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Energy

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Overview

Energy is an abstract notion that helps to understanding the nature and contributes to the creation of the civilization. The energy notion has a huge meaning not only due to practical reason – it is essential for economy and philosophy too. Therefore, the description of the development of the physical concept of energy must be preceded by the metaphysical foundations given by Aristotle. Evolution of the kinetic energy of the rigid body motion concept starting from the *vis viva* notion is presented. Further, the main problems connected with the internal energy concept in the form of "energy storage" and the transformations of different forms of energy are discussed. Balance of energy is finally presented as a sum of internal, kinetic, potential, and radiation energies in the system that are compensated by the total energy flux, which consists of working, heating, chemical, electric, magnetic, and radiation energy fluxes at the system boundaries. The law of energy conservation can be considered as the most important one which is superior over any other laws of nature.

Metaphysical Foundations of Energy Concept

In philosophy, and especially in its fundamental part, that is, metaphysics, there is no place for the concepts and methods of reasoning developed by physics and chemistry. Philosophy assumes that most of the physical and chemical concepts are not known in nature *in spe* – these are employed by science only as a kind of "mental keys" for the description and understanding of the universe. Only the concept of "energy" is accepted by the philosophers in its metaphysical sense. They consider energy as a fundamental feature of the nature which serves as a basis for other – the already known and yet not known features of the nature. Without energy in the metaphysics, there is no creation of matter, no creation of weightless fields, and no any formation and decay of all of the driving potentials of nature. In the metaphysics by Aristotle, the energy has only two forms of realization. One of them is a basic, perfect, and inaccessible potential of nature that may create a form of active and visible world during the act of creation. The second form of energy of motion is permanently involved in a process of creation and annihilation of beings. It "pours" from the unavailable source to the real world and vice versa – our reality "dies," thus becoming a perfect potential of nature again. The basic method of the physical world creation from the perfect potential is realized by an "energy action" (as mathematically defined by Maupertuis in 1744), which takes place on a quantized way, thus creating quantized real beings.

As far as the metaphysical knowledge can be assimilated by an illumination only, this part of philosophy is no longer being developed [1].

However, in an implicit manner, by the creation of the paradigms of thinking, metaphysics is still present in the process of human cognition. For example, the thesis of quantized energy action has its hidden implications in the modern *quantum mechanics*, and the thesis of the existence of "*eternal light*" is the prototype of the "*dark energy*" concept in cosmology. Metaphysical energy division into potential and active parts is an analogue of the potential energy (gravitational field) and the kinetic energy of body motion.

In summary, the metaphysics of Aristotle and his successors brought the fundamental paradigms of thought to the energy science. One is an inherent relationship between the energy and the so-called peripatetic motion, because the active energy is an integral measure of the amount of motion. The opposite to this peripatetic motion is immobility of the nature's source which can be measured only by the perfect potential. The paradigm of the peripatetic motion is still present in our reasoning concerning the principles of the energy conversion and the transformation of its forms. Peripatetic motion is a sort of quantum motion that constitutes every other motion, thus being the basis of all chemical processes, nuclear physics, mechanics, and thermodynamics. It means that the energy as an integral measure of peripatetic motion is identical in its elementary quality; therefore, energies of mechanical, heat, electrical, and magnetic motions can be added without the necessity of using of any energy conversion factors (equivalents). In other words, in Aristotle's metaphysics, all known energy equivalents as heat-mechanical (Rumford, Carnot, Joule), electro-chemical (Faraday), electro-mechanical (Thomson), mechanical-heat (Clausius) are equal one. This concept of homogenous energy was adopted from the Greek philosophy by Rankine, who assumed a quantized energy transfer by the "vortex atom" [2].

