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NEO-HERTZIAN ELECTROMAGNETISM (II)

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The neo-Hertzian wave equation is solved for linear and for circular motions of the field detector. It is shown that propagation (wave) speed in this theory is c plus the average over the photon's propagation time of the component of detector velocity parallel to propagation direction. Possible crucial experiments to distinguish neo-Hertzian from Maxwellian theory are examined.

1. Radiation Convection : Introductory Heuristics

Equation numbering will continue consecutively from Part I of this paper [1]. Perhaps the most interesting departure from expectation implied by the Galilean-invariant Hertzian equations (22) or the more generally-invariant neo-Hertzian equations (29) is that the electromagnetic field detector or absorber, by its motion relative to the observer, is predicted to convect the radiation it absorbs. That is, motion relative to an observer of the absorber of a particular photon affects the propagation speed to be attributed to that photon by that observer. In a classical model, the effect (at least in one spatial dimension) is not unlike what would be expected if the photon detector carried "the ether" along with it. Such a model, applicable to Eq. (22), must be modified to refer to detector proper time, rather than to Newtonian t-time, to fit the neo-Hertzian case, Eq. (29).

Just such an effect of "radiation convection by the absorber" was previously predicted [2] on purely kinematic grounds, as a necessary consequence of postulated length invariance, hence of physical *nonoccurrence* of the Lorentz contraction. (Light has to "hurry up" to cover the extra distance resulting from this nonoccurrence.) That is, our postulate [1] that the invariants of kinematics are length and proper time implies failure of Einstein's second postulate (universal light-speed constancy). Experimental evidence supports Einstein's postulate for source (emitter) motions, so the only way that postulate can fail is if light speed is affected by detector (absorber) motions. That such a possible failure mode may have been overlooked is apparent from the fact that radiation detectors in normal practice tend to be at rest in the observer's laboratory. (Maxwellian field detectors, as we noted in [1], are *defined* to be at rest relative to the observer).

From the standpoint of quantum mechanics it need only be noted that an influence of detector motion on light speed (*cf*. Bohr's observation that "the apparatus as a whole makes the measurement") should occasion no surprise, since "detection" of the photon is "quantum measurement", and it is known that the state of motion of a detection apparatus relative to the observer in general affects the predicted "measurement" outcome in a nonclassical way. Denial of such a physical possibility is based neither on reason nor on empiricism, but on implicit faith in all aspects of the special relativity theory -a theory that evinces such purely causal thinking about the physical nature of light as (a) to verge on determinism and (b) to be somewhat anachronistic in the era of "quantum nonlocality", "wave function reduction", etc.

In this second part of the paper we shall formulate neo-Hertzian wave equations and develop several forms of solutions. In each case quantitative predictions of radiation convection by the absorber will be derived.

2. Neo-Hertzian Wave Equation in One Dimension

Taking the curl of Eq. (29a) and applying (29b), (29c), and the vector analysis formula $\vec{\nabla}\times\vec{\nabla}\times\vec{H} = \vec{\nabla}(\vec{\nabla}.\vec{H}) - \nabla^2\vec{H}$, we get

$$-\nabla^2\vec{H} + \frac{1}{c^2}\frac{d^2}{d\tau_d^2}\vec{H} = \frac{4\pi}{c}\vec{\nabla}\times\vec{U}_m = 0, \qquad (30)$$

provided $\vec{U}_m$ is curl-free. Similarly, the curl of Eq. (29b) yields

$$-\nabla^2\vec{E} + \frac{1}{c^2}\frac{d^2}{d\tau_d^2}\vec{E} = -4\pi(\vec{\nabla}\rho + \frac{1}{c^2}\frac{d}{d\tau_d}\vec{U}_m). \qquad (31a)$$

In free space, remote from field sources, ρ and $\vec{U}_m$ vanish, so we get a second wave equation :

$$-\nabla^2\vec{E} + \frac{1}{c^2}\frac{d^2}{d\tau_d^2}\vec{E} = 0 \ . \qquad (31b)$$

To solve an equation such as (31b), one method is to combine Eqs. (26b) and (17) to obtain

$$\frac{d}{d\tau_d} = \gamma_d(\frac{\partial}{\partial t} + \vec{v}_d.\vec{\nabla}) \ , \qquad (32)$$

which can then be used in (31b) to solve for $E = E(x,y,z,t)$. This noninvariant approach, however, is mathematically more complicated than using the proper-time convective derivative,

$$\frac{d}{d\tau_d} = \frac{\partial}{\partial\tau_d} + \vec{V}_d.\vec{\nabla} \ , \qquad (33)$$

which is manifestly invariant, to solve (31b) for $E = E(x,y,z,\tau_d)$. The results will be shown to be equivalent.

