THE BIRTH OF THE PRINCIPLE OF ENERGY

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The next step

It wold probably be correct to say that Rumford gave his energies to preliminary experimental work in a field the principal significance of which eluded him. When the field next began to assume importance, 44 years later, the situation was exactly reversed. The man who reopened the question in the next generation was, in contrast, enormously impressed with its significance; but his approach was characterized by an almost complete lack of experimentation. The subject was reopened by an article which appeared in a chemistry magazine, Liebig's Annalen, in 1842, having been rejected by the principal physics publication of the day. It was written by an obscure German physician, J.R. Mayer (1814 - 1878). Lacking both scientific education and opportunities for experimental work, Mayer was thus thrown back upon reflection, selecting with marvellous sagacity, from existing physical data, the single result on which could be founded a calculation of the mechanical equivalent of heat.

The foregoing statement accompanied the belated award of the Copley medal to Mayer in 1871. The calculation of the mechanical equivalent of heat to which it refers was a part of Mayers paper of 1842. He had utilized some experimental data on the heat required to maintain the temperature of expanding air. The data themselves had long been known, but, again in the language of the award,

> No man, to my knowledge, prior to Dr. Mayer penetrated the significance of these two numbers. He first saw that the excess was not, as then universally supposed, heat actually lodged in the (isothermally expanded) gas, but heat which had been actually consumed by the gas in expanding against pressure. The amount of work here performed was accurately known, the amount of heat consumed was also accurately known, and from these data Mayer determined the mechanical equivalent of heat.

Mayer gets an Inspiration

Mayer's value, corrected for an erroneous value of the specific heat of air which he used, was in English units, 725 ft.-lbs/BTU. If this is compared with the correct value, 778, it may be recognized as a great improvement over Rumford's 1034. Yet this value was only a part and in one sense the lesser part of Mayer's contribution. His great discovery, or perhaps, in view of his lack of experimental foundations we should say his great "hunch", was what has since taken the form of the scientific doctrine of the Conservation of Energy. This was a concept toward which the scientific mind had been groping for two hundred years. In the 1842 paper he stated that force (the current term for energy) once in existence cannot be annihilated; it can only change its form.

In this and in a succceeding paper in 1845 he expanded this idea to cover what was, especially for the time, an amazing variety of phenomena. He began with inorganic manifestations of interconvertibility of work and heat, including chemical reactions, and extended it to the brand-new idea that plants and coal deposits when burned were merely yielding up the heat previously received from the sun. He included animal life - which took in man - in his idea that heat and energy output are to be equated to intake, ultimately of energy from the sun. He extended the principle to astronomical phenomena, computing the speed of fall to the earth from an infinite distance as 34,450 feet per second, and proposed the contraction theory of the origin of the sun`s heat, both of these ideas being entirely new at that time.

The opposition to Mayer and the reason for it

As a prophet in the scientific era Mayer may not have been unique, but he showed the attributes of a genius of the first order. It is sade to relate, therefore, that his life was a tragic one by the very virtue of his genius. The very insight which ultimately became the basis of his fame was at first the source of his misery. Since he was so far ahead of his time, recognition of his work was delayed, and he was treated as a freak or a madman. He attempted suicide and for a time became actually deranged. He recovered, however, and lived to experience and appreciate a considerable measure of the honor that was his due.

Every cultural group establishes its criterion of success, its "trumps", and the game of life within that group must be played accordingly. In the "manly art", for example, trumps is the knockout. A knockout automatically brings the championship, even though it may be demonstrable that the defeated contestant is unqualifiedly the more skillful of the two. In the legal profession, trumps is the winning of cases. That lawyer is the most successful who wins the largest number of decisions, even though his contentions may, aside from legal technicalities, be demonstrably contrary to fact. The scientific world, like other cultural groups, has its trumps - the numerical agreement of experimental data. Such agreement in a given area of science is considered to be a vindication of the hypotheses leading up to the experiment in question. This confidence in numerical agreements may not be justified. After decades of such agreement some of the most basic scientific doctrines have been shown to be logically untenable. But the trumps still stand.

Against that background one may see why the scientific world disregarded Rumford's work and at first poured contumely on Mayer´s. Though there were some elements in the theories of each man that were subject to experimental verification, the two men did not themselves provide such verification. One can understand too why when J.P. Joule, whose work will be considered shortly, verified numerically a few of Mayer’s pronouncements, a strong presumption was created in favor of, not merely the verified portion, but also all the rest of Mayer’s theory.

