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WEBER ELECTRODYNAMICS, PART I. GENERAL THEORY, STEADY CURRENT EFFECTS

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The original Weber action at a distance theory, valid for slowly varying effects, is extended to time-retarded fields, valid for rapidly varying effects including radiation. A new law for the force on a charge moving in this field is derived (replacing the Lorentz force which violates Newton's third law). The limitations of the Maxwell theory are discussed. The Weber theory, in addition to predicting all of the usual electrodynamic results, predicts the following crucial results for slowly varying effects (where Maxwell theory fails): 1) the force on Ampere's bridge in agreement with the measurements of Moyssides and Pappas, 2) the tension required to rupture current carrying wires as observed by Graneau, 3) the force to drive the Graneau-Hering submarine, 4) the force to drive the mercury in Hering's pump, and 5) the force to drive the oscillations in a current carrying mercury wedge as observed by Phipps.

Key words: electrodynamics, Weber theory extended, Maxwell limitations, current steady effects.

1. INTRODUCTION

The continued dissatisfaction with special relativity, the failures of Maxwell theory, and possible significance in mechanics and gravitation has led to considerable renewed interest in Weber electrodynamics. The present paper reviews some of this recent experimental and theoretical research.

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Due to the amount of material involved and its complexity it is published in three parts entitled: "Weber electrodynamics, part I: general theory, steady current effects, part II: unipolar induction, Z-antenna, and part III: mechanics, gravitation."

2. ORIGINAL WEBER ELECTRODYNAMICS

Weber [1] wrote his original action at a distance theory in 1848 to fit the then known facts: Coulomb's law, Ampere's original empirical law for the force between current elements, and Faraday's law of electromagnetic induction. Weber introduced the idea that electric current was composed of flowing charges, where each charge was quantized to fit Faraday's law of electrochemical deposition ($e = Q/N_0$ where Q is the net charge to deposit a gram atomic equivalent and N_0 is Avogadro's number). Weber postulated a velocity dependent potential between two moving charges, q at $\mathbf{r}$ and q' at $\mathbf{r}'$, as

$$U = (qq'/R)\left[1 - (dR/dt)^2/2c^2\right], \tag{1}$$

where $R = |\mathbf{r} - \mathbf{r}'|$ and the constant c was assumed to be the velocity of light. The first term on the right of Eq.(1) is simply the Coulomb potential.

Taking the time derivative of Eq.(1) gives

$$dU/dt = - \mathbf{V}\cdot\mathbf{F}_W, \tag{2}$$

where $\mathbf{V} = \mathbf{v} - \mathbf{v}'$ is the relative velocity between the charges and F_W is the Weber force on charge q at $\mathbf{r}$ due to q' at $\mathbf{r}'$,

$$c^2\mathbf{F}_W = (qq'\mathbf{R}/R^3)\left[c^2 + V^2 - 3(\mathbf{V}\cdot\mathbf{R})^2/2R^2 + \mathbf{R}\cdot d\mathbf{V}/dt\right], \tag{3}$$

where gaussian units will be assumed throughout. This force (3) clearly obeys Newton's third law, being directed along $\mathbf{R}$ and changing sign when primed and unprimed coordinates are exchanged. Since the force is derived from a potential; energy is conserved. The Weber theory is the only electromagnetic theory ever proposed that can conserve energy for an isolated system of moving charges. This result (3) is found to be in agreement with an amazingly large number of different experimental situations [2,3]. It works for slowly changing effects where time retardation is not required and action at a distance remains valid. Time intervals of interest, Δt, are assumed to be such that $\Delta t >> L/c$, where L is the size of the laboratory.

The force on an element of a conductor at $\mathbf{r}$ containing q_i stationary positive ions and $-q_e$ mobile negative electrons due to an element of a conductor at $\mathbf{r}'$ containing q_i' stationary ions and $-q_e'$ mobile negative electrons is obtained by adding the four forces involved as given by Eq.(3); thus,

