# Covariant Electrodynamics in Vacuum

H. E. Wilhelm

Department of Materials Science and Engineering, University of Utah, USA

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The generalized Galilei covariant Maxwell equations and their EM field transformations are applied to the vacuum electrodynamics of a charged particle moving with an arbitrary velocity $\boldsymbol{v}$ in an inertial frame with EM carrier (ether) of velocity $\boldsymbol{w}$. In accordance with the Galilean relativity principle, all velocities have absolute meaning (relative to the ether frame with isotropic light propagation), and the relative velocity of two bodies is defined by the linear relation $\boldsymbol{u}_G = \boldsymbol{v}_1 - \boldsymbol{v}_2$. It is shown that the electric equipotential surfaces of a charged particle are compressed in the direction parallel to its relative velocity $\boldsymbol{v}-\boldsymbol{w}$ (mechanism for physical length contraction of bodies). The magnetic field $\boldsymbol{H}(\boldsymbol{r}, t)$ excited in the ether by a charge $e$ moving uniformly with velocity $\boldsymbol{v}$ is related to its electric field $\boldsymbol{E}(\boldsymbol{r}, t)$ by the equation $\boldsymbol{H}=\varepsilon_0(\boldsymbol{v}-\boldsymbol{w})\times\boldsymbol{E}/[1+\boldsymbol{w}\cdot(\boldsymbol{v}-\boldsymbol{w})/c_0^2]$, which shows that (i) a magnetic field is excited only if the charge moves relative to the ether, and (ii) the magnetic field is weak if $\boldsymbol{v}-\boldsymbol{w}$ is not comparable to the velocity of light $c_0$. It is remarkable that a charged particle can excite EM shock waves in the ether if $|\boldsymbol{v}-\boldsymbol{w}| > c_0$. This condition is realizable for anti-parallel charge and ether velocities if $|\boldsymbol{v}| > c_0 - |\boldsymbol{w}|$, i.e., even if $|\boldsymbol{v}|$ is subluminal. The possibility of this Cerenkov effect in the ether is discussed for terrestrial and galactic situations.

## Introduction

In general, wave phenomena, e.g., acoustic, shear, or spin waves, exist only in a carrier medium. Gravitational and electromagnetic waves appear to represent exceptions, since they propagate also in "free space" or "vacuum" (space without "ordinary" matter). However, an electromagnetic (EM) signal advances in vacuum with a wave front velocity which is independent of the velocity of the emitting source [1]. Thus, the vacuum behaves like a carrier medium for EM waves, in a similar sense as gases, liquids, and solids serve as carrier media for ordinary waves. Equally remarkable is the fact that the vacuum has (nonvanishing) physical properties, namely a dielectric permittivity $\varepsilon_0 \cong 10^{-9}/36\pi$ [As/Vm] and a magnetic permeability $\mu_0 \cong 4\pi \cdot 10^{-7}$ [Vs/Am], as well as derived physical properties, such as the EM wave resistance $Z_0 = (\mu_0/\varepsilon_0)^{1/2} \cong 120\pi$ [Ω], and a characteristic EM phase velocity $c_0 = (\mu_0 \varepsilon_0)^{-1/2} \cong 3\times 10^8$ [m/s] [1].

In spite of the denial of a carrier medium ("ether") for EM waves in the special theory of relativity (STR) [2, 3], the Lorentz covariant quantum mechanics [4] and quantum electrodynamics [5] predict (i) an electron-positron vacuum with infinite mass density and (ii) an infinite EM energy density (EM zero-point energy with divergent $\omega^3$-spectrum) [2, 3, 6]. All attempts at a physical renormalization of this singular electron-positron and EM radiation vacuum, within a Lorentz covariant formalism, have failed to this date. On the other hand, Winterberg's recent EM substratum theories eliminate the singularities in relativistic quantum electrodynamics and the general theory of relativity on a physical basis [7–12]. However, our microscopic understanding of the vacuum or ether is still so insufficient that it has not been possible to calculate the fundamental physical properties $\mu_0$ and $\varepsilon_0$ (or the equivalent $Z_0$ and $c_0$) from first principles [13].

Experimentally, the average velocity $\bar{c}$ of light signals in vacuum has been determined in go-and-return paths (source → mirror → source) situations with the expected result $\bar{c} = \frac{1}{2}[(c_0 + w_{\parallel}) + (c_0 - w_{\parallel})] = c_0$, presumed that the ether or carrier velocity $w_{\parallel}$ is parallel to the light path (see Michelson and Morley [14] and Janossy [15]). The Sagnac [16] and Michelson-Gale [17] experiments show that two simultaneously emitted light signals sent in opposite directions around closed quasi-circular paths of radius $r$, take different travel times corresponding to the different light signal velocities $c_0 + \Omega r$ and $c_0 - \Omega r$, where $\Omega$ is the angular velocity of the optical plane rotating about its axis $r = 0$. The latter type experiments amount to measurements of the one-way-velocity of light [15, 19] and demonstrate that light propagates anisotropically in

Reprint requests to Prof. Dr. H. E. Wilhelm, Department of Materials Science and Engineering, Universtiy of Utah, Salt Lake City, Utah 84110, USA.

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reference frames which move relative to the ether [15–19]. The discovery of the 2.7 K microwave radiation in the universe [20] provides further experimental evidence that a preferred frame of reference or ether frame does exist [21].

The STR is based on the Lorentz transformations, which imply that the Maxwell equations (believed to hold only in the ether rest frame by Maxwell, Heaviside, Hertz, Poincaré, Lorentz, and Abraham) [3] are of the very same form in all inertial frames (in which the ether streams with different velocities!). This assumed Lorentz covariance of the Maxwell equations is equivalent to the "relativity principle" [2], according to which one and the same light signal advances not only in the inertial frame of the emitter but also in (the infinite number of) all inertial frames with the same velocity of light $c_0$! Thus, the Lorentz covariance and the relativity principle are assumptions which are incompatible with the concept of an EM wave carrier (ether) and the experimental facts [14–21].

The physical (non-trivial) interpretation of the Michelson-Morley experiment lead Fitzgerald and Lorentz to the discovery of the length contraction $L = L^\circ(1 - v^2/c_0^2)^{1/2}$ of bodies moving relative to the ether with absolute velocity $v$ ($L^\circ$ = proper length of body at rest in ether frame $\Sigma^\circ$) [3, 13]. This length contraction and the anisotropic light propagation in inertial frames $\Sigma$ moving relative to $\Sigma^\circ$ with a velocity $v$ gives rise to the slowing down $\nu = \nu^\circ(1 - v^2/c_0^2)^{1/2}$ of clocks attached to $\Sigma$ ($\nu^\circ$ = proper rate of clock at rest in $\Sigma^\circ$) [10], since a clock can be modeled by a light signal reflected hence and force between mirrors held apart by a rod [10]. By Winterberg's theorem, the clock rate $\nu$ observed in $\Sigma$ is the same, no matter what the angle between the direction of the rod of the light clock and its velocity $\boldsymbol{v}$ relative to the ether is [10].

Thus, length contraction and time dilation are not independent kinematic illusions as assumed in the STR [2, 3]. Length contraction is a genuine physical effect experienced by a body as it is accelerated to an absolute velocity $\boldsymbol{v}$ relative to the EM wave carrier (ether). Clock retardation is a direct result of the length contraction suffered by the light clock in absolute motion $\boldsymbol{v}$ relative to the ether [10]. Microscopically, length contraction is due to the deformation of the concentric spherical equipotential surfaces of the electrons and nuclei (which constitute ordinary matter) into ellipsoidal equipotential surfaces, with the longitudinal axis of the ellipsoids contracted by the ether flow $\boldsymbol{w} = -\boldsymbol{v}$ (to which the charges are exposed as they move with velocity $\boldsymbol{v}$ relative to the ether, $\Sigma^\circ$). Simultaneously, the motion $\boldsymbol{v}$ of the charged particles relative to the ether gives rise to magnetic fields in $\Sigma^\circ$ and $\Sigma$.

In view of the fundamental importance of physical length contraction of material bodies composed of negatively (electrons) and positively (nuclei) charged particles, the deformation of the Coulomb field lines and the excitation of magnetic fields by charged particles in absolute motion relative to the ether frame $\Sigma^\circ$ shall be analyzed. In particular, we want to understand the excitation of magnetic fields in the ether by uniform charge motion, and whether a moving charged particle can produce discontinuous EM waves (Cerenkov effect) in the ether. The investigations are based on the generalized Galilei covariant Maxwell equations for moving media in inertial frames $\Sigma$ with ether flow $\boldsymbol{w}$ deduced and applied earlier [23–25]. These EM field equations are here briefly rederived for the special case of EM fields in vacuum ($\varepsilon = \varepsilon_0$, $\mu = \mu_0$), which have their sources in the charges and currents of moving particles (such as electrons or nuclei).

## Theoretical Principles

For the understanding of the following considerations, it is essential to be aware that they are based exclusively on the Galilean relativity principle [3]. In any inertial frame of reference $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$, which moves with an absolute velocity $\boldsymbol{u}$ relative to the ether frame $\Sigma^\circ$, the velocity $\boldsymbol{v}$ of any material particle or object has absolute meaning [3]. The relative velocity of two particles or systems (1, 2) is always given by the linear Galilean relation $\boldsymbol{u}_G = \boldsymbol{v}_1 - \boldsymbol{v}_2$ [3].

As a brief illustration, let the Galilean relative velocity $\boldsymbol{u}_G = \boldsymbol{v}_1 - \boldsymbol{v}_2$ be compared quantitatively with the nonlinear relative velocity $\boldsymbol{u}_R = (\boldsymbol{v}_1 - \boldsymbol{v}_2)/(1 - \boldsymbol{v}_1 \cdot \boldsymbol{v}_2/c_0^2)$ of the STR in the case of antiparallel velocities $\boldsymbol{v}_{1,2}$. E.g., for particle velocities $v_{1,2} = \pm 0.9\, c_0$, $u_R = 1.8\, c_0/1.81 < c_0$, whereas $u_G = 1.8\, c_0 > c_0$. For particle velocities $v_{1,2} = \pm 10\, c_0$, one would have $u_R = 20\, c_0/101 \cong c_0/5$, whereas $u_G = 20\, c_0$. However, a physically meaningful definition of the nonlinear relative velocity $u_R$ should have given $u_R$ = imaginary (unrealizable) for $v_{1,2} > c_0$, in accordance with the STR postulate that all velocities are subluminal. More generally, one finds for systems moving in opposite directions with velocities $v_{1,2} = \pm\alpha c_0$ that $v_R = (v_1 - v_2)/(1 - v_1 v_2/c_0^2) = 2\alpha c_0/(1 + \alpha^2) < c_0$ (subluminal) for any $\alpha > 0$, whereas

$u_G = v_1 - v_2 = 2\alpha c_0 > c_0$ (superluminal) for any $\alpha > 1/2$. Thus, it is recognized that superluminal (relative) Galilean velocities $u_G > c_0$ correspond to subluminal (relative, nonlinear) STR velocities $u_R < c_0$. In other words, superluminal Galilean velocities do not contradict the (always) subluminal STR velocities.

