



ABOUT A CORRECT INTERPRETATION OF THE CONNECTION BETWEEN CLASSICAL ELECTRODYNAMICS AND THE SPECIAL RELATIVITY

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Abstract:

The purpose of this article is to bring the basic ideas of O. D. Jefimenko to the physical and mathematical community about the physical explanation of some theoretical conclusions of the Special Theory of Relativity. In this paper, we analyze the reality of length contraction and its concrete effect on electromagnetic interactions. We analyze some relativistic “paradoxes” for the concrete material objects and real physical forces, rather than from abstract viewpoint.

Keywords: Classical Electrodynamics; Special Theory of Relativity.

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1. Introduction

There is a widespread belief that according to relativity theory the length of a body becomes shorter when the body moves. However, if this question is approached from the viewpoint of the practical measurement process, then the *length* of a body is defined as the length measured when the body is at rest relative to the observer and is an invariant quantity. There is also a widespread belief that individual relativistic transformation equations have their own physical significance and can be used independently one from the other. Although *some* relativistic transformation may formally be used individually, in general, relativistic transformation equations must be used collectively, so that *all* transformable quantities in the system under consideration are properly transformed. These and similar beliefs in the understanding of relativistic concepts and equations frequently result in incorrect representations of physical phenomena and in various relativistic paradoxes that have caused some scientists to criticize and even to reject relativity theory as such. In this paper, we shall discuss some of these beliefs and show the ways to avoid them.

2. The Length Contraction

In 1887 A. Michelson and E. Morley [1] carried out an experiment attempting to detect the “quiescent world ether”, which was thought to be the invisible medium occupying the entire universe and transmitting electromagnetic effects and radiation. In spite of the great sensitivity of their apparatus, the expected orbital movement of the Earth (30 km/s) through the ether was not detected. In an attempt to explain the negative result of the experiment without abandoning the idea of the quiescent ether, G. Fitzgerald in 1889 and H. Lorentz in 1892 proposed a hypothesis [2,3] that, because of an interaction with the ether, all bodies are contracted in the direction of their motion relative to the ether by a factor $(1 - v^2/c^2)^{1/2}$. This hypothesis provides a plausible explanation of the transformation equation for the x coordinate (see Eq. (7-1.1) in [4]) in the Lorentz-Poincaré relativity theory, and the effect (albeit hypothetical) became known as “Lorentz contraction”.

A. Einstein in his famous 1905 article [5] discarded the idea of world ether as “superfluous” and presented a derivation of the Lorentz transformation equations of coordinates and time on the basis of two postulates (the generalized relativity principle and the postulate of light speed independence) and his synchronization procedure. However, the significance and validity of Einstein’s derivation of transformation equations for coordinates and time is questionable: according to the authoritative and highly regarded book by A. Miller ([6] p. 216), “*In summary, on the basis of this chapter it seems as if Einstein knew beforehand the spatial portion of the relativistic transformation and an approximate version of the correct time coordinate... It is difficult to imagine that Einstein first derived the relativistic transformations by the method described in the 1905 paper; in fact, he never used his method again.*” While rejecting the reality of ether, Einstein accepted length contraction of moving bodies as an observable effect and stated that all moving objects “viewed” from a stationary system appear shortened in the ratio 1 to $(1 - v^2/c^2)^{1/2}$. He also suggested the following method for measuring the length of a moving object (rod): observers in the stationary system ascertain at what points of the stationary system the two ends of the moving rod are located at the same time t ; the distance between these two points is the “length of the moving rod”. In a later paper, Einstein emphasized that this was a measuring procedure fundamentally different from the procedure used for measuring the length of stationary objects[7]. Therefore, Einstein’s measuring procedure actually constituted the definition of the new quantity, which he called “length of a moving body”, different from “length” in the conventional sense. It may be noted that Einstein’s procedure for measuring the length of a moving body cannot actually be implemented. Since neither the trajectory nor the length of a moving body is known beforehand, the procedure requires that observers with clocks should be placed in each and every point of space, which is clearly impossible; moreover, to measure the lengths of moving microscopic particles (electrons, for example) the observers and the clocks would have to be of subatomic dimensions; etc., etc. Clearly then, to say that the “length of a moving body” is shorter than the “length” of a body is not the same as to say that the body becomes shorter when it moves. Moreover, it is far from clear how the visual appearance of a moving body can be associated with Einstein’s measuring procedure, since the visual appearance is an optical effect unrelated to the measuring procedure proposed by Einstein. It is not surprising therefore that the reality of length contraction and its concrete effect on the appearance of moving bodies has been a subject of considerable controversy and reevaluation (see, e.g., [8-15]). It should be noted that although