$$c^2\mathbf{F}_W = (\mathbf{R}/R^3)\Big\{c^2(q_i - q_e)(q_i' - q_e') - (q_i - q_e)q_e'\big[v'^2 - 3(\mathbf{v}'\cdot\mathbf{R})^2/2R^2 - \mathbf{R}\cdot d\mathbf{v}'/dt\big] - (q_i' - q_e')q_e\big[v^2 - 3(\mathbf{v}\cdot\mathbf{R}^2/2R^2 + \mathbf{R}\cdot d\mathbf{v}/dt\big] + q_e q_e'\big[-2\mathbf{v}\cdot\mathbf{v}' + 3(\mathbf{v}\cdot\mathbf{R})(\mathbf{v}'\cdot\mathbf{R}/R^2\big]\Big\}, \quad (4)$$

where $\mathbf{v}$ and $\mathbf{v}'$ are the velocities of the electrons. The first term on the right of Eq.(4) is simply Coulomb's law for the force between two charged conductors.

Ampere's original empirical force law [4] is given by Eq.(4) when no net charges are on the conductors, or when $q_i = q_e$ and $q_i' = q_e'$; thus,

$$c^2\mathbf{F}_W = (q_e q_e'\mathbf{R}/R^3)\big[-2\mathbf{v}\cdot\mathbf{v}' + 3(\mathbf{v}\cdot\mathbf{R})(\mathbf{v}'\cdot\mathbf{R})/R^2\big]. \quad (5)$$

Identifying linear current elements with the moving charges by letting $I d\mathbf{s} = -q_e\mathbf{v}$ and $I'd\mathbf{s}' = -q_e'\mathbf{v}'$, Eq.(5) may be written in the more familiar form as

$$c^2 d^2\mathbf{F}_W = (II'\mathbf{R}/R^3)\big[-2d\mathbf{s}\cdot d\mathbf{s}' + 3(\mathbf{R}\cdot d\mathbf{s})(\mathbf{R}\cdot d\mathbf{s}')/R^2\big]. \quad (6)$$

Ampere's law (5) or (6) is seen to obey Newton's third law, like the general Weber theory, Eqs.(3) and (4) from which it is derived.

Faraday's law of electromagnetic induction concerns the force on the mobile electrons only, in contrast to a ponderomotive force that involves all the charges in a conductor. In particular, the force on the electrons in the unprimed conductor due to the accelerated electrons in the primed conductor, as given by Eq.(4), is

$$c^2\mathbf{F}_W = -(\mathbf{R}/R^3)q_e q_e'\mathbf{R}\cdot d\mathbf{v}'/dt. \quad (7)$$

The emf (electromotive force) around a closed loop is obtained by integrating the electric field $\mathbf{E} = -\mathbf{F}_W/q_e$ around the loop. Replacing the moving charges with a linear current element, where $\mathbf{R}q_e'\mathbf{R}\cdot d\mathbf{v}'/dt = -\mathbf{R}(dI'/dt)\mathbf{R}\cdot d\mathbf{s}' =$

$-R^2(dI'/dt)d\mathbf{s}'$, the emf induced in an unprimed loop due to the accelerated charges in a primed loop becomes from Eq.(7)

$$\text{emf} = -\oint d\mathbf{s}\cdot\oint(dI'/dt)d\mathbf{s}'/c^2R = -d/dt\oint d\mathbf{s}\cdot\mathbf{A}/c$$
$$= -d/dt\oint(\nabla\times\mathbf{A})\cdot\mathbf{n}\,da/c = -d/dt\int\mathbf{B}\cdot\mathbf{n}\,da/c, \tag{8}$$

where the usual definition of the magnetic potential $\mathbf{A}$ for a closed current loop has been introduced, Stokes theorem has been used, and the usual definition of the magnetic field $\mathbf{B}$ as $\mathbf{B} = \nabla\times\mathbf{A}$ has been introduced. The right side of Eq.(8) is seen to be the time rate of change of the magnetic flux Φ through the unprimed loop; and Eq.(8) is seen to be the usual Faraday law of electromagnetic induction,

$$\text{emf} = -d\Phi/dtc. \tag{9}$$

(This result (9) is a special case of induction. More general cases are considered in part II.)

It should be noted from Eq.(4) that there is also a ponderomotive force to be associated with Faraday induction; since accelerating charges $-q_e'$ will produce a nonzero force on a conductor with the charge $(q_i - q_e)$. In addition, there is an inverse effect given by the force on electrons $-q_e$ with an acceleration $d\mathbf{v}/dt$ due to a static charge $(q_i' - q_e')$.