Joule determines the mechanical equivalent of heat

James P. Joule was a brewer of Manchester, England. Like many other men of independent means in the history of science, he became a scientist by avocation. He first became interested in "electric engines", the electric motor being in somewhat of a prenatal state at that time. Before reaching his majority he had published several papers including, among other things, some measurements of the power developed by his rudimentary motors. In 1840 he presented a paper to the Royal Society on the production of heat by the electric current. It seems natural that, having measured the power and the rate of evolution of heat manifested by an electric current, he should be led to compare the two. This he did, in 1842, the year of Mayer's original paper. He deduced the value 838 ft.-lbs/B.T.U. for the mechanical equivalent of heat. That was his beginning. From that time he devoted his life to redetermining, in every way that lent itself to experimental attack, the value of this constant. In 1843 he observed the rise in temperature duu to the friction of water with the walls of capillary tubes through which it was driven, and deduced the value 770. In 1845 he measured the heat developed or absorbed when air was compressed or expanded to the accompaniment of a measured amount of work (798). In the same year he observed the rise in temperature of water churned by a paddle wheel whose work was measured (890). Dissatisfied with this he repeated the experiment in water and in oil in 1847 (781.5 and 782.1). In 1849 he repeated the same measurements (772). In 1850 he agitated mercury (774). In the same year he utilized friction in cast iron (775). In 1867 he heated water electrically instead of by a paddle wheel (783). In 1878 he repeated his paddle wheel experiment and deduced his last value, 772.55.

Joule concluded one of his papers with the following statement:

> I will therefore conclude by considering it as demonstrated by the experiments contained in this paper - (1) that the quantity of heat produced by the friction of bodies, whether solid or liquid is always proportional to the quantity of force (i.e. work) expended; and (2) that the quantity of heat capable of increasing the temperature of a pound of water (weighed in vacuo, and taken at between 55° and 60°) by 1° Fahr., requires for its evolution the expenditure of a mechanical force represented by the fall of 772 pounds through the space of 1 foot.

Joule's preoccupation with the measurement of the mechanical equivalent of heat is illustrated by a story told by Lord Kelvin, one of Joule's friends and scientific associates. Shortly after their first meeting - which occurred, it afterward developed, three days before Joule's marriage - Kelvin, who was vacationing in Switzerland, saw a young man approaching him, gingerly carrying something resembling a walking stick. It proved to be Joule, on his honeymoon, carrying a large thermometer which he had made in order to measure the temperature of the water above and below an 800-foot waterfall which he and his bride expected to visit.

Joule and the conservation of energy

Joule, like Mayer, was animated by a conviction of the conservation of energy. Though he did not particularize on this theory as Mayer did, his conception of the inclusiveness of the doctrine was no less wide. In his 1843 paper he said:

> I shall lose no time in repeating and extending these experiments, being satisfied that the grand agents of nature are, by the Creator's fiat, *indestructible*; and that wherever mechanical force is expended, an exact equivalent of heat is *always* obtained.

The italics are Joule's own. This statement is no less inclusive than Mayer's. Indeed because he did not particularize as Mayer did, it may be said to be broader. A comparison of the inclusiveness of this statement with the very limited number of ways that the principle lent itself to verification at his hands will make it clear that his experiments constituted far from conclusive evidence on the validity of his belief. Yet because he performed experiments - even experiments which had little to do with some of the aspects of his doctrine - his doctrine was accepted in its entirety. The later acceptance of Mayer's doctrine came only when it was seen to be identical with Joule's. Actually, the volume of qualitative evidence covering a wide variety of phenomena which Mayer proffered constituted better support of the broad implications of the doctrine of conservation of energy than did the close numerical agreement of Joule's results in a limited field. But Joule had the scientific trumps.

Not that Joule's ideas commanded immediate assent, however. Leading men of science, though interested in Joule's work, were dubious about its correctness for several years. Some of them based their incredulousness on the nature of Joule's experiments, remarking that he "had nothing but hundredths of a degree to prove his case by." Others considered Joule's doctrine incompatible with a theory of Carnot about heat transformations. Carnot's theory held a position of dominance at that time, and all other theories of heat that failed to agree with it were under suspicion. There are ephemeral modes of thought in science as well as in other walks of life.

