by Dr Karl August Espe (born February 1804, died in the Irrenanstalt at Stötteritz near Leipsic, 24th November 1850) with the aid of many learned and distinguished writers. A general index, Universal Register, 242 pages, was added in 1839. The 9th edition (1843–47, 15 vols., 11,470 pages, over 30,000 copies) was edited by Dr Espe. The 10th edition (1851–55, 12,564 pages) was also in 15 vols., for convenience in reference, and was edited by Dr August Kurtzel aided by Oskar Pilz. Friedrich Brockhaus had retired in 1849, and Dr Heinrich Edward, elder son of Heinrich, made partner in 1854, assisted in this edition from the beginning, and Heinrich Rudolf, the younger son, partner since 1863, in the 11th (1864–68, 15 vols. of 60 sheets, 13,366 pages). Kurtzel died 24th April 1871, and Pilz was sole editor until March 1872, when Dr Gustav Stockmann joined, who was alone from April until joined by Dr Karl Wippermann in October. Besides the Universal Register of 136 pages and about 50,000 articles, each volume has an index. The supplement, 2 vols., 1764 pages, was begun in February 1871, and finished in April 1873. The 12th edition, begun in 1875, is to be in 15 vols. of 64 sheets, 15,300 pages, to be finished in 1880. The *Conversations Lexicon* is intended, not for scientific use, but to promote general mental improvement by giving the results of research and discovery in a simple and popular form without extended details. The articles, often too brief, are very excellent and trustworthy, especially on German subjects, give references to the best books, and include biographies of living men.

The most copious German encyclopædia is Ersch and Gruber's *Allgemeine Encyclopädie der Wissenschaften und Künste*, Leipzig, 1818–75, 151 vols., 69,893 pages, and about 360 plates, being perhaps three-fifths of the work. It was designed and begun in 1813 by Professor Johann Samuel Ersch (born at Gross Glogau, 23d June 1766, chief librarian at Halle, died 16th January 1828) to satisfy the wants of Germans, only in part supplied by foreign works. It was stopped by the war until 1816, when Professor Hufeland (born at Dantzic 19th October 1760) joined, but died, 25th November 1817, while the specimen part was at press. The work is in three sections:—(1), A to G, 95 vols. 1818–75, 44,379 pages (A to Guano), edited to vol. xvii., 1828 (Chioc-Boya to Claytonia), by Ersch, who carried on nearly all the correspondence, and to vol. liv. (Gargano to Gauhe), by Professor J. G. Gruber, who joined on Hufeland's death, and was succeeded in 1851 by M. H. E. Meier, and since 1856 to vol. lxii. (Gerson to Geschlecht) by Hermann Brockhaus (third son of Friedrich Arnold, born at Amsterdam 28th Jan. 1806, professor of Sanskrit at Leipsic); (2) H to N, 31 vols., 1827–55, 14,447 pages (H to Izzo), begun by W. Müller, librarian at Dessau, who died in September 1827, and was succeeded by Professor A. G. Hoffmann of Jena; (3) O to Z, 25 vols., 11,067 pages (O to Phyxios), edited by Meier. All articles bear the authors' names, those not ready in time were placed at the end of their letter. The longest is Griechenland, vols. 80–87, 3668 pages, with a table of contents. It began to appear after vol. 73 (Götze to Gondouin), and hence does not come in its proper place, which is in vol. 91. Gross Britannien contains 700 pages, and Indien by Benfey 356. As may be expected in a work designed by a bibliographer so renowned and industrious as Ersch, the titles of books and lists of authorities and references are very full and accurate. Among the contributors are the most learned Germans of the last 60 years. It contains much original research and many of its articles rank among the best authorities on their respective subjects.

The *Encyclopædia Metropolitana* (London, 1845, 4to, 28 vols., issued in 59 parts in 1817–45, 22,426 pages, 565 plates) professed to give sciences and systematic arts entire and in their natural sequence, as shown in the introductory treatise on method by S. T. Coleridge. "The plan was the proposal of the poet Coleridge, and it had at least enough of a poetical character to be eminently unpractical" (*Quarterly Review*, cxiii., 379). However defective the plan, the excellence of many of the treatises by Archbishop Whately, Sir John Herschel, Professors Barlow, Peacock, De Morgan, &c., is undoubted. It is in four divisions, the last only being alphabetical:—I. *Pure Sciences*, 2 vols., 1813 pages, 16 plates, 28 treatises, includes grammar, law, and theology; II. *Mixed and Applied Sciences*, 8 vols., 5391 pages, 437 plates, 42 treatises, including fine arts, useful arts, natural history and its "application," the medical sciences; III. *History and Biography*, 5 vols., 4458 pages, 7 maps, containing biography (135 essays) chronologically arranged (to Thomas Aquinas in vol. 3), and interspersed with (210) chapters on history (to 1815), as the most philosophical, interesting, and natural form (but modern lives were so many that the plan broke down, and a division of biography, to be in 2 vols., was announced but not published); IV. *Miscellaneous*, 12 vols., 10,338 pages, 105 plates, including geography, a dictionary of English (the first form of Richardson's), and descriptive natural history. It is not easy to see why geography and natural history, so essentially systematic, were thus treated, or why annuities, brewing, bridges, &c., are less systematic than sculpture, agriculture, and carpentry. The index, 364 pages, contains about 9000 articles. A re-issue in 38 vols. 4to, was announced in 1849. Of a second edition, 42 vols. 8vo, 14,744 pages, belonging to divisions i. to iii., were published in 1849–58.

