of the eastern counties was chosen for the purpose. The group includes the county with the largest acreage under each of the ten crops named, with the single exception of grass.

The results for wheat are of especial interest in connection with Dr. Shaw's conclusion as to the great importance of the autumn rainfall. Mr. Hooker confirms this, and finds, further, that the autumn is more important than any other period. The critical period is, however, probably somewhat shorter, the correlation of the produce with rain exhibiting a marked negative maximum for the thirty-seventh to forty-fourth weeks, the actual coefficient being −0·62; the coefficient with the rainfall of the cereal year as a whole is slightly greater still, viz. −0·69. There are two marked coefficients with the weather of the preceding summer, *i.e.* the summer of the year in which the seed for the crop was grown, viz. −0·49 with rain during the twenty-first to twenty-eighth weeks, and +0·51 with temperature for the twenty-ninth to thirty-sixth weeks, indicating absence of rain during the flowering period and warmth at harvest as necessary for good seed. For barley the chief requirement appears to be a cool summer, and for oats the same thing holds, but the latter crop also demands rain in spring, as indicated by a coefficient of +0·70. In the case of turnips, the highest coefficient, +0·55, is with the rainfall in June–July, *i.e.* the sowing season, this being partly due, in all probability, to the fact that in a dry season the turnip-fly will eat off a young crop almost as soon as it shows above the ground. In spite of prevalent opinion, there does not seem to be any need for rain in late summer. In the case of the hay crops, the great value of the rainfall in spring and early summer is very well brought out, the coefficients attaining sharply marked maximum values of more than 0·7 in the spring.

One conclusion of remarkable generality is reached, viz. the advantage of cool weather during the late spring and summer for all the crops dealt with (except, perhaps, potatoes). Taking the period between the ninth and twenty-eighth weeks of the year, all the four coefficients with temperature are negative in the case of barley, oats, turnips, mangolds, and hay; for wheat and for beans three of the four coefficients are negative. The correlation is with cool weather as such, and not with rain, as the effect of rain is practically eliminated by the method used. The result seems to indicate that grain and roots yield the most bulky crops if developed gradually and equably; neither rains nor heat, in fact, seem to be good for the crop for some time before harvest.

The paper also brings out very clearly another fact, viz. that the condition of the seed sown may be as important as the subsequent weather. As the condition of the seed is itself dependent on the weather of the year during which it was grown, this gives rise to the observed correlations between the crop and the weather of the seed year as well as that of the harvest year. Further, the meteorological conditions necessary for seed quality appear to be, broadly speaking, somewhat opposed to those necessary for a bulky crop. Thus, in the case of wheat, absence of rain during the flowering period and warmth at harvest were found to be necessary for good seed, but for a bulky crop cool weather is desirable. Considering all the coefficients with temperature for the ninth to thirty-sixth weeks, for wheat only one out of six is positive in the harvest year, five in the seed year; for barley none is positive in the harvest year, five in the seed year; for oats none in the harvest year, four in the seed year. This result would, by itself, suffice to account for the tendency observed in the case of cereals to an alternation of good and bad crops.

Although there is considerable uncertainty in some of the less well-marked results owing to the small number of observations available (twenty-one years), the application of the laborious methods used appears to have fully justified itself by the conclusions which have been thereby reached. How great the labour must have been may be judged from the number of correlation coefficients—between six and seven hundred—which have been tabulated by the author. The paper is published, with an abstract of the discussion which took place at the meeting, in the Journal of the Royal Statistical Society for March.

FLAME THE WORKING FLUID IN GAS AND PETROL ENGINES.[1]

FLAME produced by the combustion of inflammable gas or vapour and atmospheric air forms the working fluid of gas or petrol engines.

Mechanical power can be obtained by means of flame in several different methods:—

(1) By filling a vessel or cylinder with a mixture of gas and air, and igniting this mixture, a slight explosion is caused, and the excess pressure blows off through a valve. The temperature of the flame is very high, and so when it cools the pressure in the vessel is reduced below atmosphere. This reduction of pressure may be utilised by means of an engine operating by atmospheric pressure and discharging into a partly vacuous vessel, or by a piston moving into the vacuous vessel. This method may be called the explosion-vacuum method.

