THE GROWTH OF THE STEAM-ENGINE.

CHAPTER I.

THE STEAM-ENGINE AS A SIMPLE MACHINE.

SECTION I.—THE PERIOD OF SPECULATION—FROM HERO TO WORCESTER, B. C. 200 TO A. D. 1650.

ONE of the greatest of modern philosophers—the founder of that system of scientific philosophy which traces the processes of evolution in every department, whether physical or intellectual—has devoted a chapter of his "First Principles" of the new system to the consideration of the multiplication of the effects of the various forces, social and other, which are continually modifying this wonderful and mysterious universe of which we form a part. Herbert Spencer, himself an engineer, there traces the wide-spreading, never-ceasing influences of new inventions, of the introduction of new forms of mechanism, and of the growth of industrial organization, with a clearness and a conciseness which are so eminently characteristic of his style. His illustration of this idea by reference to the manifold effects of the introduction of steam-power and its latest embodiment, the locomotive-engine, is one of the strongest passages in his work. The power of the steam-engine, and its inconceivable importance as an agent of civilization, has always been a favorite theme with philosophers and historians as well as poets. As Religion has always been, and still is, the great *moral* agent in civilizing the world, and as Science is the great *intellectual* promoter of civilization, so the Steam-Engine is, in modern times, the most important *physical* agent in that great work.

It would be superfluous to attempt to enumerate the benefits which it has conferred upon the human race, for such an enumeration would include an addition to every comfort and the creation of almost every luxury that we now enjoy. The wonderful progress of the present century is, in a very great degree, due to the invention and improvement of the steam-engine, and to the ingenious application of its power to kinds of work that formerly taxed the physical energies of the human race. We cannot examine the methods and processes of any branch of industry without discovering, somewhere, the assistance and support of this wonderful machine. Relieving mankind from manual toil, it has left to the intellect the privilege of directing the power, formerly absorbed in physical labor, into other and more profitable channels. The intelligence which has thus conquered the powers of Nature, now finds itself free to do head-work; the force formerly utilized in the carrying of water and the hewing of wood, is now expended in the God-like work of THOUGHT. What, then, can be more interesting than to trace the history of the growth of this wonderful machine?—the greatest among the many great creations of one of God's most beneficent gifts to man—the power of invention.

While following the records and traditions which relate to the steam-engine, I propose to call attention to the fact that its history illustrates the very important truth: *Great inventions are never, and great discoveries are seldom, the* *work of any one mind.* Every great invention is really either an aggregation of minor inventions, or the final step of a progression. It is not a creation, but *a growth*—as truly so as is that of the trees in the forest. Hence, the same invention is frequently brought out in several countries, and by several individuals, simultaneously. Frequently an important invention is made before the world is ready to receive it, and the unhappy inventor is taught, by his failure, that it is as unfortunate to be in advance of his age as to be behind it. Inventions only become successful when they are not only needed, but when mankind is so far advanced in intelligence as to appreciate and to express the necessity for them, and to at once make use of them.

More than half a century ago, an able New England writer, in a communication to an English engineering periodical, described the new machinery which was built at Newport, R. I., by John Babcock and Robert L. Thurston, for one of the first steamboats that ever ran between that city and New York. He prefaced his description with a frequently-quoted remark to the effect that, as Minerva sprang, mature in mind, in full stature of body, and completely armed, from the head of Jupiter, so the steam-engine came forth, perfect at its birth, from the brain of James Watt. But we shall see, as we examine the records of its history, that, although James Watt was *an* inventor, and probably the greatest of the inventors of the steam-engine, he was still but one of the many men who have aided in perfecting it, and who have now made us so familiar with it, and its tremendous power and its facile adaptations, that we have almost ceased to admire it, or to wonder at the workings of the still more admirable intelligence that has so far perfected it.

Twenty-one centuries ago, the political power of Greece was broken, although Grecian civilization had risen to its zenith. Rome, ruder than her polished neighbor, was growing continually stronger, and was rapidly gaining territory by absorbing weaker states. Egypt, older in civilization than either Greece or Rome, fell but two centuries later before the assault of the younger states, and became a Roman province. Her principal city was at this time Alexandria, founded by the great soldier whose name it bears, when in the full tide of his prosperity. It had now become a great and prosperous city, the centre of the commerce of the world, the home of students and of learned men, and its population was the wealthiest and most civilized of the then known world.

It is among the relics of that ancient Egyptian civilization that we find the first records in the early history of the steam-engine. In Alexandria, the home of Euclid, the great geometrician, and possibly contemporary with that talented engineer and mathematician, Archimedes, a learned writer, called Hero, produced a manuscript which he entitled "Spiritalia seu Pneumatica."

It is quite uncertain whether Hero was the inventor of any number of the contrivances described in his work. It is most probable that the apparatus described are principally devices which had either been long known, or which were invented by Ctesibus, an inventor who was famous for the number and ingenuity of the hydraulic and pneumatic machines that he devised. Hero states, in his Introduction, his intention to describe existing machines and earlier inventions, and to add his own. Nothing in the text, however, indicates to whom the several machines are to be ascribed.[1]

The first part of Hero's work is devoted to applications

[1] The British Museum contains four manuscript copies of Hero's "Pneumatics," which were written in the fifteenth and sixteenth centuries. These manuscripts have been examined with great care, and a translation from them prepared by Prof. J. G. Greenwood, and published at the desire of Mr. Bennett Woodcroft, the author of a valuable little treatise on "Steam Navigation." This is, so far as the author is aware, the only existing English translation of any portion of Hero's works.

of the syphon. The 11th proposition is the first application of heat to produce motion of fluids.

An altar and its pedestal are hollow and air-tight. A liquid is poured into the pedestal, and a pipe inserted, of which the lower end passes beneath the surface of the liquid, and the upper extremity leads through a figure standing at the altar, and terminates in a vessel inverted above this altar. When a fire is made on the altar, the heat produced expands the confined air, and the liquid is driven up the tube, issuing from the vessel in the hand of the figure standing by the altar, which thus seems to be offering a libation. This toy embodies the essential principle of all modern heat-engines—the change of energy from the form known as heat-energy into mechanical energy, or work. It is not at all improbable that this prototype of the modern wonder-working machine may have been known centuries before the time of Hero.

Many forms of hydraulic apparatus, including the hand fire-engine, which is familiar to us, and is still used in many of our smaller cities, are described, the greater number of which are probably attributable to Ctesibus. They demand no description here.

A hot-air engine, however, which is the subject of his 37th proposition, is of real interest.

Hero sketches and describes a method of opening temple-doors by the action of fire on an altar, which is an ingenious device, and contains all the elements of the machine of the Marquis of Worcester, which is generally considered the first real steam-engine, with the single and vital defect that the expanding fluid is air instead of steam. The sketch, from Greenwood's translation, exhibits the device very plainly. Beneath the temple-doors, in the space *A B C D*, is placed a spherical vessel, *H*, containing water. A pipe, *F G*, connects the upper part of this sphere with the hollow and air-tight shell of the altar above, *D E*. Another pipe, *K L M*, leads from the bottom of the vessel, *H*, over, in syphon-shape, to the bottom of a suspended bucket, *N X*. The suspending cord is carried over a pulley and led around two vertical barrels, *O P*, turning on pivots

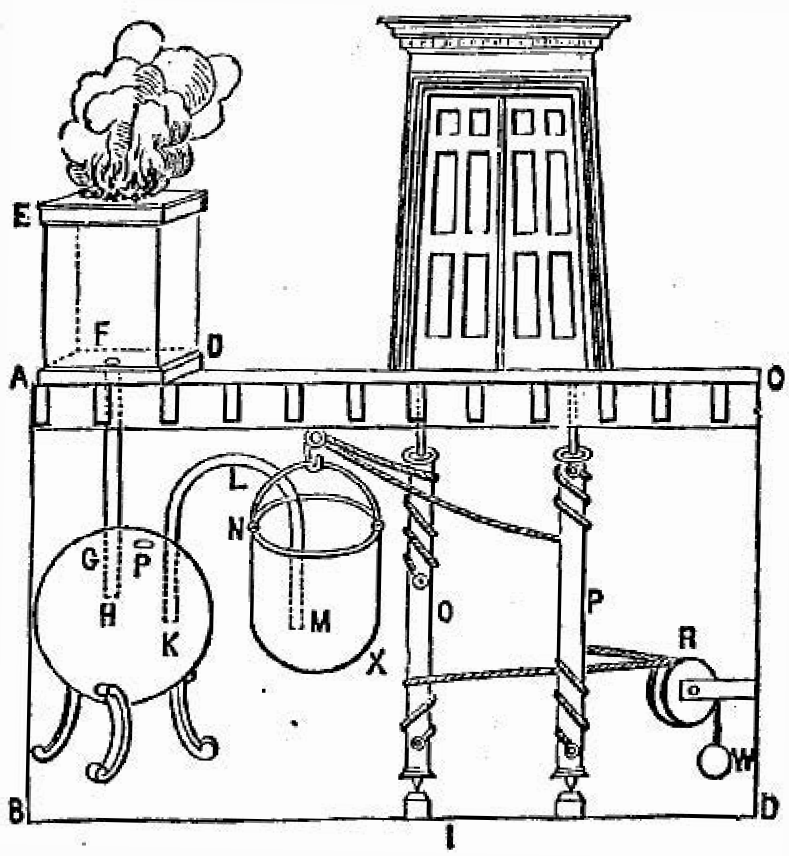

FIG. 1.—Opening Temple-Doors by Steam, B. C. 200.

at their feet, and carrying the doors above. Ropes led over a pulley, *R*, sustain a counterbalance, *W*.

On building a fire on the altar, the heated air within expands, passes through the pipe, *F G*, and drives the water contained in the vessel, *H*, through the syphon, *K L M*, into the bucket, *N X*. The weight of the bucket, which then descends, turns the barrels, *O P*, raises the counterbalance, and opens the doors of the temple. On extinguishing the fire, the air is condensed, the water returns through the syphon from the bucket to the sphere, the counterbalance falls, and the doors are closed.

Another contrivance is next described, in which the bucket is replaced by an air-tight bag, which, expanding as the heated air enters it, contracts vertically and actuates the mechanism, which in other respects is similar to that just described.

In these devices the spherical vessel is a perfect anticipation of the vessels used many centuries later by several so-called inventors of the steam-engine.

Proposition 45 describes the familiar experiment of a ball supported aloft by a jet of fluid. In this example steam is generated in a close cauldron, and issues from a pipe inserted in the top, the ball dancing on the issuing jet.

No. 47 is a device subsequently reproduced—perhaps reinvented by the second Marquis of Worcester.

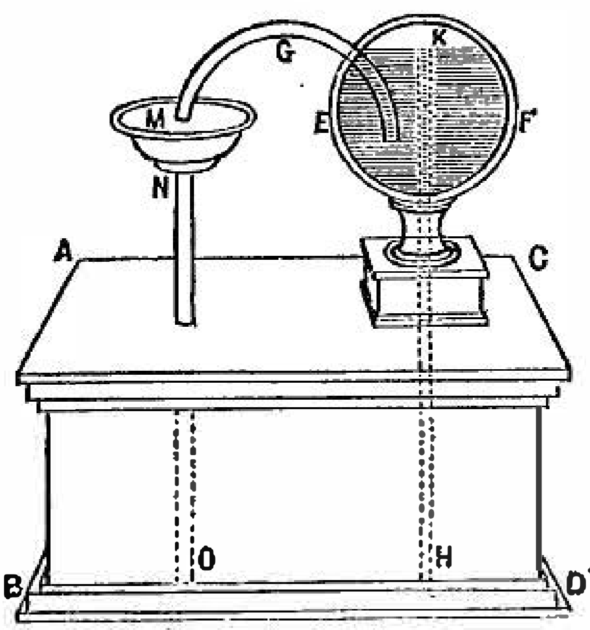

Fig. 2.—Steam Fountain, B. C. 200.

A strong, close vessel, *A B C D*, forms a pedestal, on which are mounted a spherical vessel, *E F*, and a basin. A pipe, *H K*, is led from the bottom of the larger vessel into the upper part of the sphere, and another pipe from the lower part of the latter, in the form of a syphon, over to the basin, *M*. A drain-pipe, *N O*, leads from the basin to the reservoir, *A D*. The whole contrivance is called "A fountain which is made to flow by the action of the sun's rays."

It is operated thus: The vessel, *E F*, being filled nearly to the top with water, or other liquid, and exposed to the action of the sun's rays, the air above the water expands, and drives the liquid over, through the syphon, *G*, into the basin, *M*, and it will fall into the pedestal, *A B C D*.

Hero goes on to state that, on the removal of the sun's rays, the air in the sphere will contract, and that the water will be returned to the sphere from the pedestal. This can, evidently, only occur when the pipe *G* is closed previous to the commencement of this cooling. No such cock is mentioned, and it is not unlikely that the device only existed on paper.

