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. It is doubtful whether the action was originally automatic, or depended on the periodical turning of taps by an attendant. The common story is that 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 self-acting by causing the beam itself to open and close the valves by suitable cords and catches. This 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 all. Near the close of its career the atmospheric engine was much improved in its mechanical details by John Smeaton, who built many large engines of this type about the year 1770, just after the great step which was to make Newcomen’s engine obsolete bad been taken by James Watt.

Compared with Savery’s engine, Newcomen’s had (as a pumping engine) the great advantage that the intensity of pressure in the pumps was not in any way limited by the pressure of the steam. It shared with Savery’s, in a scarcely less degree, the defect already pointed out, that steam was wasted by the alternate heating and cooling of the vessel into which it was led. Though obviously capable of more extended uses, it was in fact almost exclusively employed to raise water—in some instances for the purpose of turning water-wheels to drive other machinery. Even contemporary writers complain of its vast "consumption of fuel,” which appears to have been scarcely smaller than that of the engine of Savery.

11. In 1763 James Watt, an instrument maker in Glasgow, while engaged by the university in repairing a model of New­comen’s engine, was struck with the waste of steam to which the alternate chilling and heating of the cylinder gave rise. He saw that the remedy, in his own words, would lie in keeping the cylinder as hot as the steam that entered it. With this view he added to the engine a new organ—an empty vessel separate from the cylinder, into which the steam should be allowed to escape from the cylinder, to be condensed there by the application of cold water either outside or as a jet. To preserve the vacuum in his condenser he added a pump called the air-pump, whose function was to pump from it the condensed steam and water of con­densation, as well as the air which would otherwise accumulate by leak­age or by being brought in with the steam or with the injection water. Then, as the cylinder was no longer used as a condenser, he was able to keep it hot by clothing it with non­conducting bodies, and in particular by the use of a *steam jacket,* or layer of hot steam between the cylinder and an external casing. Further, and still with the same object, he covered in the top of the cylinder, taking the piston- rod out through a steam-tight stuffing-box, and allowed steam instead of air to press upon the piston’s upper surface. The idea of using a separate condenser had no sooner occurred to Watt than he put it to the test by constructing the apparatus shown in fig. 5. There A is the cylinder, B a surface condenser, and C the air-pump. The cylinder was filled with steam above the piston, and a vacuum was formed in the surface condenser B.

On opening the stop-cock D the steam rushed over from the cylinder and was condensed, while the piston rose and lifted a weight. After several trials Watt patented his improvements in 1769; they are described in his specification in the following words, which, apart from their immense historical interest, deserve careful study as a statement of principles which to this day guide the scientific development of the steam engine :—

“ My method of lessening the consumption of steam, and conse­quently fuel, in fire-engines, consists of the following principles :—

*“ First,* That vessel in which the powers of steam are to be em­ployed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam-vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it; first by enclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and, thirdly, by suffering neither water nor any other substance colder than the steam to enter or touch it during that time.

*“ Secondly,* In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam-vessels or cylinders, although occasionally communicating with them; these vessels I call condensers; and, whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by application of water or other cold bodies.

*"Thirdly,* Whatever air or other elastic vapour is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam-vessels or condensers by means of pumps, wrought by the engines themselves, or other­wise.

*“ Fourthly,* I intend in many cases to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner in which the pressure of the atmosphere is now employed in common fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by this force of steam only, by discharging the steam into the air after it has done its office. . . .

*“ Sixthly,* I intend in some cases to apply a degree of cold not capable of reducing the steam to water, but of contracting it con­siderably, so that the engines shall be worked by the alternate expansion and contraction of the steam.

*" Lastly,* Instead of using water to render the pistons and other parts of the engine air and steam tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver and other metals in their fluid state.”

The fifth claim was for a rotary engine, and need not be quoted here.

The “ common fire engine ” alluded to was the steam engine, or, as it was more generally called, the "atmospheric ” engine of Newcomen. Enormously important as Watt’s first patent was, it resulted for a time in the production of nothing more than a greatly improved engine of the Newcomen type, much less wasteful of fuel, able to make faster strokes, but still only suitable for pumping, still single-acting, with steam admitted during the whole stroke, the piston, as before, pulling the beam by a chain working on a circular arc. The condenser was generally worked by injection, but Watt has left a model of a surface condenser made up of small tubes, in every essential respect like the condensers now used in marine engines.@@1

12. Fig. 6 is an example of the Watt pumping engine of this period. It should be noticed that, although the top of the cylinder is closed and steam has access to the upper side of the piston, this is done only to keep the cylinder and piston warm. The engine is still single-acting; the steam in the upper side merely plays the part which was played in Newcomen’s engine by the atmosphere; and it is the lower end of the cylinder alone that îs ever put in communi­cation with the condenser. There are three valves: the “ steam ” valve *a,* the “equilibrium” valve *b,* and the “exhaust” valve *c,* At the beginning of the down-stroke *c* is opened to produce a vacuum below the piston and *a* is opened to admit steam above it. At the end of the down-stroke *a* and *c* are shut and *b* is opened. This puts the two sides in equilibrium and allows the piston to be pulled up by the pump-rod *P,* which is heavy enough to serve as a counterpoise. *C* is the condenser, and *A* the air-pump, which discharges into the hot well *H,* whence the supply of the feed-pump *F* is drawn.

13. In a second patent (1781) Watt describes the “ sun-and- planet” wheels and other methods of making the engine give

@@@1 An interesting detailed narrative of the steps leading to his invention was written by Watt as a note to the article “ Steam Engine ” in Robison’s *System of Mechanical Philosophy* (1822). Sec Ewing, *The Steam Engine and other Heat Engines,* pp. 15-19