A modification of this method exists which may be called the flame-vacuum method. In it the explosion is dispensed with.

(2) By admitting a charge of atmospheric air and inflammable gas or vapour at atmospheric pressure to a cylinder containing a piston, cutting off access to the atmosphere and the gas supply, and igniting the mixed charge, a mild explosion occurs; the pressure rises in the cylinder, and the piston is driven forward to the end of its stroke.

(3) By supplying to a cylinder containing a piston a mixture of inflammable gas and air in a compressed state, and then igniting that mixture, a motive power can be obtained.

These last two methods, (2) and (3), are respectively known as the non-compression method and the compression method of operation in gas and petrol engines. The two methods were illustrated by a specially constructed apparatus. In this apparatus the cylinder of a petrol engine was mounted so that the piston reciprocated vertically, and a guide rod was fixed vertically on the cylinder. A hundred-pound weight was arranged to slide on this guide rod, and arrangements made by which a given charge of gas could be introduced into the cylinder. It was also arranged that the weight could be let down on to the piston, firstly so as to rest without compressing the charge, and secondly allowing compression of about 10 lb. per square inch. The mixture in the cylinder was ignited, and, in the case where the charge was not compressed, the weight was thrown up by the explosion and expansion a distance of about 10 inches. In the case where the charge was compressed, the weight was thrown up about 18 inches, showing clearly the increased effect of the explosion of a given charge when under compression.

It is believed that this is the first time the effect of compression has been shown as a lecture experiment.

(4) A cylinder is supplied with gas and air under pressure, but the mixture is ignited at a grating or shield as it enters the cylinder, and so the pressure in the cylinder never rises above the pressure at which it is supplied. The power here is obtained without any increase in pressure, and is due to the fact that a small volume of cool mixture, when inflamed, becomes a larger volume, so that although a pump may be used to compress mixture the expansion in the motor side is greater, although at the same pressure as the pressure in the pump.

These four modes of action were all illustrated by means of specially constructed apparatus, in which the effect of the working flame could be seen. The four modes of action, and combinations or modifications of them, include all the fundamental methods used in obtaining motive power from flame which have been attempted by mankind for the last hundred years. In the year 1820 the Rev. W. Cecil, of Cambridge, read a paper at the Cambridge Philosophical Society in which he described an engine which he had constructed to operate according to the explosion-vacuum method, and he states that at sixty revolutions per minute the explosions take place with perfect regularity. His engine consumed, he stated, 17·6 cubic feet of hydrogen gas per hour. He also mentions an engine operated in accordance with the second method, the non-compression explosion method, and one

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[1] Abstract of a discourse delivered at the Royal Institution on Friday, February 22, by Mr. Dugald Clerk.

also operated by gunpowder. This paper gives an account of the first gas engine which appears to have been worked in Britain or elsewhere.

Six years later Samuel Brown invented and built an ingenious engine, depending on the flame-vacuum method, which appears to have been the earliest gas engine ever worked on any considerable scale. In an early number of the *Mechanics' Magazine* it is stated that Brown succeeded with his engine in propelling a boat upon the Thames and in actuating a road locomotive. This vacuum method, however, never produced a really commercial engine, its only survival being the small engine shown as illustrating a modified form of class (1).

Many engines have been built using the atmospheric, or, as it is more commonly known, the non-compression explosion principle, but the most successful was that of Lenoir. The simplest engine of this type was one which was used in considerable numbers until a comparatively recent date—the Bischoff engine. In it a mixture of gas and air is drawn into the cylinder through suitable valves. As the piston passes an igniting aperture the flame is sucked in, the mixture ignites, and a small check valve closes the flame or touch-hole aperture. In the Lenoir engine, which was the most successful of this type, however, many of the modern characteristics are found, such as the water-jacket and ignition by the electric spark. The gas consumption, however, of all these engines was very high, rather more than 90 cubic feet per indicated horse-power per hour. The power obtained for given dimensions, too, was very small.