Several steam-boilers are described, usually simple pipes or cylindrical vessels, and the steam generated in them by the heat of the fire on the altar forms a steam-blast. This blast is either directed into the fire, or it "makes a blackbird sing," blows a horn for a triton, or does other equally useless work. In one device, No. 70, the steam issues from a reaction-wheel revolving in the horizontal plane, and causes dancing images to circle about the altar. A more mechanical and more generally-known form of this device is that which is frequently described as the "First Steam Engine." The sketch from Stuart is similar in general form, but more elaborate in detail, than that copied by Greenwood, which is here also reproduced, as representing more accurately the simple form which the mechanism of

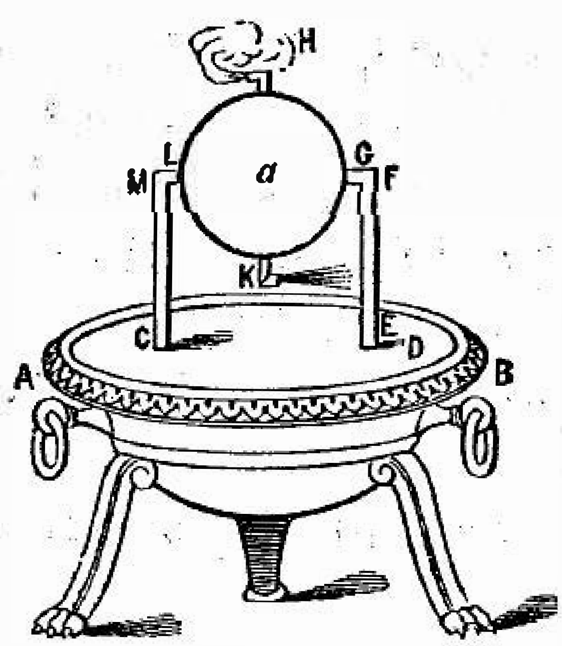

FIG. 3.—Hero's Engine, B. C. 200.

the "Æolipile," or Ball of Æolus, assumed in those early times.

The cauldron, *A B*, contains water, and is covered by the steam-tight cover, *C D*. A globe is supported above the cauldron by a pair of tubes, terminating, the one, *C M*, in a pivot, *L*, and the other, *E F*, opening directly into the sphere at *G*. Short, bent pipes, *H* and *K*, issue from points diametrically opposite each other, and are open at their extremities.

A fire being made beneath the cauldron, steam is formed and finds exit through the pipe, *E F G*, into the globe, and thence rushes out of the pipes, *H K*, turning the globe on its axis, *G L*, by the unbalanced pressure thus produced.

The more elaborate sketch which forms the frontispiece represents a machine of similar character. Its design and ornamentation illustrate well the characteristics of ancient art, and the Greek idea of the steam-engine.

This "Æolipile" consisted of a globe, *X*, suspended between trunnions, *G O*, through one of which steam enters from the boiler, *P*, below. The hollow, bent arms, *W* and *Z*, cause the vapor to issue in such directions that the reaction produces a rotary movement of the globe, just as the rotation of reaction water-wheels is produced by the outflowing water.

It is quite uncertain whether this machine was ever more than a toy, although it has been supposed by some authorities that it was actually used by the Greek priests for the purpose of producing motion of apparatus in their temples.

It seems sufficiently remarkable that, while the power of steam had been, during all the many centuries that man has existed upon the globe, so universally displayed in so many of the phenomena of natural change, that mankind lived almost up to the Christian era without making it useful in giving motion even to a toy; but it excites still greater surprise that, from the time of Hero, we meet with no good evidence of its application to practical purposes for many hundreds of years.

Here and there in the pages of history, and in special treatises, we find a hint that the knowledge of the force of steam was not lost; but it is not at all to the credit of biographers and of historians, that they have devoted so little time to the task of seeking and recording information relating to the progress of this and other important inventions and improvements in the mechanic arts.

Malmesbury states[1] that, in the year A. D. 1125, there existed at Rheims, in the church of that town, a clock designed or constructed by Gerbert, a professor in the schools there, and an organ blown by air escaping from a vessel in which it was compressed "by heated water."

Hieronymus Cardan, a wonderful mathematical genius, a most eccentric philosopher, and a distinguished physician, about the middle of the sixteenth century called attention, in his writings, to the power of steam, and to the facility with which a vacuum can be obtained by its condensation. This Cardan was the author of "Cardan's Formula," or rule for the solution of cubic equations, and was the inventor of the "smoke-jack." He has been called a "philosopher, juggler, and madman." He was certainly a learned mathematician, a skillful physician, and a good mechanic.

Many traces are found, in the history of the sixteenth century, of the existence of some knowledge of the properties of steam, and some anticipation of the advantages to follow its application. Matthesius, A. D. 1571, in one of his sermons describes a contrivance which may be termed a steam-engine, and enlarges on the "tremendous results which may follow the volcanic action of a small quantity of confined vapor;"[2] and another writer applied the steam æolipile of Hero to turn the spit, and thus rivaled and excelled Cardan, who was introducing his "smoke-jack."

As Stuart says, the inventor enumerated its excellent qualities with great minuteness. He claimed that it would "eat nothing, and giving, withal, an assurance to those par-

[1] Stuart's "Anecdotes."

[2] "Berg-Postilla, oder Sarepta von Bergwerk und Metallen." Nuremberg, 1571.

taking of the feast, whose suspicious natures nurse queasy appetites, that the haunch has not been pawed by the turnspit in the absence of the housewife's eye, for the pleasure of licking his unclean fingers."[1]

Jacob Besson, a Professor of Mathematics and Natural Philosophy at Orleans, and who was in his time distinguished as a mechanician, and for his ingenuity in contriving illustrative models for use in his lecture-room, left evidence, which Beroaldus collected and published in 1578,[2] that he had found the spirit of his time sufficiently enlightened to encourage him to pay great attention to applied mechanics and to mechanism. There was at this time a marked awakening of the more intelligent men of the age to the value of practical mechanics. A scientific tract, published at Orleans in 1569, and probably written by Besson, describes very intelligently the generation of steam by the communication of heat to water, and its peculiar properties.

The French were now becoming more interested in mechanics and the allied sciences, and philosophers and literati, of native birth and imported by the court from other countries, were learning more of the nature and importance of such studies as have a bearing upon the work of the engineer and of the mechanic.

Agostino Ramelli, an Italian of good family, a student and an artist when at leisure, a soldier and an engineer in busier times, was born and educated at Rome, but subsequently was induced to make his home in Paris. He published a book in 1588,[3] in which he described many machines, adapted to various purposes, with a skill that was only equaled by the accuracy and general excellence of his delineations. This work was produced while its author was

[1] "History of the Steam-Engine," 1825.

[2] "Theatrum Instrumentorum et Machinarum, Jacobi Bessoni, cum Franc Beroaldus, figuarum declaratione demonstrativa." Lugduni, 1578.

[3] "Le diverse et artificiose machine del Capitano Agostino Ramelli, del Ponte della Prefia." Paris, 1588.

residing at the French capital, supported by a pension which had been awarded him by Henry III. as a reward for long and faithful services.

The books of Besson and of Ramelli are the first treatises of importance on general machinery, and were, for many years, at once the sources from which later writers drew the principal portion of their information in relation to machinery, and wholesome stimulants to the study of mechanism. These works contain descriptions of many machines subsequently reinvented and claimed as new by other mechanics.

Leonardo da Vinci, well known as a mathematician, engineer, poet, and painter, of the sixteenth century, describes, it is said, a steam-gun, which he calls the "Architonnerre," and ascribes to Archimedes. It was a machine composed of copper, and seems to have had considerable power. It threw a ball weighing a talent. The steam was generated by permitting water in a closed vessel to fall on surfaces heated by a charcoal fire, and by its sudden expansion to eject the ball.

In the year 1825, the superintendent of the royal Spanish archives at Simancas furnished an account which, it was said, had been there discovered of an attempt, made in 1543 by Blasco de Garay, a Spanish navy-officer under Charles V., to move a ship by paddle-wheels, driven, as was inferred from the account, by a steam-engine.

It is impossible to say to how much credit the story is entitled, but, if true, it was the first attempt, so far as is now known, to make steam useful in developing power for practical purposes. Nothing is known of the form of the engine employed, it only having been stated that a "vessel of boiling water" formed a part of the apparatus.

The account is, however, in other respects so circumstantial, that it has been credited by many; but it is regarded as apocryphal by the majority of writers upon the subject. It was published in 1826 by M. de Navarrete, in

Zach's "Astronomical Correspondence," in the form of a letter from Thomas Gonzales, Director of the Royal Archives at Simancas, Spain.

In 1601, Giovanni Battista della Porta, in a work called "Spiritali," described an apparatus by which the pressure of steam might be made to raise a column of water. It included the application of the condensation of steam to the production of a vacuum into which the water would flow.

Porta is described as a mathematician, chemist, and physicist, a gentleman of fortune, and an enthusiastic student of science. His home in Naples was a rendezvous for students, artists, and men of science distinguished in every branch. He invented the magic lantern and the camera obscura, and described it in his commentary on the "Pneumatica." In his work,[1] he described this machine for raising water, as shown in Fig. 4, which differs from one shown by Hero in the use of steam pressure, instead of the pressure of heated air, for expelling the liquid.

The retort, or boiler, is fitted to a tank from which the bent pipe leads into the external air. A fire being kindled under the retort, the steam generated rises to the upper part of the tank, and its pressure on the surface of the water drives it out through the pipe, and it is then led to any desired height. This was called by Porta an improved "Hero's Fountain," and was named his "Steam Fountain." He described with perfect accuracy the action of condensation in producing a vacuum, and sketched an apparatus in which the vacuum thus secured was filled by water forced in by the pressure of the external atmosphere. His contrivances were not apparently ever applied to any practically useful purpose. We have not yet passed out of the age of speculation, and are just approaching the period of application. Porta is, nevertheless, entitled to credit as having pro-

[1] "Pneumaticorum libri tres," etc., 4to. Naples, 1601. "I Tre Libri de' Spiritali." Napoli, 1606.

posed an essential change in this succession, which begins with Hero, and which did not end with Watt.

The use of steam in Hero's fountain was as necessary a step as, although less striking than, any of the subsequent modifications of the machine.e In Porta's contrivance, too, we should note particularly the separation of the boiler from

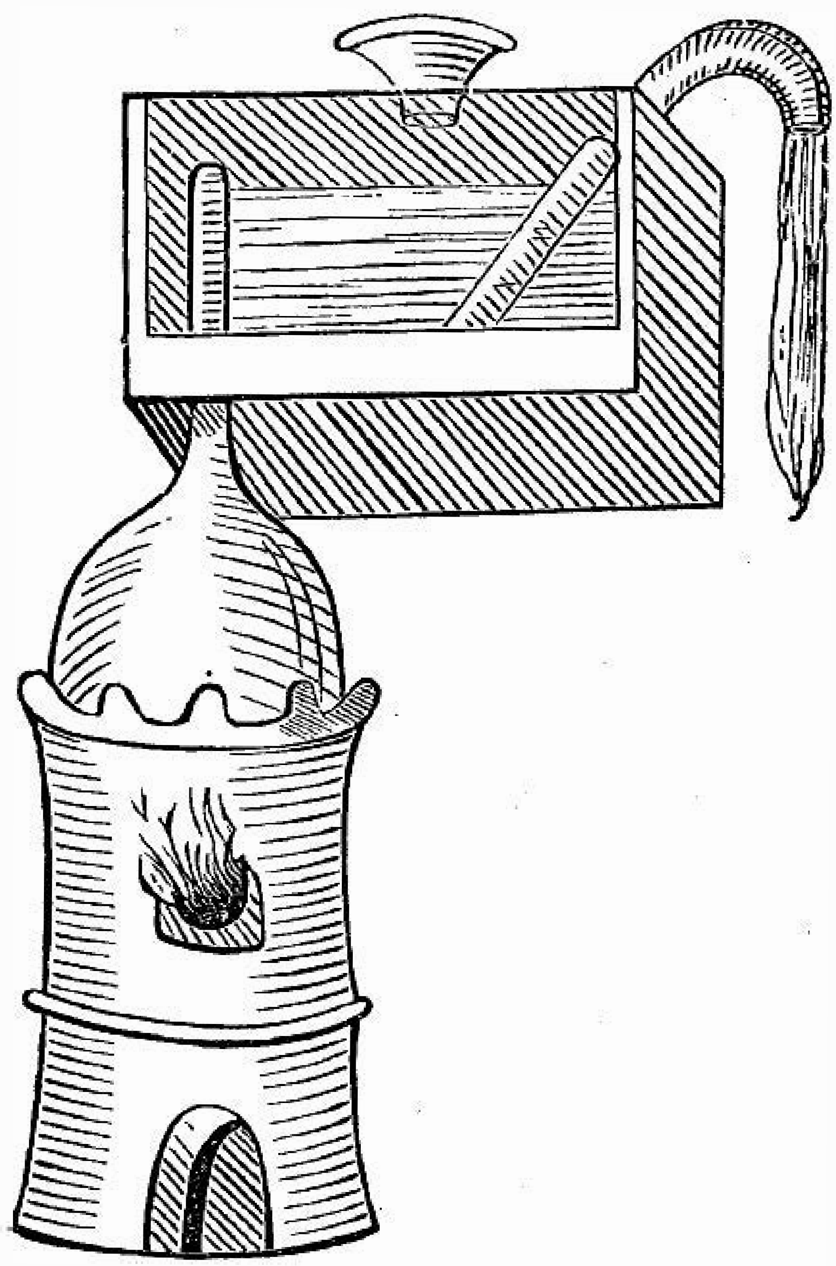

FIG. 4.—Porta's Apparatus, A. D. 1601.

thee" forcing vessel"—a plan often claimed as original with later inventors, and as constituting a fair ground for special distinction.

The rude engraving (Fig. 4) above is copied from the book of Porta, and shows plainly the boiler mounted above a furnace, from the door of which the flame is seen issuing, and above is the tank containing water. The opening in the top is closed by the plug, as shown, and the steam issuing from the boiler into the tank near the top, the water is driven out through the pipe at the left, leading up from the bottom of the tank.

