Journal of Theoretics

Comprehensive Papers Section

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Journal Home Page

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1·ABSTRACT

The special relativity theory (SRT) derives mass-increase $m = \gamma m_0$ with velocity as a consequence of a time dilation effect $dt = \gamma dt_0$ between two inertial frames of reference (IFR). This is an untenable result, since if one forbids an inertial frame of reference to accelerate or to rotate, the kinematic gamma factor defining the mass-increase with velocity is a dynamical effect due to an accelerating force within one IFR and cannot depend on the uniform relative velocity between two IFR. Correspondingly, clock mechanisms depending on mass will show up slowing down by the dynamical factor, an effect usurped by special relativity which falsely interprets it as a time dilation effect between two IFR. The four parameters $\mathbf{r}, t$ and $\mathbf{r}_0, t_0$ of SRT are usually presented in the literature as Eulerian independent variables defined in two different IFR. We will show that this not the case when we study the dynamics of a point particle submitted to a force, since the four parameters in a given IFR are no longer independent and the variables $\mathbf{r}_0, t_0$ are now Lagrangian variables. Therefore, in the presence of forces, SRT and particle dynamics are incompatible.

Key words: Special relativity, gamma-factor, particle dynamics, Lagrangian variables, Eulerian variables.

2·INTRODUCTION

It became customary in Physics to describe the same event from different inertial reference frames (IFR) on equal footing. We must recall that the definition of an inertial reference frame implies that the three orthogonal axis which extend into space must be rigidly attached to the center of mass of a body of infinite mass. The fact that the body has an infinite mass is not trivial as discussed by one of the authors in several papers /1-5/. These IFR do not interact with the physical systems under study and have unlimited extensions in 3D-space. However, within an IFR, we can write a transformation which looks like a Galilean transformation

