a very short space of time, the velocity continues the same, and the motion remains uniform as long as the effort lasts. It is from this point only that the effects of engines begin to be reckoned, because they are never employed but in that state of uniform motion; and it is with reason that the few minutes, during which the velocity regulates itself, and the transitory effects which take place before the uniform velocity is acquired, are neglected.

Now, in an engine arrived at uniform motion, the force applied by the motive power forms strictly an equilibrium with the resistance; for if that force were greater or less, the motion would be accelerated or retarded, which is contrary to the hypothesis. In a steam-engine the force applied by the motive agent is nothing more than the pressure of the steam *against the piston*, or *in the cylinder*. The pressure therefore in the cylinder is strictly equal to the resistance of the load against the piston.

Consequently the steam, in passing from the boiler to the cylinder, may change its pressure, and assume that which is represented by the resistance of the piston. This fact alone exposes all the theory of the steam-engine, and in a manner lays its play open.

From what has been said, the force applied on the piston, or the pressure of the steam in the cylinder, is therefore strictly regulated by the resistance of the load against the piston. Consequently calling P′ the pressure of the steam in the cylinder and R the resistance of the load against the piston, we have as a first analogy,

$$P' = R.$$

To obtain a second relation between the data and the quæsita of the problem, we shall observe that there is a necessary equality between the quantity of steam produced, and the quantity expended by the machine ; the proposition is self-evident. Now, if we express by S the volume of water vaporized in the boiler per minute, and effectively transmitted to the cylinder, and by m the ratio of the volume of the steam generated under the pressure P of the boiler, to the volume of water which produced it, it is clear that

$$m\,S$$

will be the volume of steam formed per minute in the boiler. This steam passes into the cylinder, and there assumes the pressure P′ ; but if we suppose that, in this motion, the steam preserves its temperature in passing from the boiler to the cylinder, or from the pressure P to the pressure P′, its volume increases in the inverse ratio of the pressures. Thus the volume m S of steam furnished per minute by the boiler will, when transmitted to the cylinder, become

$$m\,S\,.\,\frac{P}{P'}.$$

On another hand, v being the velocity of the piston, and a the area of the cylinder, $a\,v$ will be the volume of steam expended by the cylinder in a minute. Wherefore, by reason of the equality which necessarily exists between the production of the steam and the expenditure, we shall have the analogy of

$$a\,v = m\,S\,.\,\frac{P}{P'}\,;$$

which is the second relation sought.

Consequently, by exterminating P′ from the two equations, we shall have as a definitive analytic relation among the different data of the problem:

$$v = \frac{m\ S}{a} \cdot \frac{P}{R}.$$

This relation is very simple, and suffices for the solution of all questions regarding the determination of the effects or the proportions of steam-engines. As we shall develope its terms hereafter, in taking it up in a more general manner, we content ourselves to leave it for the present under this form, which will render the discussion of it easier and clearer.

The preceding equation gives us the velocity assumed by the piston of an engine under a given resistance R. If, on the contrary, the velocity of the motion be known, and it be required to calculate what resistance the engine will move at that velocity, it will suffice to resolve the same equation with reference to R, which will give

$$R = \frac{m\ S\ P}{a\ v}.$$

Finally, supposing the velocity and the load to be given beforehand, and that it be desired to know what vaporization the boiler should have to set the given load in motion at the prescribed velocity, it will still suffice to draw from that analogy the value of S, which will be

$$S = \frac{a\ v\ R}{m\ P}.$$

On these three determinations we rest for the moment, because, as will soon appear, they form the basis of all the problems that can be proposed on steam-engines.

§ 5. *New proofs of the exactitude of this theory, and of the inaccuracy of the ordinary mode of calculation.*—The theory just developed demonstrates that the steam may be generated in the boiler at a certain pressure P, but that in passing to the cylinder it necessarily assumes the pressure R, strictly determined by the resistance to the piston, whatever the pressure in the boiler may be. Consequently, according to the intensity of that resistance, the pressure in the cylinder, far from being equal to that in the boiler, or from differing from it in a certain constant ratio, may at times be equal to it, and at other times very considerably different. Hence those who, in performing the ordinary calculation, consider the force applied on the piston as indicated by the pressure in the boiler, begin by introducing into their calculation an error altogether independent of the real losses to which the engine is liable. To this cause, then, and not to the friction and losses, which can form but the smallest part of it, must be attributed the enormous difference which, in this mode of calculation, is found between the theoretical effect of the engine, and the work which it really executes.

We have already proved the mode of action of the steam in the cylinder by the consideration of uniform motion ; but in examining what passes in the engine, we shall immediately find many other proofs.

1st. The steam, in effect, being produced at a certain degree of pressure in the boiler, passes into the tube of communication, and thence into the cylinder. It first dilates, because the area of the cylinder is from ten to twenty-five times that of the tube ; but it would promptly rise to the same degree as in the boiler, were the piston immoveable. But as the piston, on the contrary, opposes only a certain resistance, determined by the load sustained by the engine, it will yield as soon as the elastic force of the steam in the cylinder shall have attained that point. The piston, in consequence, will be a valve to the cylinder. Hence the pressure in the cylinder can never exceed the resistance of the piston, for that would be supposing a vessel full of steam, in which the pressure of the steam would be greater than that of the safety valve.

2nd. Were it true that the steam flowed into the cylinder, either at the pressure of the boiler, or at any other pressure which were to that of the boiler in any fixed ratio, as the quantity of steam generated per minute in the boiler would then flow at an identical pressure in all cases, and would consequently fill the cylinder an identical number of times per minute ; it would follow, that as long as the engine should work with the same pressure in the boiler, it would assume the same velocity with all loads. Now, we know that precisely the contrary takes place, the velocity increasing when the load diminishes ; and the reason of it is, that when the load is half, the steam flowing also at a half pressure into the cylinder, and consequently acquiring a volume double what it had before, will serve for double the number of strokes of the piston.

3rd. Applying the same reasoning inversely, we perceive that were the pressure in the cylinder really bearing a constant ratio to that in the boiler, or if it be preferred, constant so long as that in the boiler did not vary, we should, in calculating the effort of which the engine would be capable, always find it the same, whatever be the velocity of the piston. Thus, at any velocity whatever, the engine would always be capable of drawing the same load; which experience again contradicts, for the greater the velocity of the piston, the lower the pressure of the steam in the cylinder, whence results, that the load of the engine lessens at the same time.

4th. Another no less evident proof of this is easily adduced. Were it true that the pressure in the cylinder were to that in the boiler in any fixed proportion, since the same locomotive engine always requires the same number of revolutions of the wheel, or the same number of strokes of the piston to traverse the same distance, it would follow that, as long as those engines worked at the same pressure, they would consume in all cases the same quantity of water for the same distance. Now, the quantity of water, far from remaining constant, decreases on the contrary with the load, as may be seen by the experiments we have published on this subject. Here therefore again it is proved, that, notwithstanding the equality of pressure in the boiler, the density of the steam expended follows the intensity of the resistance, that is to say, the pressure in the cylinder is regulated by that resistance.

5th. Similarly, the consumption of fuel being in proportion to the vaporization effected, it would follow, if the ordinary theory were exact, that the quantity of fuel consumed by a given locomotive, for the same distance, would always be the same, with whatever load. Now we again find by experience that the quantity of fuel diminishes with the load, conformably to the explanation we have given of the effects of the steam in the engine.

6th. It is again clear, that if the pressure in the cylinder were, as it is believed, constant for a given pressure in the boiler, that so soon as it was recognised that an engine could draw a certain load with a certain pressure, and communicate to it a uniform motion, it would follow that the same engine could never draw a less load with the same pressure, without communicating to it a velocity indefinitely accelerated; since the power, having been found equal to the resistance of the first load, would necessarily be superior to that of the second. Now, experience proves, that in the second case the velocity is greater, but that the motion is no less uniform than in the first; and the reason of this is, that though the steam may indeed be produced in the boiler at a greater or less pressure, and that it matters little, yet on passing into the cylinder, it always assumes the pressure of the resistance, whence results that the motion must remain uniform as before.

7th. Finally, in looking over our experiments on locomotives, it will be seen that the same engine will sometimes draw a light load with a very high pressure in the boiler, and sometimes a heavy load with a very low pressure. It is then impossible to admit, as the ordinary calculation supposes, that any fixed ratio *whatever* has existed between the two pressures. Moreover, the effect just cited is easy to explain, for it depends simply on this, that in both cases the pressure in the boiler was superior to the resistance on the piston ; and it needed no more for the steam, generated at that pressure or at any other, satisfying merely that condition, to pass into the cylinder and assume the pressure of the resistance.

It is then visible, from these various proofs, that the pressure in the cylinder is strictly regulated by the resistance on the piston, and by nothing else ; and that any method like that of the coefficients in the ordinary calculation, which tends to establish a fixed ratio between the pressure in the cylinder and that of the boiler, must necessarily be inexact.

§ 6. *Verification of the two modes of calculation by particular examples.*—We have sufficiently demonstrated the want of basis of the ordinary calculation ; but as the inaccuracy we have just exposed in that method might by some be supposed to be of slight importance, and they might conceive that, in practical examples, it amounted to the obtaining of results, which, if not quite exact, were at least very near the truth, we will now attempt to apply it to some particular cases.

The coefficient of reduction for high pressure engines, working without expansion and without condensation, not being given by the authors who have treated on these subjects, we propose, in order to determine it, the two following facts, which took place before our eyes :—

I. The *Leeds* locomotive engine, which has two cylinders eleven inches in diameter, stroke of the piston sixteen inches, wheel five feet in diameter, drew a load of 88·34 tons, in ascending a plane inclined 1 in 1300, at the velocity of 20·34 miles an hour ; the effective pressure in the boiler being 54 lbs. per square inch, or the total pressure 68·71 lbs. per square inch.

II. The same day, the same engine drew a load of 38·52 tons in descending a plane inclined 1 in 1094, at the velocity of 29·09 ; the pressure in the boiler being precisely the same as in the preceding trial, and the regulator open to the same degree. These experiments may be seen in pages 233 and 234 of our Treatise on Locomotives.

If on one hand be reckoned, according to the ordinary method, the theoretic effort applied to the piston, and on the other hand the effect really produced, viz., the resistance opposed by the load *plus* that of the air against the train, we find, on referring the pressure and the area of the pistons to the foot square :—

1st case.—Theoretic effort applied on the piston, according to the ordinary calculation 1·32× (68·71×144)	13,060 lbs.
Real effect	8,846
Coefficient of correction	0.68
2nd case.—Theoretic effort, the same as above	13,060
Real effect	6,473
Coefficient of correction	0.50

The *mean* coefficient, to apply to the total pressure, to convert the theoretic effects to the practical, is then ·59.

We find, then, three very different coefficients: choose the first case, then an error occurs in the second; choose the second, and an error must arise in the first; by taking the third, you will only divide the error between the two. In every way an error is inevitable, and that alone suffices to prove that every method, like the ordinary one, which consists in the use of a *constant* coefficient, is necessarily inexact, whatever be the coefficient chosen, and to whatever engine the application be made; for it is evident that the same fact would occur in every kind of steam-engine. Only that it might be less marked, if the velocities at which the engine were taken were less different; and this is what has hitherto prevented the error of this method from being perceived, for all the engines of the same system being imitated from each other, and moving nearly at the same velocity, the same coefficient of correction seems tolerably to suit them, from the factitious limit that had been laid down for the speed of the piston.

Besides, in stationary engines one cannot, for want of precise determinations of the friction, disengage in the result the part which is really attributable to it from that which constitutes a positive error.

But here we may easily be convinced that neither of these coefficients of correction represents, as the ordinary theory would have it, the friction, losses, and various resistances of the machine; for direct experiments made on the engine under consideration, and noted in our Treatise on Locomotives, enable us to estimate separately all these frictions, losses, and resistances. Reckoning, then, the friction of the engine at 82lbs., taking account besides of its additional friction per ton of load, and adding for each case the pressure subsisting on the opposite side of the piston by the effect of the blast pipe, we find, as the sum of the friction and indirect resistances—

1st case.—Friction . . . . 1,257 lbs.
or ·10 of the theoretic result.

2nd case.—Friction . . . . 873 lbs.
or ·07 of the theoretic result.

Thus we see, that in each of the two cases, the friction and indirect resistances, omitted in the calculation, do not in reality amount to more than 10 or 7 hundredths of the theoretic result; and if we should be disposed to add to that $\frac{1}{20}$ or ·05, for the filling of the vacant spaces of the cylinder, which we could not estimate in lbs., it will be ·15 and ·12; whereas the coefficients of correction would raise them to ·32 in one case, and ·50 in the other; that is, to 2 and 4 times what they really are. If, then, from these coefficients, be deducted the true value of the friction and losses, it will appear that the theoretic error, introduced into calculation under the denomination of friction, is 17 per cent. of the *total power of the engine* in the one case, and 38 per cent. in the other.

But it is to be remarked, that, from the preceding evaluations, viz., of the direct resistances first, and then of the friction and indirect resistances, we have, for each of the two cases in question, the sum of the total effects really produced by the machine as follows:—

1st case.—Direct resistances	8,846 lbs.
Friction	1,257
	10,103
2nd case.—Direct resistances	5,473
Friction	873
	6,346

We are therefore enabled now to compare these effects produced with the results either of the ordinary calculation or of our theory.

1°. In applying the ordinary calculation with the mean coefficient ·56 determined above, and comparing its result with the real effect, we find—

1st case.—Effort applied on the piston, according to the ordinary calculation, $1{\cdot}32 \times (68{\cdot}71 \times 144) \times {\cdot}59$	7,705 lbs.
Effect produced, including friction and every resistance	10,103
Error over and above the friction and resistances	2,398
2nd case.—Effort applied on the piston, according to the ordinary calculation, the same as above .	7,705 lbs.
Effect produced, including friction and every resistance	7,346
Error over and above the friction and resistances .	359
Mean error of the two cases	1,378

It is then evident what error would have been committed in calculating the effects of this engine from the coefficient ·59; but it is equally evident, that in applying any other coefficient *whatever*, the error would only transfer itself from one case to the other, without ever disappearing; and thus it is that the coefficient, ·59 has almost annulled the error of the second case, by transferring it to the first.

To apply our formula with reference to the same problem, viz.:—

$$a\,\mathrm{R} = \frac{m\,\mathrm{S}\,\mathrm{P}}{a\,v},$$

we have nothing more to do than to substitute for the letters their value, taking care to refer all the measures to the same unit. In making then these substitutions, which give $\mathrm{P} = 68{\cdot}71 \times 144$ lbs., $m = 411$, $a = 1{\cdot}32$, and observing that the effective vaporization of the engine has been $\mathrm{S} = {\cdot}77$ cubic foot of water per minute, we find,—

1st case.—Effort applied by the engine at the given velocity, according to our theory, $\dfrac{411 \times 0{\cdot}77 \times (68{\cdot}71 \times 144)}{298}$ . . .	10,507 lbs.
Effect produced, including friction and resistances, as above	10,103
Difference	404

2nd case.—Effort applied by the engine at the given velocity, according to our theory, $\frac{411 \times 0{\cdot}77 \times (68{\cdot}71 \times 144)}{434}$ . . . . . 7,215 lbs.

