Mr. G. Crispe said, after the philosophical toys of the early experimenters, the first approach to a practical caloric engine was that invented by Sir George Cayley (Assoc. Inst. C.E.), and described in Nicholson's Journal in 1807.[1] For many years his attention was almost exclusively devoted to the subject, and eventually, in 1837, one of these machines was reported by Mr. Goldsworthy Gurney and Mr. G. Rennie (M. Inst. C.E.), to be doing a duty equal to 5 H.P., with an expenditure of 20 lbs. to 22 lbs. of coke per hour. The chief defects appeared to be the difficulty of lubricating the piston, and the abrasion of the working parts, from the dirt apparently inseparable from the air, which had passed through the incandescent fuel.

In 1816, the Rev. Dr. R. Stirling took out a patent for an air-engine,[2] differing in all important particulars from that of Sir G. Cayley. The new machine resembled the steam-engine in the construction and arrangement of many of its parts, such as the cylinder, piston, piston-rod, parallel motion, beam, crank, &c. Motion was obtained, by heating the air in communication with one side of the piston, and cooling that in connection with the other, by which means a difference of pressure was obtained upon the opposite sides. The air was alternately heated and cooled, by having the air-chambers, one of which was connected with the top, and the other with the bottom of the cylinder, fixed respectively over two fires, by which their lower ends were kept at a temperature of about 600° Fah^{t}., whilst their upper parts were kept cool; the air, by the aid of a plunger, being made to occupy the top in one chamber, and the bottom in the other, alternately. Dr. Stirling also introduced and patented at the time, what had since been called the "regenerator," the object of which was to save a portion of that heat, which would otherwise be lost in cooling the air at each stroke of the engine: it consisted of a series of laminæ of metal, between which the heated air passed, in its progress from the bottom to the top of the air-chamber. The metallic surfaces became heated by contact with the air, which heat they retained, until the air, in its return from the top to the bottom, in its cool state, had to make its way through them, in the opposite direc-

[1] Vide Nicholson's Journal, vol. xviii., November, 1807, page 260.

[2] Vide "Repertory of Patent Inventions," vol. xxx., page 63. Date of Patent, November 16, 1816.

tion; in the return stroke it took up from them the heat which they had just received; and in proportion to the amount of heat kept back, by those means, was the saving of fuel effected. Another patent was taken in 1827 by Messrs. R. and J. Stirling.[1] An engine of the kind described was erected at the Dundee Foundry in 1843, and continued to do the work of the establishment for about four years. Mr. Stirling in describing the machine, at a meeting of this Institution in 1845,[2] stated that the economy of fuel in using the air-engine in place of steam was as 6 to 26.

Mr. Stirling had recourse to surrounding the cylinder with water, for the purpose of cooling the air, and it was evident, that one of the main features of his invention was the "regenerator," for which he at first used wire gauze, then he tried metallic discs, and at last he adopted metal plates. Whether the theory of this "regenerator" was practically borne out, or not, there could be little doubt of the invention being due to Messrs. Stirling, and up to the period of the announcement of the caloric-engines on board the 'Ericsson,' they had certainly obtained the most satisfactory results.

In 1827, Messrs. Parkinson and Crosley, well known as the inventors and manufacturers of the gas-meters bearing their name, patented a modification of the air-engine.[3] It consisted of a close cylindrical air-chamber, with its plunger piston, immersed midway in cold water and a ring of jets of gas encircling its upper part; the piston rod traversing by a stuffing box. Connected with the upper part was a working cylinder, open at the top, but with a piston and rod fitted within it. The air contained within the chamber, when at the top, being heated by contact with its hot sides, was in consequence expanded. A portion making its way through the opening into the working cylinder, pressed the piston upwards. By a proper communication of parts, this was made to give motion to the plunger, so that by the time the piston was at the top of its cylinder, the plunger had reached the top of the air-chamber.

---

[1] Vide "Repertory of Patent Inventions," vol. vi., page 100. Date of Patent, February 1, 1827.

[2] Vide "Minutes of Proceedings Inst. C. E.," 1845, vol. iv., page 348.

[3] Vide "Repertory of Patent Inventions," vol. vii., page 414. Date of Patent, August 1, 1827.

The result was evident, the air made its way down past it to the cold end of the chamber, became cooled and contracted; the piston descended, and after it the plunger: so that the operation might be repeated *ad infinitum.* It had only been tried as a model, but the rapidity with which the model worked was very remarkable. The speed was usually kept down to about 150 strokes per minute, although there seemed no reason to doubt that it would make 1500 strokes, if the experiment were ventured on. It was instructive, as showing how rapidly air might be heated and cooled.

In 1826 Lieutenant (now Captain) Ericsson, a native of the province of Vermeland, in Sweden, came to England for the purpose of introducing an air-engine, which he had invented; but, after using every exertion, the difficulties were found to be too great, and the project was soon abandoned.

He tried a long series of experiments upon a machine of considerable dimensions at the works of Messrs. Braithwaite and Co., and placed on record in the archives of this Institution the results of his invention.[1]

In 1850 a modification of the system was patented by Captain Ericsson, under the name of Edward Dunn,[2] and that machine, as now improved, was, it appeared, now erected in the caloric ship "Ericsson."

The general construction of the modern caloric-engine, as given in the descriptions transmitted to this country, was a working cylinder, beneath which a fire was made to elevate the temperature of the air within it. Under the piston of the cylinder a vessel was fixed and filled with non-conducting materials, called the heat-interceptor, its office being to prevent the heated air from coming in contact with the main body of the piston, and thus to keep it cool—an expedient which was adopted by Sir George Cayley for the same purpose, in connexion with his air-engine, and patented by him in 1838. Inverted above the working cylinder was the air-pump, or supply-cylinder, with its piston and valves, the relative areas of the upper and lower

[1] Vide O. C., No. 119, "Description of a new method of employing the Combustion of Fuel as a Motive Power," by T. Ericsson, 1827.

[2] Vide "Repertory of Patent Inventions," vol. xviii., page 93. Date of Patent, December 26, 1850.

cylinders being as 2 to 3. Air being taken in through one valve from the atmosphere, and discharged through another valve into the receiver, placed at the side, and communicating with the top of the upper cylinder and the bottom of the lower, or heating-chamber, by the slide-valve, which could be closed at pleasure.

When the slide-valve was closed, to prevent a communication between the receiver and the working cylinder, it, at the same time, opened a communication between the working cylinder, and the atmosphere under the valve, and through an opening into the regenerator, consisting of a number of layers of wire gauze, through which the air had to pass, both in its entrance to, and exit from, the cylinder.