$$\mathbf{r}_0(t) = \mathbf{r}(t) - \mathbf{U}_1 t \qquad t_0 = t \tag{1}$$

and the corresponding velocity composition law hold

$$\mathbf{U}_0 = \mathbf{U} - \mathbf{U}_1 \tag{2}$$

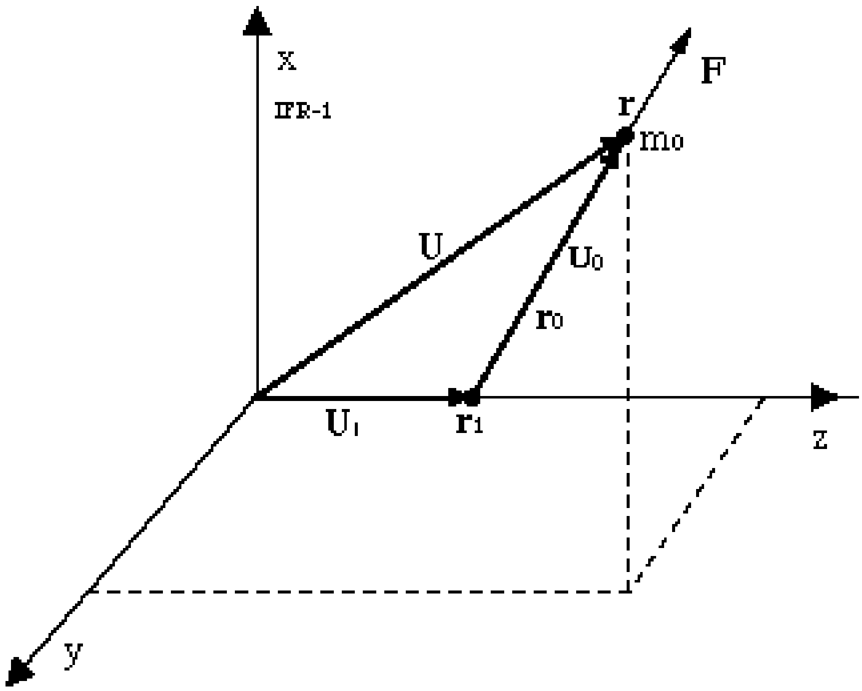

Figure 1 : two points located in the same inertial frame

The coordinates $\mathbf{r}$ and $\mathbf{r}_1 = \mathbf{U}_1 t$ and the velocities $\mathbf{U}$ and $\mathbf{U}_1$ respectively represent the positions and the velocities of two points viewed at the same time t in the same IFR-1 as shown in figure 1. Therefore, the vector quantities $\mathbf{r}_0$ and $\mathbf{U}_0$ define the distance and the relative velocity of these two points in the IFR-1. Remarkably, formulae (1) and (2) hold equally well between two relatively moving IFR but with a different physical meaning, namely they represent the same event viewed in two different IFR which are in relative motion with the uniform velocity $\mathbf{U}_1$ as illustrated in figure 2. In special relativity, however, different velocity composition laws are used within an IFR and between two IFR. In the case where the velocities $\mathbf{U}$ and $\mathbf{U}_1$ are collinear, the so called hyperbolic composition law for relative velocity $\mathbf{U}_r$ is given by the relation:

$$\mathbf{U}_r = (\mathbf{U} - \mathbf{U}_1)/(1 - \mathbf{U} \cdot \mathbf{U}_1/c^2) \tag{3}$$

The absurdity of using two different kinematics definitions for the relative velocities $\mathbf{U}_0$ and $\mathbf{U}_r$ respectively within an IFR and between two IFR was pointed out in /6/. Moreover, one can note the ambiguity concerning the classical definition of relative velocity in SRT since in classical mechanics, the relative velocity $\mathbf{U}_0$ is mainly defined in the IFR-1 while the same velocity is always defined in the IFR-2 in SRT.

The transformation equations between the four vectors $\mathbf{P}_0, E_0$ and $\mathbf{P}, E$ can be obtained by using the preceding law of addition of velocities, we get:

$$\mathbf{P}_0 = \gamma_1(\mathbf{P} - E\,\mathbf{U}_1/c^2) \tag{4}$$

$$E_0 = \gamma_1(E - \mathbf{U}_1 \cdot \mathbf{P}) \tag{5}$$

where all the velocities are collinear and knowing that $\mathbf{U}_1$ is a constant velocity. However, if we agree that the same velocity addition law has to hold within an IFR and between two IFR, that is to say $\mathbf{U}_0 = \mathbf{U}_r$, then one cannot use equation (3) to derive the transformations 4 and 5.

