2,000 years; but the principle involved has been revived, and is applied in rotatory engines at the present day.

560. De Garay's Engine.—In 1543, a Spaniard, by the name of De Garay, undertook to propel a vessel of 200 tons in the harbor of Barcelona by the force of steam. He kept his machinery a secret, but it was observed that a boiler and two wheels constituted the principal part of his apparatus. The experiment succeeded. The vessel moved three miles an hour, and was turned or stopped at pleasure; but the Emperor Charles V., by whose order the trial was made, never followed the matter up, and De Garay and his invention were forgotten.

561. Engines of De Caus and Branca.—In 1615, De Caus, a French mathematician, devised an apparatus by which water could be raised in a tube through the agency of steam. A few years afterwards, an Italian physician, named Branca, ground his drugs by means of a wheel set in motion by steam. The steam was led from a close vessel, in which it was prepared, and discharged against flanges on the rim of the wheel.

562. The Marquis of Worcester's Engine.—The Marquis of Worcester, by many regarded as the inventor of the steam-engine, greatly improved on the imperfect attempts of those who had preceded him.

Some say that Worcester derived his ideas from De Caus. Others claim that his invention was purely original, and the result of reflections to which he was led during his imprisonment in the Tower of London, in 1656, for plotting against the government of Cromwell. Observing how the steam kept moving the lid of the pot in which he was cooking his dinner, he could not help thinking that this power could be turned to a variety of useful purposes, and set about devising an engine in which it might be applied to the raising of water.

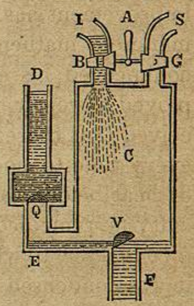
The Marquis of Worcester generated his steam in a boiler, and led it by pipes to two vessels communicating on one side with the reservoir from which it was to be drawn, and on the other with the cistern into which it was to be discharged.

559. What sort of an engine was Hero's, and what is said of it? 560. Give an account of De Garay's engine, and the experiment made with it. 561. Give an account of De Caus's engine. Of Branca's. 562. Whom do many regard as the inventor of the steam-engine? What claim has he to the honor? How was he led to reflect on the subject?

563. Papin's Engine.—The next step was taken by Papin, who devised the mode of giving a piston an up-and-down motion in a cylinder by alternately generating and condensing steam below a piston.

564. Savery's Engine.—Captain Thomas Savery, in 1698, constructed an engine superior to any before invented. He was led to investigate the subject by the following occurrence. Having finished a flask of wine at a tavern, he flung it on the fire, and called for a basin of water to wash his hands. Some of the wine remained in the flask, and steam soon began to issue from it. Observing this, Savery thought that he would try the effect of inverting the flask and plunging its mouth into the basin of cold water. No sooner had he done this than the steam condensed, and the water rushing into the flask nearly filled it. Confident that he could advantageously apply this principle in machinery, Savery rested not till he invented an engine which was employed with success in drawing off the water from mines.

Fig. 221.



565. The principle on which Savery's engine worked, may be understood from Fig. 221. S is a pipe connecting a boiler in which steam is generated (and which does not appear in the Figure) with a cylindrical vessel, C, called *the receiver*. I is known as *the injection-pipe*, and is used for throwing cold water into the receiver to condense the steam. The steam-pipe, S, and the injection-pipe, I, contain the stop-cocks, G, B, which are moved by the common handle, A, so arranged that when one is opened the other is closed. F is a pipe which descends to the reservoir whence the water is to be drawn, and is commanded by the valve V, opening upward. ED is a pipe leading from the bottom of the receiver up to the cistern, into which the water is to be discharged. This pipe contains the valve Q, opening upward.

Operation.—To work the engine, open the stop-cock G, which of course involves the shutting of B. The steam rushes in through S, and fills the receiver C, driving out the air through the valve Q. When C is full, shut G

How was the Marquis of Worcester's apparatus arranged? 563. Who took the next step? What was Papin's improvement? 564. Who constructed a superior engine in 1698? Relate the circumstances that led Savery to investigate the subject. 565. With the aid of Fig. 221, describe the parts of Savery's engine. Explain its operation.

and open B. Cold water at once enters through the injection-pipe and condenses the steam in C. A vacuum is thus formed, and the water in the reservoir or mine, under the pressure of the atmosphere, forces open the valve V, and rushes up through F into G, till the receiver is nearly filled. G is then opened and B closed; when the steam again enters through S, and by its expansive force opens the valve Q, and drives the water up through E D into the cistern.

