Weber-type Laws of Action-at-a-Distance in Modern Physics

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Recent data indicate that the law of action between electric current elements proposed by Ampere is notably superior to the Lorentz (Biot-Savart) law in its ability to describe laboratory observations of currents flowing in single circuits. Ampere's law conforms to Newton's third law and thus cannot be covariantly expressed. Since all field theories of retarded action violate Newton's third law in describing nonstatic situations, it appears that the observational evidence in question weighs against all field theories as applied to the description of force actions. A reexamination of force instant action-at-a-distance modes of description is therefore indicated. We investigate here the possible revival of such a formulation proposed by W. Weber before 1850. The virtues of this approach are (a) mathematical simplicity, (b) rigorous conformity to Newton's third law, and (*c*) agreement with Ampere's law of action between current elements—hence with the observations just mentioned. Two different "modernizations" of Weber's approach are examined, dependent on whether energy or force methods are viewed as more fundamental in mechanics. Implications for plasma physics are touched upon.

1. Introduction

A peculiarity of the physics of the nineteenth century—which has been so smoothly assimilated into that of the twentieth century as to go largely unremarked—is the insufficiency of field equations to describe the mutual actions of electric charges. This implies the necessity to supplement field equations with an intercharge force law. Since "fields" are not themselves observable, whereas charges and force-actions are, this raises the question of dispensability of the field in favor of accounting for everything observable by an intercharge force law. It may be objected that forces are not the only observable aspect of nature and that radiation must also be accounted for, hence that field theory is indispensable. But neither Maxwell's nor any other pure field theory accounts for the physically most distinctive aspect of radiation—its quantization. The photon—the thing *observed—is* as much a stranger to Maxwellian field theory as it is to Newtonian force theory. Moreover, such an abundance of raw physics, indigestible by the Maxwellian mathematical machinery, has emerged empirically in the modern era that the Einstein goal of doing the whole job of physical description via a "unified field" may justly be viewed as dated. Hence the above objection, though well taken, is not decisive in favor of field theory ... unless the reader chooses in his own mind to make it so.

Not unrelated is the question of what happened to Newton's third law (equality, oppositeness, collinearity, and instantaneousness of action-reaction between particles) in modern physics. Empirically, there is no firmer pillar of physics: Nobody has ever gone into a laboratory and observed a violation. Theoretically, it is still relied upon on alternate Tuesdays to refute perpetual motion schemes. But the rest of the week it has fallen into disfavor among relativists, who, in the words of one of their textbooks, have "very little use" for it.

Instead, the doctrines of universal covariance and causal retardation prevail, according to which spacetime symmetry obtains and all distant actions (of forces as well as radiation) are retarded at speed *c*. Founded solely upon the evidence of far-zone phenomena, such doctrine—when applied to forces (near-zone phenomena)—has no greater weight of empiricism behind it today than did Ptolemaic doctrine in its time.

On the contrary, there is growing empirical evidence against the universality of either covariance or causal retardation. It becomes increasingly clear that noncovariant forces exist in nature and have been detected and measured (Granau 1982, Granau 1985a, 1985b, Granau 1987, Granau 1988, Granau & Granau 1985, Hering 1923, Moyssides & Pappas 1986, Phipps 1990, Phipps & Phipps 1990) in the laboratory. In particular the actions of so-called *Ampere longitudinal forces* have repeatedly been observed (Granau 1985a), of sufficient magnitudes to "explode" wires carrying high currents, buckle the rails of railguns, etc. Actions of Ampere forces have also been observed (Phipps 1990, Phipps & Phipps 1990) at such low currents and frequencies as to preclude alternative explanations such as heating or inductive effects. Besides possessing a longitudinal component (parallel to current), the Ampere forces differ from the currently accepted Lorentz (Biot-Savart) forces in that they (1) obey Newton's third law and (2) cannot be covariantly expressed. Their existence counterindicates ("breaks") spacetime. symmetry. The embarassment to the "profession" of physics is that this breaking of spacetime symmetry is not some new discovery but has been known since the earliest days of Ampere.

