

Electromagnetic Field of Accelerated Charges in Inertial Frames with Substratum Flow

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By means of the generalized Galilei covariant EM field equations, the EM potentials and EM fields of a charged particle moving with an arbitrary nonuniform velocity $\mathbf{v}(t)$ in an inertial frame with substratum flow \mathbf{w} are calculated. It is shown that the dynamic EM fields are excitations of the EM ether caused by the motion $\mathbf{v}(t) - \mathbf{w}$ of the charge relative to the wave carrier with velocity \mathbf{w} . Qualitatively and quantitatively significant EM inductions and convective deformations of EM fields by the ether flow \mathbf{w} exist in inertial frames with ether velocities $w \sim c_0$ comparable to the velocity of light. For many terrestrial applications, the ordinary Maxwell equations agree in good approximation with the Galilei covariant EM field equations since $w/c_0 \sim 10^{-3}$ on the earth.

Introduction

According to Maxwell, Hertz, Heaviside, Poincaré, Lorentz, Abraham, and others, Maxwell's equations hold only in a frame of reference $\Sigma^\circ(\mathbf{r}^\circ, t^\circ, \mathbf{0})$, in which the carrier of the electromagnetic (EM) fields is at rest, $\mathbf{w}^\circ \equiv \mathbf{0}$ [1–7]. Since these EM field equations are not applicable to arbitrary inertial frames $\Sigma(\mathbf{r}, t, \mathbf{w})$ with ether flow \mathbf{w} , they are not generally valid [1–7]. The restriction of Maxwell's equations to the ether frame Σ° is apparent from the fact that they are not Galilei covariant [1–7]. A physically more meaningful observation would have been the recognition that it makes no physical sense to expect EM field equations, such as Maxwell's equations, to be covariant against physical space-time transformations of any type, if these field equations hold only in a single inertial frame (Σ°) and their form in arbitrary inertial frames (Σ) is unknown. Furthermore, Maxwell's equations can be shown to be covariant with respect to an infinite number of linear and nonlinear mathematical space-time transformations, with the Lorentz transformations representing a simple linear coordinate substitution [8]. Thus, Maxwell's equations have no unique or physically distinguished transformations [8].

In order to illustrate physical transformation theory (and the strange mathematical developments which lead to the Lorentz covariant electrodynamics)

[9], let the Galilei covariance of the familiar acoustic wave equation be discussed. In the inertial frame $\Sigma^\circ(\mathbf{r}^\circ, t^\circ, \mathbf{0})$ in which the acoustic wave carrier (e.g., a gas) is at rest, $\mathbf{w}^\circ \equiv \mathbf{0}$, the pressure $p^\circ(\mathbf{r}^\circ, t^\circ)$ of the sound waves is described by the ordinary wave equation, $\partial^2 p^\circ / \partial t^{\circ 2} = c_s^{\circ 2} \nabla^{\circ 2} p^\circ$. This wave equation is not Galilei covariant since it holds only in the carrier rest frame Σ° . By linear gasdynamics, the acoustic wave equation for an arbitrary inertial frame $\Sigma(\mathbf{r}, t, \mathbf{w})$, in which the acoustic wave carrier (gas) streams with a velocity \mathbf{w} , is of different form, namely $(\partial/\partial t + \mathbf{w} \cdot \nabla)^2 p = c_s^2 \nabla^2 p$. This wave equation is generally valid in this form, and is Galilei covariant, since the operators $\partial/\partial t + \mathbf{w} \cdot \nabla = \partial/\partial t' + \mathbf{w}' \cdot \nabla'$, $\nabla = \nabla'$, and the pressure $p(\mathbf{r}, t) = p'(\mathbf{r}', t')$ and the velocity of sound $c_s = c'_s$ are invariants in Galilei transformations $\Sigma \leftrightarrow \Sigma'$. On the other hand, the acoustic wave equation $\partial^2 p^\circ / \partial t^{\circ 2} = c_s^{\circ 2} \nabla^{\circ 2} p^\circ$ of the carrier (gas) rest frame Σ° is covariant against the Lorentz transformation if in the latter the velocity of light c_0 is replaced by the sound velocity c_s° . Thus, the Lorentz transformation is a nonphysical space-time coordinate substitution which leaves certain field equations mathematically invariant, even though these are physically not generally valid.

The Maxwell equations were generalized to a form in which they hold in arbitrary inertial frames $\Sigma(\mathbf{r}, t, \mathbf{w})$ with ether flow \mathbf{w} in 1984 [10, 11]. These generalized Maxwell equations contain explicitly the velocity \mathbf{w} of the EM wave carrier (ether), and are Galilei covariant [10, 11]. According to this theory, light signals propagate anisotropically in inertial frames $\Sigma(\mathbf{r}, t, \mathbf{w})$ with ether flow \mathbf{w} [10, 11]. E.g., the

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velocity of a light signal in vacuum is $c_0 \pm w$, depending on whether it propagates downstream (+) or upstream (−) the ether flow w [10, 11]. In the Michelson-Morley type experiments, the average go-and-return light velocity $c = \frac{1}{2} [(c_0 + w_\perp) + (c_0 - w_\perp)] = c_0$ is measured (light path parallel to w_\perp), i.e. not the actual one-way light velocity. The claim of the special theory of relativity that a light signal propagates isotropically in all inertial frames $\Sigma(r, t, w)$ is, therefore, a trivial misinterpretation of the Michelson-Morley experiment [2]. In particular, the “relativity principle” – which asserts that one and the same (vacuum) light signal propagates in all inertial frames $\Sigma^\circ(\mathbf{0})$, $\Sigma^1(w_1)$, $\Sigma^2(w_2)$, $\Sigma^3(w_3)$, ..., $\Sigma^\infty(w_\infty)$ with the same velocity c_0 – is physically untenable, since the average go-and-return light velocity is not the actual one-way velocity of a light signal.