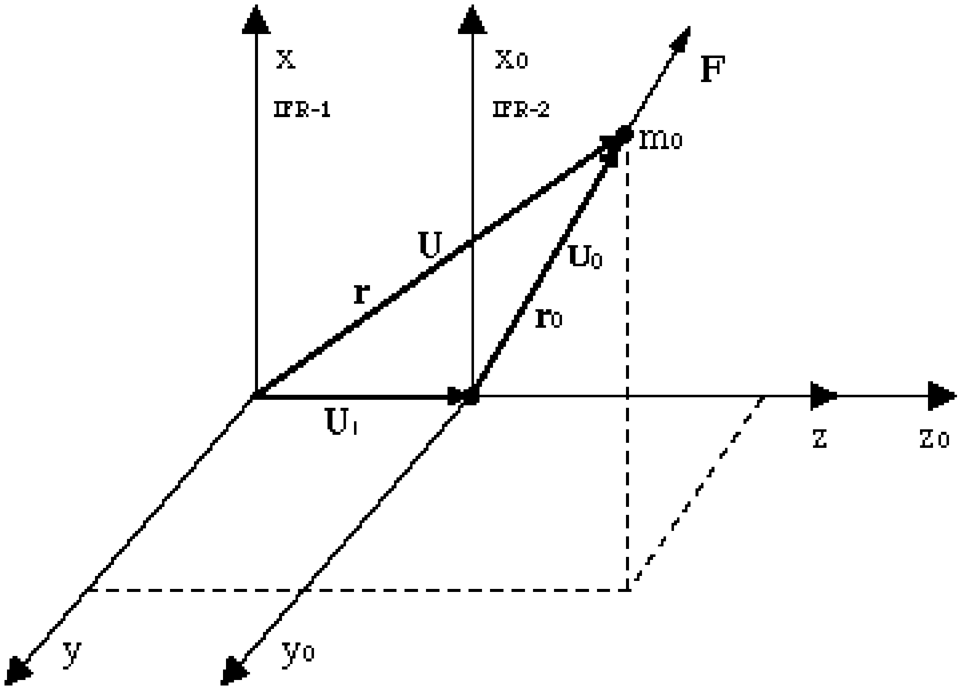

Figure 2 : the same event viewed in two inertial frames

If the particle having momentum $\mathbf{P}_0 = m_0\gamma_0\mathbf{U}_0$ and energy $E_0 = m_0\gamma_0 c^2$ is at rest in the IFR-2, we have $\mathbf{U}_0 = \mathbf{U} - \mathbf{U}_1 = 0$ and $\mathbf{U}_r = 0$, it follows the identities:

$$\mathbf{P}_0 = 0 \qquad E_0 = m_0 c^2 \tag{6}$$

$$\mathbf{P} = m_0\gamma\mathbf{U} \qquad E = m_0\gamma\, c^2 \tag{7}$$

Since $\mathbf{U}_0 = \mathbf{U}_r = 0$, the relations (6) and (7) cannot be interpreted as a proof of the validity of the velocity addition law (3). In fact these relations can be obtained, without using equation (3), directly from the invariant relation $E^2 - c^2\mathbf{P}^2 = E_0^2 - c^2\mathbf{P}_0^2 = (m_0c^2)^2$ with the initial condition $\mathbf{P}_0 = 0$ where the vectors $\mathbf{P}$ and $\mathbf{P}_0$ are defined in the same IFR. This approach is consistent with the non invariant relation $\mathbf{r}^2 - (ct)^2 = \mathbf{r}_0^2 - (ct_0)^2$ defined in equation (15) where all the quantities with a subscript zero are initial conditions defined in the same IFR.

The mass m_0 is called rest or proper mass for the particle which is at rest in IFR-2. This is also the rest mass in IFR-1 for $\mathbf{U} = 0$. Therefore, the rest mass of a particle is the same in both IFR-2 and IFR-1 and there is no ambiguity in the definition of this rest mass. Usually, in the literature /7/, one defines a co-moving reference frame for a particle moving with a non-uniform velocity where the reference frame is supposed to be instantaneously at rest at every moment during the motion of the particle. Such an approach has been rightfully criticized by one of the author /8-10/ since it leads to the faulty application of the Lorentz transformation between the proper frame of reference of a non-uniformly moving particle within an IFR by considering at every moment the non-uniform motion as uniform !. In particular, the mass-increase formula

$$m(t) = m_0[1 - U^2(t)/c^2]^{-1/2} \tag{8}$$

was recklessly introduced in the dynamics of a particle moving non-uniformly within an IFR /9/. Moreover, many textbooks and monographs claimed that mass-increase with velocity is due to a time-dilation effect between two IFR, i.e. to the switching from the time parameter t of the observer in the IFR-1 to the proper time t_0 measured by a clock co-moving with the particle.

This special relativistic procedure is mathematically not correct and is not in agreement with experiments done in particle accelerators where we do not have an access to the co-moving reference frame for doing measurements. Therefore, we will now use a different approach to solve the problem which is free of any contradiction. One can show that the dynamical gamma factor results from the integration of the dynamical relation /15/.

$$dE = \mathbf{U} \cdot d(m\mathbf{U}) = c^2 dm \tag{9}$$

It follows the result $ln(m/m_0) = ln\,\gamma$ after integration provided we used the initial condition $\mathbf{U}(0) = 0$ and we recover the relation (8) for a non-uniform velocity. Contrary to SRT, the differential equation (9) is defined in the IFR-1 where the velocity $\mathbf{U}$ is also defined. Therefore, no change of IFR and space-time units is implied in the above calculation. This is the reason why the identity $E = m_0\gamma\, c^2$ has nothing to do with time dilation and transformations, in general and with a Lorentz transformation between two IFR, in particular /12/.

