ANNALEN DER PHYSIK

Man. Nr. kf16/2002, received Okt.23, 2002

By March 25, 2003 reply from this magazine is still missing (see **Discussion** on this Site)
This article is published in:
Potjekhin A.F. RELATIVITY IN PHYSICS, Majak Publish, Odessa, 2003, 25-36

ON THE ELECTRODYNAMICS OF BODIES, MOVING IN THE INERTIAL FRAME OF REFERENCE.

A. F. Potjekhin
Odessa National Maritime University
34 Mechnikova St., 65029, Odessa, Ukraine

Abstract

The electrodynamics of bodies, moving in the inertial frame of reference, is developed in frame of notions and laws of Newton's classical mechanics. It has been found that Lorenz transformations have the limited region of their application.

Initial definitions [1]

Frame of reference, relative to which radiation, experimentally detected in the world space 2,7 K, is homogenous and isotropic, is called the absolute frame of reference (AFR) Σ^0. As a first approximation by Newton, AFR is realized by the heliocentric reference system of Copernicus, bound to stars of our Galaxy, in the following approaching - to centers of Galaxies, further to the centers of groups of Galaxies and so on. In dynamic respect AFR is segregated and often called the fixed one or, more completely, the reference system of still ether.

Inertial frames of reference (IFR) are such systems of reference that move translatory uniformly and rectilinearly relative to AFR and, consequently, one to another. The converse statement is not true, i.e. not all systems of reference, moving translatory, uniformly and rectilinearly relative each to other, are inertial. For example, systems of reference bound to coaches, driving translatory, rectilinearly and uniformly one relative to another, but with the same acceleration relative to AFR under the effect of surface forces, will not be inertial.

If the considered system of material particles is moving together with the frame of reference Σ, which in turn is moving relative to the AFR Σ^0, then Σ is called the dynamic frame of reference for the given process.

If the considered system of material particles does not participate in transport motion together with the frame of reference Σ, the last is called kinematic for the given process.

The dynamic relativity principle of Galilei is the statement of the following experimental fact: identical processes, each of which is being realized in the dynamic inertial frame of reference, flow and are described in these systems of reference identically.

The kinematic relativity principle of Copernicus is the statement of the following experimental fact: the flow of the same process does not depend on which of reference systems it is esteemed in relation, but this process will be sensed and described in each of them differently. Transition from the description of the same process in one of frame of reference to the description in another frame of reference is implemented by kinematic transformation of space coordinates and time of these systems of reference, e.g.,

$$\bar{r} = \bar{r}_{O'} + \bar{r}', \qquad t = t', \tag{1}$$

where $\bar{r}$ and $\bar{r}'$ - radius-vectors of the same point, t and t' - time in non-dashed and dashed systems of reference, $r_{0'}$ - radius-vector of the origin of dashed reference system relative to the non-dashed one.

If equations of motion upon some transformation of reference systems preserve their appearance, but don't preserve expressions for functions, constituent to them, these equations are called the covariant in relation to given transformation.

As soon as equations of motion at some transformation preserve both their appearance and expressions for their constituent functions, these equations are called the invariant relative to the given transformation.

Dynamic and kinematic relativity principles in mechanics

According to Newton, basic equation of particle dynamics

$$\frac{d}{dt}(m\bar{v}) = F(\bar{r},\bar{v},t)\,, \qquad (2)$$

is valid only in the absolute frame of reference Σ^0. However, experimentally established dynamic relativity principle of Galilei was already known to Newton. Pursuant to this principle, any mechanical processes carried out in the self-contained physical laboratory, do not allow to find out its translatory, uniform and rectilinear motions relative to AFR. Basing on the given principle Newton has formulated the first law of dynamics - law of inertia: the insulated material particle preserves invariable its velocity in an absolute system of reference. As a consequence, mutual movement of system of material particles, interacting between each other, does not depend on their common movement with the same translatory velocity: ***"Relative motions of the bodies, contained in any space, one relative to another, are equal, irrespective of whether this space is at rest or moves uniformly and straight without rotation "*** [2, Corollary V]. One should take into account the following important remark of Newton: ***"The body, moving in space, participates also in movement of this space, that is why the body, moving away from the moving place, participates in the movement of this place"*** [2]. Newton concludes the Corollary V with such comment: ***"This is confirmed by abundant experiments. All motions within the ship occur in the same way, independent of whether she is at rest or moving uniformly and rectilinearly "*** [2]. This consequent is extremely important. It allows to apply the laws of mechanics of Newton not only in an absolute frame of reference, for which they were formulated, but also in all dynamic inertial frames of reference. The dynamic inertial systems of reference are equivalent in the sense that identical mechanical processes, each of which is conducted and watched in its dynamic IFR (physical laboratory), are described identically.