For the above reasons it is very promising to develop further the Galilei covariant theory of the EM field [11–13]. Herein, the scalar and vector potentials and the EM fields of a charged particle moving with an arbitrary nonuniform velocity $v(t)$ in an inertial frame $\Sigma(r, t, w)$ with ether flow w are determined. It is shown that the EM fields associated with (i) the velocity $v(t)$ and (ii) the acceleration $\dot{v}(t) = dv(t)/dt$ are excitations of the EM substratum (ether) produced by the motion $v(t) - w$ of the charge *relative* to the ether. A pure static electric field is exhibited only by a charge at rest in the ether frame Σ° .

The induction of EM fields by charge motion $v(t) - w$ relative to the ether and the convective deformation of EM fields by the ether flow w are qualitatively and quantitatively significant effects in inertial frames with large ether velocities w , e.g., in frames of reference Σ_v comoving with “relativistic” charge or neutral particles, since there $w \sim v \sim c_0$. For many terrestrial applications, the results of Maxwell’s equations agree in good approximation with the Galilei covariant EM theory, since $w/c_0 \sim 10^{-3}$ on the earth [14].

Theoretical Foundations

The carrier of the EM fields in vacuum has the electric permittivity $\epsilon_0 \cong 10^{-9}/36\pi$ [As/Vm] and the magnetic permeability $\mu_0 \cong 4\pi \times 10^{-7}$ [Vs/Am] [2]. The inertial frame, in which experiments show isotropic propagation of (one-way) light signals in vacuum with the wave speed $c_0 = (\mu_0 \epsilon_0)^{-1/2} \cong 3 \times 10^8$ [m/s], is defined as the rest frame $\Sigma^\circ(r^\circ, t^\circ, \mathbf{0})$ of the

EM wave carrier ($w^\circ = \mathbf{0}$). In this so-called EM substratum or ether frame, the ordinary Maxwell equations hold since $w^\circ = \mathbf{0}$ in Σ° . Transforming the Maxwell equations for the ether rest frame $\Sigma^\circ(r^\circ, t^\circ, \mathbf{0})$ to an arbitrary inertial frame $\Sigma(r, t, w)$ with ether flow w , by means of the Galilean space-time transformations, leads to generalized covariant Maxwell equations which contain explicitly the ether velocity w [11, 12]. In particular, the wave equations for the magnetic vector potential $A(r, t)$ and the scalar electric potential $\Phi(r, t)$ in vacuum (μ_0, ϵ_0) are obtained for an arbitrary inertial frame $\Sigma(r, t, w)$ with ether flow w in the form [11, 12]:

$$[\mu_0 \epsilon_0 (\partial/\partial t + w \cdot \nabla)^2 - \nabla^2] A = \mu_0 (j - q w), \quad (1)$$

$$[\mu_0 \epsilon_0 (\partial/\partial t + w \cdot \nabla)^2 - \nabla^2] (\Phi - w \cdot A) = q/\epsilon_0, \quad (2)$$

where the divergence of $A(r, t)$ is determined by the generalized Lorentz gauge

$$\nabla \cdot A = -\mu_0 \epsilon_0 (\partial/\partial t + w \cdot \nabla) (\Phi - w \cdot A). \quad (3)$$

The current density $j(r, t)$ and space charge density $q(r, t)$ fields are the sources of the EM potentials. A charge e with nonuniform (accelerated) velocity $v(t)$ and instantaneous position $s = s(t)$ at time t , has the current and space charge density fields,

$$j(r, t) = q(r, t) v(t), \quad q(r, t) = e \delta(r - s(t)),$$

$$s(t) = \int_0^t v(t') dt' + r_0. \quad (4)$$

From the solutions $A(r, t)$ and $\Phi(r, t)$ of (1) and (2), the EM vacuum fields $E(r, t)$ and $H(r, t)$ result,

$$E = -\nabla\Phi - \partial A/\partial t, \quad H = \nabla \times A/\mu_0. \quad (5)$$

Equations (1)–(3) and (5) are Galilei covariant, i.e., are of the same form in all inertial frame, since [11, 12]

$$\partial/\partial t + w \cdot \nabla = \partial/\partial t' + w' \cdot \nabla', \quad (6)$$

$$\nabla = \nabla' \quad (7)$$

and

$$A(r, t) = A'(r', t'), \quad (8)$$

$$\Phi(r, t) - w \cdot A(r, t) = \Phi'(r', t') - w' \cdot A'(r', t'), \quad (9)$$

$$j(r, t) - q(r, t) w = j'(r', t') - q'(r', t') w', \quad (10)$$

$$q(r, t) = q'(r', t') \quad (11)$$

are invariant operators and fields in Galilei transformations from the inertial frame $\Sigma(r, t, w)$ to the inertial frame $\Sigma'(r', t', w')$. Σ' moves with an arbitrary uniform velocity $u = w - w' = v - v'$ relative to Σ .