Consider a one-spatial-dimensional problem. First we do it the hard (noninvariant) way, looking for a solution of type $E = E(x,t)$. With (32), Eq. (31) becomes in the case of unaccelerated detector motion in the x-direction

$$-\frac{d^2E}{dx^2} + \frac{1}{c^2}\gamma_d^2(\frac{\partial^2}{\partial t^2} + 2v_d\frac{\partial^2}{\partial x\partial t} + v_d^2\frac{\partial^2}{\partial x^2})E = 0 \ . \qquad (34)$$

A solution of the more specialized form $E = E(x + \alpha t)$ will be sought. On substituting, we get a quadratic for the constant α :

$$\alpha^2 + 2v_d\alpha - c^2 + 2v_d^2 = 0$$

with roots

$$\alpha = -v_d \pm \sqrt{c^2 - v_d^2} \ . \qquad (35)$$

Thus a d'Alembert-type solution for the E-field is

$$E = E_1(x + [\sqrt{c^2-v_d^2} - v_d]t) + E_2(x - [\sqrt{c^2-v_d^2} + v_d]t), \qquad (36)$$

where E_1 represents an arbitrary wave traveling along the x-axis to the left at speed $[c - v_d + O(v_d^2/c^2)]$, and E_2 is another wave traveling to the right at speed $[c + v_d + O(v_d^2/c^2)]$. If the detector moves to the right ($v_d > 0$) the wave traveling to the left is slowed and the wave traveling to the right is speeded up. If the detector moves to the left ($v_d < 0$) the above statements are reversed. Thus in all cases there is a first-order *convection* (pulling along) of the wave field in the direction of motion of the detector relative to the observer. This convection vanishes only if the radiation detector (absorber) is at rest in the observer's system (the usual case, as we have noted, in actual laboratory practice). Such a convective alteration of the speed of light, earlier hypothesized [2] as necessary to permit non-occurrence of the Lorentz contraction, restore definability to distant simultaneity, etc., is consistent with our present identification of *length* as a rigorous invariant of kinematics. In this one-dimensional problem the convection bears a resemblance to the effect of a wind blowing in the acoustic case -but since it represents an influence on the photon of the motion of a detector which the photon *has not yet reached* (according to a Huygenian retarded-wave "propagation" model), it is clear that neo-Hertzian electrodynamics violates deeply-held "causality" conceptions of the nineteenth and earlier centuries that were passed on intact to the twentieth century by Einstein.

Let us treat the invariant formulation of the same problem. Substituting Eq. (33) into (31b) and considering a one-dimensional solution of type $E = E(x,\tau_d)$, we have

$$-\frac{d^2E}{dx^2} + \frac{1}{c^2}\left(\frac{\partial^2}{\partial\tau_d^2} + 2V_d \frac{\partial^2}{\partial x\partial t_d} + V_d^2 \frac{\partial^2}{\partial x^2}\right)E = 0 \ . \qquad (37)$$

Looking for a solution of form $E = E(x + \beta\tau_d)$, we obtain a quadratic,

$$\beta^2 + 2V_d\beta + V_d^2 - c^2 = 0 \ ,$$

whence

$$\beta = -V_d \pm c \ . \qquad (38)$$

Our general solution is therefore

$$E = E_1(x + [c-V_d]\tau_d) + E_2(x -[c+V_d]\tau_d), \qquad (39)$$

The simplicity of this invariant form of the result will be noted. If the detector is at rest ($V_d = 0$) the customary speed-c d'Alembert solution is obtained.

From Eqs. (25) and (27) we have

$$t = \frac{\tau_d}{\sqrt{1 - \frac{v_d^2}{c^2}}} \ , \qquad \vec{V}_d = \frac{\vec{v}_d}{\sqrt{1 - \frac{v_d^2}{c^2}}} \ . \qquad (40)$$

These relations convert the argument of (39) into that of (36). For example :

$$E_1(x + [c-V_d]\tau_d) = E_1(x + [c - \frac{v_d}{\sqrt{1-(v_d/c)^2}}]\tau_d)$$

$$= E_1(x + [\sqrt{c^2-v_d^2} - v_d]\frac{\tau_d}{\sqrt{1-(v_d/c)^2}}) = E_1(x + [\sqrt{c^2-v_d^2} - v_d]t). \qquad (41)$$

The equivalence of solutions (36) and (39) is thus established.

3. Two-dimensional Wave Equation : Doppler Effect

We now extend our examination of neo-Hertzian wave equations to treatment of the two-spatial-dimensional wave equation in the invariant formulation. Detector proper velocity is denoted $\vec{V}_d = (V_x,V_y)$. By Eq. (33)

$$\frac{d}{d\tau_d} = \frac{\partial}{\partial\tau_d} + V_x \frac{\partial}{\partial x} + V_y \frac{\partial}{\partial y} \ . \qquad (42)$$

On substituting this into Eq. (31b) and seeking a solution of the plane-wave type, $E = E(k_x x + k_y y - W\tau_d)$, where $\vec{k} = (k_x, k_y)$ is an arbitrary propagation vector and W a constant, we obtain the algebraic condition

$$-c^2 - R^2c^2 + B^2 + V_x^2 + V_y^2R^2 - 2V_xB - 2V_yRB + 2V_xV_yR = 0, \quad (43)$$

where

$$R = \frac{k_y}{k_x}, \qquad B = \frac{W}{k_x} . \quad (44)$$

To study the Doppler effect, we apply a "proper" (or proper-time version of the) Galilean transformation,

$$\vec{r}\,' = \vec{r} - \vec{V}_d\,\tau_d, \qquad \tau_d' = \tau_d, \quad (45)$$

$\vec{V}_d$ being the proper velocity of the detector (Eq. (27)) referred to detector proper time τ_d, such that $\vec{V}_d\tau_d = \vec{v}_d t$, t being frame time in the laboratory intertial system S (connected to τ_d by Eq. (25a)). Eq. (45), which might be termed "neo-Galilean transformation", expresses the physical invariance of proper time rather than frame time. It replaces the classical Galilean transformation in neo-Hertzian theory and is essential to the kinematics of inertial motions, which is not our subject here. If primes denote the inertial system S' (moving with velocity $\vec{v}_d$ relative to S) in which the detector is at rest, a constant phase-value of the E-solution is expressed by

$$\vec{k}.\vec{r} - W\tau_d = \text{const.} = \vec{k}'.\vec{r}\,' - W'\tau_d' . \quad (46)$$