566. Newcomen's Engine.—Savery's engine was employed only for raising water; but Newcomen, an intelligent blacksmith, extended its sphere of usefulness, by connecting a piston, worked up and down on Papin's principle, with a beam turning on a pivot, by means of which machinery of different kinds could be set in motion.

567. About this time, also, the engine was made self-acting through the ingenuity of Humphrey Potter, a lad employed to turn the stop-cocks Preferring play to this monotonous labor, he contrived to fasten cords m the beam to the handle of the stop-cocks, in such a way that the latter were opened and closed at the proper times, while he was away, enjoying himself with his companions. His device was after a time found out, and saved so much labor that it was at once adopted as an essential part of the machine.

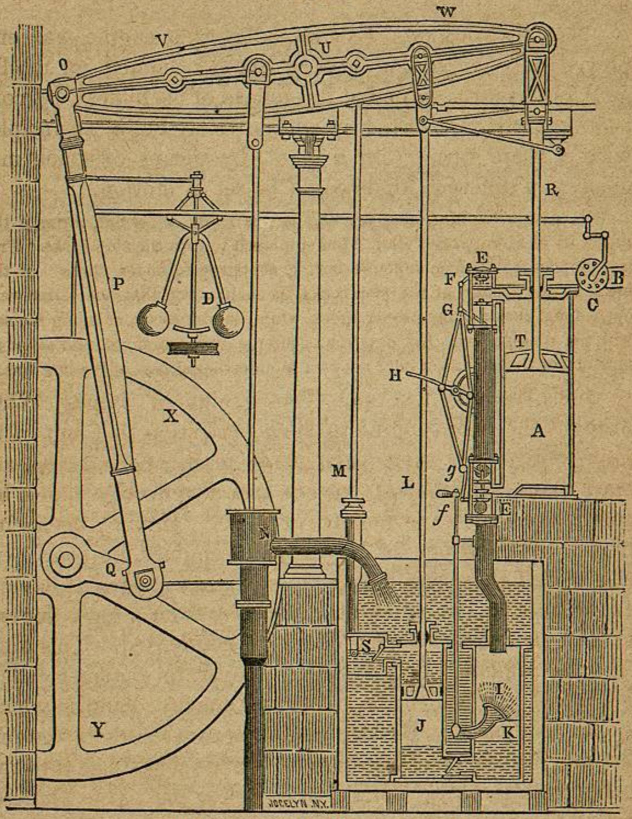
568. Watt's Engine.—The genius of James Watt brought the steam-engine to such perfection that but little improvement has since been made in it. Gifted with remarkable mathematical powers and a reflective mind, he commenced his experiments in 1763. Having been employed to repair one of Newcomen's engines, he soon perceived that there was a great loss in consequence of having every time to cool down the receiver from a high degree of heat before the steam could be condensed. This difficulty he remedied by providing a separate chamber called *a condenser*, to which the steam was conveyed and in which it was condensed. He also made the movement of the piston more prompt and effective by introducing steam into the cylinder alternately above and below it. The Double-acting Condensing Steam-engine, as improved by Watt, and

566. What was the only purpose for which Savery's engine was employed? Who extended its usefulness, and how? 567. Give an account of Humphrey Potter's improvement, and the circumstances under which it was devised. 568. Who brought the steam-engine to comparative perfection? When did Watt commence his experiments? What disadvantage did he perceive that Newcomen's engines labored under? How did he remedy the difficulty? What other improvement did he make?

now generally constructed for manufacturing establishments, is represented in Fig. 222.

569. *Description of the Parts.*—A is the *cylinder*, in which the *piston* T works. This piston is connected by the *piston-rod* R with the *working-beam*

Fig. 222.



THE DOUBLE-ACTING CONDENSING STEAM-ENGINE.

V W, which turns on a pivot, U. The other end of the working-beam, O, imparts a rotary motion to the heavy *fly-wheel* X Y, by means of the *connecting-rod* P and the *crank* Q. The fly, as explained on page 125, regulates the motion, and is directly connected with the machinery to be moved. Steam

569. Describe the parts of Watt's Double-acting Condensing Engine. Show how the

is conveyed to the cylinder A from the *boiler* (which is not seen in the figure), through the *steam-pipe* B, which is commanded by the *throttle-valve* C. This valve is connected with the *governor* D, in such a way as to be opened when the supply of steam is too small and closed when it is too great.