The first and second methods accordingly are not now used. Their disadvantages proved too great. In all modern gas or petrol engines the third method is used, that is, the charge of inflammable mixture is compressed before ignition.

Many attempts to construct engines operating on the compression principle were made before success was obtained. In such attempts England had a full share. One of the very earliest feasible compression gas engines was that described by William Barnett, an Englishman, in the year 1838. This engine had many of the features of successful engines of to-day. Later proposals were made for similar engines, both in France and in Germany; but the first inventor to succeed in overcoming difficulties to a sufficient extent to produce a commercial engine was the late Dr. Otto, of Deutz. To Dr. Otto belongs the honour of producing the first successful compression gas engine. The great majority of modern gas and petrol engines operate on what is now known as the Otto cycle. The production of a compressed charge in a motor cylinder in a safe, quiet, and economical manner is a much more difficult problem than appears at first sight. Those of us upon whom fell the brunt of working out this problem about thirty years ago appreciate fully the ability and knowledge displayed by the late Dr. Otto in producing his famous engine. In the Otto engine the characteristic feature is found in the alternate use of the same piston and cylinder for the purpose of pump and motor. In one complete revolution the cylinder is used as a pump, and in another complete revolution as a motor. The cycle is very simple.

The Otto cycle has many great advantages. The charging and discharging of the gases is accomplished easily. The heat flow through the sides of the cylinder is not too continuous, and consequently the cycle can be operated at very high speeds. Many attempts, however, have been made to obviate the main disadvantage of the Otto cycle, that is, the necessity for two complete revolutions for every power impulse. In 1881 the lecturer invented a cycle of operations which gave in the same cylinder one power impulse at each revolution. This cycle is now known as the Clerk cycle, and it comes next to the Otto cycle in order of number of engines now running in the world. Sections showing the operation of the Clerk cycle were shown. Its characteristic consists of open ports at the outer end of the stroke, which are overrun by the piston. The pressure in the cylinder rapidly falls to atmosphere, and a charge is forced into the cylinder at low pressure, about 2 lb. above atmosphere. This displaces the exhaust products remaining in the cylinder, and furnishes the fresh charge, which is compressed on the return stroke into a space at the end of the cylinder. This charge is ignited, and in this way a power impulse is obtained for every forward stroke of the piston. A second cylinder is required in order to supply the charge. The second cylinder is very light in construction, both as to the cylinder itself, the piston, and the connecting rod and cranks driving it. Working sections of a Clerk engine and Lanchester engine were shown.

The last thirty years have seen the greatest development, so far as practical matters are concerned, so that now more than two million horse-power of stationary gas engines operated by flame are in use in the world. It is difficult to form an estimate of the power of motor-car engines in use, but probably it now exceeds a million horse-power.

Although great progress has been made in the practical control and utilisation of flame and gaseous explosions for the purpose of producing motive power, little is as yet known as to the actual properties of the flame-working fluid so utilised. Accordingly, for the present it is not possible to formulate a complete theory of the internal-combustion motor. The subject is a difficult one, and involves not only the statical properties of these gases, but requires a knowledge of the conditions and rate of chemical combinations occurring in minute fractions of a second, and of the conditions of dissociation of compounds such as carbonic acid and steam at high temperatures under varying conditions of temperature and pressure. Many distinguished investigators have given the subject some attention. Bunsen in 1866 arranged a small glass tube with a safety valve, and weights to apply pressure to the valve. He provided platinum points between which the electric spark could be passed the whole length of the tubular vessel. This vessel was filled with various explosive mixtures, and ignited by the spark. The valve was loaded until it just blew off. This blow-off pressure was considered to be the maximum pressure produced by the explosion. Bunsen's apparatus was very crude, and could not have been expected to give accurate results. The maximum pressures must have far exceeded the pressures registered by his apparatus. Messrs. Mallard and Le Chatelier, and Berthelot and Vieulle, took up the subject of gaseous explosions, and made experiments also with numerous gases and oxygen, and coal-gas and air. A series of experiments was made by the lecturer in 1883. A Richards indicator, of the best construction known at that date, was used, and secured indications which were fairly trustworthy. Curves of explosion and cooling with coal-gas so obtained were shown. These experiments also showed clearly that the whole of the heat present was not evolved at maximum temperature, assuming the gases to have their ordinary specific heat at the high temperatures as well as low. Messrs. Mallard and Le Chatelier, and Berthelot and Vieulle, had come to the conclusion that the specific heat of the gases had been changed, and they considered combustion to be complete at the maximum temperature, or nearly so. The lecturer's experience with engine indicator cards, supplementing the experiments made with gas and air mixtures in a closed vessel, led to the view that combustion was not complete, and that therefore it was not safe to draw deductions as to varying specific heat without quite definite knowledge that chemical combination was completed before determinations were made of specific heat value. The absence of definite knowledge as to specific heats at high temperatures, dissociation, and rates of continued combustion, made it impossible to develop any complete theory of the internal-combustion motor.