3·CONSTANT FORCE: HYPERBOLIC MOTION

Although in the particle's proper frame of reference both velocity $\mathbf{U}$ and linear momentum $\mathbf{P}$ vanish, the acceleration is different from zero in both the co-moving frame and the IFR-1 where the velocity $\mathbf{U}$ is defined. Therefore, in the IFR-1, we have to solve the equation

$$\frac{d}{dt}(m_0\gamma\mathbf{U}) = \mathbf{F} \tag{10}$$

with the condition:

$$\mathbf{a} = \mathbf{F}/m_0 = Constant \tag{11}$$

If we define $\theta = \mathbf{n} \cdot \mathbf{a}\tau/c$ and $dt = \gamma\, d\tau$ where τ is the proper or Newtonian time ($d^2\tau = 0$), the integration of equation 10 provides:

$$c\mathbf{n} \sinh\theta = \gamma\, \mathbf{U} = \mathbf{a}t = \frac{d\mathbf{r}}{d\tau} \tag{12}$$

For a rectilinear motion ($\mathbf{U} \parallel \mathbf{a}$) and the initial conditions $\mathbf{r}(t_0) = \mathbf{r}_0, \mathbf{U}(t_0) = \mathbf{U}_0 = c\mathbf{n}\tanh\theta_0$ where the initial velocity is now different of zero, the solution of the differential equation 12 is:

$$\mathbf{r} - \mathbf{r}_0 = c[c\cosh\theta_0(\gamma - 1)\mathbf{n} + \sinh\theta_0\,\gamma\mathbf{U}]/(\mathbf{n}\cdot\mathbf{a}) \tag{13}$$

$$t - t_0 = [c\sinh\theta_0(\gamma - 1) + \cosh\theta_0\,\gamma U]/(\mathbf{n}\cdot\mathbf{a}) \tag{14}$$

with the velocity definition $\mathbf{U} = c\mathbf{n}\tanh(\theta + \theta_0)$.

It can easily be shown that:

$$\mathbf{r}^2 - (ct)^2 = \mathbf{r}_0^2 - (ct_0)^2 \tag{15}$$

This equation was studied in detail 92 years ago by Max Born /13/ and called by him, for obvious reasons, hyperbolic motion. Although showing a formal similarity with the Minkowski invariant of SRT, the quantity (15) presents fundamental differences with the Minkowski invariant:

First, it is not an invariant since it depends on the initial position $\mathbf{r}_0$ at time t_0.

Secondly, the quantity (15) was derived for constant, rather than zero, acceleration.

Thirdly, the position vectors $\mathbf{r}$ and $\mathbf{r}_0$ are defined in the same IFR-1.

Fourthly, the position vector $\mathbf{r}(t)$ is a function of the Lagrangian coordinates $\mathbf{r}_0, t_0$, while the Minkowski invariant is built from independent Eulerian coordinates defined in two different IFR /14/.

4·CLASSICAL EXPLANATION OF THE GAMMA FACTOR

One can use an analogy with solid state physics for understanding the meaning of the gamma factor. The equation of motion for a free electron moving in a solid is

$$\overset{\leftrightarrow}{\mathbf{M}} \cdot \frac{d\mathbf{U}}{dt} = \mathbf{F} \tag{16}$$

where $\overset{\leftrightarrow}{\mathbf{M}}$ is the dyadic effective mass and $\mathbf{F}$ is the external force which looks like the only force applied to the electron. However, we know that the electron is subjected to strong forces from the solid lattice which are hidden in the definition of the effective mass.