By the same token there is no empirical evidence for the retardation of gravity's action or of any other force action in nature. The absence of any known phenomenon of *gravitational aberration* is plainly suggestive of gravity's instantaneousness. Laplace

(Collected Works) examined the matter in a different context and concluded from the known data of Celestial mechanics that any retardation of gravity's force action would correspond to a speed of such action (which we might nowadays call graviton propagation speed) of not less than $10^8 c$. No lag has ever been detected in the action-reaction of any force. Mach's principle, moreover, cannot even be coherently stated without a concept of distant simultaneity. (This is the unspoken fact behind all the scholarly pussy-footing implicit in the various exacting qualifications and careful wordings of that much vexed and behexed "principle.")

From the ensuing general shipwreck of Einstein's physical presuppositions upon the rock of empiricism, certain of his doctrines can and must be salvaged. In particular, the identification of the timelike invariant of kinematics as being of the general nature of

$$d\mathbf{t}^{2} = dt^{2} - \frac{dr^{2}}{c^{2}} = \text{invariant} \qquad \text{(la)}$$

or

$$\frac{d\mathbf{t}}{dt} = \sqrt{1-\mathbf{b}^{2}}, \;\; c\mathbf{b} = \frac{dr}{dt} \qquad \text{(lb)}$$

—and all that is implied by Eq. (1) about the mechanics and motions of high-speed particles—is strongly supported by empirical evidence (Bailey et al. 1977), provided its application is limited to *happenings on the worldline of a given particle.* (We conceive here of *dr* as an arc length along a particle trajectory.) What cannot in any way be salvaged or supported empirically is spacetime symmetry and the resulting EinsteinMinkowski identification of the spacelike invariant (wherein a crucial algebraic sign is changed in Eq. (1)). The same is true of the worldline-relational deductions that follow—such as the metric nature of spacetime, Lorentz contraction, Minkowski-space representation, the "elsewhere," and all other *structural* statements about the way the world is "put together" ... including those clock-phase-relational deductions that support the "relativity of simultaneity." There are no logical links between clock rates and clock phases.

The idea that one can change a sign in the known and confirmed timelike invariant of kinematics, thereby magically endowing the result with equivalent spacelike physical descriptive power, is intellectually on a par with the idea that one can change a sign under a square root descriptive of real particles ("tardyons"), thereby magically endowing tachyons with physical existence. It is also on a par with much other learned speculation, recreational mathematics, and sympathetic magic solemnly passing for physics in our time. By a flood of such pure and rarified cerebrations the very notion of physics as a science based on facts or empiricism has tended to be washed away. The price will doubtless be paid during the next century, through a steady decline in the correlation between theory and observation—if the fever for the latest *Tanz Pest*, computerization and simulation, permits observation to remain on the agenda at all.

To repeat: What can in no way be salvaged from the relativity shipwreck is Einstein's most widely popularized conceptual enlightenment, the "relativity of simultaneity." That stands squarely in the path of progress toward the coherence and comprehensibility of physics across its entire spectrum, ranging from the understanding of Mach's principle to that of quantum nonlocality—*e.g.*, the implications of Bell's theorem or the Moessbauer effect. What does it mean that "the lattice as a whole" takes up the Moessbauer photon recoil, if not that an *extended structure* responds instantly and rigorously "simultaneously" to the action-reaction demands of Newton's third law? What does the phenomenon known as "collapse of the wave function" import, if not instantaneousness of distant action—meaning absence of speed-c retardation—at the level of extended quantum "structure"? How can such apparent *facts* speak for themselves or be cross-examined in a Physpeak language that accords *no meaning* to distant simultaneity?

Constrained by such considerations, the present writer has undertaken both experimental (Phipps 1990, Phipps & Phipps 1990) and theoretical (Phipps 1987) investigations of alternative formulations of basic physics compatible with the validity of both Eq. (1) and Newton's third law—these two being equally founded in unimpeached empiricism. To reassert Newton's third law requires a revived meaning or operational definition of distant simultaneity—for, absent the simultaneity of action-reaction, one could say that *reaction deferred is action denied.* (Case in point: radiation reaction.) The outcome of such thinking is a kinematics in which the timelike invariant resembles that of Eq. (1) and the spacelike invariantis just Euclidean length (*i.e.*, the Lorentz contraction is forbidden). A clock synchronization method compatible with such a kinematics has been specified (Phipps 1987) (termed the "V* transport method"), employing only invariant proper time, whereby a convention-free *operational meaning* is imparted to distant simultaneity on which all observers must agree. This implies the existence of an invariant "now"—hence allows the subject of action-at-a-distance force laws to be reopened and allows the implications of empirical evidence for the validity of Newton's third law (Granau 1982, Granau 1985a, 1985b, Granau 1987, Granau 1988, Granau & Granau 1985, Hering 1923, Moyssides & Pappas 1986, Phipps 1990, Phipps & Phipps 1990) to be explored. Such reopenings are the aim of the present paper.