The new principle of conservation of energy

It is perhaps unnecessary to emphasize the new "turn" that the doctrine of Mayer and of Joule gave to the old principle of conservation of energy. The old form was restricted to purely mechanical transformations. The phenomena of oscillation, of elastic impact, and of frictionless fluid motion are frequently treated with the aid of the restricted form of the principle. But wherever friction or other types of dissipation of energy are involved, accompanied as they must ultimately be by the generation of heat, only the more inclusive forms of the conservation principle is adequate. That form is variously phrased, but the following statement is perhaps as good as any:

> Energy is recognized in various forms, and when it disappears in one form it appears in others, and in each case according to a fixed rate of exchange. The total quantity of any energy, measured in terms of any one form, is constant whatever forms it may assume.

Many years were to elapse before the scientific world came to a general recognition of the full import of the doctrine of conservation of energy. Perhaps the most effective of its earlier champions was Hermann von Helmholtz, who was at that time (1847) principally known as a physiologist who was especially versed in the field of sound. It is somewhat thought-provoking to realize that the five men who were the first to comprehend the full import of the principle of conservation of energy were all young men and were all professionally outside of the field of physics at the time that they made their contributions. These were Mayer, a German physician, aged 28; Carnot, a French engineer who preceded all the rest in the discovery, aged 34; Helmholtz, a German physiologist, aged 32; Joule, an English industrialist, aged 25; and Colding, a Danish engineer who made the same discovery independently of the others and almost simultaneously, aged 27.

Perpetual motion

It was the principle of conservation of energy, a principle which Poincaré has termed "the grandest conquest of contemporary thought" that finally set in strong relief the futility of the perennial efforts to devise a perpetual motion machine. A corollary of the principle that the sum of all the forms of energy output of a machine must always be exactly equal to the total energy input is that the output can never exceed the input. What constitutes the "will-o'-the-wisp" of the perpetual motionist has been the fond hope in many quarters that a machine could be devised whose output would be greater than its input. The principle of conservation of energy alone, therefore, should be enough to dispel this illusion.

Actually the case for perpetual motion is even less valid than the conservation principle, taken by itself, allows. The statement that the total energy output of a machine is always equal to the input includes in the energy output such items as friction and heat loss, inescapable characteristics of the operations of any machine. These forms of "output" are useless whereas the perpetual motionist is naturally interested only in useful output. The useful output of any machine is consequently always less than the input, the ratio of the two being termed efficiency, a term already introduced in the study of mechanics. The efficiency of common machines is much lower than the average individual realizes. That of a high quality internal combustion engine is about 40% , of a high quality steam engine about 20% , of a locomotive engine about 5% . There are, moreover, certain losses in the transmission of mechanical or electrical energy to the locality of utilization and in its application at the point of consumption which diminish practical efficiency still further. When coal is burned to supply steam for the generation of electricity, only a small fraction of 1% of the coal´s heat energy appears in the illumination provided by the electricity. All the rest is lost along the way, dissipated in the form of heat. Even the light itself is absorbed and ultimately converted into heat.

The degradation of energy

The same can be said of any series of energy transformations whatever. There is a "tax", payable only in the form of heat, exacted at every step. All kinds of energy ultimately dissipate themselves in the form of heat. The tradegy of the process is that the heat thus generated can practically never be utilized. Once dissipated it can never be recovered or reclaimed. The user can only turn to the source, almost invariably the sun in the final analysis, for another handout, which will be similarly spent in its turn. Just as much energy resides in the dissipated heat as resided in the original handout from the sun, but it has been rendered unavailable. The process is technically termed degradation of energy.

The degradation of energy was first identified by Lord Kelvin in 1851 and is perhaps as important a scientific generalization as is the conservation of energy. Kelvin pointed out that, as a consequence of this continous universal process, the inescapable decreasing availability of energy indicates an ultimate stoppage of all energy flow in the universe, a "running down" of the cosmic clock. Long before that state is reached all life will have disappeared, for life depends on, and perhaps consists of, a peculiar form of energy flow. The end of the world is usually pictured as a state of utter frigidity. This is not necessarily a correct picture. The final state of the universe may be temperate or even hot. The important point will not be temperature level, but the entire absence of differences of temperature. Everything will be cold or medium or hot to the same degree, and consequently no energy can flow from one place to another. This state of affairs is inevitable, according to every evidence now available. Perhaps it is not necessary to take the matter too seriously, however, for even the most enthusiastic prophets of doom admit that many billions of years will elapse before that condition comes to pass, and a lot of things can happen in a billion years.