The nonlinear addition theorem represents an adhoc definition, which keeps (artificially) all velocities subluminal in the STR [3]. The alleged agreement of the nonlinear relative velocity theorem of the STR with experiments can be shown to be the result of the direct use of the STR in the theoretical interpretation of the experimental data [3]. For these reasons, Janossy proposed to define the relative velocity of two material objects in accordance with the linear Galilean relation $\boldsymbol{u}_G = \boldsymbol{v}_1 - \boldsymbol{v}_2$, not only for low, $v_{1,2} < c$, but quite generally for arbitrary large velocities $v_{1,2}$ [3]. The velocities $\boldsymbol{v}_{1,2}$ and $\boldsymbol{u}_G$ are in the same representation, i.e., they are defined in the same inertial frame of reference [3]. The Galilean relativity principle permits superluminal velocities $\boldsymbol{u}_G$ by first principles and is not in contradiction with any known experiment, if the experimental data are correctly interpreted within the frame of Galilean physics [3]. Herein, we attempt to lay further quantitative foundations of Galilei covariant electrodynamics for comparison with experiments [3, 24, 25].

The prefered reference frame $\Sigma^\circ(\boldsymbol{r}^\circ, t^\circ, \boldsymbol{0})$ in which the EM wave carrier (ether) is at rest ($\boldsymbol{w}^\circ = \boldsymbol{0}$) is that inertial frame, in which experiments show isotropic propagation of vacuum light signals with the characteristic speed $c_0 = (\mu_0 \varepsilon_0)^{-1/2}$ [7–19, 21]. According to Maxwell, Heaviside, Hertz, Poincaré, Lorentz, and Abraham [3], the usual Maxwell equations hold in $\Sigma^\circ$. The EM vacuum fields $\boldsymbol{E}^\circ(\boldsymbol{r}^\circ, t^\circ)$ and $\boldsymbol{H}^\circ(\boldsymbol{r}^\circ, t^\circ)$ in $\Sigma^\circ$ are derivable from vector $\boldsymbol{A}^\circ(\boldsymbol{r}^\circ, t^\circ)$ and scalar $\Phi^\circ(\boldsymbol{r}^\circ, t^\circ)$ potentials, by [1]

$$\boldsymbol{E}^\circ = -\nabla^\circ \Phi^\circ - \partial \boldsymbol{A}^\circ/\partial t^\circ, \quad \boldsymbol{H}^\circ = \mu_0^{-1} \nabla^\circ \times \boldsymbol{A}^\circ. \tag{1}$$

Since (1) determines only the curl of $\boldsymbol{A}^\circ$, the divergence of $\boldsymbol{A}^\circ$ is subjected to the Lorentz gauge [1]

$$\nabla^\circ \cdot \boldsymbol{A}^\circ = -\mu_0 \varepsilon_0 \, \partial \Phi^\circ/\partial t^\circ, \tag{2}$$

in order to completely specify the vector field $\boldsymbol{A}^\circ(\boldsymbol{r}^\circ, t^\circ)$. By means of (1) and (2), the Maxwell equations for the vacuum $(\mu_0, \varepsilon_0)$ can be separated into inhomogeneous wave equations for the EM potentials [1]:

$$\mu_0 \varepsilon_0 \, \partial^2 \boldsymbol{A}^\circ/\partial t^{\circ 2} - \nabla^{\circ 2} \boldsymbol{A}^\circ = \mu_0 \boldsymbol{j}^\circ, \tag{3}$$

$$\mu_0 \varepsilon_0 \, \partial^2 \Phi^\circ/\partial t^{\circ 2} - \nabla^{\circ 2} \Phi^\circ = \varrho^\circ/\varepsilon_0. \tag{4}$$

The EM vacuum potentials have their sources in the space charge $\varrho^\circ(\boldsymbol{r}^\circ, t^\circ)$ and current $\boldsymbol{j}^\circ(\boldsymbol{r}^\circ, t^\circ)$ density fields of individual charges $e$ moving with a velocity field $\boldsymbol{v}^\circ(\boldsymbol{r}^\circ, t^\circ)$, where $\boldsymbol{j}^\circ = \varrho^\circ \boldsymbol{v}^\circ$.

The EM wave equations (3)–(4) are not generally valid, since they are only applicable in the inertial frame $\Sigma^\circ(\boldsymbol{r}^\circ, t^\circ, \boldsymbol{0})$, in which the wave carrier is at rest, $\boldsymbol{w}^\circ = \boldsymbol{0}$ [3]. For this reason, it is physically not meaningful to investigate their covariance properties in space-time transformations (e.g., the Lorentz transformations) [23–25].

Accordingly, the wave equations (3)–(4) are first transformed from the ether rest frame $\Sigma^\circ$ to an arbitrary inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ which moves with an arbitrary constant velocity $\boldsymbol{U}$ relative to $\Sigma^\circ$. In $\Sigma$, the ether streams with the velocity $\boldsymbol{w} = -\boldsymbol{U}$. This transformation cannot be accomplished by means of the Lorentz transformations since these do not lead to different wave equations.

Let (3)–(4) be transformed by means of a Galilei transformation $\Sigma^\circ \to \Sigma$ to the inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with ether flow $\boldsymbol{w}$. Thus, different wave equations are obtained for the EM vacuum potentials $\boldsymbol{A}(\boldsymbol{r}, t)$ and $\Phi(\boldsymbol{r}, t)$ in the inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ that moves with arbitrary constant velocity $\boldsymbol{U} = -\boldsymbol{w}$ relative to $\Sigma^\circ$ [24, 25]:

$$[\mu_0 \varepsilon_0 (\partial/\partial t + \boldsymbol{w} \cdot \nabla)^2 - \nabla^2] \boldsymbol{A} = \mu_0 (\boldsymbol{j} - \varrho \boldsymbol{w}), \tag{5}$$

$$[\mu_0 \varepsilon_0 (\partial/\partial t + \boldsymbol{w} \cdot \nabla)^2 - \nabla^2] (\Phi - \boldsymbol{w} \cdot \boldsymbol{A}) = \varrho/\varepsilon_0. \tag{6}$$

In this Galilei transformation, the vacuum properties have been assumed to be invariant, $\mu = \mu_0$, $\varepsilon = \varepsilon_0$ [24, 25]. Note that the wave equations of the inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ contain explicitly the ether velocity $\boldsymbol{w}$.

From the simultaneous solutions $\boldsymbol{A}(\boldsymbol{r}, t)$ and $\Phi(\boldsymbol{r}, t)$ of (5) and (6), the EM fields follow via the covariant relations [24, 25],

$$\boldsymbol{E} = -\nabla \Phi - \partial \boldsymbol{A}/\partial t, \quad \boldsymbol{H} = \mu_0^{-1} \nabla \times \boldsymbol{A}. \tag{7}$$

In the inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with ether flow $\boldsymbol{w}$, the EM potentials satisfy the generalized Lorentz gauge [24, 25],

$$\nabla \cdot \boldsymbol{A} = -\mu_0 \varepsilon_0 (\partial/\partial t + \boldsymbol{w} \cdot \nabla)(\Phi - \boldsymbol{w} \cdot \boldsymbol{A}). \tag{8}$$

The wave equations of the form (5)–(6) are valid in any inertial frame $\Sigma$ if they are covariant in Galilean space-time transformations from the inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ to an arbitrary other inertial frame $\Sigma'(\boldsymbol{r}', t', \boldsymbol{w}')$:

$$\boldsymbol{r}' = \boldsymbol{r} - \boldsymbol{u} t, \quad t' = t \tag{9}$$

with

$$\partial/\partial t = \partial/\partial t' - \boldsymbol{u} \cdot \nabla', \quad \nabla = \nabla', \tag{10}$$

where $\Sigma'$ moves relative to $\Sigma$ with the arbitrary constant velocity $\boldsymbol{u}$ (0 of $\Sigma$ and 0′ of $\Sigma'$ are assumed to coincide for $t = t' = 0$). In $\Sigma'$, the ether streams with the velocity $\boldsymbol{w}' = \boldsymbol{w} - \boldsymbol{u}$. Since $\boldsymbol{u} = \boldsymbol{w} - \boldsymbol{w}'$, (10) implies the covariant operators,

$$\partial/\partial t + \boldsymbol{w} \cdot \nabla = \partial/\partial t' + \boldsymbol{w}' \cdot \nabla', \quad \nabla = \nabla'. \tag{11}$$

In the Galilei transformations $\Sigma \to \Sigma'$, the EM potentials $\boldsymbol{A}$, $\Phi$ and the source fields $\varrho, \boldsymbol{j}$ exhibit the invariance properties [24, 25],

$$\boldsymbol{A} = \boldsymbol{A}', \quad \varrho = \varrho', \tag{12}$$

$$\Phi - \boldsymbol{w} \cdot \boldsymbol{A} = \Phi' - \boldsymbol{w}' \cdot \boldsymbol{A}', \tag{13}$$

$$\boldsymbol{j} - \varrho\, \boldsymbol{w} = \boldsymbol{j}' - \varrho'\, \boldsymbol{w}'. \tag{14}$$

In view of the Galilei invariants (12)–(14), and the covariant operators in (11), it is easily recognized that the wave equations are of the same form for $\boldsymbol{A}'(\boldsymbol{r}', t')$ and $\Phi'(\boldsymbol{r}', t')$ of $\Sigma'$ as the wave equations (5) and (6) of $\Sigma$ if the vacuum properties are invariant,

$$\mu_0 = \mu_0', \quad \varepsilon_0 = \varepsilon_0'. \tag{15}$$

Accordingly, the wave equations (5) and (6) are Galilei covariant, i.e., they are applicable in any arbitrary inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with ether flow $\boldsymbol{w}$. The assumed invariance (15) of the vacuum properties $\mu_0$, $\varepsilon_0$ in Galilei transformations is obvious and agrees with known experiments. The invariants (11)–(15) with $\Sigma' \equiv \Sigma^\circ$, $\boldsymbol{w}' \equiv \boldsymbol{w}^\circ = \boldsymbol{0}$, can also be used to transform the wave equations (5)–(6) into the wave equations (3)–(4) of the ether frame $\Sigma^\circ$.