Let's thus make one very essential remark. The uniformity of formulation of laws of motion for identical processes in dynamic IFR is a consequence of experimental fact, but not of invariancy of equations of motion relative to kinematic transformation of Galilei. For example, the equation of motion of a bead dropping in reposing vessels with a liquid in each of dynamic IFR, has a view

$$m\frac{d^2\bar{r}}{dt^2} = m\bar{g} - \mu\bar{v} \qquad (3)$$

however, this equation is not invariant relative to transformation of Galilei

$$\bar{r} = \bar{r}' + \bar{u}t, \qquad t = t' \qquad (4)$$

where $\bar{u}$ - velocity of mutual movement of reference systems. Moreover, the concept of kinematic transformation of type (1) with reference to the dynamic relativity principle becomes senseless, as this principle deals with events in different systems of reference. Kinematic transformation is concerned with consideration of the same event from different systems of reference. In strict conformity with a kinematic relativity principle, this process, being considered from different systems of reference, is described in different way in each of these systems of reference.

Dynamic relativity principle in electrodynamics

According to Maxwell, Lorentz, Havyside, etc., the electrodynamic Maxwell equations are valid only in an absolute frame of reference of Newton. Quite naturally, that in the period of formation of electrodynamics there should arise a question: whether the dynamic relativity principle of Galilei remains valid as for electrodynamic processes? A series of experiments conducted in turning points of XIX and XX centuries gave the affirmative answer to this question. This should be expected already from the first law of mechanics, law of inertia, which was established for any material particles, regardless of their chemical composition and physical condition - temperature, charge, etc. ***"This is very relevant circumstance; if no external forces act on the electron, it will — completely as well as a material particle — move with constant velocity value, despite of presence of an ambient ether"*** – marked the founder of electrodynamics H. Lorentz [3]. But instead of the above formulated question another one was put: whether is a luminiferous ether captured by the moving body or there exists an ethereal wind? During looking-up for answer to this question diverse electrodynamic experiences, verifying justice of a dynamic relativity principle in electrodynamics as well, were misinterpreted [4].

Maxwell equations in vacuum for electric charge of density ρ_e^0, moving with velocity v^0 relative to the absolute frame of reference Σ^0, have the following appearance

$$
\begin{aligned}
&div\,\overline{E}^0 = \frac{1}{\varepsilon_0}\rho_e^0,\\
&rot\,\overline{E}^0 = -\frac{\partial \overline{B}^0}{\partial t^0},\\
&div\,\overline{B}^0 = 0,\\
&rot\,\overline{B}^0 = \mu_0\rho_e^0\overline{v}^0 + \frac{1}{c^2}\frac{\partial \overline{E}^0}{\partial t^0},
\end{aligned}
\qquad (5)
$$

where ε_0, μ_0 - electric and magnetic constants, i.e.

$$\varepsilon_0 = const, \quad \mu_0 = const, \quad c = (\varepsilon_0\mu_0)^{-1/2} = const \qquad (6)$$

c - rate of propagation of front of an electromagnetic wave (light velocity) in Σ^0.

Let the charge ρ_e move with some inertial frame of reference Σ and, simultaneously, relative to this reference system with velocity $\overline{v}$, i.e., in relation to the considered process Σ is dynamic IFR. In this case, in accordance with the dynamic relativity principle of Galilei, Maxwell equations in IFR Σ has the same appearance as in AFR Σ^0

$$
\begin{aligned}
&div\,\overline{E} = \frac{1}{\varepsilon_0}\rho_e,\\
&rot\,\overline{E} = -\frac{\partial \overline{B}}{\partial t},\\
&div\,\overline{B} = 0,\\
&rot\,\overline{B} = \mu_0\rho_e\overline{v} + \frac{1}{c^2}\frac{\partial \overline{E}}{\partial t}
\end{aligned}
\qquad (7)
$$

with the same constants values pursuant to (6). The physical meaning of the c constant thus remains the same – this is light velocity relative to Σ^0, which, pursuant to the experiment, is irrelevant from whether the source of light is in rest or moving relative to Σ^0. It is a consequent of that fact, that the photon has no rest-mass, therefore first Newton's law, law of inertia, is not applicable to it. The photon, contrary to the material particle, does not preserve a running velocity of its source.