The *modus operandi* of the engine was this: the engineer, having seen to the lighting of the fires, permitted the temperature of the lower part of the cylinder and the parts adjacent, to reach a temperature of 540°; then closing the slide-valve, he proceeded, with a hand-pump, to force atmospheric air into the receiver, until it had attained a pressure of some few pounds to the square inch. These arrangements completed, everything was ready for starting. He then, by the aid of such hand-gear as was usual in steam-engines, threw the slide-valve into such a position as would allow the compressed air to make its way into the working cylinder.

Imagining, then, everything to be perfectly cold—regenerator, fire, supply-cylinder, all removed; still, upon opening the slide-valve (as before described), the piston in the working cylinder would be elevated. When it had reached the top of its stroke, let the slide-valve be closed: no more air could then enter, and that already within the cylinder would make its escape under the slide-valve into the atmosphere, and thus allow the piston to descend by its own weight. When it once more reached the bottom of the cylinder, if the slide was again opened, there would be a repetition of the action just described; and this might evidently be repeated, as long as the necessary supply of air could be maintained in the receiver, precisely as a high-pressure steam-engine continued to work, whilst steam was supplied from the boiler.

But since as much air must be supplied to the receiver, at each stroke of the engine, as was removed by the working cylinder, if the air in that cylinder were of the same temperature as the air supplied to the receiver, a pump must be employed for the purpose as large as the cylinder itself, and more power would, in consequence, be required to work it, than the compressed air could possibly give. By the application of heat, however, every cubic foot of air, forced in by the pump, was doubled in volume, consequently the power required to work it was reduced, because a pump of smaller size answered the same purpose, and thus a surplus of available power was obtained.

The office of the heat, then, was not to increase the pressure of the air, when once it had entered the working cylinder (this, under the circumstances, it could not do), but, in reality, to increase its volume with the elevation of the large piston, thus making the same quantity of air fill double the space, and yet keep up the original pressure of the cold air pumped into the receiver.

The 'regenerator'—a very important feature in the contrivance, remained yet to be spoken of. As before stated, it consisted of a series of layers of iron-wire gauze, through the meshes of which the heated air had to pass, in its passage from the cylinder to the atmosphere, and which, as it came in contact with each successive layer, parted with more and more of its heat, until, before it quitted the last, it was said to be not more than about 30° or 40° hotter than the atmosphere itself. The heat left by the escaping air was supposed to be distributed in the regenerator, in such a manner, that next the cylinder the temperature was almost equal to that of the air within, whilst next the slide-valve it was but little above that of the external air.

The heat, thus taken up by the regenerator, was retained by it, until the piston, having reached the bottom of the cylinder, a fresh supply of air was allowed to enter it from the receiver; this cold air, in its passage through the regenerator, became heated, as the escaping air became cooled, by contact with the metal surfaces, and consequently entered the cylinder with its temperature considerably elevated, requiring, in consequence, so much less heat to be imparted by the fuel employed.

It was, however, contended by the opponents of the system, that the action could not be such as was stated, and that the regenerator could not make any difference to the amount of fuel employed. It was to be regretted, that those who took this view had not yet offered any adequate philosophical reason for their opinion, because, when once it was fairly shown, that there was some natural law opposed to it, the question was settled, and much valuable time and money would be saved. In the absence of this the question must be examined *pro* and *con*, as it was now popularly presented. The air in the cylinder had a temperature of say 540°, *i. e.*, about 480° above that of the atmosphere—at which temperature, according to Dulong and Petit, its original volume was doubled; upon escaping into the atmosphere, through the regenerator, from the fact of its having been employed in the cylinder under pressure, it expanded, and in so doing took up a certain amount of heat in the latent form (about 8 degrees for every pound of pressure). For instance, if the air in the cylinder had a temperature of 540°, and a pressure of 5 lbs. per inch, above that of the atmosphere, upon expanding to the pressure of the atmosphere, it would exhibit a temperature of 500° only, the 40° having become latent. Now since the air could not, by contact with the metallic surfaces, make them hotter than itself, it would at once appear, that these 40° of heat were lost, but the 500° remaining were tangible heat; which, for comparison, might be likened to that of hot iron,—heat which could be measured by a thermometer, and which would pass from one body to another by contact. If then the layers of wire gauze, through which the air had to pass, were of a low temperature, this air would assuredly pass out from it at a lower temperature than it entered. And it could not be doubted, that if cold air was made to pass through the hot gauze, its temperature would be raised, and that so much heat as it received in this way, so much less would the fuel have to give. In reference to either the quantity, or pressure of the air in the cylinder, it would be seen, that it made no difference whatever, whether it was heated by the regenerator, or by the bottom plates of the cylinder itself. The question might arise, however, whether the air, in passing through the gauze at the rate of 12 feet per second, had time to yield up, or to take up the heat in any quantity; in reference to this, the rapidity with which the air was capable of being heated and cooled in Parkinson's engine, had been already referred to, and many other examples of a similar character were familiar to engineers.

The practical objections to the general arrangement of the engine were numerous, and of such a character as, even supposing all others to be removed, would doubtless prove fatal to its ultimate success. For instance, the theoretical effect due to the air in this engine,—supposing it to make ten strokes per minute, and its volume to be doubled by heat,—was 763 H. P. Its actual effect in the working cylinder should be 600 H. P.; and out of this, 374 H. P. would be required to work the pump, leaving available only 226 H. P., or less than one-third of the power due to the air. Again, from the fact of the pressure obtainable being small, and operating only upon one side of the piston, it became necessary to have an enormous extent of piston surface. In the 'Ericsson,' for instance, four engines, such as that described, were employed with working cylinders 14 feet in diameter; also four air-pumps, or supply-cylinders, each between 11 and 12 feet in diameter, creating a vast amount of friction and liability to leakage; and in a case, be it remarked, where leakage was of the utmost importance. It was not possible, as in a steam-engine, to push on the fires to overcome the difficulty, as such a proceeding, carried beyond a certain point, would evidently be fatal to the heating-vessels. Mr. Stirling was compelled to abandon his engine, chiefly on account of the difficulty experienced in preserving his air-vessels. The plan which Captain Ericsson at present employed for heating them, was the same as that which Mr. Stirling commenced with thirty years since, and which he afterwards greatly improved upon, and yet failed. There was then no apparent reason for believing, therefore, that, by the present arrangement, Captain Ericsson could be more fortunate than his predecessor.[1]

---

[1] At the meeting of the British Association, at Liverpool, in September 1854, Mr. W. J. Macquorn Rankine, Assoc. Inst. C. E., read a paper "On the means of realizing the advantages of the Air Engine;" in which were explained the fundamental laws of the mechanical action of heat, and their application to determine the efficiency of theoretically perfect engines, working between given limits of temperature; then the "various causes of waste of heat and power in steam-engines were classified, and the actual efficiency of steam-engines was compared with their maximum theoretical efficiency, and also with the maximum actual efficiency, which might reasonably be supposed to be attainable in the steam-engine, by means of any probable mechanical improvements.