Florence Rivault, a Gentleman of the Bedchamber to

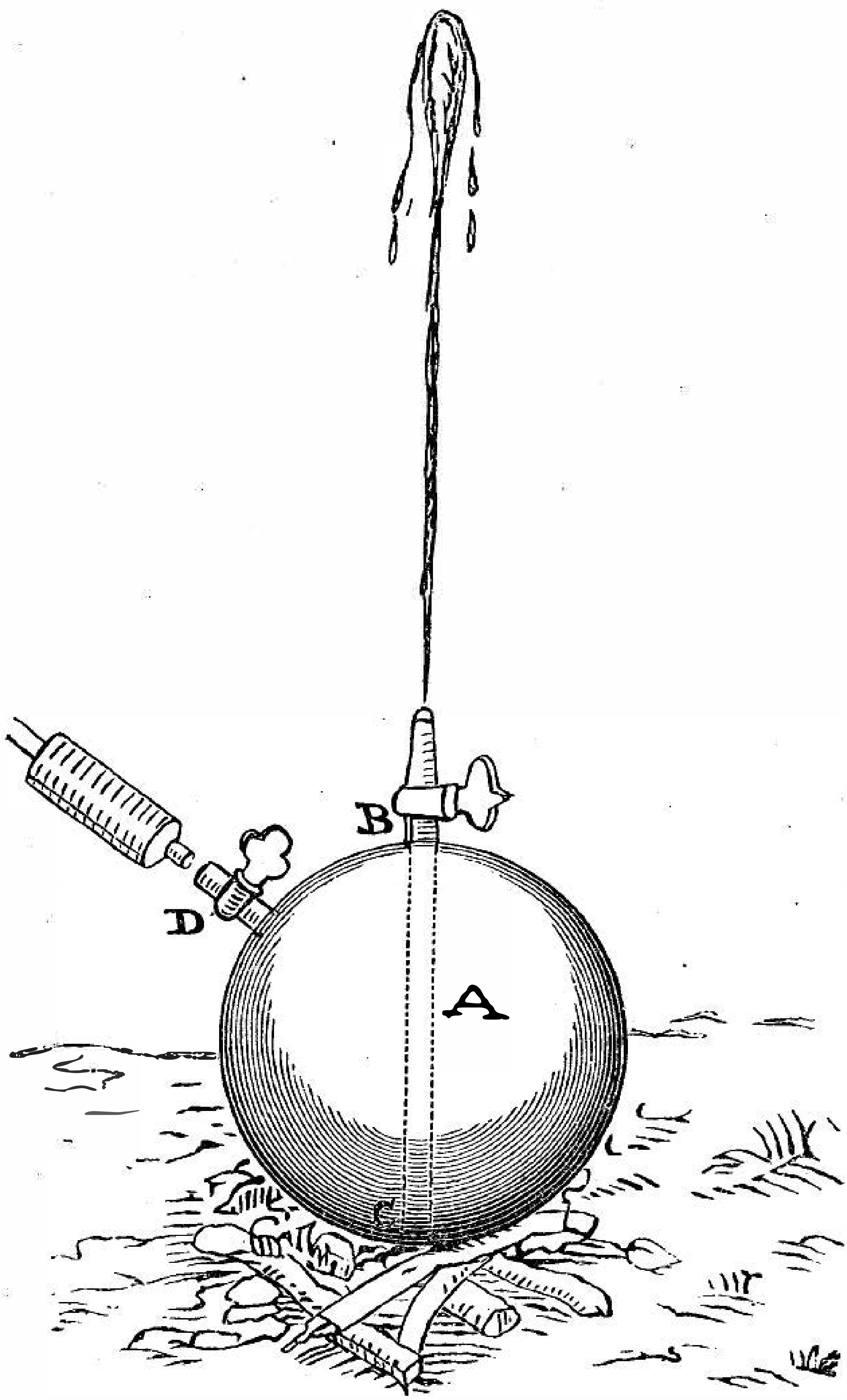

FIG. 5.—De Caus's Apparatus, A. D. 1605.

Henry IV., and a teacher of Louis XIII., is stated by M. Arago, the French philosopher, to have discovered, as early as 1605, that water confined in a bomb-shell and there heated would explode the shell, however thick its walls might be made. The fact was published in Rivault's treatise on artillery in 1608. He says: "The water is converted into air, and its vaporization is followed by violent explosion."

In 1615, Salomon de Caus, who had been an engineer and architect under Louis XIII. of France, and later in the employ of the English Prince of Wales, published a work at Frankfort, entitled "Les Raisons des Forces Mouvantes, avec diverses machines tant utile que plaisante," in which he illustrated his proposition, "Water will, by the aid of fire, mount higher than its source," by describing a machine designed to raise water by the expanding power of steam.

In the sketch here given (Fig. 5), and which is copied from the original in "Les Raisons des Forces Mouvantes," etc., *A* is the copper ball containing water; *B*, the cock at the extremity of the pipe, taking water from the bottom, *C*, of the vessel; *D*, the cock through which the vessel is filled. The sketch was probably made by De Caus's own hand.

The machine of De Caus, like that of Porta, thus consisted of a metal vessel partly filled with water, and in which a pipe was fitted, leading nearly to the bottom, and open at the top. Fire being applied, the steam formed by its elastic force drove the water out through the vertical pipe, raising it to a height limited only by either the desire of the builder or the strength of the vessel.

In 1629, Giovanni Branca, of the Italian town of Loretto, described, in a work[1] published at Rome, a number of ingenious mechanical contrivances, among which was a steam-engine (Fig. 6), in which the steam, issuing from a boiler, impinged upon the vanes of a horizontal wheel. This it was proposed to apply to many useful purposes.

[1] "Le Machine deverse del Signior Giovanni Branca, cittadino Romano, Ingegniero, Architetto della Sta. Casa di Loretto." Roma, MDCXXIX.

At this time experiments were in progress in England which soon resulted in the useful application of steam-power to raising water.

A patent, dated January 21, 1630, wasegranted to David Ramseye[1] by Charles I., which covered a number of dis-

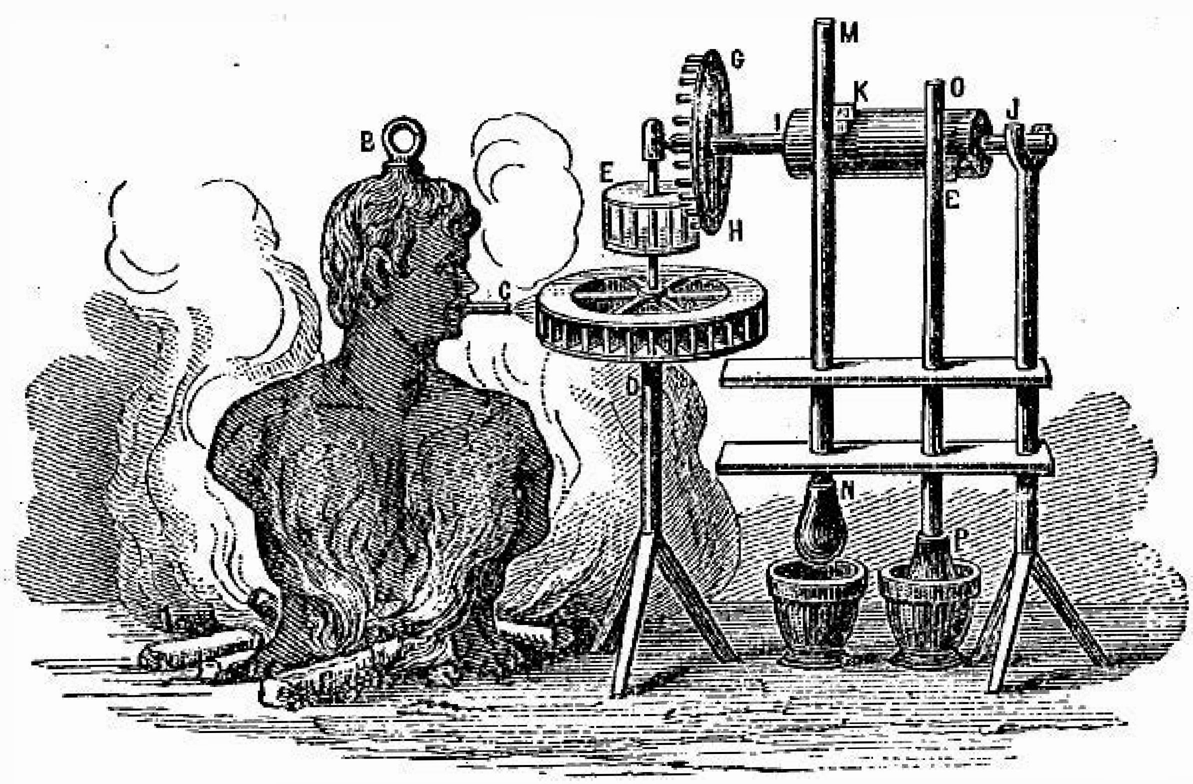

Fig. 6.—Branca's Steam-Engine, A. D. 1629.

tinct inventions. These were: "1. To multiply and make saltpeter in any open field, in fower acres of ground, sufficient to serve all our dominions. 2. To raise water from low pitts by fire.e 3. To make any sort of mills to goe on standing waters by continual motion, without help of wind, water, or horse. 4. To make all sortes of tapistrie without any weaving-loom, or waie ever yet in use in this kingdome. 5. To make boats, shippes, and barges to goe against strong wind and tide. 6. To make the earth more fertile than usual. 7. To raise water from low places and mynes, and coal pitts, by a new waie never yet in use. 8. To make hard iron soft, and likewise copper to be tuffe and soft, which is not in use in this kingdome. 9. To make yellow waxe white verie speedilie."

This seems to have been the first authentic reference to

[1] Rymer's "Fœdera," Sanderson. Ewbank's "Hydraulics," p. 419.

the use of steam in the arts which has been found in English literature. The patentee held his grant fourteen years, on condition of paying an annual fee of £3 6*s.* 8*d.* to the Crown.

The second claim is distinct as an application of steam, the language being that which was then, and for a century and a half subsequently, always employed in speaking of its use. The steam-engine, in all its forms, was at that time known as the "fire-engine." It would seeme not at all improbable that the third, fifth, and seventh claims are also applications of steam-power.

Thomas Grant, in 1632, and Edward Ford, in 1640, also patented schemes, which have not been described in detail, for moving ships against wind and tide by some new and great force.

Dr. John Wilkins, Bishop of Chester, an eccentric but learned and acutee scholar, described, in 1648, Cardan's smoke-jack, the earlier æolipiles, and the power of the confined steam, and suggested, in a humorous discourse, what he thought to be perfectly feasible—the construction of a flying-machine. He says: "Might not a 'high pressure' be applied with advantage to move wings as large as those of the 'ruck's' or the 'chariot'? The engineer might probably find a corner that would do for a coal-station near some of the 'castles'" (castles in the air). The reverened wit proposed the application of the smoke-jack to the chiming of bells, theereeling of yarn, and to rocking the cradle.

Bishop Wilkins writes, in 1648 ("Mathematical Magic"), of æolipiles as familiar and useful pieces of apparatus, and describes them as consisting "of some such material as may endure the fire, having a small hole at which they are filled with water, and out of which (when the vessels are heated) the air doth issue forth with a strong and lasting violence." "They are," the bishop adds, "frequently used for the exciting and contracting of heat in the melting of glasses or metals. They may also be contrived to be serviceable for sundry other pleasant uses, as for the moving of sails in a chimney-corner, the motion of which sails may be applied to the turning of a spit, or the like."

Kircher gives an engraving ("Mundus Subterraneus") showing the last-named application of the æolipile; and Erckern ("Aula Subterranea," 1672) gives a picture illustrating their application to the production of a blast in smelting ores. They seem to have been frequently used, and in all parts of Europe, during the seventeenth century, for blowing fires in houses, as well as in the practical work of the various trades, and for improving the draft of chimneys. The latter application is revived very frequently by the modern inventor.

SECTION II. — THE PERIOD OF APPLICATION—WORCESTER, PAPIN, AND SAVERY.

We next meet with the first instance in which the expansive force of steam is supposed to have actually been applied to do important and useful work.

In 1663, Edward Somerset, second Marquis of Worcester, published a curious collection of descriptions of his inventions, couched in obscure and singular language, and called "A Century of the Names and Scantlings of Inventions by me already Practised."

One of these inventions is an apparatus for raising water by steam. The description was not accompanied by a drawing, but the sketch here given (Fig. 7) is thought probably to resemble one of his earlier contrivances very closely.

Steam is generated in the boiler *a*, and thence is led into the vessel *e*, already nearly filled with water, and fitted up like the apparatus of De Caus. It drives the water in a jet out through the pipe *f*. The vessel *e* is then shut off from the boiler *a*, is again filled through the pipe *h*, and the operation is repeated. Stuart thinks it possible that the marquis may have even made an engine with a piston, and sketches it.[1] The instruments of Porta and of De Caus were "steam fountains," and were probably applied, if used at all, merely to ornamental purposes. That of the Mar-

Edward Somerset, the Second Marquis of Worcester.

quis of Worcester was actually used for the purpose of elevating water for practical purposes at Vauxhall, near London.

How early this invention was introduced at Raglan Castle by Worcester is not known, but it was probably not much later than 1628. In 1647 Dircks shows the marquis probably to have been engaged in getting out parts of the later engine which was erected at Vauxhall, obtaining his

[1] "Anecdotes of the Steam-Engine," vol. i., p. 61.

materials from William Lambert, a brass-founder. His patent was issued in June, 1663.