Einstein's relativistic length contraction has nothing to do with the world ether, it continues to be known as the "Lorentz contraction".

Taking into account that O.D. Jefimenko in Chapters 6 and 7 of his book [4] obtained correct relativistic transformation equations on the basis of the *retarded* length and volume of moving charge distributions, taking into account that Lorentz contraction requires not one but two observers (two point of observation, see [4]) for its exact manifestation, and taking into account that electromagnetic fields and light propagate with the same speed, we have hardly any choice but to conclude that the relativistically correct visual shape of a moving body is the retarded shape. We then also have a clear answer to why the retarded field theory [4], without using Lorentz contraction for determining the effective shape of the moving charge, yields relativistically correct fields of the charge (see Chapter 5 and Sections 7-5 and 7-6 in [4]). The answer is very simple: *as a physical phenomenon, the relativistic (kinematic) Lorentz contraction does not exist (is not objective)*. And the fact that the several revisions of this concept had no ill effect on relativistic electrodynamics or on any other branch of physics is an excellent indication that this concept does not represent a physical phenomenon in the conventional sense.

In 1888, on the basis of Maxwell's equations, Oliver Heaviside [16] obtained the equation for the electric field of a point charge q moving with a constant velocity v

$$\mathbf{E} = \frac{q(1 - v^2/c^2)}{4\pi\epsilon_0 r^3 [1 - (v^2/c^2)\sin^2\theta]^{3/2}} \mathbf{r}, \quad (1)$$

where \mathbf{r} is the vector connecting the point charge with the point of observation, and θ is the angle between \mathbf{v} and \mathbf{r} . Note that H. Poincaré did first relativistic derivation of the electric field of a point charge in [17]. Jefimenko obtained in [4] the same equation on the basis of electromagnetic retardation, and he obtained its integral form Eq. (7-6.21) in [4] by using relativistic transformations. Thus, there is no doubt in mathematical correctness of this equation. In Section 4-3 of [4] Jefimenko found on the basis of electromagnetic retardation the equations for the electric field of a moving line charge with the linear charge density λ (Eqs. (4-3.13) and (4-3.22 in [4]):

$$E_x = \frac{\lambda(1 - v^2/c^2)}{4\pi\epsilon_0 R} \left[\frac{1}{(L_1^2/R^2 + 1 - v^2/c^2)^{1/2}} - \frac{1}{(L_2^2/R^2 + 1 - v^2/c^2)^{1/2}} \right], \quad (2)$$

$$E_y = \frac{\lambda}{4\pi\epsilon_0 R^2} \left[\frac{L_2}{(L_2^2/R^2 + 1 - v^2/c^2)^{1/2}} - \frac{L_1}{(L_1^2/R^2 + 1 - v^2/c^2)^{1/2}} \right]. \quad (3)$$

Jefimenko obtained in [4] the same equation on the basis of relativistic transformations [Eqs. (7-6.25) and (7-6.27) there]. Thus, there is no doubt in mathematical correctness of these two equations also (see also [18]).