"The causes of waste of heat and power in air engines, were then classified in a manner analogous to that applied to steam-engines; and the actual effici-

Mr. Goldsworthy Gurney said it was well known, how long Sir G. Cayley's attention had been devoted to the subject of using heated air as a motive power; indeed the air-engine might be said to have originated with him. Sir George Cayley was prevented by indisposition from coming to London, to be present at the discussion, but he had transmitted to the Secretary, a few remarks, which had been understood to have received the approval of the Council, and Mr. Gurney would therefore ask that they might be read to the meeting.

The Secretary, by permission of the President, then read the following:—

"Remarks on the Use of Heated Air as a Motive Power. By Sir George Cayley, Bart., Assoc. Inst. C.E.

"The free power of Captain Ericsson's engine, arises from the difference of the areas, of the hot and the cold pistons; both receiving, in opposition to each other, during their combined

---

encies of those previous air-engines, as to which satisfactory experimental data had been obtained, namely, Stirling's engine and Ericsson's engine of 1852, were compared with the efficiencies of theoretically perfect engines, working between the same limits of temperature, the results, so far as they related to the consumption of coal of the specified quality per horse-power per hour being:—

	Actual Consumption.	Consumption of a Theoretically Perfect Engine.
Stirling's engine	2·20 lbs.	0·73 lbs.
Ericsson's engine	2·80 ,,	0·82 ,,

"Thus showing that an air-engine had actually been made to work successfully, and economically.

"A description was then given of the improved air-engine of Messrs. J. R. Napier and W. J. Macquorn Rankine. In this engine, the heating surface was increased to any required extent, by means of tubes employed in a peculiar manner. The waste of heat, by its communication to the air, at improper periods of the stroke, was prevented by a sort of plunger called the heat-screen, which prevented any access of the air to the heating surface, except when it was in the act of expanding, and so performing work. The engine might be made of the same size with a steam-engine of the same power, or smaller, according to the degree of condensation at which the air was employed.

"Independently of the amount and value of the saving of fuel, which would result from the introduction of the air-engine, it possessed the important and incontestable advantage, that even should an air-receiver burst (which was very unlikely), the explosion would be harmless, for its force would not be felt beyond the limits of the engine itself, and hot air did not scald." In the Mechanic's Magazine of October 21, 1854, there is given a diagram and short description of this engine.—Editor.

stroke, an equal average pressure per square inch, from an equal head; but the conditions of the case are such, that neither piston receives a uniform pressure during the whole of its stroke.

"When the cold air is doubled in bulk, by a temperature of say 530°, a head of 15 lbs. per square inch is obtained; and this head must be kept up for the uniform working of the engine: hence, (this head having been previously generated, for starting the engine, by injecting water on the fire, or by mechanical condensation,) only an equal weight of hot air can be permitted to escape at each stroke, with that of the cold air driven in.

"The cold pump, working against a head of 15 lbs. per square inch, will move half its stroke, gradually condensing the air within its cylinder, at an average of about 7½ lbs. It then proceeds for the other half of its stroke, against the head of 15 lbs.; averaging 11·25 lbs. to the square inch, for the whole stroke.

"On the other hand, the full pressure of 15 lbs. per inch is allowed to operate on the hot piston, for the first half of its stroke, when the supply from the head must be cut off; and the remainder be performed, under the gradual diminution of the pressure, by expansion. So that at the end of the stroke the air passes out at par with the atmospheric pressure. Here, as in the former case, half the stroke is done at 15 lbs., and the remainder at 7½ lbs., averaging 11·25 lbs. per square inch, as before. Thus the two pistons keep the same ratio, in the average of their strokes, though in the reverse order, as to the increase and decrease of the pressure upon them. Hence, as before remarked, the free power of the engine is as the difference of the areas of the pistons, multiplied by the average pressure upon them (not by the full pressure of the head) minus the friction on both: and again by the number of strokes per minute, and the length of each stroke.

"From whatever source the heat be supplied, that expands the cold air to double its bulk, the expansion must have the same dynamic effect. Hence the case of the regenerator, as applied by Captain Ericsson, is reduced merely to the following consideration. Does caloric, generated by combustion, differ from itself, after being applied to a solid metallic body? Suppose a mass of red-hot iron taken out of a fire, to be put into a vessel full of cold air, will it, or will it not expand it just in proportion to the heat communicated by conduction? By what process do steam-engines work, but by iron plates, heated by fire on one side, and transmitting that heat to water, and its steam on the other? The tendency of heat, is, with reference to mere temperature, ever to equalise itself with all contiguous bodies, according to their specific demands; and this can only take place, by its being communicated from one body to the other. Steam-engine power to some extent depends upon the heated air in the fire-flues, being cooled by the iron sides, or pipes of the boiler, in generating the steam; thus the heat of the air, from combustion, is transferred, and being so transferred, it creates power. In what then does this case differ, in principle, from the metallic meshes of Captain Ericsson's engine, heated by a similar flow of hot air? There can exist no doubt of the effective re-application of heat to an almost unlimited extent, by this beautiful invention, due originally to Mr. Stirling, and now carried out to a greater extent by Captain Ericsson.

"The approach to perpetual motion by this repetition of the action, has been considered as a refutation of the principle; but it must be recollected, that a principle of perpetuity pervades some of the most simple acts under natural laws. When a billiard ball is propelled on a smooth horizontal plain, if it were not for the resistance of the air and friction, the law of its nature would cause it to roll on for ever. The slight escape of heat from the imperfect non-conductors used in the caloric engine, resembles the friction that prevents the action of the rolling ball from being perpetual. A perfect non-conductor of heat, would render the case as nearly interminable, as the very slight loss of it, by the current of air, in its exit, not having had full time to divide its ultimate extra caloric with the last series of meshes, would permit.

"There are, as has already been observed, several difficulties attending the construction of air-engines. The main one is the bulk of the cylinders, and other parts of the engine to make good the small pressure per square inch, that can be obtained without extra condensation, which is objectionable on account of the leakage it occasions.

"Another objection, is the heat the pistons may be exposed to, without considerable precautions being taken to prevent it.