Effect produced, including friction, &c. 7,346

Difference 131

Mean difference of two cases 267

It appears, then, that by this method, the useful effect is found with a difference only of 267 lbs., a very inconsiderable difference in experiments of this kind, wherein so much depends on the management of the fire.

2°. To continue the same comparison of the two theories, let it be required to calculate what quantity of water per minute the boiler ought to vaporize, to produce either the first effect or the second. The method followed by the ordinary theory, again consists in previously supposing that the volume described by the piston has been filled with steam at the same pressure as in the boiler, and then in applying to it a fractional coefficient to account for the losses.

Now, in the first case, the volume described by the piston at the given velocity, is $1{\cdot}32 \times 298 = 393$ cubic feet. Had this volume been filled with steam at the pressure of the boiler, it would have required a vaporization of $\frac{393}{411} = {\cdot}96$ cubic foot of water per minute. But the real vaporization was but ·77; wherefore, in the first case, the coefficient necessary to lead from the vaporization indicated by the ordinary calculation, to the real vaporization, $\frac{{\cdot}77}{{\cdot}96} = {\cdot}81$.

In the second case, we find in the same manner, that the coefficient should be ·55; whence, in this problem, as in the preceding one, no constant coefficient whatever can suffice.

Performing, however, the calculation with the mean coefficient, ·68, we find,—

1st case.—Vaporization per minute, calculated by the ordinary theory, with the coefficient, $\frac{1{\cdot}32 \times 298}{411} \times {\cdot}68$ . . . . ·65

Real vaporization . . . . ·77

Error . . . . ·12

2nd case.—Vaporization per minute, calculated by the ordinary

theory, with the coefficient, $\frac{1\cdot32 \times 434}{411} \times \cdot68$ . . . . ·95

Real vaporization . . . . ·77

Error . . . . ·18

The mean error committed is then $\frac{1}{5}$ of the vaporization, and being, as it is, a mean, it may, in extreme cases, become $\frac{2}{5}$, or amount to half of the whole vaporization.

This is the error committed in seeking a coefficient *expressly* for the vaporization. But when the coefficient, determined in the preceding case, that is, by the comparison of the theoretical and practical effects, is used as a divisor, as by many authors it is, much greater errors are induced, which we will show by an example farther on.

In our theory, on the contrary, the vaporization necessary to set in motion the resistance a R at the velocity v, is given by the formula

$$S = \frac{a R \times v}{m P}.$$

We have then,—

1st case.—Vaporization calculated from our

theory, $\frac{10103 \times 298}{411 \times (68\cdot71 \times 144)}$ . . . . ·74

Real vaporization . . . . ·77

Difference . . . . ·03

2nd case.—Vaporization calculated from our

theory, $\frac{7346 \times 434}{411 \times (68\cdot71 \times 144)}$ . . . . ·78

Real vaporization . . . . ·77

Difference . . . . ·01

3°. Lastly, in the case of finding the velocity of the piston, supposing the resistance to be given, any method similar to the ordinary one must inevitably lead to errors ; but we must dispense with comparison, since this problem has never been resolved, and we shall therefore in this case merely show the verification of our own theory. The formula relative to this problem is

$$v = \frac{m S P}{a R}.$$

We find then,—

1st case.—Velocity of the piston in feet per minute, calculated from our theory, $\frac{411 \times \cdot 77 \times (68 \cdot 71 \times 144)}{10103}$ . . 310

Real velocity	298
Difference	12

2nd case.—Velocity of the piston from our theory, $\frac{411 \times \cdot 77 \times (68 \cdot 71 \times 144)}{7346}$ 426

Real velocity	434
Difference	8

It consequently appears, that in each of the three problems in question, our theory leads to the true result ; whereas the ordinary theory, besides that it leaves the third problem unresolved, may, in the other two, lead to very serious errors.

Before abandoning this comparison, we request attention to an effect, in calculating by the ordinary theory, which we have already mentioned, but which is here demonstrated, viz., that this calculation gives the same force applied by the engine in both the cases considered, notwithstanding their difference of velocity ; and such will always be the result, since the calculation consists merely in multiplying the area of the piston by the pressure in the boiler, and reducing the product in a constant proportion. This theory therefore maintains, in principle, that the engine can always draw the same load at all imaginable velocities. Again we see, that, in the same calculation of the load or effort applied, the vaporization of the engine does not appear, which would imply that the engine would always draw the same load at all velocities, whatever might be the vaporization of the boiler, which is inadmissible.

We shall also remark, that in calculating by the ordinary theory the vaporization of the engine, no notice is taken of the resistance which the engine is supposed to move ; so that the vaporization necessary to draw a given load would be independent of that load—another result equally impossible.

To these omissions, therefore, or rather to these errors in principle, are to be attributed the variations observable in the results given of the ordinary theory in the examples proposed.

PART II.

ANALYTIC THEORY OF THE STEAM-ENGINE.

ARTICLE. I.

CASE OF A GIVEN EXPANSION WITH ANY VELOCITY OR LOAD WHATEVER.

§ 1. *Of the change of temperature of the steam during its action in the engine.*—When an engine is at work, the steam is generated in the boiler at a certain pressure; it passes from thence into the cylinder, assuming a different pressure, and, in an expansive engine, the steam, after its separation from the boiler, continues to dilate itself more and more in the cylinder, till the piston is at the end of the stroke. It is generally supposed, that in all the changes of pressure which the steam may undergo, its temperature remains the same; and it is consequently concluded, that during the action of the steam in the engine, the density and volume of that steam follow the law of Mariotte, namely, that its volume varies in the inverse ratio of the presure. This supposition greatly simplifies the formulæ; but, as reason and experience prove it to be altogether inexact, we are compelled to renounce it, and will substitute in its place another law, deduced from observation of the facts themselves.

We have recognised in a numerous series of experiments, by applying simultaneously a manometer and a thermometer, both to the boiler of a steam-engine, and also to the tube through which the steam, after having terminated its effect, escaped into the atmosphere, that during all its action in the engine the steam remains in the state denoted by the name of saturated steam, that is, at the maximum density for its temperature. The steam, in fact, was produced in the boiler at a very high pressure, and escaped from the engine at a very low one; but on its issuing forth, as well as at the moment of its formation, the thermometer indicated the temperature corresponding to the pressure marked by the manometer, as if the steam were immediately generated at the pressure it had at that moment.

Thus during its whole action in the engine, the steam remains constantly at the maximum density for its temperature.

Now, in all steams, the volume depends at once on the pressure and the temperature; but in the steam at the maximum density, the temperature itself depends on the pressure. It should then be possible to express the volume of steam of maximum density, in terms of the pressure alone.

The equation which gives the volume of the steam in any state whatever, in terms of the pressure and temperature, is very simple: it is deduced from Mariotte's law combined with that of M. Gay-Lussac. The equation which gives the temperature in terms of the pressure, for the steam at the maximum density, is also known: it has been deduced from the fine experiments of Messrs. Arago and Dulong on steam at high pressures, and from those of Southern and other experimenters on steam produced under low pressures. By eliminating then the temperature in these two equations, we shall obtain the analogy required, which will give immediately, with regard to steam at the maximum density, for its temperature, the volume in terms of the pressure alone.

But here arises the difficulty. The equation of the temperatures is not invariable; or rather, the same equation does not apply to all points of the scale. To be used with accuracy, it requires to be changed according as the pressure is under that of one atmosphere, or comprised between one and four atmospheres, or again if it be above four atmospheres. Now, when steam is acting in an engine, it may happen, according to the load, or to other conditions of its motion, that the steam generated at first at a very high pressure, may act or be expanded in the engine sometimes at a pressure exceeding four atmospheres, sometimes at a pressure less than four atmospheres, but yet exceeding one, and sometimes at a pressure under that of one atmosphere. It is impossible then to know which of the three formulæ is to be used in the elimination; and consequently it is impossible by this means to attain a general formula representing the effects of the engine in all cases.

Moreover, were either one of these formulæ adopted, the high radical quantities they contain would so complicate the calculations as to render them unfit for practical purposes. And it is to be remarked, that these divers formulæ, after all, are not the expression of the true mathematical law which connects the temperature and the pressure in saturated steam, but merely empirical relations, which experiment alone has demonstrated to have a greater or less degree of approximation.

A formula of temperatures given by M. Biot is indeed adapted to all points of the scale, and may be useful in a great number of delicate researches relative to the effects of steam; but as it gives only the pressure in terms of the temperature, and is, from its form, incapable of the inverse solution, namely, the general determination of temperatures in terms of the pressure, it is unfit for the elimination proposed.

Under these circumstances the only resource is to seek a direct relation in terms of the pressure alone, whose results shall represent immediately those of the two preceding formulæ combined; that is, to calculate first by means of those formulæ a table of volumes of the steam, and then to seek a direct and simple relation to represent those results. This we have done.

M. Navier had proposed a formula for this purpose. But that formula, though sufficiently exact in high pressures, differs widely from experience in pressures below that of the atmosphere, which are useful in condensing engines; and it is possible to find one much more exact for non-condensing engines, namely, that we are about to offer. We propose then, for this purpose, the following formulæ, in which p represents the pressure of the steam expressed in pounds per square foot, and μ the ratio of the volume of the steam to that occupied by the same weight of water:

Formula for high or low pressure engines *with condensation*
$$\mu = \frac{10000}{0{\cdot}4227 + 0{\cdot}00258\,p}$$

Formula for high pressure *non-condensing* engines
$$\mu = \frac{10000}{1{\cdot}421 + 0{\cdot}0023\,p}$$

The first formula is equally suitable to pressures above and below that of the atmosphere, at least within the limits likely to be considered in applying it to condensing steam-engines. Those limits are eight or ten atmospheres for the highest pressures; and eight or ten pounds per square inch for the lowest, in consequence of the friction of the engine, the pressure subsisting against the piston after imperfect condensation in the cylinder, and the resistance of the load.

Within these limits then the proposed formula will be found to give very approximate results.

This first formula might also be applied, without any error worthy of notice, to non-condensing engines. But as, in these, the steam can scarcely operate with a pressure less than two atmopheres, by reason of the friction of the engines and the resistance of the load, it is needless to require of the formula exact results of volumes for pressures under two atmospheres.

In this case then the second formula will be found to give those results with much greater accuracy, and will consequently be preferred in practice. This will be readily recognised in a table annexed to the work, presenting a comparison of the volume of the steam calculated by the ordinary formulæ in terms of the pressure and temperature, and by the proposed formulæ in terms of the pressure alone.

We state then generally this analogy :

$$\mu = \frac{1}{n + q p} \quad . \; . \; . \; . \quad (a)$$

Consequently, if the steam pass in the engine, from a certain volume m' to another known volume m, and thereby abandon its primitive pressure P', to assume an unknown pressure p, it is easy to recognise that the following relation will exist between those two pressures, and will serve to determine the unknown quantity p, viz. :

$$\frac{p}{P'} = \frac{m'}{\mu} . \quad \frac{1 - n\mu}{1 - nm'} .$$

This is the relation which we substitute in lieu of that hitherto employed, and according to which the volume appears to vary in the inverse ratio of the pressure. It will be observed that such an hypothesis may be deduced from the analogy we have just offered, by making $n = 0$, and $q = \frac{mP}{p}$, m being the volume, and P the pressure of the steam in the boiler ; for it is plain that we shall then have,

$$\mu = \frac{mP}{p},$$

that is to say, the volumes are inversely as the pressures.

§ 2. *Of the divers problems which present themselves in the calculation of steam-engines.*—We distinguish three cases in an engine : that wherein it works with a given rate of expansion of the steam, and with a load or a velocity indefinite ; that in which it works with a given rate of expansion, and with the load and velocity proper to produce its maximum of useful effect with that expansion ; and lastly, that wherein, the engine having been previously regulated for the expansion of the steam most favourable in that engine, it bears, moreover, the load most advantageous for that expansion ; which, consequently, produces the absolute maximum of useful effect in the engine.

We have said that the three fundamental problems of the calculation of steam-engines consist in finding successively the velocity, the load, and the vaporization of the engine. After the solution of these three problems, that which first presents itself, as a corollary to them, consists in determining the *useful effect* of the engine, which may be expressed under six different forms, viz. : by the work done, or the number of pounds raised one foot high by the engine in a minute ; by the horse power of the engine ; by the actual duty or useful effect of one pound of coal ; by the useful effect of a cubic foot of water converted into steam ; and by the number of pounds of coal, or of cubic feet of water, that are necessary to produce one horse power.

Another research, in fine, no less important, is the rate of expansion at which the steam must work in an engine, in order that it may produce given effects. We shall present successively the solution of all these questions.

The various problems will be resolved in each of the three cases above mentioned. In the two last, the question will be to calculate the rate of expansion, the velocity, the load, and the effects which correspond to the maximum of, relative or absolute, useful effect of the engine.

In the ordinary calculations of steam-engines, the solution of three questions only had been attempted, viz.,—to find the load, the vaporization, and the useful effect, under its different forms ; which solution is, as we have seen, faulty. As to the determining of the velocity for a given load, and that of the rate of expansion for given effects, the calculation of these had not been proposed. Moreover, the very nature of the theory employed in those calculations did not allow of distinguishing, in the machine, the existence of the three cases which are really found in it. The distinction we establish may, therefore, at first appear obscure, expressed, as it is, in general terms, and including relations unusual in the consideration of steam-engines ; but, on a closer view of the question, these relations will be seen to be of indispensable necessity, in order to calculate with exactitude either the effects or the proportions of steam-engines of all systems.

§ 3. *Of the velocity of the piston under a given load.*—To embrace at once the most complete mode of action of the steam, we will suppose an engine working by expansion, by condensation, and with an indefinite pressure in the boiler; and to pass on to unexpansive or uncondensing engines, it will suffice to make the proper suppressions or substitutions in the general equations.

From what has been already shown of our theory, the relations sought between the various data of the problem are necessarily deduced from two general conditions; the first expressing that the engine has attained a uniform motion, and consequently that the quantity of labour impressed by the motive power is equal to the quantity of action developed by the resistance: the second, that there is a necessary equality between the emission of steam through the cylinder and the production by the boiler.

The limits of this extract will not allow us to develop those calculations, simple as they may be; but that the proceeding may be understood, we shall state that, expressing by P the pressure of the steam in the boiler, and by P′ the pressure of the same steam in the cylinder before the expansion, by L the length of stroke of the piston, and by L′ the portion traversed at the moment the expansion begins, by a the area of the piston, and by c the clearance of the cylinder, or the space at each end of the cylinder beyond the portion traversed by the piston, and which necessarily fills with steam at each stroke; lastly, by r the resistance of the load, by p the pressure subsisting on the other side of the piston after imperfect condensation, by f the friction of the engine when not loaded, and by δ the increase of. that friction per unit of the load r, these four forces, as well as the pressures, being moreover referred to the unit of surface of the piston; the first of the above conditions produces the following analogy:

$$\frac{P' a (L' + c)}{1 - n a (L' + c)} \left\{ \frac{L'}{L' + c} + \log. \frac{L + c}{L' + c} - na\,L \right\} = a\,L\Big((1 + \delta)\, r + p + f\Big) \,.\,.\,.\,.\,. \text{(A)}$$

This equation expressing that the labour developed by the mover is found entire in the effect produced, be it remarked, that it is not essentially necessary for the motion to be strictly uniform. It may equally be composed of equal oscillations, beginning from no velocity, and returning to no velocity, provided the change of velocity take place by insensible degrees, so as to avoid the loss of *vis viva*, and that the successive oscillations be performed in equal times.

