Lorentz Contraction of the Coulomb Field: An Experimental Proposal

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Despite a number of attempts, the Lorentz contraction has never been directly observed. The worldline-relational or metric "structural" statements of special relativity remain therefore empirically unsupported, and the metric nature of spacetime retains an inferential or speculative character. In these circumstances any direct evidence would be of value. It is suggested that a much more easily observable phenomenon than the Lorentz contraction of a material structure be exploited; namely, the contraction of the Coulomb field accompanying a high-speed electron pulse. A proposal is made for a simple laboratory experiment to measure this effect. To lend interest, a modernized version of an alternative electrodynamics due to W. Weber (propounded in the nineteenth century and never observationally refuted), based upon action-at-a-distance, is described and its predictions in the proposed experimental situation are contrasted with those of Lorentz-Einstein. The same is done for the original Weber theory and for a neo-Hertzian version of electromagnetism. The experiment should be "crucial" for deciding among such alternative theories.

Introduction

Special relativity theory falls neatly into two distinct Classes of theoretical assertions:

(I) Statements based upon the invariance along a particle track of the timelike interval $d\tau^2 = dt^2 - dr^2/c^2$. These describe in a non-Newtonian way the "physics of single worldlines."

(II) Statements based upon the invariance of the spacelike interval $d\sigma^2 = dr^2 - c^2dt^2$. These describe in a non-Newtonian way the nature of spatial relationships comprising the "physics of extended structures."

That these two classes of statements are logically disjoint follows from the fact that Class-I statements concern specified conceptual entities (single worldlines), whereas Class-II statements concern the *relationships* among such entities. Relational statements are not derivable from nonrelational ones. The disjointness is also obvious mathematically from the sign change of a squared quantity.

The link between the two categories of statements is an *assumption* of spacetime symmetry (or of the metric nature of spacetime, Minkowski space representability of events, universal Lorentz covariance, etc.). Spacetime symmetry traces its roots to the symmetrical occurrence in Maxwell's equations of partial derivative operators acting upon space and time variables. The persuasiveness of the symmetry assumption or inference is weakened by the existence (Phipps 1987) of an "invariant covering theory" of Maxwell's electromagnetism due to Heinrich Hertz (Hertz 1962). The covering theory is not covariant but is strictly *invariant* under inertial transformations at first order. It lacks spacetime symmetry because it substitutes total for partial time derivatives in the Maxwell equations, thereby destroying the mathematical basis of symmetry. Since it is a covering theory it reproduces all the "physics in one laboratory" yielded by Maxwell's theory.

A higher-order version of Hertz's theory, termed "neo-Hertzian electromagnetism," has been adduced (Phipps 1987). This accepts the Class-I statements of Einstein's theory as valid, but rejects all Class-II statements in favor of the simpler (Newtonian) postulate of length invariance. Thus the invariants of such an alternative kinematics are length and proper time. The retention of the proper-time invariant from Einstein's theory assures replication of all Einsteinian single-worldline predictions (mechanics of high-speed charged particles), but rejects the "elsewhere" and the Minkowski-space representability of events (*i.e.*, all metric or structural statements). This fits with a (3+1)-space, rather than a 4-space, geometry of events. Several recent theoretical studies confirm that the alternative kinematics in question gives a self-consistent description of various phenomena normally supposed to be best described by Einsteinian kinematics (*e.g.*, Einstein's train (Phipps 1987), Feynman's light clock (Phipps 1989a), the twin paradox (Phipps 1989b), stellar aberration (Phipps 1991)).

On the side of empiricism the known facts likewise fall into two distinct categories:

(i) Those experiments involving high-speed particles (individually describable in classical approximation by single worldlines) that support the above Class-I theoretical statements.

(ii) Those experiments involving spatially extended phenomena (describable by multiple worldlines bearing a coherent "structural" relationship) that support the Class-II statements.