Such a condition is sometimes referred to as "invariance of phase", but it is not an "invariant interval" statement (such as $\tau_d = \tau_d'$), because the angular frequencies W and W' are measured by single timing devices (frequency meters) at rest in S and S', respectively. Thus they cannot refer to an interval between two specified events (it being impossible for two given events to occur at the same place in each of two frames in relative motion). On putting (45) in (46) and introducing the notation

$$k_x = \frac{W}{U}\,\ell, \quad k_y = \frac{W}{U}\,m, \quad \ell^2 + m^2 = 1,$$

$$\frac{W}{U} = k = |\vec{k}| = \sqrt{k_x^2 + k_y^2} = \frac{2\pi}{\lambda}, \quad (47)$$

with corresponding primed symbols for similar quantities in S', we get

$$\frac{W}{U}\,\ell x + \frac{W}{U}\,my - W\tau_d = \frac{W'}{U'}\,\ell'(x - V_x\tau_d) + \frac{W'}{U'}\,m'(y - V_y\tau_d) - W'\tau_d, \quad (48)$$

where $\vec{V}_d = (V_x, V_y)$. Equating coefficients of the arbitrary variables x, y, τ_d, we obtain three conditions :

$$\frac{W}{U}\,\ell = \frac{W'}{U'}\,\ell' \quad (49a)$$

$$\frac{W}{U}\,m = \frac{W'}{U'}\,m' \quad (49b)$$

$$W = \frac{W'}{U'}\,\ell' V_x + \frac{W'}{U'}\,m' V_y + W' . \quad (49c)$$

Eq. (49c) can be written as

$$W = W'\left(1 + \ell'\frac{V_x}{U'} + m'\frac{V_y}{U'}\right), \quad (50)$$

which is one form of the Doppler formula. Taking the ratio of (49a), (49b), we get

$$\frac{m}{\ell} = \frac{m'}{\ell'}, \quad (51)$$

which in view of Eqs. (44), (47) implies

$$R = \frac{k_y}{k_x} = \frac{m}{\ell} = \frac{m'}{\ell'} = R' . \quad (52)$$

Substituting Eqs. (49a), (49b) in (49c), we get

$$W = \frac{W}{U}\,\ell V_x + \frac{W}{U}\,m\,V_y + W' ,$$

or

$$W' = W(1 - \ell \frac{V_x}{U} - m \frac{V_y}{U}), \qquad (53)$$

an alternate form of the Doppler formula. A symmetry emerges, in that the interchanges $W \leftrightarrow W'$, $(\ell,m) \leftrightarrow (\ell',m')$, $U \leftrightarrow U'$, $(V_x,V_y) \leftrightarrow (-V_x,-V_y)$ leave our Doppler formulas (50), (53) invariant. In the above formulas (ℓ,m), (ℓ',m') are direction cosines of the $\vec{k}$-vector of wave propagation relative to the +x-direction (coincident with the +x'-axis), W is proper angular frequency in S (defined below), and U is proper wave speed ("phase velocity") in S' in the $\vec{k}$-direction, related to ordinary wave speed in S by

$$U = \frac{u}{\sqrt{1-(v_d/c)^2}} \quad . \qquad (54)$$

We note that $v_d = 0$ in S', so

$$U' = u' = c \ , \qquad (55)$$

inasmuch as the detector's being at rest reduces Hertz's (and the neo-Hertzian) equations to Maxwell's, for which the wave speed in vacuum is known to be c. This may be proven by writing down the primed equivalent of Eq. (43) with $(V_x', V_y') = (0,0)$, which yields

$$- c^2 - R'^2 c^2 + B'^2 = 0 \ . \qquad (56a)$$

On using $B' = W'/k_x' = U'/\ell'$, and $R' = m'/\ell'$, Eq. (56a) implies

$$\frac{m'}{\ell'} = \frac{\pm\sqrt{1-\ell'^2}}{\ell'} = \pm\sqrt{\left(\frac{U'}{c\ell'}\right)^2 - 1} = \frac{\pm\sqrt{\left(\frac{U'}{c}\right)^2 - \ell'^2}}{\ell'} = \frac{m}{\ell} = \frac{\pm\sqrt{1-\ell^2}}{\ell}, \qquad (56b)$$

which leads to $U' = \pm c$, $\ell = \pm\ell'$, the ambiguity in sign of c being the same as that encountered in the one-dimensional problem, Eq. (38). For present purposes it suffices to choose the plus signs,

$$U' = c, \qquad \ell' = \ell, \qquad m' = m \quad . \qquad (57)$$

The equality of direction cosines in S, S' reflects our postulation of *length* as an invariant of kinematics. Eqs. (49a) and (57) imply that

$$\frac{W}{U} = \frac{W'}{U'} = \frac{W'}{c} \ ,$$

or

$$W = W'\left(\frac{U}{c}\right) \ . \qquad (58)$$

Comparing (58) with (50), we evaluate U as

$$U = c(1 + \ell' \frac{V_x}{U'} + m' \frac{V_y}{U'}) = c + \ell V_x + m V_y, \qquad (59)$$

which explicitly exhibits radiation convection by the absorber (detector) moving with proper velocity (V_x,V_y) in S for given propagation direction (ℓ,m). On putting

