Hertzian Invariant Forms of Electromagnetism

Thomas E. Phipps, Jr.
908 South Busey Avenue
Urbana, Illinois 61801

Abstract. Recent experimental evidence against the Lorentz force law and for the original Ampère law of current-on-current force action is cited. If valid, this motivates reexamination of Wilhelm Weber's electrodynamics, which was designed to accord with Ampère's law, with instant action-at-a-distance, and with Newton's third law. Discussion aimed at better understanding of the latter is given. Unorthodox field theories, termed Hertzian and neo-Hertzian, offer an alternative route to compatibility with the new observations and with Newton's third law. These lack compatibility with spacetime symmetry, but constitute invariant covering theories of Maxwell's equations, so they reproduce the Maxwellian "physics of one laboratory." Hertzian theory provides manifest Galilean invariance and thus expresses a relativity principle at first order in velocity. Neo-Hertzian theory employs Einstein's proper-time invariant, interpreted as being the time shown by a clock comoving with the field detector or absorber, as a plausible method of achieving higher-order invariance. The free-space neo-Hertzian wave equation is solved, physical interpretation is discussed, and an application is made to the description of stellar aberration. This example is chosen because it is one that poses unrecognized difficulties for special relativity theory and that cannot be treated at all by Hertzian first-order theory.

1. Two Systems of the World

Today, much as in the time of Galileo, there exist two grand over-arching scientific systems of the world, at swords' points with each other -- that is, two theoretical descriptive structures, both couched in terms of universals, both mutually at odds as to basic conceptions and styles of thought, and neither recognizably falsified by empiricism. And, just as in Galileo's time, only one of these systems finds advocates in academia.

In essence the two forms of description are the field (progressive contact action) mode and the action-at-a-distance mode. They are typified, respectively, by (1) universal covariance, (2) Newton's third law. These latter precepts make the most sweeping possible mutually contradictory assertions about nature or human attempts to describe it. The first claims that *all laws* of nature, when referred to inertial systems, can be expressed in Lorentz covariant four-vector form. (We do not discuss general covariance, but restrict attention here to the "special" variety.) The second is addressed to *all forces* in nature and claims that every force discoverable possesses or engenders its equal, opposite, collinear, and simultaneous reaction force. The first, incorporated in Einstein's special relativity theory, denies the premises of the second, such as the concept of distant "simultaneity." The second, incorporated in Mach's principle, denies the premises of the first, such as universal action-retardation.

In the physics of the late twentieth century a general impression exists that "action-at-a-distance" is played-out -- despite overwhelming evidence for *quantum nonlocality of action* at arbitrary distances -- and Newton's third law discredited. Research interest (for which read government funding) is indeed played-out, but this is a matter of fadism, not physics. No empirical evidence has ever been adduced against Newton's third law -- which was once so firmly established that patent offices worldwide used its violation-in-principle as sole justification for rejecting inventions of perpetual motion machines. [In consequence of special relativity's having "discredited" Newton's third law, presumably such patents are granted without challenge nowadays ... ?] Nor has any empirical failure of universal covariance ever been acknowledged ... although we shall have occasion to raise doubts on that subject.

The two world-schemes come directly into irreconcilable conflict wherever the physicist's natural *laws* address natural *forces*. In electromagnetism, which serves as a fair testing ground, universal covariance selects the Lorentz (or Grassmann, Biot-Savart, Laplace, etc.) law as the only admissible candidate. Yet at the time Maxwell wrote his treatise [1] the choice among numerous experimentally supported candidate laws describing the force exerted by one current element on another was entirely open. Maxwell in fact stated his own preference for the original force law proposed by Ampère, which had been contrived to obey Newton's third law. It this respect Ampère's law was unique and retains its unique position to this day. Ampère's law and Newton's third law are so closely bound-up that any test of one must test the other. Of course Ampère's law did not honor covariance, spacetime symmetry, or retarded action-at-a-distance.

Any allegation of instant action-at-a-distance has been viewed by Einstein and his followers as "spooky." That seems to be the prevailing judgment of modern academia. Yet the same savants, when wearing their quantum mechanical hats, acknowledge -- with reference to "quantum nonlocality" -- that there are things in heaven and earth not known in Einstein's philosophy. What they do not acknowledge is that these are precisely the things that **were** known in Newton's philosophy -- *viz.*, in that part of it built upon the feigning of no hypotheses. Incidentally, as a matter of history, when Newton embarked upon theology -- thereby feigning hypotheses -- the latter led him to express total repugnance to his own instant action-at-a-distance formulation of nature's laws. But let us not dwell on one of the more depressing chapters in the history of scientific schizophrenia.

2. Observational Evidence

Among empiricists (nowadays generally languishing outside the groves of higher learning, wherein universal covariance represents not a scientific hypothesis but an assimilated truth) renewed interest in Ampère's law has lately been stimulated by ever-mounting experimental evidence in its favor, patiently amassed by investigators such as Graneau [2], Saumont [3], Pappas [4], etc. Other chapters in this book discuss that evidence in greater detail. The experiments, taken collectively, become steadily more difficult to ignore. Of particular note is a 1994 experiment conducted at Oxford by Neal Graneau, which seems crucial against the Lorentz force law. The apparent defeat of that law creates a vacuum at the level of fundamental presuppositions in physics into which something must fly. This circumstance could conceivably open a crack in previously closed minds through which Newton's third law (as a pragmatism presumably hiding quantum-level mechanisms of truly universal purview) might enter and ultimately regain its eminence. In short we surmise that Newton's third law may recover its credit among physicists not despite but *because of* its spookiness.

To summarize the experiment of Neal Graneau: it was a slightly but crucially altered repetition of the Robson-Sethian (R&S) experiment [5]. Those investigators had the ingenious idea of settling the 150-year disagreement between Ampère and Grassmann-Lorentz by using a high-voltage circuit wherein a straight, mobile conductor, termed the "armature," was electrically coupled to, but mechanically decoupled from, a pulsed high-current source by means of arc gaps, upper and lower. The armature was suspended in such a way that *Ampère longitudinal forces*, produced by current in the external partial circuit, if existent, would cause it (the armature) to jump up in a clearly visible way. In order to prevent force cancellation, R&S were careful to arrange a vertical shape asymmetry of their external partial circuit ... but their arc gaps were symmetrical, *i.e.*, of equal width at top and bottom. (Cylindrical symmetry about the vertical armature canceled any horizontal impulses.) They reported a null result [5] -- no motion of the armature -- thus apparently establishing the nonexistence of Ampère forces as distinct from Lorentz forces.

A subsequent inquiry [6] into the theory of the R&S experiment showed that in any experiment using a straight, mobile force-sensing element the longitudinal motion of that element could not be affected (according to a wide variety of force laws, including all the likely candidates such as those of Lorentz, Ampère, Gauss-Riemann, etc.) by the shape of the external partial circuit, but only by the geometry of the arc gaps. This "shape-independence theorem" was a purely theoretical result, logically demonstrated. Thus the care taken by R&S to ensure external partial circuit *shape asymmetry* was misdirected. To render the experiment crucial by preventing force cancellation it was necessary instead to provide *gap asymmetry*. According to the Lorentz force law, neither gap nor shape asymmetry could cause the armature to jump up against gravity, because that law prescribes a cross-product force action strictly *transverse to current flow*; *i.e.*, transverse to the vertical armature and thus restricted to the horizontal plane.

In Neal Graneau's variant of the R&S experiment the lower arc gap was made smaller than the upper one. In such geometry Ampère's law predicts a net upward component of longitudinal force on the armature, because of stronger repulsive "Ampère tension" at the narrower gap. When the current flowed briefly in the arcs, the armature was observed to jump up by about the amount of impulse predicted by the Ampère law. This outcome appears inexplicable by the Lorentz force law. That law's adherents must attribute it to apparatus effects and, as far as its agreement with Ampère is concerned, to coincidence. When the experiment has been reported in the literature, it will merit the close attention of any physicists willing to consider departures from the *status quo*.