The claim of relativity textbooks that special relativity is among the best-supported of all physical theories refers entirely to experiments belonging to category (i). The evidence is indeed impressive—perhaps (insofar as science may dare to venture the claim) conclusive. But a flat assertion is made here in the hope of eliciting informed contradiction: *The class of category (ii) experiments is the null class.* A number of attempts to subject moving extended structures to laboratory interrogation (Brace 1904, Trouton & Rankine 1908, Wood *et al.* 1937, Phipps 1974, Sherwin 1987) have been made, but to date not one has yielded evidence of the slightest departure from Newtonian "world structure." Does this warrant rejecting Einstein's physics? Certainly not in itself, for meaningful experiments involving very high-speed extended structures within laboratory confines are technically so difficult as to border on the impossible. Conservatively speaking, it does warrant a verdict of "undecided" in respect to category (ii) experiments and consequently in regard to all Class-II theoretical statements. Because of the extreme experimental difficulties, this verdict may prove to be a semi-permanent one.

An "undecided" verdict leaves the door open (or at least ajar) to consideration of a host of theoretical alternatives. It also forces continued reliance on inferences. Evidently, if empiricism is not to be superseded by "religious" faith in this area of physics, we must seek those feasible experiments, suggested by theoretical alternatives, that make the chains of inference as short and simple as possible. The purpose of this paper is to propose such an experiment in simplified Gedanken form and also (rough-sketched) in more practical form.

Gedanken Experiment: Maxwell-Einstein Analysis

Our preferred goal is to verify the Lorentz contraction of an extended structure—that is, an influence of relative motion on the shape and spatial relationship of structurally-linked material particle worldlines. Since we have seen that this is impractical, our second-best objective may be to seek verification of the Lorentz contraction of an electromagnetic field—in particular of the Coulomb field. Such contraction has been inferred from the many successes of Maxwellian field theory and Einsteinian kinematics, but it has not been reported (to the writer's knowledge) as having been actually observed. Here a shortening of the chain of inference is readily accomplished, since Coulomb field sources are easily moved at high speeds in the laboratory.

Let a point charge q move in the horizontal at constant speed v past a test charge q^* at rest in the laboratory system K. Let q^* lie a distance b directly above the path of q (see

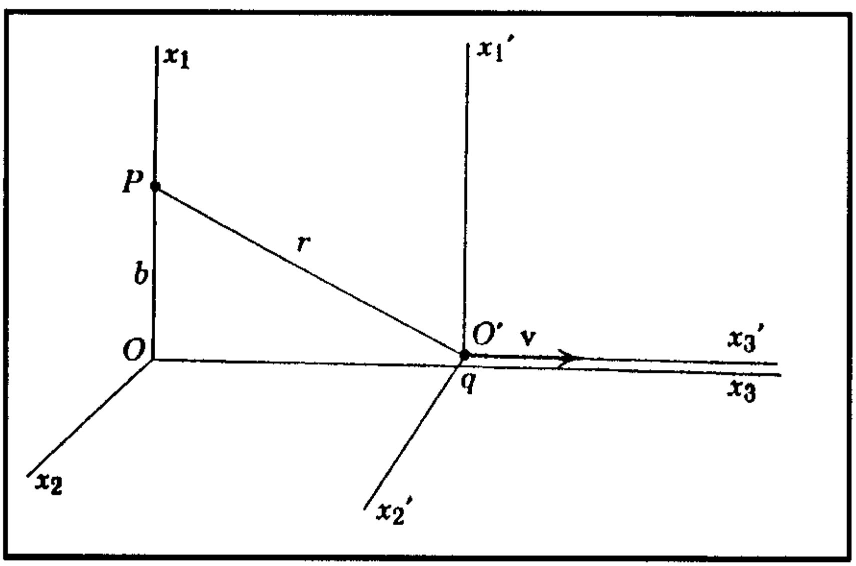

Figure 1. Source charge q passing an observation point P (where a test charge q^* is located) at impact parameter b (Jackson 1965).

Fig. 1). From the standpoint of Maxwell-Einstein theory this problem has been analyzed by Jackson (1965), who derives the vertical electric field component E_1 measured in K (produced by q at q^*) by Lorentz transforming the vertical Coulomb electric field component E_1' measured in the comoving inertial system K' of q by means of $E_1 = \gamma E_1'$, where $\gamma = 1/\sqrt{1-(v/c)^2}$. The time must also be transformed between the two inertial systems, and Jackson employs the relation $t' = \gamma t$, obtained by using the Lorentz transformation $t' = \gamma\left[t-(v/c^2)x_3\right]$, with $x_3 = 0$ since the time origin is chosen such that $t = t' = 0$ when the spatial origins of the two systems coincide at the moment of closest approach of the charges.