In this Galilei transformation, the vacuum properties are invariant (in agreement with observation),

$$\mu_0 = \mu'_0, \quad \varepsilon_0 = \varepsilon'_0. \quad (12)$$

By identifying $\Sigma' \equiv \Sigma^\circ(\mathbf{r}^\circ, t^\circ, \mathbf{0})$ with the ether frame (Σ° moves relative to Σ with the velocity $\mathbf{u} = \mathbf{w}$, since the ether is at rest in Σ° , $\mathbf{w}' \equiv \mathbf{w}^\circ = \mathbf{0}$), (6)–(8) readily transform (1)–(3) to the ether frame $\Sigma^\circ(\mathbf{r}^\circ, t^\circ, \mathbf{0})$:

$$(\mu_0 \varepsilon_0 \partial^2 / \partial t^{\circ 2} - \nabla^{\circ 2}) A^\circ = \mu_0 \mathbf{j}^\circ, \quad (13)$$

$$(\mu_0 \varepsilon_0 \partial^2 / \partial t^{\circ 2} - \nabla^{\circ 2}) \Phi^\circ = \varrho^\circ / \varepsilon_0, \quad (14)$$

$$\nabla^\circ \cdot \mathbf{A}^\circ = -\mu_0 \varepsilon_0 \partial \Phi^\circ / \partial t^\circ \quad (15)$$

with

$$\mathbf{E}^\circ = -\nabla^\circ \Phi^\circ - \partial \mathbf{A}^\circ / \partial t^\circ, \quad \mathbf{H}^\circ = \nabla^\circ \times \mathbf{A}^\circ / \mu_0, \quad (16)$$

since (5) is Galilei covariant. The transformations (10) and (11) (with $\Sigma' \equiv \Sigma^\circ$ and $\mathbf{w}' \equiv \mathbf{w}^\circ = \mathbf{0}$) give for the charge and current density fields in (13) and (14)

$$\mathbf{j}^\circ(\mathbf{r}^\circ, t^\circ) = \varrho^\circ(\mathbf{r}^\circ, t^\circ) \mathbf{v}^\circ(t^\circ),$$

$$\varrho^\circ(\mathbf{r}^\circ, t^\circ) = e \delta(\mathbf{r}^\circ - \mathbf{s}^\circ(t^\circ)), \quad (17)$$

where

$$\mathbf{v}^\circ(t^\circ) = \mathbf{v}(t) - \mathbf{w}, \quad \mathbf{s}^\circ(t^\circ) = \int_0^{t^\circ} \mathbf{v}^\circ(t') dt' + \mathbf{r}_0^\circ \quad (18)$$

are the velocity and position of the charge in the ether frame Σ° at time t° .

Equations (13)–(16) are of the same form as the conventional wave equations for the EM potentials and their EM field interrelations. Thus, the Galilei covariant EM field equations (1)–(3) contain the conventional EM field equations as a special case ($\mathbf{w} = \mathbf{0}$). These are, therefore, strictly applicable only in the ether frame Σ° .

The analytical solution of the wave equations (1) and (2) lead in many cases to mathematical difficulties, e.g. to integral equations, owing to the mixed derivatives $\mathbf{w} \cdot \nabla \partial / \partial t$ [12]. For this reason, they will be solved herein by means of the Galilei transformation method [11–13]. For this purpose, the solutions for the EM potentials in the ether frame Σ° are required.

EM Potentials in Σ° . The charge moving with non-uniform velocity $\mathbf{v}^\circ(t^\circ)$ (“acceleration” $\dot{\mathbf{v}}^\circ(t^\circ)$) produces the charge and current density fields in the ether frame Σ° . Accordingly, the retarded EM potential so-

lutions of (13) and (14) are

$$A^\circ(\mathbf{r}^\circ, t^\circ) = (\mu_0 e / 4\pi) \iiint_{-\infty}^{+\infty} [\delta(\mathbf{r}' - \mathbf{s}^\circ(\tau^\circ)) \mathbf{v}^\circ(\tau^\circ) / R^\circ] \cdot \delta(\tau^\circ - t^\circ + R^\circ / c_0) d^3 \mathbf{r}' d\tau^\circ, \quad (19)$$

$$\Phi^\circ(\mathbf{r}^\circ, t^\circ) = (e / 4\pi \varepsilon_0) \iiint_{-\infty}^{+\infty} [\delta(\mathbf{r}' - \mathbf{s}^\circ(\tau^\circ)) / R^\circ] \cdot \delta(\tau^\circ - t^\circ + R^\circ / c_0) d^3 \mathbf{r}' d\tau^\circ, \quad (20)$$

where

$$\mathbf{R}^\circ(\mathbf{r}^\circ, \mathbf{r}') = \mathbf{r}^\circ - \mathbf{r}' \quad (21)$$

is the vector from the source point \mathbf{r}' to the field point \mathbf{r}° . The retardation is represented through the temporal Dirac functions. Integration over the source points \mathbf{r}' and the retarded times τ° gives the EM potentials of the moving and the accelerated charge in the ether frame Σ° :

$$A^\circ(\mathbf{r}^\circ, t^\circ) = (\mu_0 e / 4\pi) [\mathbf{v}^\circ(\tau^\circ) / S^\circ(\mathbf{r}^\circ, \tau^\circ)]_{\tau^\circ = t^\circ - R^\circ / c_0}, \quad (22)$$

$$\Phi^\circ(\mathbf{r}^\circ, t^\circ) = (e / 4\pi \varepsilon_0) [1 / S^\circ(\mathbf{r}^\circ, \tau^\circ)]_{\tau^\circ = t^\circ - R^\circ / c_0}, \quad (23)$$

where

$$S^\circ(\mathbf{r}^\circ, t^\circ) = R^\circ(\mathbf{r}^\circ, \tau^\circ) - R^\circ(\mathbf{r}^\circ, \tau^\circ) \cdot \mathbf{v}^\circ(\tau^\circ) / c_0, \quad (24)$$

$$\mathbf{R}^\circ(\mathbf{r}^\circ, \tau^\circ) = \mathbf{r}^\circ - \mathbf{s}^\circ(\tau^\circ). \quad (25)$$

Equations (22) and (23) are the Lienard-Wiechert potentials in the ether frame Σ° [1, 2]. Note that \mathbf{R}° in (22) and (23) is now the vector from the position $\mathbf{s}^\circ(\tau^\circ)$ of the charge to the point of observation \mathbf{r}° , (25).