Disputes over *vis viva*

In the Middle Ages, the metaphysics and natural philosophy of Aristotle were discarded and the concept of peripatetic motion was limited only to the mechanical motion (Jean Buridan, c.1292-c.1360). The laws governing the mechanical motion were not known. There was a need to define a "topological charge" which ensures the continuation of arrows motion during a flight and which would define the amount of available motion. There were two candidates: mv that is, the product of mass and velocity (momentum) and other product mv^2 called by philosophers *vis viva* (Leibniz 1667). But even after Newton's discovery (1677), who found that the real cause of the mechanical motion is *vis impressa* (in a geometric version) and that the momentum of the universe is constant, there were disputes over the primary force that governs the mechanical motion, that is, *vis viva* or *vis impressa*. Such disputes were continued also after the works of Wallis (1699) and Euler (1729) who gave the analytical form of Newton's law $m\vec{a} = \vec{f}$. The historical studies by Duhem, and then also by Truesdell (1980), showed, however, that when the peripatetic motion other than mechanical motion was considered, then natural philosophers used the more general notion of *vis viva*. This dichotomy of thinking had continued through the eighteenth century. For example, Johann Bernoulli (1741), when defining the law of motion of the liquid in the pipes, employed the momentum balance (balance *vis impressa*), and apparently, Daniel Bernoulli (1739) used as a law of motion an integral form of balance of *vis viva*.

Internal Energy

It can be noticed that all of these proposals and hypotheses refer to the perfect phenomena of nature, which are not yet affected by human activity. Industrial Revolution of eighteenth century, however, resulted in application of a tremendous amount of machineries and heat engines. There was a reasonable demand for the governing laws of practical meaning – it was especially important from the economical point of view. The machines operate periodically; thus, the mechanical motion in the single cycle is a self-compensating quantity. Therefore, in the process of analyzing the operating principles, the main role played the technical concepts such as *heating* and *working*, which allowed to define usefulness of the heat engine in every single cycle. The working and heating processes, if continue for some time, may be defined by an abstract, integral in time quantities, that is, *work* and *heat*. By the fact that it was possible to measure the effects of both processes, which were accumulated in the form of work or heat "storages" located in the working medium, a new complex and abstract concept could be introduced – the concept of energy storage or energy stored in the working medium. Initially, the work storage (work supply) and heat storage (heat supply) were treated independently. Depending on whether the law of conservation of energy was formulated in units of work (Clausius 1850) or in units of heat (Thomson 1854), the substantial work or heat storages could be specified. Only Rankine (1850), writing the law of conservation of energy in an analytical manner postulated by Mayer and Joule's, concluded that there is only one universal energy storage – the *internal energy*, which possesses a single substantial carrier that is common to all forms of energy transfer. Rankine also stated that all energy equivalents are thus redundant. This was, in relation to the statements of Clausius and Thomson, an extremely radical step which broke the fundamental paradigms on separateness of energy forms.

In terms of Clausius, the substance subjected to the process of working can accumulate and store work without any losses and then, after moving the substance (working body) in another place, can release it at any time – but only in the same mechanical form. Then, under an irreversible operation, the working process can be transformed into the heating process in an amount determined by the mechanical equivalent of heat $A_{Clausius}$. It should be underlined that the concept of accumulation of work in the medium in the form of "work supply" had some origins in consideration on simple machines, where mechanical energy is transformed in the same type of energy. This led to the law of energy balance that was limited only to the mechanical phenomena (Lazar Carnot, 1803 – integral in time and space). Quite early appeared the mechanical case of internal energy per unit mass of the substance. It was Green's internal energy (1839) for three-dimensional elastic deformation of a solid body and Petit's internal energy (1818) for a three-dimensional rapid compression of gas. Whittaker (1910) noted, however, that Green's internal energy not exactly refers to solid [3]. It was Kirchhoff (1850) who used it first to derive the simplified equations of motion of a thin plate.

In terms of Thomson, the internal energy was expressed in units of heat and was defined by him as a "heat supply" that is ready to be transferred outside without any losses. Thomson's version of the internal energy conversion principle assumes that the working medium possesses the ability of accumulation of the heating process effects only as a heat. The body which is warmed in one place can transfer the energy outside in another place and time, but only during the heating process. Under irreversible processes, the heating may evolve into working, which can be calculated using the thermal equivalent of work J_{Joule}. Both Clausius and Thomson emphasized the ideality of internal energy storage, which means that nothing is lost from the "work supply" (Clausius) or "heat supply" (Thomson). The medium at first adopts and later releases the same amount of stored work or heat.

The modern definition of internal energy was finally given by Rankine (1850). His revealing hypothesis on the internal energy conversion assumes that the matter of the working medium does not store either heat or work. The working medium during heating process does not increase its heat supply but increases its internal energy, and similarly, the working medium during working process does not increase its work supply but also increases its internal energy. Thus, the conversion of energy of mechanical motion into the thermal motion possesses an intermediate step in the form of the internal energy changes. This transformation occurs during charging or emptying of internal "storage." In other words, the thermal energy transferred to the medium in the heating process leads to the increase of the medium's internal energy, and the internal energy can "leave" the medium, for example, converting itself into work (working process).