We nowhere find an illustrated description of the machine, or such an account as would enable a mechanic to

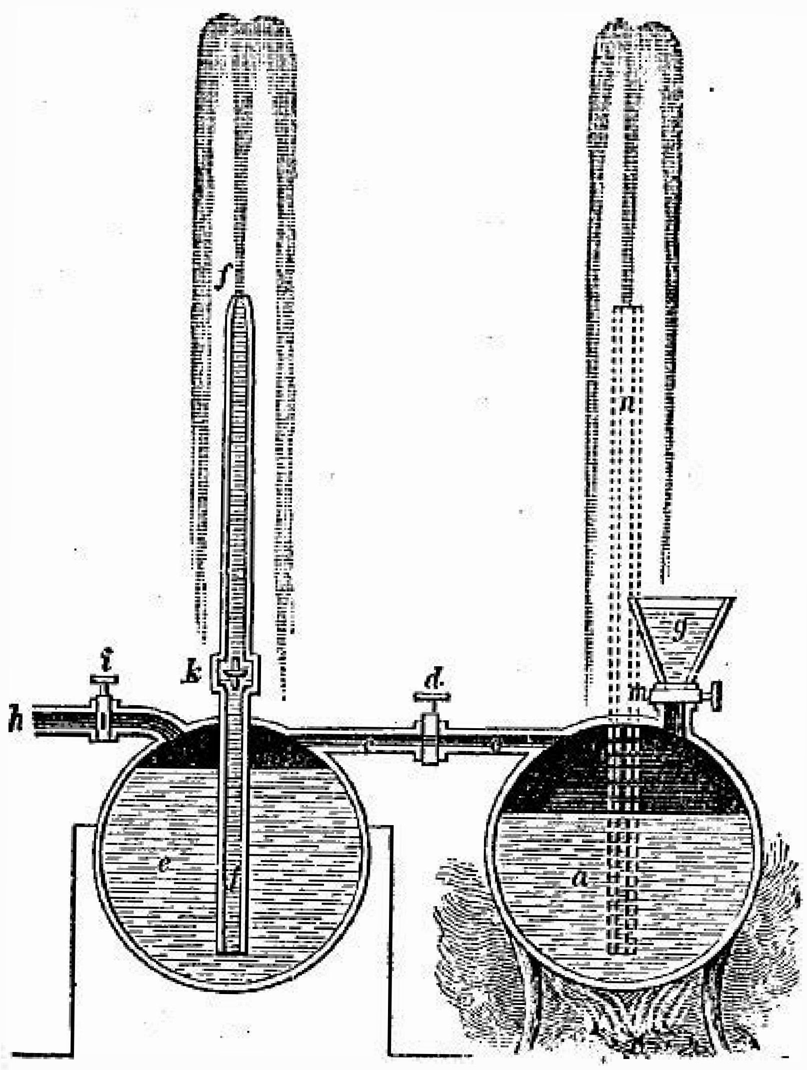

FIG. 7.—Worcester's Steam Fountain, A. D. 1650.

reproduce it in all its details. Fortunately, the cells and grooves (Fig. 9) remaining in the wall of the citadel of Raglan Castle indicate the general dimensions and arrangement of the engine; and Dircks, the biographer of the inventor, has suggested the form of apparatus shown in the sketch (Fig. 8) as most perfectly in accord with the evidence there found, and with the written specifications.

The two vessels, *A A′*, are connected by a steam-pipe, *BB′*, with the boiler, *C*, behind them. *D* is the furnace. A vertical water-pipe, *E*, is connected with the cold-water vessels, *A A′*, by the pipes, *FF′*, reaching nearly to the bottom. Water is supplied by the pipes, *G G′*, with valves, *a a′*, dipping into the well or ditch, *H*. Steam from the boiler being admitted to each vessel, *A* and *A'*, alternately, and there condensing, the vacuum formed permits the pressure of the atmosphere to force the water from the well through the pipes, *G* and *G'*. While one is filling, the steam is forcing the charge of water from the other up the discharge-pipe, *E*. As soon as each is emptied, the steam is shut off from it and turned into the other, and the condensation of the steam remaining in the vessel permits it to fill again. As will be seen presently, this is sub-

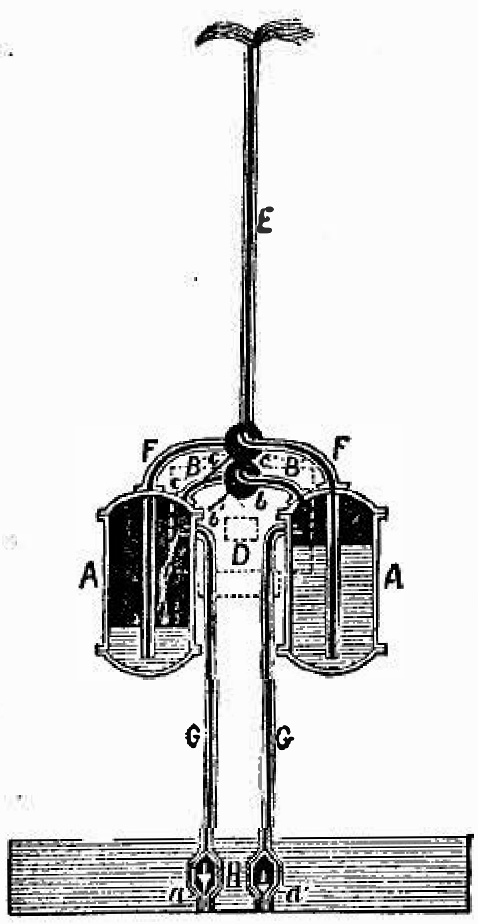

FIG. 8.—Worcester's Engine, A. D. 1665.

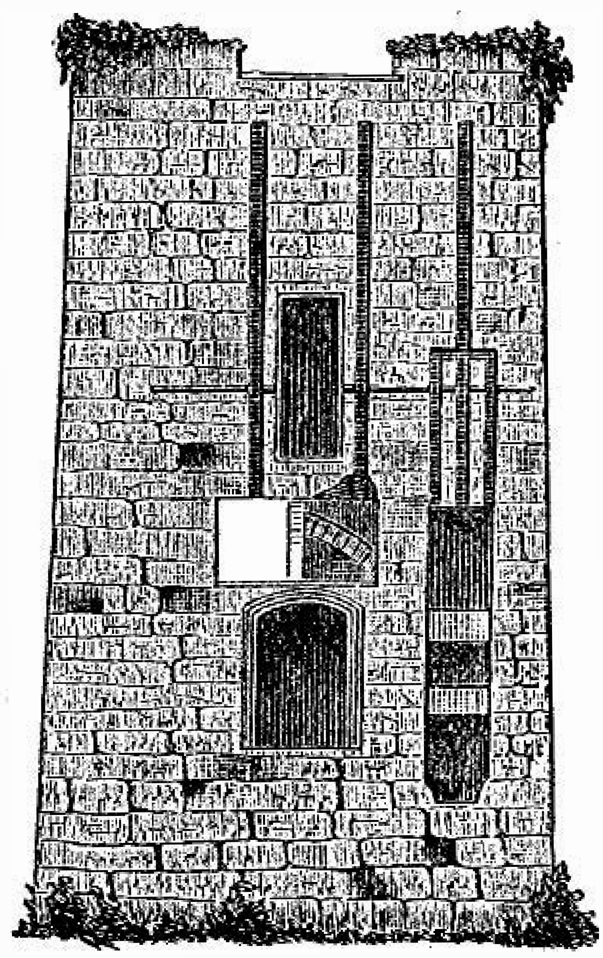

FIG. 9.—Wall of Raglan Castle.

stantially, and almost precisely, the form of engine of which the invention is usually attributed to Savery, a later inventor.

Worcester never succeeded in forming the great company which he hoped would introduce his invention on a scale commensurate with its importance, and his fate was that of nearly all inventors. He died poor and unsuccessful.

His widow, who lived until 1681, seemed to have become as confident as was Worcester himself that the invention had value, and, long after his death, was still endeavoring to secure its introduction, but with equal non-success. The steam-engine had taken a form which made it inconceivably valuable to the world, at a time when no more efficient means of raising water was available at the most valuable mines than horse-power; but the people, greatly as it was needed, were not yet sufficiently intelligent to avail themselves of the great boon, the acceptance of which was urged upon them with all the persistence and earnestness which characterizes every true inventor.

Worcester is described by his biographer as having been a learned, thoughtful, studious, and good man—a Romanist without prejudice or bigotry, a loyal subject, free from partisan intolerance; as a public man, upright, honorable, and humane; as a scholar, learned without being pedantic; as a mechanic, patient, skillful, persevering, and of wonderful ingenuity, and of clear, almost intuitive, apprehension.

Yet, with all these natural advantages, reinforced as they were by immense wealth and influence in his earlier life, and by hardly lessened social and political influence when a large fortune had been spent in experiment, and after misfortune had subdued his spirits and left him without money or a home, the inventor failed to secure the introduction of a device which was needed more than any other. Worcester had attained practical success; but the period of speculation was but just closing, and that of the application of steam had not quite yet arrived.

The second Marquis of Worcester stands on the record as the first steam-engine builder, and his death marks the termination of the first of those periods into which we have divided the history of the growth of the steam-engine.

The "water-commanding engine," as its inventor called it, was the first instance in the history of the steam-engine in which the inventor is known to have "reduced his invention to practice."

It is evident, however, that the invention of the separate boiler, important as it was, had been anticipated by Porta, and does not entitle the marquis to the honor, claimed for him by many English authorities, of being *the* inventor of the steam-engine. Somerset was simply *one* of those whose works collectively made the steam-engine.

After the time of Worcester, we enter upon a stage of history which may properly be termed a period of application; and from this time forward steam continued to play a more and more important part in social economy, and its influence on the welfare of mankind augmented with a rapidly-increasing growth.

The knowledge then existing of the immense expansive force of steam, and the belief that it was destined to submit to the control of man and to lend its immense power in every department of industry, were evidently not confined to any one nation. From Italy to Northern Germany, and from France to Great Britain, the distances, measured in time, were vastly greater then than now, when this wonderful genius has helped us to reduce weeks to hours; but there existed, notwithstanding, a very perfect system of communication, and the learning of every centre was promptly radiated to every other. It thus happened that, at this time, the speculative study of the steam-engine was confined to no part of Europe; inventors and experimenters were busy everywhere developing this promising scheme.

Jean Hautefeuille, the son of a French *boulanger*, born at Orleans, adopted by the Duchess of Bouillon at the suggestion of De Sourdis, profiting by the great opportunities offered him, entered the Church, and became one of the most learned men and greatest mechanicians of his time. He studied the many schemes then brought forward by inventors with the greatest interest, and was himself prolific of new ideas.

In 1678, he proposed the use of alcohol in an engine, "in such a manner that the liquid should evaporate and be condensed, *tour a tour*, without being wasted"[1]—the first

[1] Stuart's "Anecdotes."

recorded plan, probably, for surface-condensation and complete retention of the working-fluid. He proposed a gunpowder-engine, of which[1] he described three varieties.

In one of these engines he displaced the atmosphere by the gases produced by the explosion, and the vacuum thus obtained was utilized in raising water by the pressure of the air. In the second machine, the pressure of the gases evolved by the combustion of the powder acted directly upon the water, forcing it upwards, and in the third design, the pressure of the vapor drove a piston, and this engine was described as fitted to supply power for many purposes. There is no evidence that he constructed these machines, however, and they are here referred to simply as indicating that all the elements of the machine were becoming well known, and that an ingenious mechanic, combining known devices, could at this time have produced the steam-engine. Its early appearance should evidently have been anticipated.

Hautefeuille, if we may judge from evidence at hand, was the first to propose the use of a piston in a heat-engine, and his gunpowder-engine seems to have been the first machine which would be called a heat-engine by the modern mechanic. The earlier "machines" or "engines," including that of Hero and those of the Marquis of Worcester, would rather be denominated "apparatus," as that term is used by the physicist or the chemist, than a machine or an engine, as the terms are used by the engineer.

Huyghens, in 1680, in a memoir presented to the Academy of Sciences, speaks of the expansive force of gunpowder as capable of utilization as a convenient and portable mechanical power, and indicates that he had designed a machine in which it could be applied.

This machine of Huyghens is of great interest, not sim-

[1] "Pendule Perpetuelle, avec la manière d'éléver d'eau par le moyen de la poudre à canon." Paris, 1678.

ply because it was the first gas-engine and the prototype of the very successful modern explosive gas-engine of Otto and Langen, but principally as having been the first engine which consisted of a cylinder and piston. The sketch shows its form. It consisted of a cylinder, *A*, a piston, *B*, two relief-pipes, *C C*, fitted with check-valves and a system of pulleys, *F*, by which the weight is raised. The explosion of the powder at *H* expels the air from the cylinder. When the products of combustion have cooled, the pressure of the atmosphere is no longer counterbalanced by that of air beneath, and the piston is forced down, raising the weight. The plan was never put in practice, although the invention was capable of being made a working and possibly useful machine.

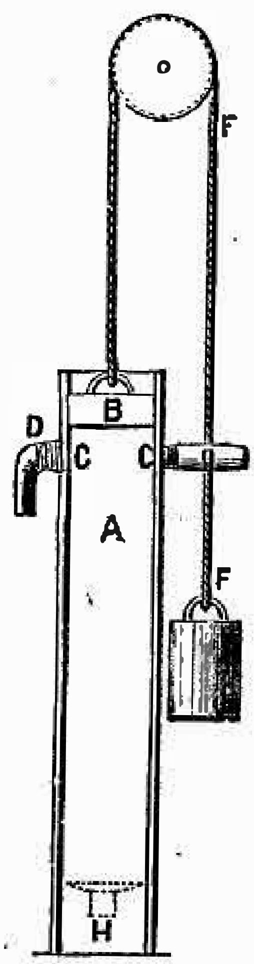

FIG. 10.—Huyghens's Engine, 1680.