On the other hand, the relativistic equation of motion for a particle of rest mass m_0 submitted to the same force $\mathbf{F}$ has for expression

$$\frac{d}{dt}(m_0\gamma\mathbf{U}) = \mathbf{F} \tag{17}$$

with the definition of the gamma factor $\gamma = (1 - \mathbf{U}^2/c^2)^{-1/2}$. The time derivative of this gamma factor gives the following identity:

$$\frac{d\gamma}{dt} = \frac{\gamma^3}{c^2}\frac{d}{dt}\left(\frac{\mathbf{U}^2}{2}\right) \tag{18}$$

This identity can be used for writing the relativistic equation of motion in a dyadic form

$$\frac{d\mathbf{U}}{dt} = [\overleftrightarrow{\mathbf{M}}]^{-1} \cdot \mathbf{F} \Rightarrow \overleftrightarrow{\mathbf{M}} \cdot \frac{d\mathbf{U}}{dt} = \mathbf{F} \tag{19}$$

where the direct and inverse dyadic masses have for definition:

$$\overleftrightarrow{\mathbf{M}} = m_0\gamma\,(\overleftrightarrow{\mathbf{I}} + \frac{\gamma^2}{c^2}\,\mathbf{UU}) \Rightarrow [\overleftrightarrow{\mathbf{M}}]^{-1} = \frac{1}{m_0\gamma}\,(\overleftrightarrow{\mathbf{I}} - \frac{1}{c^2}\,\mathbf{UU}) \tag{20}$$

where $\overleftrightarrow{\mathbf{I}}$ is the unit dyad. The equation 20 shows that the force and acceleration are generally noncollinear in the high velocity motion of a point particle. The fact that the velocity of a material particle submitted to a constant force does not increase linearly with time means that the particle is submitted to a braking force from the medium. In solid-state physics, this braking force is originated by the lattice periodic field. By analogy with the effective mass concept in solids, we can assume that the dyadic mass of an electron moving in vacuum and the dependence of its mass upon velocity can be explained in the framework of classical mechanics.

The dyadic masses may be diagnolised, for a velocity $\mathbf{U}$ directed along the $\mathbf{x}$ axis,we get:

$$\overleftrightarrow{\mathbf{M}} = m_0 \begin{pmatrix} \gamma^3 & 0 & 0 \\ 0 & \gamma & 0 \\ 0 & 0 & \gamma \end{pmatrix} \qquad [\overleftrightarrow{\mathbf{M}}]^{-1} = \frac{1}{m_0} \begin{pmatrix} \gamma^{-3} & 0 & 0 \\ 0 & \gamma^{-1} & 0 \\ 0 & 0 & \gamma^{-1} \end{pmatrix} \tag{21}$$

We recover the so-called "longitudinal" $m_l = \gamma^3 m_0$ and transverse $m_t = \gamma m_0$ masses of the particle. We can now transform the equation of motion 20 written in dyadic form in a classical equation of motion

$$\frac{d}{dt}\,m_0\mathbf{U} = \mathbf{F}_e + \mathbf{F}_b \tag{22}$$

where the force applied to the particle has been partitioned in two forces, one is the external force $\mathbf{F}_e = \mathbf{F}$ and the other one is the braking force $\mathbf{F}_b = \overleftrightarrow{\mathbf{G}} \cdot \mathbf{F}$ with the definition:

$$\overleftrightarrow{\mathbf{G}} = \begin{pmatrix} \gamma^{-3} - 1 & 0 & 0 \\ 0 & \gamma^{-1} - 1 & 0 \\ 0 & 0 & \gamma^{-1} - 1 \end{pmatrix} \tag{23}$$

Therefore, as shown by the above formula, there is no direct proof that the relativistic dependence of mass on velocity has been established. Now we must give a classical explanation concerning the presence of the braking force. First, we note that this force depends on the square of the velocity and is consequently a magnetic force. This force cannot be a magnetic Lorentz force since the Lorentz force is transverse to the direction of motion of an electron as shown in the pinch-effect. However, we know that the Ampère force has a longitudinal component /16/ along the direction of motion of the electron. Bush /17/ was the first author to use the Ampère force for calculating the transverse motion of a charged particle in Bucherer's experiment. Later, Moon and Spencer /18/ and Assis /19/ rediscovered the same calculation. These authors were able to explain the Bucherer's experiment with a calculation valid up to second order in U/c. However, their calculation concerns the transverse mass and they did not verify that this calculation applies also to the case of the longitudinal mass.