As to the second condition of the motion ; if we denote by S the volume of water vaporized by the boiler in a unit of time and transmitted to the cylinder, by m the volume of the steam formed under the pressure P of the boiler, compared with the volume of the same weight of water unvaporized, and by v the velocity of the piston, the equality between the production of the steam and its consumption will be found to furnish the second general analogy :

$$\frac{S}{n+q\,P'}=\frac{v}{L}\,a\,(L'+c)\quad\ldots\ldots\quad(B)$$

Consequently, by eliminating P′ from these two equations, and writing, for greater simplicity,

$$\frac{\frac{L_{\prime}}{L'+c}-n\,a\,L}{\frac{L'}{L'+c}+\log.\frac{L+c}{L'+c}-n\,a\,L}=\kappa,$$

we find definitively :

$$v=\frac{L}{L'+c}\cdot\frac{S}{a}\cdot\frac{1}{n+q\,\kappa\,\{(1+\delta)\,r+p+f\}}\quad\ldots\quad(1)$$

an equation which gives the velocity of the motion in terms of the load and of the other data of the problem.

This formula is quite general, and suits every kind of steam-engine with continued motion. If the engine be expansive, L′ will be replaced by its value corresponding to the point of the stroke where the steam begins to be intercepted ; if the engine be unexpansive, it will suffice to make $L'=L$, which will give at the same time $\kappa=1$. If it be a condensing engine, p must stand for the pressure of condensation ; if it be not a condenser, p will represent the atmospheric pressure. And finally, the quantities n and q will have, according to the case considered, the above-mentioned value.

§ 4. *Of the load and useful effects of the engine.*—If, instead of seeking the velocity in terms of the load it be required, on the contrary, to know the load suitable to a given velocity, the same equation resolved with reference to r becomes,

$$a\,r=\frac{\frac{L}{L'+c}\,S-n\,a\,v}{(1+\delta)\,q\,v\,\kappa}-a\,\frac{p+f}{1+\delta}\quad\ldots\ldots\quad(2)$$

3°. To find the vaporization of which the engine ought to be capable, in order to put in motion a resistance r with a known velocity v, the value of S must be drawn from the same analogy, thus :

$$S = \frac{L' + c}{L} av \left(n + q\kappa \left\{ (1+\delta) r + p + f \right\}\right) \ldots . (3)$$

4°. The useful effect produced by the machine, in the unit of time, at the velocity v, is evidently arv. Hence that useful effect will have for its measure,

$$uE. = \frac{\frac{L}{L' + c} S - nav}{(1 + \delta) q \kappa} - av \frac{p + f}{1 + \delta} \ldots . (4)$$

5°. If it be desired to know the useful effect, in horse power, of which the engine is capable at the velocity v, or when loaded with the resistance r, it suffices to observe that what is called one horse power represents an effect of 33,000 lbs. raised one foot per minute. All consists then in referring the useful effect produced by the engine in a unit of time, to the new unity just chosen, viz. to one horse power ; and it will consequently suffice to divide the expression already obtained in the equation (4) by 33,000. Thus, the useful effect in horse power will be,

$$uHP. = \frac{uE.}{33000} \ldots . (5)$$

6°. We have just expressed, in the two preceding questions, the effect of the engine by the work which it is capable of performing. We are now on the contrary about to express that effect by the force which the engine expends to produce a given quantity of work. The useful effect of the equation (4) being that which is due to the volume of water S converted into steam, in the unit of time, if we suppose that in the same unit of time N pounds of fuel be consumed, it is clear that the useful effect produced by each pound of fuel will be the Nth part of the above effect. It will then be,

$$uE.\ 1\ lb.\ co. = \frac{uE.}{N} \ldots \ldots (6)$$

To apply this formula, it will suffice to know the quantity of coal consumed in the furnace per minute, that is, during the production of the vaporization S ; and this datum may be deduced from a direct experiment on the engine, or from known experiments on boilers of a similar construction.

7°. The useful effect of the equation (4) being that which proceeds from the vaporization of the volume of water S, if it be required to know the useful effect that will be produced by each cubic foot of water, or by each unit of S, it will be sufficient to divide the total effect uE. by the number of units in S. It will then be,

$$\text{uE. 1 ft. wa.} = \frac{\text{uE.}}{\text{S}} \quad \ldots\ldots \quad (7)$$

8°. In the sixth problem we have obtained the useful effect produced by one pound of fuel. We may then, by a simple proportion, deduce from thence the quantity of fuel necessary to produce one horse power, viz.

$$\text{Q. co. for 1 hp.} = \frac{33000\ \text{N}}{\text{uE.}} \quad \ldots\ldots \quad (8)$$

9°. And similarly, the quantity or volume of water necessary to produce one horse-power will be,

$$\text{Q. wa. for 1 hp.} = \frac{33000\ \text{S}}{\text{uE.}} \quad \ldots\ldots \quad (9)$$

§ 5. *Of the expansion of steam, to be adopted in an expansive engine, in order to produce wanted effects.*

10°. Finally, if it be required to know what rate of expansion the engine must work at, in order to obtain from it determined effects, the value of L′ must be drawn from equation (1). It will be given by the formula,

$$\frac{\text{L}'}{\text{L}'+c} + \log.\frac{\text{L}+c}{\text{L}'+c} = q\,a\,\text{L}\left\{(1+\delta)r+p+f\right\}\frac{\dfrac{v}{\text{L}} - n\,a\,v\,\dfrac{\text{L}'+c}{\text{L}}}{\text{S} - n\,a\,v\,\dfrac{\text{L}'+c}{\text{L}}} + n\,a\,\text{L} \quad \ldots\ldots \quad (10)$$

This formula not being of a direct application, we annex to the work a table which gives its solutions for the expansion from hundredth to hundredth, with a very short calculation.

We confine ourselves to these inquiries as being those which may most commonly be wanted; but it is clear that by means of the same general analogies, any one whatever of the other quantities which figure in the problem may be determined, as the case may require. Thus, for instance, may be determined the area of the piston, or the pressure in the boiler, or the pressure in the condenser, corresponding to determined effects of the machine, as has been done for locomotives in our work on that subject.

ART. II.

CASE OF THE MAXIMUM USEFUL EFFECT, WITH A GIVEN RATE OF EXPANSION.

§ 1. *Of the velocity of the maximum useful effect.* We have resolved the above problems in all their generality, that is, supposing the engine to move any load whatever with any velocity whatever, under this single condition, that the load and the velocity be compatible with the capability of the machine. The question is now to find what velocity and what load are most advantageous for the working of the engine, and what are the effects which, in this case, may be expected from it; that is to say, its maxima effects for a given rate of expansion.

1°. In examining the general expression of the useful effect produced by the engine at a given velocity, we perceive that the expression attains its maximum for a given rate of expansion when the velocity is a minimum; now from the equation (B) the smallest value of v will be given by $P' = P$. The velocity corresponding to the maximum useful effect will therefore be,

$$v' = \frac{S}{a(n + qP)} \cdot \frac{L}{L' + c} \quad . \ . \ . \ . \quad (11)$$

Let us however remark, that, mathematically speaking, the pressure P' of the steam in the cylinder can never be quite equal to P, which is the pressure in the boiler; because there exist between the boiler and the cylinder conduits through which the steam has to pass, and the passage of these conduits offers a certain resistance to the motion of the steam; whence results that there must exist, on the side of the boiler, a trifling surplus of pressure equivalent to the overcoming of the obstacle. But as we have proved elsewhere, that, with the usual dimensions of engines, this difference of pressure is not appreciable by the instruments used to measure the pressure in the boiler, the introduction of it into the calculations would render the formulæ more complicated without making them more exact. For this reason we neglect that difference here.

The velocity given by the preceding equation is, then, that at which the engine will produce its maximum effect for a given expansion. This velocity will result from the condition $P' = P$, or reciprocally, when this velocity takes place in the engine, the steam enters the cylinder with full pressure, that is, with the same pressure it has in the boiler. It is necessary to remark that the velocity of full pressure will not be the same for all engines; on the contrary, it will vary in direct ratio with the vaporization, and in the inverse ratio of the area of the cylinder. It may then occur to be, in one engine, the half or the double of what it would be in another; which shows that it is an error to believe that, because the piston of stationary engines does not in general exceed a certain velocity of from 150 to 250 English feet per minute, the steam of the boiler necessarily reaches the cylinder with no change of pressure.

It is easy to be seen that a fixed limit, whatever it may be, cannot in this respect suit all engines; and that the only means of knowing the velocity of the maximum effect, or of full pressure of an engine, is to calculate it directly for that engine. Such is the object of the formula we have just given. This formula, moreover, is of a remarkable simplicity, and requires no other experimental knowledge than that of the production of steam of which the boiler is capable.

§ 2. *Of the load and maximum useful effect of the engine*—2°. The useful resistance which the machine is capable of putting in motion at its velocity of the maximum effect above, is to be drawn from equation (2), substituting for v the value just obtained. Calling the load r' we shall find it expressed by

$$ar' = \frac{a\,\mathrm{P}}{(1+\delta)\,\kappa} - a\frac{p+f}{1+\delta}; \quad . \; . \; . \; . \quad (12)$$

and it is at the same time visible that this load is the greatest the engine can put in motion with the given expansion L′, for it corresponds to the lowest value of v in equation (2). Thus, the greatest effect of the machine, with a given rate of expansion, is attainable by working the machine at its smallest velocity and with its maximum load.

It will be observed that this equation may be used to determine the friction of the engine without a load, and its additional friction per unit of the load, upon the same principles that we have employed in our Treatise of Locomotive Engines for similar determinations. This is also the mode we propose for steam-engines of every system.

3°. The vaporization necessary to an engine, in order to exert a certain maximum effort r' at its minimum velocity v', will be given by equation (3), by substituting in it r' and v', or will be drawn more simply from equation (11), thus:—

$$S = (n + q\,P)\,av' \cdot \frac{L' + c}{L} \quad \ldots\ldots \quad (13)$$

4°. The maximum of useful effect producible in the unit of time, by an engine working with a given expansion, will be known by formula (4), by introducing for v the velocity proper to produce that effect. Thus is found,

$$\text{max. uE.} = \frac{L}{L' + c} \cdot \frac{S}{(1 + \delta)(n + q\,P)} \left\{ \frac{P}{\kappa} - (p + f) \right\} \quad \ldots\ldots \quad (14)$$

It will be observed that this maximum useful effect depends particularly on the quantity of water S, evaporated per minute in the boiler. Hence we see plainly the error of those who pretend to calculate the useful effect or the power of engines from the area and the velocity of the piston, which they set in the place of the vaporization produced: this vaporization not only entering not into their calculation, but forming no part of their observations.

5°. The useful effect, in horse power, of the engine will be expressed by

$$\text{uHP.} = \frac{\text{max. uE.}}{33000} \quad \ldots\ldots \quad (15)$$

6°. 7°. 8°. 9°. The various measures of the useful effect will here be deduced from equations similar to those (6), (7), (8), and (9).

10°. The expansion at which the engine ought to be regulated, in order to draw a given load at the most advantageous velocity, or producing the maximum of useful effect with that load, will be derived from equation (12), which gives,

$$\frac{L' + c}{L} \left\{ \frac{L'}{L' + c} + \log. \frac{L + c}{L' + c} \right\} = \frac{(1 + \delta)\,r + p + f}{P} + na\,\frac{L' + c}{L} \left\{ L - L\,\frac{(1 + \delta)\,r' + p + f}{P} \right\} \quad \ldots\ldots \quad (20)$$

and the solutions of this formula will be found immediately, and without calculation, by means of the table given above, as suggested by equation (10).

ART. III.

CASE OF THE ABSOLUTE MAXIMUM OF USEFUL EFFECT.

The preceding inquiries suffice for engines working without expansion, merely by making $L'=L$; because those engines fall under the case of expansion fixed *à priori*. But it is otherwise with engines in which the rate of expansion may be varied at will. We have seen that, for a given expansion, the most advantageous way of working the engine is to give it the maximum load, which is calculated *à priori* from equation (12). Hence we know what load is to be preferred for every rate of expansion. But the question now is to determine, among the various rates of expansion of which the engine is susceptible, each accompained by its corresponding load, which will produce the greatest useful effect.

For this purpose we must recur to equation (14), which gives the useful effect produced with a maximum load r', and seek among all the values assignable to L', that which will raise the useful effect to a maximum. Now, by making the differential coefficient of that expression, taken with reference to L', equal to nothing, we find as the condition of the maximum sought:

$$\frac{L'}{L}=\frac{p+f}{P}+naL\frac{\log.\frac{L+c}{L'+c}-naL\left(1-\frac{L'}{L}\right)}{\left(\frac{L}{L'+c}-naL\right)^2}\quad\ldots\ldots(30)$$

This equation will be resolved in the same manner as the equations (10) and (20), by means of the table already given; and after having found the value of $\frac{L'}{L}$, it will be introduced in the equations of Article II.; and the corresponding velocity, load, and useful effects, will be determined.

However, as the supposition of $n=o$, $q=\frac{1}{mP}$, that is to say, the supposition that the steam preserves its temperature during its action in the engine, will give a sufficient approximation in a great many cases, we present here the corresponding results of all the formulæ. They will show, already to a very near degree, the maximum absolute effects which it is possible to obtain from an engine, in adopting simultaneously the most advantageous rate of expansion and the most advantageous load.

(21) $v'' = \frac{m\,S}{a} \cdot \frac{L\,P}{L\,(p+f) + P\,c}$	Velocity of the absolute maximum useful effect.
(22) $ar'' = a\,\frac{L\,(p+f) + P\,c}{(1+\delta)\,L}\ \log. \frac{(L+c)\,P}{L\,(p+f) + P\,c}$	Load of the piston corresponding to the absolute maximum useful effect.
(23) $S = \frac{av''}{m} \cdot \frac{L\,(p+f) + P\,c}{L\,P}$	Vaporization.
(24) $^{\text{ab. max. u.}}E = ar''\,v'' = \frac{m\,S\,P}{1+\delta}\ \log. \frac{P\,(L+c)}{L\,(p+f) + P\,c}.$	Absolute maximum of useful effect.
(25) $^{\text{u.}}HP = \frac{^{\text{ab. max. u.}}E}{33000}$	Absolute maximum of useful force in horse power.
(30) $L' = \frac{L\,(p+f)}{P}$	Rate of expansion which produces these effects.

The four determinations of the useful effects of a given quantity of fuel or water will be furnished by equations similar to those (6), (7), (8), and (9).

The only remark we shall make on the subject of these formulæ is, that the load suitable to the producing of the absolute maximum useful effect is not the maximum load that may be imposed on the engine. In effect, from equation (12), we know that the maximum load for the engine takes place when $L' = L$, and not when

$$L' = L\,\frac{p+f}{P}.$$

Thus the greatest possible load of the engine is that of the maximum useful effect without expansion ; but by applying a lighter load, that of equation (22), and at the same time the expansion of equation (30), a still greater useful effect will be obtained.

PART III.