2. Historical Background

Wilhelm Weber (1804-90) was the first and (until recently) last true relativist, in that he sought to express the law of action between two electric charges in terms of the scalar separation distance between those charges and time derivatives of that distance, without reference to external “frames” or “systems.” In other words, for Weber the two charges existed “relatively” to each other and to nothing else. In contrast, the velocity that later appeared in the Lorentz force law was relative to an observer or frame of reference. This bringing in of a “something else,” a *third body,* as a necessary reference object leads to what O’Rahilly (1965) termed “schesic” velocities. Current relativity theory is full of schesic velocities; but Weber’s experience suggests that physics at its most basic formulational level may be able to get along without them, and it seems that in a true relativity theory one should try to do so—since the observer or frame can play no physically essential role (unless we believe in three-body forces

something that in the terms of reference of causal thinking would be genuinely “spooky”).

Weber’s force law is

$$F_W = \frac{ee'}{r}\left[1-\left(\frac{dr}{dt}\right)^2\frac{1}{2c^2}-\frac{d^2r}{dt}\cdot\frac{r}{c^2}\right] \tag{2}$$

where r is the instantaneous separation distance between two point charges e,e', dr/dt is the time rate of change of that distance, and units are e.s.u. The force is directed along the instantaneous inter-charge line and is repulsive when positive. Eq. (2) is derived by means of $F = -(dV_W/dr)$ from a velocity-dependent potential energy expression known as the Weber potential,

$$V_W = \frac{ee'}{r}\left[1-\left(\frac{dr}{dt}\right)^2\frac{r}{2c^2}\right] \tag{3}$$

Because of the absence of frames from the Weber two-body problem, the vector nature of force is not explicitly indicated by the notation—but the above is readily translated into vector notation when necessary. (It should be remarked that where a distribution of charges acts upon a test charge the summation of effects is a vector sum, so a schesic approach is in fact unavoidable. Moreover, requirements of observability via apparatus in some state of motion in general imply that the apparatus constitutes a schesis or "third body" —so again practical physics must rely on frames and vector components. This need is accomodated analytically by multiplying the right side of Eq. (2) by $\mathbf{r}/r$.)

Weber showed that his force law, applied to a "two-fluid" model of electrical conductors (wherein positive and negative electric charges flow equally in opposite directions), leads to the Ampere law (Granau 1985a) of ponderomotive action between any two distinct small elements of the conductors. The Ampere law was contrived to obey Newton's third law of action-reaction between the current elements and had been confirmed by Ampere's own observations. Recent experimental evidence (Granau 1982, Granau 1985a, 1985b, Granau 1987, Granau 1988, Granau & Granau 1985, Hering 1923, Moyssides & Pappas 1986, Phipps 1990, Phipps & Phipps 1990), mentioned above, reconfirms it. Although, as we now know, the two-fluid model is not physically correct, Wesley has recently shown (Wesley to be published) that a better model (negative electron flow, positive lattice ions fixed in the conductor), employing the Weber force law, Eq. (2), also leads to the Ampere law of ponderomotive action between material conducting elements. Thus the Weber potential and its force law can be considered to be observationally confirmed at least to terms of order c^{-2}.

Objections were raised to Weber's proposal, for instance by Helmholtz (1872) , who pointed out that the negative sign of the term in the force law (2) allowed nonphysical negative mass behavior at relative speeds in excess of c. Thus the law (2) could not be valid at very high speeds. This objection was not answered during Weber's lifetime. However, the present writer recently pointed out (Phipps to be published) that Helmholtz's objection is readily met by modifying the potential in Eq. (3) as follows:

$$V = \frac{ee'}{r}\sqrt{1-b^2}, \; b = \frac{dr}{dt}\cdot\frac{1}{c} \tag{4}$$

This leads to a force law

$$F = -\frac{dV}{dr} = \frac{ee'}{r^2}\left(\sqrt{1-b^2} + \frac{r}{c^2\sqrt{1-b^2}}\cdot\frac{d^2r}{dt^2}\right) \tag{5}$$

not subject to negative-mass effects, wherein relative charge velocity dr/dt is restricted to $dr/dt < c$. (Again, practical physics benefits from the use of vector notation, with consequent insertion of $\mathbf{r}/r$ as a factor on the right side of Eq. (5).) The existence of a limiting relative velocity between any two bodies composed of charges is thus made explicit in the laws of both force and energy (potential). As previously shown (Phipps to be published), the law (5) agrees with the Weber force law (2) to order c^2 and departs from it at higher order in such a way as to remove the Helmholtz objection. Similarly, Eq. (4) agrees with (3) to order c^2.