To enable some investigation, however, to be made on different engine cycles, it appeared desirable to consider the gas engine as an air engine pure and simple, operated with air of constant specific heat, the air being a perfect gas and the chemical action being assumed as merely a means of heating the air through the desired temperature range. Calculating on this simplified theory, it became evident that the efficiency to be obtained in an air engine without heat losses was dependent upon compression mainly. Working out this theory showed that while the utmost that could be theoretically expected from a non-compression engine of the Lenoir type was 22 per cent., compression supplied means of getting theoretical efficiencies as high as 60 per cent., with practicable ranges of compressions. Considering, then, gas and petrol engines as air engines, the theory is very simple. There are three symmetrical cycles of compression air engines. It is interesting to note that for equal compressions it does not matter whether Carnot cycle, constant volume, or constant pressure engines be used—the theoretical efficiency is the same. It has been found in practice that a first-class modern engine operating on the constant-volume cycle will give in indicated power 0·7 of the heat which a perfect air engine would give under the same conditions of compression, proportions, &c. Thus an engine having an air-engine efficiency of 0·5 will give indicated work $0{\cdot}5 \times 0{\cdot}7 = 0{\cdot}35$, of all the heat given to it.

The air standard has proved its utility as a guide to the engineer for twenty-five years now, and has been adopted by a committee appointed by the Institution of Civil Engineers on the standards of efficiency in internal-combustion engines. To enable further progress to be made, however, it is now necessary to know more of the actual properties of the working fluid.

The earlier experiments made by the lecturer, and subsequent experiments made by Oliver in America, and by Messrs. Bairstow and Alexander in this country, were only in strictness applicable to the behaviour of highly heated gases in a closed vessel. No means of obtaining a cooling curve in an engine cylinder had been proposed.

At the beginning of 1905 the lecturer designed a new method, and made a considerable number of experiments on a 50-horse-power gas engine. By altering the valve arrangements of the engine so that when desired both inlet charge valve and exhaust valve can be held closed, diagrams were obtained from which a cooling curve was calculated.

In this method no gases are allowed to exhaust from the cylinder. The piston accordingly compresses the whole contents into the compression space, and the temperature which has fallen by expansion rises by compression. A point is touched on a vertical line from the end of the card. On expanding, a line below the first compression line is traced, then another compression line is obtained, and so on; a series of compression and expansion lines is obtained, each terminating under compression at certain specific points.

In this way a cooling curve is obtained which shows the real temperature drop upon the expanding and compressing lines. From this curve, by somewhat troublesome calculations, the mean apparent specific heat of the charge can be obtained for each expanding line. A curve of specific heats so obtained was shown.

These numbers give a very fair indication of the heat loss incurred in the cylinder, and the cooling curves show that for the whole stroke the mean temperature of the whole enclosing walls is about 70° C. when the water-jacket is cold and about 200° C. when the water-jacket is hot, but for the inner part of the stroke, the first three-tenths of the stroke, the mean temperature is much higher —170° C. when cold and 400° C. when hot.