The physical complexity of the solutions (22) and (23) is evident from the fact that the retarded time τ° is, for any field point $(\mathbf{r}^\circ, t^\circ)$, the (real) root of the transcendental equation

$$\tau^\circ - t^\circ + |\mathbf{r}^\circ - \mathbf{s}^\circ(\tau^\circ)| / c_0 = 0, \quad (26)$$

where $\mathbf{s}^\circ(\tau^\circ)$ is given through (18). It is remarkable that the EM potentials $A^\circ(\mathbf{r}^\circ, t^\circ)$ and $\Phi^\circ(\mathbf{r}^\circ, t^\circ)$ depend only on the velocity $\mathbf{v}^\circ(t^\circ)$, but not on the acceleration $\dot{\mathbf{v}}^\circ(t^\circ)$ of the charge.

EM Fields in Σ° . The EM fields follow as the partial derivatives (5) of the EM potentials (22) and (23). Accordingly, the EM fields of the charge moving with nonuniform velocity $\mathbf{v}^\circ(t^\circ)$ in the ether frame Σ° are superpositions of “velocity fields 1” and “acceleration fields 2”,

$$\mathbf{E}^\circ = \mathbf{E}_1^\circ + \mathbf{E}_2^\circ, \quad \mathbf{H}^\circ = \mathbf{H}_1^\circ + \mathbf{H}_2^\circ \quad (27)$$

where

$$\mathbf{E}_1^\circ(\mathbf{r}^\circ, t^\circ) = (e/4\pi\epsilon_0) \quad (28)$$

$$\cdot [(1 - \mathbf{v}^\circ(\tau^\circ)^2/c_0^2) [\mathbf{R}^\circ - \mathbf{R}^\circ \mathbf{v}^\circ(\tau^\circ)/c_0]/S^{\circ 3}]_{\tau^\circ=t^\circ-R^\circ/c_0},$$

$$\mathbf{H}_1^\circ(\mathbf{r}^\circ, t^\circ) = (e/4\pi)$$

$$\cdot [1 - \mathbf{v}^\circ(\tau^\circ)^2/c_0^2] \mathbf{v}^\circ(\tau^\circ) \times \mathbf{R}^\circ/S^{\circ 3}]_{\tau^\circ=t^\circ-R^\circ/c_0}, \quad (29)$$

and

$$\mathbf{E}_2^\circ(\mathbf{r}^\circ, t^\circ) = (e/4\pi\epsilon_0) [-\mathbf{R}^\circ \dot{\mathbf{v}}^\circ(\tau^\circ)/c_0^2 S^{\circ 2} \quad (30)$$

$$+ [\mathbf{R}^\circ \cdot \dot{\mathbf{v}}^\circ(\tau^\circ)] [\mathbf{R}^\circ - \mathbf{R}^\circ \mathbf{v}^\circ(\tau^\circ)/c_0]/c_0^2 S^{\circ 3}]_{\tau^\circ=t^\circ-R^\circ/c_0},$$

$$\mathbf{H}_2^\circ(\mathbf{r}^\circ, t^\circ) = (e/4\pi) [-\mathbf{R}^\circ \times \dot{\mathbf{v}}^\circ(\tau^\circ)/c_0 S^{\circ 2} \quad (31)$$

$$+ [\mathbf{R}^\circ \cdot \dot{\mathbf{v}}^\circ(\tau^\circ)] \mathbf{v}^\circ(\tau^\circ) \times \mathbf{R}^\circ/c_0^2 S^{\circ 3}]_{\tau^\circ=t^\circ-R^\circ/c_0}.$$

Comparison reveals that the velocity fields “1” and the acceleration fields “2” have the interrelations

$$\mathbf{H}_1^\circ = \epsilon_0 \mathbf{v}^\circ(\tau) \times \mathbf{E}_1^\circ, \quad \mathbf{H}_1 = \epsilon_0 c_0 \mathbf{R}^\circ \times \mathbf{E}_1^\circ/R^\circ \quad (32)$$

and

$$[\mathbf{H}_2^\circ + e \mathbf{R}^\circ \times \dot{\mathbf{v}}^\circ(\tau^\circ)/4\pi c_0 S^{\circ 2}] = \epsilon_0 \mathbf{v}^\circ(\tau^\circ) \times [\mathbf{E}_2^\circ + e \mathbf{R}^\circ \dot{\mathbf{v}}^\circ(\tau^\circ)/4\pi \epsilon_0 c_0^2 S^{\circ 2}], \quad (33)$$

$$\mathbf{H}_2^\circ = \epsilon_0 c_0 \mathbf{R}^\circ \times \mathbf{E}_2^\circ/R^\circ. \quad (34)$$

$\mathbf{R}^\circ = \mathbf{R}^\circ(\mathbf{r}^\circ, \tau^\circ)$ and $S^\circ = S^\circ(\mathbf{r}^\circ, \tau^\circ)$ are defined in (24) and (25). Furthermore, by (26) $\tau^\circ = \tau^\circ(\mathbf{r}^\circ, t^\circ)$ in (28)–(34) for any field point $(\mathbf{r}^\circ, t^\circ)$.