3. Weber's Electrodynamics

Ampère's law (see Chapters 22 and 23) is somewhat complicated. For all its empirical agreements, it lacks the elemental formal simplicity one would like to see in basic physical propositions. Its complexity probably reflects that of its structural unit, the "current element." Such considerations may have induced Wilhelm Weber (1804–1891) to seek a more fundamental formulation in terms of actions-at-a-distance between pairs of *point charges*. By introducing a new concept into physics -- that of the velocity-dependent potential -- he was able to discover a truly "relativistic" force law between point charges that depended only on the instantaneous value of their separation r and on the time derivatives r, r of that separation, such that this force law reproduced Ampère's law for ponderomotive actions between neutral current-carrying conductors, and such that Newton's third law was obeyed between the point particles constituting the currents. Moreover, he was able to derive his force law,

$$F = \frac{q_1 q_2}{r^2}\left(1 - \frac{\dot{r}^2}{2c^2} + \frac{r\ddot{r}}{c^2}\right),$$

by differentiation, *-dV/dr,* of an extremely simple potential energy function,

$$V = \frac{q_1 q_2}{r}\left(1 - \frac{\dot{r}^2}{2c^2}\right),$$

wherein $q_{1,}\ q_2$ denote electric charges and c is a units ratio found to be numerically equal to the speed of light. [Graneau [2] remarks that, "Weber attributed no particular importance to c. Today it appears truly astonishing that the velocity of light should have revealed itself in a simultaneous action-at-a-distance theory such as Weber's."] The Weber derivation of Ampère's law depended on a particular model of "current" as equal counterflows of plus and minus charge. This betokened the primitive knowledge in his day of the physical nature of electric current. But recent independent investigations by Wesley and by Assis [7] have shown the equivalence of Weber's and Ampère's laws to be a model-insensitive feature, so that it holds for a more realistic model of current as negative electron drift past fixed positive lattice ions.

The new book by Assis [7] may be considered essential reading for anyone who wishes to pursue Weber's theory in depth. We shall not attempt this here, but merely remark that every evidence supports a view of the original Weber theory as valid only through order $O(c^{-2})$, and that to avoid paradoxical (if not pathological) behaviors it will be necessary to modify his formulation at higher orders. One possibility [8] is to substitute for the above potential energy a modified form

$$V = \frac{q_1 q_2}{r}\sqrt{1 - \frac{\dot{r}^2}{c^2}},$$

which has the advantage of enforcing a "speed limit" on relative particle velocity. However, it is at once apparent that any attempt to modernize Weber's approach must encounter difficulty in the description of radiation, which is known to propagate retardedly at speed c (or at least to behave as if it did).

Is it out of the question to describe radiative actions by means of some kind of instant-action force law? This is one of those research topics that must be left as a challenge to the ingenuity of future mathematicians. One can say at present only that radiation obviously cannot occur without radiation reaction (*vide* Newton's third law!), and radiation reaction is traditionally described in terms of $\dddot{r}$ ... so it would appear that any force law suited to treat radiative action-reactions must include higher-order time derivatives of r than does Weber's original law or its above-suggested modification. Much -- indeed, practically everything -- remains to be learned in this subject area.

Field theory, as it relates to force action-reaction, can rather obviously be replaced by a Weber-type instant-action "true relativity" theory (which avoids reference to frames and uses particle-relative coordinates, just as Weber did), with little or no loss of empirical agreement. But to replace the radiation-descriptive side of field theory by such an alternative will require new understandings and inspirations. A clue may be found in the observations by Gray [9] (*a*) that Kirchoff was able to derive transmission-line equations, predicting retarded propagation, using only Weber's theory and (*b*) that the vacuum can be modeled as a transmission line. This appears to establish the essential principle that speed-*c* retardation *can* emerge from instant-action mathematics. The fact that this seems to lie beyond intuitive understanding may reflect some inherent difficulty or, more likely, shows the penalty to science of a century's neglect of important descriptive alternatives.

A lover of science can only deplore the manifestly bad strategy that dictates sustained neglect of one of the "two methods" to which Maxwell referred in the Preface to the First Edition of his treatise [1]: "In a philosophical point of view, moreover, it is exceedingly important that two methods should be compared, both of which have succeeded in explaining the principal electromagnetic phenomena ... while at the same time the fundamental conceptions of what actually takes place ... are radically different." It is the **radical difference** of research paths in the plural that provides science's only protection or insurance against systematic radical departures of a chosen path into idiocy or madness. The democracy of science -- mutual admiration, the rule of consensus, etc. -- has shown itself no protection at all.

History did not -- or at least has not yet seen fit to -- validate the physical path (an hypothesized ether) chosen by Maxwell himself. So, at the end of the twentieth century, physicists find themselves with neither physical nor mathematical ammunition to shoot at their manifold problems, except the paradigm of mathematical *field theory* with which Maxwell and Einstein, the master hypothesizers, provided them. Now it is four-vectors that fly straight out of our minds, into our published papers, and on through the air to deliver physical effects of the sort that Dr. Johnson stubbed his toe on. One surmises that Faraday (whom Maxwell mathematized and attempted to apotheosize, even as his intellectual heirs have apotheosized Maxwell) would not be happy with all that. Might not simple prudence, the "common sense" of the layman, counsel avoidance of a lemming-rush into one method or the other -- given the track records of both? Killing off deviant or unfit thinking is great Darwinism and first-class political strategy. It pays the air fare to the AAAS meeting, shoes the baby, and pleases the government committee. But as a strategy for the advancement of human science it carries the dominant gene of death.

4. Force and Inertia

Electromagnetic fields are defined in terms of forces -- *e.g.*, force on a unit charge. (Curiously, though, knowledge of the fields provides no information on the force they exert on a moving test charge ... that being the province of a separate "force law," usually taken to be that of Lorentz.) Force originates as a strictly mechanical concept linked to mass. Yet all (nongravitational) *force laws*, in particular electromagnetic ones, make no explicit reference to mass and seem to suggest that force in all its physical effects is granted an uncontested divorce from mass.

Very elementary considerations based on Newton's second law, however, make it clear that in all physical situations there is a hidden connection between force and inertial mass (besides the equation of motion, $\boldsymbol{F} = m\boldsymbol{a}$) such that the divorce is never absolute. To grasp this, it is necessary to recognize a distinction between (*a*) "physical force," which by integration with respect to distance is what yields change of kinetic energy, and (*b*) "formula force," which is what one finds in textbooks (or what is given by "force laws"). The relationship between the two is that *physical force is always less than or equal to formula force*. This simple fact, which ought to be known to freshmen, is demonstrated as follows:

Let two point masses M and m occupy positions x_M, x_m on a horizontal x-axis in an inertial "laboratory" frame. They attract or repel each other with a "formula force" or force law $F_{law}(r)$, where $r = |x_M - x_m|$, due to electrostatics or any other physical cause. We confine attention to low speeds, for which reliance can be placed on Newton's second law, which states that

$$\frac{d}{dt}(MV) = -\frac{d}{dt}(mv) = F_{law} ,$$

where $V = |\dot{x}_M|$, etc. Note that it is the formula force that appears in the equation of motion. Both bodies are initially held at rest in the laboratory. We consider two cases:

Case A. *Mass m is held fixed while mass M is released and allowed to move freely along the x-axis.* Since $x_m = \text{const}$, we have

$$u = \frac{d}{dt}r = |\dot{x}_M - 0| = |\dot{x}_M| = V .$$

For constant mass M the equation of motion yields

$$\frac{d}{dt}(MV) = M\frac{d}{dt}V = M\frac{dr}{dt}\frac{d}{dr}V = MV\frac{d}{dr}V = F_{law}(r) ,$$

which integrates to

$$\frac{1}{2}MV^2 = (KE)_M = \int F_{law}(r)dr .$$

In this case in which the force exerter m is held fixed, which is the one usually considered, the full formula force $F_{law}(r)$ is effective in imparting kinetic energy (KE) to the test mass M. This is exactly what one would expect.