Let us show that the same two equation can be obtained by integrating Heaviside's Eq. (1) over the actual length of the moving charge, but not by integrating over the Lorentz-contracted length (thus demonstrating that Lorentz contraction is not a true physical effect).

Replacing in Eq. (1) q by λdx and integrating the x component of Eq. (1) between L_2 and L_1 (see Fig.1), we obtain for E_x (observe that \mathbf{r} is directed toward the point of observation so that its x and y components are negative)

$$\begin{aligned}
 E_x &= -\frac{\lambda}{4\pi\epsilon_0} \int_{L_1}^{L_2} \frac{(1 - v^2/c^2)}{r^3 [1 - (v^2/c^2) \sin^2 \theta]^{3/2}} x dx \\
 &= -\frac{\lambda(1 - v^2/c^2)}{4\pi\epsilon_0} \int_{L_1}^{L_2} \frac{x dx}{[x^2 + R^2(1 - v^2/c^2)]^{3/2}} \\
 &= \frac{\lambda(1 - v^2/c^2)}{4\pi\epsilon_0 R} \left[\frac{1}{(L_1^2/R^2 + 1 - v^2/c^2)^{1/2}} - \frac{1}{(L_2^2/R^2 + 1 - v^2/c^2)^{1/2}} \right].
 \end{aligned} \tag{4}$$

For E_x we similarly obtain

$$\begin{aligned}
 E_y &= -\frac{\lambda}{4\pi\epsilon_0} \int_{L_1}^{L_2} \frac{(1 - v^2/c^2)}{r^3 [1 - (v^2/c^2) \sin^2 \theta]^{3/2}} R dx \\
 &= -\frac{\lambda(1 - v^2/c^2)R}{4\pi\epsilon_0} \int_{L_1}^{L_2} \frac{dx}{[x^2 + R^2(1 - v^2/c^2)]^{3/2}} \\
 &= \frac{\lambda}{4\pi\epsilon_0 R^2} \left[\frac{L_2}{(L_2^2/R^2 + 1 - v^2/c^2)^{1/2}} - \frac{L_1}{(L_1^2/R^2 + 1 - v^2/c^2)^{1/2}} \right].
 \end{aligned} \tag{5}$$

These are exactly the same equations as Eqs. (2) and (3).

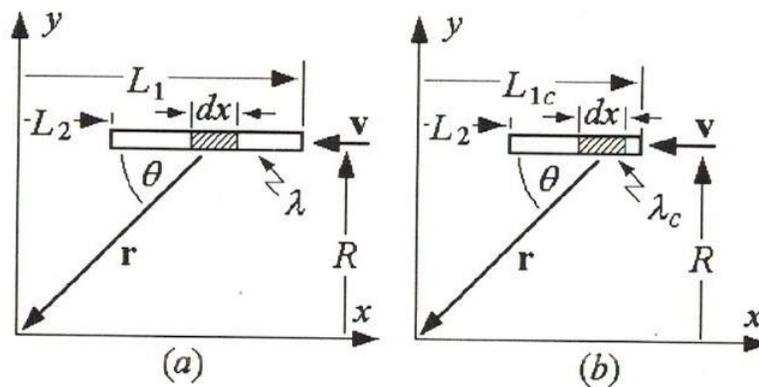


Figure 1: A line charge is moving with velocity $\mathbf{v} = -v\mathbf{i}$. To obtain the correct expression for the electric field of the charge, one must use the ordinary length of the charge (a). If the Lorentz-contracted length is used (b), then the resulting field becomes incorrect.