We recall below the expression of the electromagnetic force obtained from the Weber theory between two charges dq_1 and dq_2 moving with velocities $\mathbf{U}_1$ and $\mathbf{U}_2$ with respect to any reference frame

$$\mathbf{F}_W = dq_1 dq_2 \Big[\frac{1}{R^2} - \frac{1}{(acR)^2}\,[3(\mathbf{V}\cdot\mathbf{n})^2 - 2\mathbf{V}^2] + \frac{2}{(acR)^2}\,\mathbf{R}\cdot\frac{d\mathbf{V}}{dt}\Big]\,\mathbf{n} \qquad (24)$$

with the definitions:

$$\mathbf{R}(t) = \mathbf{r}_1(t) - \mathbf{r}_2(t) = \mathbf{n}R \qquad \mathbf{V}[\mathbf{r}_1(t), \mathbf{r}_2(t), t] = \mathbf{U}_1[\mathbf{r}_1(t), t] - \mathbf{U}_2[\mathbf{r}_2(t), t] \qquad (25)$$

The quantity a is a parameter that will be defined later. In this expression, the first term is the electrostatic force, the second and third terms are the magnetic force and the last term is the radiation force which will be neglected in the following calculation.

A linear accelerator is a capacitor made with two parallel metal plates as shown in figure 3 where the electron of charge $q = q_1$ has a rectilinear motion along the z axis defined by the velocity $\mathbf{U} = \mathbf{U}_1$ in the laboratory frame. This electron is submitted to two Weber forces exerted by the charges $dq = \pm q_2 dS = \pm q_2 r dr d\phi$ located on each plate of the capacitor at rest, $\mathbf{U}_2 = 0$, in the laboratory frame.