The very excellent and useful *English Cyclopædia* (London, 1854–62, 4to, 23 vols., 12,117 pages; supplements, 1869–73, 4 vols., 2858 pages), conducted by Charles Knight, based on the *Penny Cyclopædia* (London, 1833–46, 4to, 29 vols., 15,625 pages), of which he had the copyright, is in four divisions all alphabetical, and evidently very unequal as classes:—1, geography; 2, natural history; 3, biography (with 703 lives of living persons); 4, arts and sciences. History is given under geography, but very slightly; the nomenclature of natural history is partly popular and partly scientific; and the work contains much valuable matter, but also much that is undigested and imperfectly edited. The synoptical index, 168 pages, has four columns on a page, one for each division, so that the order is alphabetical and yet the words are classed.

Chambers's Encyclopædia (Edinburgh, W. and R. Chambers) 1860–68, 8vo, 10 vols., 8283 pages, edited in part by the publishers, but under the charge of Dr Andrew Findlater as "acting editor" throughout, was founded on the 10th edition of Brockhaus. A revised edition appeared in 1874, 8320 pages. In the list of 126 contributors are J. H. Burton, Emmanuel Deutsch, Prof. Goldstücker, &c. The index of matters not having special articles contains about 1500 headings. The articles are generally excellent, more especially on Jewish literature, folk-lore, and practical science; but as in Brockhaus the scope of the work does not allow extended treatment.

The New American Cyclopædia, New York (Appleton & Co.), 1858–63, 16 vols., 12,752 pages, is the work of the editors, George Ripley and Charles Anderson Dana, and 364 contributors, chiefly American. A supplementary work, *The American Annual Cyclopædia*, a yearly 8vo vol. of about 800 pages and 250 articles, has been published since 1861. In a new edition, *The American Cyclopædia*, 1873–76, 8vo, 16 vols., 13,484 pages, by the same editors, 4 associate editors, 31 revisers, and a librarian, each article passed through the hands of 6 or 8 revisers. It is, for its extent, one of the very best encyclopædias, particularly on American subjects. (P.A.L.)

ENDIVE, *Cichorium Endivia*, L., an annual esculent plant of the natural order *Compositæ*, commonly reputed to have been introduced into Europe from the East Indies, but, according to some authorities, more probably indigenous to Egypt. There are numerous varieties of the endive, forming two groups, namely, the curled or narrow-leaved (*C. E. crispa*), and the Batavian or broad-leaved (*C. E. latifolia*), the leaves of which are not curled. The former varieties are those most used for salads, the latter being grown chiefly for culinary purposes. The plant requires a light, rich, and dry soil, in an unshaded situation. In the climate of England, sowing for the main crop should commence about the second or third week in June; but for plants required to be used young it may be as early as the latter half of April, and for winter crops up to the middle of August. The seed should be finely spread in drills 4 inches asunder, and then lightly covered. After reaching an inch in height, the young plants are thinned; and when about a month old they may be placed out at distances of 12 or 15 inches, in drills 3 inches in depth, care being taken in removing them from the seed-bed to disturb their roots as little as possible. The Batavian require more room than the curled-leaved varieties. Transplantation, where early crops are required, has been found inadvisable. Rapidity of growth is promoted by the application of liquid manures. The bleaching of endive, in order to prevent the development of the natural bitter taste of the leaves, and to improve their appearance, is begun about three months after the sowing, and is best effected either by tying the outer leaves around the inner, or, as in damp seasons, by the use of the bleaching-pot. The bleaching may be completed in ten days or so in summer, but in winter it takes three or four weeks. For late crops, protection from frost is requisite; and to secure fine winter endive, it has been recommended to take up the full-grown plants in November, and to place them under shelter, in a soil of moderately dry sand or of half-decayed peat earth. Where forcing-houses are employed, endive may be sown in January, so as to procure by the end of the following month plants ready for use.

ENDOR, an ancient town of Palestine, originally belonging to the Philistines, and chiefly memorable as the abode of the sorceress whom Saul consulted on the eve of the battle of Gilboa, in which he perished. Although situated in the territory of the tribe of Issachar, it was assigned to Manasseh. In the time of Eusebius and Jerome it still existed as a large village 4 miles south of mount Tabor; and at the same distance, on the northern slope of the lower ridge of Hermon, there is still a village of this name.