At about this period the English attained some superiority over their neighbors on the Continent in the practical application of science and the development of the useful arts, and it has never since been lost. A sudden and great development of applied science and of the useful arts took place during the reign of Charles II., which is probably largely attributable to the interest taken by that monarch in many branches of construction and of science. He is said to have been very fond of mathematics, mechanics, chemistry, and natural history, and to have had a laboratory erected, and to have employed learned men to carry on experiments and lines of research for his satisfaction. He was especially fond of the study and investigation of the arts and sciences most closely related to naval architecture and navigation, and devoted much attention to the determination of the best forms of vessels, and to the discovery of the best kinds of ship-timber. His brother, the Duke of York, was equally fond of this study, and was his companion in some of his work.

Great as is the influence of the monarch, to-day, in forming the tastes and habits and in determining the direction of the studies and labors of the people, his influence was vastly more potent in those earlier days ; and it may well be believed that the rapid strides taken by Great Britain from that time were, in great degree, a consequence of the well-known habits of Charles II., and that the nation, which had an exceptional natural aptitude for mechanical pursuits, should have been prompted by the example of its king to enter upon such a course as resulted in the early attainment of an advanced position in all branches of applied science.

The appointment, under Sir Robert Moray, the superintendent of the laboratory of the king, of Master Mechanic, was conferred upon Sir Samuel Morland, a nobleman who, in his practical knowledge of mechanics and in his ingenuity and fruitfulness of invention, was apparently almost equal to Worcester. He was the son of a Berkshire clergyman, was educated at Cambridge, where he studied mathematics with great interest, and entered public life soon after. He served the Parliament under Cromwell, and afterward went to Geneva. He was of a decidedly literary turn of mind, and wrote a history of the Piedmont churches, which gave him great repute with theeProtestant party. He was induced subsequently, on the accession of Charles II., to take service under that monarch, whose gratitude he had earned by revealing a plot for his assassination.

He received his appointment and a baronetcy in 1660, and immediately commenced making experiments, partly at his own expense and partly at the cost of the royal exchequer, which were usually not at all remunerative. He built hand fire-engines of various kinds, taking patents on them, which brought him as small profits as did his work for the king, and invented the speaking-trumpet, calculating machines, and a capstan. His house at Vauxhall was full of curious devices, the products of his own ingenuity.

He devoted much attention to apparatus for raising water. His devices seem to have usually been modifications of the now familiar force-pump. They attracted much attention, and exhibitions were made of them before the king and queen and the court. He was sent to France on business relating to water-works erected for King Charles, and while in Paris he constructed pumps and pumping apparatus for the satisfaction of Louis XIV. In his book,[1] published in Paris in 1683, and presented to the king, and an earlier manuscript,[2] still preserved in the British Museum, Morland shows a perfect familiarity with the power of steam. He says, in the latter: "Water being evaporated by fire, the vapors require a greater space (about two thousand times) than that occupied by the water; and, rather than submit to imprisonment, it will burst a piece of ordnance. But, being controlled according to the laws of statics, and, by science, reduced to the measure of weight and balance, it bears its burden peaceably (like good horses), and thus may be of great use to mankind, especially for the raising of water, according to the following table, which indicates the number of pounds which may be raised six inches, 1,800 times an hour, by cylinders half-filled with water, and of the several diameters and depths of said cylinders."

He then gives the following table, a comparison of which with modern tables proves Morland to have acquired a very considerable and tolerably accurate knowledge of the volume and pressure of saturated steam.

[1] "Elevation des Eaux par toute sorte de Machines réduite à la Mesure au Poids et à la Balance, présentée a Sa Majesté Très Chrétienne, par le Chevalier Morland, Gentilhomme Ordinaire de la Chambre Privée et Maistre de Mechaniques du Roy de la Grande Bretagne, 1683."

[2] "Les Principes de la Nouvelle Force de Feu, inventée par le Chevalier Morland, l'an 1682, et présentée a Sa Majesté Très Chrétienne, 1683."

Cylinders.		Pounds.
Diameter in Feet.	Depth in Feet.	Weight to be Raised.
1	2	15
2	4	120
3	6	405
4	8	960
5	10	1,876
6	10	3,240
Number of cylinders having a diameter of 6 feet and a depth of 12 feet.		
1	12	3,240
2	12	6,480
3	12	9,720
4	12	12,960
5	12	16,200
6	12	19,440
7	12	22,680
8	12	25,920
9	12	29,190
10	12	82,400
20	12	64,800
30	12	97,200
40	12	129,600
50	12	162,000
60	12	194,400
70	12	226,800
80	12	259,200
90	12	291,600

The rate of enlargement of volume in the conversion of water into steam, as given in Morland's book, appears remarkably accurate when compared with statements made by other early experimenters. Desaguliers gave the ratio of volumes at 14,000, and this was accepted as correct for many years, and untile Watt's experiments, which were quoted by Dr. Robison as giving the ratio at between 1,800 and 1,900. Morland also states the "duty" of his engines in the same manner in which it is stated by engineers to-day.

Morland must undoubtedly have been acquainted with the work of his distinguished contemporary, Lord Worcester, and his apparatus seems most likely to have been a modification—perhaps improvement—of Worcester's engine. His house was at Vauxhall, and the establishment set up for the king was in the neighborhood. It may be that Morland is to be credited with greater success in the introduction of his predecessor's apparatus than the inventor himself.

Dr. Hutton considered this book to have been the earliest account of the steam-engine, and accepts the date—1682—as that of the invention, and adds, that "the project seems to have remained obscure in both countries till 1699, when Savery, who probably knew more of Morland's invention than he owned, obtained a patent," etc. We have, however, scarcely more complete or accurate knowledge of the extent of Morland's work, and of its real value, than of that of Worcester. Morland died in 1696, at Hammersmith, not far from London, and his body lies in Fulham church.

From this time forward the minds of many mechanicians were earnestly at work on this problem—the raising of water by aid of steam. Hitherto, although many ingenious toys, embodying the principles of the steam-engine separately, and sometimes to a certain extent collectively, had been proposed, and even occasionally constructed, the world was only just ready to profit by the labors of inventors in this direction.

But, at the end of the seventeenth century, English miners were beginning to find the greatest difficulty in clearing their shafts of the vast quantities of water which they were meeting at the considerable depths to which they had penetrated, and it had become a matter of vital importance to them to find a more powerful aid in that work than was then available. They were, therefore, by their necessities stimulated to watch for, and to be prepared promptly to take advantage of, such an invention when it should be offered them.

The experiments of Papin, and the practical application of known principles by Savery, placed the needed apparatus in their hands.

THOMAS SAVERY was a member of a well-known family of Devonshire, England, and was born at Shilston, about 1650. He was well educated, and became a military engineer. He exhibited great fondness for mechanics, and for mathematics and natural philosophy, and gave much time

Thomas Savery.

to experimenting, to the contriving of various kinds of apparatus, and to invention. He constructed a clock, which still remains in the family, and is considered an ingenious piece of mechanism, and is said to be of excellent workmanship.

He invented and patented an arrangement of paddle-wheels, driven by a capstan[1] for propelling vessels in calm weather, and spent some time endeavoring to secure its adoption by the British Admiralty and the Navy Board,

[1] Harris, "Lexicon Technicum," London, 1710.

but met with no success. The principal objector was the Surveyor of the Navy, who dismissed Savery, with a remark which illustrates a spirit which, although not yet extinct, is less frequently met with in the public service now than then : "What have interloping people, that have no concern with us, to do to pretend to contrive or invent things for us ?"[1] Savery then fitted his apparatus into a small vessel, and exhibited its operation on the Thames. The invention was never introduced into the navy, however.

It was after this time that Savery became the inventor of a steam-engine. It is not known whether he was familiar with the work of Worcester, and of earlier inventors. Desaguliers[2] states that he had read the book of Worcester, and that he subsequently endeavored to destroy all evidence of the anticipation of his own invention by the marquis by buying up all copies of the century that he could find, and burning them. The story is scarcely credible. A comparison of the drawings given of the two engines exhibits, nevertheless, a striking resemblance ; and, assuming that of the marquis's engine to be correct, Savery is to be given credit for the finally successful introduction of the "semi-omnipotent" "water-commanding" engine of Worcester.

The most important advance in actual construction, therefore, was made by Thomas Savery. The constant and embarrassing expense, and the engineering difficulties presented by the necessity of keeping the British mines, and particularly the deep pits of Cornwall, free from water, and the failure of every attempt previously made to provide effective and economical pumping-machinery, were noted by Savery, who, July 25, 1698, patented the design of the first engine which was ever actually employed in this work. A working-model was submitted to the Royal Society of Lon-

[1] "Navigation Improveds, or, The Art of Rowing Ships of all rates in Calms, with a more Easy, Swift, and Steady Motion, than Oars can," etc., etc. By Thomas Savery, Gent. London, 1698.

[2] "Experimental Philosophy," vol. ii., p. 465.

don in 1699, and successful experiments were made with it. Savery spent a considerable time in planning his engine and in perfecting it, and states that he expended large sums of money upon it.

Having finally succeeded in satisfying himself with its operation, he exhibited a model "Fire-Engine," as it was called in those days, before King William III. and his court, at Hampton Court, in 1698, and obtained his patent without delay. The title of the patent reads: "A grant to Thomas Savery, Gentl., of the sole exercise of a new invention by him invented, for raising of water, and occasioning motion to all sorts of mill-works, by the impellant force of fire, which will be of great use for draining mines, serving towns with water, and for the working of all sorts of mills, when they have not the benefit of water nor constant winds; to hold for 14 years; with usual clauses."

Savery now went about the work of introducing his invention in a way which is in marked contrast with that usually adopted by the inventors of that time. He commenced a systematic and successful system of advertisement, and lost no opportunity of making his plans not merely known, but well understood, even in matters of detail. The Royal Society was then fully organized, and at one of its meetings he obtained permission to appear with his model "fire-engine" and to explain its operation; and, as the minutes read, "Mr. Savery entertained the Society with showing his engine to raise water by the force of fire. He was thanked for showing the experiment, which succeeded, according to expectation, and was approved of." He presented to the Society a drawing and specifications of his machine, and "The Transactions"[1] contain a copperplate engraving and the description of his model. It consisted of a furnace, *A*, heating a boiler, *B*, which was connected by

[1] "Philosophical Transactions, No. 252." Weld's "Royal Society," vol. i., p. 357. Lowthorp's "Abridgment," vol. i.

pipes, *C C*, with two copper receivers, *D D*. There were led from the bottom of these receivers branch pipes, *F F*, which turned upward, and were united to form a rising main, or "forcing-pipe," *G*. From the top of each receiver was led a pipe, which was turned downward, and these pipes united to form a suction-pipe, which was led down to the bottom of the well or reservoir from which the water was to be drawn. The maximum lift allowable was stated at 24 feet.

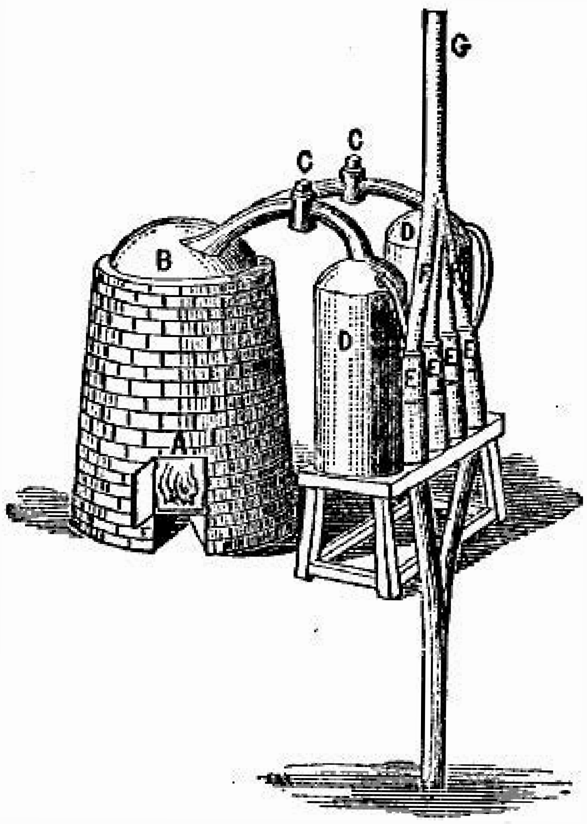

FIG. 11.—Savery's Model, 1698.

The engine was worked as follows: Steam is raised in the boiler, *B*, and a cock, *C*, being opened, a receiver, *D*, is filled with steam. Closing the cock, *C*, the steam condensing in the receiver, a vacuum is created, and the pressure of the atmosphere forces the water up, through the supply-pipe, from the well into the receiver. Opening the cock, *C*, again, the check-valve in the suction-pipe at *E* closes, the steam drives the water out through the forcing-pipe, *G*, the clack-valve, *E*, on that pipe opening before it, and the liquid is expelled from the top of the pipe. The valve, *C*, is again closed; the steam again condenses, and the engine is worked as before. While one of the two receivers is discharging, the other is filling, as in the machine of the Marquis of Worcester, and thus the steam is drawn from the boiler with tolerable regularity, and the expulsion of water takes place with similar uniformity, the two systems of receivers and pipes being worked alternately by the single boiler.