Case B. *The masses are released simultaneously and are both free to move along the x-axis after release.* Before release the total momentum of the bodies is zero. After release it is also zero: $M\dot{x}_M + m\dot{x}_m = 0$ or $\dot{x}_m = -(M/m)\dot{x}_M$. As before we have $V = |\dot{x}_M|$ and find that

$$u = \frac{d}{dt}r = |\dot{x}_M - \dot{x}_m| = \left(1 + \frac{M}{m}\right)|\dot{x}_M| = \left(\frac{M+m}{m}\right)V ,$$

or

$$V = \left(\frac{m}{M+m}\right)u .$$

Thus

$$\frac{d}{dt}(MV) = M\frac{d}{dt}V = M\left(\frac{m}{M+m}\right)\frac{d}{dt}u = \mu\frac{d}{dt}u ,$$

where μ is reduced mass. The equation of motion then yields

$$\frac{d}{dt}(MV) = \mu\frac{d}{dt}u = \mu\frac{dr}{dt}\frac{d}{dr}u = \mu u\frac{d}{dr}u = F_{law}(r) ,$$

which integrates to

$$\frac{1}{2}\mu u^2 = \int F_{law}(r)dr .$$

It follows that

$$\frac{1}{2}\mu u^2 = \frac{1}{2}\left(\frac{Mm}{M+m}\right)\left(\frac{M+m}{m}\right)^2 V^2 = \frac{1}{2}MV^2\left(\frac{M+m}{m}\right)$$
$$= (KE)_M\left(\frac{M+m}{m}\right) = \int F_{law}(r)dr .$$

This can alternatively be written in terms of a physically effective "reduced force,"

$$(KE)_M = \int F_{red}(r)dr ,$$

where

$$F_{red}(r) = \left(\frac{m}{M+m}\right)F_{law}(r) .$$

Note that Case A is the special limiting situation, $F_{red} = F_{law}$, of Case B in which $m \to \infty$; that is, the force exerter m has infinite inertial (not gravitational) mass -- which is equivalent to supposing the mass m to be "anchored" in the initial rest inertial system, so that (for whatever physical reason) it cannot move with respect to that system. This is another way of saying that the anchored m can *sustain the full reaction force* of its action on M. We see that in general for $m < \infty$ we have $F_{red} < F_{law}$. This means that any force exerter of relatively low mass, imperfect "anchoring," or poor "footing," cannot impart as much kinetic energy to the object on which it acts as the force formula (or force law employed in the equation of motion) would lead us to believe. This shortfall of motional energy is quantified by the "force reduction factor" [$m/(M+m)$], where these masses are inertial ones associated with the force exerter (m) and exertee (M).

Another way to put this proposition is that in stating or defining force laws it is universal practice to make the **tacit assumption** that the force exerter whose action is quantified by F_{law} *does not recoil* under reaction force. But of course it does recoil physically -- that is made explicit by Newton's third law -- so "physical force," here quantified by F_{red}, is always less than or equal to "formula force," F_{law}. We thus acquire a new insight into the third law: Its basic meaning is that in the real world of observable consequences it is impossible to exert more action than the equivalent of what is sustainable as reaction; that is:

Precept: *Observable action is limited by sustainable reaction.*

This precept has been developed and supported here solely through theoretical arguments. Is there any empirical evidence for it? Yes, there is ... but let us return to that topic after first considering a theoretical counter-argument. It has been suggested [6] that for a very short time after the masses are released no measurable motion of either of them will occur, so during this interval there is no operational meaning to the "force reduction" claimed here. That is, there is a least-count displacement of the masses that is physically detectable, and for interaction times less than required to produce such a displacement it may be that the full formula force should be used. Of course one could with equal plausibility employ a parallel argument to assert the opposite conclusion, but it is more satisfactory, since this is a matter of physics, to appeal to empirical facts.

Consider the Neal Graneau experiment already mentioned. The factual outcome was that the armature jumped up a distance concurrent with the impulse (time integral of force) predicted by the Ampère force law, supposed to act from the instant of initiation of current flow in the circuit, but omitting arc-gap currents and treating forces produced by currents within the external conductive part of the circuit at the full force-formula value. If the full formula force had acted within the arc gaps, there could have been no analytic distinction between solid conductors and gaps, so that the gaps might as well have been filled with metal. Had the gaps been filled with metallic conductor, they would have been of zero width at both top and bottom. This would have corresponded to the case of symmetrical gaps -- which by a corollary of the above-mentioned shape-independence theorem [6] would have resulted in force cancellation and no motion of the armature, in contradiction of the observed facts.

So, the full formula force cannot have acted in the arc gaps. Instead, the force that acted physically may be presumed to be F_{red}. The force reduction factor in the arc gaps was $[m/(M+m)]$, where the force exerter mass m was the mass of a stream of ions in the arc plasma (a very small fraction of a gram), and the force exertee (armature) mass M was several grams, so that $m << M$. Consequently the reduced force physically acting from the arc gaps was so much less than the formula force F_{law} that no great error was anticipated to result from ignoring the arc-gap currents entirely. On the other hand, the fixed metallic conductive parts of the external circuit were idealized as being rigidly attached to an essentially infinitely massive earth, so that the force exerter mass $m \to \infty$ and the force reduction factor was unity. It was therefore considered justified to use the full Ampère "formula force" in the calculations associated with the solid portions of the external partial circuit. In short the gaps were treated as containing no force exerters and the solid parts of the external partial circuit as exerting F_{law}. Such calculations using the Ampère force law (whether done numerically for the actual circuit shape or in the filamentary approximation for a simplified equivalent shape) led to semi-quantitative agreement with observation. This fact lends inferential support not only to the Ampère force law but to the assumption that in the arc gaps the force $F_{red} \approx 0$, not F_{law}, acted on the armature *from the start* -- *i.e.*, from the earliest initiation of current flow.

It is of course not possible to **prove** any theoretical proposition by any finite amount of empiricism, and the reader may justly feel that a heavy demand is being placed upon one experiment in asking it to validate both a force law and a general precept concerning Newton's third law. Other experiments of quite different physical character could be cited with comparable results. There can never be too much empirical data, though, so it might not be amiss to suggest humbly to the reader that he or she go into the laboratory and gather its own data -- which will be of far more enduring value than any amount of theorizing or argumentation.

5. Hertzian First-order Invariant Field Equations

The task of all electromagnetic theory, whether of the field or action-at-a-distance variety, is to describe observable effects of electric charge interactions. The field is only a device to that end. We have briefly considered some of the alternatives to field theory ... now let us turn to alternatives within field theory itself. A major choice-point arises at the start, where a selection must be made between invariant and covariant mathematical formulations. For sake of argument (though this has been challenged [10]) let us suppose that Maxwell got the physics "right in one laboratory." The issue then concerns how to make a mathematical "covering theory" (one that reproduces all results of the covered theory "in one laboratory" but extends the description to laboratories in other states of motion) embodying the relativity of motion of all inertial systems. (Motional relativity was recognized as an *empirical fact* not only in Newtonian mechanics but in electromagnetism during the last decades of the nineteenth century from experiments of Mascart and others at first order in (v/c) and from the Micheson-Morley experiment at second order.)

The covering theory chosen by Einstein was a trivial identity transformation. That is, Maxwell's theory, without any change of parametrization, was simply replicated in all other inertial systems. Since such formal replication did not follow mathematically from application of the Galilean transformation to the description of inertial motions, that difficulty was evaded by associating such motions with the Lorentz transformation and by substituting the concept of covariance for invariance. Covariance was assumed to be "just as good" as invariance -- and the distinction was soon virtually dropped.