The forces between static charges and charges moving with the velocity squared, terms involving v'^2, $(\mathbf{v}'\cdot\mathbf{R})^2/R^2$, v^2, and $(\mathbf{v}\cdot\mathbf{R})^2/R^2$ in Eq.(4), represent very small forces [3] which may ordinarily be neglected (These terms are taken into consideration in part III.).

Neglecting the velocity squared forces and replacing the moving point charges with charge and current volume densities, the Weber force per unit volume d^3r at $\mathbf{r}$ containing the charge and current densities ρ and $\mathbf{J}$ due to charge and current densities ρ' and $\mathbf{J}'$ in a volume element d^3r' at $\mathbf{r}'$ becomes from Eq.(4)

$$c^2d^6\mathbf{F}_W/d^3r\,d^3r' = (\mathbf{R}/R^3)\left[c^2\rho\rho' - 2\mathbf{J}\cdot\mathbf{J}'\right.$$
$$\left.+\,3(\mathbf{R}\cdot\mathbf{J})(\mathbf{R}\cdot\mathbf{J}')/R^2 - \rho\mathbf{R}\cdot\partial\mathbf{J}'/\partial t + \rho'\mathbf{R}\cdot\partial\mathbf{J}/\partial t\right]. \tag{10}$$

The effect of moving conductors may also be deduced from Eq.(3) [3]. Pseudo-effects, where charge and current *densities* change but there is no corresponding charge motion, may also be taken into account [3].

Because of occassional misunderstanding, it is important to note that *point* charges q and *linear* current elements $I\mathbf{ds}$ are mathematical singularities, that, implying infinite forces, cannot exist in nature. Only formulas, such as (10), that involve the charge *density* ρ and current *density* $\mathbf{J}$ are empirically correct; as they involve no mathematical singularities implying infinite forces.

3. WEBER ELECTRODYNAMICS EXTENDED TO FIELDS AND RADIATION

An action at a distance theory can be represented directly in terms of the force between two particles, such as Eq.(3); or it can be represented in terms of intermediate fields. In the field representation a particle, or distribution of particles, is viewed as first giving rise to an intermediate field. It is then the field that acts on another particle thereby giving rise to the observed force. Although these two representations may evoke different images of physical mechanisms involved; they are, in fact, mathematically isomorphic (when no time retardation is involved). For example, the introduction of the classical gravitational potential field to help solve problems says nothing more than Newton's inverse square law of gravitation.

Weber electrodynamics, as given by Eq.(10), has been written by Wesley [2,3] as a field theory. This can be done by integrating Eq.(10) over a fixed volume in $\mathbf{r}'$-space containing the sources $\rho'(\mathbf{r}',t)$ and $\mathbf{J}'(\mathbf{r}',t)$. The unprimed quantities $\rho(\mathbf{r},t)$ and $\mathbf{J}(\mathbf{r},t)$ upon which the primed sources act are taken out from under the integral sign. The desired result is

$$
\begin{aligned}
d^3\mathbf{F}_W/d^3r = &- \rho\nabla\Phi + \mathbf{J}\times(\nabla\times\mathbf{A})/c - \rho\partial\mathbf{A}/\partial tc - \mathbf{J}\nabla\cdot\mathbf{A}/c \\
&+ (\partial\mathbf{J}/\partial t)\Phi/c^2 + (\mathbf{J}\cdot\nabla)\nabla\Gamma/c + \rho\nabla\partial\Gamma/\partial tc - [(\partial\mathbf{J}/\partial t)\cdot\nabla]\mathbf{G}/c^2,
\end{aligned}
\tag{11}
$$

where

$$
\begin{aligned}
\Phi &= \int d^3r'\rho'(\mathbf{r}',t)/R, & \mathbf{A} &= \int d^3r'\mathbf{J}'(\mathbf{r}',t)/cR, \\
\Gamma &= \int d^3r'\mathbf{R}\cdot\mathbf{J}'(\mathbf{r}',t)/cR, & \mathbf{G} &= \int d^3r\,\mathbf{R}\rho'(\mathbf{r}',t)/R,
\end{aligned}
\tag{12}
$$

where Φ and $\mathbf{A}$ are the usual electric and magnetic potentials and Γ and $\mathbf{G}$ are two new potentials. This result (11) and (12) may be readily proven to be correct by simply showing that Eqs.(11) and (12) yield Eq.(10). In particular, first, Eqs.(12) may be substituted into (11); second, all terms may be placed under the integral sign; and, third, the del operator ∇, which operates on $\mathbf{r}$, may be allowed to operate on R and $\mathbf{R}$. The resulting integrand is then precisely the right side of Eq.(10). Since the fixed region of integration is arbitrary; the direct force representation, Eq.(10), and the field representation, Eqs.(11) and (12), are mathematically isomorphic.

