INDEPENDENCE OF MASS FROM SPEED

Etkin V.A.

Integrative Research Institute (Haifa, Israel)

v_a_etkin@bezeqint.net

ABSTRACT

It is shown that the dependence of mass on dpeed contradicts the law of conservation of mass in isolated systems. This makes necessary the modification of Newton's 2nd law with the addition along with the mass of a correction factor, which would take into account the nonlinear dependence of the accelerating force on the speed, due to the existence of its limit. The reasons for the apparent increase in mass with speed , which make the concept of the relativistic mass superfluous

***Keywords*:** theory of relativity, Newton's law, its modification, relativistic and invariant mass, acceleration process, its irreversibility and efficiency

1. INTRODUCTION

100 years have passed since the emergence of the theory of relativity A. Einstein. However, discussions still continue on whether the mass of bodies depends on their velocity, whether the mass is additive when the bodies are combined into a system, and whether it remains in isolated systems when the kinetic energy of the relative motion of their parts is transformed into rest energy? Classical mechanics, as we know, denied the change in mass with velocity, considering it to be additive and retained in isolated systems for any transformations of energy in them. The theory of A. Einstein's relativity (TO) considered more general the famous formula [1]

$$E = mc^2 , \tag{1}$$

where E, m are the energy and mass of the system, and c is the speed of light in a vacuum.

According to this formula, any body with energy E (including a photon) has a mass $m = E/c^2$, which grows not only with increasing velocity of the material particle, but also its rest energy E_o. Conversely, an increase in any form of energy of the system E_i implies a co-increase in the corresponding mass m_i. In connection with this, physics was replenished with concepts of "rest mass", "relativistic", "inert", "electromagnetic", "heavy", etc. masses.

This expression of the equivalence of mass and energy entered the science so firmly that it became a symbol of the theory of relativity and a criterion of its practical significance. This view was held not only by A. Einstein himself, but also by other outstanding physicists of the last century, such as M. Born, V. Pauli, R. Tolmen, R. Feynman, V. Fock E. Taylor and J. Wheeler, not to mention the authors of numerous textbooks, manuals and popular books on this subject.

Only recently, not only "dissidents from science", but also experts in this field appeared among researchers who consider the only correct expression

$$E_o = mc^2, \tag{2}$$

also found in the works of A. Einstein.

According to this expression, the mass of the body m is equivalent to the energy of the resting body E_o and therefore does not change with its acceleration, and the photon moving with the speed of light has no mass. One of the most persistent and consistent adherents of this point of view is the russian scientist acad. L.B. Ocun [2].

As a result of the increased turmoil, somehow the elusive fact escaped the attention of researchers that the principles of relativity of Galileo and Einstein are not related to non-mechanical systems, including thermodynamics, which operates the concept of internal energy as its part, which by definition does not depend from the motion or position of the system relative to the environment. Therefore, it is of interest to consider the mass question from the standpoint of thermodynamics, which Einstein referred to as the only theory of general content, whose consequences, in his opinion, will never be refuted by anyone. A preliminary consideration of this question [3] will be supplemented with an analysis of the reasons that led to the conclusion about the existence of a relativistic mass and the modification proposed by the author of Newton's second law, which excludes such conclusions.

2. The concept of mass in pre-relativistic physics.

It is known that I. Newton himself did not allow any duality in the understanding of the mass, defining it as "the amount of matter proportional to its density and volume [4]. It is in this sense that it appears in its law of universal gravitation

$$\mathbf{F} = GmM/r^2, \tag{3}$$

according to which the attraction force of two point masses m and M is directly proportional to their product and inversely proportional to the square of the distance between them r.

In this law the force **F** appears as the reason for the emergence of the process of transformation of gravitational energy into some other form of it and as a function of state, i.e. a value depending on whether or not the specified process is flowing. As for the definition of force in his second postulate

$$\mathbf{F} = m\boldsymbol{a}, \tag{4}$$

then it concerns only the process of acceleration and determines rather not the concept of force, but a concrete method of measuring it from the magnitude of this acceleration $\boldsymbol{a}$. This is confirmed by the fact that initially Newton recorded the law of force (4) in the form of proportionality of the force **F** of the rate of change of the momentum **P** of the relation $\mathbf{F} = d\mathbf{P}/dt$, which is equivalent to (4) only with the tacit assumption of constancy of mass m ($d\mathbf{P}/dt = m\boldsymbol{a}$). From this law it follows that when the same force **F** acts on the body, its acceleration $\boldsymbol{a}$ will be the smaller, the larger the mass of the body m, and only then. Thus, the mass m has acquired the sense of the measure of the inertial properties of the body, and the force **F** is a meaning different from expression (3).