It is necessary to mark a substantial contribution of Prof. H. Willhelm [5] - [7] into creation of the Galilei-covariant theory of electrodynamics of moving bodies. But following Maxwell, Lorentz etc., Prof. H. Willhelm considers Maxwell equations valid only in a unique, absolute system of reference $\sum^0$.

Kinematic relativity principle in electrodynamics

In the theory of moving charges also another problem has arisen: it is necessary to describe in kinematic IFR Σ' a field of a charge ρ_e, the motion of which is preset in dynamic IFR Σ. At this, IFR Σ' is moving relative to IFR Σ with velocity $\bar{u} = const$. In this case we deal with a kinematic relativity principle. To describe in IFR Σ' process, taking place in IFR Σ, let's apply kinematic transformation of Galilei (4) to the set of equations (7).

Let's derive some auxiliary relations. Applying Galilei transformation (4) to the function $f(\bar{r},t)$, we obtain

$$f(\bar{r},t) = f(\bar{r}'+\bar{u}t',t') = f'(r',t') \qquad (8)$$

Further we find

$$\frac{\partial f}{\partial t} = \frac{\partial f'}{\partial t'}\frac{\partial t'}{\partial t} + \frac{\partial f'}{\partial \bar{r}'}\frac{\partial \bar{r}'}{\partial t} \qquad (9)$$

$$\frac{\partial f}{\partial \bar{r}} = \frac{\partial f'}{\partial \bar{r}'}\frac{\partial \bar{r}'}{\partial \bar{r}} \qquad (10)$$

Taking into account, that

$$\frac{\partial t'}{\partial t} = 1, \quad \frac{\partial r'}{\partial t} = -\bar{u}, \quad \frac{\partial \bar{r}'}{\partial \bar{r}} = \delta, (\delta_{ij} = 1, i = j; \ \delta_{ij} = 0, i \neq j) \qquad (11)$$

from (9) and (10) we get the following relations between the operators in dashed and non-dashed reference systems

$$\frac{\partial}{\partial t} = \frac{\partial}{\partial t'} - \bar{u}\bar{\nabla}', \quad \bar{\nabla} = \bar{\nabla}' \qquad (12)$$

With account of (12), Maxwell equations (7), upon application of Galilei transformation to them, take the following appearance in the dashed kinematic IFR

$$\begin{aligned}
&div\bar{E}' = \frac{1}{\varepsilon_0}\rho_e,\\
&rot\,\bar{E}' == -(\frac{\partial}{\partial t'} - \bar{u}\bar{\nabla}')\bar{B}',\\
&div\,\bar{B}' = 0, \qquad (13)\\
&rot\,\bar{B}' = \mu_0\rho_e(\bar{u} + \bar{v}') + \frac{1}{c^2}(\frac{\partial}{\partial t'} - \bar{u}\bar{\nabla}')\bar{E}'.
\end{aligned}$$

again, with the same values of constants pursuant to (6). Let's select in the last set of equations the members, conditioning non-covariance of Maxwell equations concerning Galilei transformation

$$\begin{aligned}
&div\bar{E}' = \frac{1}{\varepsilon_0}\rho_e,\\
&rot\,\bar{E}' == -\frac{\partial}{\partial t'}\bar{B}' + \left[(\bar{u}\bar{\nabla}')\bar{B}'\right],\\
&div\,\bar{B}' = 0, \qquad (14)\\
&rot\,\bar{B}' = \mu_0\rho_e\bar{v}' + \frac{1}{c^2}\frac{\partial}{\partial t'}\bar{E}' + \left[\mu_0\rho_e\bar{u} - \frac{1}{c^2}(\bar{u}\bar{\nabla}')\bar{E}'\right].
\end{aligned}$$

As should to expect, the non-covariance is conditioned by the convective current and convective derivative of field vectors - members in square brackets.

Example.

The sets of equations (7) and (13) deplete the solution of a problem of description of fields of moving charges in inertial frames of reference. Let's consider an example.