Such internal transformation is possible due to the motion of atoms, electrons, molecules, etc. In the working medium, there is only one universal type of reversible energy storage. Rankine's model of internal energy conversion that bases on the anticipated concept of "vortex atom" does not differ much from the contemporary models of the atom, the nucleus, and electrons. The external energy fluxes related to heating and working processes inside the Rankine vortex atom transform into a hidden Aristotelian active energy or hidden generalized *vis viva*: $m\vec{v}\cdot\vec{v}+\vec{\omega}\cdot\vec{I}\vec{\omega}$, which consists of translational and rotational *vis viva*. The conversion of energy, which is received by an external observer as a replacement of heating by working process, also takes place inside the Rankine vortex atom in a reversible manner as a change of $\vec{\omega}\cdot\vec{I}\vec{\omega}$ into $m\vec{v}\cdot\vec{v}$. In the frame of Rankine vortex atom (1851), temperature and entropy (called by Rankine *a thermodynamic function*) have a clear geometric presentation. They are introduced as parameters of state, that is, the parameters associated with reversible energy storage. It is fundamentally different concept than one presented by Clausius (1865), who needed 14 years to come with the concept of entropy embedded in the chaotic motion of millions of moving gas molecules.

Rankine's internal energy concept was creatively extended by Gibbs (1876), who was probably one researcher, except Truesdell, able to properly interpret the work of Rankine. Gibbs perceived that Rankine's model of vortex atom is so comprehensive that it can also describe the chemical, magnetic, and electric energy storages. Therefore, instead of many different storages, Gibbs introduced a universal internal energy, which is responsible for the implicit transformation of energy. Rankine's internal energy paradigm, supplemented further by Gibbs, is still in use in the thermodynamics of continuum, and perhaps also in the whole physics and chemistry. Idea of internal energy describes the mechanism of reversible accumulation of energy, which is transferred to the mass unit of the medium during different processes such like mechanical working, heating, electrical, magnetic and chemical working, etc. Internal energy is a primary quantity which cannot be measured directly.

Kinetic Energy

Rankine's concept of internal energy can be treated to some extent as an analytical representation of Aristotle's division of entelechy of motion into the potential and active parts. It is also mentioned by Rankine (1855) during development of the "kinetic energy" concept: $\frac{1}{2}m\vec{v}\cdot\vec{v}$. He treated all perceptible physical world of matter as a manifestation of an active motion. This motion can be divided into balanced internal motion, measured quantitatively by the internal energy, and an external energy of motion, which is only a qualitative component of *vis viva*, called the "kinetic energy." Because both the internal and kinetic energies are of the same nature, these can be calculated using the same units without employing Joule's equivalent of energy. Rankine was in some opposition to Joule, whose goal was to find the equivalent as a ratio of internal energy to the kinetic energy ($J_{Joule}=\mathcal{U}/\mathcal{K}$). Joule's approach was also innovative, but only in relation to the concept of Sadi Carnot who was preferring the equivalent of work in the form $J_{Carnot}=\mathcal{W}_{cycle}/Q_{cycle}$.

Thermodynamical Parameters of State

Together with the concept of the internal energy, a new notion has been introduced by Rankine – the thermodynamical parameters of state, which allow to estimate the change of internal energy. Two kinds of parameters were attributed to the every form on energy – primary one, which is intensive mass dependent and a secondary one, which is dual, extensive mass independent. The first parameter was named a *metaphoric* function, and the second was called a *metamorphic* function (Rankine 1855). The first examples of the parameters of state for gas were the specific volume and the specific entropy (intensive parameters) and complementary to them, thermodynamic pressure and temperature (extensive parameters). More parameters appear when the solid body is considered, namely, tensor of deformation density and tensor of specific entropy and complementary to them, tensor of stresses (pressure) and tensor of temperature.