APPLICATION OF THE FORMULÆ TO THE VARIOUS SYSTEMS OF STEAM ENGINES.

We shall not give here the applications to different systems of steam-engines, which are developed in this part of the work. We shall confine ourselves to what concerns Watt's steam-engines, because they are the most generally employed in the arts.

Watt's rotative double-acting steam-engine.—These engines being without expansion, the proper formulæ for calculating their effects will be deduced from the general formulæ by making $L' = L$, which will give also $\kappa = 1$, and by replacing the quantity p by the pressure of condensation. We see, moreover, that for these engines, the expansion being susceptible of no variation, since that detent does not exist, the third case, considered as to engines in general, cannot occur. There will be then but two circumstances to consider in their working, viz., the case wherein they operate *with their maximum load, or load of greatest useful effect,* and the case in which they operate *with any load whatever.* The effects therefore of these engines will visibly be determined by the following equations :

General case, or of indefinite load.	*Case of maximum useful effect.*
$v = \frac{L}{L+c} \cdot \frac{S}{a} \cdot \frac{1}{n + q\{(1+\delta)r + p + f\}}$	$v' = \frac{L}{L+c} \cdot \frac{S}{a\,(n + q\,P)}$
$ar = \frac{L}{L+c} \cdot \frac{S}{q\,(1+\delta)\,v} - \frac{a}{1+\delta}\left(\frac{n}{q} + p + f\right)$	$ar' = \frac{a}{1+\delta}\,(P - p - f)$
$S = \frac{L+c}{L} \cdot av\left[n + q\left\{(1+\delta)\,r + p + f\right\}\right]$	$S = \frac{L+c}{L} \cdot av'\,(n + q\,P)$
$u.E = arv = \frac{L}{L+c} \cdot \frac{S}{q\,(1+\delta)} - \frac{av}{1+\delta}\left(\frac{n}{q} + p + f\right)$	$max.\,u.E = ar'v' = \frac{L}{L+c} \cdot \frac{S}{(1+\delta)(n + q\,P)}\left\{P - p - f\right\}$
$u.HP = \frac{u.E}{33000}$	$u.HP = \frac{max.\,u.\,E}{33000}$,
$u.E_{\text{1 lb. co.}} = \frac{u.E}{N}$	$u.E_{\text{1 lb. co.}} = \frac{max.\,u.\,E}{N}$,
$u.E_{\text{1 ft. wa.}} = \frac{u.E}{S}$	$u.E_{\text{1 ft. wa.}} = \frac{max.\,u.\,E}{S}$,
$Q_{\text{co. for 1 hp.}} = \frac{33000\,N}{u.E}$	$Q_{\text{co. for 1 hp.}} = \frac{33000\,N}{max.\,u.\,E}$,
$Q_{\text{wa. for 1 hp.}} = \frac{33000\,S}{u.E}$	$Q_{\text{wa. for 1 hp.}} = \frac{33000\,S}{max.\,u.\,E}$.

Athough these formulæ may at first sight appear complicated, they will nevertheless be found very simple in the calculation. It is only necessary to fix attention to refer all the measures to the same unit, as will be seen in the following example. It must be remarked also, that as soon as the velocity and load of the engine are determined, the useful effect will be known immediately, being their produce.

To apply, however, these formulæ, some previous observations are necessary.

In good engines of that system the pressure in the condenser is usually 1·5 lb. per square inch, but the pressure in the cylinder itself, and under the piston, is in general 2·5 lbs. more, which gives $p=4 \times 144$lbs. It has been deduced, moreover, from a great number of trials made on Watt's engines, that their friction, when working with a moderate load, varies from 2·5 lbs. per square inch of the piston, in engines of smaller dimensions, to 1·5 lb. in the more powerful ones; which includes the friction of the parts of the machinery and the force necessary for the action of the feeding and discharging pumps, &c. By moderate load in these engines is meant about 8 lbs. per square inch of the piston. Now, our experiments on locomotives, showing the *additional* friction of an engine to be $\frac{1}{8}$ of the resistance, give room to think that the *additional* friction caused in the engine by that load may be about 1 lb. per square inch. The above information attributes then to Watt's engines, working unloaded, a friction of from 1·5 lb. to ·5lb. per square inch, according to their dimensions, which would give 1 lb. for engines of a medium size: this information, agreeing with what we have deduced from our inquires on locomotives, as has been said above, we shall continue to admit, in this place, respecting the friction, the data already indicated in this respect, viz.:—

$$f=1 \times 144 \text{ lbs.} \qquad \delta = \cdot 14.$$

As an application of these formulæ, we will submit to calculation an engine constructed by Watt at the *Albion Mills* near London. The following were its dimensions:—

Diameter of the cylinder, 34 inches, or $a=6 \cdot 287$ square feet;

Stroke of the piston 8 feet, or $L=8$ feet;

Clearance of the cylinder, $\frac{1}{20}$ of the stroke, or $c = \cdot 4$ foot;

Effective vaporization, ·927 cubic foot of water per minute, or $S = \cdot 927$ cubic foot;

Consumption of coal in the same time, 6·71 lbs. or $N=6 \cdot 71$ lbs.;

Pressure in the boiler, 16·5 lbs. per square inch, or $P=16 \cdot 5 \times 144$ lbs.;

Mean pressure of condensation, 4 lbs. per square inch, or $p=4\times 144$ lbs.

And finally, the engine being a condensing one, we have $n=\cdot 4227$ and $q=\cdot 000000258$.

The engine had been constructed to work at the velocity of 256 feet per minute, which was considered its normal velocity; but when put to trial by Watt himself, shortly after its construction, it assumed, in performing its regular work, esteemed 50 horse-power, the velocity of 286 feet per minute, consuming at the same time the quantity of water and fuel which we have just reported.

If then we seek the effects it was capable of producing at its velocity of maximum effect, and then at those of 256 and 286 feet per minute, we shall find, by the formulæ already exposed:

Maximum useful effect.

v	=	286	256	$v'=214$	Velocity of the piston in feet per minute;
ar	=	5,621	6,850	9,133	Total load of the piston in lbs.;
$\frac{r}{144}$	=	6·21	7·57	10·09	Load of the piston in lbs. per square inch;
S	=	·927	·927	·927	Vaporization in cubic feet of water per minute;
$^{u.}E$	=	1,607,610	1,753,600	1,957,180	Useful effect in lbs. raised to one foot per minute.
$^{u.}HP$	=	49	53	59	Useful effect in horse power.
$^{u.}E_{1\ lb.\ co.}$	=	239,585	261,340	291,680	Useful effect of 1 lb. of coal, in lbs. raised to one foot per minute.
$^{u.}E_{1\ p.\ e.}$	=	1,734,200	1,891,700	2,111,300	Useful effect due to the vaporization of one cubic foot of water, in lbs. raised to one foot per minute.

$Q^{\text{co. for 1 h.}}$ =	·138	·126	·113	Quantity of coal in lbs., producing the effect of one horse power.
$Q^{\text{wa. for 1 h.}}$ =	·019	·017	·016	Quantity of water, in cubic feet, producing the effect of one horse power.

Such are the effects that this engine should produce, and we se, in consequence, that in performing a labour estimated at fifty horses, it was to be expected the engine would acquire the velocity which in fact it did, viz., that of 256 feet per minute.

Let us now see to what results we should have been led, had we applied the ordinary calculations to the experiment of Watt, which we have just reported. In this experiment, the engine vaporizing ·927 cubic foot of water, and exerting the force of fifty horses, assumed a velocity of 286 feet per minute.

We then find that, since the engine had a useful effect of no more than fifty horses, and that the theoretical force, calculated according to that method, from the area of the cylinder, the effective pressure in the boiler, and the velocity of the piston, was,

$$\frac{6{\cdot}287 \times (16{\cdot}5 - 4) \times 144 \times 286}{33000} = 98 \text{ horses.}$$

It resulted that, to pass from the theoretical effects to the practical, it was necessary to use the coefficient ·51. Consequently, by following the reasonings of that theory, the following conclusions were to be drawn :—

1°. The observed velocity being 286 feet per minute, the vaporization calculated on the quantity of water, which reduced to steam at the pressure of the boiler, might occupy the volume described by the piston, and afterwards divided, as is done, by the coefficient, to take the losses into account, would have been :

$$\frac{\frac{1}{1530} \times 6{\cdot}287 \times 286}{{\cdot}51} = 2{\cdot}305 \text{ cubic feet per minute, instead of } {\cdot}927.$$

2°. The engine having vaporized only ·927 cubic foot of water per minute, the velocity calculated on the volume of steam formed, at the pressure of the boiler, and afterwards reduced by the coefficient, not as has been done, since this problem was not resolved, but as must naturally be concluded from the signification attributed to that coefficient, could but be $\frac{1530 \times \cdot 927}{6 \cdot 287} \times \cdot 51 = 115$ per minute, instead of 286.

3°. The coefficient found by the comparison of the theoretical effects to the practical being ·51, the various frictions, losses, and resistances of the engine would amount to ·49 of the effective power; whereas these frictions, losses, and resistances, consisting merely of the friction of the engine and the clearance of the cylinder, could be estimated only as follows:—

Total friction (including the additional friction) 2 lbs. per square inch, or as a fraction of the effectual pressure, $\frac{2}{12}$	·17
Clearance of the cylinder, $\frac{1}{20}$ of the effective force, or . .	·05
	·22

Some authors also employ constant coefficients, not however using the same to determine the vaporization as to find the useful effect. This manner of calculating has arisen from those authors having recognised from experience, that the steam has in the cylinder a less pressure and density than in the boiler; but as they cannot settle *à priori* what is that pressure in the cylinder, and that they always seek to deduce it from that of the boiler, instead of concluding it directly and in principle, from the resistance on the piston, as we do; the diminution of pressure observed by them could not be defined in its limits, and it remained simply a practical fact which they used to explain the coefficient. This change in the coefficient employed, avoids the first and second of the contradictions we have just indicated; but the third, as well as all the objections we have developed in the first part against the use of any constant coefficient, remain in full force; that is to say, that in this method, the power of the engine is calculated independently of the vaporizing force of the boiler, and the vaporization independently of the resistance to be moved; that the effort exerted by the machine is found always the same at all velocities; that no account can be taken of the opening of the regulator, unless a new series of coefficients be introduced to that end, as well as for all the changes of velocity, &c.

In consequence, we conclude from this comparison, as well as from what precedes, that the theory in general use for calculating the effects or the proportions of steam-engines, cannot lead to any sure results ; while the one, which we have deducted from the best known principles in mechanics, and from the direct observation of what takes place in the engines, represents their effects with accurancy.

HASWELL'S VALVE

FOR

INJECTION, BLOW-OFF, AND DISCHARGE-PIPES

OF

STEAM VESSELS.

In the body of the work, a valve invented by Mr. Haswell, of the United States Steam-frigate Fulton, has been referred to. A draught and description has, since that part was printed, been furnished by that gentleman. It is intended to be applied to the injection, blow-off, and delivering-pipes in steam vessels, for the purpose of cutting off at pleasure all communication between them and the water in which the vessel floats. These pipes may, in consequence, be removed and repaired without the necessity of going into dock; and the vessel may be prevented from being filled with water, should they be injured by violence or burst by the frost.

The annexed Fig. 1. represents a half-breadth plan, and Fig. 2. a vertical section of the valve and fixtures, as applied to an injection pipe.

Note. When applied to blow-off pipes, one valve will answer for any number of boilers, by giving the top of the valve chamber a conical or hemispherical form, with flanges for the connecting of branch pipes from the different boilers.

DESCRIPTION OF PLATE.

Fig. 1.

A, Opening through the bottom or side of the vessel.

a, Lead pipe to shield the opening.

B, Oak planking, to which the valve is first fitted and bolted, and then firmly secured to the shin of the vessel by the copper screws *b*.

C, C, C, Valve chamber, of brass.

D, Valve, sliding in grooves *z*, *planed* in the sides of the chamber.

d, Valve stem, of copper.

e, Stuffing box, for valve stem.

f, Coupling, connecting valve stem and iron screw *g*, by which the valve is thrown forward to close the opening, or drawn back to admit of the water flowing through it.

h, Standard and Binder, in which is placed the nut *i*.

K, The Pipe, secured to the valve chamber by the Flange *l*.

m, A Thumb screw, by which, when the valve closes the pipe, the water is drawn off in cold weather, to prevent its freezing and bursting the pipe.

Scale. Three inches to a foot.

Fig. 1.

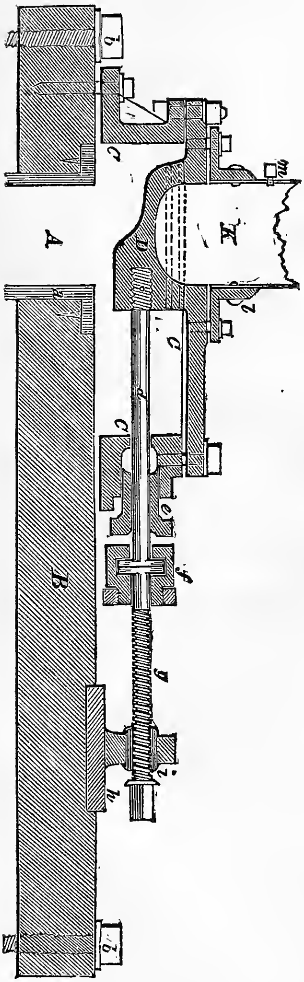
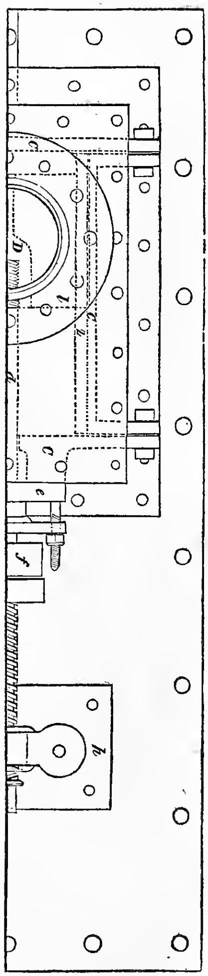
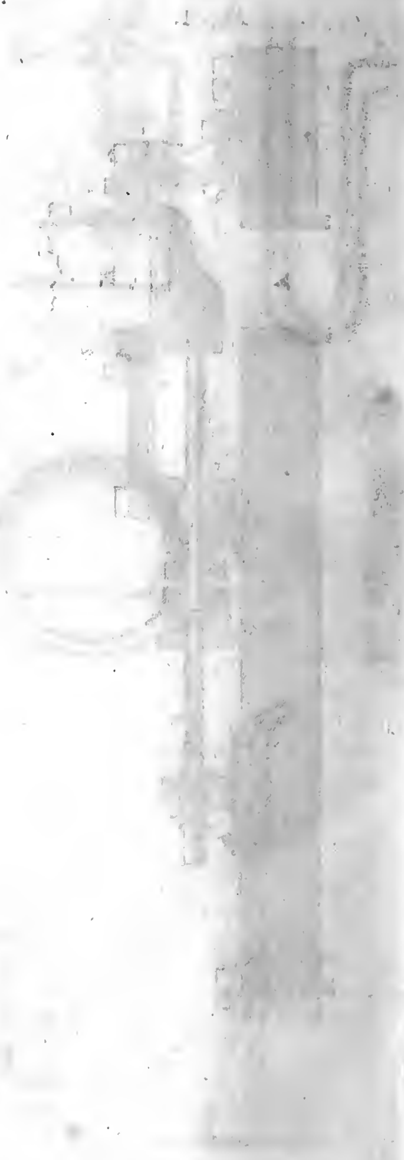


Fig. 2.