Let us now assume that the line is Lorentz contracted. Then its charge density will be not λ but $\lambda_c = \gamma\lambda$ (because the total charge must remain unchanged one). Furthermore, if the position of the leading end of the charge is L_2 , then the position of the trailing end will be $L_{1c} = L_2 + (L_1 - L_2)/\gamma$. Therefore the Lorentz-contracted versions of Eqs. (4) and (5) are

$$E_x = \frac{\lambda_c(1 - v^2/c^2)}{4\pi\epsilon_0 R} \left[\frac{1}{(L_{1c}^2/R^2 + 1 - v^2/c^2)^{1/2}} - \frac{1}{(L_2^2/R^2 + 1 - v^2/c^2)^{1/2}} \right] \quad (6)$$

and

$$E_y = \frac{\lambda_c}{4\pi\epsilon_0 R^2} \left[\frac{L_2}{(L_2^2/R^2 + 1 - v^2/c^2)^{1/2}} - \frac{L_{1c}}{(L_{1c}^2/R^2 + 1 - v^2/c^2)^{1/2}} \right], \quad (7)$$

Which are quite different from the correct Eqs. (2) and (3).

3. The Right-Angle Lever Paradox in Short

Numerous “relativistic paradoxes” can be found in the literature on relativity. They frequently reflect a lack of understanding of the physical significance of relativistic equations. One of the oldest of such paradoxes is so-called “right-angle lever”, or “L-shaped lever paradox”, also known as the “Lewis-Tolman lever paradox”. It was first reported in 1909 [19].

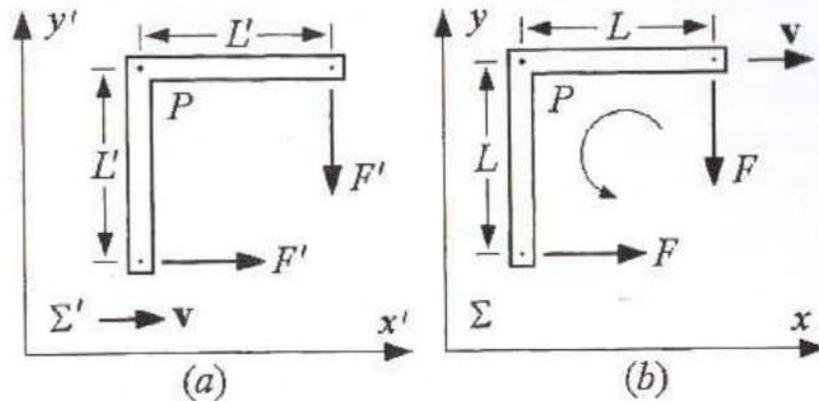


Figure 2: The right-angle lever is in equilibrium in the moving reference frame (Fig. 1a) but, according to seemingly correct calculations, should be rotating when observed in the stationary reference frame (Fig. 2b).

The essence of the paradox is as follows. Consider an L-shaped lever at rest in the reference frame Σ' moving with velocity v relative to the laboratory frame Σ (Fig. 2). Two equal forces F' are applied to the lever at right angles to the arms and at equal distances L' from the pivot P . Since

$$L'_x F'_y = L'_y F'_x = L' F', \quad (8)$$

(L'_x and L'_y are lever arms along x and y axes) the torque is

$$T' = L'_x F'_y - L'_y F'_x = 0, \quad (9)$$

so that the lever is in equilibrium in Σ' . Using now Eqs. (8-6.11) -(8-6.13) from [4] to transform the torque to the laboratory frame Σ , and substituting $T'_z = 0$, we obtain

$$T_z = -(v^2/c^2)r'_x F'_y = -(v^2/c^2)L'_x F'_y. \quad (10)$$

Thus, in the laboratory frame Σ the lever experiences a net torque and appears to be not in equilibrium. This result is considered as a paradox, because by the principle of relativity, if a physical system is in equilibrium in one inertial reference frame, then it must be in equilibrium when observed in any other inertial reference frame.

Numerous articles in scientific journals have been devoted to this paradox proposing a variety of solutions of ever-increasing complexity. Among the proposed solutions are: to redefine the torque, to invoke elastic forces in the lever, to reexamine the relation between torque and angular momentum, to redefine the concept of force, to invoke energy flow in the lever (see, for example, [20-23]), etc.