In contrast to the EM potentials (22) and (23), the electric and magnetic fields [(28)–(31)] of the moving charge depend not only on its velocity $\mathbf{v}^\circ(\tau^\circ)$ but also on its acceleration $\dot{\mathbf{v}}^\circ(\tau^\circ) \equiv d\mathbf{v}^\circ(\tau^\circ)/d\tau^\circ$. This indicates that the EM potentials have a more fundamental physical meaning than their EM fields.

EM Potentials in $\Sigma(\mathbf{r}, t, \mathbf{w})$

The EM potentials of the accelerated charge in the ether frame $\Sigma^\circ(\mathbf{r}^\circ, t^\circ, \mathbf{0})$ are given in (22) and (23). The corresponding EM potentials $\mathbf{A}(\mathbf{r}, t)$ and $\Phi(\mathbf{r}, t)$ in an arbitrary inertial frame $\Sigma(\mathbf{r}, t, \mathbf{w})$ with ether flow \mathbf{w} which moves relative to the ether frame Σ° with the velocity $\mathbf{u} \equiv -\mathbf{w}$, are obtained through a Galilei transformation. With $\Sigma' \equiv \Sigma^\circ$ and $\mathbf{w}' \equiv \mathbf{w}^\circ = \mathbf{0}$, the required Galilei transformations follow from (8) and (9),

$$\mathbf{A}(\mathbf{r}, t) = \mathbf{A}^\circ(\mathbf{r}^\circ, t^\circ), \quad (35)$$

$$\Phi(\mathbf{r}, t) = \Phi^\circ(\mathbf{r}^\circ, t^\circ) + \mathbf{w} \cdot \mathbf{A}^\circ(\mathbf{r}^\circ, t^\circ), \quad (36)$$

where

$$t^\circ = t, \quad \mathbf{r}^\circ = \mathbf{r} + \mathbf{u}t, \quad \mathbf{u} = -\mathbf{w}, \quad (37)$$

$$\mathbf{v}^\circ(t^\circ) = \mathbf{v}(t) - \mathbf{w}, \quad (38)$$

$$\mathbf{r}^\circ - \mathbf{s}^\circ(t) = \mathbf{r} - \mathbf{s}(t): \Rightarrow \mathbf{R}^\circ(\mathbf{r}^\circ, t^\circ) = \mathbf{R}(\mathbf{r}, t), \quad (39)$$

$$t^\circ - R^\circ(\mathbf{r}^\circ, t^\circ)/c_0 = t - R(\mathbf{r}, t)/c_0: \Rightarrow \tau^\circ = \tau. \quad (40)$$

Substitution of (22) and (23) into (35) and (36) yields, under consideration of (37)–(40), the EM potentials of the charge with velocity $\mathbf{v}(t)$ and acceleration $\dot{\mathbf{v}}(t)$ in the inertial frame $\Sigma(\mathbf{r}, t, \mathbf{w})$ with ether flow \mathbf{w} :

$$\mathbf{A}(\mathbf{r}, t) \quad (41)$$

$$= \frac{\mu_0 e}{4\pi} \left[\frac{\mathbf{v}(\tau) - \mathbf{w}}{R(\mathbf{r}, \tau) - \mathbf{R}(\mathbf{r}, \tau) \cdot [\mathbf{v}(\tau) - \mathbf{w}]/c_0} \right]_{\tau=t-R(\mathbf{r}, \tau)/c_0},$$

$$\Phi(\mathbf{r}, t) \quad (42)$$

$$= \frac{e}{4\pi\epsilon_0} \left[\frac{1 + \mathbf{w} \cdot [\mathbf{v}(\tau) - \mathbf{w}]/c_0^2}{R(\mathbf{r}, \tau) - \mathbf{R}(\mathbf{r}, \tau) \cdot [\mathbf{v}(\tau) - \mathbf{w}]/c_0} \right]_{\tau=t-R(\mathbf{r}, \tau)/c_0},$$

where

$$\mathbf{R}(\mathbf{r}, \tau) = \mathbf{r} - \mathbf{s}(\tau), \quad \mathbf{s}(\tau) = \int_0^\tau \mathbf{v}(t) dt + \mathbf{r}_0, \quad (43)$$

and

$$\tau - t + |\mathbf{r} - \mathbf{s}(\tau)|/c_0 = 0 \quad (44)$$

determines the retarded time τ at any observation point (\mathbf{r}, t) .

Comparison of (41) and (42) indicates the interrelation between vector and scalar potentials,

$$\mathbf{A}(\mathbf{r}, t) = \Phi(\mathbf{r}, t) \mu_0 \quad (45)$$

$$\cdot \epsilon_0 [[\mathbf{v}(\tau) - \mathbf{w}]/[1 + \mathbf{w} \cdot (\mathbf{v}(\tau) - \mathbf{w})/c_0^2]]_{\tau=t-R(\mathbf{r}, \tau)/c_0}.$$

In the special case of uniform charge motion, $\mathbf{v} = \mathbf{w}$, with the ether velocity, (41) and (42) reduce to

$$\mathbf{A}(\mathbf{r}, t) = \mathbf{0}, \quad \Phi(\mathbf{r}, t) = e/4\pi\epsilon_0 R(\mathbf{r}, t); \quad \mathbf{v} = \mathbf{w}, \quad (46)$$

where

$$\tau = t - |\mathbf{r} - \mathbf{w}\tau - \mathbf{r}_0|, \quad \mathbf{v} = \mathbf{w} \quad (47)$$

gives the retarded time τ for any field point (\mathbf{r}, t) . Even though $\mathbf{v} = \mathbf{w} \neq \mathbf{0}$, the EM potentials in (46) are quasi-static. Comparison with (41) and (42) reveals that the dynamic EM potentials for $\mathbf{v}(\tau) \neq \mathbf{w}$ are excitations of the ether produced by charge motion $\mathbf{v}(t) - \mathbf{w} \neq \mathbf{0}$ relative to the ether.