The parameters of state in the Rankine proposal were a practical way for calculating the amount and the change of the internal energy. The primary intensive parameters of state do not reflect individualism of the internal motion; they are anthropocentric, convenient for measurements averages over the internal motion. Unfortunately, the internal energy conversion so clearly imagined by "vortex atom," when analyzed in terms of parameters of the state, is no longer a simple representation. It is hard to imagine graphically an exemplary conversion as for the case when the internal energy remains constant, but the specific volume decreases at the expense of the specific entropy increase. The internal energy concept expressed by primary parameters of state was finally formulated by Gibbs (1873), who defined the relationship between primary and dual parameters of state:

$$\text{dual parameter of state} = \frac{\partial(\text{specific internal energy})}{\partial(\text{primary parameter of state})} \quad (1)$$

This equation is one of the most fortunate in the thermodynamics foundations. It allows to relate the set of equations describing the arbitrary process with the law of energy conservation. The equations which describe the physical processes, such as heat conduction in the solid body, may be erroneously formulated in the sense that they can lead to the violation of the law of energy conservation. Therefore, in order to transform the governing equations, such as Schrödinger equation, into the energetic relationship, it is necessary to know Gibb's constitutive relation (1) and the well-defined partial energy fluxes for working and heating processes of all kind.

Gibbs realized that for the internal energy changes occurring due to changes of the primary parameters of state, it is important to determine the total internal changes expressed by changes of both primary and dual parameters of state:

$$d(\text{specific internal energy}) = \sum \begin{pmatrix} \text{dual} \\ \text{parameter of state} \end{pmatrix} d \times \begin{pmatrix} \text{primary} \\ \text{parameter of state} \end{pmatrix} \quad (2)$$

which have exemplary form

$$\text{for fluids:} \quad \mathrm{d}\varepsilon = \mathrm{p}\mathrm{d}\mathrm{v} + \theta \mathrm{d}\eta + \mu \mathrm{d}\mathrm{c} + \ldots \quad (3)$$

$$\text{for solids:} \quad d\varepsilon = p_{ij} dv_{ij} + \theta_{ij} d\eta_{ij} + \mu_{ij} dc_{ij} + \ldots \quad (4)$$

Here, increment d means the substantial differentiation in time (d/dt). For the solid bodies, which accumulate not only volumetric but also shape changes, exist tensors of specific deformations, specific entropy, specific concentration, etc.

Potential Energy

The concept of the energetic potential Φ was introduced by Laplace in 1797 for the description of the gravitational force (*vis viva moltara* later *vis latente*) acting between two massive bodies (action at distance). Laplace assumed that each of the massive bodies coming from the nature's source of potential possess the spatial memory of this source, which is described by involved energy of the source Φ. In other words, Laplace's concept described the action of the anticipated gravitational field by the potential, later called the potential energy. This concept had a huge advantage over Newton's gravity model – in this concept, there is no need for adjustments in the form of additional postulate of the existence of "eternal light." Recall that Newton's model had a serious drawback. His concept did not describe the permanence of the firmament (*stellae fixae*), and to explain why the stars do not fall one another, Newton postulated additional unknown, that is, the pressure of light – "eternal light," which repelled the stars from each other. Today, the role of the eternal light in cosmology meets the "dark energy" notion, also postulated ex nihilo [7]. Under earthly conditions, the Laplace potential is described accurately enough by the distance of the body from the Earth's surface enlarged by Earth's radius (position vector). Now extending the Gibbs-Rankine's concept of state parameters also for the potential energy Φ, it can be concluded that the position vector $\vec{x}$ plays a role of the primary state parameter and the gravitational acceleration $\vec{b}$ is a dual state parameter: $\vec{b} = -\partial\Phi/\partial\vec{x}$.

Energy of Radiation

There exists also an additional internal energy – energy of radiation – which is not associated with the substance of the working medium and which is localized in space. In 1865, Maxwell proposed that this non-substantial energy of electromagnetic field ε_{em} can be expressed by the primary state parameters as electric field $\vec{E}$ and magnetic field $\vec{H}$. Maxwell identified also the dual state parameters of radiation energy, that is, the electric displacement vector $\vec{D} = \partial e_{em}/\partial\vec{E}$ and the magnetic displacement vector $\vec{B} = \partial e_{em}/\partial\vec{H}$. This concept allows later to formulate the energetically consistent theory of radiative heat transfer by Planck (1905).