Since $\boldsymbol{u} = \boldsymbol{w} - \boldsymbol{w}' = \boldsymbol{v} - \boldsymbol{v}'$ in the Galilei transformations $\Sigma \to \Sigma'$, (11), (13) and (14) imply the Galilei invariants

$$\partial/\partial t + \boldsymbol{v} \cdot \nabla = \partial/\partial t' + \boldsymbol{v}' \cdot \nabla', \tag{16}$$

$$\Phi - \boldsymbol{v} \cdot \boldsymbol{A} = \Phi' - \boldsymbol{v}' \cdot \boldsymbol{A}', \tag{17}$$

$$\boldsymbol{j} - \varrho \boldsymbol{v} = \boldsymbol{j}' - \varrho' \boldsymbol{v}'. \tag{18}$$

Application of (7) to the Galilei invariants (12), (13), and (17) yields, under consideration of (15), the EM field invariants in Galilei transformations $\Sigma \to \Sigma'$:

$$\boldsymbol{E} + \mu_0\, \boldsymbol{w} \times \boldsymbol{H} = \boldsymbol{E}' + \mu_0\, \boldsymbol{w}' \times \boldsymbol{H}', \tag{19}$$

$$\boldsymbol{E} + \mu_0\, \boldsymbol{v} \times \boldsymbol{H} = \boldsymbol{E}' + \mu_0\, \boldsymbol{v}' \times \boldsymbol{H}', \tag{20}$$

$$\boldsymbol{H} = \boldsymbol{H}', \tag{21}$$

where

$$\boldsymbol{w} - \boldsymbol{w}' = \boldsymbol{v} - \boldsymbol{v}' = \boldsymbol{u}. \tag{22}$$

Equation (20) indicates that the Lorentz force $\boldsymbol{F} = e(\boldsymbol{E} + \mu_0\, \boldsymbol{v} \times \boldsymbol{H})$ acting on a charged particle $e$ in an EM field is Galilei invariant ($e$ is a Galilei invariant). More remarkable is (21), which shows that the magnetic field $\boldsymbol{H} = \boldsymbol{H}'$ is an exact Galilei invariant.

The corresponding Galilei covariant generalized Maxwell equations for the EM vacuum ($\mu_0, \varepsilon_0$) fields $\boldsymbol{E}(\boldsymbol{r}, t)$, $\boldsymbol{H}(\boldsymbol{r}, t)$ in an arbitrary inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with ether flow $\boldsymbol{w}$ are given by [22, 23]

$$\nabla \times (\boldsymbol{E} + \mu_0\, \boldsymbol{w} \times \boldsymbol{H}) = -(\partial/\partial t + \boldsymbol{w} \cdot \nabla)\, \mu_0 \boldsymbol{H}, \tag{23}$$

$$\nabla \cdot \varepsilon_0 (\boldsymbol{E} + \mu_0\, \boldsymbol{w} \times \boldsymbol{H}) = \varrho, \tag{24}$$

$$\nabla \times \boldsymbol{H} = (\partial/\partial t + \boldsymbol{w} \cdot \nabla)\, \varepsilon_0 (\boldsymbol{E} + \mu_0\, \boldsymbol{w} \times \boldsymbol{H}) + \boldsymbol{j} - \varrho\, \boldsymbol{w}, \tag{25}$$

$$\nabla \cdot \mu_0 \boldsymbol{H} = 0. \tag{26}$$

These EM field equations reveal the fundamental asymmetry of the time-dependent EM field, caused by the existence of electric charges and the nonexistence of magnetic charges. The Galilei covariance of (23)–(26) follows from the Galilei invariants (11), (14), (15), (19), and (21). For $\boldsymbol{w} = \boldsymbol{0}$, the generalized Maxwell equations (23)–(26) reduce to the ordinary Maxwell equations, which hold only in the ether frame $\Sigma^\circ$. Similarly, application of the invariants (11), (14), (15), (19), and (21) to the Galilei transformation $\Sigma \to \Sigma^\circ (\boldsymbol{w}' = \boldsymbol{w}^\circ \equiv \boldsymbol{0})$ transforms (23)–(26) to the Maxwell equations of the ether frame $\Sigma^\circ$.

In order to provide a physical understanding of the Galilei covariant electrodynamics of the vacuum, the EM vacuum field of a charge in uniform motion $\boldsymbol{v}$ in inertial frames $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with different ether velocities $\boldsymbol{w} \leftrightarrow \boldsymbol{v}$ will be discussed, as exact solutions of the new wave equations (5) and (6). Then, the fundamental asymmetry of the EM field in (19)–(20) will be investigated by means of the generalized Maxwell equations (23)–(26). Among many interesting predictions, it will be shown that the STR equation $\boldsymbol{H} = \varepsilon_0\, \boldsymbol{v} \times \boldsymbol{E}$ holds in the ether rest frame $\Sigma^\circ$ for a charge moving there with a velocity $\boldsymbol{v}$. In inertial frames $\Sigma$ in which the charge moves with a velocity $\boldsymbol{v} = \boldsymbol{w}$ (no motion relative to the ether, $\Sigma^\circ$), no magnetic field is excited by the moving charge. Thus, magnetic fields have to be understood as excitations produced by charge motion relative to the ether. Accelerated charges move always relative to the (uniformly moving or resting) ether in any inertial frame, and therefore always excite magnetic fields (necessary condition for radiation).

## EM Field of Charge Moving in Ether

The static EM field of a point charge $e$, which is at rest ($\boldsymbol{v}^\circ = \mathbf{0}$) at the origin ($0^\circ$) of the ether inertial frame $\Sigma^\circ(\boldsymbol{r}^\circ, t^\circ, \mathbf{0})$ is at the field point $\boldsymbol{r}^\circ$ given by

$$\boldsymbol{E}^\circ(\boldsymbol{r}^\circ) = (e/4\pi\varepsilon_0)\,\boldsymbol{r}^\circ/r^{\circ 3}, \quad \boldsymbol{H}^\circ(\boldsymbol{r}^\circ) = \mathbf{0}\,. \tag{27}$$

These equations express the fundamental asymmetry $\boldsymbol{E}^\circ \neq \mathbf{0}$, $\boldsymbol{H}^\circ = \mathbf{0}$ of the static EM field (caused by the existence of electric charges and nonexistence of magnetic charges). Let us now investigate the EM field of a charged particle which moves with arbitrary uniform velocity $\boldsymbol{v}$ in inertial frames $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with different ether velocities $\boldsymbol{w}$ relative to $\boldsymbol{v}$.

### *1. Charge Moving with Ether Velocity in Inertial Frame*

Consider a charge $e$ moving uniformly with the velocity $\boldsymbol{v} = \boldsymbol{w}$ of the ether flow in the inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ which travels relative to the ether frame $\Sigma^\circ$ with the velocity $\boldsymbol{u} = -\boldsymbol{w}$, Figure 1. In $\Sigma$, the ether streams with velocity $\boldsymbol{w} = -\boldsymbol{u} = \boldsymbol{v}$, i.e., the charge is at rest relative to the ether ($\Sigma^\circ$). Since $\boldsymbol{v} = \boldsymbol{w}$, the convective derivatives of the EM field of the uniformly moving charge vanish in $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$,

$$\partial/\partial t + \boldsymbol{v}\cdot\nabla = 0 \;\Rightarrow\; \partial/\partial t + \boldsymbol{w}\cdot\nabla = 0; \quad \boldsymbol{v} = \boldsymbol{w}. \tag{28}$$

Accordingly, the generalized Maxwell equations (23) to (26) reduce for the charge with uniform velocity $\boldsymbol{v} = \boldsymbol{w}$ to

$$\nabla \times \boldsymbol{H} = \boldsymbol{j} - \varrho\,\boldsymbol{w} = e\,\delta(\boldsymbol{r} - \boldsymbol{v}t)\,\boldsymbol{v} - e\,\delta(\boldsymbol{r} - \boldsymbol{v}t)\,\boldsymbol{w} = \mathbf{0}, \tag{29}$$

$$\nabla\cdot\boldsymbol{H} = 0 \tag{30}$$

and

$$\nabla \times \boldsymbol{E} = \mathbf{0}, \tag{31}$$

$$\nabla\cdot\varepsilon_0\boldsymbol{E} = e\,\delta(\boldsymbol{r} - \boldsymbol{v}t)\,. \tag{32}$$

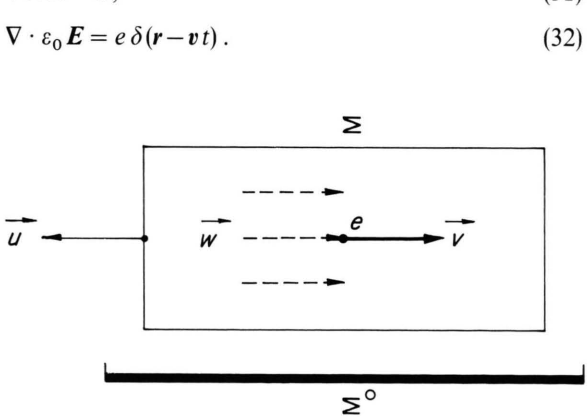


Fig. 1. Charge $e$ moving with ether velocity $\boldsymbol{v} = \boldsymbol{w}$ in $\Sigma$.