Electrical charge q' is rest in the origin of the dashed IFR $\Sigma'(x',y',z',t)$ of moving tram, while the charge q is rest at the origin of non-dashed IFR $\Sigma(x,y,z,t)$ of orbiting Earth. Thus the dashed reference system is moving together with the non-dashed one and at the same time relative to it with the velocity $\overline{u}$ in positive direction of x-axis . Find fields of these charges in each of these reference systems.

a)The field of the charge q' in IFR Σ'. The Σ' is the dynamic IFR for the charge q', therefore it's necessary to apply Maxwell set of equations (7). As a result, we find scalar and vector potentials

$$\phi' = \frac{1}{4\pi\varepsilon_0}\frac{q'}{r'}, \qquad \overline{A}' = 0 \qquad (15)$$

b) The field of the charge q in IFR Σ. This case is analogous to the previous one, i.e. Σ is a dynamic IFR for charge q, and for this reason one should apply Maxwell set of equations (7). In the issue we get scalar and vector potentials

$$\phi = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}, \qquad \overline{A} = 0 \qquad (15)$$

c) The field of the charge q' in IFR Σ. The charge q' moves with the reference system Σ and at the same time relative to it with the velocity $\overline{v} = \overline{u}$. Therefore, Σ is a dynamic IFR for the charge q', and that's why it is necessary to apply Maxwell set of equations (7). Applying the method of retarded integrals, offered by Heavicide [8] and potently advanced by Prof. O.Yefimenko [9], [10], to solve this set of equations, we find out

$$\phi = \frac{1}{4\pi\varepsilon_0}\frac{q'}{\left[(x-ut)^2 + (1-\frac{u^2}{c^2})(y^2+z^2)\right]^{1/2}} \qquad (17)$$

$$\overline{A} = \frac{1}{4\pi\varepsilon_0}\frac{q'\overline{v}}{c^2\left[(x-ut)^2 + (1-\frac{u^2}{c^2})(y^2+z^2)\right]^{1/2}} \qquad (18)$$

d). The field of the charge q in IFR Σ'. The charge q does not move with the reference system Σ', but is moving relative to it with the velocity $\overline{v}' = -\overline{u}$. Hence, Σ' is the kinematic IFR for the charge q, and therefore it's necessary to apply the set of equations (13), which in this case takes the form

$$\begin{aligned} div\overline{E}' &= \frac{1}{\varepsilon_0}\delta(x'-ut), \\ rot\overline{E}' &= 0, \\ div\overline{B}' &= 0, \\ rot\overline{B}' &= 0. \end{aligned} \qquad (19)$$

Here is considered, that as well as the field of charge q in the Σ system is stationary, then

$$\frac{\partial}{\partial t} = \frac{\partial}{\partial t'} - \bar{u}\bar{\nabla}' = 0 \tag{20}$$

and, besides this, $\bar{u}' + \bar{v} = 0$. From the set of equations (19) we find

$$\phi' = \frac{1}{4\pi\varepsilon_0} \frac{q}{\left[(x'+ut)^2 + y'^2 + z'^2\right]^{1/2}}, \qquad \bar{A}' = 0 \tag{21}$$

It follows from (21): I) equipotential surfaces

$$\left[(x'+ut)^2 + y'^2 + z'^2\right] = const \tag{22}$$

of the charge q in kinematic IFR Σ' are spherical surfaces moving together with this charge in the negative direction of x'-axis; II) convective current, conditioned by the movement of kinematic IFR, does not produce magnetic field. Both these conclusions are in accordance with the experiment and Wilhelm's theory [6] and refute the Einsteinian SRT, pursuant to which the solution for case d) is got from the solution of case c) by replacement of the velocity $\bar{v}$ with the velocity $\bar{v}' = -\bar{v}$: ***"It's clear, -*** writes Einstein in his fundamental article, - ***that the same results are received for bodies quiescent in a "reposing" system, but considered from the system, which is uniformly moving "*** [11].

About Lorentz transformation.

