THE EVOLUTION OF THE THEORY OF THE HEAT ENGINE.*

At the outset of his remarks, Mr. Clerk dealt with the position of the steam engine at the middle of the last century. Even at that time it had attained to a high degree of perfection. Its development was, it is true, incomplete, but it had been successfully applied to all the great duties of the mine, the waterworks, the factory, the railway, and the steamship. The engines were mechanically excellent; the fuel economy was good, and they were built in units of thousands of horse-power. Steam power, in fact, was revolutionizing the whole of the social and industrial conditions of the globe. Notwithstanding this great material and engineering success, the world was in complete darkness as to the connection between steam motive power and heat. It was seen that motive power of almost any magnitude could be obtained by the agency of heat; but how it was obtained, and how much power was connected with a given quantity of heat was quite unknown. The fuel consumptions of existing engines were known, and certain modes of improving economy were evident, and engineers were busily engaged in testing these modes by the slow but sure methods of invention, design, construction, and operation in practical work; but in this they had but little aid from pure science. The science of thermo-dynamics did not yet exist. New light was dawning, however, which gradually illumined the whole world of pure science and engineering practice.

Men of the first rank in intellect—Newton, Cavendish, Rumford, Young, and Davy—had long before expressed the opinion that heat was not material in its nature, but was a mode of motion; but their opinions, although to some extent supported by experiment, made little impression upon the scientific world, and in 1850 we still find the most distinguished physicists adhering to the "caloric" or material theory of heat.

The great change from the errors of the old theories to the truth of the new was due to the work of Joule, Thomson, and Rankine, in Great Britain, and of Carnot, Meyer, Clausius, Helmholtz, and Hirn on the Continent. The story begins with the work of Carnot in 1824, who published in Paris that year a pamphlet, entitled "Reflections upon the Motive Power of Heat." He was attracted by the problem of the steam engine and the air engine. He saw that heat and motive power were connected in some manner, and he endeavored to settle in a quantitative way the limits of that connection by the invention of an ideal series of operations, by means of which the greatest conceivable amount of mechanical power might be obtained from a given quantity of heat under given circumstances.

To the acute and brilliant intellect of William Thomson it became apparent that he had in the Carnot cycle a powerful instrument capable of widely general use, apart altogether from the theory of heat engines; and he used it in a most skilful way to give definiteness and universal application to the idea of temperature, as Professor Larmor states, "elevating the idea of temperature from a mere featureless record or comparison of thermometers into a general principle of physical nature."

After discussing Thomson's work on the subject, the address stated that long before 1850 the equivalence of mechanical work and heat quantity had been accepted by many scientific men, and Rumford had, indeed, made measurements of a rough kind. It remained, however, for Joule experimentally to determine the mechanical equivalent in the most accurate manner, and place what is now known as the first law of thermo-dynamics upon the sure basis of absolute experimental determination. His first paper was read before the Cork meeting of the British Association in 1843, and at the Oxford meeting, in 1847, he read another on "The Mechanical Equivalent of Heat," describing the results of experiments with paddles rotating in liquids driven by falling weights. By these years of work he had absolutely demonstrated the equivalence of heat quantity and mechanical work, so that no loophole of escape seemed possible; it appeared as if the material theory was rendered intellectually impossible to the trained intellect. This was not the fact, however, as is evident from both Joule's and Thomson's accounts of that British Association meeting.

The brilliant work of Meyer, published so early as 1842, is held by some to have anticipated to a large extent both the work of Thomson and of Joule. Undoubtedly Meyer formulated true ideas, and carried his generalizations through a wide range. Helmholtz also very early arrived at similar conclusions to those of Joule and Thomson. Undoubtedly great credit is due to Meyer, Helmholtz, Clausius, and Hirn, and Thomson himself recognized this in the most generous way. The ideas of Thomson and Joule now form so much of the basis of all reasoning upon motive-power engines that there is some little danger to the present generation of forgetting what they owe to these two great men. To appreciate the step made by them it is necessary to consider the position of motive power produced by heat at about the middle of the last century. At that time many attempts had been made to displace the steam engine as a heat engine by air engines in various forms—both engines heated externally and those heated internally, now known as internal combustion engines. Papers read at the Institution of Civil Engineers in 1845 and 1853, and the discussion of those papers by eminent men of the day, supply an accurate measure of the knowledge possessed by the engineer of the principles of action of his heat engines. Many distinguished names occur in these papers and discussions, including James Stirling, Robert Stephenson, Sir George Cayley, Charles Manby, James Leslie, C. W. Siemens, Hawksley, Pole, W. G. Armstrong (afterwards Lord Armstrong), Edward Woods, E. A. Cowper, D. K. Clark, Benjamin Cheverton, Goldsworthy Gurney, George P. Bidder, Professor Faraday, Isambard K. Brunel, Captain Fitzroy, and F. Braithwaite. At the date of the later of these discussions Brunel had already designed the "Great Eastern," in 1852, with her engines of 11,000 horse-power. Armstrong was a Fellow of the Royal Society, and had started the Elswick Works and invented the Armstrong gun. Robert Stephenson was at the height of his fame. He was then a member of Parliament, president of the Institution of Civil Engineers, and a Fellow of the Royal Society. Siemens was a young man, but was busy on the regenerative furnace; he had considered regeneration as applied to steam engines, although his work on the air engine was still to come.

In conclusion, the author remarked that the modern internal combustion motor is the successor to the air engine, so fully discussed by eminent engineers of fifty-five years ago; and the forebodings of even so eminent a man as Faraday as to its ultimate success have proved unfounded. Great difficulties have been encountered, and many discrepancies have had to be explained, but a minute study of the nature of the working fluid has rendered it more and more possible to calculate the efficiencies to be expected under practical conditions. At the present time we can deal with almost any cycle or any working fluid with some fair approximation to an accurate result. Much work, however, is required before all problems of the working fluid can be said to be solved with regard to any heat engine. Indeed, it may be said that, under modern conditions of the use of steam, even the properties of the working fluid—steam—have not yet been satisfactorily determined. The mere question of specific heat, for example, of steam and its variations of temperature and pressure, is now under review, and important experiments are in progress in Britain and on the Continent to determine those properties. The properties of the working fluid of the internal combustion motor are also the subject of earnest study by many Continental and British investigators. Notwithstanding all the perplexities involved in the minute study of the imperfect heat engine cycles, we are in a very different position to-day compared with the engineer of 1853. We know all the broad laws as to the conversion of heat into work, or of work into heat; and, numerous as are the problems yet to be solved, we, at least, profit by the guiding light set out for us by Kelvin, Joule, and Rankine.

*Abstract of the address of Dr. Dugald Clerk, F.C.S., before the Engineering Section of the British Association.