Equations (31)–(32) hold in $\Sigma(r, t, w)$ since $\boldsymbol{H} = \mathbf{0}$ by (29)–(30). Thus, the electric field of the uniformly moving charge is irrotational, $\boldsymbol{E} = -\nabla\Phi$, and derivable from the Poisson equation for its scalar potential $\Phi(r, z, t)$

$$\nabla^2\Phi = -(e/\varepsilon_0)\,[\delta(r)/2\pi r]\,\delta(z - vt), \tag{33}$$

where the coordinate system $(r, \phi, z)$ attached to $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ is chosen such that the $z$-axis is parallel to the charge velocity $\boldsymbol{v}$. Since the Green's function of (33) is $G(\boldsymbol{r}, \boldsymbol{r}') = 1/4\pi\,[(r-r')^2 + (z-z')^2]^{1/2}$, there follows

$$\Phi(r, z, t) = (e/4\pi\varepsilon_0) \int_0^\infty \int_{-\infty}^{+\infty} [(r-r')^2 + (z-z')^2]^{-1/2} \cdot [\delta(r')/2\pi r']\,\delta(z' - vt)\,2\pi r'\,\mathrm{d}r'\,\mathrm{d}z'. \tag{34}$$

Hence, the electric potential and field of the uniformly moving charge are in $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$:

$$\Phi(r, z, t) = (e/4\pi\varepsilon_0)/[r^2 + (z - vt)^2]^{1/2}, \tag{35}$$

$$\boldsymbol{E}(r, z, t) = (e/4\pi\varepsilon_0)\,\{r\,\boldsymbol{a}_r + (z - vt)\,\boldsymbol{a}_z\}/[r^2 + (z - vt)^2]^{3/2}, \tag{36}$$

whereas

$$\boldsymbol{A}(r, z, t) = \mathbf{0}, \quad \boldsymbol{H}(r, z, t) = \mathbf{0} \tag{37}$$

by (29) and (30), since the charge $e$ does not move relative to the ether in $\Sigma$ ($\boldsymbol{v} = \boldsymbol{w}$, Figure 2).

Equation (35) shows that the equipotential surfaces are given by $r^2 + (z - vt)^2 = \text{const} > 0$,. i.e. these are spherical surfaces $r = \text{const}$ centered about the instantaneous position $z = vt$ of the charge. Thus, the Coulomb field configuration is not contracted, since the charge moving with the velocity $\boldsymbol{v} = \boldsymbol{w}$ experiences no ether flow.

Equation (37) indicates a more remarkable result: A charge moving with a velocity $\boldsymbol{v}$ in an inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ has no magnetic fields if the charge does not move relative to the ether ($\Sigma^\circ$), $\boldsymbol{v} = \boldsymbol{w}$. As will be shown quite generally, magnetic field occur if the charge moves relative to the ether. Hence, magnetic fields are excitations of the ether produced by charge motion relative to the ether.

According to the STR [1] (in which the charge velocity $\boldsymbol{v}$ has no absolute but only "relative" meaning), the magnetic field of a uniformly moving charge is always $\boldsymbol{H} = \varepsilon_0\,\boldsymbol{v} \times \boldsymbol{E}$ in any inertial frame $\Sigma$. Thus, the Galilei covariant Maxwell equations show that the STR equation $\boldsymbol{H} = \varepsilon_0\,\boldsymbol{v} \times \boldsymbol{E}$ is inapplicable, if the charge does not move relative to the ether, $\boldsymbol{v} = \boldsymbol{w}$.

At present, no comparison with experiments can be made, since the EM field of individual charges (at rest

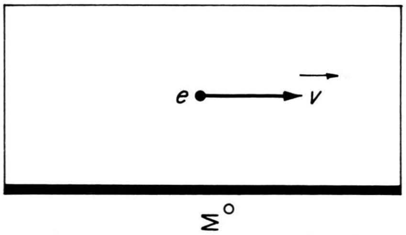


Fig. 2. Charge $e$ moving with arbitrary velocity $\boldsymbol{v}$ in $\Sigma^\circ$ ($\boldsymbol{w}=\mathbf{0}$).

in $\Sigma^\circ$) has not been measured in inertial frames $\Sigma$ where the charge velocity is relativistic, $|\boldsymbol{v}|<c_0$. For non-relativistic charge velocities, $|\boldsymbol{v}|\ll c_0$, the STR field $\boldsymbol{H}=\varepsilon_0\boldsymbol{v}\times\boldsymbol{E}\cong\mathbf{0}$ is relativistically small and agrees approximately with the Galilean field $\boldsymbol{H}=\mathbf{0}$ for $\boldsymbol{v}=\boldsymbol{w}$.

## 2. Charge Moving in Ether Frame

Consider a charge $e$ moving with an arbitrary constant velocity $\boldsymbol{v}$ in the ether rest frame $\Sigma^\circ(\boldsymbol{r},t,\mathbf{0})$ with $\boldsymbol{w}\equiv\mathbf{0}$, Fig. 2 (the ether superscript "$\circ$" is omitted on all variables since no confusion is possible). By (5) and (6), the EM potentials $\boldsymbol{A}=A(\boldsymbol{r},t)\,\boldsymbol{a}_z$ and $\Phi(\boldsymbol{r},t)$ of the charge in uniform motion $\boldsymbol{v}$ are determined by the wave equations of the inertial frame $\Sigma^\circ$:

$$\nabla^2\boldsymbol{A}-c_0^{-2}\,\partial^2\boldsymbol{A}/\partial t^2=-\mu_0\,e\,[\delta(r)/2\pi r]\,\delta(z-vt)\,\boldsymbol{v}, \quad (38)$$

$$\nabla^2\Phi-c_0^{-2}\,\partial^2\Phi/\partial t^2=-(e/\varepsilon_0)\,[\delta(r)/2\pi r]\,\delta(z-vt), \quad (39)$$

where the coordinate system $(r,\phi,z)$ is chosen with the $z$-axis parallel to the charge velocity $\boldsymbol{v}=v\,\boldsymbol{a}_z$ (Figure 2). Comparison of (38) and (39) shows that the vector potential is given in terms of the scalar potential,

$$\boldsymbol{A}(r,z,t)=\mu_0\,\varepsilon_0\,\boldsymbol{v}\,\Phi(r,z,t). \quad (40)$$

In an inertial frame $\Sigma_v$ attached to the uniformly moving charge, the EM field is time-independent. Hence

$$\partial/\partial t+\boldsymbol{v}\cdot\nabla=0,\quad \partial^2/\partial t^2=v^2\,\partial^2/\partial z^2. \quad (41)$$

Equation (41) reduces the wave equation (39) to the Poisson equation,

$$[r^{-1}\partial(r\,\partial/\partial r)/\partial r+\partial^2/\partial\zeta^2]\,\Phi$$
$$=-(e/\varepsilon_0)\,[\delta(r)/2\pi r]\,\delta(\sqrt{1-v^2/c_0^2}\,\zeta-vt), \quad (42)$$

where

$$\zeta=z/(1-v^2/c_0^2)^{1/2} \quad (43)$$

is a "dilated" axial coordinate. Since the Green's function of (42) is $G(\boldsymbol{r},\boldsymbol{r}')=1/4\pi\,[(r-r')^2+(\zeta-\zeta')^2]^{1/2}$, its solution is

$$\Phi(r,\zeta,t)=(e/4\pi\varepsilon_0)\int_0^\infty\int_{-\infty}^{+\infty}[(r-r')^2+(\zeta-\zeta')^2]^{-1/2}$$
$$\cdot\,[\delta(r')/2\pi r']\,\delta(\sqrt{1-v^2/c_0^2}\,\zeta'-vt)\,2\pi r'\,\mathrm{d}r'\,\mathrm{d}\zeta'. \quad (44)$$

Thus, under consideration of (40), the EM potentials of the uniformly moving charge in the ether frame $\Sigma^\circ$ are found as

$$\Phi(r,z,t)=(e/4\pi\varepsilon_0)/[(1-v^2/c_0^2)\,r^2+(z-vt)^2]^{1/2}, \quad (45)$$

$$\boldsymbol{A}(r,z,t)=(\mu_0\,e\,\boldsymbol{v}/4\pi)/[(1-v^2/c_0^2)\,r^2+(z-vt)^2]^{1/2} \quad (46)$$

with

$$\boldsymbol{E}(r,z,t)=(e/4\pi\varepsilon_0)(1-v^2/c_0^2) \quad (47)$$
$$\cdot\,\{r\,\boldsymbol{a}_r+(z-vt)\,\boldsymbol{a}_z\}/[(1-v^2/c_0^2)\,r^2+(z-vt)^2]^{3/2},$$

$$\boldsymbol{H}(r,z,t) \quad (48)$$
$$=(e\,v/4\pi)\,(1-v^2/c_0^2)\,r\,\boldsymbol{a}_\phi/[(1-v^2/c_0^2)\,r^2+(z-vt)^2]^{3/2}$$

the associated EM fields in $\Sigma^\circ$. Comparison of (47) and (48) reveals the interrelation between the electric and magnetic fields ($\boldsymbol{v}$ is the absolute charge velocity relative to the ether, $\Sigma_0$),

$$\boldsymbol{H}=\varepsilon_0\,\boldsymbol{v}\times\boldsymbol{E}. \quad (49)$$

Equation (47) indicates that the electric field $\boldsymbol{E}(r,z,t)$ points radially away from the source point $\boldsymbol{r}_e=(0,0,vt)$ of the charge ($e$) to the field point $\boldsymbol{r}=(r,0,z)$. The longitudinal field component along the path of motion ($z=vt$, $r=0$) of the charge,

$$E_z(0,z,t)=(e/4\pi\varepsilon_0)(1-v^2/c_0^2)(z-vt)/|z-vt|^3, \quad (50)$$

is reduced by the factor $(1-v^2/c_0^2)$ behind ($z<vt$) and ahead ($z>vt$) of the charge, with $E_z(0,z,t)\to 0$ for $v\to c_0$. The field component at right angles ($z=vt$) to the line of motion of the charge,

$$E_r(r,vt,t)=(e/4\pi\varepsilon_0)/r^2(1-v^2/c_0^2)^{1/2}, \quad (51)$$

is increased by the factor $1/(1-v^2/c_0^2)^{1/2}$. This deformation of the Coulomb field is also seen from the equipotential surfaces of (45),

$$r^2+[(z-vt)/(1-v^2/c_0^2)^{1/2}]^2=\text{const}>0, \quad (52)$$

which represent ellipsoids of revolution with the axis in the longitudinal direction ($z$) contracted by the factor $(1-v^2/c_0^2)^{1/2}$. For $v\to c_0$, the ellipsoid become "flat discs" in the plane $z=vt$. Note that the solutions (45)–(46) exhibit no wave fronts (discontinuities) for charge velocities $v<c_0$.