The pathway of genuine invariance was explored by Heinrich Hertz [11]. At first order he chose to stick with the Galilean transformation as descriptor of inertial motions. He was able to achieve rigorous invariance under this transformation by developing a nontrivial covering theory of Maxwell's vacuum equations (not the identity transformation) involving an extra velocity-dimensioned parameter, which we shall here denote $\mathbf{v}_d$. The main mathematical trick used to accomplish this was to substitute for Maxwell's partial time derivatives, wherever they appeared, total time derivatives of the form

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \mathbf{v}_d \cdot \nabla \ . \qquad (1a)$$

Naturally, this spoiled the "spacetime symmetry" of Maxwell's equations (since no corresponding change was made in the spatial partial derivatives) -- but since no empirical or operational basis has ever emerged to independently validate such symmetry it may be considered no loss to physics. That Hertz had achieved a covering theory of Maxwell's was evident from the fact that Maxwell's partial time derivatives were recovered identically on setting $\mathbf{v}_d = 0$. (The Maxwellian source terms also had to be modified by a Galilean velocity transformation involving $\mathbf{v}_d$, but again Maxwell's equations were recovered whenever this parameter vanished.)

Hertz's equations for the vacuum case thus took the form

$$\nabla \times \mathbf{B} - \frac{1}{c}\frac{d\mathbf{E}}{dt} - \frac{4\pi}{c}\mathbf{j}_m = 0, \qquad (1b)$$

$$\nabla \times \mathbf{E} + \frac{1}{c}\frac{d\mathbf{B}}{dt} = 0, \qquad (1c)$$

$$\nabla \cdot \mathbf{B} = 0, \qquad (1d)$$

$$\nabla \cdot \mathbf{E} - 4\pi\rho = 0, \qquad (1e)$$

where

$$\mathbf{j}_m = \mathbf{j} - \rho\mathbf{v}_d , \qquad (2)$$

$\mathbf{j}$ being the Maxwellian current density. (Actually, we have considerably streamlined Hertz's equations, both as to vector notation and as to eliminating his provision for magnetic monopoles, etc., as well as by the assumption of a constant $\mathbf{v}_d$ parameter without space-variable dependence. The reader interested in the mathematics of possible broader formulations involving "Helmholtz derivatives" -- *i.e.*, generalized forms of total derivative -- might wish to consult Mocanu [12]. We are not interested here in either historical accuracy or maximum generality, but in conveying ideas.)

6. Proof of Invariance

To show the invariance of Eq. (1), including true invariance of the field vectors,

$$\mathbf{E}' = \mathbf{E} , \quad \mathbf{B}' = \mathbf{B} , \qquad (3)$$

under the Galilean transformation

$$\mathbf{r}' = \mathbf{r} - \mathbf{v}t , \qquad t' = t , \qquad (4)$$

requires only the assumption of the Galilean velocity addition law, as applied to the Hertzian velocity parameter,

$$\mathbf{v}'_d = \mathbf{v}_d - \mathbf{v} \qquad (5)$$

and of the constancy of the units ratio,

$$c' = c . \qquad (6)$$

It is important not to confuse the inertial system relative velocity parameter $\mathbf{v}$ with the Hertzian parameter $\mathbf{v}_d$, the distinction, Eq. (5), being crucial to the invariance proof. First we note the Galilean source transformation equations,

$$\rho'(\mathbf{r}',t') = \rho(\mathbf{r},t) \qquad (7)$$

and

$$\mathbf{j}'(\mathbf{r}',t') = \mathbf{j}(\mathbf{r},t) - \rho(\mathbf{r},t)\mathbf{v} . \qquad (8)$$

From equation (4) follow the operator relations

$$\nabla' = \nabla, \qquad \frac{\partial}{\partial t'} = \frac{\partial}{\partial t} + \mathbf{v}\cdot\nabla , \qquad (9)$$

which, together with (7) and (8), have been previously noted by numerous writers such as Jammer and Stachel [13].

We now proceed to the invariance proof. First we establish the invariance of the total time derivative operator:

$$\left(\frac{d}{dt}\right)' = \left(\frac{\partial}{\partial t} + \mathbf{v}_d \cdot\nabla\right)' = \frac{\partial}{\partial t'} + \mathbf{v}'_d \cdot\nabla'$$
$$= \left(\frac{\partial}{\partial t} + \mathbf{v}\cdot\nabla\right) + (\mathbf{v}_d - \mathbf{v})\cdot\nabla = \frac{\partial}{\partial t} + \mathbf{v}_d \cdot\nabla = \frac{d}{dt} \qquad (10)$$

by application of Eqs $(1a)$, (5), and (9). Next, the invariance of the "measured" current density,

$$\mathbf{j}'_m = (\mathbf{j} - \rho\mathbf{v}_d)' = \mathbf{j}' - \rho'\mathbf{v}'_d$$
$$= (\mathbf{j} - \rho\mathbf{v}) - \rho(\mathbf{v}_d - \mathbf{v}) = \mathbf{j} - \rho\mathbf{v}_d = \mathbf{j}_m \ , \qquad (11)$$

follows from Eqs. (2), (5), (7), and (8). Given these preliminaries, verification of invariance of the field equations becomes merely a matter of inspection. Invariance of Eq. $(1d)$,

$$(\nabla \cdot \mathbf{B})' = \nabla' \cdot \mathbf{B}' = \nabla \cdot \mathbf{B} = 0 \ , \qquad (12)$$

follows from Eqs. (3) and (9). That of Eq. $(1e)$,

$$\nabla' \cdot \mathbf{E}' - 4\pi\rho' = \nabla \cdot \mathbf{E} - 4\pi\rho = 0 \ , \qquad (13)$$

from the same plus Eq. (7). Our Eqs. (12) and (13) agree with Eqs. $(1c')$ and $(1a')$, respectively, of Jammer and Stechel [13]. Invariance of Eq. $(1c)$, above,

$$\nabla' \times \mathbf{E}' + \frac{1}{c'}\left(\frac{d}{dt}\right)' \mathbf{B}' = \nabla \times \mathbf{E} + \frac{1}{c}\frac{d}{dt}\mathbf{B} = 0 \ , \qquad (14)$$

follows from Eqs. (3), (6), (9), and (10). That of Eq. $(1b)$,

$$\nabla' \times \mathbf{B}' - \frac{1}{c'}\left(\frac{d}{dt}\right)' \mathbf{E}' - \frac{4\pi}{c'}\mathbf{j}'_m = \nabla \times \mathbf{B} - \frac{1}{c}\frac{d}{dt}\mathbf{E} - \frac{4\pi}{c}\mathbf{j}_m = 0 \ , \qquad (15)$$

from the same plus Eq. (11). The results (14) and (15) were not given by Jammer and Stachel, but are obviously crucial to the whole enterprise.

From this demonstration the reader can ascertain the meaning of true invariance probably better than from any attempted rigorous mathematical definition. Each symbol transforms in place, and Eq. (3) shows that each component of vector quantities also transforms in place -- in stark contrast to covariance, wherein vector components are "scrambled" by a rule of linear combination, the only true "invariance" being that of the rule itself. The invariance of a continuity equation,

$$\nabla' \cdot \mathbf{j}'_m + \left(\frac{d}{dt}\right)' \rho' = \nabla \cdot \mathbf{j}_m + \frac{d}{dt}\rho = 0 \ , \qquad (16)$$

as well as invariant formulations of electromagnetic potential definitions, using invariant total time derivatives instead of partial time dervatives, are readily established. So much for formal manipulations. Let us now seek some physical understanding of what we have been doing.

7. Physical Interpretation: $\mathbf{v}_d$

To judge from the number and persistence of mistakes made, physical interpretation is by far the hardest part of the theoretical physicist's job. In fact one could say it is the only part of his job with any physics in it, if the mathematics be left to people we can call mathematicians. On this basis there are not many theoretical physicists around, given that the people we call that are mostly doing mathematics. Anyway, there can be no controversy about the mathematics of above-proven invariance of the equations of Hertzian vacuum electromagnetism. But there can and probably will be controversy about physical interpetation of the Hertzian velocity parameter $\mathbf{v}_d$. The invariant mathematics has been repeatedly rediscovered, mostly by people who were not aware of Hertz's priority or even of his being implicated. But no two of these rediscoverers have agreed among themselves or with Hertz on what $\mathbf{v}_d$ means physically.