We pause to remark that Jackson's relation $t' = \gamma t$ seems anomalous, since t', the clock or frame time of K', is also the proper time τ of particle q at rest in K'. If q were, for instance, a charged muon that had been brought up to speed v by the operation of some ordinary particle accelerator in the laboratory K, we know from CERN observations (Bailey *et al.* 1977) that its lifetime t, as measured in K, would be *increased* by a gamma-factor; that is, $t = \gamma\tau = \gamma t'$. But Jackson's reversed relationship $t' = \gamma t$ seemingly implies a *decrease* of lifetime by the same gamma factor, as measured in the laboratory. Such an anomaly is an unavoidable feature of Jackson's indirect method of employing Maxwell's theory, since the "observer's point P" (as Jackson puts it) moves at speed $-v$ in K'. Point P is actually the test charge q^* or an equivalent field detector ... and Maxwell's theory is not parametrized to describe moving detectors, nor is the Maxwell field in K' *defined* as what a moving detector detects. (By contrast, the Hertzian field (Phipps 1987) *is* defined in just this way and Hertzian theory contains the necessary extra velocity parameters to permit description of field detector motional freedoms.)

Maxwell's theory having thus abdicated and declared its ignorance of the moving test-charge (moving field detector) case, the burden of producing physical predictions is shifted to the (Einsteinian) kinematics. In effect K' becomes a preferred system in which description simplifies to the Coulombic one. Therefore a back-transformation from K' to K becomes necessary, and this flips the roles of γ and γ^{-1}, with the seemingly nonphysical consequence (from the laboratory observer's viewpoint) of muon time contraction instead of dilatation.

The situation is in fact triply anomalous: (1) Because of the γ-flip just mentioned, which if objectively true would startle experimentalists by causing their muon beams to travel a γ^2-times shorter distance in the laboratory (before decay) than CERN evidence would lead them to expect. (2) Because Maxwell's theory is so parametrized as to make K seemingly the natural system in which to analyze this problem ("field detector" or test particle q^* at rest in K, moving particle q a "current" for which source-motion descriptive parameters are provided in Maxwell's equations); so that the switch away from this natural system puts us into a system K' in which the "Maxwell field" *as measured by a moving detector* (the test charge q^*) is not even conceptually defined. (Note here that Jackson's E_1' is a different quantity from whatever affects the moving q^*—*viz.*, E_1', is a quantity measured by a field detector *at rest* in K' and only instantaneously present at the moving field point P with which q^* comoves.) (3) Because the failure to use Maxwell's theory in the inertial system K in which the desired Maxwell field E_1 *is* defined, with resort instead to a "preferred" system K', raises a question about the relativity principle: If K is as good a system as K' in which to express the laws of physics, why ever leave K? (*Answer*: One leaves K in order to avoid the necessity to introduce extra assumptions lying outside both field theory and kinematics, such as a retarded-action force law. In effect Jackson's treatment is a "swindle" to avoid adducing a force law by substituting kinematic manipulations. By transforming to K' we can utilize fewer "laws of physics." The swindle induces the anomalies noted. However, its result agrees with the prediction of the accepted retarded-action force law of Lienard-Wiechert or Lienard-Schwarzschild (O'Rahilly 1965).)

Being this as it may, the outcome is a predicted (Jackson 1965) vertical component of electric field

$$E_1 = \frac{\gamma q b}{(b^2+\gamma^2 v^2 t^2)^{3/2}} \tag{1}$$

The vertical force on test charge q^*, measured as positive in the upward direction, is $F_1 = q^* E_1$. Defining a normalized upward force F and introducing dimensionless parameters

$$\mu = v^2/c^2,\; u = v^2t^2/b^2,$$

this becomes

$$F = \frac{b^2F_1}{qq^*} = \frac{1-\mu}{(1-\mu+u)^{3/2}} \quad \text{(Maxwell-Einstein)} \tag{2}$$