The longitudinal contraction of the equipotential surfaces of the Coulomb field of electrons and nuclei

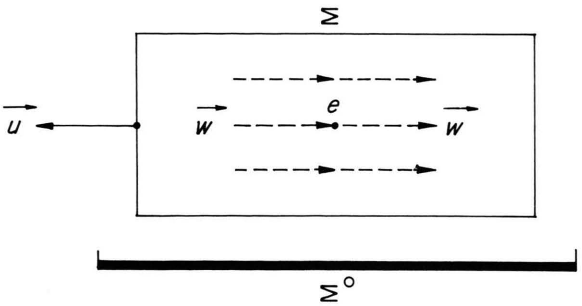


Fig. 3. Charge $e$ at rest in $\Sigma$ with ether flow $\boldsymbol{w}$.

is the physical reason for the length contraction of bodies in absolute motion $\boldsymbol{v}$ relative to the ether [3, 10]. The longitudinal "compression" of the Coulomb equipotential surfaces of a charge is readily understandable in the inertial frame $\Sigma_v$ co-moving with the charge, as a convection effect by the ether flow $\boldsymbol{w}=-\boldsymbol{v}$.

By (49), the magnetic field of the charge in absolute motion $\boldsymbol{v}$ relative to $\Sigma^\circ$ is $\boldsymbol{H}=\varepsilon_0\,\boldsymbol{v}\times\boldsymbol{E}$ in the ether rest frame $\Sigma^\circ$. Hence, the "general" STR equation $\boldsymbol{H}=\varepsilon_0\,\boldsymbol{v}\times\boldsymbol{E}$ is valid in the ether frame. As seen from Case 1 ($v=\boldsymbol{w}$ in $\Sigma$), the STR equation $\boldsymbol{H}=\varepsilon_0\,\boldsymbol{v}\times\boldsymbol{E}$ does not hold in every inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$.

### 3. Charge Resting in Inertial Frame with Ether Flow

Consider a charge $e$ at rest in the origin $\boldsymbol{r}=\boldsymbol{0}$ of an inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with ether flow $\boldsymbol{w}$, Figure 3. In this case, the charge moves with velocity $\boldsymbol{v}^\circ=-\boldsymbol{w}$ relative to the ether ($\Sigma^\circ$). In this situation, we expect the interesting result that the charge at rest in $\Sigma$ has not only a Coulomb field $\boldsymbol{E}(\boldsymbol{r})$ but also a small stationary magnetic flux density of order $B(\boldsymbol{r})\sim|\boldsymbol{w}\times\boldsymbol{E}|/c_0^2$ induced by the ether flow $\boldsymbol{w}$ transverse to the Coulomb field.

In the inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with ether flow $\boldsymbol{w}$, a charge $e$ at rest in the origin, $\boldsymbol{r}=\boldsymbol{0}$ (Fig. 3), is the source of $t$-independent EM potentials, which are determined by (5) and (6), with $\varrho(\boldsymbol{r})=e\,\delta(\boldsymbol{r})$,

$$[\mu_0\varepsilon_0(\boldsymbol{w}\cdot\nabla)^2-\nabla^2]\,\boldsymbol{A}=-\mu_0\,\varrho\,\boldsymbol{w}, \tag{53}$$

$$[\mu_0\varepsilon_0(\boldsymbol{w}\cdot\nabla)^2-\nabla^2](\Phi-\boldsymbol{w}\cdot\boldsymbol{A})=\varrho/\varepsilon_0, \tag{54}$$

where

$$[\mu_0\varepsilon_0(\boldsymbol{w}\cdot\nabla)^2]\,\Phi=(1-w^2/c_0^2)\,\varrho/\varepsilon_0, \tag{55}$$

$$\boldsymbol{A}(r,z)=-\mu_0\varepsilon_0\,\boldsymbol{w}\,\Phi(r,z)/(1-w^2/c_0^2) \tag{56}$$

by elimination respectively comparison. Obviously, $\boldsymbol{A}(\boldsymbol{r})$ is parallel to $\boldsymbol{w}$.

In a cylindrical coordinate system $(r, \phi, z)$ with the $z$-axis in the direction of $\boldsymbol{w}$, (55) becomes

$$[r^{-1}\partial(r\,\partial/\partial r)/\partial r+\partial^2/\partial\zeta^2]\,\Phi = -(1-w^2/c_0^2)(e/\varepsilon_0)\,[\delta(r)/2\pi r]\,\delta(\sqrt{1-w^2/c_0^2}\,\zeta), \tag{57}$$

where

$$\zeta=z/(1-w^2/c_0^2)^{1/2}. \tag{58}$$

The solution of this Poisson equation is analogous to (44), and gives, under consideration of (56), the EM potentials:

$$\Phi(r,z)=(e/4\pi\varepsilon_0)(1-w^2/c_0^2)/[(1-w^2/c_0^2)\,r^2+z^2]^{1/2}, \tag{59}$$

$$\boldsymbol{A}(r,z)=-(\mu_0\,e\,\boldsymbol{w}/4\pi)/[(1-w^2/c_0^2)\,r^2+z^2]^{1/2} \tag{60}$$

with

$$\boldsymbol{E}(r,z)=(e/4\pi\varepsilon_0)(1-w^2/c_0^2)\cdot\{(1-w^2/c_0^2)\,r\,\boldsymbol{a}_r+z\,\boldsymbol{a}_z\}/[(1-w^2/c_0^2)\,r^2+z^2]^{3/2}, \tag{61}$$

$$\boldsymbol{H}(r,z)=-(e\,w/4\pi)(1-w^2/c_0^2)\,r\,\boldsymbol{a}_\phi/[(1-w^2/c_0^2)\,r^2+z^2]^{3/2} \tag{62}$$

the EM field of the charge $e$ resting at $r=0$ in the ether flow $\boldsymbol{w}$. By (61) and (62), the EM fields are interrelated through

$$\boldsymbol{H}=-\varepsilon_0\,\boldsymbol{w}\times\boldsymbol{E}/(1-w^2/c_0^2). \tag{63}$$

By (61), the electric field is not radial in the ether flow, since $E_z/E_r=z/r(1-w^2/c_0^2)\neq z/r$. In particular, $E_z/E_r\to\infty$ for $w\to c_0$. Thus, the ether flow $\boldsymbol{w}$ deforms the electric field configuration by convection.

The electric field component parallel to the ether flow $\boldsymbol{w}$ along the ray $r=0$ in front ($z>0$) and behind ($z<0$) the charge at $r=0$, $z=0$,

$$E_z(0,z)=(e/4\pi\varepsilon_0)(1-w^2/c_0^2)\,z/|z|^3, \tag{64}$$

is reduced by the ether flow factor $(1-w^2/c_0^2)$, with $E_z(0,z)\to 0$ for $w\to c_0$. The field component perpendicular to the ether flow $\boldsymbol{w}$ and in the plane $z=0$ of the charge,

$$E_r(r,0)=(e/4\pi\varepsilon_0)(1-w^2/c_0^2)^{1/2}/r^2, \tag{65}$$

decreases with increasing ether speed $w$, too, with $E_r(r,0)\to 0$ for $w\to c_0$. On the other hand, (62) shows that the magnetic field in the charge plane $z=0$,

$$H_\phi(r,0)=-(e\,w/4\pi)\,r^{-2}/(1-w^2/c_0^2)^{1/2}, \tag{66}$$

increases with the ether speed $w$, with $-H_\phi(r,0)\to\infty$ for $w\to c_0$. But, $H_\phi(r,z)\to 0$ in front ($z>0$) and behind ($z<0$) the charge for $w\to c_0$ by (62).

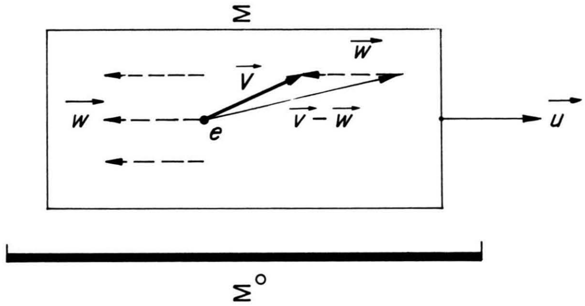


Fig. 4. Charge $e$ moving with arbitrary velocity $\boldsymbol{v}$ in $\Sigma$ with ether flow $\boldsymbol{w}$.

Accordingly, a magnetic field is excited not only by a charge moving relative to the ether, but also by an ether flow $\boldsymbol{w}$ relative to a charge at rest. Equation (63) explains the magnetic field of a charge at rest as a magnetic induction by the ether flow across the electric flux density $\boldsymbol{D}=\varepsilon_0 \boldsymbol{E}$.

On the earth, the ether velocity has been measured to be $w \approx 3\times 10^5$ m/s, with $w/c_0 \approx 10^{-3}$, and $1-w^2/c_0^2 \approx 1-10^{-6} \cong 1$. For this reason, the interesting effects of electric field reduction and magnetic field excitation by the ether flow $\boldsymbol{w}$ across a resting charge are probably too small to be observed under terrestrial conditions.