Although there is no mathematical restriction on the volume over which the integration is taken to define the potential field variables, Eqs.(12); the physical meaning depends upon the choice made. The appropriate choice will depend upon the particular physical problem under consideration. For bounded sources an integration over all $\mathbf{r}'$-space may be appropriate.

Frequently the field variables may be found without having to perform the integrations indicated in Eqs.(12) directly. The integral expressions (12) imply certain differential equations and associated boundary conditions. It may be possible to solve the differential equation for the field variable. Thus, for example, in electrostatics the first of Eqs.(12) for a bounded source ρ implies an electrostatic potential Φ that is a solution to Poisson's equation,

$$\nabla^2 \Phi = -4\pi\rho\,, \tag{13}$$

subject to the conditions that Φ and $\nabla\Phi$ are continuous. The power of such field theoretic techniques are well known, and the subject need not be pursued any further here.

The expression for the force on a unit volume with charge density ρ and current density $\mathbf{J}$ due to a Φ, $\mathbf{A}$, Γ, $\mathbf{G}$ field, as given by Eq.(11), replaces the Lorentz force of the Maxwell theory. The Lorentz force involves only the first three terms on the right and requires only the Φ and $\mathbf{A}$ fields. It becomes immediately obvious that Maxwell theory is merely a limited special case of Weber electrodynamics where $\nabla\cdot\mathbf{A} = 0$, $(\partial\mathbf{J}/\partial t)\Phi/c$ is ignored, and the expressions involving Γ and $\mathbf{G}$ vanish.

Once having Weber electrodynamics expressed in terms of fields, it may be immediately extended to rapidly varying effects and electromagnetic radiation by introducing time retardation. This takes into account a finite propagation time R/c for an effect to proceed with the velocity of light c from a source point to the point of observation. In this case the potential field is defined by replacing the time in Eqs.(12) by the retarded time,

$$t^* = t - R/c. \tag{14}$$

In particular, the retarded potentials are defined by

$$\Phi = \int d^3r'\,\rho'(\mathbf{r}',t^*)/R, \qquad \mathbf{A} = \int d^3r'\mathbf{J}(\mathbf{r}',t^*)/cR,$$
$$\Gamma = \int d^3r'\mathbf{R}\cdot\mathbf{J}'(\mathbf{r}',t^*)/cR, \qquad \mathbf{G} = \int d^3r'\mathbf{R}\rho'(\mathbf{r}',t^*)/R. \tag{15}$$

The force Eq.(11) is assumed to remain valid when the retarded potential field, Eqs.(15), is introduced. It may be readily shown that these field variables are solutions to appropriate wave equations with the phase velocity c. For example, the retarded electric potential satisfies the wave equation

$$\nabla^2\Phi - \partial^2\Phi/\partial t^2c^2 = -4\pi\rho\,. \tag{16}$$

Although from time to time there have been attempts to introduce time retardation directly in force laws between two particles without an intermediate field [5]; these attempts have not been successful. The only way to introduce time retardation is apparently via fields!

Without time retardation the field variables for an action at a distance theory may be regarded as merely a convenient mathematical representation of the direct interaction between particles. But once time retardation is introduced a very different physical interpretation becomes necessary. In this case the field must be viewed as having a true physical existence all its own, capable of transmitting energy and momentum. For example, light, as electromagnetic radiation, makes the independent existence of fields evident, quite apart from original sources or final sinks.