This method of investigation gives a more accurate knowledge of the properties of the working fluid, so far as the thermodynamics of the engine are concerned, and it enables us to make an entire heat balance-sheet from the diagram only. Full-load diagrams taken from the engine have been examined by this method, and account for 105 thermal units, when the calorimeter shows 106 thermal units to be present. The method appears capable of very considerable accuracy.

Prof. Hopkinson has attacked the problem of heat loss to the closed vessel by another method, using a calorimeter by which the heat leaving the hot gases at any time is measured electrically, while at the same time the pressure is indicated. This arrangement promises to give important information as to the rate of loss in gaseous explosions, from which observations some deductions may be drawn as to specific heat and as to time of termination of combustion.

The lecturer is continuing investigations on various sizes of engines with a new form of optical indicator. An indicator card taken with this instrument was shown. The appearance of this indicator card is most interesting. There is slight discontinuity in the rising line, and just as maximum pressure is approached the indicator begins to oscillate rapidly through a small distance. These oscillations continue all down the explosion stroke, die out gradually, and do not terminate until the end of the compression stroke. The period of the oscillations is about 600 per second; the amplitude gradually decreases until it has practically ceased at the end of the first compression.

The period of the indicator is about 200 to the second, so far as ordinary piston displacement is concerned. From this it follows that considerable pressure disturbances within the cylinder must have occasioned the oscillation. In this particular engine, the explosion is always accompanied by a peculiar whistling sound, which seems to start just about the time the diagrams show the beginning of the oscillations, that is, immediately after ignition. It is somewhat difficult to account for this peculiar action, but it appears to have some connection with the discontinuous nature of combustion of a mixture of inflammable gas or vapour with air. This was illustrated by an experiment in which inflammable mixture was ignited at the open end of a long tube. The flame travels back along the tube, accompanied at first by a low, roaring sound, which increases in intensity as the end of the tube is reached, terminating in a loud snap. When this occurs, the flame flashes back again, and there is obvious oscillation of some kind proceeding. It is not known why the mixture flame burns in this way, but this particular roaring or whistling seems to occur only when combustion is going on, and is noticed in all pressure flames in the open air. It appears highly probable, then, that wherever this oscillation goes on combustion is still proceeding.

Experiments have also been made by Messrs. Holborn and Austen on the specific heat of air and carbonic acid by an entirely different method, and there is reason to hope that as a result of experiments which are progressing in this country and on the Continent the whole question will be cleared up in the next few years in a satisfactory manner.

As one who has given thirty years' study to the practical and scientific problems involved in this matter, it is exceedingly gratifying to find a great and increasing interest in the subject which will lead to the complete investigation of the complex properties of the working fluid.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

DR. W. PEDDIE, lecturer in natural philosophy in the University of Edinburgh, has been appointed to the Harris chair of physics in University College, Dundee, in succession to Prof. Kuenen.

PROF. MIALL, F.R.S., who was appointed professor of biology in the Yorkshire College of Science in 1876, is retiring from his chair in the University of Leeds at the end of the present session. We understand that the council has decided to establish separate chairs of zoology and botany, and will shortly proceed to appoint professors of these subjects.

THE province of Saskatchewan is only eighteen months old, but already (says the *Times*) it is devoting its resources to the establishment of a State university. A Bill just introduced by the Provincial Government in the Legislative Assembly at Regina provides for the incorporation of such a university under a chancellor, convocation, senate, board of governors, and council. The number and nature of the faculties to be established will be decided by the university senate. The maintenance of the university is to be provided out of the general revenues of the province and also by a percentage of the net receipts of the province under the Succession Duties Ordinance.

THERE has been serious divergence of opinion for more than two years as to the policy of the Marine Biological Association of the West of Scotland. This association was founded in order, according to the first article of its constitution, to investigate the marine fauna and flora of the Clyde sea area, to maintain a biological station at Millport or other suitable locality, and generally to foster and encourage biological research. At the annual meeting of the association on March 27 an amendment was carried by a majority of one vote "that while approving generally