diagrams of gas-engines is found to be in all cases much less than the calculated rise of pressure which would be caused by a strictly instantaneous explosion. An actual diagram from an Otto engine working in its normal manner is given in fig. 147, where the reference letters distinguish the parts of a complete cycle, as in fig. 146. It shows a rapid rise of pressure on explosion, so rapid that the vol­ume has not very materially altered when the maximum of pressure is reached ; and the specific heat at constant volume may therefore be used without serious error in calculating the amount of heat which this rise accounts for. When this calculation is made,@@1 it turns out that only about 60 or 70 per cent. of the potential heat of combustion in the mixture is required to produce the rise of temperature corresponding to the point of greatest pressure. The re­mainder continues to be slowly evolved during the subse­quent expansion of the hot gases. The process of com­bustion—a term evidently more appropriate than explosion

—is essentially gradual; when ignition takes place it be­gins rapidly, but it continues to go on at a diminishing rate throughout the stroke. That part which takes place after the maximum pressure is passed is the phenomenon of after-burning to which allusion has been made above.

258. The existence of “after-burning” is proved not only by the fact that the maximum pressure after ignition is much less than it would be if combustion were then com­plete, but also by the form which the curve of subsequent expansion takes. During expansion the gases are losing much heat by conduction through the cylinder walls. The water-jacket absorbs rather more than half of the whole heat developed in the engine,@@2 and the greater part of this is of course taken up from the gases during the working stroke. Notwithstanding this loss, the curve of expansion does not fall much below the adiabatic curve ; in some cases it even lies higher than the adiabatic curve. This shows that the loss to the sides of the cylinder is being made up by continued development of heat within the gas. The process of combustion is especially protracted when the explosive mixture is weak in gas ; the point of

maximum pressure then comes late in the stroke ; and it is probable that the products which are discharged in the exhaust contain some incom­pletely-burnt fuel. Fig. 148 is the indicator diagram of an Otto engine supplied with a mixture containing an ex­ceptionally large proportion of air : it exhibits well the

very gradual character of the explosion in such a case.

259. Much light has been thrown on this subject by the experiments of Mr Clerk, who has exploded mixtures of gas and air, and also mixtures of hydrogen and air, in a closed vessel furnished with an apparatus for recording the time-rate of variation of pressure. In these experi­ments the pressure fell after the explosion only on account of the cooling action of the containing walls. The tem­perature before ignition being known, it became possible to calculate from the diagrams of pressure the highest temperature reached during combustion (on the assump­tion that the specific heat of the gases remained unchanged

at high temperatures), and to compare this with the tem­perature which would have been produced had combustion been at once complete. Mixtures of gas and air were exploded, the proportion of gas varying from 1/15 to 1/5, and the highest temperature produced was generally a little more than half that which would have been reached by instantaneous combustion of the mixture. With the best proportion of coal-gas to air (1 to 6 or 7) the greatest pressure and hottest state was found one-twentieth of a second after ignition, and the temperature was then 1800° C.,—instead of 3800° , which would have been the value had all the heat been at once evolved. With the weakest mixtures about half a second was taken to reach a maxi­mum of temperature, and its value was 800° C., instead of 1800° C. In this case, however, the degree of com­pleteness of the combustion is not fairly shown by a com­parison of these temperatures, since much cooling occurred during the relatively long interval that preceded the instant of greatest pressure.

260. Ίο explain the phenomenon of after-burning or delayed combustion, it has been supposed that the high temperature to which the gases are raised in the first stages of the explosion prevents union from being com­pleted,—just as high temperature would dissociate the burnt gases were they already in chemical union,—until the fall of temperature by expansion and by the cooling action of the cylinder walls allows the process of union to go on. The maximum temperature attained in the gas- engine is high enough to cause a perceptible amount of dissociation of the burnt products ; it may therefore be admitted that this explanation of delayed combustion is to some extent true. On the other hand, the phenomenon is most noticeable with mixtures weak in gas, in which the maximum temperature reached is low, and the dis­sociation effect is correspondingly small. It appears, therefore, that dissociation is not the main cause of the action ; apart from it the process of combustion of a gaseous mixture is gradual, beginning fast and going on at a continuously-diminishing rate as the combustible mixture becomes more and more diluted by the portions already burnt. If the mixture is much diluted to begin with, the process is comparatively slow from the first.

261. Much stress has been laid by some makers of gas- engines on the desirability of having a stratified mixture of gases in the cylinder, with a part rich in gas near the ignition port and a greater proportion of residual product or air near the piston. It has even been supposed that stratification of the gases is the cause of their gradual combustion. Mr Clerk’s experiments are conclusive against this ; the mixtures he used, which gave in some cases very gradual explosions, were allowed to stand long enough to become sensibly homogeneous. In dealing with weak mixtures it is no doubt of advantage to have a small quantity of richer fluid close to the igniting port to start the ignition of the rest,—but beyond this stratification has probably little or no value. And it may be questioned whether, in the ordinary working of a gas-engine, any general stratification can occur, when account is taken of the commotion which the air and gas cause as they rush into the cylinder at a speed exceeding that of an express train.

262. A compression gas-engine of the Otto type burns from 20 to 25 cubic feet of coal-gas per hour per indicated horse-power. Good coal-gas has a heating power equiva­lent to about 500,000 foot-pounds per cubic foot, and hence, with a consumption of 20 cubic feet the efficiency which the engine realizes is nearly 0·2. The efficiency of a large steam-engine is about 0·14, and in steam-engines that are small enough to be fairly compared with actual gas-engines the efficiency is not more than 0·1. The superiority of gas-engines over steam-engines, from the

@@@1 See two important papers by Mr Dugald Clerk, “ Οn the Theory of the Gas- Engine,” and “ Οn the Explosion of Homogeneous Gaseous Mixtures,” *Min. Proc. Inst. C.E.,* 1882 and 1886. Reference should also be made, on the subject of gas- engines generally, to Mr Clerk’s book. *The Gas-Engine,* 1886.

@@@2 Clerk, *loc. cit.* Also, Brooks and Steward, *Van Nostrand’s Eng. Mag.,* 1883; Ayrton and Perry, *Phil. Mag.,* July 1884; Slaby, Report quoted in F. Jenkin’s *Lecture,* Inst. C.E., 1884.