THERMODYNAMICS. In a strict interpretation, this branch of science, sometimes called the Dynamical Theory of Heat, deals with the relations between heat and work, though it is often extended so as to include all trans­formations of energy. Either term is an infelicitous one, for there is no direct reference to force in the majority of questions dealt with in the subject. Even the title of Carnot’s work, presently to be described, is much better chosen than is the more modern designation. On the other hand, such a German phrase as *die bewegende Kraft der Wärme* is in all respects intolerable.

It has been shown in a previous article (Energy) that Newton’s enunciation of the conservation of energy as a general principle of nature was defective in respect of the connexion between work and heat, and that, about the beginning of the present century, this *lacuna* was com­pletely filled up by the researches of Rumford and Davy (see also Heat). In the same article Joule’s experimental demonstration of the principle, and his determination of the work-equivalent of heat by various totally independent processes, have been discussed.

But the conservation of energy, alone, gives us an altogether inadequate basis for reasoning on the work of a heat-engine. It enables us to calculate how much work is equivalent to an assigned amount of heat, and *vice versa,* provided the transformation can be effected ; but it tells us nothing with respect to the percentage of either which can, under given circumstances, be converted into the other. For this purpose we require a special case of the law of transformation of energy. This was first given in Carnot’s extraordinary work entitled *Reflexions sur la Puissance Motrice du Feu,* Paris, 1824.@@1

The chief novelties of Carnot’s work are the introduction of the idea of a cycle of operations, and the invaluable discovery of the special property of a *reversible cycle.* It is not too much to say that, without these wonderful novelties, thermodynamics as a theoretical science could not have been developed.

Carnot’s work seems to have excited no attention at the time of its publication. Ten years later (1834) Clapeyron gave some of its main features in an ana­lytical form, and he also employed Watt’s diagram for the exhibition of others. Even this, however, failed to call attention properly to the extremely novel processes of Carnot, and it was reserved for Sir W. Thomson (in 1848, and more at length in 1849) to point out to scientific men their full value. His papers on Carnot’s treatise, follow­ing closely after the splendid experimental researches of Colding and Joule, secured for the dynamical theory of heat its position as a recognized branch of science. James Thomson, by Carnot’s methods, predicted in 1849 the low­ering of the freezing point of water by pressure, which was verified experimentally in the same year by his brother. Von Helmholtz had published, two years before, a strikingly original and comprehensive pamphlet on the conservation of energy. The start once given, Rankine, Clausius, and W. Thomson rapidly developed, though from very different standpoints, the theory of thermodynamics. The methods adopted by Thomson differed in one special characteristic from those of his concurrents,—they were based entirely on the experimental facts and on necessary principles ; and, when hypothesis was absolutely required, attention was carefully directed to its nature and to the reasons which appeared to justify it.

Three specially important additions to pure science followed almost directly from Carnot’s methods :—(1) the *absolute* definition of temperature ; (2) the thermodynamic function or entropy ; (3) the dissipation of energy. The first (in 1848) and the third (in 1852) were given by W. Thomson. The second, though introduced by Rankine, was also specially treated by Clausius.

In giving a brief sketch of the science, we will not adhere strictly to any of the separate paths pursued by its founders, but will employ for each step what appears to be most easily intelligible to the general reader. And we will arrange the steps in such an order that the neces­sity for each may be distinctly visible before we take it.

1. *General Notions.—*The conversion of mechanical work into heat can always be effected completely. In fact, friction, without which even statical results would be all but unrealizable in practical life, interferes to a marked extent in almost every problem of kinetics,—and work done against friction is (as a rule) converted into heat. But the conversion of heat into work can be effected only in part, usually in very small part. Thus heat is regarded as the lower or less useful of these forms of energy, and when part of it is elevated in rank by con­version into work the remainder sinks still lower in the scale of usefulness than before.

There are but two processes known to us for the con­version of heat into work, viz., that adopted in heat- engines, where the changes of volume of the “working substance” are employed, and that of electromagnetic engines driven by thermoelectric currents (see Electricity, vol. viii. p. 96). To the latter we will not again refer. And for simplicity we will suppose the working substance to be fluid, so as to have the same pressure throughout, or, if it be solid, to be isotropic, and to be subject only to hydrostatic pressure, or to tension uniform in all directions and the same from point to point.

@@@1 The author, N-L-Sadi Carnot (1796-1832), was the second son of Napoleon’s celebrated minister of war, himself a mathematician of real note even among the wonderful galaxy of which France could then boast. The delicate constitution of Sadi was attributed to the agitated circumstances of the time of his birth, which led to the proscription and temporary exile of his parents. He was admitted in 1812 to the École Polytechnique, where he was a fellow-student of the famous Chasles. Late in 1814 he left the school with a commission in the Engineers, and with prospects of rapid advancement in his profession. But Waterloo and the Restoration led to a second and final proscrip­tion of his father ; and, though Sadi was not himself cashiered, he was purposely told off for the merest drudgeries of his service; il fut “envoyé successivement dans plusieurs places fortes pour y faire son métier d’ingénieur, compter des briques, réparer des pans de murailles, et lever des plans destinés à s’enfouir dans les cartons,” as we learn from a biographical notice written by his younger brother. Disgusted with an employment which afforded him neither leisure for original work nor opportunities for acquiring scientific instruction, he presented himself in 1819 at the examination for admission to the staff-corps (état-major), and obtained a lieutenancy. He now devoted himself with astonishing ardour to mathematics, chemistry, natural history, technology, and even political economy. He was an enthusiast in music and other fine arts ; and he habitually practised as an amuse­ment, while deeply studying in theory, all sorts of athletic sports, including swimming and fencing. He became captain in the engineers in 1827, but left the service altogether in the following year. His naturally feeble constitution, farther weakened by excessive devotion to study, broke down finally in 1832. A relapse of scarlatina led to brain fever, from which he had but partially recovered when he fell a victim to cholera. Thus died, at the early age of thirty-six, one of the most profound and original thinkers who have ever devoted them­selves to science. The work named above was the only one he published. Though of itself sufficient to put him in the very fore­most rank, it contains only a fragment of Sadi Carnot’s discoveries. Fortunately his manuscripts have been preserved, and extracts from them have been appended by his brother to a reprint (1878) of the Puissance Motrice. These show that he had not only realized for himself the true nature of heat, but had noted down for trial many of the best modern methods of finding its mechanical equivalent, such as those of Joule with the perforated piston and with the internal friction of water and mercury. W. Thomson’s experiment with a current of gas forced through a porous plug is also given. One sentence of extract, however, must suffice, and it is astonishing to think that it was written over sixty years ago. “ On peut donc poser en thèse générale que la puissance motrice est en quantité invariable dans la nature, qu’elle n’est jamais, à proprement parler, ni produite, ni détruite. À la vérité, elle change de forme, c’est-à-dire qu’elle

produit tantôt un genre de mouvement, tantôt un autre; mais elle n’est jamais anéantie.”