In another and still simpler little machine,[1] which he

[1] Bradley, "New Improvements of Planting and Gardening." Switzer, "Hydrostatics," 1729.

erected at Kensington (Fig. 12), the same general plan was adopted, combining a suction-pipe, *A*, 16 feet long and 3 inches in diameter; a single receiver, *B*, capable of containing 13 gallons; a boiler, *C*, of about 40 gallons

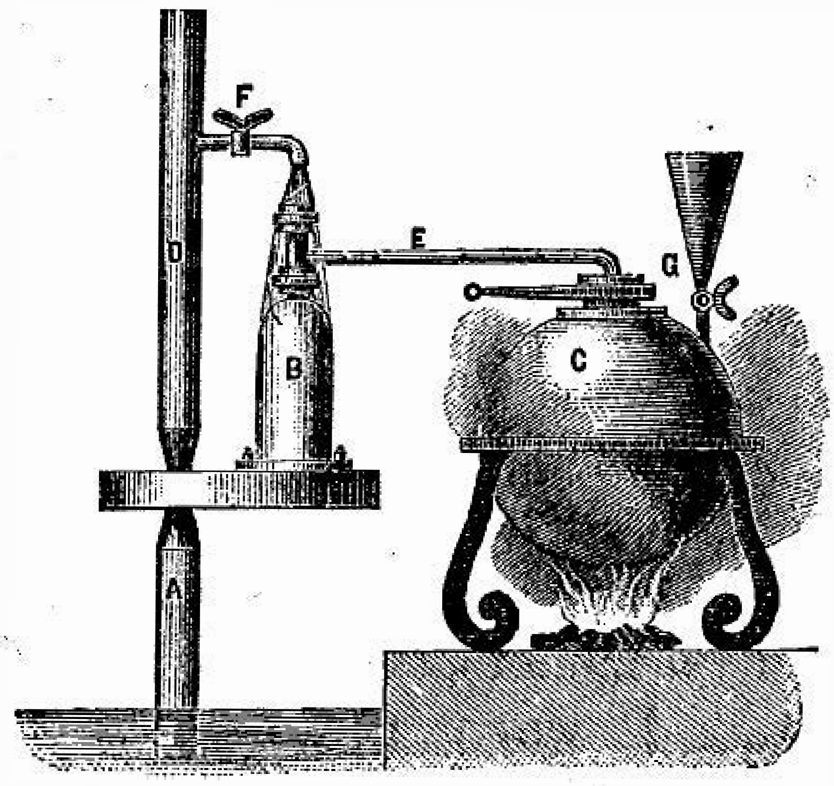

FIG. 12.—Savory's Engine, 1698.

capacity; a forcing-pipe, *D*, 42 feet high, with the connecting pipe and cocks, *E F G;* and the method of operation was as already described, except that *surface-condensation* was employed, theecock, *F*, being arranged to shower water from the rising main over the receiver, as shown. Of the first engine Switzer says: "I have heard him say myself, that the very first time he played, it was in a potter's house at Lambeth, where, though it was a small engine, yet it (the water) forced its way through the roof, and struck off the tiles in a manner that surprised all the spectators."

The Kensington engine cost £50, and raised 3,000 gallons per hour, filling the receiver four times a minute, and required a bushel of coal per day. Switzer remarks: "It must be noted that this engine is but a small one in comparison with many others that are made for coal-workse; but this is sufficient for any reasonable family, and other uses required of it in watering all middlingegardens." He cautions the operatore "When you have raised water enough, and you design to leave off working the engine, take away all the fire from under the boiler, and open the cock (connected to the funnel) to let out the steam, which would otherwise, were it to remain confined, perhaps burst the engine."

With the intention of making his invention more generally known, and hoping to introduce it as a pumping-engine in the mining districts of Cornwall, Savery wrote a prospectus for general circulation, which contains the earliest account of the later and more effective form of engine. He entitled his pamphlet "The Miner's Friend; or, A Description of an Engine to raise Water by Fire described, and the Manner of fixing it in Mines, with an Account of the several Uses it is applicable to, and an Answer to the Objections against it." It was printed in London in 1702, for S. Crouch, and was distributed among the proprietors and managers of mines, who were then finding the fiow of water at depths so great as, in some cases, to barefurther progress. In many cases, the cost of drainage left no satisfactory margin of profit. In one mine, 500 horses were employed raising water, by the then usual method of using horse-gins and buckets.

The approval of the King and of the Royal Society, and the countenance of the mine-adventurers of England, were acknowledged by the author, who addressed his pamphlet to them.

The engraving of the engine was reproduced, with the description, in Harris's "Lexicon Technicum," 1704; in Switzer's "Hydrostatics," 1729; and in Desagulier's "Experimental Philosophy," 1744.

The sketch which here follows is a neater engraving of the same machine. Savery's engine is shown in Fig. 13, as described by Savery himself, in 1702, in "The Miner's Friend."

L L is the boiler in which steam is raised, and through the pipes *O O* it is alternately let into the vessels *P P.*

Suppose it to pass into the left-hand vessel first. The valve *M* being closed, and *r* being opened, the water con-

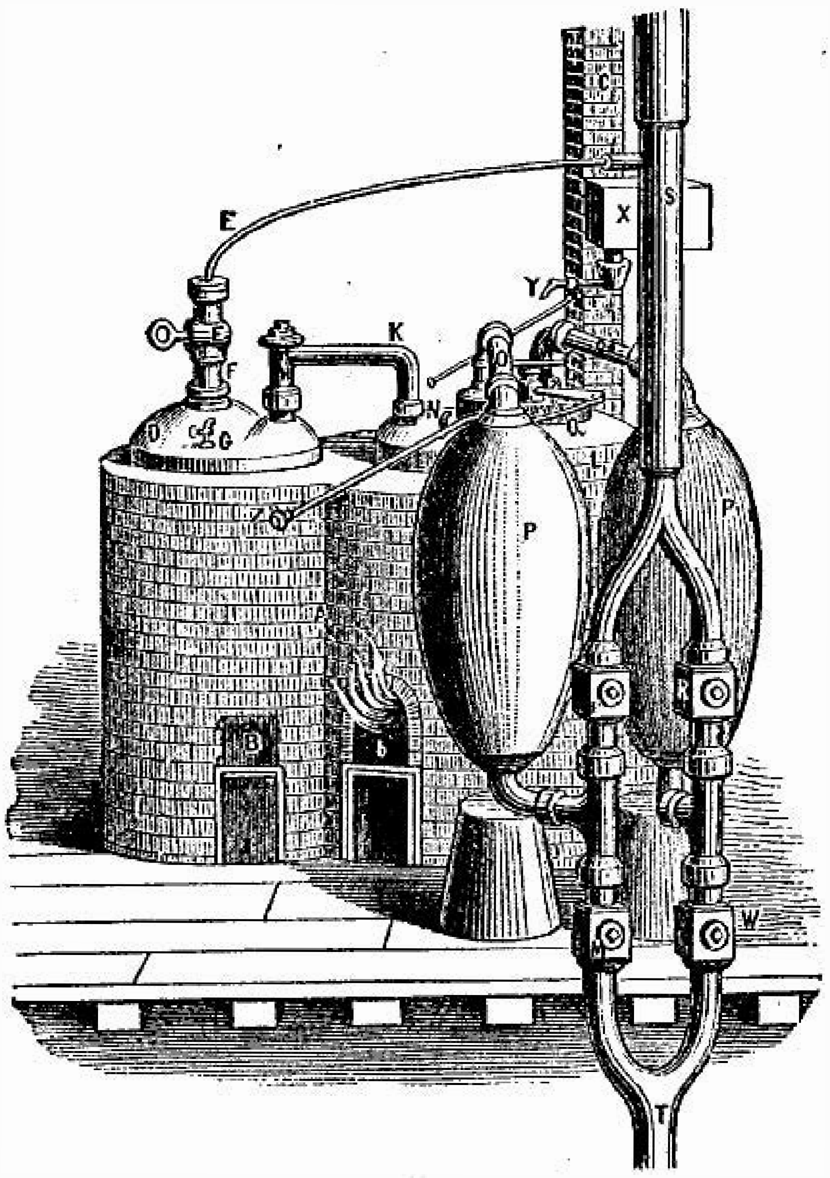

Fig. 13.—Savery's Engine, A. D. 1702.

tained in *P* is driven out and up the pipe *S* to the desired height, where it is discharged.

The valve *r* is then closed, and the valve in the pipe *O*; the valve *M* is next opened, and condensing water is turned upon theeexterior of *P* by the cock *Y*, leading water from the cistern *X*. As the steam contained in *P* is condensed, forming a vacuum there, a fresh charge of water is driven by atmospheric pressure up the pipe *T*.

Meantime, steam from the boiler has been let into the right-hand vessel *Pp*, the cock *W* having been first closed, and *R* opened.

The charge of water is driven out through the lower pipe and the cock *R*, and up the pipe *S* as before, while the other vessel is refilling preparatory to acting in its turn.

The two vessels are thus alternately charged and discharged, as long as is necessary.

Savery's method of supplying his boiler with water was at once simple and ingenious.

The small boiler, *D*, is filled with water from any convenient source, as from the stand-pipe, *S*. A fire is then built under it, and, when the pressure of steam in *D* becomes greater than in the main boiler, *L*, a communication is opened between their lower ends, and the water passes, under pressure, from the smaller to the larger boiler, which is thus "fed" without interrupting the work. *G* and *N* are *gauge-cocks*, by which the height of water in the boilers is determined; they were first adopted by Savery.

Here we find, therefore, the first really practicable and commercially valuable steam-engine. Thomas Savery is entitled to the credit of having been the first to introduce a machine in which the power of heat, acting through the medium of steam, was rendered generally useful.

It will be noticed that Savery, like the Marquis of Worcester, used a boiler separate from the water-reservoir.

He added to the "water-commanding engine" of the marquis the system of *surface-condensation*, by which he was enabled to charge his vessels when it became necessary to refill them; and added, also, the secondary boiler, which enabled him to supply the working-boiler with water without interrupting its work.

The machine was thus made capable of working uninterruptedly for a period of time only limited by its own decay.

Savery never fitted his boilers with safety-valves, although it was done earlier by Papin; and in deep mines he was compelled to make use of higher pressures than his rudely-constructed boilers could safely bear.

Savery's engine was used at a number of mines, and also for supplying water to towns; some large estates, country houses, and other private establishments, employed them for the same purpose. They did not, however, come into general use among the mines, because, according to Desaguliers, they were apprehensive of danger from the explosion of the boilers or receivers. As Desaguliers wrote subsequently: "Savery made a great many experiments to bring this machine to perfection, and did erect several which raised water very well for gentlemen's seats, but could not succeed for mines, or supplying towns, where the water was to be raised very high and in great quantities; for then the steam required being boiled up to such a strength as to be ready to tear all the vessels to pieces." "I have known Captain Savery, at York's buildings, to make steam eight or ten times stronger than common air; and then its heat was so great that it would melt common soft solder, and its strength so great as to blow open several joints of the machine; so that he was forced to be at the pains and charge to have all his joints soldered with spelter or hard solder."

Although there were other difficulties in the application of the Savery engine to many kinds of work, this was the most serious one, and explosions did occur with fatal results. The writer just quoted relates, in his "Experimental Philosophy," that a man who was ignorant of the nature of the engine undertook to work a machine which Desaguliers had provided with a safety-valve to avoid this very danger, "and, having hung the weight at the further end of the steelyard, in order to collect more steam in order to make his work the quicker, he hung also a very heavy plumber's iron upon the end of the steelyard; the consequence proved fatal; for, after some time, the steam, not being able, with the safety-cock, to raise up the steelyard loaded with all this unusual weight, burst the boiler with a great explosion, and killed the poor man." This is probably the earliest record of a steam-boiler explosion.

Savery proposed to use his engine for driving mills, but there is no evidence that he actually made such an application of the machine, although it was afterward so applied by others. The engine was not well adapted to the drainage of surface-land, as the elevation of large quantities of water through small heights required great capacity of receivers, or compelled the use of several engines for each case. The filling of the receivers, in such cases, also compelled the heating of large areas of cold and wet metallic surfaces by the steam at each operation, and thus made the work comparatively wasteful of fuel. Where used in mines, they were necessarily placed within 30 feet or less of the lowest level, and were therefore exposed to danger of submergence whenever, by any accident, the water should rise above that level. In many cases this would result in the loss of the engine, and the mine would remain "drowned," unless another engine should be procured to pump it out. Where the mine was deep, the water was forced by the pressure of steam from the level of the engine-station to the top of the lift. This compelled the use of pressures of several atmospheres in many cases; and a pressure of three atmospheres, or about 45 pounds per square inch, was considered, in those days, as about the maximum pressure allowable. This difficulty was met by setting a separate engine at every 60 or 80 feet, and pumping the water from one to the other. If any one engine in the set became disabled, the pumping was interrupted until that one machine could be repaired. The size of Savery's largest boilers was not great, their maximum diameter not exceeding two and a half feet. This made it necessary to provide several of his engines, usually, for a single mine, and at each level. The first cost and the expense of repairs were exceedingly serious items. The expense and danger, either real or apparent, were thus sufficient to deter many from their use, and the old method of raising water by horse-power was adhered to.

The consumption of fuel with these engines was very great. The steam was not generated economically, as the boilers used were of such simple forms as only could then be produced, and presented too little heating surface to secure a very complete transfer of heat from the gases of combustion to the water within the boiler. This waste in the generation of steam in these uneconomical boilers was followed by still more serious waste in its application, without expansion, to the expulsion of water from a metallic receiver, the cold and wet sides of which absorbed heat with the greatest avidity. The great mass of the liquid was not, however, heated by the steam, and was expelled at the temperature at which it was raised from below.

Savery quaintly relates the action of his machine in "The Miner's Friend," and so exactly, that a better description could scarcely be asked: "The steam acts upon the surface of the water in the receiver, which surface only being heated by the steam, it does not condense, but the steam gravitates or presses with an elastic quality like air, and still increasing its elasticity or spring, until it counterpoises, or rather exceeds, the weight of the column of water in the force-pipe, which then it will necessarily drive up that pipe; the steam then takes some time to recover its power, but it will at last discharge the water out at the top of the pipe. You may see on the outside of the receiver how the water goes out, as well as if it were transparent; for, so far as the steam is contained within the vessel, it is dry without, and so hot as scarcely to endure the least touch of the hand; but so far as the water is inside the vessel, it will be cold and wet on the outside, where any water has fallen on it; which cold and moisture vanish as fast as the steam takes the place of the water in its descent."