"The dust from the coke was, in some constructions of the first air-engines, where the whole heat generated by combustion, was received by the air in an air-tight generator, found inconvenient for the sufficient lubrication of the pistons, although in a great measure shielded from the heat, by the plungers. It may prove difficult to combine the economical production of heat, by consuming the fuel in an air-tight vessel; with the principle of its continued application by the regenerator, as the fine wire meshes may get so clogged up by the loaded vapour, or, external oxidation, as to impede that rapid absorption and restoration of caloric, on which their efficacy depends; but it must be hoped that even such a primary result, will not eventually prove beyond the remedy of chemical science, applied with mechanical skill; and should this combination be ever practically carried out, the consumption of fuel in the air-engine will be reduced to an infinitesimal quantity. The attention of some of the members of this Society, will therefore not be ill-directed, when applied to the utmost practicable improvement in the means of using air as a motive power.

"For locomotive purposes, on shore, it seems probable, that steam and air can only come into competition with each other, by their expansion—the weight of water necessary for the condensation of the steam; and the slowness with which air can be cooled, render both inapplicable, by condensation, for speedy locomotion.

"When water has been converted into steam, from its mean *temperature, by the application of 1127° of heat, it may then,* if the supply be cut off, be doubled in volume, under atmospheric pressure, at a temperature of 692° (212° + 480°), a very inconvenient heat for any piston, and if steam has to be brought up to this temperature, by an external fire, and its flues, the whole of the air heated by combustion must part from the boiler, under the best construction, at a temperature rather exceeding 692°; a heat considerably greater than that required to work the air-engine, is, therefore, in this case, totally wasted. But steam will exceed atmospheric pressure (15lb. to the square inch), when remaining in contact with the boiling water, at a temperature of 250°, when its density is very nearly doubled, and the caloric required is increased in much the same ratio; it is, therefore, by far the most economical way to form steam, required expansively, by using the air-tight generator, and driving the whole heated air, in streamlets of minute bubbles, rising through the water. The difficulties, as to the dust and the heat of the pistons, stated to have been experienced, only had reference to the engine of 5 H.P, then under notice at Millbank.

"The report of the meeting of June 10, 1845, is incorrect in two points. It is there stated, that the slide-valves were torn by the dust (which was correct), and that the conical valves, though, in some degree, avoiding the evil, were considerably abraded, also the passages, the pistons, and the cylinders were destroyed by the heat and dust. It is true that the pistons were injured, but neither the cylinders, nor passages, nor conical valves were hurt. It is stated also that the evil of the heat of the piston was attempted to be obviated by appending a drum "below the piston;" now this drum, or plunger, was placed above the piston in every engine made, and therefore, could not have been spoken of as being below it.[1]

"A one horse-power engine, previously made, had very little, if any, of these defects, and it was from two accidental circumstances a much better engine, though prior in the order of construction. The hot cylinder, being made of sheet copper, which cools with double the rapidity of iron, and much more than double in this case, from the quadruple thickness of the iron ones, kept the working part of the piston from injury, aided by the plunger; and the more than double area of the generator, in proportion to the air driven through it in a given time, nearly cured the evil of dust; it had also conical valves, which were quite uninjured.

"From circumstances distinct from the nature of the evils the Millbank engine had shown, and which probably a water-jacket would have much remedied, no further experiments were made with it.

"The one-horse engine, when examined by Mr. Gurney, worked perfectly well for several days in succession, while being tested by friction both to ascertain its power and its consumption of fuel. It is no bad omen that so small an engine, where there was so much more heated and rubbing surface, in proportion to its power, than in larger engines, without any attempt

[1] Vide Minutes of Proceedings, Inst. C. E., 1845, vol. iv., page 359.

to economize heat by non-conducting covers, should have produced a horse-power by the expenditure of 7 lbs. of coke per hour. It is right to state these matters, that a true view of the case may not be wanting, towards a further experimental investigation of the subject. The exact particulars of this engine are these :—

"In the single-horse engine;—the cold piston $10\frac{1}{2}$ inches in diameter; the hot one, $13\frac{1}{2}$ inches, both a foot stroke; the fire-place 10 inches in diameter, by 11 deep, within a generator containing about 20 cubic feet of air; head of pressure, by mercurial gauge, from 8 to 9 lbs., made ninety strokes per minute, that is, ninety revolutions of the fly-wheel. The weight of 550 lbs., raised one foot high, per second, being taken as the test of one-horse power.

"The air, or mixed air and steam engines, with the internal combustion of the fuel, may be made to imitate animal muscular power, in as instantaneous and violent an increase of action, by a small jet of water on the fire; this instantly produces the effect for a limited time. Oil of tar, or other inflammable fluids, might perhaps prolong this action considerably."[1]

---

[1] Although the experimental air-engines have not had the advantage of Mr. Stirling's, or Captain Ericsson's renovators of heat, yet having made use of all the heat generated by the combustion taking place within the reservoir, containing the head of expanded air, very much compensates for that deficiency, and is undoubtedly the most economical way of communicating heat to the air. Theoretically, according to present chemical data (at the particular degrees of caloric and condensation specified), it would require about one pound and a half of dry charcoal to sustain one horse-power for an hour, by the expansion of air, were there no loss by external cooling: and although the products of this internal combustion may render the application of Captain Ericsson's wire-gauge meshes more difficult; yet the economy in generating the caloric is so great, as will probably render this ultimate refinement of the engine of more cost and trouble than advantage, in a mercantile point of view.

Engineers should be induced to carry out the internal combustion principle, at present, and subsequently to test the Ericsson principle, in connexion with it. The plunger, which is almost an indispensable part of the air-engine, as by its means the working portion of the piston may be kept at any required moderate temperature, deserves some notice; as experience has proved, that hitherto it has never been taken advantage of to the proper extent. It was first thought of and applied by Sir G. Cayley to the engine made in the year 1837. It was not, then, perhaps, longer than half the stroke; in the subsequent engines it has been elongated to be rather more than the length of the stroke; but although it is a troublesome and weighty appendage, there is reason to believe, that it would be advantageous to make it double the length of the stroke.—G. C.

Mr. Goldsworthy Gurney resumed:—It was almost needless to enter into the question of Sir G. Cayley's engine, after the remarks that had been read. It was however incumbent on him to corroborate their correctness. In the improved engine there was little inconvenience from the dust, and after the conical valves were adopted there was little trouble from abrasion. The consumption of fuel was about 6 lbs. of coke per horse-power per hour.