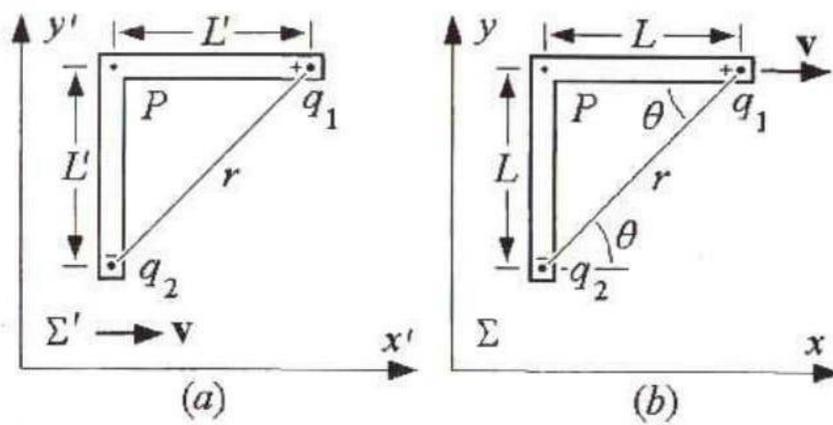


Figure 3: The right-angle lever paradox can be resolved if instead of the unspecified abstract forces one uses real physical forces (of electromagnetic nature), such as the forces created by two interacting opposite electric charges.

To reveal the error in the reasoning which leads to the paradox, Jefimenko considers in [4] the system shown in Fig. 3. This system is similar to the one shown in Fig. 2, except that instead of the two undefined forces applied to the lever, the forces applied to the lever are now caused by two equal and opposite electric charges q_1 and q_2 placed on the two arms of the lever at equal distances L from the pivot. In the Σ' reference frame, the forces between the charges are purely electrostatic, each charge exerting on the other a force of the same magnitude but in opposite direction

$$\mathbf{F}' = \frac{q_1 q_2}{4\pi\epsilon_0 r'^3} \mathbf{r}' = -\frac{q^2}{4\pi\epsilon_0 r'^3} \mathbf{r}', \tag{11}$$

where q is the magnitude of the charges, r' is the distance between the charges, and \mathbf{r}' is directed from the field-producing to the field-experiencing charge. By the symmetry of the system, the net force and torque acting on the lever is zero. Further, Jefimenko shows that the right-angle lever paradox can arise from an incomplete statement of the problem, when instead of real physical forces (of electromagnetic nature) one uses unspecified forces applied to an imaginary lever that has no physical properties (see Section 9-4 in [4]).

Similar to the right-angle lever paradox is the “Trouton-Noble paradox”. In this paradox, an “inexplicable” torque appears to act on a moving parallel-plate capacitor, although there is no torque on the stationary capacitor. The paradox arises from ignoring mechanical forces that prevent the capacitor’s plates from moving toward each other. For the further description of this paradox, electromagnetic analysis and references - see in [24]. Note, however, that although this paper correctly demonstrates the conservation of momentum in the system under consideration, the resolution of the paradox suggested in the paper is incorrect.

Now we will answer in detail the question: is the magnetic field due to an electric current a relativistic effect?

4. Is the Magnetic Field Generated by the Electric Current a Consequence of the Special Theory of Relativity?

Many authors assert that the magnetic field due to an electric current is a relativistic effect. This assertion is based on the fact that if the interaction between electric charges is entirely due to an electric field in the laboratory, then relativistic transformation equations manifest the existence of a magnetic interaction between these charges in a moving reference frame [24, 25].

Show that one could assert with equal justification that the electric field, rather than the magnetic field, is a relativistic effect. Therefore, since it is impossible for both fields to be the consequence of relativistic effects (at least one of fields must be the base field), neither field should be regarded as a relativistic effect (see also [27]).