If the charge q is an electron of kinetic energy T, such that

$$T = m_e c^2\left(\frac{1}{\sqrt{1-(v/c)^2}}-1\right) \tag{3}$$

(a result that follows solely from Class-I statements and assumptions) and if $T/m_ec^2 = \lambda$, then μ can be expressed as

$$\mu = 1-\frac{1}{(\lambda+1)^2},\quad \lambda = \frac{V}{0.52} \tag{4}$$

where V is the potential drop in megavolts through which the electron has fallen in acquiring its kinetic energy and 0.52 represents the electron rest energy in *Mev*. The maximum value F_o of F occurs at $u = 0$ and approaches infinity as $\mu \to 1$ from below. This corresponds to the famous phenomenon of the Coulomb field of a speeding-up point source turning into infinite plane waves of electromagnetic *radiation*. (Such an alleged phenomenon is itself anomalous, since

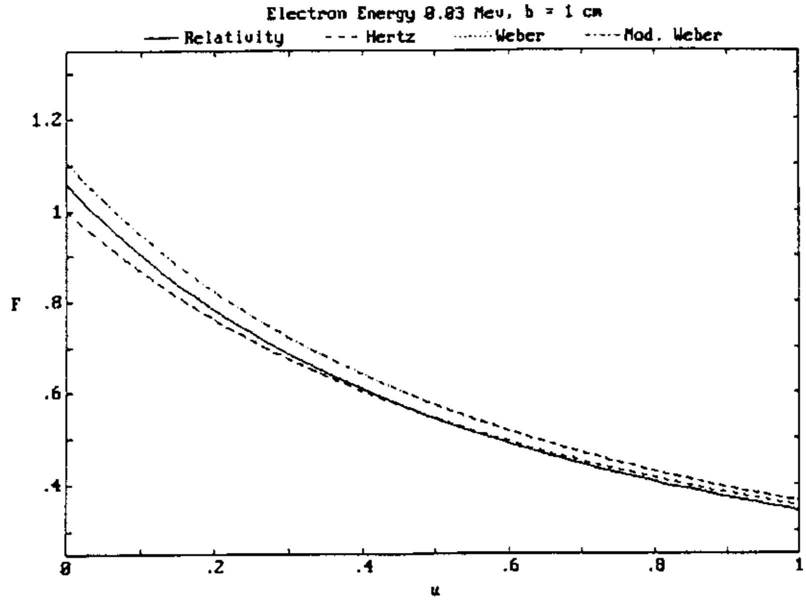

***Figure 2.** Normalized force $F = {b^2 F_1}/{qq^*}$ exerted by q on q^* (Fig. 1) as a function of $u = {v^2 t^2}/{b^2}$, for both charges electrons, according to four theories: Relativity, Eq. (2); Hertz, Eq. (7); Weber, Eq. (13); modified Weber, Eq. (21). Impact parameter $b = 1$ cm, electron energy 0.03* Mev.

