Concepts of Mass and energy since Aristotle's to Einstein's era

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Abstract

The concepts of mass and energy are extremely useful physical quantities. The study of these physical quantities has started since days of Aristotle or even before. G. Corolis made a significant breakthrough by defining work as W=**F.S** = FScos θ and derived kinetic energy equal to $mv^2/2$. Newton initiated the discussion on inter-conversion of mass and light energy. Then various scientists such as S. Tolver Preston, Jules Henri Poincaré, Olinto De Pretto, Fritz Hasenohrl, Frederick Soddi, derived equation for inter conversion of energy before Einstein. Some of the scientists, who did significant work in this regard are least known. Then Einstein in 1905, derived light energy-mass equation ($L = \Delta mc^2$) about which Newton had mentioned about two centuries before. Further from $L = \Delta mc^2$ Einstein speculated more general equation without any specific derivation $= \Delta mc^2$.

1.0 The contributors to Mass and Energy concepts

The mass and energy are basic concepts in every physical phenomena. The word 'energy' derives from energeia which was coined by Aristotle for first time [1]. Whenever the energy has to be calculated, initially work is calculated, e.g. calculation of potential energy. Both energy and work have same dimensions.

Further mass is quantity of matter contained in the body, the real understanding of mass started when Newton defined second law of motion in *the Principia* [2]. The mass and energy are studied both in absolute sense and also in the terms of inter conversion to each other. Newton also stated inter conversion of light energy to mass [3], thus initiated important debate on this issue.

The following legends have contributed to the topic.

(i) **Aristotle** [384-322 BC] believed that all matter on the earth consisted of four pure substances or elements, which were earth, air, fire, and water [1]. Here fire may be regarded as energy.

(ii) **Antoine Lavoisier** (1743-1794) French Chemist was the first to formulate a law of conservation of matter in chemical reactions [4] i.e.

'matter can neither be created nor be destroyed but can be transformed from one to other form.'

(iii) **Gottfried Wilhelm Leibniz [**1646-1716], German Mathematician put forth idea of vis viva (from the *latin* living force) as mv^2 i.e. $E = mv^2$ (m is mass and v velocity of body) and stated that it is conserved [5-6].

(iv) **Thomas Young** [1773 -1829] was first to use term 'energy' instead of vis viva [7] in 1807.

(v) **Gustave Coriolis** [1792-1843] was first to define work as product of force and distance ($W=\mathbf{F.S} = \mathbf{FS}\cos\theta$); in 1829 he described kinetic energy as $mv^2/2$ [8]. In this regard $W=\mathbf{F.S}$ is regarded as the most significant equation, as it is used in both relativistic and non-relativistic calculations. The trigonometric functions have been studied by Hipparchus [180-125BC] and by other following mathematicians and philosophers.

1.1 Inter-conversion of mass and energy.

Mass energy inter-conversion processes are the oldest in nature and constitute the basis of various phenomena. Further the energies have various forms (e.g. sound energy, heat energy, chemical energy, energy emitted volcanic reactions nuclear energy, magnetic energy, electrical energy, energy emitted in form of invisible radiations, energy emitted in cosmological and astrophysical phenomena energies co-existing in various forms etc.) which are converted into mass. In antiquity, heat energy is being created by combustion of wood, grass and dry leaves etc. At different times various scientists have studied this significant topic in different ways and study is continuous process even now. When mass is annihilated the equivalent amount energy is calculated.

(i) Newton [3] has quoted in his book 'Opticks' in 1704 that

"Gross bodies and light are convertible into one another...",

It implies that energy is other form of mass. Neither Lavoisier nor Newton gave any mathematical equation relating to mass and energy, hence the deduction is qualitative only. But Newton started the real discussion on the inter-conversion of mass to energy and vice-versa. Newton did not give any quantitative equation in the regard, however after this scientists tried to provide the mathematical equations.

(ii) **S. Tolver Preston** [9] proposed that a vast amount of energy can be produced from matter in his book (now rare book) *Physics of the Ether* in 1875. Preston determined that one grain (one grain = 0.0647989 grams) could lift a 100,000-ton object up to a height of 1.9 miles. This deduction yields $\Delta E \propto \Delta mc^2$, on the basis of relevant calculations.

(iii) **Jules Henri Poincaré** [10,11] in 1900 applied the calculations in a recoil process and reached at the conclusion in the form, $mv = (E/c^2)c$. From the viewpoint of dimensional analysis, E/c^2 takes on the role of 'mass' associated with radiation, which yields $E=mc^2$.

(iv) **Olinto De Pretto** [12] speculated $E=mc^2$, on the basis of $E= mv^2$ (Leibniz's vis viva), in 1903-04. If $v = c$ then $E=mv^2$ becomes $E=mc^2$. Also Pretto published his findings in scientific journal *"Ipotesi dell'etere nella vita dell'universo",*

(v) **Fritz Hasenohrl** [13, 14] in 1904, concluded

"to the mechanical mass of our system must be added an apparent mass which is given by, $m=8E/3c^2$ where E is the energy of the radiation."