Communicating with the cylinder at its top and bottom on the left, are two hollow *steam-boxes*, E, E, each of which is divided into three compartments by two valves. F is called the *upper induction-valve*, and opens or closes communication between the steam-pipe and the upper part of the cylinder, so as to admit or intercept a supply of steam. G, called the *upper exhaustion-valve*, opens or closes communication between the upper part of the piston and the *condenser* K, so that the steam may either be allowed to escape into the latter or confined in the cylinder. The *lower induction-valve g*, and the *lower exhaustion-valve f*, stand in the same relation to the lower part of the cylinder, the former connecting it with the steam-pipe, and the latter with the condenser K. These valves are connected by a system of levers with a common handle, H, called a *spanner*, which is made to work at the proper intervals by a pin projecting from the rod L, which is moved by the working-beam. The spanner works so as to open and close the valves by pairs. When it is pressed up, it opens F and *f*, and closes G and *g*; when pressed down, it closes F and *f* and opens G and *g*.

Below is the condensing apparatus, consisting of two cylinders, I and J, immersed in a cistern of cold water. A pipe, K, having an end like the rose of a watering-pot, conveys water from the cistern to the cylinder I (the supply being regulated by a stop-cock), and thus condenses the steam which is from time to time admitted into I. The other cylinder, J, called the *air-pump*, contains a piston with a valve in it opening upward, which works like the bucket of a common pump, and draws off the surplus water that collects at the bottom of the cylinder I into the *upper reservoir* S. The *hot-water pump* M then conveys this water to the cistern that supplies the boiler. To keep the water around the condensing apparatus at the right temperature, a fresh supply is constantly introduced through the *cold-water pump* N; which, like the hot-water pump and the air-pump, is kept in operation by rods connected with the working-beam.

570. *Operation.*—The working of the engine is as follows:—Let the piston be at the top of the cylinder, and all the space below be filled with steam. The upper induction-valve and the lower exhaustion-valve are then opened by the spanner, while the upper exhaustion-valve and the lower induction-valve are closed. By this means steam is introduced above the piston, while the steam beneath is drawn off into the condenser, where it is converted into water. The pressure of the steam above at once forces the piston to the bottom of the cylinder. Just at this moment the spanner is moved in the opposite direction, and the valves that were before opened are closed, while those that were previously closed are opened. The steam is now admitted beneath the piston, and the steam above is drawn off into the condenser and converted into water as before. While this action is going on, the cold-water pump

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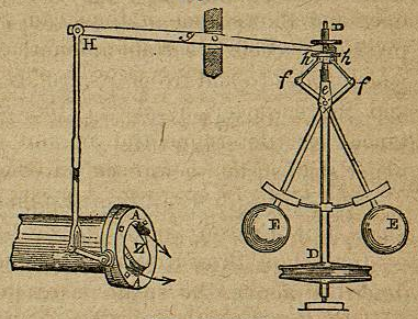
valves work. Describe the condensing apparatus. 570. How is the engine worked?

is constantly supplying the cistern in which the condenser is immersed; while the air-pump is drawing off the hot water from the condenser to the upper reservoir, whence it is conveyed by the hot-water pump to the cistern that supplies the boiler. An up-and-down motion is thus communicated to the piston, and by it to the working-beam, which causes the fly to revolve, and moves the machinery with which it is connected.

571. *The Governor.*—The Governor, an ingenious piece of mechanism, by which the throttle-valve in the steam-pipe is opened and closed, and the supply of steam regulated as the machinery requires, is worthy of further description.

Fig. 223.



THE GOVERNOR.