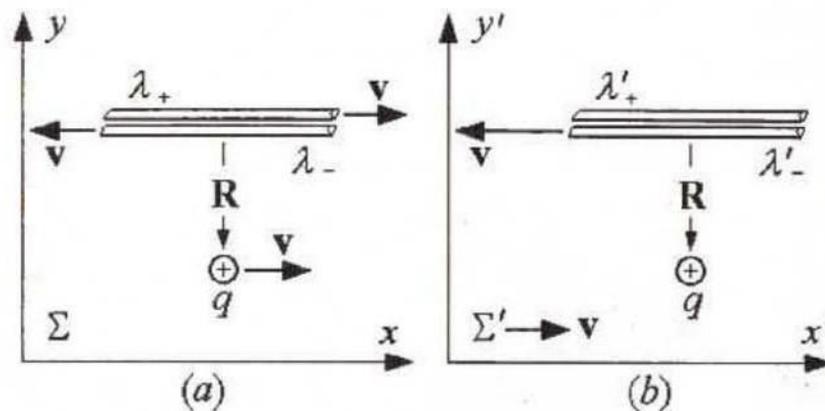


Figure 4: In the laboratory reference frame Σ (Fig. 4a) the point charge q experiences a magnetic force. But in the moving reference frame Σ' (Fig. 4b) the charge experiences an electric force.

Let us consider two “infinitely long” (very long) line charges of opposite polarity adjacent to each other along their entire length and observed in the laboratory reference frame Σ . Let the charges be parallel to the x axes and let the magnitude of the line charge density in each line charge be λ . Let the positive line charge move with velocity $\mathbf{v} = v\mathbf{i}$ and let the negative line charge move with $\mathbf{v} = -v\mathbf{i}$ (Fig. 4). Let us now assume that a positive point charge q is present in the xy plane at a distance R from the line charges and let us assume that it moves with velocity \mathbf{v} in the positive direction of the x axes.

In the laboratory reference frame Σ , the two-line charges constitute a current $2\lambda v$. By Amper's law [28], the magnetic flux density field that this current produces at the location of q is

$$\mathbf{B} = \mu_0 \frac{\lambda \mathbf{v} \times \mathbf{R}}{\pi R^2}, \quad (12)$$

where $\mathbf{v} = v\mathbf{i}$, and where \mathbf{R} is the vector joining the line charge with q and directed toward q . The force exerted by \mathbf{B} on q is

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B}) = q \left(\mathbf{v} \times \mu_0 \frac{\lambda \mathbf{v} \times \mathbf{R}}{\pi R^2} \right), \quad (13)$$

or

$$\mathbf{F} = -\mu_0 \frac{q\lambda v^2}{\pi R^2} \mathbf{R}. \quad (14)$$

Let us now look at the two line charges and the point charge from a reference frame Σ' moving with velocity $\mathbf{v} = v\mathbf{i}$ relative to the laboratory. The point charge q is stationary in this reference frame and therefore experiences no magnetic force at all.

However, according to the force transformation equations [4],

$$F_x = F'_x + \frac{vu'_y}{c^2(1 + vu'_x/c^2)} F'_y + \frac{vu'_z}{c^2(1 + vu'_x/c^2)} F'_z, \quad (15)$$

$$F_y = \frac{1}{\gamma(1 + vu'_x/c^2)} F'_y, \quad (16)$$

$$F_z = \frac{1}{\gamma(1 + vu'_x/c^2)} F'_z, \quad (17)$$

with $u'_x = u'_y = u'_z = 0$, if q experiences a force \mathbf{F} (in the y direction) in the laboratory, then the force \mathbf{F}' that it experiences in the moving reference frame Σ' can be found by using the transformation

$$\mathbf{F}' = \mathbf{F}(1 - v^2/c^2)^{-1/2}, \quad (18)$$

which, with Eq. (14), becomes

$$\mathbf{F}' = -\mu_0 \frac{q\lambda v^2}{\pi R^2(1 - v^2/c^2)^{1/2}} \mathbf{R} \quad (19)$$