### 4. Charge Moving in Arbitrary Inertial Frame

Let us now regard the general case of a point charge $e$ moving with uniform velocity $\boldsymbol{v} \neq \boldsymbol{w}$ in an inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ which travels with velocity $\boldsymbol{u}$ relative to the ether frame $\Sigma^\circ(\boldsymbol{w}=-\boldsymbol{u})$, Figure 4. By (5) and (6), the EM potentials of the charge are determined by the coupled wave equations of $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$

$$[\mu_0 \varepsilon_0 (\partial/\partial t + \boldsymbol{w}\cdot\nabla)^2 - \nabla^2]\, \boldsymbol{A} = \mu_0\, \varrho(\boldsymbol{v}-\boldsymbol{w}), \tag{67}$$

$$[\mu_0 \varepsilon_0 (\partial/\partial t + \boldsymbol{w}\cdot\nabla)^2 - \nabla^2](\Phi - \boldsymbol{w}\cdot\boldsymbol{A}) = \varrho/\varepsilon_0, \tag{68}$$

where

$$\varrho(\boldsymbol{r}, t) = e\,\delta(\boldsymbol{r}-\boldsymbol{v}t), \quad \boldsymbol{j} = e\,\delta(\boldsymbol{r}-\boldsymbol{v}t)\,\boldsymbol{v}. \tag{69}$$

In this form, (67)–(68) are not readily solvable owing to the mixed derivatives "$\boldsymbol{w}\cdot\nabla\partial/\partial t$" [24]. For this reason, (67) and (68) are transformed by means of the Galilei transformations,

$$\boldsymbol{A}(\boldsymbol{r}, t) = \boldsymbol{A}^\circ(\boldsymbol{r}^\circ, t^\circ), \quad \varrho(\boldsymbol{r}, t) = \varrho^\circ(\boldsymbol{r}^\circ, t^\circ), \tag{70}$$

$$\Phi(\boldsymbol{r}, t) - \boldsymbol{w}\cdot\boldsymbol{A}(\boldsymbol{r}, t) = \Phi^\circ(\boldsymbol{r}^\circ, t^\circ), \tag{71}$$

$$\boldsymbol{v} - \boldsymbol{w} = \boldsymbol{v}^0 \tag{72}$$

[see Eqs. (12)–(14)] to the ether frame $\Sigma^\circ(\boldsymbol{r}^\circ, t^\circ, \boldsymbol{0})$, in which the mixed derivatives do no longer occur [24],

$$[\mu_0 \varepsilon_0\, \partial^2/\partial t^{\circ 2} - \nabla^{\circ 2}]\, \boldsymbol{A}^\circ = \mu_0\, e\,\delta(\boldsymbol{r}^\circ - \boldsymbol{v}^\circ t^\circ)\, \boldsymbol{v}^\circ, \tag{73}$$

$$[\mu_0 \varepsilon_0\, \partial^2/\partial t^{\circ 2} - \nabla^{\circ 2}]\, \Phi^\circ = (e/\varepsilon_0)\,\delta(\boldsymbol{r}^\circ - \boldsymbol{v}^\circ t^\circ), \tag{74}$$

where

$$\boldsymbol{v}^\circ = \boldsymbol{v} + \boldsymbol{u} \tag{75}$$

and

$$\boldsymbol{A}^\circ(\boldsymbol{r}^\circ, t^\circ) = \mu_0 \varepsilon_0\, \boldsymbol{v}^\circ\, \Phi^\circ(\boldsymbol{r}^\circ, t^\circ) \tag{76}$$

by comparison of (73) and (74). By (76), the solution for $\Phi(\boldsymbol{r}^\circ, t^\circ)$ gives also the solution $\boldsymbol{A}^\circ(\boldsymbol{r}^\circ, t^\circ)$.

Both (67)–(68) and (73)–(74) indicate that the EM field of the moving charge has no axial symmetry with respect to the direction of the charge velocity $\boldsymbol{v}$, but is axially symmetric with respect to the direction of the velocity $\boldsymbol{v}^\circ = \boldsymbol{v} - \boldsymbol{w}$ of the charge in the ether frame $\Sigma^\circ$. Once again, we recognize the EM field as an excitation of the ether.

Choosing cylindrical coordinates $(r^\circ, \phi^\circ, z^\circ)$ with the $z^\circ$-axis parallel to $\boldsymbol{v}^\circ$, (73) and (74) are solved as in Case 2, with the result

$$\Phi^\circ(r^\circ, z^\circ, t^\circ) = (e/4\pi\varepsilon_0)/[(1-v^{\circ 2}/c_0^2)\, r^{\circ 2} + (z^\circ - v^\circ t^\circ)^2]^{1/2}, \tag{77}$$

$$\boldsymbol{A}^\circ(r^\circ, z^\circ, t^\circ) = (\mu_0 e \boldsymbol{v}^\circ/4\pi)/[(1-v^{\circ 2}/c_0^2)\, r^{\circ 2} + (z^\circ - v^\circ t^\circ)^2]^{1/2}. \tag{78}$$

The Galilei transformations $\boldsymbol{A}(\boldsymbol{r}, t) = \boldsymbol{A}^\circ(\boldsymbol{r}^\circ, t^\circ)$ and $\Phi(\boldsymbol{r}, t) = \Phi^\circ(\boldsymbol{r}^\circ, t^\circ) + \boldsymbol{w}\cdot\boldsymbol{A}^\circ(\boldsymbol{r}^\circ, t^\circ)$ give with $(\boldsymbol{v}-\boldsymbol{w} \parallel \boldsymbol{a}_z)$

$$\begin{aligned} r^{\circ 2} &= (x+u_x t)^2 + (y+u_y t)^2 \\ &= (x-w_x t)^2 + (y-w_y t)^2, \end{aligned} \tag{79}$$

$$z^\circ - v^\circ t^\circ = (z^\circ - u_z t) - v_z t = z - v_z t,$$

$$w_x = v_x, \quad w_y = v_y \tag{80}$$

for a coordinate system $(x, y, z, t)$ attached to $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ and the $z$-axis chosen parallel $\boldsymbol{v}-\boldsymbol{w}=\boldsymbol{v}^\circ$, the EM potentials in $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$

$$\begin{aligned} \Phi(x, y, z, t) &= (e/4\pi\varepsilon_0)[1 + \boldsymbol{w}\cdot(\boldsymbol{v}-\boldsymbol{w})/c_0^2]/[(1-(\boldsymbol{v}-\boldsymbol{w})^2/c_0^2) \\ &\quad \cdot \{(x-v_x t)^2 + (y-v_y t)^2\} + (z-v_z t)^2]^{1/2}, \end{aligned} \tag{81}$$

$$\begin{aligned} \boldsymbol{A}(x, y, z, t) &= [\mu_0 e(\boldsymbol{v}-\boldsymbol{w})/4\pi]/[(1-(\boldsymbol{v}-\boldsymbol{w})^2/c_0^2) \\ &\quad \cdot \{(x-v_x t)^2 + (y-v_y t)^2\} + (z-v_z t)^2]^{1/2}. \end{aligned} \tag{82}$$

In $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$, the EM field of the charge moving $(\boldsymbol{v})$ uniformly in the ether flow $\boldsymbol{w}$ is obtained by means of the Galilei covariant relations (7) from (81)–(82):

$$E(x, y, z, t) = (e/4\pi\varepsilon_0)[1-(v-w)^2/c_0^2] \cdot \{[1+w\cdot(v-w)/c_0^2][(x-v_x t)a_x+(y-v_y t)a_y] + [(z-v_z t)-(v_z-w_z) \cdot (v_x(x-v_x t)+v_y(y-v_y t))/c_0^2]a_z\}/[(1-(v-w)^2/c_0^2) \cdot \{(x-v_x t)^2+(y-v_y t)^2\}+(z-v_z t)^2]^{3/2}, \quad (83)$$

$$H(x, y, z, t) = [e(v_z-w_z)/4\pi][1-(v-w)^2/c_0^2] \cdot \{-(y-v_y t)a_x+(x-v_x t)a_y\}/[(1-(v-w)^2/c_0^2) \cdot \{(x-v_x t)^2+(y-v_y t)^2\}+(z-v_z t)^2]^{3/2}. \quad (84)$$

Comparison shows that the EM fields of the uniformly moving ($v$) charge are interrelated for arbitrary ether velocities $w$ by

$$H = \varepsilon_0(v-w)\times E/[1+w\cdot(v-w)/c_0^2]. \quad (85)$$

The solutions (81)–(84) are real throughout the entire space $|r| \leqq \infty$ if $|v-w| < c_0$, whereas they are real only behind and imaginary ahead of an advancing wave front if $|v-w| > c_0$. Such discontinuous solutions are typical for hyperbolic equations [24].

If $|v-w| < c_0$, the EM fields are continuous and the equipotential surfaces [see (81)] are the oblate ellipsoids of revolution

$$(x-v_x t)^2+(y-v_y t)^2+(z-v_z t)^2/[1-(v-w)^2/c_0^2] = \text{const} > 0. \quad (86)$$

The ellipsoid axes in the $z$-direction (parallel to $v-w$) are contracted by the factor $[1-(v-w)^2/c_0^2]^{1/2}$.

If $|v-w| > c_0$, the EM fields are discontinuous and the equipotential surfaces [see (81)] are the hyperboloids of revolution,

$$(x-v_x t)^2+(y-v_y t)^2-(z-v_z t)^2/\gamma^2 = \text{const} < 0 \quad (87)$$

about the axis $x = v_x t$, $y = v_y t$, and behind the wave front. The wave front is the cone of revolution with vertex at $r = v t$,

$$v_z t - z = \gamma[(x-v_x t)^2+(y-v_y t)^2]^{1/2}, \quad (88)$$

where

$$\gamma = [(v-w)^2/c_0^2-1]^{1/2} > 0. \quad (89)$$

The above solutions for arbitrary velocity fields $v = \{v_x, v_y, v_z\}$ and $w = \{w_x, w_y, w_z\}$ are geometrically complicated. For this reason, let us discuss in more detail these solutions for the practically important case of parallel charge and ether velocities, $v = v a_z$ and $w = w a_z$. In cylindrical coordinates $(r, \phi, z)$, (81)–(84) become for $v \parallel w \parallel a_z$:

$$\Phi(r, z, t) = (e/4\pi\varepsilon_0) \cdot [1+w\cdot(v-w/c_0^2]/[(1-(v-w)^2/c_0^2)r^2+(z-vt)^2]^{1/2}, \quad (90)$$

$$A(r, z, t) = [\mu_0 e(v-w)/4\pi]/[(1-(v-w)^2/c_0^2)r^2+(z-vt)^2]^{1/2} \quad (91)$$

and

$$E(r, z, t) = (e/4\pi\varepsilon_0)[1-(v-w)^2/c_0^2] \cdot \{[1+w\cdot(v-w)/c_0^2]r a_r + (z-vt)a_z\}/[(1-(v-w)^2/c_0^2)r^2+(z-vt)^2]^{3/2}, \quad (92)$$

$$H(r, z, t) = [\mu_0 e(v-w)/4\pi][1-(v-w)^2/c_0^2]r a_\phi / [(1-(v-w)^2/c_0^2)r^2+(z-vt)^2]^{3/2}. \quad (93)$$

Comparison shows that the EM fields of the uniformly moving charge ($v$) are interrelated for arbitrary ether velocities $w$ by (85). The solutions (90)–(93) are real throughout the entire space $|r| \leqq \infty$ if $|v-w| < c_0$, whereas they are real only behind and imaginary ahead of an advancing wave front if $|v-w| > c_0$. Note that $v-w$ is the Galilean relative velocity.

