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.

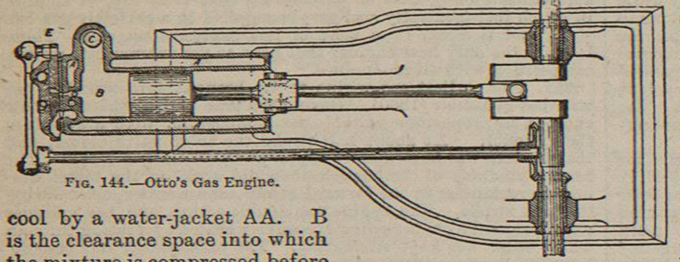

FIG. 144.—Otto's Gas Engine.

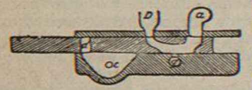

Fig. 145.

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.

Theoretical indicator diagram of Otto engine.

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.

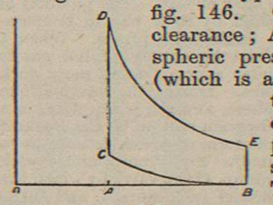

Fig. 146.

257. The rise of pressure observed in the indicator

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.

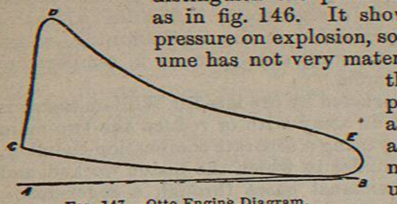

FIG. 147.—Otto Engine Diagram.

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.

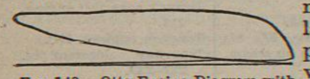
FIG. 148.—Otto Engine Diagram with weak explosive mixture.

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 $\frac{1}{15}$ to $\frac{1}{5}$, 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.

Dissociation.

260. To 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.

Stratification.

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

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[1] See two important papers by Mr Dugald Clerk, "On the Theory of the Gas-Engine," and "On 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.

thermodynamic point of view, is well shown by comparing their consumption of fuel. In the steam-engine we find in good engines of large size a consumption of 2 lb or $1\frac{3}{4}$ lb of coal per I.H.P. per hour, and by triple expansion this is reduced in large marine engines to about $1\frac{1}{3}$ lb. On the other hand, in small-power engines the consumption is at least $2\frac{1}{2}$ lb, and is generally 3 lb or more. When Mr Dowson's cheap gas,[1] which is produced by passing a mixture of superheated steam and air through red-hot anthracite, is used to drive an Otto engine, the consumption of coal has been found to be only 1·1 lb per I.H.P. per hour, or less than half the amount used by a steam-engine of similar size. What gives this comparison additional interest is the fact that the gas-producer for a 40 or 50 H.P. engine need not take up more space than the boiler of a steam-engine of the same power.

263. In another sense the gas-engine is much less perfect than the steam-engine. The actual efficiency of the latter is about half the ideal efficiency which a perfect engine would show when working through the same range of temperature. In the gas-engine the actual is less than one-fourth of the ideal efficiency. Taking the highest temperature as 1900° C.—a value reached in some of Mr Clerk's experiments—and the lowest temperature as 15° C., the efficiency of a perfect engine would be 0·87, while that of the actual engine is 0·2. This only means that the gas-engine has all the greater margin for future improvement.

264. At present the main causes of waste in gas-engines are the action of the sides of the cylinder and the water-jacket, and the high temperature of the exhaust gases The water-jacket absorbs about half the whole heat, only to keep the cylinder cool enough to permit of lubrication. The waste gases are discharged at a temperature of about 420° C., and so carry away a large amount of heat which might in part be saved by having a greater ratio of expansion, or by the use of a regenerator. Another source of thermodynamic imperfection is the after-burning, which gives heat to the working substance at a temperature lower than the maximum.

In an engine constructed by the late Sir William Siemens it was attempted to do away with or reduce the two main causes of loss—(1) by using a separate combustion-chamber, distinct from the cylinder in which the piston worked, and (2) by passing the exhaust gases through a regenerator, which afterwards gave up heat to the incoming air and gas.[2] The late Prof. Fleeming Jenkin endeavoured to attain the same ends by adapting the Stirling type of engine to internal combustion, a mixture of gas and air being exploded under a displacer like that of fig. 141. Practical difficulties have hitherto prevented regenerative internal-combustion engines from coming into use, but it can scarcely be doubted that their development is only a question of time. With regard to the probable future of heat-engines, it is important to notice that the internal-combustion engine using gaseous fuel, though already much more efficient than the steam-engine, is crude and full of defects which further invention ought to remove, while the steam-engine has been improved so far that little increase in its efficiency can be expected, and more than a little is impossible. (J. A. E.)

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[1] *Min. Proc. Inst. C.E.*, vol. lxxiii. p. 311.

[2] Siemens, "Discussion on the Theory of the Gas-Engine." *Min. Proc. Inst. C.E.*, 1882.

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The numerals refer to the sections.

STEAM HAMMER. See Hammer.

STEARINE, in commerce, designates a solid mixture of fatty acids (chiefly palmitic and stearic) which is being produced industrially from animal fats and used largely for the making of candles. In chemistry it is a generic term for the three "esters" derivable from glycerin, $C_3H_5(OH)_3$, by the replacement of one or more of the three (OH)'s by the residue $C_{18}H_{35}O_2$, which, in stearic acid, is combined with "H." Of these tri-stearine, $C_3H_5(C_{18}H_{35}O_2)_3$, is the most important; it occurs in animal fats only, largely in tallow. It crystallizes from ether in white pearly nodules, insoluble in cold but easily soluble in boiling alcohol. It can be distilled undecomposed *in vacuo*. On gradual exposure to higher temperatures it fuses at 55° C.; it then resolidifies, and then fuses again (permanently) at 71°·5 (Heintz). The specific gravity of the liquid is 0·9245 at 65°·5 C. (Duffy).