EM Fields in $\Sigma(\mathbf{r}, t, \mathbf{w})$

Equation (5) gives the EM field in $\Sigma(\mathbf{r}, t, \mathbf{w})$ as derivatives of the EM potentials (41) and (42). The resulting EM field is decomposable into fields “1” related to the velocity $\mathbf{v}(t)$ and fields “2” related to the acceleration $\dot{\mathbf{v}}(t)$,

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2, \quad \mathbf{H} = \mathbf{H}_1 + \mathbf{H}_2. \quad (48)$$

Thus, the EM field excited by the charge with velocity $\mathbf{v}(t)$ and acceleration $\dot{\mathbf{v}}(t)$ in the inertial frame $\Sigma(\mathbf{r}, t, \mathbf{w})$ with ether flow \mathbf{w} is obtained in the form

$$\mathbf{E}_1(\mathbf{r}, t) = \frac{e}{4\pi\epsilon_0} \left[\left(1 - \frac{[\mathbf{v}(\tau) - \mathbf{w}]^2}{c_0^2} \right) \cdot \left\{ \left(1 + \frac{\mathbf{w} \cdot [\mathbf{v}(\tau) - \mathbf{w}]}{c_0^2} \right) \mathbf{R}(\mathbf{r}, \tau) - \frac{[\mathbf{v}(\tau) - \mathbf{w}]}{c_0} \right. \right. \\ \left. \left. \cdot \left(\mathbf{R}(\mathbf{r}, \tau) + \frac{\mathbf{w} \cdot \mathbf{R}(\mathbf{r}, \tau)}{c_0} \right) \right\} / S(\mathbf{r}, \tau)^3 \right]_{\tau=t-R(\mathbf{r}, \tau)/c_0}, \quad (49)$$

$$\mathbf{H}_1(\mathbf{r}, t) = \frac{e}{4\pi} \left[\left(1 - \frac{[\mathbf{v}(\tau) - \mathbf{w}]^2}{c_0^2} \right) \cdot \frac{[\mathbf{v}(\tau) - \mathbf{w}] \times \mathbf{R}(\mathbf{r}, \tau)}{S(\mathbf{r}, \tau)^3} \right]_{\tau=t-R(\mathbf{r}, \tau)/c_0}, \quad (50)$$

and

$$\mathbf{E}_2(\mathbf{r}, t) = \frac{e}{4\pi\epsilon_0} \left[-\frac{\mathbf{R}(\mathbf{r}, \tau) \cdot \dot{\mathbf{v}}(\tau)}{c_0^2 S(\mathbf{r}, \tau)^2} \right. \\ \left. + \left(1 + \frac{\mathbf{w} \cdot [\mathbf{v}(\tau) - \mathbf{w}]}{c_0^2} \right) \frac{[\mathbf{R}(\mathbf{r}, \tau) \cdot \dot{\mathbf{v}}(\tau)] \mathbf{R}(\mathbf{r}, \tau)}{c_0^2 S(\mathbf{r}, \tau)^3} \right. \\ \left. - \frac{\mathbf{R}(\mathbf{r}, \tau) [\mathbf{v}(\tau) - \mathbf{w}]}{c_0^3 S(\mathbf{r}, \tau)^3} \left(1 + \frac{\mathbf{w} \cdot \mathbf{R}(\mathbf{r}, \tau)}{c_0} \right) \mathbf{R}(\mathbf{r}, \tau) \cdot \dot{\mathbf{v}}(\tau) \right. \\ \left. + \frac{\mathbf{w} \times [\mathbf{R}(\mathbf{r}, \tau) \times \dot{\mathbf{v}}(\tau)]}{c_0^3 S(\mathbf{r}, \tau)^2} \right]_{\tau=t-R(\mathbf{r}, \tau)/c_0}, \quad (51)$$

$$\mathbf{H}_2(\mathbf{r}, t) = \frac{e}{4\pi} \left[-\frac{\mathbf{R}(\mathbf{r}, \tau) \times \dot{\mathbf{v}}(\tau)}{c_0 S(\mathbf{r}, \tau)^2} \right. \\ \left. + \frac{[\mathbf{R}(\mathbf{r}, \tau) \cdot \dot{\mathbf{v}}(\tau)] [\mathbf{v}(\tau) - \mathbf{w}] \times \mathbf{R}(\mathbf{r}, \tau)}{c_0^2 S(\mathbf{r}, \tau)^3} \right]_{\tau=t-R(\mathbf{r}, \tau)/c_0}, \quad (52)$$

where the retarded time τ is given through (44) for any field point (\mathbf{r}, t) . $\mathbf{R}(\mathbf{r}, \tau)$ is defined in (43), and

$$S(\mathbf{r}, \tau) = R(\mathbf{r}, \tau) - \mathbf{R}(\mathbf{r}, \tau) \cdot [\mathbf{v}(\tau) - \mathbf{w}] / c_0. \quad (53)$$

