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 continuous revolving motion to a shaft pro­vided with a fly-wheel. He had invented the crank and connecting-rod for this purpose, but it had meanwhile been patented by one Pickard, and Watt, rather than make terms with Pickard, whom he regarded as a plagiarist of his own ideas, made use of his sun-and-planet motion until the patent on the crank expired. The reciprocating motion of earlier forms had served only for pumping; by this invention Watt opened up for the steam-engine a thousand other channels of usefulness. The engine was still single-acting ; the connecting rod was attached to the far end of the beam, and that carried a counterpoise which served to raise the piston when steam was admitted below it.

14. In 1782 Watt patented two further improvements of the first importance, both of which he had invented some years before. One was the use of double action, that is to say, the application of steam and vacuum to each side of the piston alternately. The other (invented as early as 1769) was the use of steam expansively, in other words the plan (now used in all engines that aim at economy of fuel) of stopping the admission of steam when the piston had made only a part of its stroke, and allow­ing the rest of the stroke to be performed by the expan­sion of the steam already in the cylinder. To let the piston push as well as pull the end of the beam Watt devised his so-called parallel motion, an arrangement of links connecting the piston-

rod head with the beam in

such a way as to guide

the rod to move in a

very nearly straight

line. He further added

the throttle-valve, for

regulating the rate of

admission of steam, and

the centrifugal gover­

nor, a double conical

pendulum, which con­

trolled the speed by

acting on the throttle-

valve. The stage of de­

velopment reached

at this time is illus­

trated by the en­

gine of fig. 7 (from

Stuart’s *History of*

*the Steam-Engine),*

which shows the

parallel motion *pp,*

the governor *g,* the

throttle-valve *t,* and a pair of steam and exhaust valves at each end of the cylinder. Among other inventions of Watt were the “ indicator,” by which diagrams showing the relation of the steam-pressure in the cylinder to the movement of the piston are automatically drawn ; a steam tilt-hammer ; and also a steam locomotive for ordinary roads,—but this invention was not prosecuted.

In partnership with Matthew Boulton, Watt carried on in Birmingham the manufacture and sale of his engines with the utmost success, and held the field against all

rivals in spite of severe assaults on the validity of his patents. Notwithstanding his accurate knowledge of the advantage to be gained by using steam expansively he continued to employ only low pressures—seldom more than 7 lb per square inch over that of the atmosphere. His boilers were fed, as Newcomen’s had been, through an open pipe which rose high enough to let the column of water in it balance the pressure of the steam. He intro­duced the term “horse-power” as a mode of rating engines, defining one horse-power as the rate at which work is done when 33,000 lb) are raised one foot in one minute. This estimate was based on trials of the work done by horses ; it is excessive as a statement of what an average horse can do, but Watt purposely made it so in order that his customers might have no reason to complain on this score.

15. In the fourth claim in Watt’s first patent, the second sentence describes a non-condensing engine, which would have required steam of a higher pressure. This, however, was a line of invention which Watt did not follow up, perhaps because so early as 1725 a non-con­densing engine had been described by Leupold in his *Theatrum Machinarum.* Leupold’s proposed engine is shown in fig. 8, which makes its action sufficiently clear. Watt’s aversion to high-pressure steam was strong, and its influence on

steam-engine practice long sur­

vived the expiry of his patents.

So much indeed was this the

case that the terms “high-

pressure” and “non-condens­

ing” were for many years

synonymous, in contra­

distinction to the “low-

pressure ” or condensing

engines of Watt. This

nomenclature no longer

holds ; in modern practice

many condensing engines

use as high pressures as

non-condensing engines,

and by doing so are able

to take advantage of

Watt’s great invention

of expansive working to a degree which was impossible in his own practice.

16. The introduction of the non-condensing and, at that time, relatively high-pressure engine, was effected in England by Trevithick and in America by Oliver Evans about 1800. Both Evans and Trevithick applied their engines to propel carriages on roads, and both used for boiler a cylindrical vessel with a cylindrical flue inside— the construction now known as the Cornish boiler. In partnership with Bull, Trevithick had previously made direct-acting pumping-engines, with an inverted cylinder set over and in line with the pump-rod, thus dispensing with the beam that had been a feature in all earlier forms. But in these “ Bull ” engines, as they were called, a con­denser was used, or, rather, the steam was condensed by a jet of cold water in the exhaust-pipe, and Boulton and Watt successfully opposed them as infringing Watt’s patents. To Trevithick belongs the distinguished honour of being the first to use a steam-carriage on a railway ; in 1804 he built a locomotive in the modern sense, to run on what had formerly been a horse-tramway in Wales, and it is noteworthy that the exhaust steam was discharged into the funnel to force the furnace draught, a device which, 25 years later, in the hands of George Stephenson, went far to make the locomotive what it is to-day. In this con­nexion it may be added that as early as 1769 a steam-