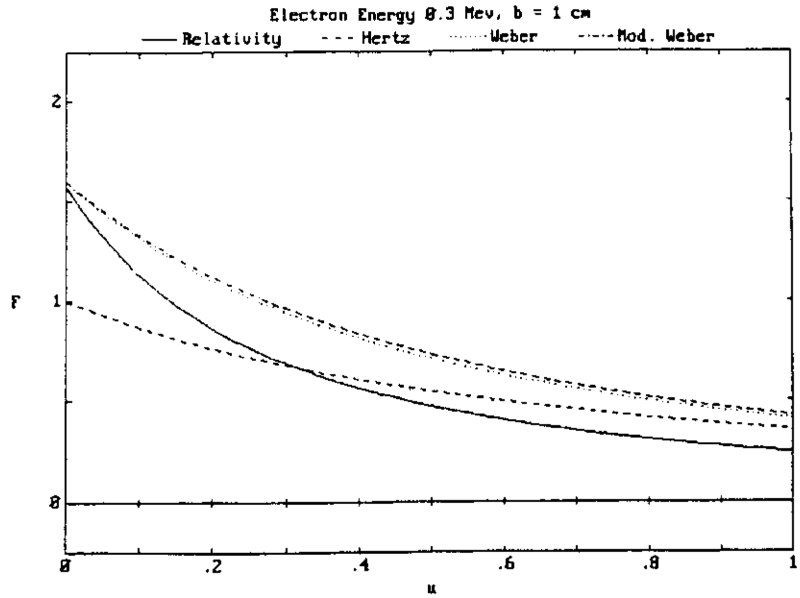

***Figure 3.** Same for energy 0.3* Mev.

the quantum force-action processes of a Coulomb field are nonlocal, "uncompleted," and apparently nonquantized; whereas radiation absorptions are locally "completed" processes and thus constitute seemingly objective Einsteinian "point events," evidencing the "quantum" aspect of the "field." As $v \to c$, our K' observer sees at all times a "smooth" Coulomb force field whereas the K observer sees an increasingly "lumpy" radiative photon field. That quantum-level *events* can thus occur or not occur, depending upon the observer's viewpoint, is a strain upon language and model... as well as a contradiction of Einstein's basic Ansatz of the physical invariance and uniqueness of point events.) The half-width $u_{1/2}$ of the force pulse (which measures its time duration) at half-maximum ${F_0}/{2}$ is seen to be

$$u_{1/2} = 2^{2/3}(1-\mu) - 1 + \mu \tag{5}$$

which goes to zero as $\mu \to 1$, in agreement with the plane-wave picture. This concludes our discussion of the Maxwell-Einstein predictions. They have the virtue of being explicit and unambiguous regarding what is observable in the laboratory.

Gedanken Experiment: Alternative Theories

In neo-Hertzian electromagnetic (field) theory (Phipps 1987) there is no Lorentz contraction of the field. Hence we might as well confine attention to the laboratory system K in which charge q moves with speed v, in the same geometry

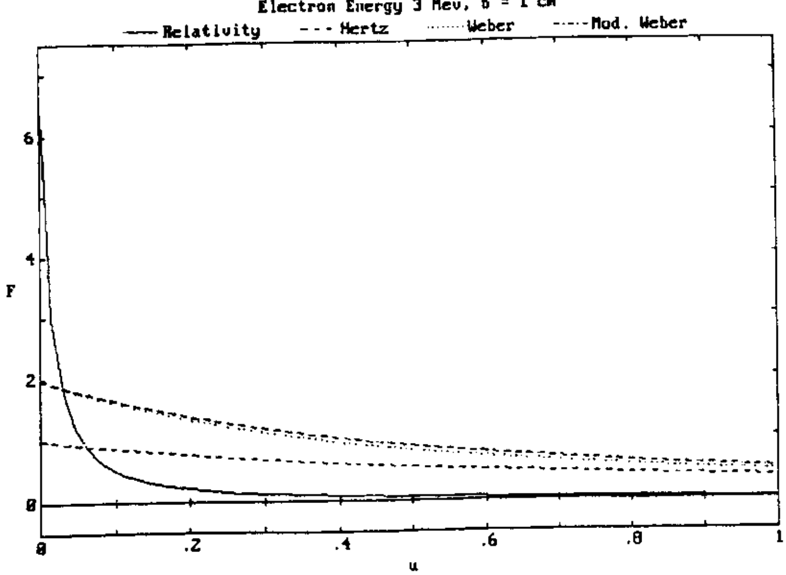

Figure 4. Same for energy 3 Mev.

as above. The separation distance of q from the stationary test charge q^* at time t is

$$r=\sqrt{b^2+v^2t^2}$$

Hence at low speeds the vertical electric field component at q^* is

$$E_1=\frac{qb}{\left(b^2+v^2t^2\right)^{3/2}} \tag{6}$$

Whether modification is needed at high speeds or not depends on whether distant actions are retarded (and on the form of a force law, if one is postulated) . This aspect of the theory remains to be probed. The modified kinematics mentioned previously allows for an invariant meaning (Phipps 1987) of "distant simultaneity." Hence the need for retardation of distant force action is not self-evident in mathematical terms. But it still may be physically correct. Since the theory is presently incomplete in this respect, we shall let Eq. (6) stand—with the understanding that modification may be called for. In terms of the same dimensionless quantities as before, Eq. (6) becomes

$$F=\frac{b^2F_1}{qq^*}=\frac{1}{(1+u)^{3/2}} \quad \text{(Hertz)} \tag{7}$$

This has a maximum value $F_o=1$ at $u=0$ and a half-width at half maximum of

$$u_{1/2}=2^{2/3}-1=0.587401$$

We next turn to a radically different approach to electrodynamics—the direct use of a *force law* (between point charges) to do the whole job of describing observable charged particle motions without separately postulating the existence of any "field." Our starting point, both logically and historically, is the once-famous law of instant action-at-a-distance proposed before 1850 by Wilhelm Weber (Whittaker 1960) , based on a velocity-dependent potential energy,