A further modification is needed to include the effect of absolute space or the lumeniferous ether. The velocity of energy propagation of electromagnetic waves is known to be c fixed with respect to absolute space from the observations of Roemer [6], Bradley [7], Sagnac [8], Michelson and Gale [9], Conklin [10,11], Marinov with his coupled mirrors experiment [12], and Marinov with his toothed wheels experiment [13]. The Michelson-Morley result [14] was predicted by

Voigt [15] in 1887 as a nonclassical Doppler effect using absolute space and time. As shown by Wesley [2,16], the Voigt-Doppler effect for an observer moving with the absolute velocity $\mathbf{v}_0$ in the positive x direction and source moving with the absolute velocity $\mathbf{v}_s$ is given by

$$\mathbf{k}' = k_s \frac{\gamma_0(c_x - v_0)\mathbf{e}_x + c_y\mathbf{e}_y + c_z\mathbf{e}_z}{c\gamma_s(1 - \mathbf{v}_0\cdot\mathbf{c}/c^2)(1 - \mathbf{v}_s\cdot\mathbf{c}/c^2)} ,$$

$$\omega' = \omega_s\gamma_0(1 - \mathbf{v}_0\cdot\mathbf{c}/c^2)/\gamma_s(1 - \mathbf{v}_s\cdot\mathbf{c}/c^2), \tag{17}$$

$$\mathbf{c}' = (c_x - v_0)\mathbf{e}_x + (c_y\mathbf{e}_y + c_z\mathbf{e}_z)/\gamma_0, \qquad \mathbf{c}^* = \mathbf{c} - \mathbf{v} ,$$

where $\mathbf{k}'$ is the observed propagation constant, $k_s = \omega_s/c$ where ω_s is the angular frequency of the source, $\mathbf{c}'$ is the observed phase velocity, $\mathbf{c}^*$ is the observed velocity of energy propagation, $\mathbf{e}_x$, $\mathbf{e}_y$, and $\mathbf{e}_z$ are unit vectors in the Cartesian coordinate directions, $\gamma_0 = 1/\sqrt{1 - v_0^2/c^2}$ and $\gamma_s = 1/\sqrt{1 - v_s^2/c^2}$, and ω' is the observed angular frequency. The motion of the source only modifies the frequency and wavelength of emitted radiation as a function of direction. The light, once emmitted, then propagates without change with the fixed velocity c with respect to absolute space. The major effect arises from the motion of the observer with respect to absolute space. For most purposes Eq.(14) for the retarded time need only be modified by replacing c by the phase velocity c'; thus,

$$c \rightarrow c' = c(1 - \mathbf{v}_0\cdot\mathbf{c}/c^2), \tag{18}$$

to take into account this effect of the motion of the observer with respect to absolute space.

4. MAXWELL ELECTRODYNAMICS

According to Maxwell electrodynamics [17-19] the force on an element of volume d^3r at $\mathbf{r}$ containing a charge and current density ρ and $\mathbf{J}$ is given by the Lorentz force

$$d^3\mathbf{F}_M/d^3r = -\rho\nabla\Phi - \rho\partial\mathbf{A}/\partial tc + \mathbf{J}\times(\nabla\times\mathbf{A})/c, \tag{19}$$

where the scalar and magnetic potentials Φ and $\mathbf{A}$ are defined by the first two of Eqs.(12). Combining Eqs.(19) and (12) the Maxwell-Lorentz force on a volume element d^3r at $\mathbf{r}$ with charge and current densities ρ and $\mathbf{J}$ due to a volume element

d^3r' at $\mathbf{r}'$ with charge and current densities ρ' and $\mathbf{J}'$ is

$$c^2 d^6\mathbf{F}_M/d^3r\,d^3r' = c^2\rho\rho'\mathbf{R}/R^3 - \rho(\partial\mathbf{J}'/\partial t)/R \\ - (\mathbf{J}\cdot\mathbf{J}')\mathbf{R}/R^3 + (\mathbf{R}\cdot\mathbf{J})\mathbf{J}'/R^3. \tag{20}$$

In terms of moving charges, the Maxwell-Lorentz force on a charge q with velocity $\mathbf{v}$ at $\mathbf{r}$ due to a charge q' with velocity $\mathbf{v}'$ at $\mathbf{r}'$ is given by

$$c^2\mathbf{F}_M = qq'\left[c^2\mathbf{R}/R^3 - (d\mathbf{v}'/dt)/R - (\mathbf{v}\cdot\mathbf{v}')\mathbf{R}/R^3 + (\mathbf{R}\cdot\mathbf{v})\mathbf{v}'/R^3\right]. \tag{21}$$

These Eqs.(20) and (21) may be compared with the corresponding Weber expressions given by Eqs.(10) and (3). Time retardation has been neglected here; Eqs.(20), (21), (10), and (3) all refer to slowly varying effects.