Hertz's own interpretation of this parameter was something of a comedy of errors -- although the historical outcome, that his invariant mathematics was discarded and forgotten, must be viewed as one of the great tragedies of physics. A modern mind, confronted with a set of equations invariant under Galilean inertial transformations, would immediately think "relativity" and banish all thought of ethers. The fact that the transformations leave the equations unaltered and independent of the Galilean velocity parameter $\mathbf{v}$ would be judged conclusive. But Hertz was a child of his times, and in those times *every physicist* thought in terms of ether. (Note again the strategic penalties of failure to maintain a plurality of presumptions in science.) Therefore, Hertz automatically interpreted his new velocity parameter as ether velocity. This initial mistake was at once compounded by another one: He hypothesized (contrast the wisdom of Newton in not feigning hypotheses) a Stokesian ether, 100% convected by material bodies. So his $\mathbf{v}_d$ became the velocity in the laboratory of just any material body.

Though honesty profited from a definition imparting such specificity and tangibility to "ether," physics suffered. Soon after Hertz's untimely death experiments were done (Eichenwald [14]) that showed some of the predictions of Hertz's mathematics plus his dreadfully explicit ether interpretation to be counterfactual. For some reason this was assumed to mean that Hertz's mathematics was wrong, so his theory was discarded and forgotten. It becomes difficult to understand such an assumption, if we recall that Maxwell's mathematics plus his ether interpretation also and equally led to counterfactual predictions. [Maxwell's noninvariant equations, when subjected to a Galilean inertial transformation, yield a plethora of false predictions, such as unobserved fringe shifts at first order in (v/c).]

In Maxwell's case the failure of an ether interpretation was made the occasion for glorifying and perpetuating his equations, so that now they blossom forth on the sweatshirts of sophomores; whereas in Hertz's case the failure of an ether interpretation induced exactly opposite behavior. We point this out as a counterexample to any claim that consensus in physics leads to rational decision-making. Rationality might still be salvaged in this example, were it true that Hertz's mathematics is in some intrinsic sense poorer, more degraded, less elegant, etc., than Maxwell's mathematics. But in fact Hertz's mathematics is a **covering theory** of Maxwell's mathematics -- and an invariant covering theory at that. So in purely mathematical terms all the degradation and poorness lie on the side of Maxwell's noninvariant special case of Hertz's more comprehensive formulation. Any ugliness you can find in Hertz's equations is already there in Maxwell's. Of course Hertz's equations are not covariant. That is in fact their proudest boast. Through true invariance they embody the rigorous **form preservation** that covariance loosely advertizes itself to represent. And if our fine-tuned experts in interpretation are to interpret covariance as the mathematical expression of a physical relativity principle, are they to do less for invariance?

On examining the parametrization of Maxwell's equations we quickly make a rather surprising discovery never mentioned in textbooks: Those equations are parametrized to describe field source motions but not field sink motions. The field sink, absorber, or detector must remain at rest with respect to the observer or his inertial frame or his "field point" -- not because such objects cannot move physically but because Maxwell's equations contain no parameters descriptive of their nonzero velocity. That is, if the Maxwell "field" is to be defined by any sort of measurement operations, the instrument involved must be always at rest in the observer's inertial frame (normally at his "field point"). In contrast, the field sources -- point charges -- have their velocity parameters present in good order, incorporated in the Maxwell current density **j**. Why this asymmetry between sources and sinks, in a theory generally considered to support reciprocity among those entities? Such a question is all the more critical for a theory that is about to be apotheosized into the basis for a world *kinematics patterned upon electromagnetism*, which will march under a banner (borne mid snow and ice) with a strange device: **Relativity**. For some might *interpret* the enforced permanent immobilty of a gross composition of matter such as a field detector with respect to an observer as conferring a "preference" upon that observer, and therefore as unsuiting such theory to serve as the logical basis for any motional relativity theory whatsoever.

At this point it becomes blindingly clear what physical interpretation we are to make of the new velocity-dimensioned parameter $\mathbf{v}_d$ with which Hertz's invariant mathematics has obligingly furnished us:

Interpretation. *The Hertzian velocity parameter* $\mathbf{v}_d$ *is the velocity of the absorber or field detector with respect to the observer or his inertial frame.*

The reason this works is that when $\mathbf{v}_d$ is set equal to zero we know on the mathematical side that this causes $d/dt \to \partial/\partial t$, so that Maxwell's mathematics is recovered; and on the physical side it accomplishes a bringing to rest of the field detector in the observer's frame of reference, so that Maxwell's physics is recovered. The interpretation is unique in harmonizing the mathematics and physics in this way and also in specifying a tangible object whose state of motion is quantified by the Hertzian parameter. Since Hertz himself favored tangible objects as the basis for what we today might call operational definitions, it seems likely that he would approve such an interpretation, given the failure of his first choice. The presence in Hertzian electromagnetism of an absorber velocity parameter removes the source-sink parametrization asymmetry of Maxwell's theory and corrects the under-parametrization responsible for that theory's first-order noninvariance. We shall seek no further justification of this interpretation.

8. Physical Interpretation: The Field Quantities

The Hertzian and Maxwellian field quantities are physically as well as mathematically strongly distinguished from each other -- though we have used the familiar **E**, **B** symbols for both. The Hertz fields are operationally or instrumentally defined in a more complicated way than the Maxwell fields, in that an extra velocity parameter $\mathbf{v}_d$ must be specified (according to the above interpretation, this is the velocity of the field detector with respect to the observer) in order to define the Hertz field quantities. The compensation for this extra operational complexity is simplification of the mathematical transformation properties of those field quantities, as testified by Eq. (3). In contrast, the Maxwell field quantities have rather simple operational definitions: The field components are what is registered by instruments permanently at rest at the observer's field point. But this simplicity is paid for in complexity of the mathematical treatment of those components, which get "scrambled" unmercifully. Hitherto it was thought that this scrambling was a matter of physics -- an objective aspect of the world -- but now we see that it has nothing to do with description-independent physical facts but is an artifact of mathematical parametrization, or the lack of it.

What physical model of the Hertzian field detection process are we to associate with the mathematical property of field invariance, Eq. (3)? Since the motion of a field detector (which we can idealize as a black box on the outside of which appear digital readouts of three electric and three magnetic field components) is described by an arbitrary (constant) velocity parameter present in the field equations, it is apparent that any inertial observer can describe the relative motion of *that particular instrument*. The field components E_x, E_y, E_z, etc., stand for numbers on the digital readout of the given instrument. Mathematical invariance of those components or field quantities has just the trivial meaning that observers in all different states of motion will at any event of reading always perceive exactly the same numbers. So, the Hertzian picture is that of many different observers reading numbers off of one unique physical instrument. (Obviously that instrument can be at rest at the field point of at most one inertial observer. For each of the others, it *passes through* his field point at the event of instrument reading in some non-zero state of motion -- all field points being supposed to ccincide at that event.)

The physical model appropriate to the Maxwellian field detection process is complementary to that just described, but sounds more complicated. Since the field detection instrument is now anchored at rest at the field point of each inertial observer, this means that, given a plurality of observers and their concomittant field points, there must be a plurality of instruments present. The instruments must comove with the field points, and, like the latter must in concept occupy the same space-time point at the event of simultaneous reading of the spatially coincident instruments. Each observer reads his own set of field component numbers at this event of coincidence, and the sets of numbers so determined are related by linear combination ("scrambling"). In order for one observer to predict from his own set of readings what the numbers are in some other observer's set of readings, mathematical calculation must be done using the linear scrambling-rule and a knowledge of relative velocity of the observers.