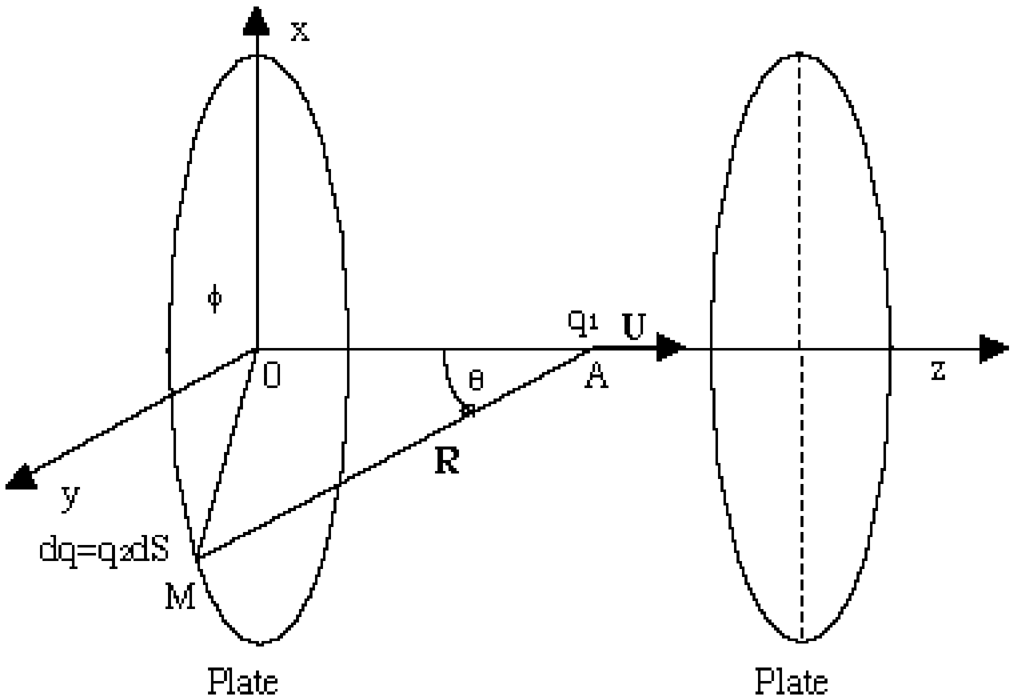

Figure 3 : charge q accelerated between
the two plates of a capacitor

The definitions

$$\delta S = \frac{1}{2}\, d(r^2) d\phi = \frac{1}{2}\, d(z^2 \tan^2\theta) d\phi = z^2\, \frac{\sin\theta}{\cos^3\theta}\, d\theta d\phi \tag{26}$$

$$OA = z = R\cos\theta \quad OM = r = z\tan\theta \quad \mathbf{AM} = \mathbf{R} = \frac{z}{\cos\theta}\,\mathbf{n} \tag{27}$$

can be used in the expression of the Weber force for one plate which becomes after integration on the ϕ angle:

$$d\mathbf{F}_W = 2\pi\, q_1 q_2\, \frac{\sin\theta}{\cos\theta}\, d\theta \left[1 - \frac{1}{a}\,(3\cos^2\theta - 2)\beta^2\right] \mathbf{n} \tag{28}$$

The unit vector $\mathbf{n}$ has only two components $\sin\theta, \cos\theta$. Moreover, we note that the above force does not depend on z, therefore for the other plate with charge $q_3 = -q_2$, the radial forces cancel and the axial forces are added, finally the total force exerted by the plates on the electron is:

$$F_z = 4\pi\, q_1 q_2 \int_0^{\pi/2} \left[1 - \frac{1}{a}\,(3\cos^2\theta - 2)\beta^2\right] \sin\theta\, d\theta \tag{29}$$

After integration, the preceding integral has for value:

$$\frac{d}{dt}\, m_0 U_z = F_z = 4\pi\, q_1 q_2 \left(1 + \frac{1}{a}\,\beta^2\right) \tag{30}$$

In the above equation, the first term represent the force exerted by a constant electric field produced by two infinite charged plates with surface charge density $\pm q_2$. The relation in equation 22 gives the corresponding relativistic formula:

$$\frac{d}{dt}\, m_0 U_z = F_e \gamma^{-3} = 4\pi\, q_1 q_2 \gamma^{-3} \approx 4\pi\, q_1 q_2 \left(1 + \frac{3}{2}\,\beta^2\right) \tag{31}$$

To recover the high velocity formula for the longitudinal mass m_l up to second order in U/c, we must take $a = 2/3$ while for the transverse mass m_t, we have $a = 2$ as demonstrated by Bush, Moon and Assis. Therefore, we cannot take the same value for the parameter a in the Weber force for explaining both the longitudinal and the transverse masses. The situation is hopeless if the effective mass is dyadic. The relation $m = \gamma\, m_0$ expressing the dependence of mass on velocity where m is included in the definition of $\mathbf{P}$ is in contradiction with the dyadic formulation of mass where the gamma factor is excluded of $\mathbf{P}$ if the vacuum is an isotropic medium as assumed by the special relativity theory. There is a fundamental contradiction which is seldomly emphasized in the literature. To understand the reason why this contradiction has nothing to do with the concept of a speed limit in a particle accelerator, let us see how the equation of motion is deduced from the equation of energy in both classical and relativistic theories:

In classical mechanics, we substitute the kinetic energy $E_K = m_0\mathbf{U}^2/2$ in the relation

$$\frac{dE_K}{dt} = \mathbf{U}\cdot\mathbf{F} \tag{32}$$

to obtain the identity:

$$\frac{d\mathbf{P}}{dt} = \mathbf{F} \tag{33}$$

with the definition $\mathbf{P} = m_0\mathbf{U}$.