$$V_W=\frac{qq^*}{r}\left(1-\frac{\dot{r}^2}{2c^2}\right) \tag{8}$$

(We use e.s.u. in this paper.) From this follows a force law,

$$\vec{F}_W=-\vec{\nabla}_r V_W=-\frac{\vec{r}}{r}\frac{d}{dr}V_w$$
$$=\frac{qq^*\vec{r}}{r^3}\left(1-\frac{\dot{r}^2}{2c^2}+\frac{r\ddot{r}}{c^2}\right) \tag{9}$$

which (in contrast to the Lorentz force law) has the interesting properties (a) of being directed along the instantaneous intercharge axis (hence of obeying Newton's third law) and (b) of depending only on the charge scalar separation distance and its time derivatives.

It is natural to revive interest in this type of theory because it was devised to match the Ampère law of force between current elements (Whittaker 1960, Graneau 1985), for which Ampère furnished observational verification. Both Ampère's law of force between current elements and Weber's law of force between point charges obey Newton's third law (equality of action-reaction), but are noncovariant—*i.e.*, not spacetime symmetrical. Recent empirical evidence (Graneau 1985) supports Ampère's law (against the covariant law of Lorentz), hence motivates reexamination of Weber-type theories.

Since no frame- or observer-related coordinates necessarily enter Eqs. (8), (9), Weber's treatment may lay historical claim to being the first "true relativity theory." It is, however, a computational convenience to use vectors and Cartesian frames, which we may introduce as follows: Referring to Fig. 1, let $\vec{r}_1$ denote the position vector of q^* with respect to an arbitrary coordinate origin in our laboratory inertial system K and let $\vec{r}_2$ denote the position vector of q with respect to the same origin. Let $\vec{r}=\vec{r}_1-\vec{r}_2$, $r=|\vec{r}|$, $\hat{r}=\vec{r}/r$, $\dot{r}=dr/dt$,

$\ddot{r} = d^2r/dt^2$, $\vec{v} = d\vec{r}/dt = \vec{v}_1 - \vec{v}_2$, $\vec{a} = d\vec{v}/dt = \vec{a}_1 - \vec{a}_2$. With this notation we obtain

$$\dot{r} = \hat{r}\cdot\vec{v}, \qquad \frac{d}{dt}\hat{r} = \frac{1}{r}\left[\vec{v} - \hat{r}(\hat{r}\cdot\vec{v})\right],$$
$$\ddot{r} = \frac{1}{r}\left[\vec{v}\cdot\vec{v} - (\hat{r}\cdot\vec{v})^2\right] + \hat{r}\cdot\vec{a} \tag{10}$$

Eq. (10) converts (9) into vector form,

$$F_W = \frac{qq^*\vec{r}}{r^3}\left[1 + \frac{\vec{v}\cdot\vec{v}}{c^2} - \frac{3}{2c^2r}(\vec{r}\cdot\vec{v})^2 + \frac{\vec{r}\cdot\vec{a}}{c^2}\right] \tag{11}$$

On applying this to our problem, with $r = \sqrt{b^2 + v^2t^2}$, and taking the vertical component (of the upward force exerted by q on q^*), we find

$$\frac{F_1}{qq^*} = \frac{b}{r^3}\left[1 + \frac{v^2}{c^2}\left(1 - \frac{3v^2t^2}{2r^2}\right)\right] \tag{12}$$

Expressed in terms of the previously-defined dimensionless parameters, this yields

$$F = \frac{b^2F}{qq^*} = \frac{1}{(1+u)^{3/2}}\left[1 + \mu\left(\frac{1 - [u/2]}{1+u}\right)\right] \quad \text{(Weber)} \tag{13}$$

This has a maximum value of $1+\mu$ at $u = 0$, and a half width at half maximum that approaches $u_{1/2} = 0.366614$ in the limit $\mu \to 1$.