$$B = \frac{W}{k_x} = \frac{U}{\ell} = \frac{c}{\ell} + V_x + R\,V_y, \quad \text{with} \quad R^2 = \frac{1-\ell^2}{\ell^2} \ , \qquad (60)$$

into Eq. (43), we find that Eq. (43) is satisfied as an algebraic identity for arbitrary ℓ. Therefore the direction of the $\vec{k}$-vector remains arbitrary and unaltered. Making use of $(\ell,m) = (k_x/|\vec{k}|,\ k_y/|\vec{k}|)$, one can express Eq. (59) in vector notation:

$$U = c + \frac{\vec{V}_d \cdot \vec{k}}{|\vec{k}|} \ , \qquad (61a)$$

or

$$u = \sqrt{c^2 - v_d^2} + \frac{\vec{v}_d \cdot \vec{k}}{|\vec{k}|} \ , \qquad (61b)$$

the latter being in agreement with Eq. (36) for the one-dimensional case, the former with Eq. (39). Eq. (61) indicates that only the *component* of detector velocity parallel to light propagation direction affects light speed, and there is no change of propagation *direction* associated with coordinate transformation.

Returning to the Doppler formulas and using Eq. (59) in (53), we get

$$W' = W\left(1 - \frac{\ell V_x + m V_y}{c + \ell V_x + m V_y}\right) = W\left(\frac{c}{c + \ell V_x + m V_y}\right)$$

or

$$W' = W\left(1 + \ell \frac{V_x}{c} + m \frac{V_y}{c}\right)^{-1} . \qquad (62)$$

To proceed, we must be certain of the operational definitions of our symbols. In particular, let

ω_0 = angular frequency of radiation measured with all instruments at rest in S.

W' = angular frequency of radiation measured with all instruments at rest in S'.

W = "proper angular frequency in S" = 2π times number of waves received between events E_1 and E_2 at a detector stationary in S, given that E_1 and E_2 occur with unit time separation as recorded by two clocks at rest in S' that spatially coincide with E_1 and E_2.

Note that the detector at rest in S used in defining W is a *different detector* from the one at rest in S' (associated with proper velocity $\vec{V}_d$) with which our discussion is mainly concerned. The detector at rest in S does not convect radiation in the view of the S-observer, so (by the definition of W and ω_0)

$$W \tau_d = \omega_0 t . \qquad (63)$$

The emitter and detector involved in defining W and ω_0 are both at rest in S, and ω_0 is simply the "source" or "emitted" angular frequency. W and ω_0 differ only by the choice of frame in which the time-measuring device is at rest. On recalling the relation between t and $\tau_d = t'$ (frame times in S and S', respectively), Eq. (40), we get from (63)

$$W = \frac{\omega_0}{\sqrt{1-(v_d/c)^2}} . \qquad (64)$$

To repeat : The quantity W is a sort of hybrid, which is "in S" as far as radiation detection is concerned, but which

refers its time mesurements to clocks at rest in S'. Thus "detection" and "time measurement" are treated in neo-Hertzian theory as distinct physical operations, whereas the distinction is immaterial to Einstein's physics. Eq. (64) shows the choice of time measurement system to be essentially a trivial matter, easily compensated by a square-root factor.

The quantity W' is the Doppler-shifted angular frequency measured by the moving detector and its comoving clock. From Eqs. (62) and (64)

$$W' = \omega_0\left(1 - \frac{v_d^2}{c^2}\right)^{-\frac{1}{2}} \left(1 + \ell \frac{V_x}{c} + m \frac{V_y}{c}\right)^{-1} . \qquad (65)$$

A related quantity of interest (also of a hybrid nature) is the angular frequency, measured by a clock at rest in S, of the radiation received by a detector at rest in S', connected to the clock by flexible leads. That is, "time measurement" occurs in S but "detection" occurs in S'. Such an angular frequency -call it ω^*- is given by Eq. (65) with the square-root factor omitted. Whether W' or ω^* represents the "true" Doppler effect depends on details of the measurement process. In general conventional relativity theory conditions us to view W' as embodying the "real" Doppler shift, but to make this true in practice would require putting frequency meters into motion in the laboratory. It would seem that in earth-bound laboratory experiments involving moving detectors ω^* would generally be the quantity relevant to electromagnetic Doppler observations.

On expressing proper velocity components in terms of S-frame-time components by Eq. (40), we get

$$W' = \omega_0\left(1 - \frac{v_d^2}{c^2}\right)^{-\frac{1}{2}} \left(1 + \frac{\ell}{c} \frac{v_x}{\sqrt{1-(v_d/c)^2}} + \frac{m}{c} \frac{v_y}{\sqrt{1-(v_d/c)^2}}\right)^{-1}$$

$$= \omega_0\left(1 - \ell \frac{v_x}{c} - m \frac{v_y}{c} + \frac{1}{2} \frac{v_d^2}{c^2}\right) + O(v^3/c^3), \qquad (66)$$

which agrees to second order with the Einstein Doppler formula,

$$\omega_E' = \omega_0\left(1 - \frac{v_d^2}{c^2}\right)^{-\frac{1}{2}}\left(1 - \frac{\ell}{c} v_x - \frac{m}{c} v_y\right)$$

$$= \omega_0\left(1 - \ell \frac{v_x}{c} - m \frac{v_y}{c} + \frac{1}{2}\frac{v_d^2}{c^2}\right) + O(v^3/c^3) \ . \qquad (67)$$