It may be seen from the second and fourth terms on the right of Eq.(21) that the Maxwell-Lorentz force between two point charges violates Newton's third law; as these forces do not act along the line **R** joining the two charges, and interchanging primes and unprimes does not yield merely a change in sign. It should be remarked that a failure to obey Newton's third law is a very serious matter; as it implies drastic consequences, such as the violation of the conservation of energy, the ability to propel a space craft using only forces internal to the space craft itself, and the ability to lift oneself by ones own boot straps. Even a casual glance at Eq.(21) is, thus, sufficient to show that the Maxwell theory cannot be based solely upon the forces between isolated point charges, in contrast to the Weber theory. In addition, as will be shown below, Eqs.(20) and (21) do not agree with the experimental evidence. The Maxwell theory, being incapable of prescribing the correct force between two moving point charges, cannot be regarded as a fundamental theory. The special situations and limiting conditions under which the Maxwell theory works are outlined below in Section 4.3.

4.1. The Biot-Savart law

The Biot-Savart law, involving the force between steady current elements, is given by the last two terms on the right of Eq.(20) or (21); thus, in terms of linear current elements

$$c^2 d^2\mathbf{F}_B = II'd\mathbf{s}\times(d\mathbf{s}'\times\mathbf{R})/R^3. \tag{22}$$

As is well known, this law (22) violates Newton's third law.

Grassmann [20] (who apparently was the first to propose the Biot-Savart law) justified the law as follows: 1) It is mathematically simpler than Ampere's law (6). 2) It yields precisely the same result as the Ampere law (6) when the source current I'**ds**' is integrated around a closed current loop; and, thus, it obeys Newton's third law for the net force on an entire closed current loop. And 3) all currents necessarily form closed current loops.

Considering Grassmann's first point, it is not at all apparent that the Biot-Savart law is mathematically simpler; in some instances it yields greater mathematical difficulties. Considering Grassmann's second point, if the Ampere and Biot-Savart laws were equivalent (which they are not), the Ampere law, obeying Newton's third law from the outset, should be chosen in preference to the Biot-Savart law, which violates Newton's third law and can only satisfy Newton's third law after being integrated around a closed current loop. Grassmann's third point is drastically in error; not all currents form closed current loops. For example, the current in an open ended wire antenna (e.g., an electric dipole antenna) flows out and back and does not flow in a closed current loop. Isolated moving point charges do not in general form closed current loops (e.g., the electrons in a cathode tube). In addition, it is the *mechanical force* that must be integrated around a closed current loop to make the Biot-Savart law satisfy Newton's third law for the whole loop; the existence or nonexistence of a closed current loop is, thus, not necessarily relevant.

Ampere [4] recognized this point. He demonstrated this with the force on a hairpin shaped wire (the Ampere bridge) with ends making electrical contact in two troughs with mercury as shown in Fig. 1. The bridge is repelled down the troughs when current is sent through the bridge. Although a closed current loop is involved; the net force on the bridge is obtained by integrating the elements of force only over the bridge and not around the entire current loop. The Ampere bridge is propelled by the repulsive forces between colinear current elements, as given by Ampere's law (6). No such force is predicted by the Biot-Savart law (22); as the force on a current element is suppose to be always normal to the element. The Ampere tension or repulsion between colinear current elements also accounts quantitatively for the force necessary to rupture current carrying wires, as observed by Graneau [21-23]. The Ampere repulsion accounts for the force that drives the Graneau-Hering submarine [24, 25]. The Ampere repulsion yields the force that drives the