Indeed, in expression (3), **F** appears as a function of the process, i.e. the quantity vanishing in the absence of the acceleration process, i.e. as a reaction of the system to an external disturbance (in the spirit of the Le Chatelier-Brown principle). In the expression (4), the force **F** is active (driving) and is determined by a more general way as a function of the state, depending on whether the acceleration process passes, or not. It is not known whether Newton's contemporaries understood this nuance, but already in classical mechanics prerequisites for a dual understanding and distinction of the "heavy" and "inertial" masses arose.

In classical thermodynamics, the concept of mass came from mechanics and is not connected with any process. The latter was due to the specifics of thermodynamics, which operated with the concept of the internal energy of the system U as part of its total energy E that did not depend on its motion or position as a whole with respect to the environment, and therefore could not be a measure of the inertia of the system. The internal energy of the simplest thermomechanical systems as a function of their state had the form $U = U(S, V)$, i.e. was an extensive quantity, like its arguments (entropy S and volume V). In this case, the mass m served for all its arguments with a single coefficient of proportionality, reflecting only the amount of matter in the system. This understanding of it was further consolidated in the generalization of classical thermodynamics to open systems that exchange matter with the environment. So the mass m became one of the independent parameters of the state and acquired the meaning of the coordinate of the process of mass exchange, i.e. an extensive state parameter, with the necessity of changing in this process.

However, such unambiguity in the understanding of mass was retained in thermodynamics only as long as equilibrium systems were considered in it, in which the internal energy U was regarded as a scattered (lost working capacity) part of the total energy of the system E (minus the external kinetic energy E^k and the external potential E^p energy) . In this case, the internal energy U was identical to the rest energy E_o, and it was quite natural to divide the total energy E by the rest energy E_o and the energy of the motion $E^k = \mathbf{P}^2/2m$.

The situation became gradual when the methods of thermodynamics began to apply to multicomponent, multiphase, open and complex systems (performing other types of work besides expansion work). Then the kinetic energy of ordered relative motion of macroscopic masses, chemical energy, energy of electrostatic and electromagnetic induction, inhomogeneous deformation, etc., appeared at the system. The internal energy of such systems U already included an ordered (convertible) part of the energy, remaining in an equilibrium (homogeneous) environment independent of the motion of the system as a whole with respect to it. Accordingly, there appeared the ability to perform other types of work besides the work of expansion, changing not only the internal, but also the external energy of the system. The magnitude of the external energy was determined by the work that must be spent on transferring the system from the initial state to the given state, i.e. depended on the frame of reference. Therefore, with the establishment of the equality of all inertial frames in the SRT by A. Einstein (1905), there arose a desire to impart to the equations of thermodynamics a form that would be invariant in all inertial frames of reference. The first to do this was M. Planck, who in 1907, with the approval of A. Einstein, proposed the formula for the relativistic transformation of internal energy in the form [5]:

$$U = U_o\gamma\ , \tag{5}$$

where U, U_o is the internal energy of the moving and stationary system, $\gamma = (1 - \upsilon^2/c^2)^{-½} \geq 1$ is the Lorentz coefficient.

However, after half a century of physics, H. Ott (1963) and H. Arzels (1966) discovered that these Planck transformations lead to an absurd result: they did not leave the expression of the relativistic Carnot cycle (with a rapidly moving heat source) invariant [6, 7]. According to Planck, the efficiency of the relativistic cycle of Carnot was less than that of the classical one. Moreover, for certain values of the Lorentz factor γ, this efficiency proved to be even negative! Since the expression of efficiency through temperatures was one of the mathematical formulations of the second law of thermodynamics, which was subject to the requirement of invariance, the principles of both thermodynamics and STR were affected.