Weber's law agrees with Ampère's empirically validated law of force between current elements (Graneau 1985, Wesley 1990) and also agrees with the facts of induction. However, Helmholtz (Helmholtz 1872) pointed out a flaw at high speeds: If v exceeds c there is a possibility of negative-mass behavior, which may be judged nonphysical. The present author has proposed (Phipps 1990) a modification of Weber's law that retains its main features of instant action-at-a-distance, velocity-dependent potential, and strictly particle-relative coordinates, but that imposes a limiting particle velocity c and thus removes the possibility of the behavior to which Helmholtz objected. The proposed modified potential (to be compared with Eq. (8)) is

$$V = \frac{qq^*}{r}\sqrt{1 - \frac{\dot{r}^2}{c^2}} \tag{14}$$

A simple "derivation" or plausibility argument for this modified form of Weber's law is the following: Starting from the invariance properties of an energy-time product, we postulate that for two point charges q, q' in arbitrary relative motion there exists a scalar potential energy function V, symmetrical between them, such that for each charge the product of its proper time differential and this energy expression remains at all times invariant:

$$V_\tau d\tau = V_{\tau'} d\tau' \tag{15}$$

Consider the primed charge to be at rest in our laboratory. Then we may identify its proper time τ' with lab frame time t and V_τ, with the potential energy V_{lab} measured in the laboratory, which we seek to evaluate. Thus

$$V_\tau d\tau = V_{lab} dt \tag{16}$$

An observer S comoving with q (considered as a "source" charge), whose proper time is τ, will by definition see q as permanently at rest and will see q' (considered as a "test" charge) as moving at some instantaneous separation distance r. The history of motion by which q' arrived at this relative position being of no concern, we may suppose the test charge to have been "brought from infinity" to the instantaneous separation distance r. Observer S recognizes the potential energy of the stationary source charge q in the presence of the test charge q' as just the Coulomb energy,

$$V_\tau = V_{Coul} = \frac{qq'}{r} \tag{17}$$

From Eqs. (16), (17), and the definition of proper time interval $d\tau = \gamma^{-1}dt$ (for t the time measured in an inertial frame, our laboratory) we obtain

$$V_{lab} = V_{Coul}\left(\frac{d\tau}{dt}\right) = \frac{qq'}{r}\sqrt{1-\beta^2}, \quad \beta = \frac{\dot{r}}{c} \tag{18}$$

in agreement with Eq. (14). The $\dot{r}$ appearing in (18) is a derivative with respect to laboratory time t. Consistency is verified by recovering the Coulomb law from (18) in the case $\dot{r} = 0$ of co-motion of q, q', or the case of one charge circling around the other. The particle-relative velocity β used here is not the Lorentz-Einstein frame-relative velocity, but Eq. (10) shows how one can translate between the two. Only the radial component of relative velocity enters (18) because any "sideways" or angular motion component corresponds to work-free motion on equipotentials and thus (though significant for time dilatation) makes no energy contribution.

The force law obtained by taking the negative r-gradient of Eq. (14) or (18) is

$$\vec{F} = \frac{qq^*\vec{r}}{r^3}\left(\sqrt{1 - \frac{\dot{r}^2}{c^2}} + \frac{r\ddot{r}}{c^2\sqrt{1 - \frac{\dot{r}^2}{c^2}}}\right) \tag{19}$$

The vertical component of this force in the geometry of Fig. 1 is

$$\frac{F_1}{qq^*} = \frac{b}{(b^2 + v^2t^2)^2}\frac{\left[b^2\left(1 + \frac{v^2}{c^2}\right) + v^2t^2\left(1 - \frac{v^2}{c^2}\right)\right]}{\sqrt{b^2 + v^2t^2\left(1 - \frac{v^2}{c^2}\right)}} \tag{20}$$

or, in terms of our dimensionless quantities,

$$F = \frac{1 + \mu + (1-\mu)u}{(1+u)^2\sqrt{1 + (1-\mu)u}} \quad \text{(modified Weber)} \tag{21}$$

The maximum value of this force is $F_0 = 1 + \mu$, at $u = 0$, and the half-width at half maximum in the limit $\mu \to 1$ is $u_{1/2} = \sqrt{2} - 1 = 0.414214$. It is worth remarking that all laws considered in the present paper reduce in the low-speed limit to the same formula, namely that of Eq. (7).

This completes our discussion of alternative theories, although it does not begin to exhaust the options for historical theories never empirically disproven, or for new opportunities of invention. A more complete study would examine additional laws such as those of Gauss-Riemann and Ritz, as developed, *e.g.* by O'Rahilly (1965). We stop here arbitrarily because to go on would not make the case for experimentation substantially more compelling.