In a later paper he further improved result that mass exchanged is, $m=4E/3c^2$ or $E= 0.75mc^2$. Thus in this case also $E \propto \Delta mc^2$.

Ebenezer Cunningham [15] has further improved **Hasenohrl** 's equation as $E =\Delta mc^2$ by taking an elusive factor in account. This is exactly the same equation which Einstein proposed.

(vi) **Frederick Soddi** [16] and M. Henri Becquerel both have predicted that in radioactive emissions the mass of body decreases i.e. energy of radiations is at the cost of mass. Thus higher the decrease in mass more would be energy of radiation and no conversion factor was given, this inference is like above one. It also corresponds to $E \propto \Delta m$ or $E \propto \Delta mc^2$.

(vii) **Einstein** [17] derived under certain conditions that the conversion factor between mass and light energy is precisely equal to c^2. This perception of light energy –mass inter conversion was given by Newton. Then Einstein also generalized in speculative way, conversion factor c^2 for 'every energy', as it is in case of light energy.

Einstein [17] perceived that let there be a luminous body at rest in co-ordinate system (x, y, z). The system (ξ, η, ζ) is in uniform parallel translation w.r.t. system (x, y, z); and origin of system (ξ, η, ζ) moves along x-axis with relative velocity v. Let a system of plane light waves have energy ℓ relative to system (x, y, z), the ray direction makes angle φ with x-axis of the system (ξ, η, ζ). The quantity of light measured in system [ξ, η, ζ] has the energy [17-18].

$$\ell^* = \ell\{1 - v \cos \varphi/c\} /\sqrt{[1 - v^2/c^2]} \qquad (1)$$

Einstein has given eq.(1) in his paper known as Special Theory of Relativity [18] and called eq.(1) as Doppler principle for any velocities whatever.

Let E_o and H_o are energies in coordinate system (x,y,z) and system (ξ, η, ζ) before emission of light energy, further E_1 and H_1 are the energies of body in the both systems after it emits light energy. Thus Einstein wrote various equations as

Energy of body in system (x,y,z)

$$E_o = E_1 + 0.5L + 0.5L = E_1 + L \qquad (2)$$

Energy of body in system (ξ, η, ζ)

$$H_o = H_1 + 0.5 \beta L\{(1 - v/c \cos\varphi) + (1+ v/c \cos \varphi) \} \qquad (3)$$

where $\beta = 1/ [1 - v^2/c^2]^{1/2}$.

$$H_o = H_1 + \beta L \qquad (4)$$

$$\text{Or } (H_o - E_o) - (H_1 - E_1) = L [\beta - 1] \qquad (5)$$

Einstein calculated , kinetic energy of body before emission of light energy, K_0 ($m_b v^2/2$) and kinetic energy of body after emission of light energy, K ($m_a v^2/2$) as

$$K_o - K = L \{1/\sqrt{(1 - v^2/c^2)} - 1\} \qquad (6)$$

Einstein considered the velocity in classical region thus applying binomial theorem ,

$$K_o - K = L \{1+v^2/2c^2+ 3v^4/8c^4 + 15v^6/48c^6 +105v^8/384c^8 + \cdots - 1\} \qquad (7)$$

Further Einstein quoted [18]

Neglecting magnitudes of fourth and higher orders, we may place.

$$K_o - K = L v^2/2c^2 \qquad (8)$$

$$M_b v^2/2 - M_a v^2/2 = L v^2/2c^2 \qquad (9)$$

$$\text{or } L = (M_b - M_a)c^2 = \Delta mc^2 \qquad (10)$$

or Mass of body after emission (M_a) = Mass of body before emission (M_b) - L /c^2

Now replacing L (light energy) by E (total energy or every energy) Einstein wrote

$$\text{or } E = (M_b - M_a)c^2 = \Delta mc^2 \qquad (11)$$

or Mass of body after emission (M_a) = Mass of body before emission (M_b) - E /c^2

Thus Einstein hypothesized that whatever (concept or mathematical equation) is true for the light energy is true for every energy. So, Einstein derived that conversion factor between mass and light energy is precisely equal to c^2 , this aspect is elaborated by Fadner [19]. But Einstein's this derivation has been critically discussed by many such a Planck [20], Stark [21], Ives [22], Stanchel [23], Okun [24] and N. Hamdan [25] etc. At the same time in some references [26] it is expressed that Einstein has taken hints to derive equation $E = \Delta mc^2$ and from existing literature without acknowledging the work of preceding scientists in some of his papers [29-30]. Max Born [28] has expressed that Einstein should have given references of existing literature like other scientists as Planck [20, 28-29] mentioned Einstein's work.

(viii) Max Planck [28-29] in 1907 made an in-depth investigation of the energy "confined" within a body, but he did not use Einstein's approach at all. Planck derived an expression $m\text{-}M= E/c^2$, for heat energy and mass and interpreted that

" The inertia mass of body is altered by absorption or emission of heat energy. The increments of mass of body are equal to heat energy divided by square of speed of light."

Planck acknowledged Einstein's previous derivation but did not agree with correctness of Einstein's derivation, especially in eq.(6) .However Fadner [19] and Stanchel[23] tried to justify the Einstein's approach.

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