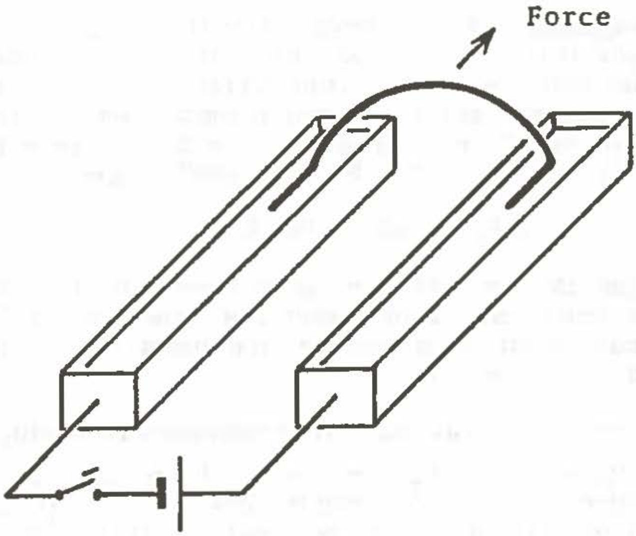

Fig. 1. Diagram of the experiment Ampere performed to refute the Biot-Savart law. The force on the bridge when current flows is in the direction indicated.

mercury in Hering's pump [25]. And the Ampere tension drives the oscillations in Phipps' mercury wedge [26].

It may be readily demonstrated that the Biot-Savart law is *absurd* [27]. The Biot-Savart law predicts a net nonvanishing self force on a closed current loop. Dividing a current carrying loop mathematically into two portions 1 and 2, the element of force on a current element Ids on portion 1 (due to a current element Ids') plus the element of force on current element Ids' on portion 2 (due to a current element Ids), as given by Eq.(22), may be integrated to give the total self force on the current loop as

$$c^2F_B = I^2\int_1\int_2 \left\{[\mathrm{d}s \times (\mathrm{d}s' \times \mathbf{R})]/R^3 - [\mathrm{d}s' \times (\mathrm{d}s \times \mathbf{R})]/R^3\right\}$$
$$= -I^2\int_1\int_2 \mathbf{R} \times (\mathrm{d}s \times \mathrm{d}s')/R^3 . \tag{23}$$

Depending upon how one chooses portions 1 and 2, one can obtain a nonvanishing force with any value at all (within limits). Such a loop would be very convenient to drive an automobile or propel a space ship. One could obtain the desired magnitude of the force without having to change anything physically; one need only alter the mathematical labels. In addition, using the criteria that Grassmann provides, that the force between elements when integrated around a closed current loop should yield the Ampere result, a completely equivalent "Biot-Savart law" is given by

$$c^2 d^2 \mathbf{F}_B = I^2 \mathbf{ds}' \times (\mathbf{ds} \times \mathbf{R})/R^3, \tag{24}$$

where $\mathbf{ds}$ and $\mathbf{ds}'$ are interchanged as compared with Eq.(22). Using this equivalent "Biot-Savart law" the net self force on a closed current loop becomes the negative of Eq.(23). The *absurdity* is complete.

4.2. Faraday's law of electromagnetic induction

The Maxwell-Lorentz force on a charge due to a time changing current or an accelerating charge, the second term in Eq.(20) or (21), does not obey Newton's third law. Thus, the Maxwell-Lorentz theory again fails; it cannot predict correctly the force between a stationary and an accelerating charge. However, it can predict the correct electromotive force around a closed loop due to another closed loop with current changing with time, the Faraday law of electromagnetic induction; thus, from Eq.(19), where $\mathbf{B} = \nabla \times \mathbf{A}$,

$$\text{emf} = -\oint \mathbf{ds}\cdot\partial \mathbf{A}/\partial tc = -(\partial/\partial t)\int da\,\mathbf{n}\cdot\mathbf{B}/c = -\partial\Phi/\partial tc. \tag{25}$$

This integral result (25) satisfies Newton's third law. Again, as for the Biot-Savart law, it is a matter of integrating an incorrect formula around a closed loop to get a correct result. This result (25) is identical to the Weber result (9).

The Maxwell-Lorentz theory is completely incapable of predicting localized unipolar induction (discussed in part II). The Weber theory, on the other hand, easily predicts all of the experimental results.

4.3. Limitations of the Maxwell theory

From the discussion above (and to follow) it may be seen that for slowly varying effects the Maxwell theory is valid only for limited situations where:

1) The interaction between moving point charges must not be involved. Maxwell theory does not provide valid expressions for the interaction between moving point charges in submicroscopic systems, such as needed to substitute into

Schroedinger's equation to obtain valid quantum theoretic predictions.