Pl. 1.

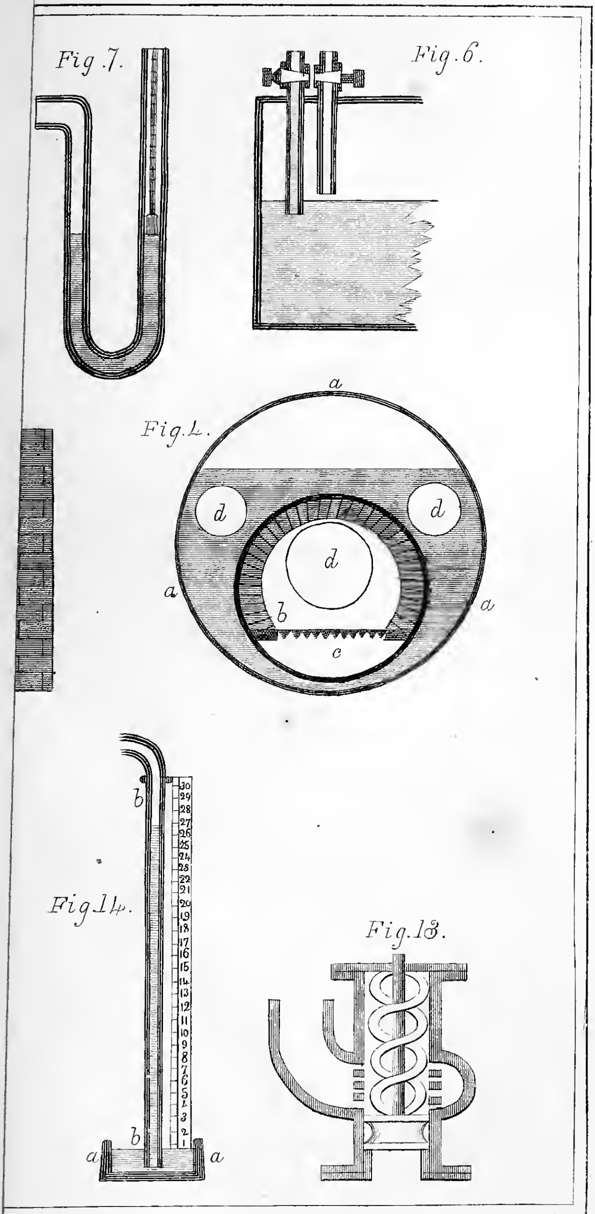


Fig. 7.
Fig. 6.
Fig. 4.
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Fig. 14.
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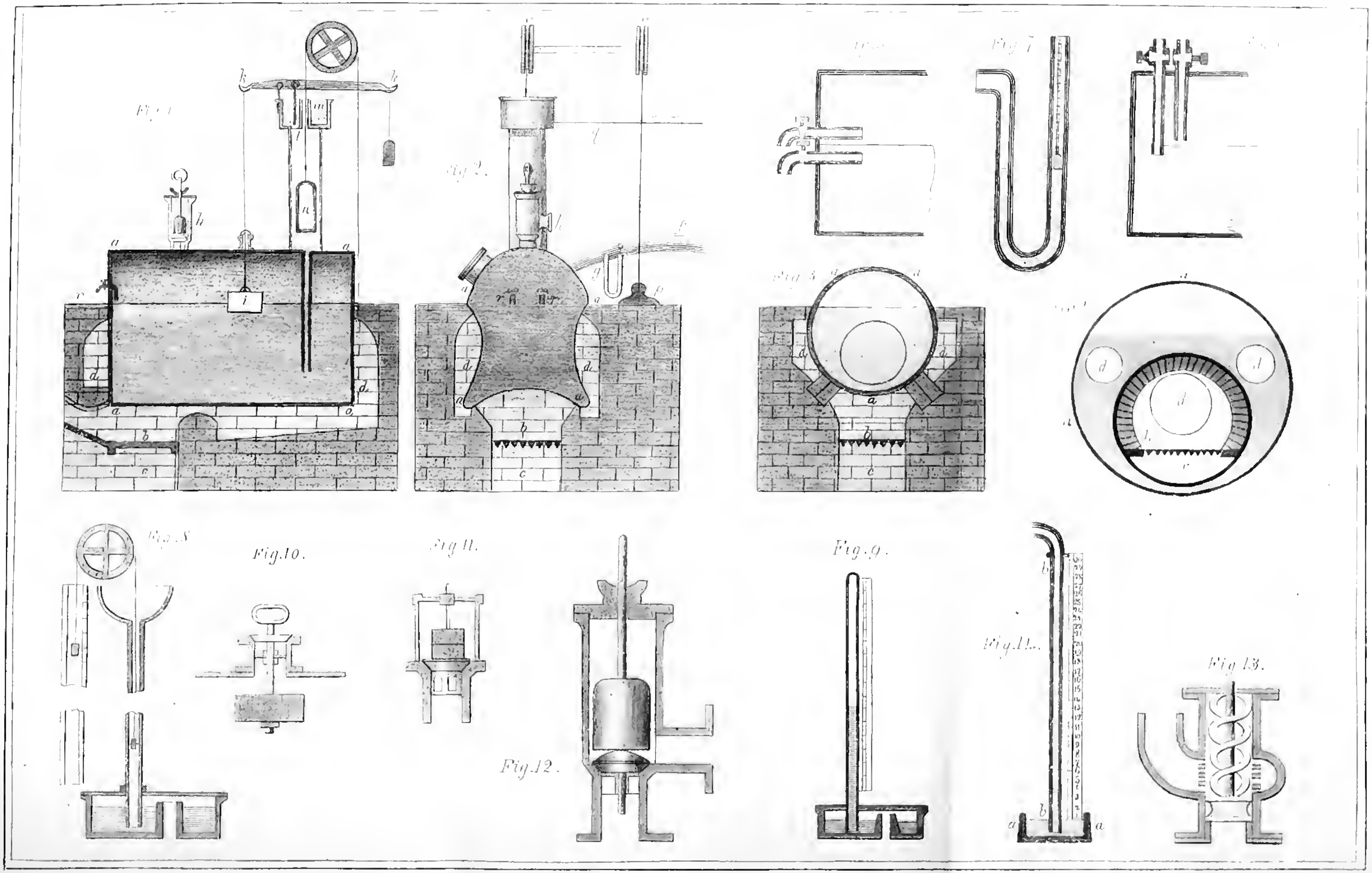
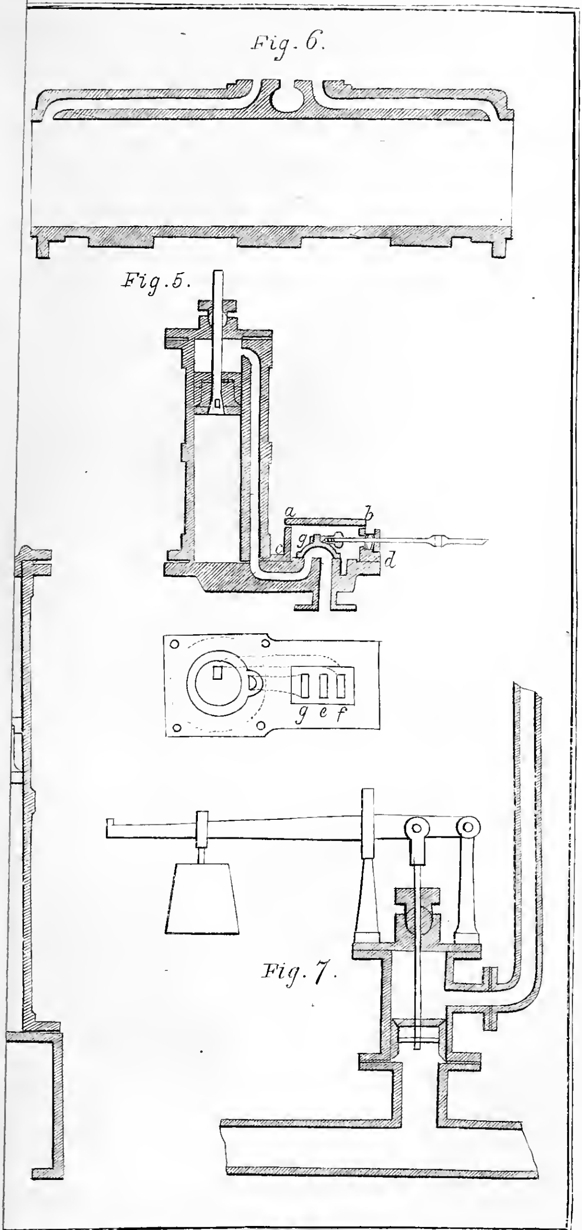
Fig. 13.

Pl. 1



Pl. II.



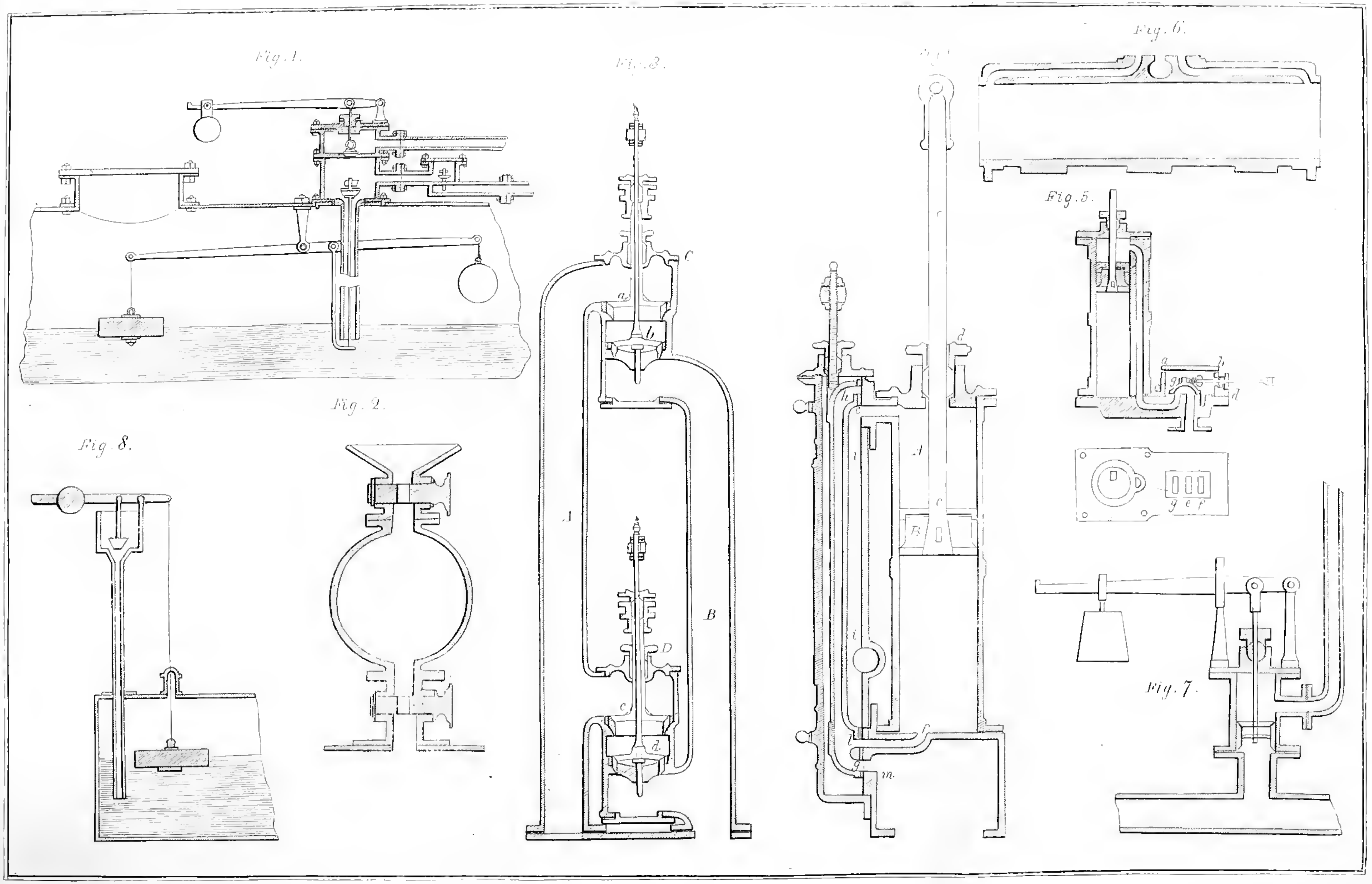


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.