Mathematical Denotation of the Fundamental Concepts

It is necessary to assign the mathematical objects to the verbal concepts of energy. Since in literature exist dozens of different signs for the same quantities, it is reasonable to employ the system of denotations as proposed in the papers of pioneers, mostly Rankine, Gibbs, Duhem, and Natanson (Kestin 1980). The method of description bases here on the foundations of rational thermodynamics given by Truesdell [4] and Kestin [5, 6].

Let us mark the finite volume by the sign $d\mathcal{V}$, and the volume of thermodynamic system $\mathcal{B}$ by letter $\mathcal{V}$. The system $\mathcal{B}$ interacts with the external environment by the processes acting at the system boundary $\partial\mathcal{V}$. The internal, kinetic, and potential energy can be denoted by $\mathcal{U}, \mathcal{K}, \Phi$ respectively, and the energy of radiation by ε_{em}. All these quantities are expressed in the energy unit – joule (1 J = 0.62415·10^{19} eV). These integrals for the system amounts of the energy reflect in a good manner the anthropocentric character of our knowledge, and they are commonly employed in the science and technique. Beside the integral quantities, there are some quantities related to the unit of mass, as:

Internal energy

$$\mathcal{U} = \iiint_V \rho\varepsilon d\mathcal{V} = \iiint_{V_0} \rho_0 \varepsilon d\mathcal{V} \tag{5}$$

Kinetic energy

$$\mathcal{K} = \iiint_V \frac{1}{2}\rho\vec{v}\cdot\vec{v}d\mathcal{V} = \iiint_{V_0} \frac{1}{2}\rho_0\vec{v}\cdot\vec{v}d\mathcal{V} \tag{6}$$

Potential energy

$$\Phi = \iiint_V \rho\Phi\ d\mathcal{V} = \iiint_{V_0} \rho_0\Phi d\mathcal{V} \tag{7}$$

Two volumes of system can be distinguished – the referential volume $\mathcal{V}_0$ non-deformed, used in Lagrange's description, and the actual volume $\mathcal{V}$ reelated to Euler's description.

Let us denote by ρ_0 and ρ the mass density in its initial state and actual state, respectively. Following Gibbs, the specific internal energy (J/kg) related to the unit mass can be denoted by ε. The quantities $\rho\varepsilon$ and $\rho_0\varepsilon$ are volumetric energy densities related to actual and initial volumes, respectively. Fourth kind of energy that undergoes balancing is an energy of radiation:

$$\mathcal{E}_{em} = \iiint_\infty e_{em} d\mathcal{V} \tag{8}$$

where e_{em} (J/m^3) is a volumetric density of energy of electromagnetic field postulated by

Maxwell (1874). It means that the field quantity cannot be related to the mass of substance, only to the volume where the radiation is acting. Let us, according to Rankine, assume that the energy fluxes are additive. It allows to formulate the total energy flux as the sum of particular processes:

$$\begin{aligned}\mathcal{F}_{energy} = \mathcal{F}_{working} + \mathcal{F}_{heating} + \mathcal{F}_{chem} \\ + \mathcal{F}_{elec} + \mathcal{F}_{mag} + \ldots\end{aligned} \quad (9)$$

where respectively appear working, heating, chemical, electric, and magnetic energy fluxes. This mathematical set can be treated as universal one – there is a place for new, yet unknown processes. There is a lack of radiative flux, described by Poynting's vector (1899), because it is directly related to the system substantial boundary. The substantial boundary $\partial\mathcal{V}$ is oriented outside by the normal unit vector $\vec{n}$ that allows to write the energy flux as a normal component of the total energy vector:

$$\begin{aligned}\mathcal{F}_{energy} = \iint_{\partial V} (\vec{\mathcal{F}}_{work} + \vec{\mathcal{F}}_{heat} + \vec{\mathcal{F}}_{chem} \\ + \vec{\mathcal{F}}_{elec} + \vec{\mathcal{F}}_{mag} + \ldots) \cdot \vec{n} dA\end{aligned} \quad (10)$$

Two first energy fluxes are very well known in literature: $\vec{\mathcal{F}}_{work}$ is a mechanical energy flux of Umov (1874) and Volterra (1899) and $\vec{\mathcal{F}}_{heat}$ is a heat energy flux of Rankine (1850) and Stokes (1851).