The generally accepted technique of solving electrodynamics problem of moving bodies bases on application of Lorentz transformations. Frankly speaking, Lorentz has failed to find the formulas of transformation of all dynamic quantities, ensuring full covariance of Maxwell equations. In a final form the well-known nowadays Lorentz transformations were established by A. Poincare [12]. However, the modern representations about these transformations are far from pre-requisites, laid into them by Lorentz [3]. At first, the confrontation of Lorentz transformations in electrodynamics with transformations of Galilei in mechanics is ill-conditioned: in mechanics only kinematic transformations of Galilei are applied, while the Lorentz transformations are a unified complex of transformations of kinematic (time-space coordinates) and dynamic values (charge and current density, force, etc.). Secondly, the Maxwell equations are not invariant, and only are covariant concerning Lorentz transformatios. And, at last, thirdly, two systems of reference, bound with Lorentz transformations, should necessarily be dynamic IFR **for essentially the same** considered system of charges. Such and only such "enclosed" one into another systems of reference were esteemed by Lorentz [3] at the substantiation of his transformations. For example, in the fore-quoted example the reference system of a tram "is enclosed" into a system of reference of the Earth and is displaced together with the latter. Only in this case (by virtue of a dynamic relativity principle) the Maxwell equations in each of these systems of reference have the same form and (by virtue of a kinematic relativity principle) these systems of reference can be related by kinematic transformation. Thereof, the setting a problem by Lorentz about looking-up of the covariant transformations of Maxwell equations is lawful.

In spite of the fact that Lorentz did not distinguish such concepts as dynamic and kinematic relativity principles, he nevertheless intuitively, up to 1905, moved in proper direction, not allowing for substitution of one of these concepts by the other. But Lorentz, up to the end of his life, failed to discern such substitution of concepts in the Einsteinian *Relativity theory*. ***"It's worth to pay special attention, -*** he writes, - ***to the remarkable reversibility, which Einstein has indicated. Till now research of phenomena in a fixed system had been conducted by the spectator A_0, whereas A had been limited by a moving frame of reference*** (stand of Lorentz before 1905 — A. P.)… ***The reversibility is encompassed by the fact, that if the spectator A will start to describe a field of a fixed system in completely the same way, he will describe it quite precisely*** (wrong stand of Einstein, with which Lorentz has agreed - A. P.)", [3]. However, the last statement assumes equal rights for dynamic and kinematic IFR, which is not true – see example deduced above.

Conclusion.

By virtue of dynamic relativity principle, in all dynamic inertial systems of reference Maxwell equations have the same form as in a fixed reference system Σ^0. Then we can take as "fixed" reference system that dynamic IFR Σ, together with which the considered dynamic IFR Σ' (for the system of charges S) is moving. For example, for reference system Σ', bound with the Earth surface, heliocentric reference system of Copernicus can be taken as the fixed one Σ_0; for the reference system Σ'' of tram, moving together with Σ' and at the same time translatory, uniformly and rectilinearly relative to the Earth surface, Σ' can be treated as the fixed Σ_0, and so far. Thus, the absolute frame of reference Σ^0 of still ether again retreats on a background, eluding our perception. Practically, we always deal not with the absolute, but with inertial reference systems of that or diverse level. But implicitly, the absolute reference system is always present at the above-given definition of inertial systems of reference and is manifested by dynamic force of inertia [1] - in mechanics, dynamic (magnetic part) force of Lorentz [6] - in an electrodynamics and global constant c the velocity of light [3]- in optics.

References

[1] A. F. Potjekhin, A Short Course of Theoretical Mechanics in Questions and Answers with Analysis of basic Concepts. (Textbook, in Ukrainian), OSMU, Odessa, 2000.

[2] I. Newton, Mathematical Principles of Natural Philosophy. (In Russ), Nauka Publish., Moscow, 1989.

[3] H. A. Lorentz, The Theory of Electrons. (In Russian), Gostechizdat, Moscow, 1956.

[4] A .F. Potjekhin, Hadronic Journal Supplement. **14**, 297-313 (1999).

[5] H. E. Wilhelm, Radio Science **20**, 5, 1006-1018 (1985).

[6] H. E. Wilhelm, Z.Naturforschung **45a**, 736-748 (1990)

[7] H. E. Wilhelm, Hadronic Journal **19**, 1-39 (1996).

[8] O.Heavicide, The Electrician, **31**, 281-282 (1893).

[9]. O. D. Jefimenko, Galilean Electrodinamics, **5**, 2, 25-33 (1994).

[10] O. D. Jefimenko, Electromagnetic Retardation and Theory Relativity, Star City, West Virginia, 1997.

[11] A. Einstein, Ann.Physik, **17**, 891-921 (1905).

[12] H.Poincare, Selected Papers. **III** (In Russian) Nauka Publishers, Moscow 1974.