Gedanken Experiment: Calculated Results

Employing formulas (2), (7), (13), and (21) we obtain the results shown in Figs. 2 - 4 for the four theories chosen for present consideration. In each figure the quantity u is plotted on the abscissa and our normalized vertical force $F = b^2F_1/qq^*$ is shown as ordinate. Actual force response *vs.* time is given by the plus and minus square root of the curve shown (since $t = \pm(b/v)\sqrt{u}$)—*i.e.*, by a curve symmetrical with respect to time zero (the instant of closest approach of source charge to test charge). Both q and q^* are assumed to be electrons. The various graphs are plotted for different values of electron beam energy. It is seen that energies of a few *Mev* suffice to give a clear decision between relativity theory (Maxwell-Einstein) and the other theories. In fact, very careful measurements might show a distinction at energies as low as 100 *Kev*. But to distinguish between the Weber and modified Weber laws would require energies in excess of 10 *Mev*, and might not be feasible at any energy, the two laws being surprisingly similar in their predictions at all energies. It is supposed in this idealized Gedanken experiment that some means of observing and measuring force action on the test charge q^* exists, and that the detector of such electromotive action has sufficient bandwidth that it can respond in a time short compared to the time-half-width $u_{1/2}$ of the force pulse.

It is apparent that "high energies," as understood in the modern particle physics sense, are not needed to eliminate alternatives and to prove quite convincingly the Lorentz contraction of the Coulomb field and the validity of the Maxwell-Einstein theory, if such is nature's way. We now sketch a more practical experiment to address this same issue.

Proposed Experiment

The only feature of the Gedanken experiment that needs significant improvement of realism is the field detector. Let the test charge q^* be replaced by a vertical conducting fine wire stationary in the laboratory. The impact parameter b may be likened to the clearance distance between the passing electron beam and the tip of this "antenna" wire. The wire is connected through coaxial cable to a high-speed sampling oscilloscope. The electron beam may consist of a sequence of identical spatially very short pulses emitted at uniform time intervals, the repetition interval being used to synchronize the oscilloscope trace. Pulse duration must be short compared to the characteristic interaction time $t = (b/v)\sqrt{u_{1/2}}$ of the experiment, where the minimum $u_{1/2}$-value is in general given by Eq. (5). The choice of impact parameter is dictated by a tradeoff of oscilloscope bandwidth and sensitivity: The greater b the slower the scope that can be used and the greater the demands on its sensitivity.

The vertical fine wire is supposed to pick up by induction a pulse of electromotive force with the passage of each electron pulse. The latter must be produced and propagated, of course, in high vacuum. The method of calculating the predicted signal amplitude vs. time profile will differ for the various theories—even qualitatively as to the physics involved. For example, analysis based on field equations supposes that, within a certain frequency dependent skin depth at the surface of the conductor, currents flow rapidly in such a way as to cause boundary conditions to be satisfied, *e.g.*, to orient the net exterior electric field in the direction normal to the conductor surface. It is presumably the resulting charge motions at or near the surface of the wire that produce the observable response of the oscilloscope trace. (It is never discussed what criteria replace boundary conditions if their instantaneous satisfaction is frustrated by causal retardation of skin-current flow. The important subject of causality-frustrated or transient boundary conditions is a largely unexplored area of field theory.)

By contrast, action-at-a-distance theories such as the Weber and modified Weber laws suppose that each passing electron of the beam acts upon every mobile charge (electron) in the wire directly and instantaneously to produce the observable vertical component of electromotive force. Thus an integration over the entire volume of the wire is required in order to predict the observable signal, and there is no reason to suppose that near-surface electrons contribute more than others do.

The dimensions of the pickup wire must be determined by signal sensitivity (and signal-to-noise) requirements, by the need to speed detector response, and possibly by skin depth considerations. Fortunately the Gedanken experiment results calculated here exhibit such a dramatic difference between the Maxwell-Einstein theory and all others—at electron beam energies in the low *Mev* range—that exact theoretical analysis and prediction may not be required in order to arrive at a practical verdict. It behooves physicists—if they wish to continue talking assuredly about the metric nature of spacetime—to make the minimal effort to acquire *some* empirical evidence for the Lorentz contraction, if only of the Coulomb field.

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