Apart from the need to answer Helmholtz and to exhibit a limiting velocity, no motivation was apparent for the proposed (Phipps to be published) law (4) or (5). In the next section we offer a sort of "derivation" of Eq. (4) that relates it more closely to first principles of physical description. In Section 4 the same will be attempted for Eq. (5).

3. "Derivation" of the Modified Weber Potential, Eq. (4)

Suppose we have a point test charge e' at rest in our laboratory and a source charge e free to move arbitrarily. Let t be the proper time of the source charge and t the laboratory frame time. The latter is equivalent to the proper time t' of the frame-stationary test charge. We are dealing with two (invariant) proper times and thus could eliminate the "frame" from discussion entirely ... but we keep it for convenience. The kinematics assumed is that mentioned in the preceding section and developed elsewhere (Phipps 1987) wherein the timelike invariant is postulated to be proper time interval and the spacelike invariant is Euclidean length. In such a kinematics there is meaning to distant simultaneity, so the instantaneous Weber charge separation coordinate r is well-defined. We may think of the laboratory frame as inertial and of r as the instantaneous Newtonian quantity defined in that frame. Since r is a kinematic invariant, all observers will agree on its numerical value.

In recognition of the well-known invariance properties of an energy-time product, we postulate that, regardless of the relative motions of these two charges, there exists a scalar potential energy function V symmetrical between them such that for either charge its product with the corresponding proper time differential remains at all times invariant:

$$V_t dt = V_{t'} dt' \tag{6}$$

This is plausible both from charge symmetry and from dimensional considerations. (If the energy function were written as $V = h$, then $Vd = \mathrm{h} =$ invariant.) Since the primed charge is at rest in the laboratory, we may identify with t and V with the potential energy V measured in the laboratory; hence

$$V_t = V_{Coul} = \frac{ee'}{r} \tag{7}$$

An observer O comoving with the unprimed (source) charge, whose proper time is t, will by definition see that charge as permanently at rest and will see the primed (test) charge as in motion and as located at some instantaneous separation distance r. The historical path by which it arrived at this relative position being of no consequence, we may suppose the test charge to have been "brought from infinity" to the separation distance r. In this geometry observer O knows the potential energy of the static source charge in the presence of the test charge. It is by definition just the Coulomb energy,

$$V_t = V_{Coul} = \frac{ee'}{r} \tag{8}$$

From Eqs. (7), (8), and (1b) we obtain

$$V_{lab} = V_{Coul}\left(\frac{d\mathbf{t}}{dt}\right) = \frac{ee'}{r}\sqrt{1-\mathbf{b}^2},\ \ \mathbf{b} = \frac{dr}{dt}\cdot\frac{1}{c} \tag{9}$$

This is the Eq. (4) that we set out to derive. It leads by r-differentiation to the force law (5), which to first order in c^{-2} (the only order that can be checked observationally) is in agreement with the Weber force, Eq. (2), and with the Ampere law of ponderomotive action between current elements. The dr/dt appearing in (9) is a derivative with respect to laboratory time t. Consistency is assured by recovery of the Coulomb law from Eq. (9) in the case $dr/dt = 0$ of co-motion of e,e'.