(\mathbf{R} is the same in both reference frames because of $y = y'$). Of course, Eq. (19) is not really meaningful unless λ in it is transformed to λ' pertaining to the moving reference frame Σ' . To transform λ to λ' we use the equation from [4]

$$\rho' = \gamma[\rho - (v/c^2)J_x]. \quad (20)$$

The charge density ρ in the laboratory reference frame Σ is $\rho = (\lambda_+ + \lambda_-)/S = 0$ and the current density is $J_x = 2\lambda v/S$, where S is the cross-section of the positive and the negative line charge. Substituting ρ and J_x into Eq. (20) and multiplying by S , we obtain the transformation relation

$$\lambda' = -\gamma \frac{2\lambda v^2}{c^2} = -\frac{2\lambda v^2}{c^2(1 - v^2/c^2)^{1/2}}. \quad (21)$$

Substituting Eq. (21) into Eq. (19), we obtain for the force acting on the point charge q in the moving reference frame Σ'

$$\mathbf{F}' = \mu_0 \frac{c^2 q \lambda'}{2\pi R^2} \mathbf{R}, \quad (22)$$

and, since $\mu_0 c^2 = 1/\epsilon_0$,

$$\mathbf{F}' = \frac{q \lambda'}{2\pi \epsilon_0 R^2} \mathbf{R}, \quad (23)$$

which is exactly what we would have obtained for the force exerted on q in the moving reference frame Σ' by the electric field produced by the line charge of density λ' as measured in the moving reference frame Σ' (see, for example, [28] pp. 89-90 and 98-99).

As it is clear from Eqs. (12)-(23), relativistic force transformation equations manifest the presence of an electric field in Σ' when the interactions between electric charges are assumed to be entirely due to a magnetic force in Σ . We could interpret this result as evidence that the electric field is a relativistic effect. But the well-known fact [25] that similar calculations manifest the presence of a magnetic field in Σ' , if the interaction between the charges are assumed to be entirely due to an electric field in Σ , makes such interpretation impossible (unless we are willing to classify *both the magnetic and the electric field as relativistic effects*, which is absurd). We must conclude therefore that *neither the magnetic nor the electric field is a relativistic effect* (for some other misinterpretations of the relativity theory see [29]).

The only correct interpretation of the above calculations must then be that interactions between electric charges that are either entirely velocity independent or entirely velocity dependent is incompatible with the relativity theory. Both fields: the electric field (producing a force *independent* of the velocity of the charge experiencing the force) and the magnetic field (producing a force *dependent* of the velocity of the charge experiencing the force) are simultaneously necessary to make interactions between electric charges relativistically correct. By inference then, any force field compatible with the special theory of relativity must have an electric-like “subfield” and magnetic-like “subfield”.

5. Conclusion

Thus, in the article we considered the reality of length contraction from the viewpoint of the procedure of measurement as such, some paradoxes and an interpretation of the magnetic field genesis. The definition of a new quantity “length of a moving body” is quite different from

“length” in the conventional sense. Since neither the trajectory nor the length (and orientation) of a moving body is known beforehand, Einstein's measuring procedure cannot practically be implemented. The visual appearance of the moving rod is an optical effect unrelated to this measuring procedure also. The relativistically correct visual shape of a moving body is the retarded shape. Besides, only integrating over the actual (not contracted) length leads to correct equations for electromagnetic fields. Therefore, length contraction (relativistic kinematic effect) is not objective (does not exist as a physical phenomenon). The right-angle lever paradox and the Trouton-Noble paradox can be resolved, if real electromagnetic forces will be used. Since not only magnetic, but also electric fields can be obtained each from other with the help of transformation equations, therefore neither the magnetic nor the electric field is a relativistic effect. Both fields (producing forces independent and dependent of the velocity of the charge) are simultaneously necessary to correctly describe interactions between electric charges.

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