of the vacuum so formed to raise water by suction from a level lower than that of the engine, Savery’s engine was probably an improvement on Worcester’s ; in any case it found what Worcester’s engine had failed to find,—consider­able employment in pumping mines and in raising water to supply houses and towns, and even to drive water­wheels. A serious difficulty which prevented its general use in mines was the fact that the height through which it would lift water was limited by the pressure the boiler and vessels could bear. Pressures as high as 8 or 10 atmospheres were employed—and that, too, without a safety-valve—but Savery found it no easy matter to deal with high-pressure steam ; he complains that it melted his common solder, and forced him, as Desaguliers tells us, “to be at the pains and charge to have all his joints soldered with spelter.” Apart from this drawback the waste of fuel was enormous, from the condensation of steam which took place on the surface of the water and on the sides of the displacement-chamber at each stroke ; the consumption of coal, was, in proportion to the work done, some twenty times greater than in a good modern steam- engine. In a tract called *The Miner's Friend,* Savery alludes thus to the alternate heating and cooling of the water-vessel : “On the outside of the vessel you may see how the water goes out as well as if the vessel were trans­parent, for so far as the steam continues within the vessel so far is the vessel dry without, and so very hot as scarce to endure the least touch of the hand. But as far as the water is, the said vessel will be cold and wet where any water has fallen on it ; which cold and moisture vanishes as fast as the steam in its descent takes place of the water.” Before Savery’s engine was entirely displaced by its suc­cessor, Newcomen’s, it was improved by Desaguliers, who applied to it the safety valve (invented by Papin), and substituted condensation by a jet of cold water within the vessel for the surface condensation used by Savery.

7. So early as 1678 the use of a piston and cylinder (long before known as applied to pumps) in a heat-engine had been suggested by Jean Heautefeuille, who proposed to use the explosion of gunpowder either to raise a piston or to force up water, or to produce, by the subsequent cooling of the gases, a partial vacuum into which water might be sucked up. Two years later Huygens described an engine in which the explosion of gunpowder in a cylinder expelled part of the gaseous contents, after which the cooling of the remainder caused a piston to descend under atmospheric pressure, and the piston in descending did work by raising a weight.

8. In 1690 Denis Papin, who ten years before had invented the safety-valve as an adjunct to his “digester,” 'suggested that the condensation of steam should be em­ployed to make a vacuum under a piston previously raised by the expansion of the steam. Papin’s was the earliest cylinder and piston steam-engine, and his plan of using

steam was that which afterwards took practical shape in the atmo­spheric engine of Newcomen. But

his scheme was made unworkable by the fact that he pro­posed to use but one vessel as both boiler and cylinder.

A small quantity of water was placed at the bottom of a cylinder and heat was applied. When the piston had risen the fire was removed, the steam was allowed to cool, and the piston did work in its down-stroke under the pressure of the atmosphere. After hearing of Savery’s engine in 1705 Papin turned his attention to improving it, and devised a modified form, shown in fig. 3, in which the displacement- chamber A was a cylinder, with a floating diaphragm or piston on the top of the water to keep the water and steam from direct contact with one another. The water was de­livered into a closed air-vessel B, from which it issued in a continuous stream against the vanes of a water-wheel. After the steam had done its work in the displacement- chamber it was allowed to escape by the stop-cock C instead of being condensed. Papin’s engine was in fact a non-con­densing single-acting steam-pump, with steam-cylinder and pump-cylinder in one. A curious feature of it was the heater D, a hot mass of metal placed in the diaphragm for the pur­pose of keeping the steam dry. Among the many inventions of Papin was a boiler with an internal fire-box,—the earliest example of a construction that is now almost universal.@@1

9. While Papin was thus going back from his first notion of a piston-engine to Savery’s cruder type, a new inventor had appeared who made the piston-engine a practical success by separating the boiler from the cylinder and by using (as Savery had done) artificial means to con­dense the steam. This was Newcomen, who in 1705, with his assistant Cawley, gave the steam-engine the form shown in fig. 4. Steam admitted from the boiler to the cylinder allowed the piston to be

raised by a heavy counterpoise

on the other side of the beam.

Then the steam-

valve was shut and

a jet of cold water

entered the cylinder

and condensed the

steam. The piston

was consequently

forced down by the

pressure of the at­

mosphere and did

work on the pump.,

The next entry of

steam expelled the

condensed water

from the cylinder

through an escape

valve. The piston was kept tight by a layer of water on its upper surface. Condensation was at first effected by cooling the outside of the cylinder, but the accidental leak­age of the packing water past the piston showed the advan­tage of condensing by a jet of injection water, and this plan took the place of surface condensation. The engine used steam whose pressure was little if at all greater than that of the atmosphere ; sometimes indeed it was worked with the manhole lid off the boiler.

10. About 1711 Newcomen’s engine began to be intro­duced for pumping mines; and in 1713 a boy named Humphrey Potter, whose duty it was to open and shut the valves of an engine he attended, made the engine self­acting by causing the beam itself to open and close the valves by suitable cords and catches. Potter’s rude device was simplified in 1718 by Henry Beighton, who suspended from the beam a rod called the plug-tree, which worked the valves by means of tappets. By 1725 the engine was in common use in collieries, and it held its place without material change for about three-quarters of a century in

@@@1 For an account of Papin’s inventions, see his *Life and Letters,* by Dr E. Gerland, Berlin, 1881.