On the other hand our hybrid quantity ω^*,

$$\omega^* = \omega_0\left(1 + \frac{\ell}{c}\frac{v_x}{\sqrt{1-(v_d/c)^2}} + \frac{m}{c}\frac{v_y}{\sqrt{1-(v_d/c)^2}}\right)^{-1}$$

$$= \omega_0\left(1 - \ell \frac{v_x}{c} - m \frac{v_y}{c}\right) + O(v^3/c^3) \ , \qquad (68)$$

agrees with the other formulas to first order and with classical theory to second order. Thus a second-order Doppler experiment, such as that of Ives-Stilwell [3], can at best verify time dilatation, not distinguish neo-Hertzian from Maxwell-Einstein theory. Similarly, there is no possibility from a first-order effect such as stellar aberration to derive any observable distinction between the theories. We omit discussion of Fresnel drag from this paper, since this lies in the subject area of kinematics (velocity composition law) rather than electromagnetism. Preliminary investigation suggests that no feasible crucial experiment lies in that direction.

For completeness we record a set of field-component solutions that satisfy the neo-Hertzian field equations, Eq. (29). They are

$$E_x = -k_y F, \qquad E_y = k_x F, \qquad E_z = 0,$$

$$H_x = 0 \ , \qquad H_y = 0 \ , \qquad H_z = k F, \qquad (69)$$

where $F = F(k_x x + k_y y - W\tau_d)$ is any smooth function and $\vec{k} = (k_x, k_y)$ is an arbitrary propagation vector. The only departures from the corresponding solution of Maxwell's equations are hidden in the notation ; e.g., $k = \sqrt{k_x^2 + k_y^2} = W/U$, vice $k = \omega/c$. The proof that Eq. (69) satisfies (29) involves repeated usage of Eqs. (47), (53), and (58).

4. Two-dimensional Wave Equation : Circular Motion of Detector

Interest in circular planar motion of a radiation detector arises in the astronomical context (earth's orbital and axial rotations) as well as in connection with possible laboratory experiments. Suppose the detector moves in a circle of radius R at constant angular velocity ω and speed $|\vec{v}_d| = v = R\omega$, with coordinates

$$\vec{r}_d = \hat{\imath}\, x + \hat{\jmath}\, y = \hat{\imath}\, R\cos(\omega t+\theta_0) + \hat{\jmath}\, R\sin(\omega t+\theta_0) \ .$$

The detector velocity is

$$\vec{v}_d = d\,\vec{r}_d/dt = \hat{\imath}\, v_x + \hat{\jmath}\, v_y = -\hat{\imath}\, v\sin(\omega t+\theta_0) + \hat{\jmath}\, v\cos(\omega t+\theta_0),$$

and its proper velocity is $\vec{V}_d = d\vec{r}_d/d\tau = \vec{v}_d/\sqrt{1-(v/c)^2} = \hat{\imath}\, V_x + \hat{\jmath}\, V_y$, whence

$$V_x = -A\sin(\omega_d\tau_d + \theta_0), \qquad V_y = A\cos(\omega_d\tau_d + \theta_0), \qquad (70)$$

where $A = v/\sqrt{1-(v/c)^2}$ and we have made use of $\omega_d\tau_d = \omega t$, $t = \tau_d/\sqrt{1-(v/c)^2}$, $\omega_d = \omega/\sqrt{1-(v/c)^2}$. From (70),

$$\left(\frac{\partial V_x}{\partial \tau_d}\right) = -A\,\omega_d\cos(\omega_d\tau_d + \theta_0) = -\omega_d V_y, \qquad (71a)$$

$$\left(\frac{\partial V_y}{\partial \tau_d}\right) = -A\,\omega_d\sin(\omega_d\tau_d + \theta_0) = \omega_d V_x \ . \qquad (71b)$$

We shall seek a solution of the neo-Hertzian wave equation, Eq. (31b), of the form

$$E = E(k_x x + k_y y - W(\tau_d)\tau_d), \qquad (72)$$

where $W(\tau_d)$ is a function to be determined and $\vec{k} = (k_x, k_y)$ is the propagation vector of incident plane-wave radiation. Eq. (31b) may be rewritten, with the help of Eq. (33), as

$$-\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)E + \frac{1}{c^2} L^2 E^2 = 0 \tag{73a}$$

$$L \equiv \frac{d}{d\tau_d} = \frac{\partial}{\partial\tau_d} + V_x \frac{\partial}{\partial x} + V_y \frac{\partial}{\partial y} . \tag{73b}$$

From Eqs. (72), (73b) we obtain

$$LE = K(\tau_d)E', \tag{74a}$$

where

$$K(\tau_d) = -\alpha' + k_x V_x + k_y V_y, \tag{74b}$$

$$\alpha = \alpha(\tau_d) \equiv \tau_d W(\tau_d), \tag{74c}$$

and primes denote differentiation. Hence

$$L^2E = L(LE) = L(K(\tau_d)E') = (LK)E' + K(LE') = (LK)E' + K^2E''. \tag{75}$$

Eq. (71) indicates that $LV_x = -\omega_d V_y$, $LV_y = \omega_d V_x$. Hence

$$(LK) = -\alpha'' - k_x \omega_d V_y + k_y \omega_d V_x . \tag{76}$$

Eqs. (73a), (75) yield

$$-(k_x^2+k_y^2)E'' + \frac{1}{c^2} L^2E = -k^2E'' + \frac{1}{c^2} K^2E'' + \frac{1}{c^2}(LK)E' = 0. \tag{77}$$