*Solutions for* $|v-w| < c_0$. In this case, the transient EM fields are continuous and exist throughout the entire space $|r| \leqq \infty$. The equipotential surfaces [see (90)] are the oblate ellipsoids of revolution centered about the position ($r = 0$, $z = vt$) of the charge,

$$r^2+(z-vt)^2/[1-(v-w)^2/c_0^2] = \text{const} > 0. \quad (94)$$

The ellipsoid axes in the $z$-direction (parallel to $v-w$) are contracted by the factor $[1-(v-w)^2/c_0^2]^{1/2}$.

*Solutions for* $|v-w| > c_0$. In this case, the transient EM fields exist only behind a wave front at which the fields drop discontinuously to zero. The equipotential surfaces [see (90)] are the hyperboloids of revolution inside the wave front cone (Figure 5),

$$r^2-(z-vt)^2/\gamma^2 = \text{const} < 0, \quad (95)$$

about the $z$-axis (parallel to $v-w$). Equation (95) gives $r = \pm(z-vt)/\gamma$ for const $= 0$, i.e., the EM wave front is the cone of revolution about the $z$-axis,

$$vt - z = \gamma r \quad (96)$$

with

$$\operatorname{tg}\theta = r/(vt-z) = \gamma^{-1} \quad (97)$$

the relation for the half-angle $\theta$ of the cone (Figure 5). The conical wave front (96) is the envelope of spherical EM waves originating from the "past" positions ($r = 0$,

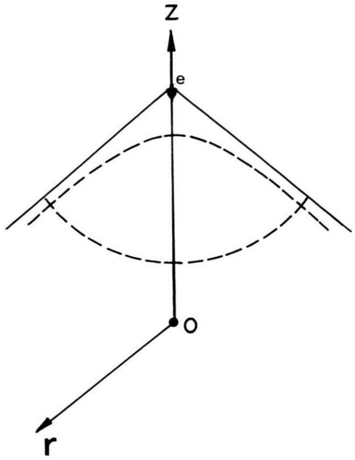


Fig. 5. Mach cone of EM shock wave in ether (vacuum Cerenkov effect).

$z=vt$) of the charge. At time $t>0$, the charge $e$ is at $z=vt$ (vertex of cone, Figure 5).

Thus, the EM potentials in (90)–(91) are wave fields which are discontinuous at the conical wave front $z=vt-\gamma r$:

$$\begin{aligned}\Phi(r,z,t) &= (e/4\pi\varepsilon_0)\,[1+\boldsymbol{w}\cdot(\boldsymbol{v}-\boldsymbol{w})/c_0^2]/[(vt-z)^2-\gamma^2 r^2]^{1/2},\\ &\qquad vt-z>\gamma r,\\ &= 0,\quad vt-z<\gamma r,\end{aligned} \tag{98}$$

$$\begin{aligned}\boldsymbol{A}(r,z,t) &= [\mu_0\, e(\boldsymbol{v}-\boldsymbol{w})/4\pi]/[vt-z)^2-\gamma^2 r^2]^{1/2},\\ &\qquad vt-z>\gamma r,\\ &= \boldsymbol{0},\quad vt-z<\gamma r.\end{aligned} \tag{99}$$

In a similar way, (92)–(93) for the electric and magnetic fields are restricted to the spatial region behind the wave front $z<vt-\gamma r$:

$$\begin{aligned}\boldsymbol{E}(r,z,t) &= (e/4\pi\varepsilon_0)\,[1-(\boldsymbol{v}-\boldsymbol{w})^2/c_0^2]\\ &\quad\cdot\{[1+\boldsymbol{w}\cdot(\boldsymbol{v}-\boldsymbol{w})/c_0^2]\,r\,\boldsymbol{a}_r+(z-vt)\,\boldsymbol{a}_z\}/\\ &\quad[(vt-z)^2-\gamma^2 r^2]^{3/2},\quad vt-z>\gamma r,\\ &= \boldsymbol{0},\qquad\qquad vt-z<\gamma r,\end{aligned} \tag{100}$$

$$\begin{aligned}\boldsymbol{H}(r,z,t) &= [e(v-w)/4\pi]\,[1-(\boldsymbol{v}-\boldsymbol{w})^2/c_0^2]\,r\,\boldsymbol{a}_\phi/\\ &\quad[(vt-z)^2-\gamma^2 r^2]^{3/2},\quad vt-z>\gamma r,\\ &= \boldsymbol{0},\qquad\qquad vt-z<\gamma r.\end{aligned} \tag{101}$$

The singular EM field discontinuity at the shock front, $z=vt-\gamma r$, can be shown to be caused by the point charge model used.

Equations (83) and (84) indicate that a charge $e$, e.g. an electron, moving at a speed $\boldsymbol{v}$ emits EM waves (radiation) if its velocity relative to the ether is such that $|\boldsymbol{v}-\boldsymbol{w}|>c_0$. Accordingly, our theory predicts the emission of Cerenkov radiation by an electron moving in vacuum ($\varepsilon=\varepsilon_0$, $\mu=\mu_0$) if its (Galilean) velocity $\boldsymbol{v}-\boldsymbol{w}$ relative to the ether exceeds in magnitude the speed of light $c_0$.

The optimum experimental arrangement for the observation of the ether Cerenkov effect is an electron beam with a velocity $\boldsymbol{v}$, which is antiparallel to the terrestrial ether velocity $w\sim 3\times 10^5$ m/s. In this case, (100) and (101) yield for the emission of radiation by a relativistic electron beam the condition $|\boldsymbol{v}|>c_0-|\boldsymbol{w}|\equiv v_{cr}$. With $w\cong 3\times 10^5$ m/s at the earth, the required beam speed would be $|\boldsymbol{v}|>2.997925\times 10^8.\,(1-10^{-3})$ m/s.

The general condition for the excitation of the discontinuous EM wave solutions (83)–(84) is $|\boldsymbol{v}-\boldsymbol{w}|>c_0$, i.e., the charge has to move with a (Galilean) velocity $\boldsymbol{v}-\boldsymbol{w}$ relative to the ether ($\boldsymbol{w}$), which exceeds the characteristic wave speed $c_0$ of the ether. Accordingly, the discontinuous EM waves (83)–(84) represent shock waves in the ether. The reality of these solutions for $|\boldsymbol{v}-\boldsymbol{w}|>c_0$ shows that the EM field equations do not exclude such superluminal Galilean velocities.

## Asymmetry of EM Field

The fascination by the beauty of symmetry has played an ominous role in the development of physics. E.g., in spite of the experimental evidence provided by Kepler, his and Galilei's contemporaries continued to insist that the planets move in perfect circles about the sun. In our times, we confide in the equally divine symmetries of the Lorentz covariance of the laws of physics, which were also supposed to be invariant against inversion of coordinates. The latter symmetry collapsed in 1965 when Lee and Yang showed that parity is not conserved in the decay of radioactive nuclei, in which neutrinos or antineutrinos participate. It is remarkable that the neutrino $\nu$ with right-handed spin and the antineutrino $\bar{\nu}$ with left-handed spin (Fig. 6) can be understood as quasi-particles (excitations) of the ether [12, 26]. They permit no P-invariance due to their screw-structure.

The most beautiful (and even more incomprehensible) symmetry assumption is the relativity principle, according to which one and the same light signal ad-

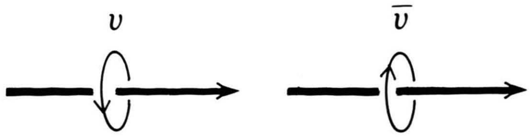


Fig. 6. Neutrino and antineutrino as quasi-particles of ether.

vances isotropically with the same velocity $c_0$ in all inertial frames [2, 3]! This symmetry is contained in the Lorentz transformations for (the space-time coordinates and) the EM fields, between the inertial frames $\Sigma$ and $\Sigma'$ [1, 2]:

$$E'_\perp = \varkappa(\boldsymbol{E}+\mu_0 \boldsymbol{u}\times \boldsymbol{H})_\perp, \quad E'_\parallel = E_\parallel,$$

$$H'_\perp = \varkappa(\boldsymbol{H}-\varepsilon_0 \boldsymbol{u}\times \boldsymbol{E})_\perp, \quad H'_\parallel = H_\parallel, \tag{102}$$

where $\boldsymbol{u}$ is the velocity of $\Sigma'$ relative to $\Sigma$, and $\varkappa=(1-u^2/c_0^2)^{-1/2}$. The symmetry of these equations is nearly perfect, except for a sign anti-symmetry (see Maxwell curl equations). The corresponding transformations (20)–(22) of the Galilei covariant EM field equations (23)–(26) show that the electric field changes whereas the magnetic field is invariant, in Galilei transformations $\Sigma \to \Sigma'$:

$$\boldsymbol{E}' = \boldsymbol{E}+\mu_0 \boldsymbol{u}\times\boldsymbol{H}, \quad \boldsymbol{H}'=\boldsymbol{H}. \tag{103}$$

Thus, the electric and magnetic fields do no longer transform in similar, but in qualitatively different ways in Galilei covariant electrodynamics. The relations (103) explain the performance of electric generators (conductors moving across magnetic fields) and the non-performance of magnetic generators (conductors moving across electric fields), respectively.

In discussing the EM fields of moving ($\boldsymbol{v}$) charges in inertial frames $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with different ether velocities $\boldsymbol{w}$, we have demonstrated that the STR holds in the ether frame $\Sigma^\circ$ (no ether flow, $\boldsymbol{w}^\circ \equiv \boldsymbol{0}$). Accordingly, the STR is approximately valid on the earth, where the ether velocity is negligible small, $|\boldsymbol{w}| \sim 3\times 10^{-5}$ m/s $\ll c_0$. In inertial frames with large ether velocities $w$ (e.g., distant galaxies) [27], the STR equation $\boldsymbol{H}=\varepsilon_0 \boldsymbol{v}\times\boldsymbol{E}$ (in which $\boldsymbol{v}$ is the velocity of the charge relative to the observer at the field point $\boldsymbol{r}, t$) has to be replaced by the general equation (85),

$$\boldsymbol{H} = K\varepsilon_0(\boldsymbol{v}-\boldsymbol{w})\times\boldsymbol{E}, \tag{104}$$

$$K = 1/[1+\boldsymbol{w}\cdot(\boldsymbol{v}-\boldsymbol{w})/c_0^2]. \tag{105}$$

In the ether rest frame $\Sigma^\circ$ ($\boldsymbol{w}\equiv\boldsymbol{0}$) we have $K=1$. There, (104) reduces only formally to the STR equation $\boldsymbol{H}=\varepsilon_0 \boldsymbol{v}\times\boldsymbol{E}$, since $\boldsymbol{v}$ in (104) and (105) is the absolute Galilean velocity.