ENDOWED SCHOOLS ACTS. Since the beginning of the present reign a number of statutes have been passed dealing with the endowed grammar schools of England. The Act 3 and 4 Vict. c. 77, which notices in the preamble the great number of grammar schools in England, both of royal and private foundation, and remarks that the term "grammar" had been construed to mean Greek and Latin, and that the governers and trustees of such schools were unable to establish any other education than that expressly provided for by the foundation, empowered courts of equity to make decrees or orders extending the systems of instruction and the right of admission to any school, and to establish schemes for the application of its revenues, having due regard to the intentions of the founder. The Act 23 Vict. c. 11 enabled and required the trustees and governors of endowed schools to make such order as, without interfering with the religious teaching of the other scholars or authorizing any new religious teaching, should admit children of other denominations than that to which the foundation belongs, except where the foundation expressly requires the children to be instructed according to the formularies of such denomination. The most important public schools—Eton, Harrow, Westminster, &c.—were expressly exempted from the operation of both of these Acts. The Act 31 and 32 Vict. c. 23 annexed certain conditions to the appointment of officers in endowed schools. The most important Act of the series was the 32 and 33 Vict. c. 56 (The Endowed Schools Act 1869) which authorized the appointment of commissioners, with power "in such manner as may render any educational endowment most conducive to the advancement of the education of boys and girls, and either of them, to alter and add to any existing, and to make new trusts, directions, and provisions in lieu of any existing trusts, directions, and provisions which affect such endowment and the education promoted thereby." The powers of the commissioners extend to all school endowments other than those specified in section 8 of the Act, which, *inter alia*, excludes schools under the Public Schools Act 1868, voluntary schools, schools aided by parliamentary grant, endowments not necessarily educational, &c. The 36 and 37 Vict. c. 87 continues and amends in various particulars the Act of 1869. The 37 and 38 Vict. c. 87 transfers the powers of the Endowed Schools Commissioners to the Charity Commissioners (see CHARITIES). The Public Schools Act 1868, above referred to, deals with the following schools, only —Eton, Winchester, Westminster. Charterhouse, Harrow, Rugby, and Shrewsbury.

ENDYMION. In the genealogy of the Iapetids Endymion is said to be the son of Aethlius, who is the son of Zeus by Protogeneia, the daughter of Deucalion and Pyrrha. The legend of Endymion was localized in Elis, the westernmost land in the Peloponnesus, where his tomb was shown in the days of Pausanias. The simplest form of the story is perhaps that of Apollodorus (i. 7, 5), who merely says that Selene (the moon) loved him, and that Zeus left him free to choose anything that he might desire, his choice being an everlasting sleep, in which he might remain youthful for ever. This is simply a reversing of the myth of Eos (the morning), who forgot to ask eternal youth for her husband Tithonus, whose decrepit form she was glad to hide in a cave. In other versions Endymion is a beautiful youth, whom Selene visits while he lies asleep in the cave of Latmus. She thus becomes the mother of his fifty daughters, who have been supposed by Preller (*Griechische Mythologie*, i. 384) to denote the fifty moons of the Olympian festal cycle, but who in their number must be compared with the fifty sons or daughters of Ægyptus, Danaus, or Priam. As the parent of these children, Selene is called Asterodia, the being whose path is among the stars. These names of themselves show that this myth was so transparent that it could never be more than thinly disguised. Endymion is, in short, as his name denotes, simply the sun setting opposite to the rising moon, the word being formed in a manner analogous to Hyperion, a name signifying the ascending or high soaring Helios or sun. The Latmian cave is the cave of forgetfulness or sleep, into which the sun plunges beneath the sea. Hence he is naturally spoken of as the son of Aethlius (the child of Protogeneia, the early dawn), who struggles and toils through his long journey across the heaven. There is nothing in the myth which warrants the idea that Endymion is a personification of sleep. Hypnus, the true god of slumber, is a conqueror whom none can resist; Endymion is simply one who cannot shake off his own sleep, a sleep so profound that they who are vexed in heart may well envy it (Theocr., *Idyll.* iii. 49).

ENERGY may be defined as the power of doing work, or of overcoming resistance. A bent spring possesses energy, for it is capable of doing work in returning to its natural form, a charge of gunpowder possesses energy, for it is capable of doing work in exploding; a Leyden jar charged with electricity possesses energy, for it is capable of doing work in being discharged. A complete account of our knowledge of energy and its transformations would require an exhaustive treatise on every branch of physical science, for natural philosophy is simply the science of energy. There are, however, certain general principles to which energy conforms in all the varied transformations which it is capable of undergoing, and of these principles we propose to give a brief sketch.