Fig 2

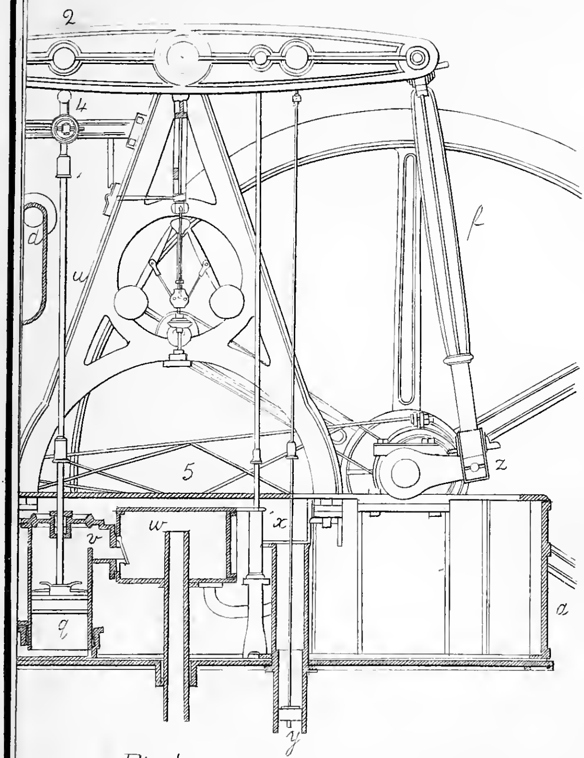


Fig 4

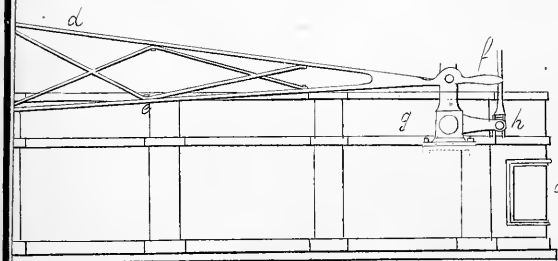


Fig 1

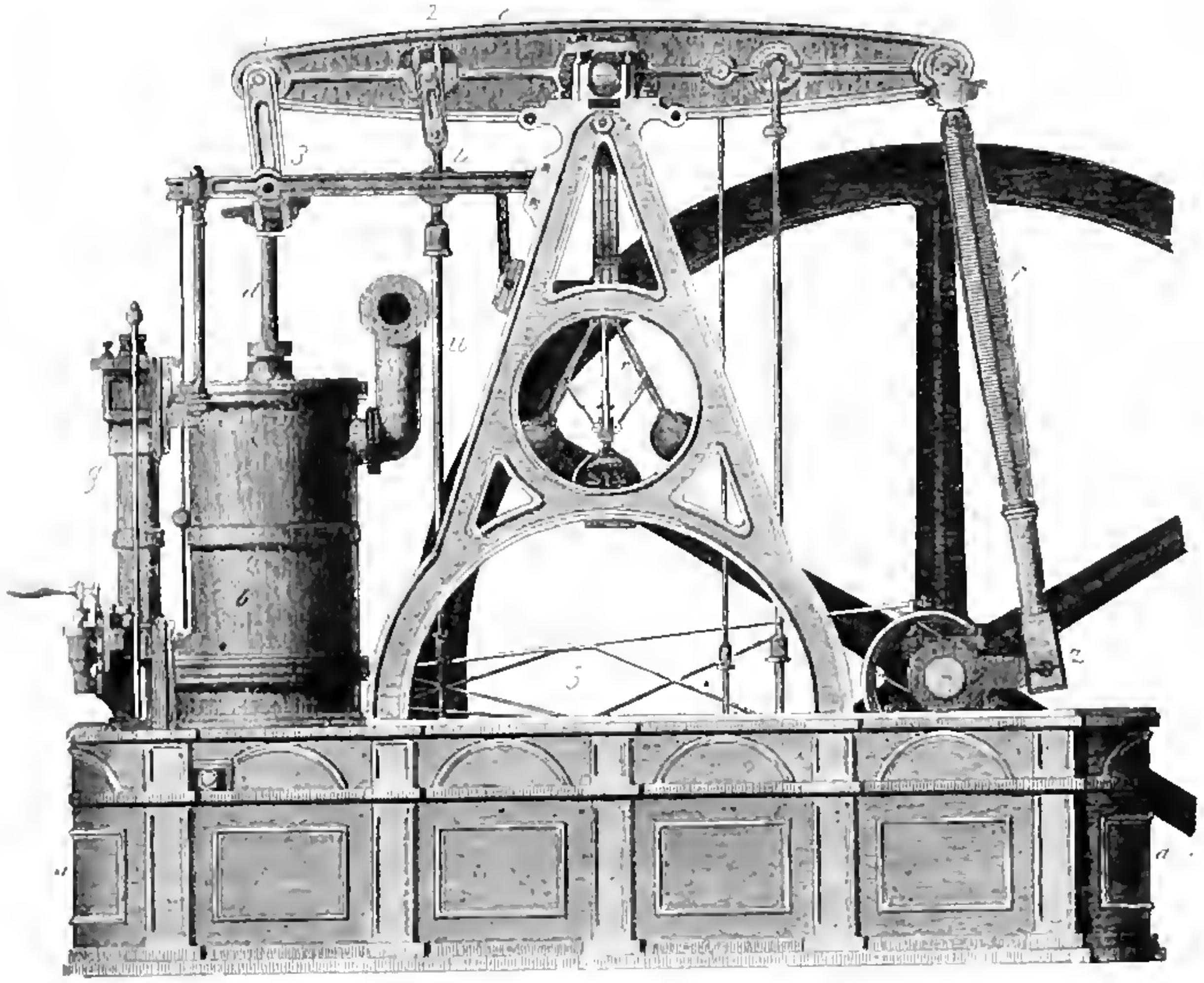


Fig 2

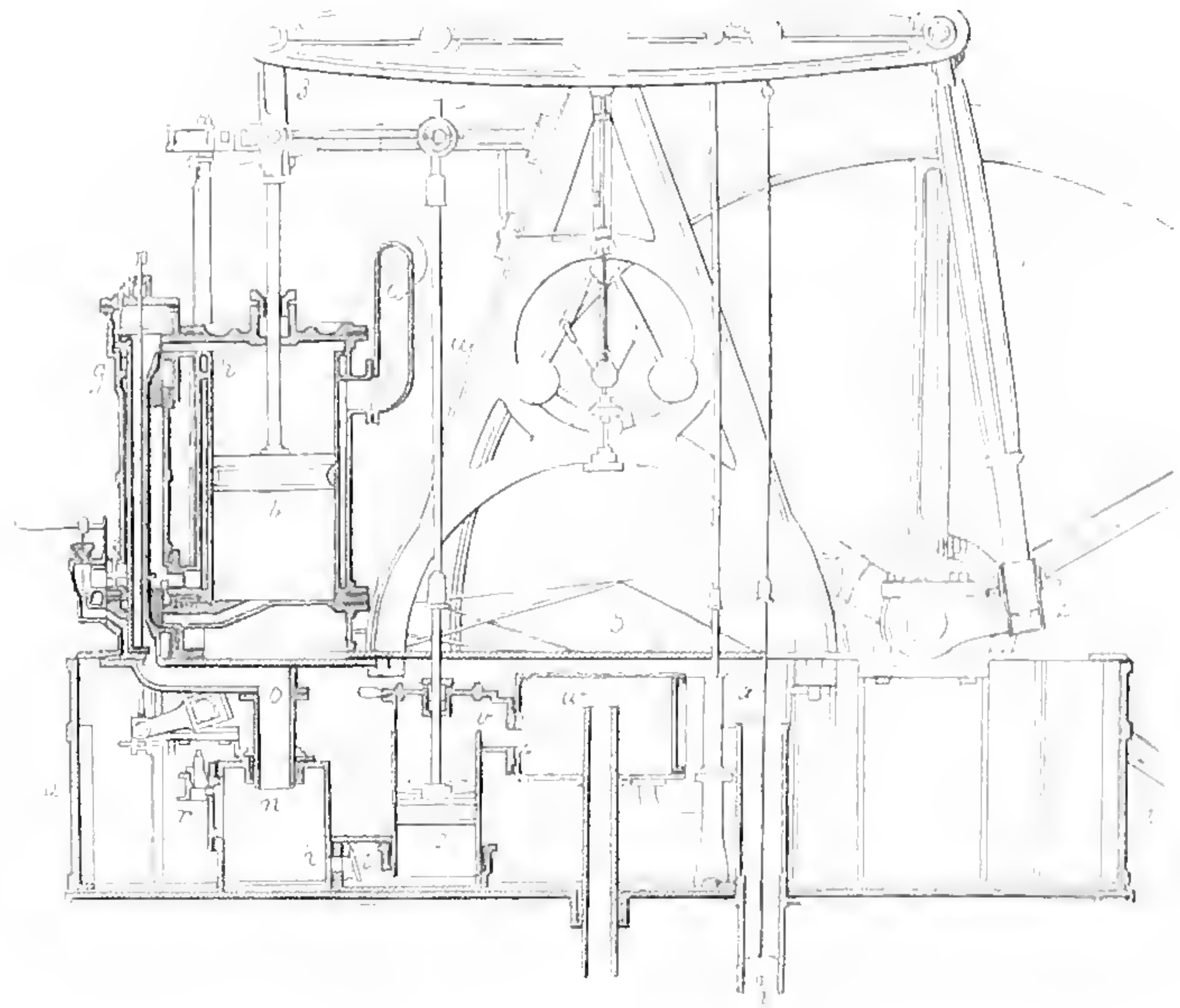


Fig 3

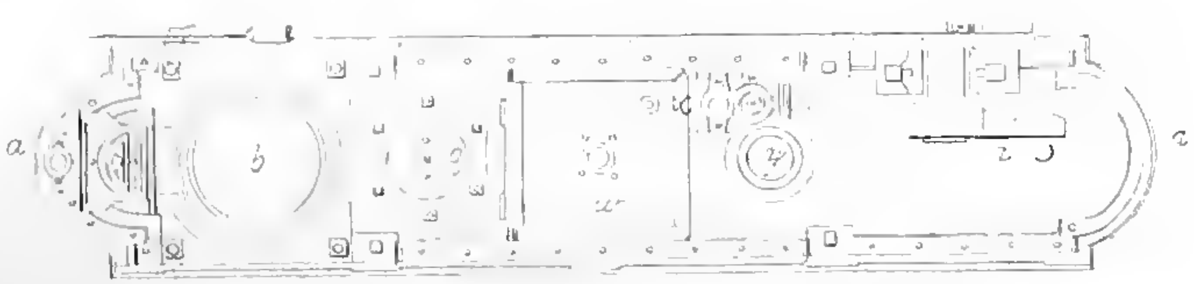
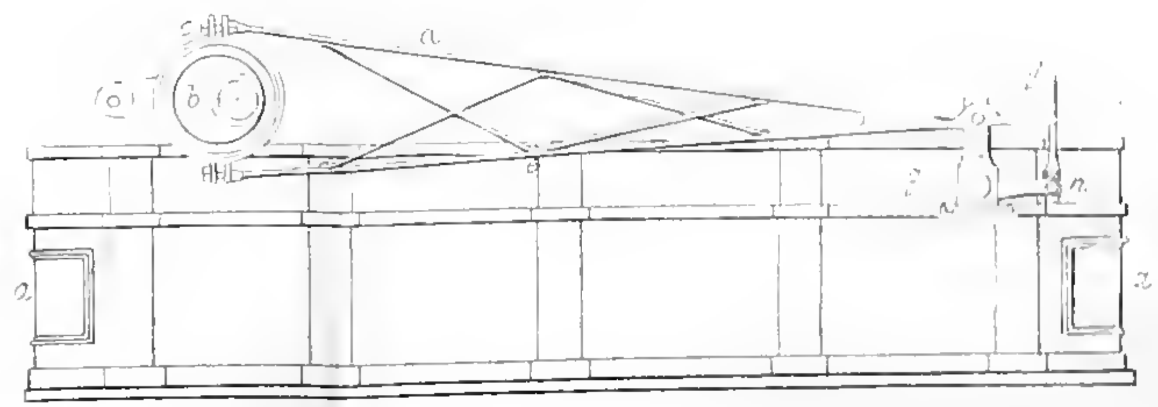


Fig 4



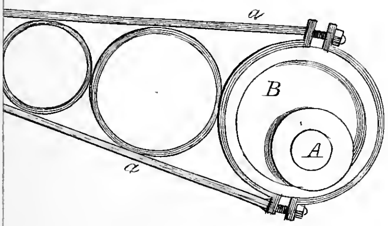
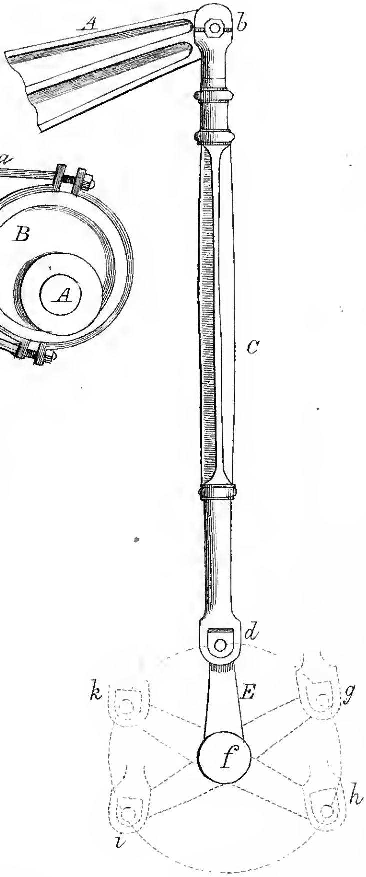
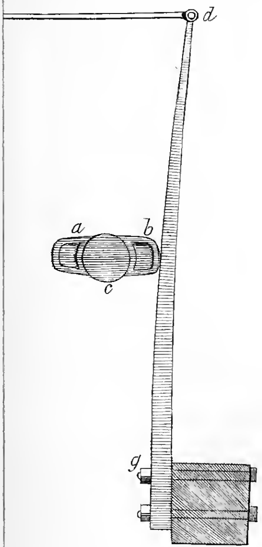
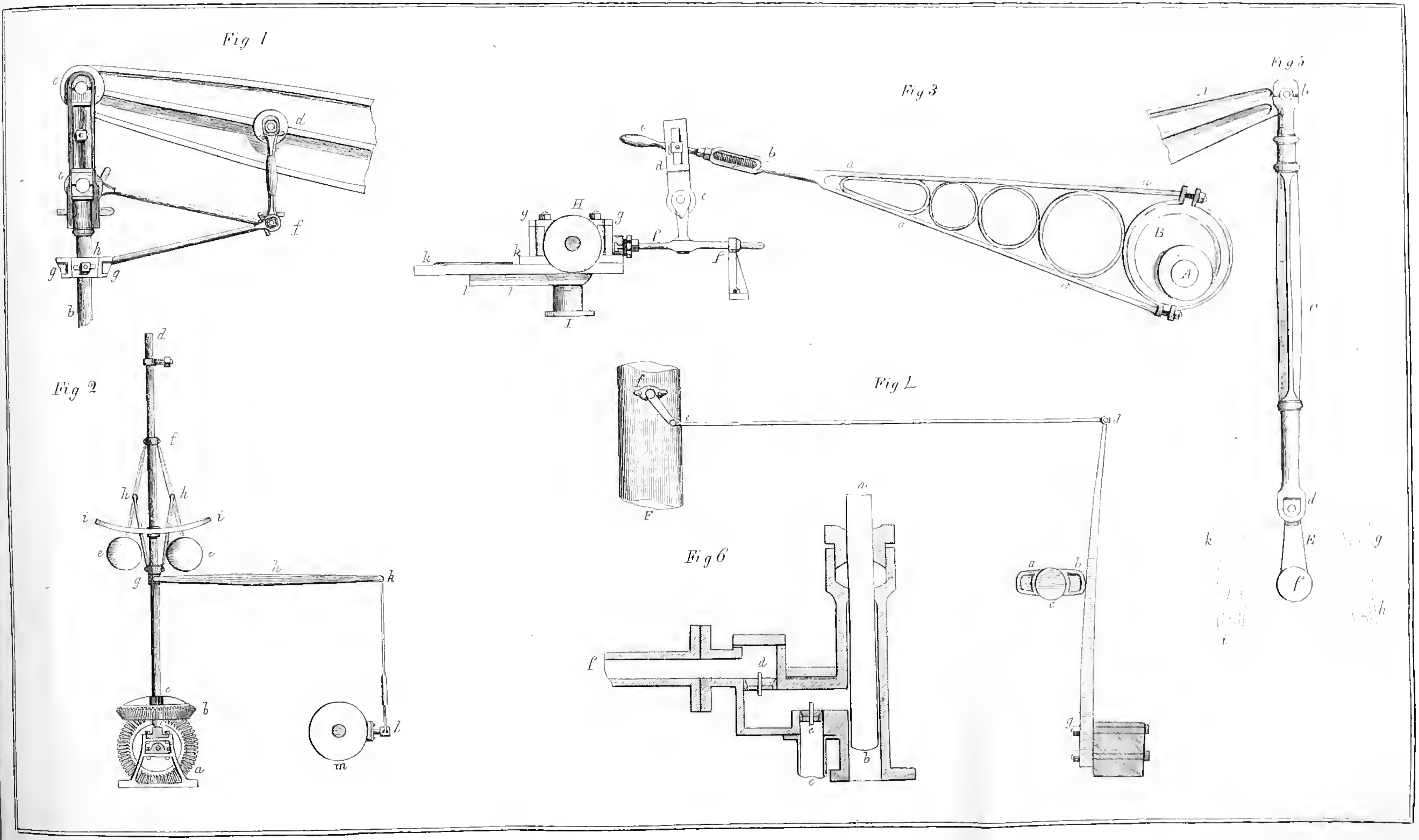