4. Force Law Variant

The above "derivation" proceeds from a postulate about energy. It fits with a view of energy as fundamental in mechanics. There is convincing support for that view, including the success of such formulations of classical mechanics as that of Hamilton-Jacobi, which takes an energy Hamiltonian as its basis and which has proven most fruitful in providing a formal model for quantum mechanics and perhaps for more advanced developments in mechanics (Phipps 1987) not yet recognized. However, there is an older tradition stemming from Newton that views force as fundamental. Pursuing this alternative as another way of looking at the problem, we may define (Phipps 1987) an "invariant force" by means of a Newtonian law, modified by substitution of particle proper time for frame time:

$$\mathbf{F}_{inv} = m_0 \frac{d^2}{d\tau^2}\mathbf{r} \tag{10}$$

This assumes constant particle ("rest") mass m and uses vector notation. By applying an analog of Eq. (1) we find that

$$\begin{gathered} F_{inv} = \frac{dt}{d\tau}\cdot\frac{d}{dt}\left(m_0 \frac{dr}{dt}\cdot\frac{dt}{d\tau}\right) = \gamma\frac{d}{dt}\left(\frac{m_0\mathbf{v}}{\sqrt{1-\beta^2}}\right) \\ \beta = \frac{u}{c},\quad \gamma = \frac{1}{\sqrt{1-\beta^2}} \end{gathered} \tag{11}$$

From standard textbooks (Rosser 1964) we recognize the multiplier of γ on the right as the force F_{lab} observable in the laboratory. Hence Eq. (11) implies that

$$\mathbf{F}_{lab} = \gamma^{-1}\mathbf{F}_{inv} = \sqrt{1-\beta^2}\cdot\mathbf{F}_{inv} \tag{12}$$

Just this result was stated in Ref. 7, Eq. (5.72). For an observer instantaneously at rest with respect to the source charge the invariant force on the test charge exerted by the source charge is known to be given by the Coulomb law,

$$\mathbf{F}_{inv} = \vec{\nabla}_r V_{Coul} = -\frac{\mathbf{r}}{r}\cdot\frac{d}{dr}V_{Coul},\ V_{Coul} = \frac{ee'}{r} \tag{13a}$$

or

$$\mathbf{F}_{inv} = \frac{\mathbf{r}}{r} \cdot \frac{ee'}{r} \tag{13b}$$

Hence

$$\mathbf{F}_{lab} = \sqrt{1-b^2} \cdot \mathbf{F}_{inv} = \frac{\mathbf{r}}{r} \cdot \frac{ee'}{r^2}\sqrt{1-b^2} \tag{14}$$

This result is seen by comparison with Eq. (5) to differ from the energy-based result by omission of a force term in d^2r/dt^2.

The writer's present guess is that Eqs. (5) and (9) are the correct expressions (at order c^2) and that Eq. (14) is wrong. Since Eq. (14) is not obviously derivable from a potential, it suffers from doubts about conservation of energy. The physical situation is certainly conservative, so a potential should exist. For this reason we shall not pay any more attention to the results of this section, beyond noting that by inference they cast doubt on Eq.(10) as a satisfactory starting point for advanced mechanics, hence on some of the analysis in my book (Phipps 1987, Chap. 5, Sect. 6). More properly, the issue between Eqs. (5) and (14) should be settled by experiment, not by guesswork.

5. Summation

Our derivation of Eq. (9) or its force law, Eq. (5), represents the main result of this paper. The law is a modernized version, previously suggested (Phipps to be published), of Weber's original force law, modified to circumvent the Helmholtz objection and to express the existence of a limiting relative charge velocity *c*. It conforms to the original Weber method in using purely relative quantities in the description of the fundamental charge pair: source charge and test charge. If we know all there is to know about this fundamental pair, do we not know all that is needed for (near-zone) electrodynamics? Do we also need field theory? Surely npt for describing force actions. (Here one must re-emphasize the profound physical distinction between force and radiation. There has been altogether too much feckless "unification" for the health of physics. If we could get a theory that would do *one thing right* would be a step forward.)

The salient feature of Weber-type laws is that they rigorously obey Newton's third law and agree with Ampere's law of ponderomotive action between current elements. The latter is the important "new" constraint that viable physical theory must obey—and that field theories and established relativity theory based on the Lorentz force law violate. Rather, it is an ancient constraint (over 160 years old) the empirical validity of which has been ignored until recently... and it remains controversial (Christodoulides 1987, 1988, Jolly 1985, Ternan 1985).