The subsequent heated discussions in Brussels (1968) and Pittsburgh (1969) revealed such a difference in the definitions and interpretations of the basic concepts of thermodynamics that their participants saw in this clear signs of a crisis of thermodynamics. Meanwhile, a detailed analysis of this question [8] shows that the point here is not in thermodynamics, but in an attempt to relativistically convert quantities that in principle are independent of velocity. In this respect, the "justification" of the relation (5), proposed by Tolman [9], is characteristic on the basis of the following thought experiment. Let two identical bodies with a mass of each m and an internal energy U move towards each other at a speed υ. Then, at the moment of their absolutely inelastic collision (at the onset of their relative quiescence), the kinetic energy $E^k = E - E_o = mc^2(\gamma -1)$ of each of them turns into the internal thermal energy U_o, increasing it by the amount $U_o - U = E^k$. Wherein

$$U = U_o + mc^2(\gamma - 1) = U_o\gamma\ . \tag{6}$$

At first glance it may seem that expression (6) confirms the relation (5). However, it suffices to consider the set of mutually moving bodies as an isolated system as a whole, in order to verify the opposite. Indeed, it follows from the same relation (6) that $mc^2(\gamma - 1) = U_o(\gamma - 1)$, so that the principle of equivalence of mass m and internal energy $U_o = mc^2$ is fulfilled irrespective of the value of γ, i.e. presence or absence of the process of acceleration. Thus, it suffices to go on to consider an isolated system that includes the entire set of interacting (mutually moving), for which the concept of external energy loses all meaning to make sure that the assumption of the dependence of mass on velocity is incompatible with the law of its conservation.

3. Origins of the paralogism of the relativistic mass

In order to discover the reasons for the erroneous conclusion about the dependence of mass on velocity, let us turn to non-equilibrium thermodynamics [10, 11], which studies non-static (irreversible) processes of simultaneous heat transfer, matter, charge, impulse, etc in inhomogeneous systems. As shown in it, the rate of scattering processes in a system where several irreversible processes with generalized velocities $\mathbf{J}_i$ occur simultaneously depends on the driving forces $\mathbf{F}_i$ of all these processes and is expressed by the dissipative functions $\Psi(\mathbf{F}_i, \mathbf{J}_i)$:

$$\Psi(\mathbf{F}_i, \mathbf{J}_i)= \Sigma_i\, \mathbf{F}_i \cdot \mathbf{J}_i,\ \text{Вт} \qquad (7)$$

This feature reflects the intensity (power) of the scattering processes in the system, expressing it through the concept of thermodynamic forces $\mathbf{F}_i$ access (given here in their "energy" representation [11], and streams $\mathbf{J}_i$ as the generalized velocities of non-static (irreversible) processes. Energodynamics as a unified theory of the processes of energy transfer and transformation [12] allows us to go even further, generalizing this position to the processes of the useful transformation of energy from any i-th of its form into the j-th ($j \neq i$). According to this, if any of these processes is linked to useful energy conversion which power $N_j = \mathrm{F}_j \cdot \mathrm{J}_j$, the efficiency of this process will be different from zero and equal

$$\eta_j = N_j / N_i = \mathbf{F}_j \cdot \mathbf{J}_j / \mathbf{F}_i \cdot \mathbf{J}_i. \qquad (8)$$

Consider from these positions the acceleration of a charged particle ($\mathbf{J}_j = d\mathbf{P}/dt = m\boldsymbol{a}$) in a cyclotron under the influence of an external (electromagnetic) force $\mathbf{F}_i$. Assuming that the Newton’s law for the inertial forces $\mathbf{J}_j = \mathbf{F}_j$ can be generalized to other processes ($\mathbf{J}_i = \mathbf{F}_i$), in accordance with (8) we find that $\mathbf{F}_j / \mathbf{F}_i = \eta_j^{\,½}$, i.e.