The essence of the proper definition for the various fluxes is to find the proper relationship for the energy flux with the fluxes of momentum, angular momentum, mass, entropy, electricity, etc. If the internal energy ε is expressed by the primary parameters of the state and there are no spatial and time gradients of the parameters of state, then fluxes of the mechanical energy and heat can be expressed by a relatively simple combination of the momentum flux tensor $\vec{\tau}$ and entropy flux vector $\vec{h}$ [4–6]:

$$\vec{\mathcal{F}}_{work} = \vec{\tau}\vec{v} \quad \vec{\mathcal{F}}_{heat} = \theta\vec{h} \quad (11)$$

where $\vec{v}$ is the velocity vector of the substance and θ is the absolute temperature. In the case of the field energy, there exists the pointing radiation energy flux defined as $\vec{\mathcal{F}}_{em} = \vec{E} \times \vec{H}$.

The universal law of energy conservation can be now anticipated. This universal law states that the change of the system of the energy storage occurs at the expense of processes (fluxes) or mathematically:

$$\begin{aligned}&\frac{d}{dt}(\mathcal{U} + \mathcal{K} + \Phi + \mathcal{E}_{\mathrm{em}}) \\ &= \iint_{\partial V} \vec{\mathcal{F}}_{energy} \cdot \vec{n} dA + \iint_{\infty} \vec{\mathcal{F}}_{em} \cdot \vec{n} dA + \mathcal{S}_e\end{aligned} \quad (12)$$

Here, the energy source $\mathcal{S}_e$ is a measure of non-conservation of the energy. For the phenomenon occurring between time t_{in} and t_{out} (time scale associated with human activity), this energy balance equation can be integrated.

Due to the reversibility of the total energy storage, the integral on LHS of (12) depends only on the initial and final state of the storage. As far as the occurring processes are summed exactly, (12) finally transforms into

$$\begin{aligned}&(\mathcal{U} + \mathcal{K} + \Phi + \mathcal{E}_{em})_{|t_{out}} \\ &- (\mathcal{U} + \mathcal{K} + \Phi + \mathcal{E}_{em})_{|t_{in}} \\ &= \int_{t_{in}}^{t_{out}} (\mathcal{F}_{energy} + \mathcal{F}_{em}) d\tau\end{aligned} \quad (13)$$

It is a formulation known as an integral in time and space form of the primary energy conservation law (12).

Special integral form can be obtained for the phenomenon occurring periodically. In this case, the summary energy changes in a single cycle are equal zero, and the balance can be simplified to the closed integrals of fluxes, which compensate each other. If considered phenomenon consists of heating and working only, then their line integrals are called the cycle heat and cycle work, and (13) can be written as

$$\mathcal{F}^{cycle}_{work} + \mathcal{F}^{cycle}_{heat} = 0 \quad (14)$$

which can be read as follows. After single, complete cycle of transformations, the internal, kinetic, and potential energies stored in the working medium take on their initial value, and the cycle work is equal the cycle heat:

$$\begin{aligned}\mathcal{F}_{work}^{cycle} &= \oint \left(\iint_{\partial V} \vec{\mathcal{F}}_{work} \cdot \vec{n} dA \right) d\tau \\ &= \oint \left(\iint_{\partial V} \overline{\overline{\tau}} \vec{v} \cdot \vec{n} dA \right) d\tau \\ \mathcal{F}_{heat}^{cycle} &= \oint \left(\iint_{\partial V} \vec{\mathcal{F}}_{heat} \cdot \vec{n} dA \right) d\tau \\ &= \oint \left(\iint_{\partial V} \theta \vec{h} \cdot \vec{n} dA \right) d\tau \end{aligned} \quad (15)$$

Here, in (13) and (14), it has been assumed that $\mathcal{S}_e = 0$ but strictly speaking, only the law of energy conservation, known as the first law of thermodynamics, should decide about the existence of the internal energy source $\mathcal{S}_e$.