If we now substitute the relativistic kinetic energy $E_K = m_0c^2(\gamma - 1)$ in equation 32, we get instead:

$$m_0\gamma^3\,\frac{d\mathbf{U}}{dt} = \mathbf{F}_l \tag{34}$$

which is the relation of motion for the longitudinal mass.

Let us write the equation

$$\mathbf{U}\cdot\frac{d\mathbf{P}}{dt} = \frac{dE_K}{dt} = \mathbf{U}\cdot\mathbf{F} \tag{35}$$

where we impose the definition $\mathbf{P} = m_0\gamma\mathbf{U}$, then we get the equation of motion:

$$\frac{d\mathbf{P}}{dt} = \mathbf{F} \tag{36}$$

with $\mathbf{F} \neq \mathbf{F}_l$. There is no contradiction between the equations 32,34,35,36 because we verify the identity $\mathbf{U}\cdot\mathbf{F} = \mathbf{U}\cdot\mathbf{F}_l$ where the forces $\mathbf{F}$ and $\mathbf{F}_l$ have different directions and magnitudes in the general case.

Another expression for the relativistic kinetic energy $E_K = m_0c^2(1 - 1/\gamma)$ has been proposed by several physicists /20/ and /21/ which gives the equation of motion:

$$m_0\gamma\,\frac{d\mathbf{U}}{dt} = \mathbf{F}_t \tag{37}$$

which is the relation of motion for the transverse mass. This equation has the same dependence of mass on velocity as defined by equation 9 but now this dependence is isotropic in vacuum which is not the case for the equation 36. Therefore, we have demonstrated in the preceding equations that the anisotropy concept and the speed limit concept are two separate phenomena. It is clear that if we choose the equation of motion 37, then we can take the parameter a equal to 2 in equation 24 with no need to make a distinction between transverse and longitudinal motion.

5·THE BERTOZZI'S EXPERIMENT

In order to separate the law of electromagnetic motion of charged particles from the mass-velocity law, Bertozzi /22/ performed an experiment in which the speeds of electrons with kinetic energies in the range 0.5 to 15 MeV were determined by measuring the time required for the electrons to traverse a given distance and the kinetic energy $E_K = m_0c^2(\gamma - 1)$ was determined by calorimetry. His result shows that the dependence of the kinetic energy on the speed of the electrons is in good agreement with the formula:

$$\beta^2 = 1 - \Big(\frac{1}{1 + E_K/m_0c^2}\Big)^2 \qquad (38)$$

while the kinetic energy $E_K = m_0c^2(1 - 1/\gamma)$ proposed by several physicists /20/ and /21/ gives the formula:

$$\beta^2 = 1 - \Big(1 - \frac{E_K}{m_0c^2}\Big)^2 \qquad (39)$$

This last formula is certainly not in agreement with the Bertozzi's experiment for $E_K > m_0c^2$. Therefore, we cannot use the relation 37 in order to reduce the dyadic mass to an isotropic mass in vacuum.

6·CONCLUSION

In conclusion, the variation of mass with velocity is not a consequence of the special relativity theory. This conclusion cannot be challenged from a mathematical point of view. To explain the mass velocity law from a classical point of view, one can use the Weber theory. However, we face the difficulty to explain why the parameter a is not the same for both the transverse and longitudinal masses. Maybe, one must add some terms to the Weber force law to solve this problem or take into account the radiation term in equation 24. Finally, it seems that the new kinetic energy formula proposed by several authors does not fit the experiments done in particle accelerators. The breaking force and the non-isotropic effective mass seem to provide support for a medium in space, having a lattice structure. Perhaps, one could quote the "epola" model of Simhony /23/ concerning an electron-positron lattice with a NaCl structure

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