After Savery's death, in 1716, several of these engines were erected in which some improvements were introduced. Dr. Desaguliers, in 1718, built a Savery engine, in which he avoided some defects which he, with Dr. Gravesande, had noted two years earlier. They had then proposed to adopt the arrangement of a single receiver which had been used by Savery himself, as already described, finding, by experiment on a model which they had made for the purpose, that one could be discharged three times, while the same boiler would empty two receivers but once each. In their arrangement, the steam was shut back in the boiler while the receiver was filling with water, and a high pressure thus accumulated, instead of being turned into the second receiver, and the pressure thus kept comparatively low.

In the engine built in 1718, Desaguliers used a spherical boiler, which he provided with the lever safety-valve already applied by Papin, and adopted a comparatively small receiver—one-fifth the capacity of the boiler—of slender cylindrical form, and attached a pipe leading the water for condensation into the vessel, and effected its distribution by means of the "rose," or a "sprinkling-plate," such as is still frequently used in modern engines having jet-condensers. This substitution of jet for surface-condensation was of very great advantage, securing great promptness in the formation of a vacuum and a rapid filling of the receiver. A "two-way cock" admitted steam to the receiver, or,

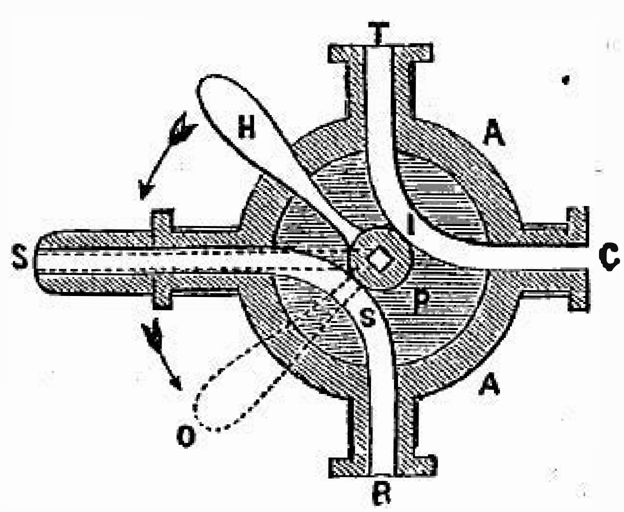

FIG. 14.—Papin's Two-Way Cock.

being turned the other way, admitted the cold condensing water. The dispersion of the water in minute streams or drops was a very important detail, not only as securing great rapidity of condensation, but enabling the designer to employ a comparatively small receiver or condenser.

The engine is shown in Fig. 15, which is copied from the "Experimental Philosophy" of Desaguliers.

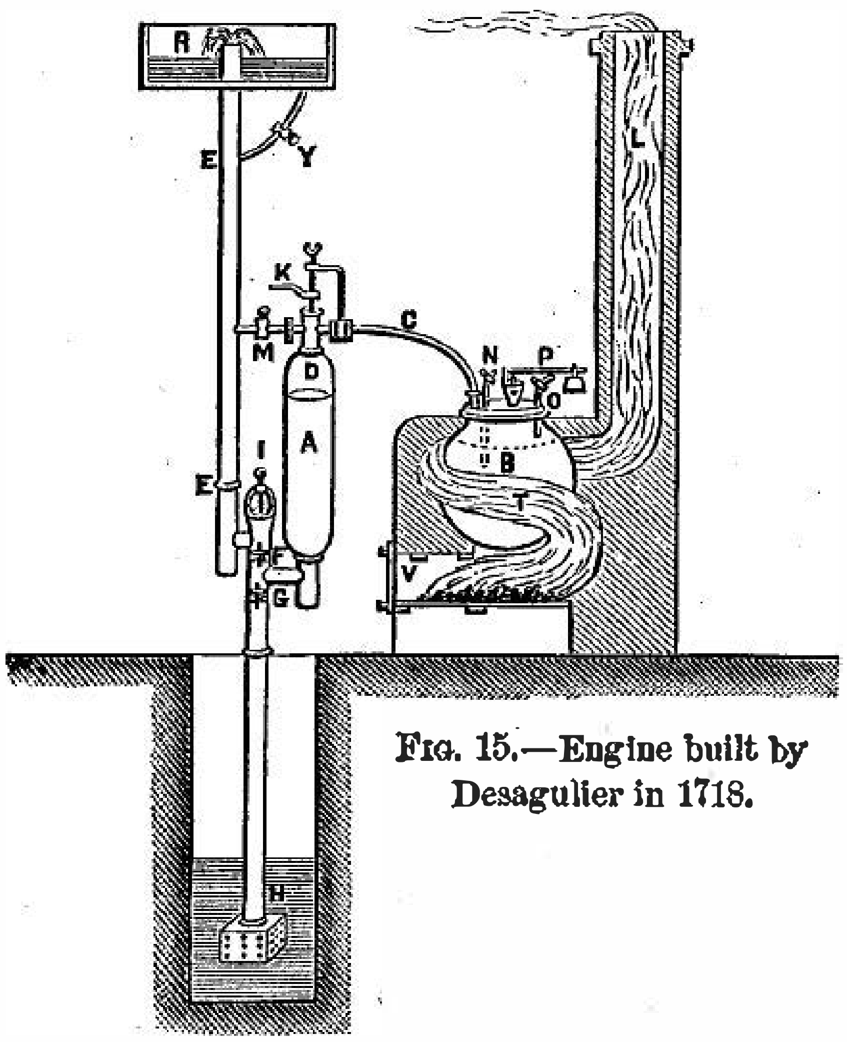

FIG. 15.—Engine built by Desagulier in 1718.

The receiver, *A*, is connected to the boiler, *B*, by a steam-pipe, *C*, terminating at the two-way cock, *D*; the "forcing-pipe," *E*, has at its foot a check-valve, *F*, and the valve *G* is a similar check at the head of the suction-pipe. *H* is a strainer, to prevent the ingress of chips or other bodies carried to the pipe by the current; the cap above the valves is secured by a bridle, or stirrup, and screw, *I*, and may be readily removed to clear the valves or to renew them; *K* is the handle of the two-way cock; *M* is the injection-cock, and is kept open during the working of the engine; *L* is the chimney-flue; *N* and *O* are gauge-cocks fitted to pipes leading to the proper depths within the boiler, the water-line being somewhere between the levels of their lower ends; *P* is a lever safety-valve, as first used on the

"Digester" of Papin; *R* is the reservoir into which the water is pumped; *T* is the flue, leading spirally about the boiler from the furnace, *V*, to the chimney; *Y* is a cock fitted in a pipe through which the rising-main may be filled from the reservoir, should injection-water be needed when that pipe is empty.

Seven of these engines were built, the first of which was made for the Czar of Russia. Its boiler had a capacity of "five or six hogsheads," and the receiver, "holding one hogshead," was filled and emptied four times a minute. The water was raised "by suction" 29 feet, and forced by steam pressure 11 feet higher.

Another engine built at about this time, to raise water 29 feet "by suction," and to force it 24 feet higher, made 6 "strokes" per minute, and, when forcing water but 6 or 8 feet, made 8 or 9 strokes per minute. Twenty-five years later a workman overloaded the safety-valve of this engine, by placing the weight at the end and then adding "a very heavy plumber's iron." The boiler exploded, killing the attendant.

Desagulier says that one of these engines, capable of raising ten tons an hour 38 feet, in 1728 or 1729, cost £80, exclusive of the piping.

Blakely, in 1766, patented an improved Savery engine, in which he endeavored to avoid the serious loss due to condensation of the steam by direct contact with the water, by interposing a cushion of oil, which floated upon the water and prevented the contact of the steam with the surface of the water beneath it. He also used air for the same purpose, sometimes in double receivers, one supported on the other. These plans did not, however, prove satisfactory.

Rigley, of Manchester, England, soon after erected Savery engines, and applied them to the driving of mills, by pumping water into reservoirs, from whence it returned to the wells or ponds from which it had been raised, turning water-wheels as it descended.

Such an arrangement was in operation many years at the works of a Mr. Kiers, St. Pancras, London. It is described in detail, and illustrated, in Nicholson's "Philosophical Journal," vol. i., p. 419. It had a "wagon-boiler" 7 feet long, 5 wide, and 5 deep; the wheel was 18 feet in diameter, and drove the lathes and other machinery of the works. In this engine Blakely's plan of injecting air was adopted. The injection-valve was a clack, which closed automatically when the vacuum was formed.

The engine consumed 6 or 7 bushels of good coals, and made 10 strokes per minute, raising 70 cubic feet of water 14 feet, and developing nearly 3 horse-power.

Many years after Savery's death, in 1774, Smeaton made the first duty-trials of engines of this kind. He found that an engine having a cylindrical receiver 16 inches in diameter and 22 feet high, discharging the water raised 14 feet above the surface of the water in the well, making 12 strokes, and raising 100 cubic feet per minute, developed $2\frac{2}{3}$ horse-power, and consumed 3 hundredweight of coals in four hours. Its duty was, therefore, 5,250,000 pounds raised one foot per bushel of 84 pounds of coals, or 62,500 "foot-pounds" of work per pound of fuel. An engine of slightly greater size gave a duty about 5 per cent. greater.

When Louis XIV. revoked the edict of Nantes, by which Henry IV. had guaranteed protection to the Protestants of France, the terrible persecutions at once commenced drove from the kingdom some of its greatest men. Among these was Denys Papin.

It was at about this time that the influence of the atmospheric pressure on the boiling-point began to be observed, Dr. Hooke having found that the boiling-point was a fixed temperature under the ordinary pressure of the atmosphere, and the increase in temperature and pressure of steam when confined having been shown by Papin with his "Digester."

Denys Papin was of a family which had attached itself to the Protestant Church; but he was given his education in the school of the Jesuits at Blois, and there acquired his knowledge of mathematics. His medical education was

Denys Papin.

given him at Paris, although he probably received his degree at Orleans. He settled in Paris in 1672, with the intention of practising his profession, and devoted all his spare time, apparently, to the study of physics.

Meantime, that distinguished philosopher, Huyghens, the inventor of the clock and of the gunpowder-engine, had been induced by the linen-draper's apprentice, Colbert, now the most trusted adviser of the king, to take up his residence in Paris, and had been made one of the earliest members of the Academy of Science, which was founded at about that time. Papin became an assistant to Huyghens, and aided him in his experiments in mechanics, having been introduced by Madame Colbert, who was also a native of Blois. Here he devised several modifications of the instruments of Guericke, and printed a description of them.[1] This little book was presented to the Academy, and very favorably noticed. Papin now became well known among contemporary men of science at Paris, and was well received everywhere. Soon after, in the year 1675, as stated by the *Journal des Savants*, he left Paris and took up his residence in England, where he very soon made the acquaintance of Robert Boyle, the founder, and of the members of the Royal Society. Boyle speaks of Papin as having gone to England in the hope of finding a place in which he could satisfactorily pursue his favorite studies.

Boyle himself had already been long engaged in the study of pneumatics, and had been especially interested in the investigations which had been original with Guericke. He admitted young Papin into his laboratory, and the two philosophers worked together at these attractive problems. It was while working with Boyle that Papin invented the double air-pump and the air-gun.

Papin and his work had now become so well known, and he had attained so high a position in science, that he was nominated for membership in the Royal Academy, and was elected December 16, 1680. He at once took his place among the most talented and distinguished of the great men of his time.

He probably invented his "Digester" while in England, and it was first described in a brochure written in English, under the title, "The New Digester." It was subsequently published in Paris.[2] This was a vessel, *B* (Fig. 16), capable of being tightly closed by a screw, *D*, and a lid, *C*, in

[1] "Nouvelles Expériences du Vuide, avec la description des Machines qui servent à le faire." Paris, 1674.

[2] "La manière d'amollir les os et de faire cuire toutes sortes de viandes," etc.

which food could be cooked in water raised by a furnace, *A*, to the temperature due to any desired safe pressure of steam. The pressure was determined and limited by a weight, *W*, on the safety-valve lever, *G*. It is probable that this essential attachment to the steam-boiler had previously been used for other purposes; but Papin is given the credit of having first made use of it to control the pressure of steam.