It will be observed that incorporated in the Maxwellian model is a tacit assumption that the readings of various macroscopic instruments present at the same physical event do not in any sense *interfere* with each other. There is of course the problem of physical collision damage -- but let us suppose that that can be evaded by arranging for "near misses" of very small instruments, so that difficulty can be ignored. With such an understanding, there was nothing known about interference of instruments at the time Einstein did his work on special relativity. But in 1925 it was recognized that macroscopic instruments suffer from a subtler and more profound form of mutual interference -- that detection events occurring within one piece of macroscopic apparatus are physically unique and cannot *in principle* be replicated by events occurring within any other piece of macroscopic apparatus. Thus the idealization foundational to the Maxwellian picture, involving the tacit assumption that *two relatively-moving field detection instruments could share the same detection event (or, barring that, could replicate events)*, was ruled impermissible at the quantum level. So, after 1925, the Maxwell (multi-instrument) field became clearly the wrong "field" for quantum description and the Hertz (single-instrument) field became the right one (if the field approach is the "right" one at all).

9. Neo-Hertzian Electromagnetism

So far our discussion has been limited strictly to first-order approximation. We now address the higher-order description of electromagnetic phenomena. In seeking a clue as to how to proceed, we take note of the fact that in advancing from Maxwell's "in one laboratory" equations to Hertz's invariant covering theory we left the spatial variables strictly alone and tampered only with the time variable. Let us see if this theme can be extended. (The main thing of which to be aware is that *spacetime symmetry* is an artifact of Maxwell's noninvariant equations, which we have abandoned in favor of a Hertzian invariant formulation. Keep in mind, also, that a "spacetime symmetry," or any other formal feature, lost at first order can never be restored at higher orders. Therefore we are under no obligation to tamper with space variables at higher orders, having left them alone at first order.) Leaving the space variables alone means treating them as higher-order kinematic invariants -- so obviously this subject cannot be examined without at least implicit assumptions about kinematics. Here we cannot rely on Einstein, because the spacetime symmetry basis of his kinematics, borrowed from Maxwell's theory, is violated at the outset in Hertzian theory.

Nevertheless, let us in our turn borrow from Einstein what we can. He had useful enlightenments about *time*, which we cannot afford to ignore. Particularly valuable in his physics is the recognition that the different types of operational definition of "time" can entail different clock running-rates. That is, the "proper time" told by a single clock in an arbitrary state of motion is physically an entirely different proposition from the "frame time" told by a collection of comoving clocks spatially extended and somehow synchronized. That the single clock's time can be considered a kinematic invariant is an important insight we shall here seek to preserve. There is no use for covariance in Hertzian theory or in any generalization of it, but Einstein's identification of the *timelike invariant* of kinematics can readily be shown to be the key to the agreements of the on-worldline aspects of his theory with the high-energy particle data that constitute most of the empirical validation of his special theory. The fact that states of motion can affect clock rates, by the way, does not imply the relativity of simultaneity -- that is, it does not mean that distant simultaneity or instant action-at-a-distance is necessarily nonphysical. Simultaneity is a matter of clock phasing, requiring separate analysis [15]. Phase equality of two events in each of many systems does not demand rate agreement among those systems.

We take the present position that there is little or no evidence supporting the physical validity of the Einstein-Minkowski spacelike invariant. The same is true of other worldline-relational claims supporting the alleged **metric nature** of spacetime. Required to stand on its own, without support from the assumption of "spacetime symmetry" as a physical fact, Minkowski's "elsewhere" collapses for the most part into rhetoric. There is a small amount of high-energy physics testimony that may dispute this ... but it is undeniable that the great bulk of experimentation to date provides strictly on-worldline, not inter-worldline (or world-structural), evidence. And all on-worldline evidence is ascribable solely to the invariance of the timelike interval. (All particle motions are traced out by sequences of event pairs separated by purely timelike intervals!)

Therefore, as a plausible first alternative pathway to explore, we propose to employ a higher-order kinematics wherein the postulated spacelike invariant is ordinary length or distance (no Lorentz contraction) and the timelike invariant is the proper-time interval. In application to electromagnetism, since proper time is always "proper" to some identifiable object, we have to say what the time parameter in the field equations refers to. This problem practically solves itself, since we have been at great pains to call attention (by parametrization of its motions relative to observers) to the central object of field theory -- *viz.*, the *field detector* that measures the components of the field. So, to attain a higher-order formulation of electromagnetism, which we term "neo-Hertzian," we need only replace t wherever it appears in Hertz's equations with τ_d, the proper time of the field detector or absorber. Thus, our proposed neo-Hertzian equations are

$$\nabla \times \mathbf{B} - \frac{1}{c}\frac{d\mathbf{E}}{d\tau_d} - \frac{4\pi}{c}\mathbf{j}_m = 0 \qquad (17a)$$

$$\nabla \times \mathbf{E} + \frac{1}{c}\frac{d\mathbf{B}}{d\tau_d} = 0 \qquad (17b)$$

$$\nabla \cdot \mathbf{B} = 0 \qquad (17c)$$

$$\nabla \cdot \mathbf{E} - 4\pi\rho = 0 \ , \qquad (17d)$$

where $\mathbf{j}_m$, the current density measured by a detector comoving with the field detector, is related to the Maxwellian current density by whatever higher-order velocity composition law replaces the Galilean law of Eq. (2). (This purely kinematic topic has been explored elsewhere [16] and need not detain us here.) It is understood that we adopt Einstein's definition of the proper-time invariant interval $d\tau$, namely,

$$d\tau^2 = dt^2 - dr^2/c^2 = \textit{invariant}. \qquad (18)$$

10. Neo-Hertzian Wave Equation

The formal similarity of Eq. (17) to Maxwell's equations permits us to write down the wave equation at once,

$$-\nabla^2\mathbf{E} + \frac{1}{c^2}\frac{d^2}{d\tau^2}\mathbf{E} = 0 \ , \qquad (19)$$

for electric wave propagation in vacuum. Here we have dropped the d-subscript from τ for simplicity, it being understood that time is measured by a clock comoving with the field detector. From Eq. (18) we obtain

$$\frac{d}{d\tau}=\frac{dt}{d\tau}\frac{d}{dt}=\frac{1}{\sqrt{1-v^2/c^2}}\frac{d}{dt}=\gamma\frac{d}{dt} \quad . \tag{20}$$

Here v and γ both refer to motion of the field detector at rest in inertial system K' relative to our laboratory system K. That is, v is the previous v_d, which could also be identified with the velocity appearing in the Galilean transformation for that particular inertial system in which the field detector happens to be at rest. (We treat this velocity and γ as constant for inertial motion.) To show its higher-order invariance the Galilean transformation in question could be written as

$$\mathbf{r}'=\mathbf{r}-\mathbf{V}\tau \,, \qquad \tau' = \tau \,, \tag{21a}$$

where all quantities are manifestly invariant in view of $\mathbf{V}=d\mathbf{r}/d\tau=\gamma\mathbf{v}$, as follows from (18). In the same way we see that $\mathbf{V}\tau=\mathbf{v}t$, so the spatial part of the transformation might as well be written in the original Galilean form,

$$\mathbf{r}'=\mathbf{r}-\mathbf{v}t \quad . \tag{21b}$$

The time part of (21a) is not quite what we want, because it merely states the triviality that observers in K, K' (or any other inertial system) will read the same numbers off the digital clock comoving with the field detector. More to the point is to replace the time increments employed in Eq. (20) with finite time intervals, so that $t/\tau=\gamma$, and then recognize that the clock comoving with the field detector and reading τ-time is actually one of the comoving clock set in K' that defines t' time. Thus $t/t'=\gamma$ or

$$t'=t/\gamma \quad . \tag{21c}$$

Eqs. (21b) and (21c) are probably the most useful form of the higher-order or "neo-" Galilean transformation appropriate to the kinematics we have postulated. The more general case in which the field detector moves in both K and K' has been treated elsewhere [16].