How could the force law (5) be tested? Actually it is (2) that presents itself for testing, since it is not practical to probe beyond the order c^2 with currents (the speeds of which are of the order of millimeters per second) in solid conductors. It should be rather easy to verify the combination of $(dr/dt)^2$ and d^2r/dt^2 terms in Eq. (2) with modern sensitive detection techniques. Separating out the individual effects of these terms is more problematical—but seemingly needs to be done in order to rule out alternatives such as that treated in Section 4. The writer has in mind the outlines of a program of simple experiments to treat questions of ponderomotive actions upon conductors and to go on to deal subsequently with higher-order refinements. (There is little question that experiments with charges in vacuum could be devised to probe the higher-order distinction between laws (2) and (5).) Is it not both surprising and shameful that so much time has passed without experimental investigations in this field by either academia (chartered to seek and defend truth) or the world's governmental organizations (chartered to develop electrical measurement standards)? Why has so little curiosity been displayed about the law of force between charges? Could it be that curiosity is a more fragile attribute of the human mind than has been supposed?

As to the importance of all this for physics: If there is anything important in modern physics—on the evidence a debatable point—it would seem to be the question of existence of noncovariant forces in nature, the status of Newton's third law, and the identification of the basic law of force between electric charges. This was all supposed to have been settled in the nineteenth century. It is perhaps the universality of this comfortable supposition that must take the blame, a century later, for any discomfort attendant on its not being true. Consensus physics is a tissue of such comfortable suppositions, heaven help us. The writer is constrained to close this depressing topic by paraphrasing certain lines of Max Beerbohm *(Zuleika Dobson):*

> *You cannot make a physicist by standing a sheep on its hind legs. But by standing a flock of sheep in that position you can make a crowd of physicists.*

Finally, there is the question of how extensive the damage is (from the alleged discovery of noncovariant forces in nature) to presuppositions throughout the whole of physics. Can the damage be limited to the small area of actual experimental discovery— namely, the area of current flow in metallic conductors? In the opinion of Graneau (Granau 1985a) this is the case. He feels that the Ampere law applies only to metallic conductors, not to charges in vacuum—where the Lorentz law appears to him preferable. But the present writer and certain others (Wesley to be published, Assis 1989, Assis & Clemente to be published) consider a Weber-type force law (compatible with the Ampere law) to apply either universally or not at all ... similarly for Newton's third law.

There is also a school of thought (Rambaut & Vigier 1989, to be published) that accepts the existence of noncovariant forces in nature but maintains that this does not overthrow Einstein's physics—though it may put a dent in "universal covariance." Special relativity has proven very resilient in adversity. For instance the Lorentz contraction was once thought to possess "universality," but the quiet withdrawal of this claim (in the face of the Ehrenfest paradox (Phipps 1987) , which showed that the rim of a disk set into rotation could not contract) has left not a single guilty conscience within the fraternity of teachers and scholars. Such toughness or infrangibility is not so admirable a quality in physical theory as it might seem. Rather, it is a recognizable feature of theories of the epicyclic pedigree. It mainly testifies to poverty of imagination and consequent dearth of theoretical alternatives. Here we have made a start on a radical alternative theory, enough to provide some basis for experiments.

Wherever charges move in closed loops, forming closed-circuit currents, we know (Christodoulides 1987, 1988, Jolly 1985, Ternan 1985) that Ampere's law and Lorentz's law are predictively equivalent. Otherwise, they are not even approximately equivalent. There is an entire field of "otherwise" physics known as the "fourth state of matter"—namely, plasma physics—wherein charges interact but do not necessarily move in closed loops. Any plasma physics calculations employing the Lorentz force law must implicitly violate Newton's third law at the rudimentary level of charge-on-charge action. That Newton's third law can with impunity be ignored is one of the most foothardy assumptions on which a "hard" science could conceivably be founded. The physics of plasmas *begins* with the physically correct law of interaction of a pair of charges. If the present ideas have any foundation, it is apparent by this criterion that plasma physics (despite billions poured into tokamaks, etc.) has not yet begun. A useful starting point might be to make test calculations of some known plasma configuration with the Weber force law, Eq. (2) or (5), and to compare the results with Lorentz force law predictions and with observed facts. The writer would be gratified to see this done by someone with the necessary (super)computer resources and background.

Finally, let it be said that any mention in this paper of *acausal* (instantaneous) distant actions is not intended to strike at the rule of law in physics or at the idea that effects have causes—merely at the idea that all effects must be preceded by speed-*c* retarded causes. The issue can alternatively be stated in terms of the quantum locality-nonlocality dichotomy. The Wheeler-Feynman half-advanced-half-retarded mode (Phipps 1987) of description (compatible with Maxwell's equations) is actually a more damaging blow to "causal thinking" than any intended to be struck here.

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