Before we can treat energy as a physical quantity we must possess some means of measuring it. If we raise 1 ℔ of matter through a foot we do a certain amount of work against the earth's attraction. If we raise 2 ℔ through the same height we do twice this amount of work, and so on for any number of pounds, so that the work done is proportional to the mass raised, and therefore to the resistance overcome. Also, if we neglect the variation of the intensity of gravity, the work done in raising 1 ℔ through 2 feet will be double of that done in raising it 1 foot. Hence we conclude that the work done varies as the resistance overcome and the distance through which it is overcome conjointly.

Now, we may select any definite quantity of work we please as our unit, as, for example, the work done in lifting a pound a foot high from the sea-level in the latitude of London, which is the unit of work generally adopted by British engineers, and is called the "foot-pound." The most useful unit for scientific purposes is one which depends only on the fundamental units of length, mass, and time, and is hence called an absolute unit. Such a unit is independent of gravity or of any other quantity which varies with the locality. Taking the centimetre, gramme, and second as our fundamental units, the most convenient unit of force is that which, acting on a gramme for a second, produces in it a velocity of a centimetre per second; this is called a Dyne. The unit of work is that which is required to overcome a resistance of a dyne over a centimetre, and is called an Erg. In the latitude of Paris the dyne is equal to the weight of about $\frac{1}{981}$ of a gramme, and the erg is the amount of work required to raise $\frac{1}{981}$ of a gramme vertically through one centimetre. A megalerg is one million ergs.

Energy is the capacity for doing work. The unit of energy should therefore be the same as that of work, and the centimetre-gramme-second (or, as it is usually called, the C.G.S.) unit of energy is the erg.

The forms of energy which are most readily recognized are of course those in which the energy can be most readily employed in doing mechanical work, and it is manifest that masses of matter which are large enough to be seen and handled are more readily dealt with mechanically than are smaller masses. Hence when useful work can be obtained from a system by simply connecting visible portions of it by a train of mechanism, such energy is more readily recognized than is that which compels us to control the behaviour of molecules before we can transform it into useful work. The former is sometimes, though very improperly, called visible energy, because its transformation is always accompanied by a visible change in the system itself.

The conception of work and of energy was originally derived from observation of purely mechanical phenomena, that is to say, phenomena in which the relative positions and motions of visible portions of matter were all that were taken into consideration. Hence it is not surprising that, in those more subtle forms in which energy cannot be so readily converted into work, it should for a long while have escaped recognition after it had become familiar to the student of dynamics.

If a pound weight be suspended by a string passing over a pulley, in descending through 10 feet it is capable of raising nearly a pound weight, attached to the other end of the string, through the same height, and thus can do nearly 10 foot-pounds of work. The smoother we make the pulley the more nearly does the amount of useful work which the weight is capable of doing approach 10 foot-pounds, and if we take into account the work done against the friction of the pulley, we may say that the work done by the descending weight is 10 foot-pounds, and hence when the weight is in its elevated position we have at disposal 10 foot-pounds more energy than when it is in the lower position. It should be noticed, however, that this energy is possessed by the system consisting of the earth and pound together, in virtue of their separation, and that neither could do work without the other to attract it. The system consisting of the earth and the pound therefore possesses an amount of energy which depends on the relative positions of its two parts, and the stresses existing between them. In most mechanical systems the stresses acting between the parts can be determined when the relative positions of all the parts are known; and the energy which a system possesses in virtue of the relative positions of its parts, or its *configuration*, is called its "Potential Energy," to distinguish it from another form of energy which we shall presently consider. The word potential does not imply that this energy is not real and exists only in potentiality; it *is* energy, and has as much claim to the title as it has in any other form in which it may appear.

It is a well-known proposition in dynamics that, if a body be projected vertically upwards in vacuo, with a velocity of v centimetres per second, it will rise to a height of $\frac{v^2}{2g}$ centimetres, where g represents the numerical value of the acceleration produced by gravity in centimetre-second units. Now, if m represent the mass of the body in grammes, its weight will be mg dynes, for it will require a force of mg dynes to produce in it the acceleration denoted by g. Hence the work done in raising the mass will be represented by $mg\frac{v^2}{2g}$, that is, $\frac{1}{2}mv^2$ ergs. But it is merely in virtue of the velocity of projection that the mass is capable of rising against the resistance of gravity, and hence we must conclude that at the instant of projection it possessed $\frac{1}{2}mv^2$ units of energy. Now, whatever be the direction in which a body is moving, a frictionless constraint, like a string attached to the body, can cause its velocity to be changed into the vertical direction without any change taking place in the magnitude of the velocity. Hence we may say that if a body of mass m be moving in any direction relative to the earth, we have at disposal, in virtue of this motion, $\frac{1}{2}mv^2$ units of *energy*, and this is converted into potential energy if the body come to rest at the highest point of its path. Like potential energy, this energy is relative and is due to the motion of the body relative to the earth, for we know nothing about absolute motion in space; and, moreover, when we have brought the body to rest relative to the earth, we shall have deprived it of all the energy which we can derive from its motion. The energy is therefore possessed in common by the system consisting of the earth and the body; and the energy which a system possesses in virtue of the relative motions of its parts is called "Kinetic Energy."