The destruction of the heating vessel was the principal difficulty; the same radical defect must exist in Ericsson's engine, as the plates must be heated to upwards of 500°, or else the air would not attain the necessary temperature. The difference of area between the two cylinders would be found a practical difficulty, and unless some modification of the machine was adopted, something like cutting off the steam at a portion of the stroke, the available effect of the expansion of the air by heat, would be in a great measure lost. The action of the regenerator, rapidly absorbing and giving out heat, was very remarkable, and afforded an important auxiliary. Considered as a whole, the arrangement devised by Sir George Cayley was, Mr. Gurney thought, superior to that of Captain Ericsson. In Sir G. Cayley's engine, the air was heated by actual contact with the incandescent fuel. The destruction of the heating vessel, common to all air-engines heated externally, was therefore avoided in this engine, where the combustion was confined to an internal fire-place, much modified, and in which any injured part could be readily renewed.

To use economically the power of air expanded by heat, the supply must be cut off from the power cylinder, as fully explained in the letter just read. The early accounts were written and published in the 'Philosophical Journal' for 1817, several years after the first experiment had been tried at Newcastle, where the engine was so ill-executed and leaky, as to show no free power. All the principles since applied in the subsequent engines, excepting that of keeping the working piston cool by a plunger, were fully developed in the diagram of the engine then given—even the arrangement adjusted by Capt. Ericsson of placing the cold-air pump, and hot-air power piston, on the same rod, were shown. The plunger, which was almost a *sine quâ non* in every air-engine, was employed in the one-horse power engine made in 1837.

Mr. H. MAXWELL LEFROY stated, that his attention having been directed to this subject by Mr. Gordon, he had made an investigation of the quantity, volume, and elastic force, of the gases into which 1 lb. of Jones' anthracite coal was decomposed by combustion, on the assumption that the whole caloric developed by the combustion of the coal should be received and retained by the gases.[1]

The constituents of 1 lb. of this coal, as given in Sir H. De la Bèche's Report on Steam Coal, were,

	lbs.
Carbon . . .	0·9144
Hydrogen . . .	0·0344
Nitrogen . . .	0·0021
Sulphur . . .	0·0079
Oxygen . . .	0·0258
Ash	0·0152

One part of carbon combining with 2·66 parts of oxygen, the carbon above given would be converted into $0{\cdot}9144\ \{1 + 2{\cdot}66\} = 3{\cdot}346$ lbs. carbonic acid.

One part of hydrogen combining with 8 parts of oxygen, the hydrogen above given would be converted into $0{\cdot}0344\ \{1 + 8\} = 0{\cdot}3114$ lbs. of steam.

Twenty-one parts of oxygen combining with 78 parts of nitrogen in the atmosphere, the nitrogen, combined with the oxygen which would be required for the combustion of the carbon, would be $0{\cdot}9144 \times 2{\cdot}66 \times \frac{78}{21} = 9{\cdot}055$ lbs.

Similarly, the nitrogen combined with the oxygen required for the combustion of the hydrogen, would be $0{\cdot}0346 \times 8 \times \frac{78}{21} = 1{\cdot}029$ lb.

Therefore the total nitrogen, which would be forced into the closed furnace, in combination with the oxygen required to support the combustion of the carbon and hydrogen, in 1 lb. of that coal, was $9{\cdot}055 + 1{\cdot}029 = 10{\cdot}084$ lbs.

[1] The MS. of this portion of the discussion was corrected by Mr. Lefroy, but in consequence of his departure from England it was not possible to submit the proof to him; the calculations, therefore, remain as in the original MS.—EDITOR.

13,268 units of caloric were developed by the combustion of 1 part of carbon.

Also 62,470 units of caloric were developed by the combustion of 1 part of hydrogen.

Therefore the heat developed by the combustion, that is, the conversion into carbonic acid and steam, of the above given quantities of carbon and hydrogen, would be $0{\cdot}9144 \times 13268 + 0{\cdot}0346 \times 62470 = 14092$ units.[1]

The pressure being constant, the relation of volume and temperature of a constant quantity of any gas, was defined by the formula $V_1 = \frac{459 \times t_1}{459 \times t_2} V_2$ where V_1 t_1 V_2 t_2 respectively were corresponding values of the volume and temperature in degrees of Fahrenheit. As the carbonic acid, nitrogen, and steam occupying the same space (the closed furnace) would have a common temperature, the 14092 units of caloric must be absorbed by these bodies, in the proportion of the products of the quantities of the bodies and their specific heats, respectively.

Therefore, if x = the caloric received by the nitrogen, $\frac{x \times 3{\cdot}346 \times 0{\cdot}2210}{10{\cdot}146 \times 0{\cdot}2754} = 0{\cdot}2649\,x$, would be the caloric received by the carbonic acid, and $\frac{x \times 0{\cdot}3114 \times 0{\cdot}8470}{10{\cdot}146 \times 0{\cdot}2754} = 0{\cdot}0946\ x$, the caloric received by the steam.

But the sum of these quantities of caloric was 14092 units. Therefore $x\ \{1 + 0{\cdot}264 + 0{\cdot}0946\} = 14092 \therefore x = \frac{14092}{1{\cdot}359}$

[1] By unit of caloric, throughout this investigation, was meant the quantity which would raise the temperature of 1 lb. of water from 39° to 40° Fahrenheit, that is, by one degree measured at the temperature of maximum density.

The specific heat of steam was assumed to be	0·8470	
,, ,, nitrogen	0·2754	
,, ,, carbonic acid	0·2210	
The volume of 1 lb. of steam	27·66	cubic feet.
,, ,, atmospheric air	13·02	,,
,, ,, nitrogen	13·1	,,
,, ,, carbonic acid	8·36	,,
,, ,, Jones' anthracite coal	1·	,,
	85·78	

H. M. L.

$= 10375$. Therefore the caloric received by the carbonic acid, $= 0{\cdot}256\,x = 2746$, and the caloric received by the steam, $= 0{\cdot}094\,x = 979$.

That is the caloric received by the nitrogen would raise its temperature $\frac{10434}{10{\cdot}1426 + 0{\cdot}2754} = 3735°$ Fahrenheit.

That of the carbonic acid and steam would be increased by the same quantity.

If the temperature of the external air be 60° and it be pumped on under a pressure of three atmospheres, its temperature deduced from the formula $\frac{V_1}{V_2} = \frac{459 + t_1}{459 + t_2}$, would be 1098°.

Then the volume of the nitrogen in the furnace, under pressure 45 lbs. per inch, and temperature 1098° + 3735° would be $10{\cdot}146 \times \frac{13{\cdot}1}{3} \times \frac{459 + 1098 + 3735}{459 + 1098} = 10{\cdot}146 \times 4{\cdot}37 \times \frac{5292}{1557} = 150{\cdot}4$ cubic feet.