The interrelation (105) between the magnetic and electric field of a moving ($\boldsymbol{v}$) charge in an arbitrary inertial frame $\Sigma(\boldsymbol{r}, t, \boldsymbol{w})$ with ether velocity $\boldsymbol{w}$ could have been guessed by dimensional reasoning, under consideration of the fact that the charge velocity $\boldsymbol{v}-\boldsymbol{w}$ relative to the ether is relevant in the excitation of the magnetic field. In this sense, let the factor $K$ in (105) be rederived by substituting the Ansatz (104) into the Galilei covariant field equations (23)–(26). Clearly, (26) is satisfied by (104) for any $0<K<\infty$,

$$\nabla\cdot\boldsymbol{H}/K = \varepsilon_0\nabla\cdot[(\boldsymbol{v}-\boldsymbol{w})\times\boldsymbol{E}]$$

$$= \mu_0\varepsilon_0\,\partial[(\boldsymbol{v}-\boldsymbol{w})\cdot\boldsymbol{H}]/\partial t = 0, \tag{106}$$

since $\nabla\times\boldsymbol{E} = -\mu_0\,\partial\boldsymbol{H}/\partial t$ by (23), where $\nabla\times(\boldsymbol{w}\times\boldsymbol{H}) = -\boldsymbol{w}\cdot\nabla\boldsymbol{H}$, and $\boldsymbol{H}\perp(\boldsymbol{v}-\boldsymbol{w})$ by (104). The curl of (104) yields, under consideration of (24),

$$\nabla\times\boldsymbol{H}/K = \varepsilon_0(\boldsymbol{v}-\boldsymbol{w})\,\nabla\cdot\boldsymbol{E} - \varepsilon_0(\boldsymbol{v}-\boldsymbol{w})\cdot\nabla\boldsymbol{E} \tag{107}$$

$$= \varrho(\boldsymbol{v}-\boldsymbol{w}) - \mu_0\varepsilon_0(\boldsymbol{v}-\boldsymbol{w})\,\nabla\cdot(\boldsymbol{w}\times\boldsymbol{H}) - \varepsilon_0(\boldsymbol{v}-\boldsymbol{w})\cdot\nabla\boldsymbol{E},$$

whence

$$\nabla\times\boldsymbol{H}[K^{-1}-\boldsymbol{w}\cdot(\boldsymbol{v}-\boldsymbol{w})/c_0^2]$$

$$= \varrho(\boldsymbol{v}-\boldsymbol{w}) + \varepsilon_0(\partial/\partial t+\boldsymbol{w}\cdot\nabla)(\boldsymbol{E}+\mu_0\,\boldsymbol{w}\times\boldsymbol{H}), \tag{108}$$

since $\boldsymbol{v}\cdot\nabla = -\partial/\partial t$ by (41) and $(\boldsymbol{v}-\boldsymbol{w})\times(\boldsymbol{w}\times\boldsymbol{H}) = -[(\boldsymbol{v}-\boldsymbol{w})\cdot\boldsymbol{w}]\,\boldsymbol{H}$. Equation (108) agrees with the EM field equation (25) if $[K^{-1}-\boldsymbol{w}\cdot(\boldsymbol{v}-\boldsymbol{w})/c_0^2]=1$, i.e., if $K$ is given by (105). This completes the derivation of (85) directly from the Galilei covariant EM field equations (23)–(26).

Equation (85) or (104) is Galilei covariant. This can be shown by means of the transformations in (22) and (103). Equations (104) and (105) give the interrelation of the magnetic and electric fields of a uniformly moving charges treated under 1)–4) as special cases.

**Case 1,**
$\boldsymbol{v}=\boldsymbol{w}$ in $\Sigma$: $K=1$, $\boldsymbol{H}=\boldsymbol{0}$, $\boldsymbol{E}\neq\boldsymbol{0}$. → The STR symmetry $\boldsymbol{H}=\varepsilon_0\boldsymbol{v}\times\boldsymbol{E}$ is inapplicable.

**Case 2,**
$\boldsymbol{v}\neq\boldsymbol{0}$, $\boldsymbol{w}\equiv\boldsymbol{0}$ in $\Sigma^\circ$: $K=1$, $\boldsymbol{H}=\varepsilon_0\boldsymbol{v}\times\boldsymbol{E}$. → The STR symmetry $\boldsymbol{H}=\varepsilon_0\boldsymbol{v}\times\boldsymbol{E}$ holds.

**Case 3,**
$\boldsymbol{v}=\boldsymbol{0}$, $\boldsymbol{w}\neq\boldsymbol{0}$ in $\Sigma$: $K=1/(1-w^2/c_0^2)$, $\boldsymbol{H}=-K\varepsilon_0\boldsymbol{w}\times\boldsymbol{E}$. → The STR symmetry $\boldsymbol{H}=\varepsilon_0\boldsymbol{v}\times\boldsymbol{E}=\boldsymbol{0}$ for $\boldsymbol{v}=\boldsymbol{0}$ is inapplicable.

**Case 4,**
$\boldsymbol{v} \neq \mathbf{0}$, $\boldsymbol{w} \neq \mathbf{0}$ in $\Sigma$: $K = 1/[1 + \boldsymbol{w} \cdot (\boldsymbol{v} - \boldsymbol{w})/c_0^2]$,
$\boldsymbol{H} = K \varepsilon_0 (\boldsymbol{v} - \boldsymbol{w}) \times \boldsymbol{E}$. $\rightarrow$ The STR symmetry $\boldsymbol{H} = \varepsilon_0 \boldsymbol{v} \times \boldsymbol{E}$ holds approximately if $|\boldsymbol{w}| \ll |\boldsymbol{v}| < c_0$.

The asymmetry of the EM field transformations follows directly from the asymmetry of the Galilei covariant EM field equations (23)–(24) versus (25)–(26). This nonsymmetry becomes more apparent if (23) is written in the form $\nabla \times \boldsymbol{E} = -\mu_0 \, \partial \boldsymbol{H}/\partial t$ (which renders its Galilei covariance less obvious). As explained earlier, the asymmetry of the Galilei covariant EM field equations and their transformation is caused by the existence of electric and the absence of magnetic charges.

In spite of continued high energy experiments, which have lead to the discovery of numerous new particles, there is no experimental evidence of the existence of magnetic charges.

## Conclusion

As an alternative to the formal kinematic STR, we have shown that electrodynamic phenomena can be understood by means of Galilei covariant EM field equations in which the velocity of the EM wave carrier (ether) $\boldsymbol{w}$ appears explicitly. In this theory, the velocity of a charge or a conductor is no longer "relative" to an arbitrary observer in an inertial frame, but represents an absolute velocity in an inertial frame, since the latter moves with an absolute velocity relative to the ether. Even within the context of the $L$-covariant Maxwell equations, one can show that the forces between charges and dipoles do not depend on the relative velocity of the interaction partners, but on their absolute velocities (this contradiction in the STR was first exposed by Builder [28, 29].

The advantage of the EM ether theory lies in high energy applications (electron and proton beams, atomic and nuclear systems, astrophysical systems, under high energy conditions). With regard to basic physics, the removal of the contradictions and singularities in relativistic quantum mechanics, quantum electrodynamics, and the general theory of relativity on a physical basis by means of the ether concept is remarkable [7–12]. In particular, Maxwell's equations, and the equations of quantum electrodynamics and the Dirac spinors can be derived by means of a microscopic ether model involving positive and negative mass Planckions [12]. Furthermore, the EM ether concept has lead to the prediction of new physical effects, such as the interrelation of length contraction and time dilation, the non-zero relaxation times for the change of the length of actual bodies and the rate of real clocks, and charge quantization as a result of circulation quantization of ether vortices [7–12].

The present investigation has resulted in a physical understanding of EM fields as excitations of the EM wave carrier of the vacuum, and further development of Galilei covariant electrodynamics [24, 25]. We have predicted EM shock waves and a Cerenkov effect in the vacuum ($\varepsilon = \varepsilon_0$, $\mu = \mu_0$) if superluminal Galilean velocities of charged particle beams relative to the ether are realizable, $|\boldsymbol{v} - \boldsymbol{w}| > c_0$. It can be shown that the spectral energy density of the Cerenkov radiation in vacuum is [26]

$$\mathrm{d}W/\mathrm{d}\omega = L(\mu_0 e^2/4\pi) \, |(\boldsymbol{v} - \boldsymbol{w})/v|^3 \, [1 - c_0^2/(\boldsymbol{v} - \boldsymbol{w})^2] \, \omega, \quad 0 \leqq \omega \leqq \omega_0,$$

where $\omega_0 = 2\pi c_0/(e^2/4\pi\varepsilon_0 m c_0^2)$ is the frequency cut-off due to the nonvanishing radius of the charged particle. Since $\mathrm{d}W/\mathrm{d}\omega \propto \omega$ increases with frequency $\omega$ and $\omega_0 \sim 10^{23}\,\mathrm{s}^{-1}$ for electrons, the experimental discovery of this Cerenkov radiation would require radiation detectors which are sensitive up to the $x$- and $\gamma$-regions of the EM spectrum.

Distant galaxies move with relativistic velocities $0.1\,c_0 < u < 0.9\,c_0$ as known from redshift measurements, and probably drag the ether along through gravitational interactions [27]. For this reason, the predicted ether Cerenkov effect might be observable within the quasi-inertial frames of distant galaxies when cosmic rays travel upstream this ether flow $\boldsymbol{w}$. Quite generally, the ether concept appears to be promising for the interpretation of high energy astrophysical phenomena, e.g., the redshift anomaly [24]. Under certain astrophysical conditions (magnetic stars, pulsars, black holes) also interesting high-energy ether flow effects are conceivable during compression of magnetic flux or radiation [24, 30–32]. *

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* *Note added in proof:* For the special case $\boldsymbol{w} = \mathbf{0}$ of the ether rest frame $\Sigma^{\circ}$, the vacuum Cerenkov effect was first predicted by A. Sommerfeld, Goett. Nachr. **99,** 363 (1904).

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