A good example of the transformation of kinetic energy into potential energy, and *vice versa*, is seen in the pendulum. When at the limits of its swing, the pendulum is for an instant at rest, and all the energy of the oscillation is potential. When passing through its position of equilibrium, since gravity can do no more work upon it without changing its fixed point of support, all the energy of oscillation is kinetic. At intermediate positions the energy is partly kinetic and partly potential.

Kinetic energy is possessed by a system of two or more bodies in virtue of the relative motion of its parts. Since our conception of velocity is essentially relative, and we know nothing about absolute velocities in space, it is plain that any property possessed by a body in virtue of its motion can be possessed by it only in relation to those bodies with respect to which it is moving, and thus a single rigid body can never be said to possess kinetic energy in virtue of the motion of its centre of mass. If a body whose mass is m grammes be moving with a velocity of v centimetres per second relative to the earth, the kinetic energy possessed by the system is $\frac{1}{2}mv^2$ ergs if m be small relative to the earth. But if we consider two bodies each of mass m and one of them moving with velocity v relative to the other, we can only obtain $\frac{1}{4}mv^2$ units of work from this system alone, and we ought not to say that the system considered by itself possesses more than $\frac{1}{4}mv^2$ units of energy. If we include the earth in our system the whole energy will depend on the velocities of the bodies relative to the earth, and not simply on their velocities relative to one another. Hence whenever we say that the kinetic energy of a body is $\frac{1}{2}mv^2$, we mean its kinetic energy relative to the earth, and the statement is only true when the mass of the body is very small compared with that of the earth. Any general expression for the energy of a system ought to be true whatever body in the system we consider fixed. It is manifest that the expression $\frac{1}{2}mv^2$ will not be a true representation of the kinetic energy of the earth and a cannon shot if we choose to consider the shot fixed and the earth moving towards it. In fact any general expression for the energy of a system must involve the masses of *all* the bodies concerned; but if the mass of one body be infinite compared with that of any of the others we may adopt the expression $\frac{1}{2}\Sigma(mv^2)$ for the kinetic energy, the body of infinite mass being supposed at rest.

It is only when a body possesses no motion of rotation that we may speak of its velocity as a whole. If a body be rotating about an axis, it follows from D'Alembert's principle that the work it is capable of doing while being brought to rest is the same as if each particle were perfectly free and moving with the velocity which it actually possesses. Hence if the moment of inertia of a body about its axis of rotation be represented by I, and its angular velocity by ω, the work which can be done by it if we can succeed in bringing it to rest will be $\frac{1}{2}I\omega^2$. We shall see hereafter how this energy may be transformed without the help of any external body if we suppose the rotating body indefinitely extensible in any direction at right angles to the axis of rotation, so that there is a sense in which we may speak of the kinetic energy of rotation as really belonging to the rotating body.

When the stresses acting between the parts of a system depend *only* on the relative positions of those parts, the sum of the kinetic energy and potential energy of the system is always the same, provided the system be not acted upon by anything without it. Such a system is called *conservative*, and is well illustrated by the swinging pendulum above referred to. But there are some stresses the *direction* of whose action depends on that of the relative *motion* of the visible bodies between which they appear to act, while there are others whose *magnitude* also depends on the relative velocities of the bodies. When work is done against these forces no equivalent of potential energy is produced, at least in the form in which we have been accustomed to recognize it, for if the motion of the system be reversed the forces will be also reversed and will still oppose the motion. It was long believed that work done against such forces was lost, and it was not till the present century that the energy thus transformed was traced, and the principle of conservation of energy established on a sound physical basis.

The principle of the Conservation of Energy has been stated by Professor Clerk Maxwell as follows :—

"*The total energy of any body or system of bodies is a quantity which can neither be increased nor diminished by any mutual action of those bodies, though it may be transformed into any one of the forms of which energy is susceptible.*

Hence it follows that, if a system be unaffected by any agent external to itself, the whole amount of energy possessed by it will be constant, and independent of the mutual action of its parts. If work be done upon a system or energy communicated to it from without, the energy of the system will be increased by the equivalent of the work so done or by the energy so communicated; while if the system be allowed to do work upon external bodies or in any way to communicate energy to them, the energy of the system will be diminished by the equivalent of the work so done or energy so communicated.