Under the same conditions the volumes of the carbonic acid and steam would be $3{\cdot}346 \times \frac{8{\cdot}36}{3} \times \frac{5292}{1557} = 31{\cdot}53$, and $0{\cdot}3114 \times \frac{27{\cdot}66}{3} \times \frac{5292}{1557} = 9{\cdot}73$ cubic feet respectively.

Therefore the aggregate volume, under these conditions, of the nitrogen, carbonic acid, and steam in the furnace, would be $150{\cdot}4 + 31{\cdot}53 + 9{\cdot}73 = 191{\cdot}66$ cubic feet.

Now the oxygen in combination with the carbon and hydrogen being $0{\cdot}9144 \times 2{\cdot}66 + 0{\cdot}0344 \times 8 = 2{\cdot}4323 + 0{\cdot}2752 = 2{\cdot}7075$ lbs., and the atmospheric air holding it $= 2{\cdot}7075 \times \frac{100}{21} = 12{\cdot}89$ lbs. the volume of this air under pressure 45 lbs. per inch and temperature 1098° would be $12{\cdot}89 + \frac{13{\cdot}02}{3} = 55{\cdot}909$ cubic feet.

Therefore the net volume of the gases, derived from the combustion of 1 lb. of this coal, theoretically available as a mechanical force, was $191{\cdot}66 - 55{\cdot}90 = 135{\cdot}76$ cubic feet, under pressure 45 lbs. per inch, temperature 4833°.

If this body be allowed to expand, till its pressure be reduced to 15 lbs. per inch and temperature to 60°, the volume would become $135{\cdot}76 \times 3 \times \frac{459 + 4833}{459 + 60} = 135{\cdot}76 \times 3 \times \frac{5292}{519} =$ 4153 cubic feet.

The mechanical effect due to the expansion of $\frac{1}{85{\cdot}78}$ (the volume of 1 lb. of this coal) into 4153 cubic feet, was $\left\{\frac{1728}{85{\cdot}78}\right\}^{\frac{2}{3}}$ $\times 15 \times 4153 \times 85{\cdot}78 \times \frac{2{\cdot}721}{12} = 8{,}979{,}842$ lbs. raised 1 foot.

To compare the mechanical value of these gases, with that of the steam derived from the combustion of the same quantity of coal, upon the assumption that the whole caloric developed by the combustion, was transmitted into the water, it should be mentioned, that the quantity of water, upon the above hypothesis, convertible into steam at 212° by 1 lb. of this coal, as given by Sir H. De la Bèche, was 13563 lbs.

Consequently, the weight of one cubic foot of water being 62·5 lbs., atmospheric pressure 14·75 lbs. per inch, and the volume of the steam 1700 times that of the water, the duty due was, $\frac{13563}{625} \times 14{\cdot}75 \times 1700 \times 144 = 783{,}399$ lbs. raised 1 foot.

In each case the use of condensation was supposed to be omitted.

Mr. Lefroy then proceeded to state, that he had devoted much attention to the question of the practicability of conducting the combustion of the coal, in such a manner as should render the application of the elastic forces of the gaseous products of combustion, really convenient and economical. It appeared to him, that these bodies, having nearly the same specific heats as atmospheric air, and the caloric being developed in combination with their molecules, there must be an economy in using the elasticities of these bodies, in preference to the elastic force, either of atmospheric air, or of steam, due to that portion of the caloric of these bodies which it might be possible to abstract from them, in their rapid passage through the flues, and acting through the metal plates of the vessel, containing the air, or water.

The practical difficulties which had hitherto prevented the economical use of the elastic forces of these gases, resulted from their high temperature, and the grit, or incombustible parts of the fuel, which they carried with them from the furnace; but Mr. Lefroy thought, that in the form of apparatus which he would proceed to describe, these difficulties would be entirely overcome.

He proposed to place within the same circular boiler, but near its circumference, a number, probably four, of closed furnaces, each completely immersed in the water; they would be separately stoked, by orifices in the boiler, corresponding to each furnace, and which would be closed by plates screwed tightly down after the stoking.

Each furnace would also be separately supplied with air, and the gases generated in each, would be poured out, near the bottom of the water in the boiler, by three, or more pipes, springing from the upper part of each furnace, and each terminating in a small perforated box, through which the gases would be poured in five columns, into the water, whence it was supposed they would rise purified from all grit and with their temperature reduced.

If it were found by experiment, that this arrangement did not insure a sufficient purification of the gases, a number of wire gratings, each covered with a stratum of gravel, or sand of different degrees of fineness, could be horizontally extended through the boiler, and the gases being compelled to pass through these as they rose through the water, could be purified to any degree required.

A hollow metal ball would be placed in each of the perforated boxes, which would be forced against and completely close the extremity of each pipe, when by opening the orifices to stoke the furnace, to which it was attached, the pressure in that furnace should be reduced to that of the atmosphere.

The ash, grit, &c., which would be poured down the gas-pipes into the boiler, would sink to the lower part of the spherical bottom of the boiler, whence they would be ejected through the brine pipe.

On account of the intense heat, it would probably be found advantageous to use hollow fire-bars, through which it might be advantageous to pass the supply water into the lower part of the boiler.

If the system were worked under high-pressure, say of 30 or 40 lbs. per inch, it was supposed, that the combustion of the coal, would be so rapid and perfect, that an apparatus of comparatively small dimensions would furnish very considerable power.

Should it be found, that under the conditions of very high temperature and pressure, gases of a much more elastic nature than those he had assumed, were generated in the furnaces, Mr. Lefroy expected no inconvenience, but rather increased economy, in many respects from it, for the form of the apparatus which was proposed, appeared so simple and to be so susceptible of indefinite strength, both from diminution of dimensions, and increased thickness of the parts, that he could conceive no elasticity too great to be safely handled, in a properly proportioned apparatus of the form proposed.

Finally he would enumerate, as the principal advantages of the apparatus and power he proposed to use, over the steam furnaces at present constructed, a suppression of the funnel, or chimney, a considerable saving of fuel, and a great economy in prime cost, space occupied, and labour of attendance.