The Law of Energy Conservation

One of the most fascinating steps of civilization is related to the energy conservation law – its anticipation, development, and the rational explanation. Until today, there is no any empirical evidence of the conservation of energy; nevertheless, in the opinion of researchers, it is the most unquestionable and inviolable law of nature. Its philosophical origins come from Greek's metaphysics who assumed that even more general law of the conservation of peripatetic motion is valid in the nature. This law can be split then into many special laws of conservation, which cannot necessarily be a scalar one, as in the case of energy. Leonardo da Vinci (1499) disagreed with this concept. He compared the nature and the man himself to the great machine, and hence, da Vinci proposed to split the law of the conservation of peripatetic motion into two special laws: (a) there is no possibility of existence of the eternal engine in the nature (*perpetuum mobile* of the first kind) and (b) there is no possibility of any mechanical perpetual motion in the nature (*perpetuum mobile* of the second kind). This concept had enormous impact on the scientific investigations in the nineteenth century. It became the prototype for the *first and second laws of thermodynamics*. Kuhn noticed that there were at least 12 researchers who contributed to the final formulation of the law of energy conservation and its mathematical representation [7]. In fact, more than 12 researchers should be considered [8]. For example, already Sadi Carnot in 1824 postulated the law (14) in the form 2.7 $\mathcal{F}_{work}^{cycle} + \mathcal{F}_{heat}^{cycle} = 0$ which did not require a prior knowledge of the concept of "internal energy." On the other hand, Mayer (1842) and Joule (1847) formulated the law of indestructibility of energy and assumed that the system is not affected by any processes, that is, $\mathcal{F}_{energy} = 0$ and the law of conservation of energy has a simple form that consists of three parts:

$$\mathcal{U} + \mathcal{K} + \Phi = const \quad (16)$$

In the case of a large system, such like the universe, this balance leads to $E_{Universe} = \mathcal{U} + \mathcal{K} + \Phi = \text{const} = \text{nE}_{\text{Sun}}$. It was formulated by Mayer (1851) in the form of, energy of the universe is constant and approximately equals the numbers of stars in the firmament, multiplied by the energy of the sun.

The universal conversion law for all energy fluxes was verbally formulated by Grove (1841) and mathematically written by Helmholtz (1847). The principle of energy conversion stated that the substance has the ability to receive the energy by one process, is able to store it without any losses, and is able to release energy by another process. The final theory of energy conversion was developed by Rankine (1855), and now, it is an inviolable foundation of the mathematical description of all the natural phenomena.

Today, there is an agreement that the key hypothesis of energy conservation given by Mayer and Joule's saying that energy is indestructible can be used even in the smallest subatomic scale. In practice, the source of energy in total energy balance (12) must always be equal to zero, regardless the volume of the considered system:

$$\mathcal{S}_e = \iiint_V \rho s_e d\mathcal{V} = 0 \qquad (17)$$

It means that in the nature, there are no any processes which can create a new amount of energy. Researchers are convinced that the energy is indestructible despite of the fact that energy is only a scalar, coarse, and abstract invariant of processes occurring in nature.

Cross-References

▶ Energy and First Law of Thermodynamics

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Energy and First Law of Thermodynamics

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Synonyms

Conservation of energy; Energy; First law of thermodynamics; Thermodynamic system

Overview

Energy belongs to the fundamental concepts of thermodynamics and plays an important role in numerous engineering applications. The classical concept of thermodynamics distinguishes between work and heat as different appearances of energy. It may be stored within or transferred between systems. Work and heat may also be converted interchangeably, however, with some restrictions applicable. Therefore, the concept of energy, e.g., work and heat, is extended by the first law of thermodynamics that is commonly referred to as conservation of energy. Consequently, energy cannot be created or destroyed. Thus, the first law of thermodynamics describes the interaction of a thermodynamic system with its surroundings in terms of transfer of heat and work and relates it to the inner thermodynamic state of the system itself.

Energy

Energy is one of the fundamental concepts of thermodynamics and dealt with in a large number of engineering applications [1]. Some basic ideas about energy include that energy may be stored within systems, is transformable from one form to another, or may be transferred between systems.

Work

Work W is commonly referred to as the result of a force $\vec{F}$ moving along a certain path between s_1 and s_2:

$$W = \int_{s_1}^{s_2} \vec{F} \cdot \vec{ds} \qquad (1)$$

where the integral is defined as the scalar product of the force vector $\vec{F}$ and the displacement vector $\vec{ds}$ and thus, yields work as a scalar quantity [2]. Consequently, a definition of positive and negative work may be as follows:

> Work is positive if it is added to a system.

In order to evaluate the integral of (1), the variation of the force with displacement has to