Fig 5

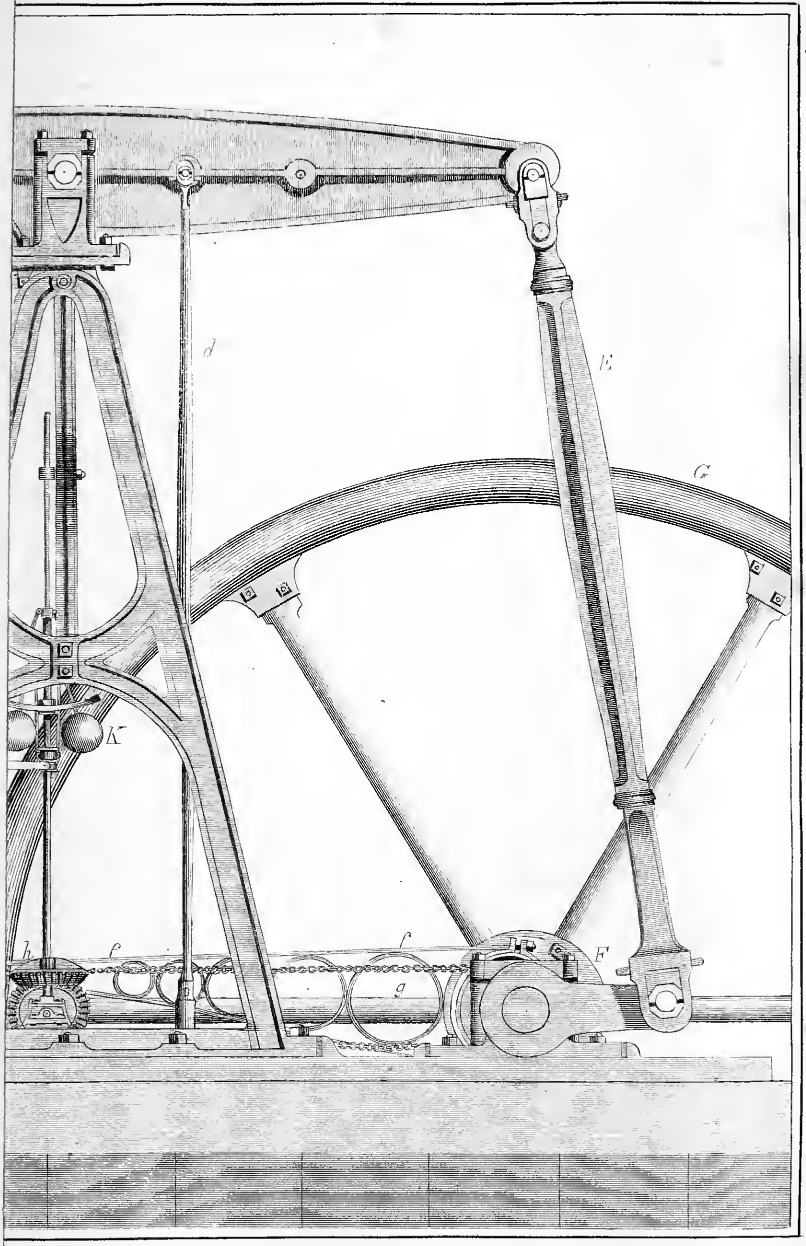


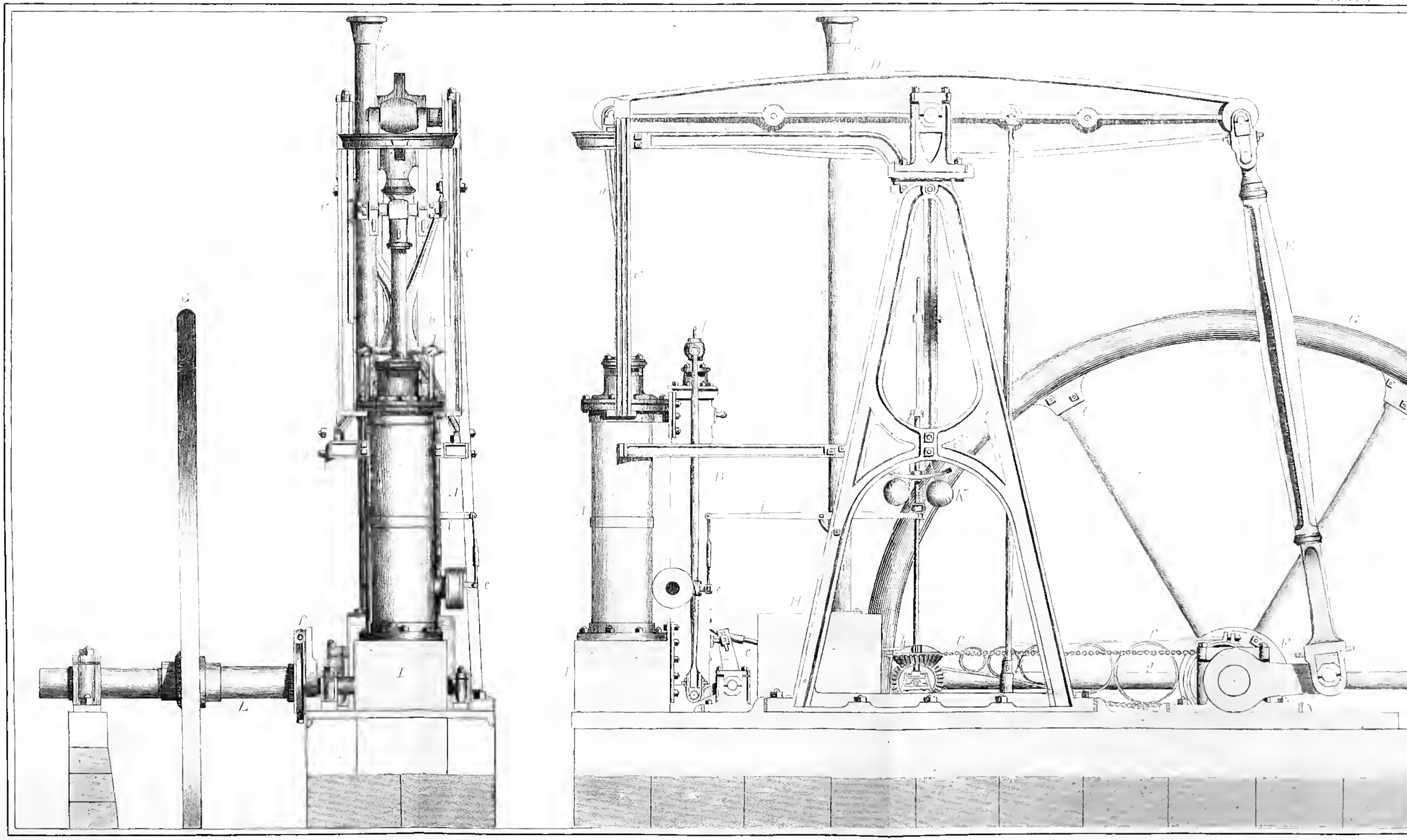


Pl. XV

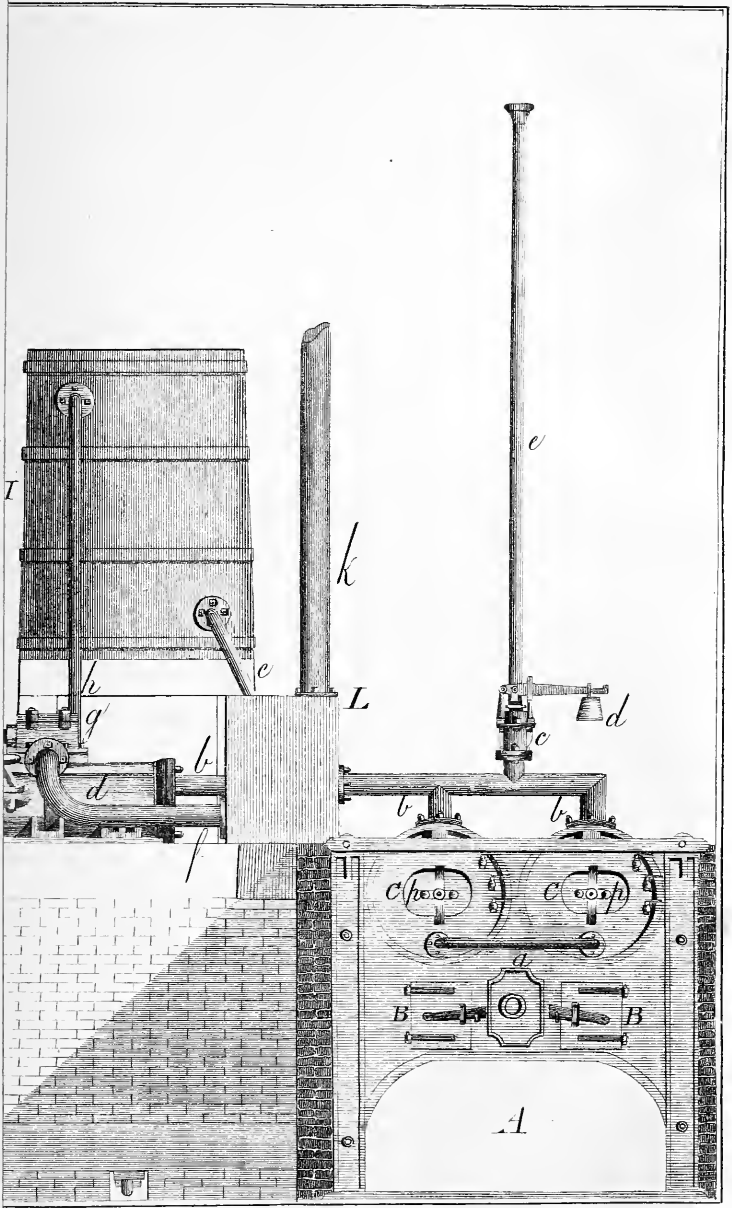


PL. V.