In order to establish this principle it might at first sight appear necessary to make direct measurements of energy in all the forms in which it can possibly present itself. But there is one form of energy which can be readily measured, and to which all other forms can be easily reduced, viz., heat. If then we transform a quantity of energy from the form in which it is possessed by the earth and a raised weight, and which can be at once determined in foot-pounds or ergs, into heat, and measure the amount of heat so produced,—and if subsequently we allow an equal amount of energy to undergo various intermediate transformations, but to be finally reduced to heat,—and if we find that under all conditions the amount of heat is the same, and in different sets of experiments proportional only to the amount of energy with which we started, we shall be justified in asserting that no energy has been lost or gained during the transformations. It is the experimental proof of this which Joule has given us during the last thirty years, but we shall refer more at length to his work shortly.

It has been recently pointed out by Thomson and Tait (*Natural Philosophy*, arts. 262 *sqq.*) that Newton was acquainted with the principle of the conservation of energy, so far as it belongs purely to mechanics. But what became of the work done against friction and such non-conservative forces was entirely unknown to Newton, and for long after his time this work was supposed to be lost. There were, however, some, even before Newton's time, who had more than a suspicion that heat was a form of energy. Bacon expressed his conviction that heat consists of a kind of motion or "brisk agitation" of the particles of matter. In the *Novum Organum*, after giving a long list of the sources of heat, some of which may fairly be adduced in support of his opinion, he says, "From these examples, taken collectively as well as singly, the nature whose limit is heat appears to be motion." In the following quotation Bacon appears to rise to the most complete appreciation of the dynamical nature of heat, nor do the most recent advances in science enable us to go much further. "It must not be thought that heat generates motion or motion heat (though in some respects this is true), but the very essence of heat, or the substantial self of heat, is motion and nothing else." Although Bacon's essay contains much sound reasoning, and many observations and experiments are cited which afford very strong evidence in favour of the theory he maintains, yet these are interspersed with so many false analogies, and such confusion between heat and the acrid or irritant properties of bodies, that we must reserve for those who came after him the credit of having established the dynamical theory of heat upon a strictly scientific basis.

After Newton's time the first important step in the history of energy was made by Benjamin Thompson, Count Rumford, and was published in the *Phil. Trans.* for 1798. Rumford was engaged in superintending the boring of cannon in the military arsenal at Munich, and was struck by the amount of heat produced by the action of the boring bar upon the brass castings. In order to see whether the heat came out of the chips he compared the capacity for heat of the chips abraded by the boring bar with that of an equal quantity of the metal cut from the block by a fine saw, and obtained the same result in the two cases, from which he concluded that "the heat produced could not possibly have been furnished at the expense of the latent heat of the metallic chips."

Rumford then turned up a hollow cylinder which was cast in one piece with a brass six-pounder, and having reduced the connection between the cylinder and cannon to a narrow neck of metal, he caused a blunt borer to press against the hollow of the cylinder with a force equal to the weight of about 10,000 ℔, while the casting was made to rotate in a lathe. By this means the mean temperature of the brass was raised through about 70° Fahr., while the amount of metal abraded was only 837 grains. The cylinder, when it was subsequently removed from the rest of the casting, was found to weigh 113·13 ℔.

In order to be sure that the heat was not due to the action of the air upon the newly exposed metallic surface, the cylinder and the end of the boring bar were immersed in 18·77 ℔ of water contained in an oak box. The temperature of the water at the commencement of the experiment was 60° Fahr., and after two horses had turned the lathe for 2½ hours the water boiled. Taking into account the heat absorbed by the box and the metal, Rumford calculated that the heat developed was sufficient to raise 26·58 ℔ of water from the freezing to the boiling point, and in this calculation the heat lost by radiation and conduction was neglected. Since one horse was capable of doing the work required, Rumford remarked that one horse can generate heat as rapidly as nine wax candles burning in the ordinary manner.

Finally, Rumford reviewed all the sources from which the heat might have been supposed to be derived, and concluded that it was simply produced by the friction, and that the supply was inexhaustible. "It is hardly necessary to add," he remarks, "that anything which any insulated body or system of bodies can continue to furnish *without limitation* cannot possibly be *a material substance;* and it appears to me to be extremely difficult, if not quite impossible, to form any distinct idea of anything capable of being excited and communicated in the manner that heat was excited and communicated in these experiments, except it be *motion.*"

About the same time that Rumford's experiments were published, Sir Humphry Davy showed that two pieces of ice could be melted by rubbing them together in a vacuum although everything surrounding them was at a temperature below the freezing point. He did not, however, see that since the heat could not have been supplied by the ice, for ice absorbs heat in melting, this experiment afforded conclusive proof of the dynamical nature of heat.