$$\mathbf{F}_i = \eta_j^{\,½}\, d\mathbf{P}/dt\,. \qquad (9)$$

This expression differs from Newton's law in that it involves an external ("alien") force $\mathbf{F}_i$ applied externally to convert the electromagnetic energy of the current source into the kinetic energy of the accelerated particle (briefly: the accelerating force). Due to this, the energodynamics by the very equation (9) takes into account the inevitable losses in the process of acceleration (irreversibility of this process). In non-equilibrium thermodynamics this circumstance is taken into account by recording the kinetic equations of thermal conductivity, electrical conductivity, diffusion, viscous friction, and so on. In the more general (matrix) form of Onsager's laws:

$$\mathbf{F}_j = \Sigma_i\, R_i \mathbf{J}_i, \qquad (10)$$

according to which the driving force of the process of transformation of the j^{th} form of energy $\mathbf{F}_j$ meets the opposition from all the forces $\mathbf{F}_i$ existing in the system. This is illustrated in Fig.1, where, as an example, the case of counteraction to the gravitational force $\mathbf{F}_g$ from other forces and the resulting "side effects" of the transformation of gravitational energy into other forms are shown. Such a "branching" of the trajectory of the process in many directions is one of the main reasons for the irreversibility of the process, since even in the absence of "dissipation" (transformation of the ordered energy into thermal one), it is necessary to reverse the sign of not one but all those operating in the system Forces, while preserving their previous relationship, which is physically unrealizable. Newton's second law, like all equations of mechanics, describes reversible processes in which the "alien" reaction forces are absent, and therefore, both the accelerating force and the inertia force can appear on the left side of (4). In real (non-equilibrium) processes, these forces are not equal, which generates the process of energy conversion from one form to another. This disequilibrium of real processes also created the problem of the compatibility of mechanics and thermodynamics [13].

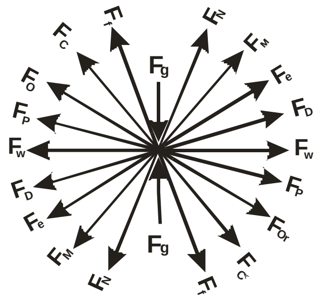

Fig.1. Different-type force of counteraction

F_g - gravitational forces; F_w acceleration forces;
F_e - electrical forces; F_m magnetic forces;
F_l - deformation forces; F_d dissipative forces;
F_o - orientation forces; F_c chemical forces;
F_n - nuclear forces; F_p polarizing forces

If we consider the process of acceleration from these positions, it becomes completely obvious that the efficiency of the accelerator becomes zero when the velocity of the particles reaches a limit, since no forces and energy costs can in this case increase their energy. Consequently, the Newton law in the form $\mathbf{F} = d\mathbf{P}/dt$ is non-linear and requires taking into account the irreversibility of the acceleration process by introducing into the 2nd Newton's law the velocity-dependent coefficient of proportionality $R(\upsilon)$:

$$\mathbf{F} = R(\upsilon) d\mathbf{P}/dt \,. \tag{11}$$

As u approaches the limiting value, the resistance coefficient $R(\upsilon)$ increases and when $\upsilon = c$ (when the acceleration process ceases), it becomes infinite regardless of mass. Such an increase in resistance to the process of acceleration as acceleration itself can be explained by the phenomenon of "potential retardation" [14]. The latter is due to the fact that the velocity of propagation of perturbations in force fields is limited by the speed of light in a vacuum, so that the action of rapidly moving particles on the field potential weakens as the rate of their removal increases. There are other possible reasons connected with the change in the qualitative composition of the particle's own energy as it accelerates in accordance with Fig. 1 and with the change in the nature of the forces of its interaction with the environment. Probably, it is these reasons that explain the results of Kaufmann's experiments [15], which revealed the weakening of the effect of the electromagnetic field on charged particles with increasing their speed [12].

Especially convincing evidence of the incompleteness of Newton's dynamics was the recent discovery of discrepancies between the rotational curves of galaxies at a considerable distance from their nucleus [16]. This forced astrophysicists to raise the question of the modification of Newton's dynamics (MOND) by, in particular, introducing an acceleration-dependent correction into Newton's second law [17]. This article gives additional arguments in support of this statement of the problem. Its main conclusion is that it is inadmissible to interpret the observed decrease in the acceleration a as the velocity v increases as a consequence of an increase in the mass m. Thus, not only with methodological [2] but also with thermodynamic positions, we come to the conclusion that there is a unique (invariant) mass that is a measure of the amount of matter, and the concepts of "rest mass", "relativistic", "inert", "electromagnetic", "gravitational", and so on masses must be discarded as superfluous.

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