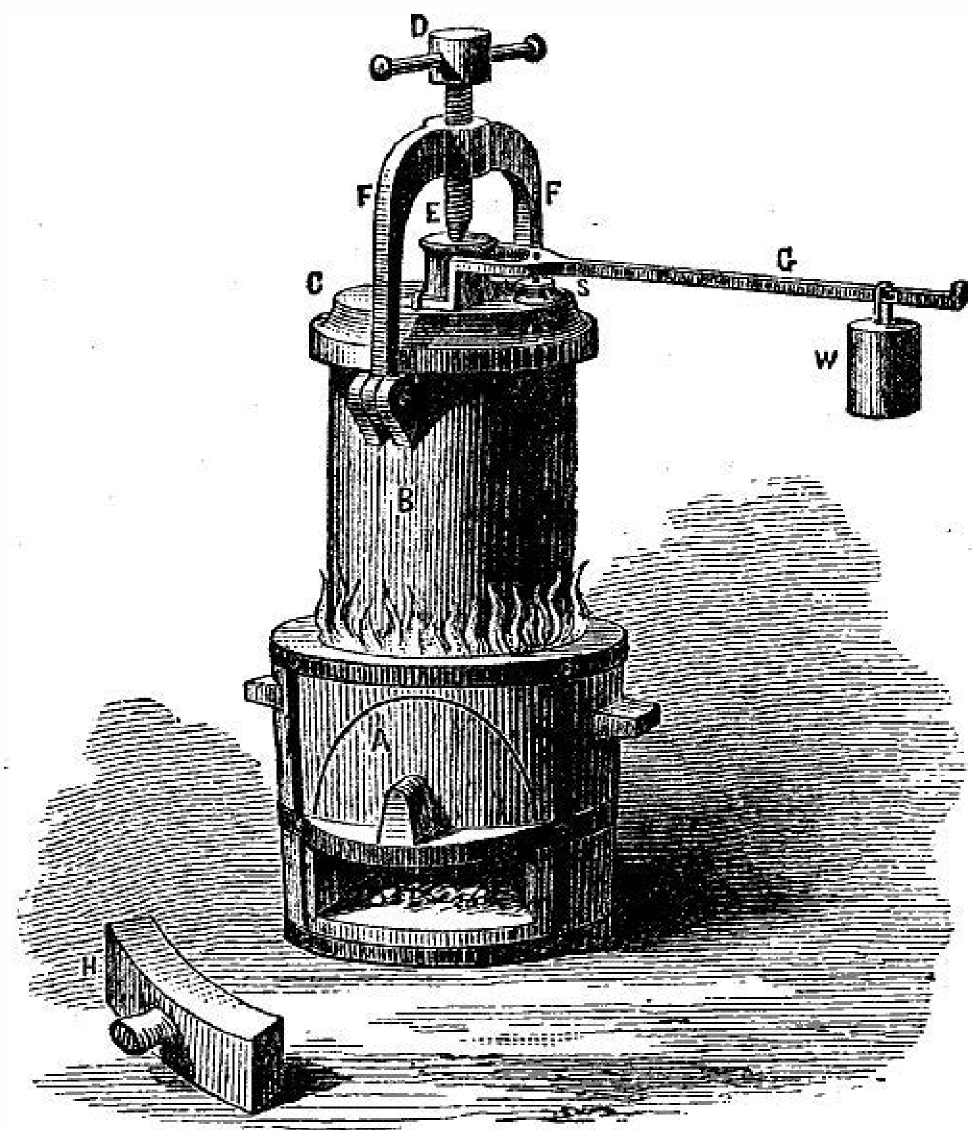

FIG. 16.—Papin's Digester, 1680.

From England, Papin went to Italy, where he accepted membership and held official position in the Italian Academy of Science. Papin remained in Venice two years, and then returned to England. Here, in 1687, he announced one of his inventions, which is just becoming of great value in the arts. He proposed to transmit power from one point to another, over long distances, by the now well-known "pneumatic" method. At the point where power was available, he exhausted a chamber by means of an air-pump, and, leading a pipe to the distant point at which it was to be utilized, there withdrew the air from behind a piston, and the pressure of the air upon the latter caused it to recede into the cylinder, in which it was fitted, raising a weight, of which the magnitude was proportionate to the size of the piston and the degree of exhaustion. Papin was not satisfactorily successful in his experiments; but he had created the germ of the modern system of pneumatic transmission of power. His disappointment at the result of his efforts to utilize the system was very great, and he became despondent, and anxious to change his location again.

In 1687 he was offered the chair of Mathematics at Marburg by Charles, the Landgrave of Upper Hesse, and, accepting the appointment, went to Germany. He remained in Germany many years, and continued his researches with renewed activity and interest. His papers were published in the "Acta Eruditorumé" at Leipsic, and in the "Philosophical Transactions" at London. It was while at Marburg that his papers descriptive of his method of pneumatic transmission of power were printed.[1]

In the "Acta Eruditorum" of 1688 he exhibited a practicable plan, in which he exhausted the air from a set of engines or pumps by means of pumps situated at a long distance from the point of application of the power, and at the place where the prime mover—which was in this case a water-wheel—was erected.

After his arrival at the University of Marburg, Papin exhibited to his colleagues in the faculty a modification of Huyghens's gunpowder-engine, in which he had endeavored to obtain a more perfect vacuum than had Huyghens in the first of these machines. Disappointed in this, he finally adopted the expedient of employing steam to displace the

[1] "Recucil des diverscs Pieces touchant quelques Nouvclles Machines et autres Sujets Philosophiques," M. D. Papin. Cassel, 1695.

air, and to produce, by its condensation, the perfect vacuum which he sought; and he thus produced *the first steam-engine with a piston*, and the first piston steam-engine, in which condensation was produced to secure a vacuum. It was described in the "Actae" of Leipsic,[1] in June, 1690, under the title, "Nova Methodus ad vires motrices validissimas leri pretio comparandeoe" ("A New Method of securing cheaply Motive Power of considerable Magnitude"). He describes first the gunpowder-engine, and continues by stating that, "until now, all experiments have been unsuccessful; and after the combustion of the exploded powder, there always remains in the cylinder about one-fifth its volume of air." He says that he has endeavored to arrive by another route at the same end; and "as, by a natural property of water, a small quantity of this liquid, vaporized by the action of heat, acquires an elasticity like that of the air, and returns to the liquid state again on cooling, without retaining the least trace of its elastic force," he thought that it would be easy to construct machines in which, "by means of a moderate heat, and without much expense," a more perfect vacuum could be produced than could be secured by the use of gunpowder.

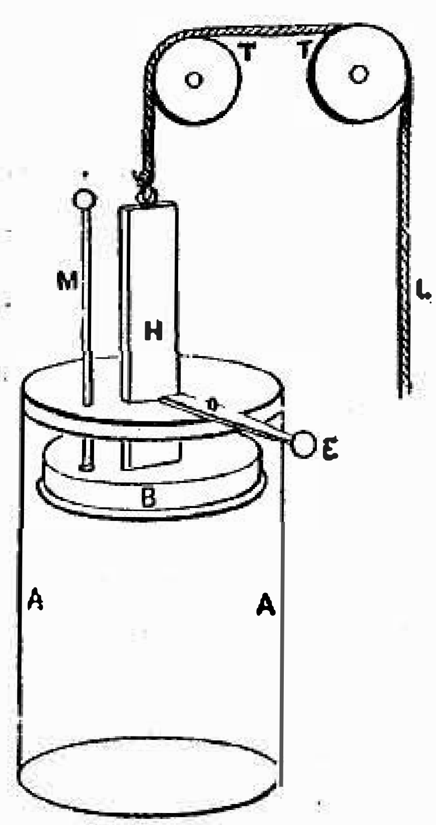

Fig. 17.—Papin's Engine.

The first machine of Papin (Fig. 17) was very similar to the gunpowder-engine already described as the invention of Huyghens. In place of gunpowder, a small quantity of water is placed at the bottom of the cylinder, *A*; a fire is built beneath it, "the bottom being made of very thin metal," and the steam formed soon raises the piston, *B*, to the top, where a latch, *E*, engaging a notch in the piston-rod, *H*, holds it up until it is desired that it shall

[1] "Acta Eruditorum," Leipsic, 1690.

drop. The fire being removed, the steam condenses, and a vacuum is formed below the piston, and the latch, *E*, being disengaged, the piston is driven down by the superincumbent atmosphere and raises the weight which has been, meantime, attached to a rope, *L*, passing from the piston-rod over pulleys, *T T*. The machine had a cylinder two and a half inches in diameter, and raised 60 pounds once a minute; and Papin calculated that a machine of a little more than two feet diameter of cylinder and of four feet stroke would raise 8,000 pounds four feet per minute—i. e., that it would yield about one horse-power.

The inventor claimed that this new machine would be found useful in relieving mines from water, in throwing bombs, in ship-propulsion, attaching revolving paddles—i. e., paddle-wheels—to the sides of the vessel, which wheels were to be driven by several of his engines, in order to secure continuous motion, the piston-rods being fitted with racks which were to engage ratchet-wheels on the paddle-shafts.

"The principal difficulty," he says, answering anticipated objections, "is that of making these large cylinders."

In a reprint describing his invention, in 1695, Papin gives a description of a "newly-invented furnace," a kind of fire-box steam-boiler, in which the fire, completely surrounded by water, makes steam so rapidly that his engine could be driven at the rate of four strokes per minute by the steam supplied by it.

Papin also proposed the use of a peculiar form of furnace with this engine, which, embodying as it does some suggestions that very probably have since been attributed to later inventors, deserves special notice. In this furnace, Papin proposed to burn his fuel on a grate within a furnace arranged with a *down-draught*, the air entering above the grate, passing *down* through the fire, and from the ash-pit through a side flue to the chimney. In starting the fire, the coal was laid on the grate, covered with wood, and the latter was ignited, the flame, passing downward through the coal, igniting that in turn, and, as claimed by Papin, the combustion was complete, and the formation of smoke was entirely prevented. He states, in "Acta Eruditorum," that the heat was intense, the saving of fuel very great, and that the only difficulty was to find a refractory material which would withstand the high temperature attained.

This is the first fire-box and flue boiler of which we have record. The experiment is supposed to have led Papin to suggest the use of a hot-blast, as practised by Neilson more than a century later, for reducing metals from their ores.

Papin made another boiler having a flue winding through the water-space, and presenting a heating surface of nearly 80 square feet. The flue had a length of 24 feet, and was about 10 inches square. It is not stated what were the maximum pressures carried on these boilers; but it is known that Papin had used very high pressures in his digesters—probably between 1,200 and 1,500 pounds per square inch.

In the year 1705, Leibnitz, then visiting England, had seen a Savery engine, and, on his return, described it to Papin, sending him a sketch of the machine. Papin read the letter and exhibited the sketch to the Landgrave of Hesse, and Charles at once urged him to endeavor to perfect his own machine, and to continue the researches which hee had been intermittently pursuing since the earlier machine had been exhibited in public.

In a small pamphlet printed at Cassel in 1707,[1] Papin describes a new form of engine, in which he discards the original plan of a modified Huyghens engine, with tight-fitting piston and cylinder, raising its load by indirect action, and makes a modified Savery engine, which he calls the "Elector's Engine," in honor of his patron. This is the engine shown in the engraving, and as proposed to be used by him in turning a water-wheel.

[1] "Nouvelle manière d'élever l'Eau par la Force du Feu, mis en Lumière," par D. Papin. Cassel, 1707.

The sketch is that given by the inventor in his memoir. It consists (Fig. 18) of a steam-boiler, *a*, from which steam is led through the cock, *c*, to the working cylinder, *n*. The water beneath the floating-piston, *h*, which latter serves simply as a cushion to protect the steam from sudden condensation or contact with the water, is forced into the vessel *r r*, which

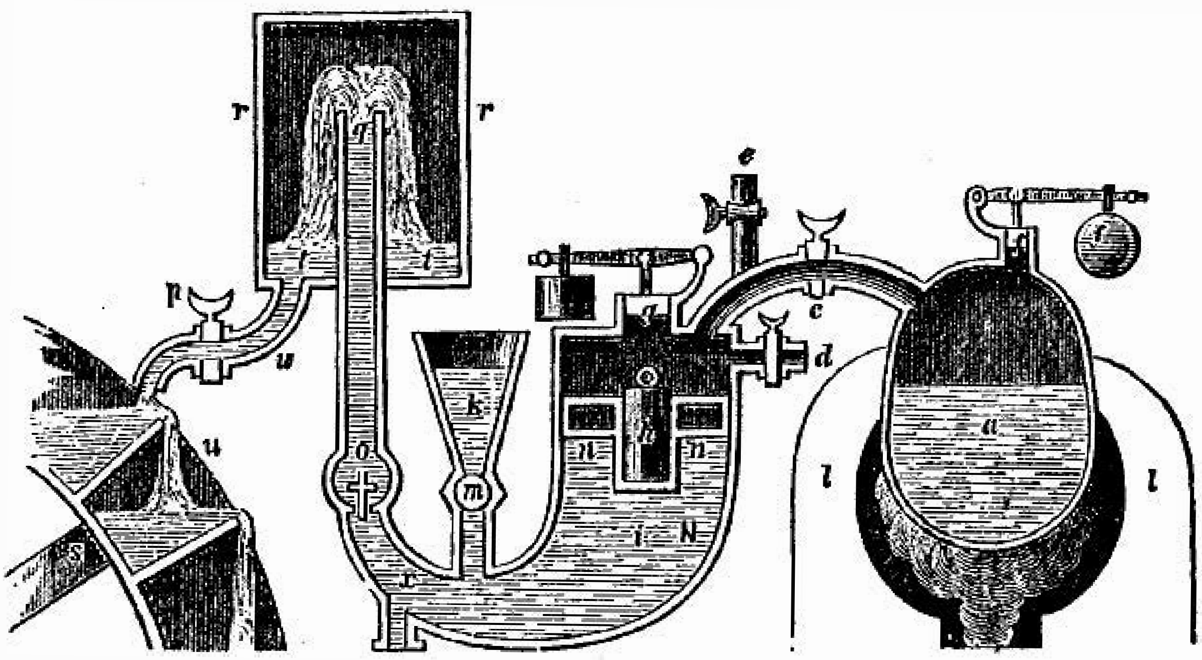

FIG. 18.—Papin's Engine and Water-Wheel, A. D. 1707.

is a large air-chamber, and which serves to render the outflow of water comparatively uniform, and the discharge occurs by means of the pipe *g*, from which the water rises to the desired height. A fresh supply of water is introduced through the funnel *k*, after condensation of the steam in *n*, and the operation of expulsion is repeated.

This machine is evidently a retrogression, and Papin, after having earned the honor of having invented the first steam-engine of the typical form which has since become so universally applied, forfeited that credit by his evident ignorance of its superiority over existing devices, and by attempting unsuccessfully to perfect the inferior device of another inventor.

Subsequently, Papin made an attempt to apply the steam-engine to the propulsion of vessels, the account of which will be given in the chapter on Steam-Navigation.

Again disappointed, Papin once more visited England, to renew his acquaintance with the *savans* of the Royal Society; but Boyle had died during the period which Papin had spent in Germany, and the unhappy and disheartened inventor and philosopher died in 1710, without having seen any one of his many devices and ingenious inventions a practical success.