An easier derivation of (49)–(52) consists in transforming the EM fields (28)–(31) of the ether frame

$\Sigma^\circ(\mathbf{r}^\circ, t^\circ, \mathbf{0})$ to the inertial frame $\Sigma(\mathbf{r}, t, \mathbf{w})$ by means of the Galilean field transformations [11, 12],

$$\mathbf{H}(\mathbf{r}, t) = \mathbf{H}^\circ(\mathbf{r}^\circ, t^\circ),$$

$$\mathbf{E}(\mathbf{r}, t) = \mathbf{E}^\circ(\mathbf{r}^\circ, t^\circ) - \mu_0 \mathbf{w} \times \mathbf{H}^\circ(\mathbf{r}^\circ, t^\circ) \quad (54)$$

under consideration of the interrelations (37)–(40). These transformations follow from the transformations (8) and (9) with the help of (5), for $\Sigma' \equiv \Sigma^\circ$ and $\mathbf{w}' \equiv \mathbf{0}$.

The velocity fields “1” and the acceleration fields “2” exhibit the interrelations,

$$\mathbf{H}_1(\mathbf{r}, t) = \epsilon_0 [\mathbf{v}(\tau) - \mathbf{w}] \times \mathbf{E}_1(\mathbf{r}, t) / \{1 + \mathbf{w} \cdot [\mathbf{v}(\tau) - \mathbf{w}] / c_0^2\}, \\ \tau = \tau(\mathbf{r}, t), \quad (55)$$

$$\mathbf{H}_1(\mathbf{r}, t) = \epsilon_0 c_0 \mathbf{R}(\mathbf{r}, \tau)^{-1} \mathbf{R}(\mathbf{r}, \tau) \times \mathbf{E}_1(\mathbf{r}, t) / \\ \{1 + \mathbf{R}(\mathbf{r}, \tau) \cdot \mathbf{w} / R(\mathbf{r}, \tau) c_0\}, \quad \tau = \tau(\mathbf{r}, t) \quad (56)$$

and

$$[\mathbf{H}_2(\mathbf{r}, t) + e \mathbf{R}(\mathbf{r}, \tau) \times \dot{\mathbf{v}}(\tau) / 4\pi c_0 S(\mathbf{r}, \tau)^2] \\ = \epsilon_0 [\mathbf{v}(\tau) - \mathbf{w}] \times [\mathbf{E}_2(\mathbf{r}, t) + e \mathbf{R}(\mathbf{r}, \tau) \dot{\mathbf{v}}(\tau) / \\ 4\pi \epsilon_0 c_0^2 S(\mathbf{r}, \tau)^2] / \{1 + \mathbf{w} \cdot [\mathbf{v}(\tau) - \mathbf{w}] / c_0^2\}, \\ \tau = \tau(\mathbf{r}, t), \quad (57)$$

$$\mathbf{H}_2(\mathbf{r}, t) = \epsilon_0 c_0 \mathbf{R}(\mathbf{r}, \tau)^{-1} \mathbf{R}(\mathbf{r}, t) \times \mathbf{E}_2(\mathbf{r}, t) / \\ \{1 + \mathbf{R}(\mathbf{r}, \tau) \cdot \mathbf{w} / R(\mathbf{r}, \tau) c_0\}, \quad \tau = \tau(\mathbf{r}, t). \quad (58)$$

In (55)–(58), the retarded time τ for any field point (\mathbf{r}, t) is given through (44).

It is recognized that \mathbf{H}_1 , \mathbf{E}_1 , and $\mathbf{v}(\tau) - \mathbf{w}$ or \mathbf{R} are, pairwise, mutually perpendicular. At large distances, \mathbf{H}_1 and \mathbf{E}_1 fall off like R^{-2} ($S \sim R$). Therefore, the velocity field has the character of a quasistatic field which moves along with the charge.

The fields \mathbf{E}_2 , \mathbf{H}_2 decrease with distance like R^{-1} . \mathbf{H}_2 , \mathbf{R} , and \mathbf{E}_2 are, pairwise, mutually perpendicular. Thus, the acceleration field has the character of a wave or radiation field. \mathbf{H}_2 is in general not perpendicular to $\mathbf{v}(\tau) - \mathbf{w}$ (except where $\mathbf{v}(\tau)$ is parallel to \mathbf{R}).

In order to understand the physical implications of (49)–(52), consider the special situation of a charge moving uniformly with a velocity $\mathbf{v}(t) = \mathbf{w}$ equal to the ether velocity in $\Sigma(\mathbf{r}, t, \mathbf{w})$. In this case, (49)–(52) reduce to

$$\mathbf{E}_1(\mathbf{r}, t) = e/4\pi\epsilon_0 \mathbf{R}(\mathbf{r}, \tau) / R(\mathbf{r}, \tau)^3, \quad \mathbf{H}_2 = \mathbf{0}; \quad \mathbf{v} = \mathbf{w} \quad (59)$$

and

$$\mathbf{E}_2(\mathbf{r}, t) = \mathbf{0}, \quad \mathbf{H}_2(\mathbf{r}, t) = \mathbf{0}; \quad \mathbf{v} = \mathbf{w}, \quad (60)$$

where $\tau = \tau(\mathbf{r}, t)$ for any field point (\mathbf{r}, t) , (47). Since the charge motion is unaccelerated, $\mathbf{E}_2 = \mathbf{0}$ and $\mathbf{H}_2 = \mathbf{0}$, (60). Even though $\mathbf{v} \neq \mathbf{0}$ in $\Sigma(\mathbf{r}, t, \mathbf{w})$, $\mathbf{H}_1 = \mathbf{0}$ if $\mathbf{v} - \mathbf{w} = \mathbf{0}$ and \mathbf{E}_1 is quasi-static. Accordingly, the dynamic EM fields (49), (50) and (51), (52) are, for $\mathbf{v}(t) \neq \mathbf{w}$, excitations of the ether caused by the motion $\mathbf{v}(t) - \mathbf{w}$ relative to the ether and acceleration $\dot{\mathbf{v}}(t)$ of the charge, respectively.