We are now ready to solve the wave equation. Following the customary d'Alembertian approach, we look for a solution of the form $\mathbf{E}=\mathbf{E}(p)$, where

$$p \;=\; \mathbf{k}\cdot\mathbf{r}-\omega t \;=\; xk_x+yk_y+zk_z-\omega t \quad . \tag{22}$$

We find that

$$\nabla^2\mathbf{E}(p) \;=\; \left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)\mathbf{E}(p) \;=\; \left(k_x^2+k_y^2+k_z^2\right)\mathbf{E}''(p)=k^2\mathbf{E}'' \,, \tag{23a}$$

where double-prime denotes two differentiations with respect to p. Similarly, using Eqs. (20) and (1a), we have

$$\begin{aligned}\frac{d^2}{d\tau^2}\mathbf{E}(p) \;&=\; \gamma\frac{d}{dt}\gamma\frac{d}{dt}\mathbf{E}(p) \;=\; \gamma^2\left(\frac{\partial}{\partial t}+\mathbf{v}\cdot\nabla\right)^2\mathbf{E}(p)\\ &=\; \gamma^2\left[\frac{\partial^2}{\partial t^2}+2\frac{\partial}{\partial t}(\mathbf{v}\cdot\nabla)+(\mathbf{v}\cdot\nabla)^2\right]\mathbf{E}(p)\\ &=\; \gamma^2\left[\omega^2-2\omega(\mathbf{v}\cdot\mathbf{k})+(\mathbf{v}\cdot\mathbf{k})^2\right]\mathbf{E}'' \;=\; \gamma^2\left[\omega-(\mathbf{v}\cdot\mathbf{k})\right]^2\mathbf{E}'' \quad .\end{aligned} \tag{23b}$$

From (19) and (23) it follows that

$$\left\{-k^2+\frac{\gamma^2}{c^2}\left[\omega-(\mathbf{v}\cdot\mathbf{k})\right]^2\right\}\mathbf{E}'' \;=\; 0 \,, \tag{24}$$

or, from the vanishing of the coefficient of $\mathbf{E}''$, it follows that

$$ck = \gamma|\omega - \mathbf{v}\cdot\mathbf{k}| \qquad \text{or} \qquad \frac{\omega}{k} = \pm\frac{c}{\gamma} + \frac{\mathbf{k}}{k}\cdot\mathbf{v} \ . \tag{25}$$

It is useful to define a phase velocity u, measured in the laboratory system K, as

$$u = \frac{\omega}{k} = \pm\sqrt{c^2 - v_d^2} + \frac{\mathbf{k}}{k}\cdot\mathbf{v}_d \ . \tag{26}$$

We have restored the d-subscript here to emphasize that the phase velocity is altered by field detector or absorber motion in the laboratory. In effect there is "convection of light by the absorber," as has been noted before [16], it being easily seen that the light speed is increased in whatever direction the absorber moves, so that in effect photons are pulled along by their destined absorber. However, it can be shown that such apparent acausality is not really observable, for the same reason that ether winds and one-way phase velocities are not observable. (In fact the dot-product relationship $\mathbf{k}\cdot\mathbf{v}_d$ is mathematically exactly what is encountered in *Potier's principle*, by which it was demonstrated [16] in the last century from Fermat's principle that no first-order effects of an ether wind are observable.)

The most general d'Alembertian expression for the solution of the wave equation can, by use of (22) and (26), be written as

$$\mathbf{E} = \mathbf{E}_1\left[\mathbf{k}\cdot\mathbf{r} + \left(k\sqrt{c^2 - v_d^2} - \mathbf{k}\cdot\mathbf{v}_d\right)t\right] + \mathbf{E}_2\left[\mathbf{k}\cdot\mathbf{r} - \left(k\sqrt{c^2 - v_d^2} + \mathbf{k}\cdot\mathbf{v}_d\right)t\right] \tag{27}$$

where $\mathbf{E}_1, \mathbf{E}_2$ are arbitrary vector functions. Invariance of the field equations and their solutions under the neo-Galilean transformation implies invariance of the wave equation and of its solution. Thus the invariance of Eq. (3), $\mathbf{E}(p) = \mathbf{E}'(p')$, implies

$$p = p' \rightarrow \qquad \mathbf{k}\cdot\mathbf{r} - \omega t = \mathbf{k}'\cdot\mathbf{r}' - \omega' t' \tag{28}$$

which describes a constant phase value of the propagating field in frames K and K'. Eliminating $\mathbf{r}', t'$ by means of Eqs. (21b) [with $\mathbf{v}$ identified with detector velocity $\mathbf{v}_d$] and (21c), and using the fact that $\mathbf{r}, t$ are arbitrary, so that their coefficients vanish, we find

$$\textit{Coeff. of } \mathbf{r}: \qquad \mathbf{k}' = \mathbf{k} \tag{29a}$$

$$\textit{Coeff. of } t: \qquad \omega' = \gamma(\omega - \mathbf{k}\cdot\mathbf{v}_d) \tag{29b}$$

The first of these results describes aberration, the second the Doppler effect. We shall not discuss the latter, but will examine stellar aberration, since at first glance Eq. (29a) seems to deny its possibility.

11. Stellar Aberration

We shall give only one example of application of the neo-Hertzian wave equation solution just derived, namely, to stellar aberration. First, we remark that special relativity or Maxwell's equations seem to have some difficulty with this phenomenon. The problem is that such disciplines, built on "spacetime symmetry," must use a covariant four-vector formulation in describing all phenomena of nature. No failures can be allowed. In the case of aberration it is customary to form the four-vector from the light propagation **k**-vector for the spacelike components and from the frequency parameter subject to Doppler shift for the timelike component. Aberration comes in because in general the **k**-vector does not stay parallel to itself under the Lorentz transformation. Thus $\mathbf{k}'/k' \neq \mathbf{k}/k$, and the resulting turning of the **k**-vector may be interpreted as an aberration effect. There are problems about that we need not go into, but the basic problem is this:

The Lorentz transformation between two inertial systems is parametrized by a single velocity parameter, call it **v**. The Doppler effect is known to depend on the relative velocity of light source and detector, call it $\mathbf{v}_{sd}$. So, in order to describe the transformation of frequency so as to get the right first-order Doppler formula, we must take $\mathbf{v} = \mathbf{v}_{sd}$. On the other hand the phenomenon of stellar aberration is known to have an annual periodicity and a property of conformality (such that stars in a given small region of the sky all show about the same aberration, independently of their various proper motions). These characteristics imply that description of stellar aberration must be parametrized by $\mathbf{v}_{orb}$, the earth's orbital velocity around the sun. Thus, in order to describe stellar aberration so as to yield the correct first-order formula we must take $\mathbf{v} = \mathbf{v}_{orb}$. But in general $\mathbf{v}_{sd}$ and $\mathbf{v}_{orb}$ are entirely different parameters -- the former being dependent on source velocity, the latter independent of it. Because $\mathbf{v}_{sd} \neq \mathbf{v}_{orb}$, it follows that $\mathbf{v} \neq \mathbf{v}$. This is an undesirable consequence in any theory founded upon logic. Thus the doctrine of universal covariance runs into a severe logical impediment when trying to incorporate stellar aberration and the Doppler effect into the same four-vector.

No such difficulties are encountered in describing stellar aberration by means of the neo-Hertzian formalism, because there is no conceptual linkage to the Doppler effect, so one is free to use different velocity parameters. Moreover, the "radiation convection" exhibited by the phase velocity expression, Eq. (26), directs attention to the *velocity of the absorber* or detector (telescope in the case of traditional aberration) *relative to the observer*. That is the meaning of the parameter $\mathbf{v}_d$. Although we have remarked that one-way phase velocity is generally viewed as impossible to measure in the laboratory, in the phenomenon of stellar aberration we deal with strictly one-way propagation of light, so the neo-Hertzian mathematics should be directly relevant to description of this phenomenon. If we consider our earth-based telescope at one time of year and wish to know how much it must be tilted in order to view a given star at a slightly later time of year, the detector relative velocity between these two occasions is just $\mathbf{v}_d = \mathbf{v}_{orb}$, the earth's orbital velocity, so we get automatically the right velocity parametrization to describe the phenomenon.