Though we may allow that the results obtained by Rumford and Davy demonstrate satisfactorily that heat is in some way due to motion, yet they do not tell us to what particular dynamical quantity heat corresponds. For example, does the heat generated by friction vary as the friction and the time during which it acts, or is it proportional to the friction and the distance through which the rubbing bodies are displaced,—that is, to the work done against friction,—or does it involve any other conditions? If it can be shown that, however the duration and all other conditions of the experiment maybe varied, the same amount of heat can in the end be always produced when the same amount of *energy* is expended, then, and only then, can we infer that heat is a form of energy, and that the energy consumed has been really transformed into heat. This Joule has done, and his experiments conclusively prove that heat and energy are of the same nature, and that all other forms of energy with which we are acquainted can be transformed into an equivalent amount of heat; and this is the condition ultimately assumed by the energy employed in doing work against friction and similar forces, which energy was in Newton's time supposed to be lost.

DEFINITION.—*The quantity of energy which, if entirely converted into heat, is capable of raising the temperature of the unit mass of water from* 0° *C. to* 1° *C. is called the mechanical equivalent of heat.*

One of the first who took in hand the determination of the mechanical equivalent of heat was Séguin, a nephew of Montgolfier. He argued that, if heat be energy, then, when it is employed in doing work, as in a steam-engine, some of the heat must itself be consumed in the operation. Hence he inferred that the amount of heat given up to the condenser of an engine when the engine is doing work must be less than when the same amount of steam is blown through the engine without doing any work. Séguin was unable to verify this experimentally, but in 1857 Hirn succeeded, not only in showing that such a difference exists, but in measuring it, and hence determining a tolerably approximate value of the mechanical equivalent of heat.

In 1839 Séguin endeavoured to determine the mechanical equivalent of heat from the loss of heat suffered by steam in expanding, *assuming* that the whole of the heat so lost was consumed in doing external work against the pressure to which the steam was exposed. This assumption, however, cannot be justified, because it neglected to take account of work which might possibly have to be done *within the steam itself* during the expansion.

In 1842, Mayer, a physician at Heilbronn, published an attempt to determine the mechanical equivalent of heat from the heat produced when air is compressed. Mayer made an assumption the converse of that of Séguin, asserting that the whole of the work done in compressing the air was converted into heat, and neglecting the possibility of heat being consumed in doing work within the air itself or being produced by the transformation of internal potential energy. Joule afterwards proved (see below) that Mayer's assumption was in accordance with fact, so that his method was a sound one as far as experiment was concerned, and it was only on account of the values of the specific heats of air at constant pressure and at constant volume employed by him being very inexact that the value of the mechanical equivalent of heat obtained by Mayer was very far from the truth.

Passing over Colding, who in 1843 presented to the Royal Society of Copenhagen a paper entitled "Theses concerning Force," which clearly stated the "principle of the perpetuity of energy," and who also performed a series of experiments for the purpose of determining the heat developed by the compression of various bodies which entitle him to be mentioned among the founders of the modern theory of energy, we come to Dr Joule of Manchester, to whom we are indebted more than to any other for the establishment of the principle of the conservation of energy on the broad basis on which it now stands. The best known of Joule's experiments was that in which a brass paddle consisting of eight arms of complicated form arranged symmetrically round an axis was made to rotate in a cylindrical vessel of water containing four fixed vanes, which allowed the passage of the arms of the paddle but prevented the water from rotating as a whole. The paddle was driven by weights connected with it by strings which passed over friction rollers, and the temperature of the water was observed by thermometers which indicated $\frac{1}{200}$th of a degree Fahrenheit. Special experiments were made to determine the work done against resistances outside the vessel of water, which amounted to about ·006 of the whole, and corrections were made for the loss of heat by radiation, the buoyancy of the air affecting the descending weights, and the energy dissipated when the weights struck the floor with a finite velocity. From these experiments Joule obtained 772·692 foot-pounds in the latitude of Manchester as equivalent to the amount of heat required to raise 1 ℔ of water through 1° Fahr. from the freezing-point. Adopting the centigrade scale, this gives 1390·846 foot-pounds as the mechanical equivalent of heat.

With an apparatus similar to the above, but smaller, made of iron and filled with mercury, Joule obtained results varying from 772·814 foot-pounds when driving weights of about 58 ℔. were employed to 775·352 foot-pounds when the driving weights were only about 19½ ℔. By causing two conical surfaces of cast-iron immersed in mercury and contained in an iron vessel to rub against one another when pressed together by a lever, Joule obtained 776·045 foot-pounds for the mechanical equivalent of heat when the heavy weights were used, and 774·93 foot-pounds with the small driving weights. In this experiment a great noise was produced, corresponding to a loss of energy, and Joule endeavoured to determine the amount of energy necessary to produce an equal amount of sound from the string of a violoncello and to apply a corresponding correction.

The close agreement between the results of these experiments, differing widely as they do in their details, at least indicates that "the amount of heat produced by friction is proportional to the work done and independent of the nature of the rubbing surfaces." Joule inferred from them that the mechanical equivalent of heat is probably about 772 foot-pounds, or, employing the centigrade scale, about 1390 foot-pounds.