The governor and its connection with the throttle-valve are represented in Fig. 223. It consists of two heavy balls of iron, E, E, suspended by metallic arms from the point *e*. At *e* they cross, forming a joint, and are continued to *f*, *f*, where they are attached by pivots to other bars, *f h*, *f h*. These bars are joined to one end of a lever, the other end of which, H, is connected at W with the handle of the valve Z. The spindle D D, to which the balls are attached, turns with the fly-wheel. When the fly-wheel revolves very rapidly, the balls E E, under the influence of the centrifugal force, fly out from the spindle, and with the aid of the bars *f h*, *f h*, pull down the end of the lever *g*. The other end, H, is of course raised, and with it the handle of the valve Z, which is thus made to close the mouth of the steam-pipe A and cut off the supply of steam. On the other hand, when the motion of the fly diminishes, the centrifugal force of the balls E E also diminishes, and they fall towards the spindle. The nearer end of the lever *g* is thus raised, while the end H is depressed. The valve Z is by this means opened, and admits a full supply of steam. The governor thus acts almost with human intelligence, now admitting, and now cutting off the steam, just as is required.

572. *The Boiler.*—The boiler is made of thick wrought-iron or copper plates, riveted as strongly as possible, so as to resist the expansive force of the steam generated within.

How are the cisterns supplied? 571. What is the Governor? Describe the governor, and its connection with the throttle-valve. Show the workings of the gov-

The fire is applied in an apartment beneath or within the boiler called the Furnace.

Boilers are made of different shapes, but are generally cylindrical, because this form is one of the strongest. Watt made his concave on the bottom, in order to bring a greater extent of surface in contact with the flame.

573. *The Safety Valve.*—The pressure on the boiler, in consequence of the expansive force of steam, is immense. If it is allowed to become too great, the boiler bursts, often with fatal effects. To prevent such catastrophes, a Safety Valve is fixed in the upper part of the boiler, which is forced open and allows some of the steam to escape whenever the pressure exceeds a certain amount. A lever, with a weight which slides to and fro on its arm, is attached to the valve; and the engineer, by placing the weight at different distances, can determine the amount of pressure which the boiler shall sustain before the valve will open.

574. Kinds of Engines.—Engines are divided into two kinds, Low Pressure and High Pressure.

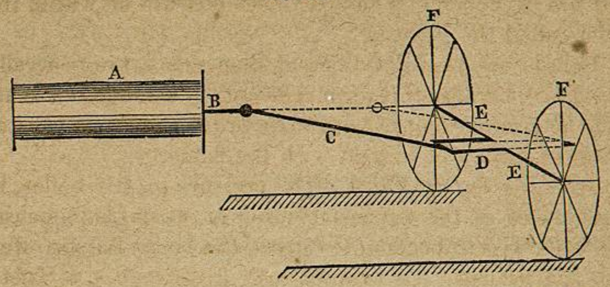
In the Low Pressure Engine, one form of which has been described above, the steam is carried off and condensed; while in the High Pressure Engine it is allowed to escape into a chimney, and thence into the open air. The latter, having no condensing apparatus, is much the simpler in its construction. It is noisy when in operation, in consequence of the puffing sound made by the steam as it escapes.

575. As regards their use, engines may be divided into three classes; Stationary Engines, employed in manufacturing, Marine Engines, for propelling boats, and Locomotive Engines, for drawing wheeled carriages.

576. The Locomotive Engine.—The Locomotive is a high pressure engine. The principle on which it works may be understood from Fig. 224.

ernor. 572. Of what is the boiler made? Where is the fire applied? What is the usual shape of boilers? What shape did Watt make his, and why? 573. What is the use of the Safety Valve? How is it worked? 574. How are engines divided? What constitutes the difference between Low Pressure and High Pressure Engines? Which are the simpler? Which are the more noisy, and why? 575. As regards their use,

Fig. 224.



The cylinder A in this engine is horizontal instead of vertical, and the piston works horizontally. B, the piston-rod, is connected by a crank, D, with the axle E E of the wheels, F, F. The piston, moving alternately in and out of the cylinder, with the aid of the crank causes the axle and wheels to revolve; and the wheels, by their friction on the rails, move forward the engine and whatever may be attached to it. The heavy line represents the position of the parts when the piston is at the remote extremity of the cylinder; the dotted line shows their position, when the piston has reached the other end. Steam is first introduced on one side of the piston, and then on the other, being allowed to escape as soon as it has done its work,—that is, driven the piston to the opposite extremity. The rest of the machinery consists of arrangements for boiling the water, for regulating the admission of steam into the cylinder and its discharge, for providing draught for the fire, and for giving the driver the means of starting and stopping the engine, and reversing the direction of its motion.