To facilitate solution we impose the condition that the coefficient of E' vanish ; i.e., from Eq. (76),

$$(LK) = -\alpha'' + f(\tau_d) = 0, \tag{78a}$$

$$f(\tau_d) \equiv \omega_d(-k_x V_y + k_y V_x) . \tag{78b}$$

Thus

$$\alpha' = \int f(\tau_d)d\tau_d + C, \qquad C = \text{const.} \tag{79}$$

On integrating we find

$$\alpha' = A[k_y \cos(\omega_d\tau_d+\theta_0) - k_x \sin(\omega_d\tau_d+\theta_0)] + C$$
$$= k_y V_y + k_x V_x + C . \tag{80}$$

From Eqs. (74b) and (80) we get

$$K = -\alpha' + k_x V_x + k_y V_y = -C. \tag{81}$$

Eq. (77) yields

$$-k^2E'' + \frac{1}{c^2} K^2E'' = (-k^2 + \frac{1}{c^2} C^2)E'' = 0. \tag{82}$$

Thus $C^2 = c^2k^2$, or, if we choose the positive root,

$$C = ck, \qquad k = \sqrt{k_x^2 + k_y^2} . \tag{83}$$

Eqs. (80) and (83) evaluate $\alpha' = (\tau_d W)'$. Integrating this,

$$\tau_d W = \int \alpha' \, d\tau_d + C_0 , \tag{84}$$

we get finally

$$W(\tau_d) = ck + \frac{A}{\omega_d\tau_d} \, k_y[\sin(\omega_d\tau_d+\theta_0)-\sin\theta_0]$$
$$+ k_x[\cos(\omega_d \tau_d+\theta_0) - \cos\theta_0] \tag{85}$$

wherein the integration constant C_0 has been evaluated by imposing the condition that $W(\tau_d)$ remain finite as $\tau_d \to 0$. Eq. (85) confirms the existence of a solution of the form (72).

Specializing to the case $k_y = 0$, $k_x = -k$, and using the fact that $A = v/\sqrt{1-(v/c)^2} = R\omega/\sqrt{1-(v/c)^2} = R\omega_d$, we get

$$W = ck\left\{1 - \frac{R}{c\tau_d}[\cos(\omega_d\tau_d+\theta_0) - \cos\theta_0]\right\}, \tag{86}$$

where θ_0 is the initial phase of the detector's circular motion. The corresponding proper wave speed of light, by Eq. (47) -written in terms of "frame time" t of the inertial system in which the center of the circle is at rest- is

$$U = \frac{W}{k} = c\{1 - \frac{R}{ct\sqrt{1-(R\omega/c)^2}}[\cos(\omega t + \theta_0) - \cos\theta_0]\}. \qquad (87a)$$

A simple physical interpretation of this result can be obtained by evaluating the time average of the "longitudinal" component of detector proper velocity $\vec{V}_d$ (parallel to the direction of light propagation). We find, with $\theta(t) = \theta_0 + \omega t$, $d\theta = \omega\, dt$,

$$\langle \text{Longitudinal component} \rangle = \frac{\int_0^t V_d \sin\theta(t)dt}{\int_0^t dt} = \frac{V_d}{\omega t}\int_{\theta_0}^{\theta_0+\omega t} \sin\theta\, d\theta$$

$$= -\frac{V_d}{\omega t}[\cos(\omega t+\theta_0) - \cos\theta_0] \quad .$$

Since $V_d = v/\sqrt{1-(v/c)^2} = R\omega/\sqrt{1-(R\omega/c)^2}$, comparison with Eq. (87a) shows that

(Photon proper speed) = U = c + (Time average during photon's time-of-flight of longitudinal component of detector proper velocity) (87b)

The adjective "proper" can be dropped from both sides of this equation through multiplication by $\sqrt{1-(R\omega/c)^2}$. The longitudinal velocity component is negative if detector and photon motion directions are opposed, positive otherwise. By "time-of-flight" is meant the time between photon emission (t = 0) and absorption (t = t) events. Although this result, Eq. (87b), has been obtained for the special case of circular motion, it is likely that it applies for arbitrary detector trajectories.

5. Possible Crucial Experiments

Several special cases of application of Eq. (87) are of interest.

Case A. Suppose R is the radius of the earth's orbit, considered circular, and t is the propagation time of a light signal from an astronomical event occurring outside the solar system at time t = 0 and distance D = ct, detected by an earthbound telescope. Since D >> R, Eq. (87a) shows that $U \simeq c$, regardless of the detector's instantaneous state of motion. Hence such distant event signals cannot be used to distinguish neo-Hertzian from Maxwellian physics. Here U is signal "proper speed", $dx/d\tau_d$, reckoned in terms of earth time, which is detector proper time.

Case B. Let R be earth's radius or distance from earth's axis to surface at some latitude of observation. Then, for all astronomical events (e.g., explosions on the sun) at distances ct = D >> R, the same considerations as for Case A apply. In neither case does detector motion produce an appreciable effect on light speed. One cannot by such generalities rule out all astronomical attempts at "crucial testing" of neo-Hertzian vs. Maxwellian electromagnetism, but it is clear that very special circumstances are required to reveal any noticeable distinction, and that existing data seem unlikely to provide a test.