The fact that the dynamic EM fields (49)–(52) are excitations of the ether is also evident when $|\mathbf{w}| \gg |\mathbf{v}(t)|$. In this case, \mathbf{E}_1 and \mathbf{H}_1 are independent of $\mathbf{v}(\tau)$, since $\mathbf{v}(\tau) - \mathbf{w} \cong -\mathbf{w}$ (in (49) and (50)) is the motion of the charge relative to the ether. Since \mathbf{w} is uniform (certainly within large regions of space), an accelerated charge motion $\mathbf{v}(t)$ represents a motion relative to the ether, $\mathbf{v}(t) - \mathbf{w} \neq \mathbf{0}$. For this reason, the acceleration field \mathbf{E}_2 , \mathbf{H}_2 depends on $\dot{\mathbf{v}}(\tau)$ even if $|\mathbf{v}(t)| \ll |\mathbf{w}|$. This again shows that the radiation field is an excitation of the ether caused by a nonuniform motion of the charge relative to the ether.

Conclusion

In applied science, the Galilean transformations for the EM field have found widespread use (e.g., in the theory of EM induction generators and motors). On the other hand, the STR is frequently avoided because of the physical contradictions it generates in non-trivial applications (see, e.g., the contradictions associated with the nonlinear velocity addition theorem) [15]. Furthermore, the Lorentz covariant Maxwell equations have been shown to have an infinite number of linear and nonlinear covariant transformations (non-uniqueness of Lorentz transformations) [8]. It has been the merit of Builder, who demonstrated that the EM forces between moving charges and magnetic dipoles to not depend on their relative velocities (as postulated by the STR), but on their absolute velocities [16, 17]. Thus, Builder clearly proved that the Galilean relativity principle holds and that of the STR fails.

Lienard and Wiechert emphasized explicitly that their EM potentials are valid only in the ether “rest” frame Σ° [1, 2]. In this respect, the theory presented gives a generalization of the EM potentials of a non-uniformly moving charge to arbitrary inertial frames

Σ with ether flow \mathbf{w} . Dynamic EM fields are now recognized as excitations of the EM substratum or ether by uniform or accelerated charge motion $\mathbf{v}(t) - \mathbf{w} \neq \mathbf{0}$ relative to the ether. An accelerated charge motion, $d\mathbf{v}(t)/dt \neq \mathbf{0}$, is always a motion $\mathbf{v}(t) - \mathbf{w} \neq \mathbf{0}$ relative to the ether, since \mathbf{w} is uniform within large spatial regions (at least of the order of galactic dimensions). The general, necessary condition for generation of radiation (e.g., Cerenkov radiation of a uniformly moving charge [13] or brems-strahlung of a deaccelerated charge) is, therefore, $\mathbf{v}(t) - \mathbf{w} \neq \mathbf{0}$, i.e., charge motion relative to the EM substratum or ether. A pure static EM field ($\mathbf{H} \equiv \mathbf{0}$) exists only in the ether frame Σ° in the presence of a charge at rest there, and represents a static stress state of the ether surrounding the charge.

This and our previous work [10–13] demonstrate that the EM substratum of the vacuum (ether) is not only the carrier of the EM fields, but also of their EM energy $\gamma = \mathbf{E}^2/2\epsilon_0 + \mathbf{H}^2/2\mu_0$ and mass $\rho = \gamma/c_0^2$ densities. The widespread conception that a charge carries the energy and mass equivalents of its EM field “on its back” as it moves through the “empty vacuum” is, therefore, physically misleading. In an other investigation we will present the first *physical* deductions of (i) the mass-energy equivalence $\Delta E = \Delta m c_0^2$ and (ii) the experimentally observed (effective) velocity dependence of the charge-mass ratio $(e/m)_{\text{exp}} = (e_0/m_0) f(\mathbf{v} - \mathbf{w})$ of charged particles in crossed (external) EM fields, based on the ether concept.

Considerable progress has also been made by others in further developing the EM ether theory [2, 16–22]. Most remarkable is a fundamental microscopic ether theory, which treats the substratum of the vacuum as an assembly of negative and positive mass Planckions [22]. Inter alias, this theory explains the observed charge quantization $e_n = n e_0$ as the result of circulation quantization of ether vortices [22]. It appears that this theory explains also the mysterious fine-structure constant

$$e_0^2/4\pi\epsilon_0\hbar c_0 = (\mu_0/\epsilon_0)^{1/2}/(4\pi\hbar/e_0^2) \sim 1/137$$

of the vacuum. Hopefully, this theory will lead to a quantitative microscopic explanation of the fundamental ether properties μ_0 and ϵ_0 . Thus, finally a microscopic understanding of the characteristic wave velocity $c_0 = (\mu_0\epsilon_0)^{-1/2}$ and wave impedance $Z_0 = (\mu_0/\epsilon_0)^{1/2}$ of the ether would be achieved.

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