577. *History.*—Watt seems to have been the first to conceive the idea of propelling wheeled carriages by steam; but he was so engaged in perfecting the stationary engine that he did not attempt to carry out his idea. William Murdoch, in 1784, first constructed a locomotive. Though little more than a toy, it worked successfully, and travelled so fast that on one occasion its inventor in vain tried to keep pace with it.

Eighteen years passed before any use was made of Murdoch's invention; at the end of that time, in 1802, Richard Trevithick publicly exhibited a locomotive engine, so con-

into what three classes may engines be divided? 576. With Fig. 224, show the principle on which the locomotive engine works. What does the rest of the machinery consist of? 577. Who first conceived the idea of the locomotive engine? Who first carried out the idea? What is said of Murdoch's engine? Who exhibited an imstructed that it could be used for transporting cars. Important modifications and improvements have since been made, for many of which the world is indebted to George Stephenson, who shares with Trevithick the honor of this great invention.

EXAMPLES FOR PRACTICE.

1. (*See* § 510.) A joint of meat stands 2 feet from a fire, a fowl 4 feet; how does the heat which strikes the former compare with that received by the latter?
2. How does the heat which my finger receives from the blaze of a candle, when held an inch from it, compare with what it receives when held a foot from it?
3. If we were but one-fifth of our present distance from the sun, how many times as much heat would we receive from it?
4. The planet Neptune is about 30 times as far from the sun as the earth is; how does its solar heat compare with ours?
5. To receive a certain amount of heat from a fire, an object is placed 3 feet from it; to receive only one-fourth as much heat, how far from the fire must it be placed?
6. (*See* § 526.) A quantity of water at the freezing-point measures 22 gallons; how much will it measure when its temperature has increased to the boiling-point?
7. I have a vessel which holds 46 gallons; how much water at a temperature of 32° must I put in it, to exactly fill the vessel when it boils?
8. What will be the increase in measure of 18 gallons of alcohol, when raised from 32° to 212°? What will be the increase in weight?
9. (*See* § 554.) Under a pressure of one atmosphere, how many cubic inches of steam will be generated from 2 cubic inches of water? From 10 cubic inches of water?
10. If 3,400 cubic feet of steam (under a pressure of one atmosphere) be condensed, how much water will it make?
11. (*See* § 555.) Under a pressure of two atmospheres, about how many cubic inches of steam will two inches of water generate? How many, under a pressure of three atmospheres?
12. About how many cubic inches of steam will be required, to raise 10 tons 10 feet high? If the steam were condensed, how many cubic inches of water would it make?

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proved locomotive in 1802? Who subsequently made important improvements in the locomotive?

CHAPTER XIV.

OPTICS.

578. OPTICS is the science that treats of light and vision.

Nature of Light.

579. Light is an agent, by the action of which upon the eye we are enabled to see.

Light is imponderable; for it moves with great velocity, and if it had any weight, though it were ever so little, its striking force would be felt by every object with which it comes in contact. Yet it does not affect even the most sensitive balance.

580. With respect to the nature of light, two theories have been advanced, the Corpuscular and the Undulatory.

581. *Corpuscular Theory.*—The Corpuscular Theory teaches that light consists of extremely minute particles of matter, thrown off from luminous bodies, which strike the eye and produce the sensation of light, just as particles thrown off by an odoriferous substance affect the organ of smell. This theory, held as long ago as the days of Pythagoras, was received by Newton; but, failing to account for many of the facts more recently discovered in connection with light, it has now but few supporters.

582. *Undulatory Theory.*—According to the Undulatory Theory, light is produced by the undulations of an exceedingly subtile imponderable medium, known as Ether, with which space is filled; just as sound is produced by the vibrations of air. A luminous object millions of miles away causes the ether in contact with it to move in minute waves, like the surface of a pond rippled by throwing in a stone. These undulations are transmitted with inconceivable rapidity, till they reach the eye, strike the sensitive membrane that lines it, and produce the phenomena of vision. This theory, advanced by Descartes [*dā-kart'*], but first definitely laid down by Huygens, explains most of the phenomena of optics, and is now generally received.

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578. What is Optics? 579. What is Light? How is it proved that light is imponderable? 580. What two theories have been advanced with respect to the nature of light? 581. State the chief points of the Corpuscular Theory. By whom was it held? 582. According to the Undulatory Theory, how is light produced? By whom was the Undulatory Theory advanced? Which of these theories is now generally received?