Case C. Let R be the radius of a disk in the laboratory, on the rim of which are mounted two diametrically opposed photodetectors, both facing a distant light source. In this case parameters can be chosen to reveal any effect of detector motion. Taking $\theta_0 = 90°$, we get from Eq. (87a)

$$U = c\left\{1 \pm \frac{R\sin\omega t}{ct\sqrt{1-(R\omega/c)^2}}\right\} \quad . \qquad (88)$$

For small t, $\omega t \ll 1$, the detector motions are quasi-linear advances and retreats parallel to the light propagation direction. We have $\sin\omega t \simeq \omega t$, hence

$$U \simeq c\left\{1 \pm \frac{R\omega}{c\sqrt{1-(R\omega/c)^2}}\right\} = c\left\{1 \pm \frac{v/c}{\sqrt{1-(v/c)^2}}\right\} \qquad (89)$$

for $\theta_0 = \pm 90°$, $\omega t \ll 1$ or $vt \ll R$.

Since $U\tau_d = ut$, where u is light propagation speed reckoned in laboratory time t, we have $u = U(\tau_d/t) = U\sqrt{1-(v/c)^2}$. Hence

$$u \approx c[\sqrt{1-(v/c)^2} \pm v/c] = \sqrt{c^2-v^2} \pm v, \qquad (90a)$$

which corresponds to our one-dimensional result, Eq. (35). (The sign difference is eliminated by considering the minus root in Eq. (83).) To first order Eq. (90a) yields

$$u \approx U \approx c \pm v \qquad \text{for} \quad vt \ll R. \qquad (90b)$$

If the light source is at distance D = ct from the disk, we may choose the disk radius R such that

$$vt \ll R \ll D, \quad \text{or} \quad v \ll \frac{R}{t} \ll c, \qquad (91)$$

which assures that the light arrives at the disk as essentially a plane wave, and that the distance the detector moves during propagation of the light is small compared to R. If at t = 0, when a light flash or sudden modulation of duration E is emitted, the two detectors are at $\theta_0 = \pm 90$ (i.e., interdetector line exactly perpendicular to light propagation direction) then according to Maxwell-Einstein the signal arrival-time difference at the two detectors is to first order

$$(\Delta t)_E \doteq 2Dv/c^2, \qquad (92)$$

because the advancing detector meets the signal before the retreating one does. But according to Hertzian or neo-Hertzian theory, Eq. (90b), the retreating detector convects light with speed c + v, and the advancing detector slows it to c - v, so these first-order effects cancel and the predicted first-order signal reception time difference is nil,

$$(\Delta t)_{Hertz} \doteq 0 \ . \qquad (93)$$

In order to have a feasible experiment to decide between these conflicting predictions it is necessary that $(\Delta t)_E > E$, or

$$D > \frac{E c^2}{2v} \ . \qquad (94)$$

Inserting reasonable numerical values, we find that either D must be large (many miles) or E very short (say, $\sim 10^{-13}$ sec.). So the experiment, though feasible with modern techniques, is not a trivial one. The chance that past laboratory observations (incidental to other objectives) might fortuitously have decided the issue is judged to be negligible. It is certainly out of the question (e.g., with reference to the technology of fast photo-detection) that an empirical resolution could have been achieved in Maxwell's or Hertz's day, or in the era when Einstein's theory initially gained widespread acceptance. The foregoing considerations apply to visible light signals. The possibility of using gamma-ray bursts has not been examined, but might prove experimentally attractive.

Case D. To conclude regarding astronomy, consider an intermediate-distance event, say, an eclipse of a Jovian satellite, simultaneously observed near sunrise and sunset at two observatories on opposite sides of the earth. The geometry is that of Case C, with R, the earth's radius, of the order of 5×10^8 cm, $v = \omega R$ of the order of 3.5×10^4 cm/sec, hence $v/c \approx 10^{-6}$. The distance to Jupiter might be of the order of $D = 6.5\ 10^{13}$ cm, so $(\Delta t)_E = 2Dv/c^2 = 4\times10^{-3}$ sec. Thus the observed event duration E would have tho be less than 4 milliseconds to permit a crucial experiment. Even if there were no problems of "scheduling" the event to occur at proper phase of earth's rotation, it seems unlikely that observable planetary events would be thus sharply defined in time.

Our conclusion regarding crucial experiments is that astronomical tests appear unpromising. The best hope is a carefully engineered photon time-of-flight measurement of the type described in Case C, above. It is judged highly unlikely that already existing observations can decide between Maxwell's theory and the versions of Hertz's theory (termed Hertzian and neo-Hertzian) presented in this paper.

6. Summary

Hertz proposed a Galilean-invariant "covering theory" of Maxwell's electromagnetism that contained an extra velocity-dimensioned parameter. His version of electromagnetism failed because he interpreted the extra parameter as ether velocity, which he further identified with velocity of ponderable matter in the laboratory -a view that led to conflict with observation.

We have proposed here a different interpretation of the extra parameter ; namely, that it is the velocity of the field detector with respect to the observer. Through such explicit recognition of field detector degrees of freedom the operational definition of "field" is changed. This leads to a "neo-Hertzian" electromagnetism, which attains form invariance at all orders of velocity through substitution of (detector) proper time for (observer's) frame time. The resulting generally invariant theory evinces acausal behavior of light (influence of detector motion relative to observer on the speed attributed to light by that observer, in violation of Einstein's second postulate). Such a non-Einsteinian electromagnetism fits with a previously proposed [4],[5] non-Einsteinian kinematics, the invariants of which are length and proper time. Together, the alternative kinematics and electromagnetism appear to comprise a consistent "test theory" of Lorentz-Einstein physics. The latter features simple (causal) light and complicated (Lorentz-contracted) matter. The neo-Hertzian alternative proposes simple (length-invariant) matter and complicated (acausal) light. Only experiment can decide between these rival physical possibilities. A sampling of candidate experiments suggests that none performed adventitiously in the past, nor any involving astronomical data, is likely to be decisive between Maxwellian and Hertzian electromagnetism. A laboratory experiment equivalent to measurement of photon time-of-flight as affected by detector motion should be crucial.