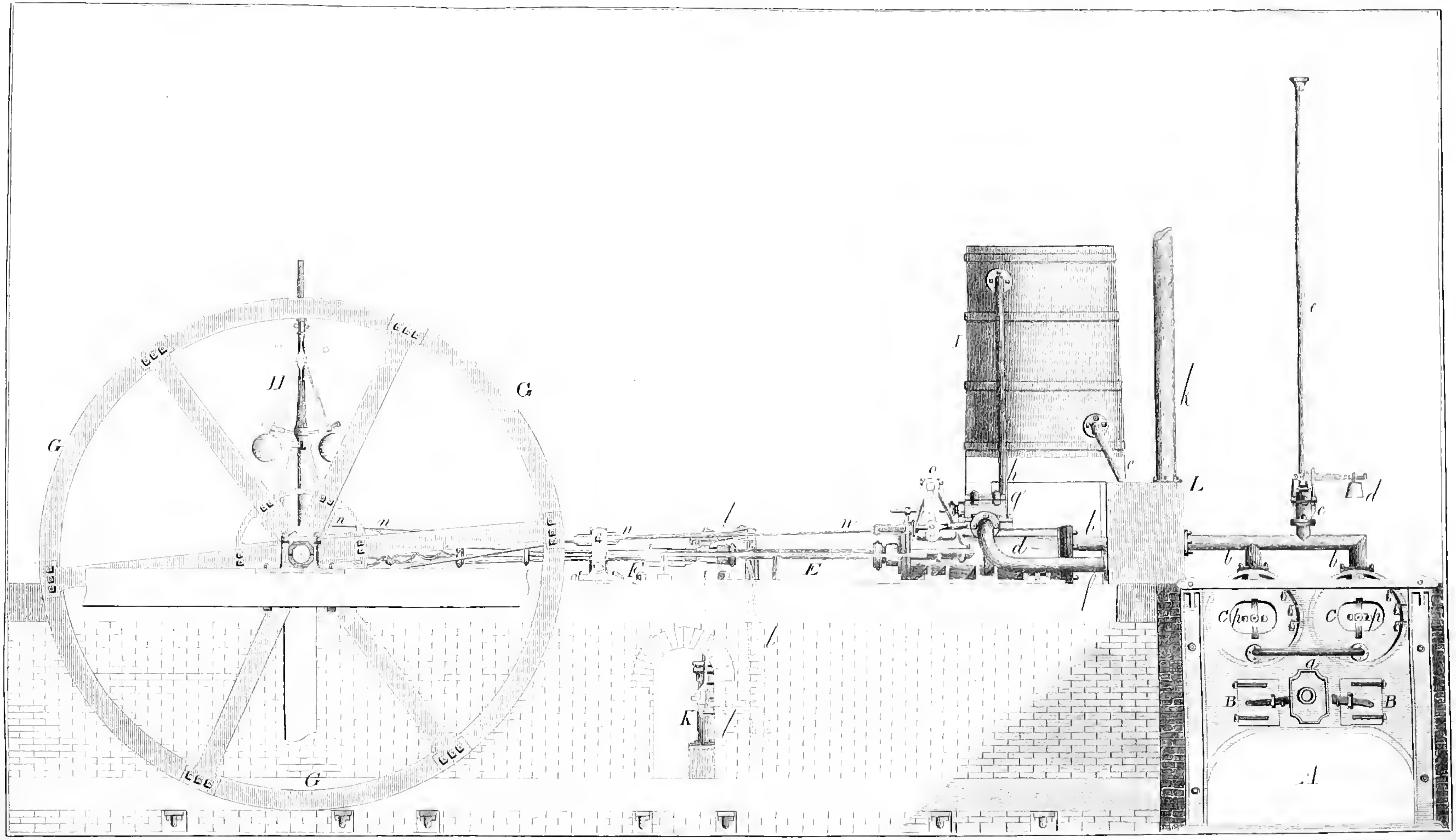


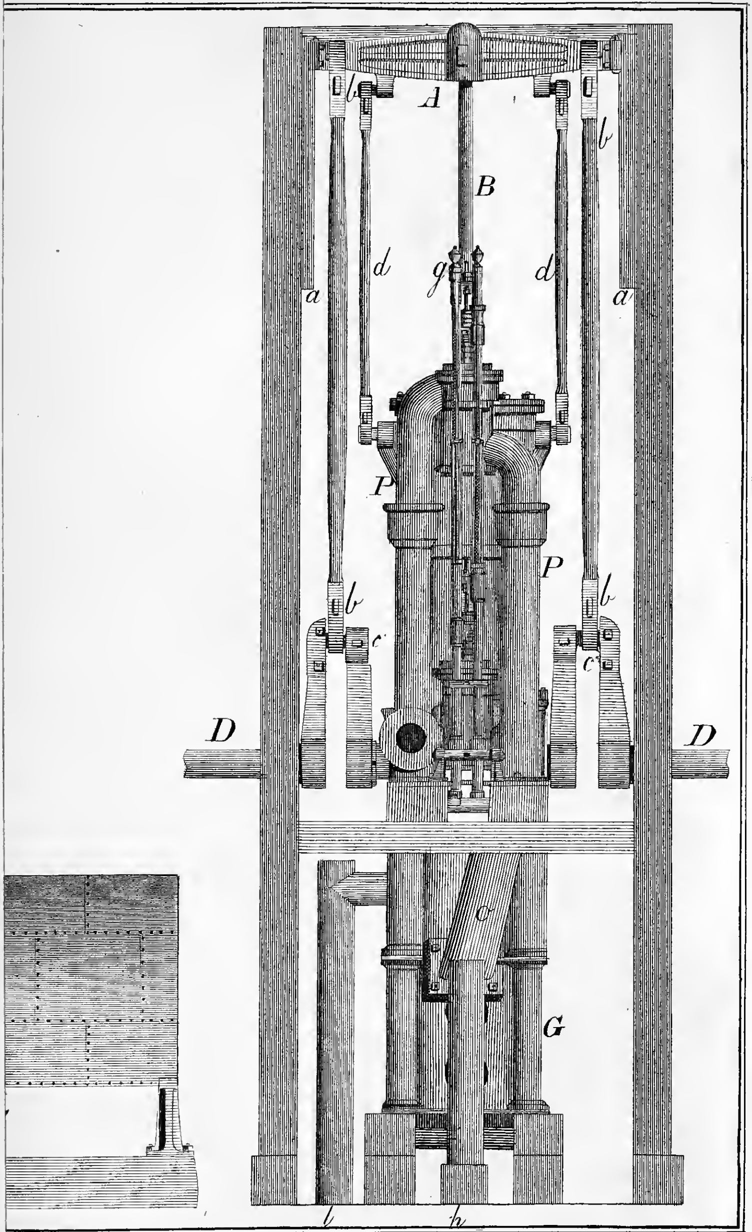


Pl. VI



Pl. VI

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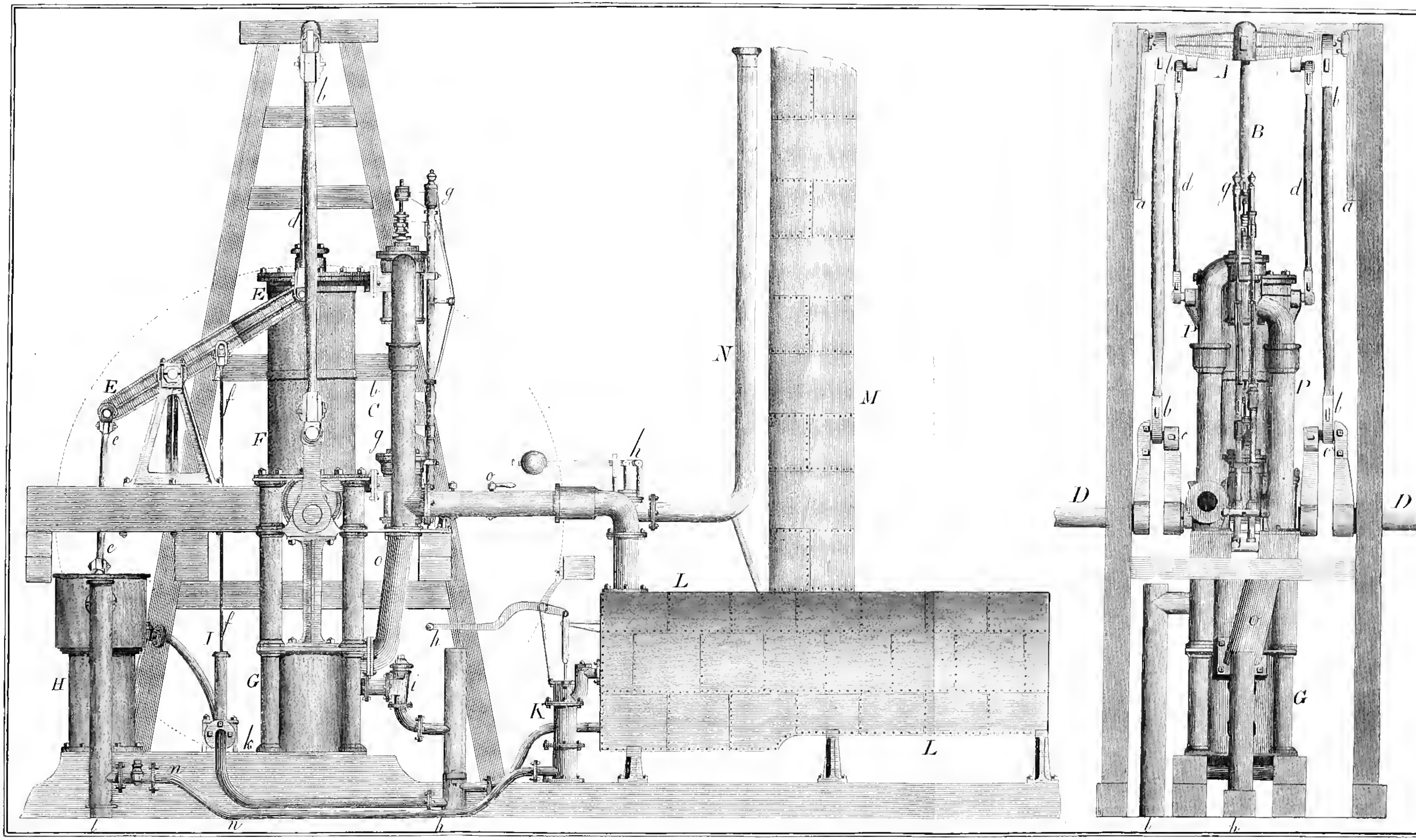
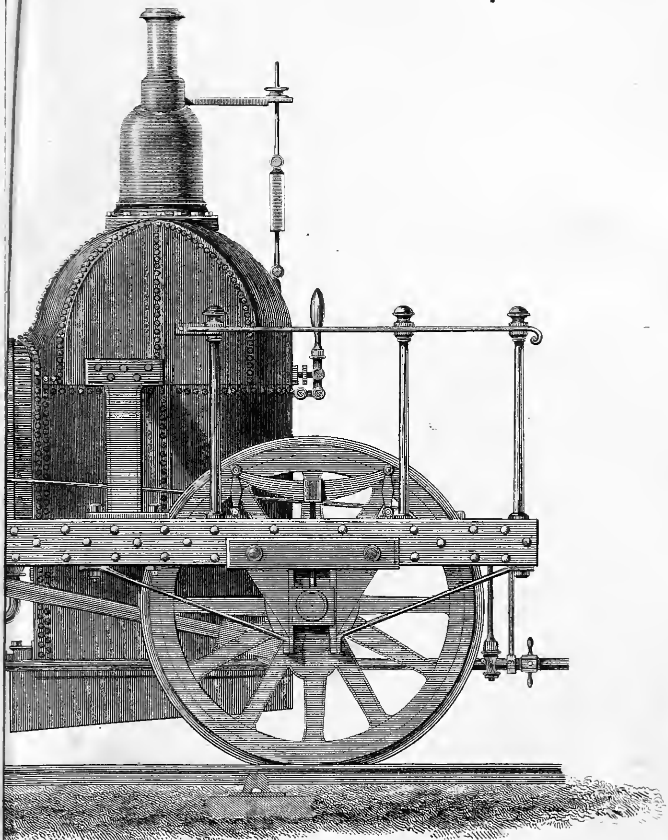
Pl. VII





Scale . $\frac{3}{8}$ to the foot

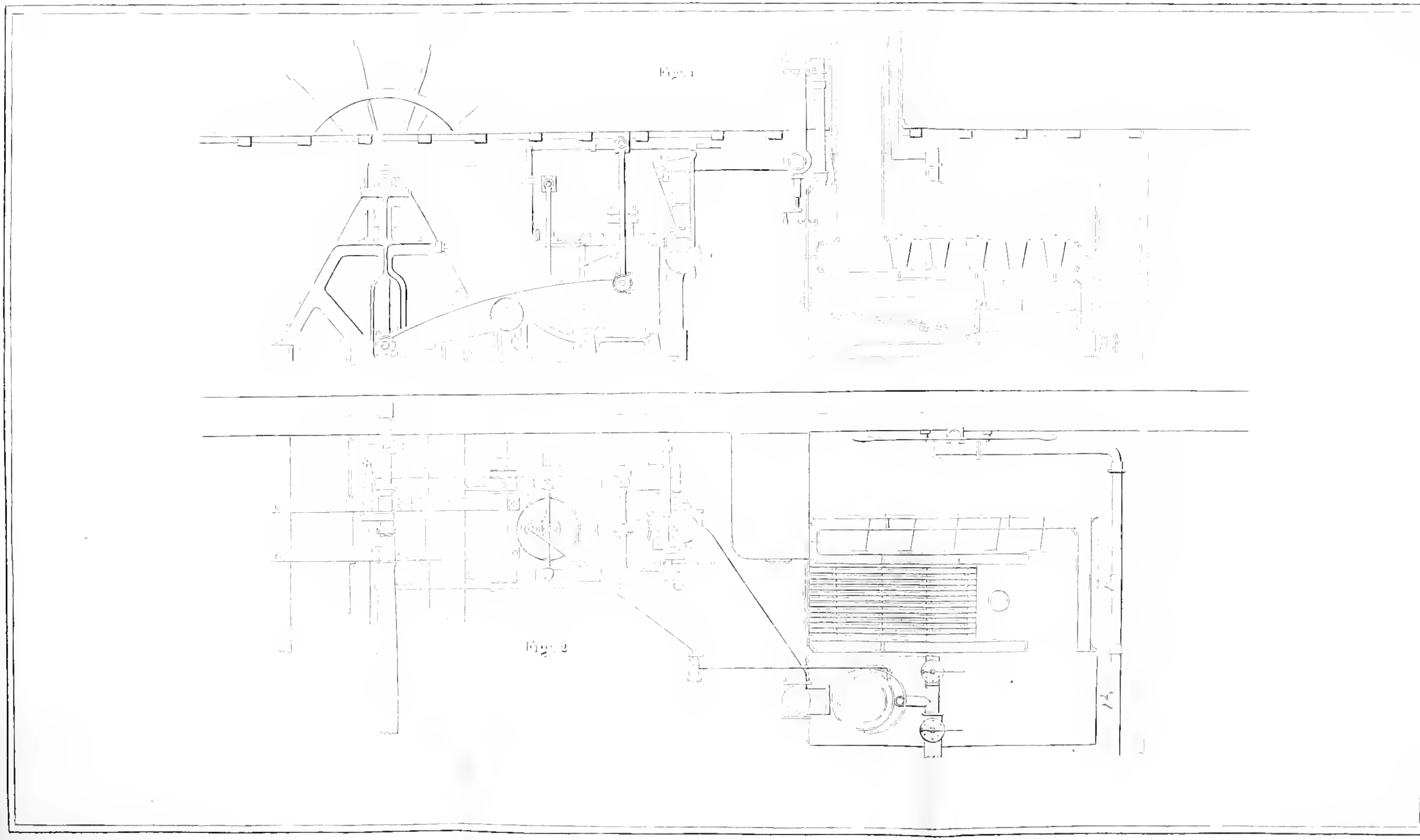
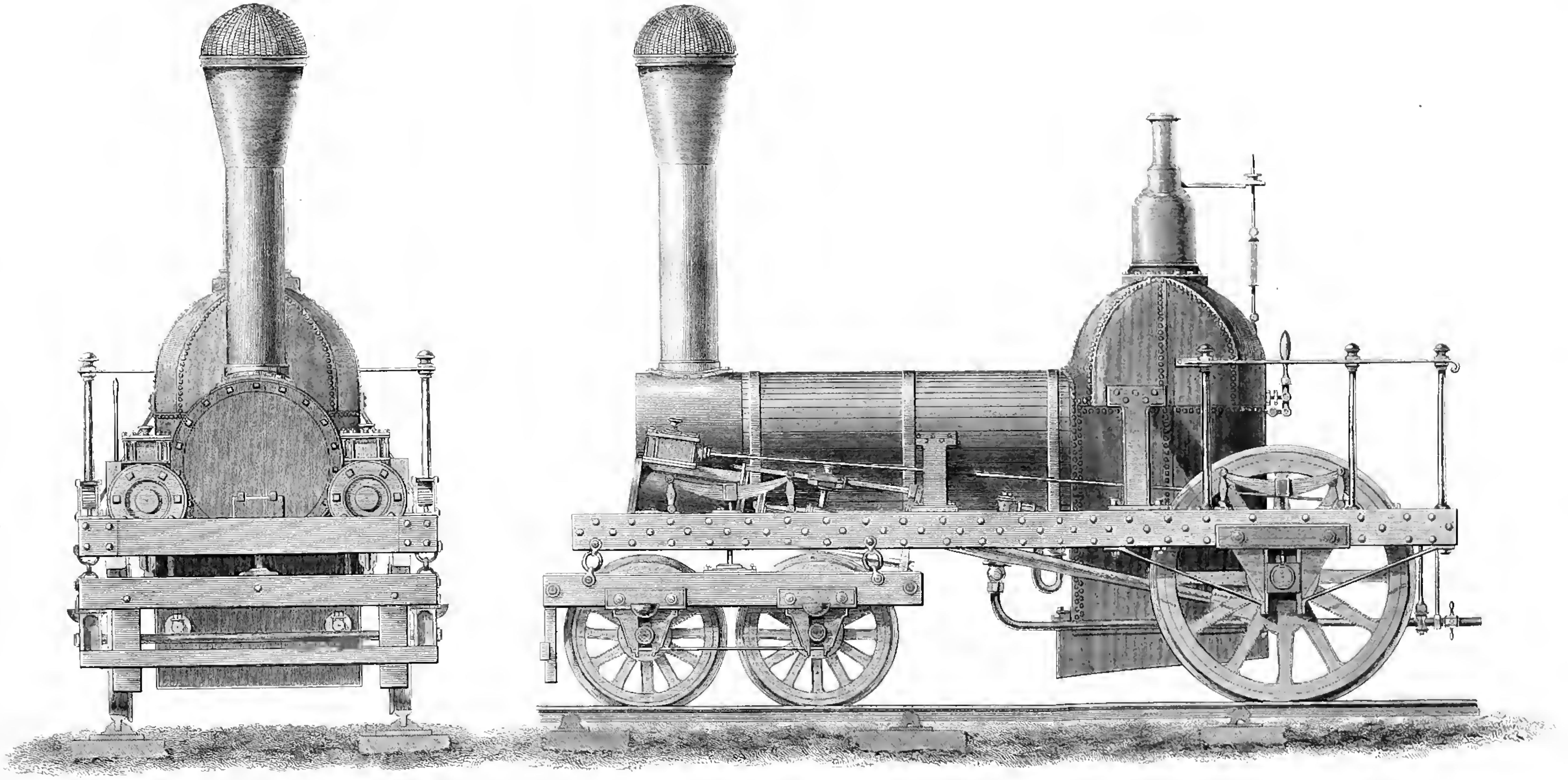


Fig. 1
Fig. 2



LOCOMOTIVE ENGINE.

MANUFACTURED BY H. R. DUNHAM. & Co NY.

Scale ⅝ to the foot