STEEL. See Iron.

STEELE, Sir Richard (1672–1729), one of the most active and prominent men of letters in the reign of Queen Anne, inseparably associated in the history of literature with his personal friend Addison. He cannot be said to have lost in reputation by the partnership, because he was far inferior to Addison in purely literary gift, and it is Addison's literary genius that has floated their joint work above merely journalistic celebrity; but the advantage was not all on Steele's side, inasmuch as his more brilliant coadjutor has usurped not a little of the merit rightly due to him. Steele's often-quoted generous acknowledgment of Addison's services in *The Tatler* has proved true in a somewhat different sense from that intended by the writer:—"I fared like a distressed prince, who calls in a powerful neighbour to his aid; I was undone by my auxiliary; when I had once called him in I could not subsist without dependence on him." The truth is that in this happy alliance the one was the complement of the other; and the balance of mutual advantage was much more nearly even than Steele claimed or posterity has generally allowed.

The famous literary pair were born in the same year, 1672,—Steele in Dublin, the senior by less than two months. Steele's father, who is said to have been a lawyer, died before he had reached his sixth year, but the boy found a protector in his maternal uncle, Henry Gascoigne, secretary and confidential agent to two successive dukes of Ormonde. Through his influence he was nominated to the Charterhouse in 1684, and there first met with Addison. Five years afterwards he proceeded to Oxford, and was a postmaster at Merton when Addison was a demy at Magdalen. Their schoolboy friendship was continued at the university, and probably helped to give a more serious turn to Steele's mind than his natural temperament would have taken under different companionship. Addison's reverend father also took an interest in the warm-hearted young Irishman; but their combined influence did not steady him sufficiently to keep his impulses within the lines of a regular career; without waiting for a degree he volunteered into the army, and served for some time as a cadet "under the command of the unfortunate duke of Ormonde." This escapade was made without his uncle's consent, and cost him, according to his own account, "the succession to a very good estate in the county of Wexford in Ireland." Still, he did not lack advancement in the profession he had chosen. A poem on the funeral of Queen Mary (1695), dedicated to Lord Cutts, colonel of the Coldstream Guards, brought him under the notice of that nobleman, who took the gentleman trooper into his household as a secretary, made him an officer in his own regiment, and ultimately procured for him a captaincy in Lord Lucas's fusiliers. His name was noted for promotion by King William, but the king's death took place before anything had been done for Captain Steele. He would seem to have remained in the army, though never on active service, for several years longer.

Steele probably owed the king's favour to honest admiration of the excellent principles of *The Christian Hero*, his first prose treatise, published in 1701. The "reformation of manners" was a cherished purpose with King William and his consort, which they tried to effect by proclamation and Act of Parliament; and a sensible well-written treatise, deploring the irregularity of the military character, and seeking to prove by examples—the king himself among the number—"that no principles but those of religion are sufficient to make a great man," was sure of attention. Steele complained that the reception of *The Christian Hero* by his comrades was not so respectful; they persisted in trying him by his own standard, and would not pass "the least levity in his words and actions" without protest. The sensitive and hot-headed "hero" would seem to have been teased into fighting a duel,—his first and last, for he wounded his antagonist dangerously, and from that time was a staunch opponent of affairs of honour. His uneasiness under the ridicule of his irreverent comrades had another curious result: it moved him to write a comedy. "It was now incumbent upon him," he says, "to enliven his character, for which reason he writ the comedy called *The Funeral*." Although, however, it was Steele's express purpose to free his character from the reproach of solemn dulness, and prove that he could write as smartly as another, he showed greater respect for decency than had for some time been the fashion on the stage. The purpose, afterwards more fully effected in his famous periodicals, of reconciling wit, good humour, and good breeding with virtuous conduct was already deliberately in Steele's mind when he wrote his first comedy. It was produced and published in 1701, was received on the stage with favour, and owing to its comparative purity helped, along with *The Christian Hero*, to commend its author to King William. In his next comedy, *The Lying Lover, or the Ladies' Friendship*, produced two years afterwards, in 1703, Steele's moral purpose was directly avowed; and the play, according to his own statement, was "damned for its piety." *The Tender Husband*, produced eighteen months later (in April 1705), though not less pure in tone, was more successful; in this play he gave unmistakable evidence of his happy genius for conceiving and embodying humorous types of character, putting on the stage the parents or grandparents of Squire Western, Tony Lumpkin, and Lydia Languish. It was seventeen years before Steele again tried his fortune on the stage with *The Conscious Lovers*, the best and most successful of his comedies, produced in 1722.

Meantime the gallant captain had turned aside to another kind of literary work, in which, with the assistance of his friend Addison, he obtained a more enduring reputation. There never was a time when literary talent was so much sought after and rewarded by statesmen. Addison had already been waited on in "his humble lodgings in the Haymarket," and advanced to office, when his friend the successful dramatist was appointed to the office of gazetteer. This was in May 1707. It was Steele's first connexion with journalism. The periodical was at that time taking the place of the pamphlet as an instrument for working on public opinion. *The Gazette* gave little opening for the play of Steele's lively pen, his main duty, as he says, having been to "keep the paper very innocent and very insipid"; but the position made him familiar with a new field of enterprise in which his inventive mind soon discerned materials for a project of