came down, this time in gear with the shaft, and doing work. The burnt gases were discharged during the last part of the down-stroke. A friction-coupling allowed the piston to be automatically thrown out of gear when rising, and into gear when descending. This “ atmospheric ” gas engine used about 40 cubic feet of gas per horse-power per hour, and came into somewhat extensive use in spite of its noisy and spasmodic action. After a few years it was displaced by a greatly improved type, in which the direct action of Lenoir’s engine was restored, but the gases were compressed before ignition.

253. Dr Otto’s “silent” engine, introduced in 1876, was the first successful motor of the modern type. It is a single-acting engine, generally horizontal in form, and the explosive mixture is compressed in the working cylinder itself. This is done by making the cycle of the action extend through two revolutions of the engine. During the first forward stroke gas and air are drawn in by the piston. During the first back-stroke the mixture is com­pressed into a large clearance space at the end of the cylinder. The mixture is then ignited, and the second forward stroke (which is the only working stroke in the cycle) is performed under the pressure of the heated pro­ducts of combustion. During the second back-stroke the products are discharged, with the exception of so much as remains in the clearance space, which serves to dilute the explosive mixture in the next cycle. The principal parts of Otto’s engine (as made by Messrs Crossley) are shown in the diagram section, fig. 144. The cylinder is kept

cool by a water-jacket AA. B

is the clearance space into which

the mixture is compressed before

explosion. Its volume is usually about two-thirds of the stroke, or 40 per cent. of the whole volume to which the gases afterwards expand. C is the exhaust-valve, which is opened during the second back-stroke of each cycle. Gas and air are admitted at D, through a slide-valve E, which reciprocates once in each complete cycle of two revolutions. This slide-valve is shown to a larger scale in fig. 145, in the position it occupies while gas is entering from *g* and air from *a.* To ignite the mixture a gas- jet is kept burning at *c.* In the slide-valve there is an igniting port *d,* which is supplied with gas from a groove in the cover. As the slide moves towards the right, the igniting port *d* carries a flame from *c* to D.

Just before reaching D a little of the compressed mixture from the cylinder enters the igniting port by a small open­ing which does not appear in the figure, and by the time D is reached the contents of *d* are so much raised in pres­sure by their own combustion that a tongue of flame shoots into the cylinder, firing the mixture there. The speed is regulated by a centrifugal governor, which cuts off the sup­ply of gas when the speed exceeds a certain limit. In some small Otto engines of recent construction the inertia of a reciprocating piece is used instead of the inertia of revolving pieces to effect the same end.

254. In Mr Clerk’s engine the cycle of operations is essentially the same as in Otto’s, but a charging cylinder

is introduced, with the effect of allowing an explosion to take place in the working cylinder once in every revolution. As in Otto’s, there is a large clearance space behind the piston, and the mixture is compressed into this space by the backward movement of the working piston. The peculiar­ity of the engine lies in the manner in which the charge is introduced. As the piston advances after an explosion it uncovers exhaust ports in the sides of the cylinder, close to the end of its forward stroke. While it is passing the dead-point there the plunger of the charging cylinder (which has meanwhile taken in a mixture of gas and air) delivers this mixture into the cylinder, driving the products of the previous combustion out of the cylinder through the exhaust ports. The charging cylinder is so arranged that the first part of the charge consists almost wholly of air, and this is followed by the explosive mixture of gas and air. The working piston then returns, closing the exhaust ports and compressing the mixture, which is ignited after compression by means of a slide-valve similar to Otto’s. In Otto’s engine the explosive mixture is diluted, and the sharpness of the explosion thereby reduced, by the residue of burnt products which fill the clearance space at the end of the discharge stroke. In Clerk’s en­gine the mixture is diluted by an excess of air. It does not appear that this difference has any material effect on the action.

255. Over 20,000 Otto engines are now in use, of power ranging up to about 40 H.P. Besides the engines which have been named, others are manufactured in which the

operations are essentially of the same kind, though in some cases the mechanical details are widely varied. In one of these, Mr Atkinson’s ingenious “ differen­tial ” engine, the working chamber consists of the space between two pistons working in one cylinder. During exhaust the pistons come close together ; they recede from each other to take in a fresh charge ; they approach for compression ; and finally they re­cede again very rapidly and farther than before, after ignition of the mixture, thus giving a comparatively large ratio of expansion. At the same time, by mov­ing bodily along through the cylinder, the pistons uncover admission and exhaust ports and an ignition-

tube, which is kept permanently incandescent.

256. If the explosion of a gaseous mixture were practi­cally instantaneous, producing at once all the heat due to the chemical reaction, and if the expansion and compres­sion were adiabatic, the theoretical indicator diagram of an engine of the Otto type would have the form shown in

fig. 146. OA represents the volume of clearance ; AB is the admission, at atmo­spheric pressure ; BC is the compression (which is assumed to be adiabatic) ; CD is the rise of pressure caused by explosion ; DE is adiabatic ex­pansion during the working stroke ; and EBA is the exhaust. The height of the point D above C may be calculated when we know the temperature at C (an element of considerable uncertainty in practice), the specific heat (at constant vol­ume) of the burnt mixture, the amount of heat evolved by explosion, and the change of specific density due to the change of chemical constitution which explosion brings about. With the proportion of coal-gas and air ordinarily employed this last consideration may generally be neg­lected, as the volume of the products would differ by less than 2 per cent. from the volume of the mixture before explosion if both were reduced to the same pressure and

temperature.

257. The rise of pressure observed in the indicator