Mr. W. G. Armstrong observed, that the first question to be considered was, whether a given quantity of heat applied to vaporize water, would produce a greater, or a less expansive effect, than when it was applied to the heating of air. If an estimate was made of the quantity of heat, by degrees of temperature, the comparison would appear to be in favour of water, but when it was taken into account, that the "specific" heat of water was nearly four times greater, than that of air, and consequently, that one degree of temperature in water was equivalent to nearly four degrees of temperature in air, it was easy to show, that the actual quantity of heat consumed, in expanding air to a given volume, was less, than was necessary to produce a corresponding effect with water. On the other hand, the feed-pump of an air-engine would absorb an enormously larger proportion of power, than the feed-pump of a steam-engine; but if it were practicable, as he believed it was, to recover and use over again a large proportion of the heat applied, he conceived the balance of economy, so far as theory was concerned, would be found in favour of air. What the practical difficulties might prove to be, was another question; but he thought the system was too much in its infancy, to enable any one to speak confidently on that point. The extraordinary size of the cylinders and pistons required in Captain Ericsson's engine, appeared to be a great difficulty, but time might develop some means of obviating that objection.

Mr. RENNIE said he was present at the trials of Sir G. Cayley's engine, which had to a certain extent performed satisfactorily. It must, however, be borne in mind, that to place air on an equality with water the air must be heated to 360°, in order to double its bulk, and the chief practical difficulties arose from the destruction of the material of the heating chambers, from the direct action of the fire; this was the cause of the cessation of employment of Stirling's engine, which in its form and arrangement was a decided improvement on any of its predecessors, and in fact on any of its successors.

In 1806 a somewhat similar system had been tried, in France, by Niepce, by the ignition of an explosive powder in the cylinder. The machine had, however, never proceeded beyond a mere model.

Mr. C. W. SIEMENS, after sketching a diagram explanatory of the action of Ericsson's engine, stated that he had not seen the machine, but he believed the description which had been given of the arrangement (p. 327) was substantially correct. He had followed its progress with considerable interest, having himself been engaged, for a number of years, in maturing an engine, in which steam was employed in a highly heated state.

The pistons being on their bottom stroke, the air from the reservoirs was admitted below, urging the working piston upward. Being heated, in its passage through the regenerator to 400° Fahrenheit, the volume of the air was increased in the proportion of 2 to 3, and hence the reservoirs were deprived of only two-thirds the contents of a working cylinder of compressed air. An additional means of economising the supply of compressed air was, by shutting off the admission, before the upward stroke was completed; allowing it to act expansively.

The pumping cylinder had, in the mean time, discharged its contents of fresh atmospheric air into the reservoir, to make up for the supply of the working cylinder, so that the pressure of 10 lbs. per square inch was always maintained. The position of the slide-valve being then reversed, the air from beneath the working piston was free to escape into the atmosphere, but having to pass through the regenerator, the free and sensible heat contained in it was restored to the metallic wire gauze, in the inverse order to that in which it was taken up, issuing finally at little above the temperature at which it entered from the reservoir.

The descending stroke was effected by the mere weight of the pistons. When completed, the position of the slide-valve was again altered, and the air from the reservoir entered and forced the piston upward. In its passage through the regenerator it absorbed the heat which had been deposited there, and with an additional supply from the fire, its volume was again doubled, in filling the working cylinder.

Supposing the action of the regenerator could be made perfect, so that the air left the regenerator at precisely the same temperature at which it had entered, it might seem, at first sight, that the engine would work without any expenditure of heat, beyond the mere losses from radiation, &c.

This view had indeed been maintained by Captain Ericsson and others; but upon consideration it became apparent, that there was a theoretical consumption of heat, which might be very accurately calculated, from the fact that the air entered the regenerator in a compressed state and returned through it, after expansion to atmospheric pressure had taken place. This expansion was accompanied by a diminution of temperature of some 70° or 80° Fahrenheit, which became latent and had to be replaced by the fire.

The theoretical consumption of a perfect caloric engine, amounted to only one-fourteenth part of the theoretical consumption of a Boulton and Watt condensing engine. The practical arrangement of Ericsson's engine, however, rendered the attainment of such a result impossible, for the following reasons:—

Fully two-thirds of the power of the engine must be expended in working the air-pump, independent of the resisting pressure of the atmosphere, which was equal to 3-5ths lb. the total working pressure. The consequence was, that to produce the effective displacement of the piston, for one single volume of air at its full pressure, from 7 to 8 volumes had to be cooled and heated alternately.

The working piston of Ericsson's engine had, moreover, to work air-tight in a heated cylinder, which Mr. Siemens had practically found to be a matter of great difficulty. The lubricating material would become rapidly carbonised and would fill up the meshes of the regenerator.

The extent of heating surface provided, also appeared to be too small for the quantity of heat required to be transmitted. It was understood, from good authority, that the present working cylinders of 14 feet diameter, were now being replaced by others of 16 feet, which was the greatest size the breadth of beam of the vessel would permit.

Mr. Armstrong's views required correction, owing to the evolution of heat, in compressing the air in the pump, which would produce expansion and increased resistance. A corresponding cooling effect was, moreover, produced through its expansion in the working cylinder, which would diminish the power shown by him to be obtainable. These objections would, he expected, mar the anticipated results of this interesting experiment.

Mr. Bidder thought so little was known, accurately, either of the dimensions of Ericsson's engine, or of the results obtained, that the discussion could hardly be conclusive. Still, reasoning from the data before the meeting, it appeared, that unless the regenerator enabled any given portion of heat to be utilized over and over again, it was obvious, that no theoretical advantage was obtained, in using heated air, instead of vaporized water, as a motive power, and it was incapable of being applied practically with as much convenience. This was evidenced by the enormous size of the cylinders on board the "Ericsson,"—viz., 12 feet and 14 feet diameter,—by which, however, a speed of only 6 to 7 miles per hour had been attained. As the power was as the cube of the velocity, it followed, that to obtain a velocity of 14 miles per hour, with the same vessel, there would be required cylinders of between 30 feet and 40 feet diameter. He had carefully investigated the operation of the regenerator, supposing it to be theoretically perfect, and had arrived at the conclusion, that no mechanical advantage could be attained by its use.

Mr. Spiller had also, from the data, reported by the public prints to have been furnished by Captain Ericsson himself, made a calculation of the power of the engines, and, assuming those data to be correct, he computed the total motive force produced by the expansion of the air, to be 208 H.P., taking 33,000 lbs. raised 1 foot per minute, as the standard of the horse-power;—that whether in a steam, or an air-engine, friction and waste were inevitable, and if only a sufficient amount was deducted, for these causes of loss, it would be found, that many of the marine-engines were producing power more economically, than the heated air engines in question. He also remarked, that although any given amount of heat, acting on air, might produce more motive force, than the same amount employed to produce motive force by steam, still he believed, that in consequence of the very low pressure of air, except at so high a temperature as to be destructive of the necessary perfection of the working parts of every engine, steam would be found more economical than air, as an agent for the production of motive power, and hence however laudable the attempt might be, he could see but little prospect of success in this trial for substituting air for steam.