Previously to determining the mechanical equivalent of heat by the most accurate experimental method at his command, Joule established a series of cases in which the production of one kind of energy was accompanied by a disappearance of some other form. In 1840 he showed that when an electric current was produced by means of a dynamo-magneto-electric machine the heat generated in the conductor, when no external work was done by the current, was the same as if the energy employed in producing the current had been converted into heat by friction, thus showing that electric currents conform to the principle of the conservation of energy, since energy can neither be created nor destroyed by them. He also determined a roughly approximate value for the mechanical equivalent of heat from the results of these experiments. Extending his investigations to the currents produced by batteries, he found that the total voltaic heat generated in any circuit was proportional to the number of electrochemical equivalents electrolysed in each cell multiplied by the electromotive force of the battery. Now, we know that the number of electrochemical equivalents electrolysed is proportional to the whole amount of electricity which passed through the circuit, and the product of this by the electromotive force of the battery is the work done by the latter, so that in this case also Joule showed that the heat generated was proportional to the work done.

During his experiments on the heat produced by electric currents, Joule showed that, when a platinum wire was heated by the current so as to emit light, the heat generated in the circuit for the same amount of work done by the battery was less than when the wire was kept cold, proving that when light is produced an equivalent amount of some other form of energy must disappear.

In 1844 and 1845 Joule published a series of researches on the compression and expansion of air. A metal vessel was placed in a calorimeter and air forced into it, the amount of energy expended in compressing the air being measured. Assuming that the whole of the energy was converted into heat, when the air was subjected to a pressure of 21·5 atmospheres Joule obtained for the mechanical equivalent of heat about 824·8 foot-pounds, and when a pressure of only 10·5 atmospheres was employed the result was 796·9 foot-pounds.

In the next experiment the air was compressed as before, and then allowed to escape through a long lead tube immersed in the water of a calorimeter, and finally collected in a bell jar. The amount of heat absorbed by the air could thus be measured, while the work done by it in expanding could be readily calculated. In allowing the air to expand from a pressure of 21 atmospheres to that of 1 atmosphere the value of the mechanical equivalent of heat obtained was 821·89 foot-pounds. Between 10 atmospheres and 1 it was 815·875 foot-pounds, and between 23 and 14 atmospheres 761·74 foot-pounds.

But, unlike Mayer and Séguin, Joule was not content with assuming that when air is compressed or allowed to expand the heat generated or absorbed is the equivalent of the work done and of that only, no change being made in the internal energy of the air itself when the temperature is kept constant. To test this two vessels similar to that used in the last experiment were placed in the same calorimeter and connected by a tube with a stop-cock. One contained air at a pressure of 22 atmospheres, while the other was exhausted. On opening the stop-cock no work was done by the expanding air against external forces, since it expanded into a vacuum, and it was found that no heat was generated or absorbed. This showed that Mayer's assumption was true. On repeating the experiment when the two vessels were placed in different calorimeters, it was found that heat was absorbed by the vessel containing the compressed air, while an equal quantity of heat was produced in the calorimeter containing the exhausted vessel. The heat absorbed was consumed in giving motion to the issuing stream of air, and was reproduced by the impact of the particles on the sides of the exhausted vessel.[1]

The more recent researches of Dr Joule and Sir William Thomson (*Phil. Trans.*, 1853, p. 357, 1854, p. 321, and 1862, p. 579) have shown that the statement that no *internal work* is done when a gas expands or contracts is not quite true, but the amount is very small in the cases of those gases which, like oxygen, hydrogen, and nitrogen, can only be liquefied by intense cold and pressure. It is worthy of note that mixtures of nitrogen and oxygen behaved more like theoretically perfect gases than either of the gases alone.

For the other contributions of Joule to our knowledge of energy, and for those of Sadi Carnot, Rankine, Clausius, Helmholtz, Sir William Thomson, James Thomson, Favre, and others, we must refer the reader to the articles on the several branches of physics, especially to HEAT.

Though we can convert the whole of the energy possessed by any mechanical system into heat, it is not in

---

[1] Joule's papers will be found scattered through the *Philosophical Magazine* from 1839 to 1864; also in the *Memoirs of the Manchester Society* (2) vii. viii. ix. and (3) i.; the *Proceedings of the Manchester Society*, 1859–60, 175; *Phil. Trans.*, [1850] i. 61, [1853] 357, [1854] 321, [1859] 91, [1859] 133, [1863] 579; *Proceedings of Roy. Soc.*, vi. 307, vi. 345, viii. 41, 178, viii. 355, viii. 556, viii. 564, ix. 3, ix. 254, ix. 496, x. 502; and the *Reports of the British Association* [1859] ii. 12, and [1861] i. 83.