It is to be hoped that experimentalists will exploit the present opportunity to strengthen the kinematic/electromagnetic foundations of physics -for, as T.S. Kuhn has aptly observed, a theory is never tested in all its aspects, nor really tested at all except against other theories. It must be acknowledged that the number of nontrivially different kinematic/electromagnetic test theories to challenge Einstein/Maxwell has not been very great. An up-dated Hertzian electromagnetism deserves its day in court, if only because the prevailing fashion of mathematical *covariance* has long needed to be confronted with the alternative of true *invariance*. The vastly superior symmetry (transformation group invariance) properties of the neo-Hertzian alternative -even more apparent within kinematics/mechanics [4],[5] than within the electromagnetism discussed here- make it inherently attractive to explore. A great deal remains to be done on the side of theory (particularly kinematics), as well as experiment -the present paper being no more than an initial survey of selected topics.

Lest any connotations of what has been said here be construed as derogatory of one of the premier physicists of history, let the last word be said by Maxwell [6] :

"The facts of electro-magnetism are so complicated and various, that the explanation of any number of them by different hypotheses must be interesting, not only to physicists, but to all who desire to understand how much evidence the explanation of phenomena lends to the credibility of a theory ..."

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ADDENDUM

The foregoing two-part paper, originally submitted to *Il Nuovo Cimento*, was rejected on the advice of a referee who felt that (a) "No equation of motion of charged particles is given", hence the field quantities cannot be defined, as in Maxwell-Lorentz theory, "by their action upon test-charges", and (b) consequently, "Lacking any physical description of the detector, ... the theory formulated in the submitted papers cannot be considered as a well defined theory of classical electromagnetism". Concerning item (a), it may be mentioned that a neo-Hertzian (or rather, neo-Lorentzian) force law has been discussed in other papers rejected by other journals, one of which has, however, been published (*Journal of Classical Physics*, 2, 1-23 (1983)) subsequently to the referee's comments. Mechanical equations of motion consistent with the kinematics sketched in Part I of this paper (i.e., having length and proper time as invariants) appeared in Ref. 7 cited in Part I.

Concerning item (b), it is unquestionably true that the present papers skim too lightly over the matter of operational definition of the neo-Hertzian field quantities. I merely described the detector as a "'black box' with a pointer and scale on it, calibrated to read numerical 'field value'". In order to measure Maxwell's field quantities, let us consider what this box must contain. To measure electric field, a charged test body, say, a pith ball, may be employed. The (x,y,z) force components that must be applied to this test body to prevent it from moving relatively to the walls of the box are proportional to the Maxwellian electric field components at the test body's position. By suitable calibration and translation the measured forces can be caused to register as pointer readings or digital readouts on three scales on the outside of the box, labeled (E_x, E_y, E_z).

In Maxwell's theory the box is at rest with respect to the laboratory observer -but (according to Einstein and common sense) observers in arbitrary states of motion will agree on the numerical readings the pointers point to. That is, the pointer or digital readings are *general motional invariants*.

Similarly, magnetic field component values can be displayed by arranging within the box three independent short wire segments carrying known currents, each under frictionless constraints to move within one of three orthogonal planes. Three more scales with pointers thus appear on the outside of the box, displaying (H_x, H_y, H_z) components at the locality of the current elements. As before, these field-component values are proportional to the forces that must be applied to the current elements to keep them immobile with respect to the walls of the box. This completes the operational definition of the Maxwell field quantities. Note that since all material elements are immobile at all times, no equations of motion are needed to discuss any aspect of the operational definition -so electromagnetism is a science logically independent of mechanics.

To define the neo-Hertzian field quantities, we employ the same black box just discussed, identically calibrated, and simply impart to it by definition the arbitrary irrotational velocity (v_x, v_y, v_z) with respect to the laboratory observer. As before, the field quantities are proportional to the forces that must be applied to the test objects to keep them *immobile with respect to the walls of the box*. And, as before, the pointer readings are general motional invariants, hence perfectly well-defined in the view of the laboratory observer, who -at any fixed point P in the laboratory- uses the instantaneous values he reads from the pointers on a collinear stream of such black boxes in identical states of motion passing through P as his (time-dependent) measured "field values" at P in verifying the neo-Hertzian equations and their invariance properties. I emphasize again : The measurements carried out by means of the relatively *moving* boxes are the *laboratory observer's* instantaneous "neo-Hertzian field values". They differ numerically, of course, from the same laboratory observer's "Maxwellian field values", defined by reading on boxes stationary in the laboratory. Neo-Hertzian "fields" are different from Maxwellian "fields"... as emphasized in the text. Though different, they are equally qualified as the basis for "a well defined theory of classical electromagnetism".

Only by *parameterizing* the detection instrument's motion (by means of v_x, v_y, v_z) can the laboratory observer take explicit cognizance of the degrees of freedom that this instrument actually possesses in the physical world. His reward for this recognition of physical fact is an invariant covering theory of Maxwell's, with *scalar* invariant transformation properties of the field components. This mathematical (Galilean) invariance property was first discovered by Hertz and deserves to bear his name. The equations referred to incorrectly by Einstein in his 1905 paper as "Maxwell-Hertz" equations do not have this invariance property and should presumably be attributed to Maxwell-Lorentz.