Consider a star at the zenith, a direction which we shall suppose for simplicity to coincide with the pole of the ecliptic. Eq. (29*a*) would seem to say that our mathematics cannot predict a telescope tilt, since the 3-vector of light propagation is claimed in neo-Hertzian theory to be physically invariant -- that is, unaffected by inertial transformation. However, let us work through the problem, taking account of the effect of detector velocity on phase velocity, as given by Eq. (26). Since our targeted star is on the celestial sphere at the pole of the ecliptic, its **k**-vector according to Eq. (29*a*) is constantly aligned with the zenith direction at all times of year. This means it is rigorously perpendicular to the earth's orbital plane, hence to the earth's velocity vector and the telescope velocity vector $\mathbf{v}_d$. Therefore at all times $\mathbf{k} \cdot \mathbf{v}_d = 0$, exactly. Hence by Eq. (26)

$$|u| = \sqrt{c^2 - v_d^2} \qquad (30)$$

Thus the phase velocity of light coming straight down from the zenith is slightly slowed below the velocity *c,* which we know the light must have relative to an observer who comoves with the telescope (or relative to the tube of the telescope itself). [This *c*-speed requirement can be demonstrated analytically from equations already given [17], but it follows in any case from basic principles -- namely, that the neo-Hertzian field equations are a *covering theory* of the Maxwell equations, which reduces to the latter in the special inertial system that comoves with the detector (telescope) ... and we know that Maxwell's equations allow only the speed *c* speed of light.] Since the light speed must be *c* with respect to the telescope tube and less than *c* with respect to the zenith direction, it follows that the telescope tube cannot be pointed parallel to the zenith direction but must be tilted through a small angle α. It is an easy exercise to show by the Pythagorean theorem that

$$\alpha = \sin^{-1} v_{orb}/c\,, \qquad \text{or} \qquad \alpha = v_{orb}/c + O\left(v_{orb}^2/c^2\right) \ \textit{radians}, \qquad (31)$$

the first-order result being all that can be confirmed observationally. Eq. (31) agrees with the observed aberration constant of about 20.5 arc-seconds.

That the sense of the telescope tilt is "forward" along the direction tangent to the earth's orbital motion, and that the correct first-order result is obtained also for off-zenith stars for which $\mathbf{k}\cdot\mathbf{v}_d \neq 0$, has been shown elsewhere [18] and need not detain us here. The phenomenon of stellar aberration, as we have seen, is rather baffling for any theory that takes "spacetime symmetry" seriously, to the extent of accepting the teaching of Minkowski (entailed in "universal covariance") that the distinction among the components of any four-vector (specifically, that of stellar light propagation) has "faded to mere shadows." But we have just seen that it is easily handled by neo-Hertzian theory (despite its assertion of 3-vector invariance of the **k**-vector) precisely because the wave equation solution (26) calls for the *one-way speed of light* to vary with relative motion between field detector and observer. This bizarre and counter-intuitive notion is the key to success in describing stellar aberration, a physical phenomenon of one-way light propagation.

Incidentally, we note that Hertzian first-order theory fails this test. It agrees with neo-Hertzian theory that the **k**-vector is invariant under inertial transformations [Eq. (29*a*)]. But it does not yield the second-order result of Eq. (30), which is crucial to prediction of existence of any first-order aberration at all. In short, the original Hertzian (first-order valid) formalism, without allowance for time dilatation (*i.e.*, for proper-time invariance), predicts zero stellar aberration.

Neo-Hertzian electromagnetism exhibits much less symmetry (starting with the absence of spacetime symmetry) than does Maxwell-Einstein theory. In particular, in considering such phenomena as the Doppler effect, one finds no interchangeability of motions among light source, detector, and observer. This does not fit with classical ideas of source-sink symmetry -- but it fits very well with the Wheeler-Feynman idea of the absorber as the "mechanism of radiation," or with the quantum mechanical idea of irreversible "reduction" that drives the quantum process to its localized "completion" or converts the "particle" from virtual to real. Neo-Hertzian theory shares with quantum mechanics an emphasis on instrumentalism and on the need always to be aware of the relative states of motion of macroscopic apparatus. In both disciplines the instrument can have a seemingly acausal effectuating influence on the phenomenon.

Following Newton's precept, it might be wise to avoid speculating or model-making to explain the apparent instantaneousness of distant influences in electromagnetism or quantum theory. But if we must have models, then the **quantum pure state** provides one ready-to-hand that introduces no new hypotheses into physics. In the pure or "basking" state particles are effectively "virtual," in that they can run freely forward and backward in time, because of time reversiblity of their equations of motion. In such states particles are inaccessible and unaccountable to causality. The reckoning comes only with *process completion* (or observability) ... and why should that not occur in conformity with a universal simultaneity? The attempt to marry field theory to quantum mechanics has led to a conception of the Coulomb field as action-at-a-distance "mediated" by a swarm of virtual particles. To recognize the unearthliness of such particles is to open the mind to descriptive possibilities destructive of many of the old shibboleths.

We have ventured deeply into the fringes of heresy in this chapter, but may conclude it with a thought that will grate upon many of the most free-thinking of genuine heretics; namely, that it will probably turn out -- hostile to scientific progress as the protracted interlude of Einstein-Minkowski intellectual dictatorship may have been -- that future physics will grow in understanding and validity precisely to the degree that the physicists of the next century are able to acquire unbiased comprehensions of where Einstein went right as well as wrong. Eventually there must emerge a much more interesting story than has been dreamt of in the philosophies of any physicists of this century.

REFERENCES

1. J. C. Maxwell, *A Treatise on Electricity and Magnetism* (Dover, NY, 1954).
2. P. Graneau, *Ampère-Neumann Electrodynamics of Metals* (Hadronic Press, Nonantum, MA, 1985).
3. R. Saumont, Phys. Lett. A **165** (1992) 307.
4. P. T. Pappas, "Non Relativistic Forces on Antennas" in Proceedings of the Conference on Foundation of Mathematics and Physics (Perugia, Italy, 1989), U. Bartocci and J. P. Wesley, eds. (B. Wesley, 7712 Blumberg, Germany, 1990).
5. A. E. Robson and J. D. Sethian, *Am. J. Phys*. **60** (1992) 1111.
6. T. E. Phipps, Jr., *Apeiron* No. 17 (October 1993) 1.
7. A. K. T. Assis, *Weber's Electrodynamics* (Kluwer, Holland, forthcoming).
8. T. E. Phipps, Jr., *Phys. Essays* **5** (1992) 425.
9. R. I. Gray, "The Transmission-line Vacuum," (private communication, 1993).
10. G. N. Pellegrini, "Evidence Violating Relativistic Electrodynamics in the Non-radiative (First Order in V^2/C^2) Macroscopic Domain," (private communication, 1994).
11. H. R. Hertz, *Electric Waves*, translated by D. E. Jones (Dover, NY, 1962).
12. C. I. Mocanu, *Hertzian Relativistic Electrodynamics and its Associated Mechanics*, (Hadronic Press, Palm Harbor, FL, 1991), 2 vols.
13. M. Jammer and J. Stachel, *Am. J. Phys.* **48** (1980) 5.
14. A. A. Eichenwald, *Ann. Phys. (Leipzig)* **11** (1903) 1; *ibid.*, 421.
15. T. E. Phipps, Jr., *Found. Phys.* **21** (1991) 1071.
16. T. E. Phipps, Jr., *Heretical Verities: Mathematical Themes in Physical Description* (Classic Non-fiction Library, Urbana, IL, 1987).
17. T. E. Phipps, Jr., "Neo-Hertzian Wave Equation and Aberration," *Galilean Electrodynamics* **5**, 46 (1994).
18. T. E. Phipps, Jr., *Phys. Essays* **4** (1991) 368.