As to the regenerator, which had excited so much interest,—that some economy might be produced by such an apparatus, there could be no reasonable doubt, notwithstanding what had been said of the impossibility of employing heat a second time, or "over again." The metallic wire acted as a reservoir, to embody, or take up a portion of the heat in the outgoing air; which heat, so embodied, was given out to the incoming air, for the succeeding stroke,—a principle carried into effect in every non-condensing engine, where the eduction-steam was employed to heat the feed-water, before it entered the boiler, and also by Messrs. Maudslay and Field, in ocean steamers, where the brine pumps, &c., were so arranged, as to communicate a very large portion of the heat of the outgoing water, to that drawn in to feed the boilers.

Dr. Faraday said, that twenty years ago he had directed his attention to this question, and from theoretical views, he had been induced to hope for the successful employment of heated air as a motive power; but even then he saw enough to discourage his sanguine expectation, and he had, with some diffidence, ventured to express his conviction of the almost unconquerable practical difficulties surrounding the case, and of the fallacy of the presumed advantages of the regenerator. He still retained his doubts as to the success of the innovation and feared the eventual results, even of Captain Ericsson's spirited and ingenious efforts.

Mr. BRUNEL, V.P., agreed in considering the regenerator to be a mystification, and the difficulty of the matter arose from its plausibility. It was extremely difficult to disprove that which did not exist at all. He believed the stated gain of power, from the action of the regenerator, to be mere assumption, and he was inclined to regard it just as he would any attempt to produce perpetual motion; still he admitted the difficulty of exposing the fallacy, as he contended it to be, when it was asserted, that the power derived from the expansion of air by heat, could be used effectively, and then be recovered and used again.

He could not gather, from any of the statements, how power was actually obtained; and he could only arrive at the conviction, that if there was any development of power, in lending heat to the metallic webs and borrowing it again, the natural consequence must be, that after a time there might be such an accumulation of borrowed heat, as would enable the machine to work, without any fire under the heating vessels. It was scarcely worth while to expend time in the refutation of such a fallacy. The same kind of error had been fallen into, with respect to the hot water from the condenser of a steam-engine; but in that case it was clear, that the advantage arose, not from recovering heat which had been previously used, but by obtaining some that had not been used before, and which would otherwise have been wasted.

He was of opinion, that Stirling's engine was not only a prior introduction, but that it was a better machine than Ericsson's; still he thought that neither of them could be advantageously compared with a steam-engine.

Mr. HAWKSLEY believed, that the machine involved a mechanical fallacy, as the regenerator produced no mechanical effect whatever. It might be granted, that the regenerator of Ericsson's engine received and redelivered the heat in the manner described, and that when the working piston was descending, the heat was deposited, and when ascending, the heat was restored; but that operation could only result as a consequence of the motion of the piston and not as a cause of its motion—hence no mechanical effort was made. This result was easily shown by assuming the contents of the pump to be 1, and the contents of the working cylinder to be 2. If the working piston was at the bottom of the cylinder, and in equilibrio with the external atmosphere, as regarded the pressure on a unit of surface, and then began to move and the air to be heated, in its passage through the regenerator, from 32° to a temperature of 512°, so as to double its volume, the lower piston would constantly produce a vacuity, so to speak, of 2, to be constantly fed by a supply of 1, from the pump, expanded into 2 by the increase of temperature,—consequently the piston, at every instant of its motion, remained in equilibrio with the external atmosphere, and no mechanical effect could result. Still in Ericsson's engine a mechanical effect had been produced; but then this mechanical effect was no greater than would be produced without the aid of the regenerator, by the simple action of the furnace itself, and not so economically as by the use of steam.

Captain Fitzroy, R.N., said it appeared, that after imparting motion to the piston, the heated air, in passing through the regenerator, gave out to the metallic web 520 parts out of 570 parts of heat it contained, and that a part of that heat was taken up again by the next supply of cold air on entering; therefore, the mystery consisted in the action of the regenerator, by which the same caloric, husbanded and given out again, could, by a small addition of heat, continue to impart motion to the pistons. The chief argument against the imputed fallacy, was the fact of the ship "Ericsson" having actually been propelled at a given speed through the water. The relative economy of the system, compared with steam, was entirely another question.

Mr. Bidder begged it might be understood, that in his remarks he had assumed the regenerator to have taken nearly all the heat, but he contended that when so taken up, it was not of any practical utility; in fact, this was, to some extent, shown by the result obtained in the "Ericsson" ship; for, with so fine a model, even a small engine and a much less consumption of fuel would have produced a greater speed.

Mr. Brunel, V.P., had also assumed the regenerator to be perfect. He believed that such a mass of wire-gauze would take up the heat perfectly, but he could not admit the soundness of the reasoning, as to the assumed gain of power from the regenerator.

Mr. F. BRAITHWAITE recalled the circumstances attending the first trials of Ericsson's caloric engine, in England: there was not any regenerator, but there was a separate vessel for heating the air, and a refrigerator for cooling it. There was not any difficulty in obtaining power from the expanded air, but there was great difficulty in finding any lubricator, that would enable the pistons to work for any length of time continuously, as the high temperature carbonized all the fatty matters that were tried. The caloric-engine was tested by pumping water, but the results were not equal to those of the steam-engine, in a commercial point of view.

He did not consider the regenerator to be necessary for the engine; it certainly was not a source of power, and it was problematical whether it was a means of economy.

Mr. W. G. ARMSTRONG said his view of the action of the regenerator was, that it retained a portion of the heat, which would otherwise have been lost; whether that heat was practically as beneficial, in the subsequent working of the engine, as had been assumed by the advocates of the system, did not yet appear to be fully proved. He thought, that for the credit of the Institution, the question should be more carefully considered.

Mr. RENDEL,—PRESIDENT,—would not have the meeting arrive at a hasty, or erroneous conclusion, on the question of this engine; and he, therefore, suggested, that Mr. Siemens should draw up a paper on the subject, and that the Members should collect, for a future meeting, all the information within their reach, in order to the calm and deliberate discussion of the question.

February 22nd, 1853.

JAMES MEADOWS RENDEL, President, in the Chair.

THE discussion upon the Paper No. 886.—"On the use of Heated Air as a Motive Power," by Mr. B. CHEVERTON, being renewed, was extended to such a length as to preclude the reading of any other communication.