2) Macroscopic quantities of material and macroscopic distributions of charge must always be assumed.

3) A source must be confined to a finite volume, and it must vanish on the surface of this volume.

4) A detector must be confined to a finite volume, where source and detector do not occupy the same volume.

5) As limitations 3) and 4) imply, source currents must form closed current loops so that $\nabla\cdot A = \Gamma = 0$.

6) The force on an accelerating charge or time varying current due to a static charge distribution must not be involved.

7) Induction must be limited to closed current loops due to the net time rate of change of the magnetic flux through the loop.

8) Induction in only a portion of a closed loop cannot be involved.

9) Induction in open circuits cannot be involved.

In contrast, the Weber theory, being a fundamental theory based upon the interaction between two moving charges, appears to have no limitations at all.

5. DETERMINATION OF THE FORCE ON AMPERE'S BRIDGE

A crucial experiment that decides between Ampere's orginal empirical law (6) for the force between current elements and the Biot-Savart law (22) (and, thus, helps to decide between the Maxwell theory and the Weber theory) involves the measurement of the force on Ampere's bridge indicated in Fig. 1. Ampere [4], Cleveland [28], Robertson [29], Pappas [30,31], and Graneau [32-34] have shown that the bridge is repelled by the remainder of the circuit, as would be expected by Ampere's law. But these earlier experiments yielded no adequate *quantitative* measurements.

The difficulties in obtaining *quantitative* results have been both experimental and theoretical. A valid expression for the force on Ampere's bridge derived from Ampere's law, given by Eq.(26) below, that can be compared quantitatively with experiments has only been recently available. And it has only been recently that Moyssides and Pappas [35] and Peoglos [36] (analyzed by Wesley [37]) have been able to get quantitative results for the force on Ampere's bridge that can be adeqautely compared with the theory. The theoretical difficulties in the past [28-34] arose from using Ampere's law written for linear current elements, Eq.(6). This linear form yields an *infinite* force when two colinear current elements are brought together, the force varying as the inverse square of the separation distance. This infinite force arises from having assumed *infinite* current densities, finite currents I and I' being carried by wires of vanishing cross section. The empirically correct formula must involve the volume current densities; thus, instead of Eq.(6), the Ampere force should be taken from the second and third terms of Eq.(10),

$$c^2 d^6\mathbf{F}_A/d^3r\,d^3r' = (\mathbf{R}/R^3)\left[-2\mathbf{J}\cdot\mathbf{J}' + 3(\mathbf{J}\cdot\mathbf{R})(\mathbf{J}'\cdot\mathbf{R})/R^2\right]. \quad (26)$$

It may be readily shown that integrating this empirically correct Ampere's law (26), using continuous finite current densities **J** and **J'**, can yield no infinities, in agreement with observations.

5.1. Force on bridge with straight ends from Ampere's law

The force on Ampere's bridge with straight ends with the geometry shown in Fig. 2 has been calculated [3] by performing all 6 of the integrations indicated in Eq.(26). The analysis is lengthy but straightforward. All integrations yield expressions in closed form. When the width w is equal to the laminar thickness and is small, the magnitude of the force is given by

$$c^2F_A/2I^2 = C + \sqrt{1 + L^2/M^2} - ln(1 + \sqrt{1 + L^2/M^2}) + ln(L/w), \quad (27)$$

where $C = 13/12 - \pi/3 + (2/3)\,ln\,2 = 0.49822\ldots$, and the dimensions L, M, N, and w are indicated in Fig. 2.

The lower portion of the circuit diagrammed in Fig. 2 also forms an Ampere bridge. The force on this lower portion is given by merely changing the sign of Eq.(27) and replacing N by M - N. Since N does not occur, the force on the lower portion is simply the negative of Eq.(27). The net force on the current loop is, thus, zero; and Newton's third law is satisfied.

5.2. Force on bridge with straight ends from Biot-Savart law

For wires of finite cross section the Biot-Savart law must be written in terms of current densities. From the last two terms of (20) or from (22) the appropriate form of the Biot-Savart law is

$$c^2 d^6F_B/d^3r\,d^2r' = \mathbf{J}\times(\mathbf{J}'\times\mathbf{R})/R^3. \quad (28)$$

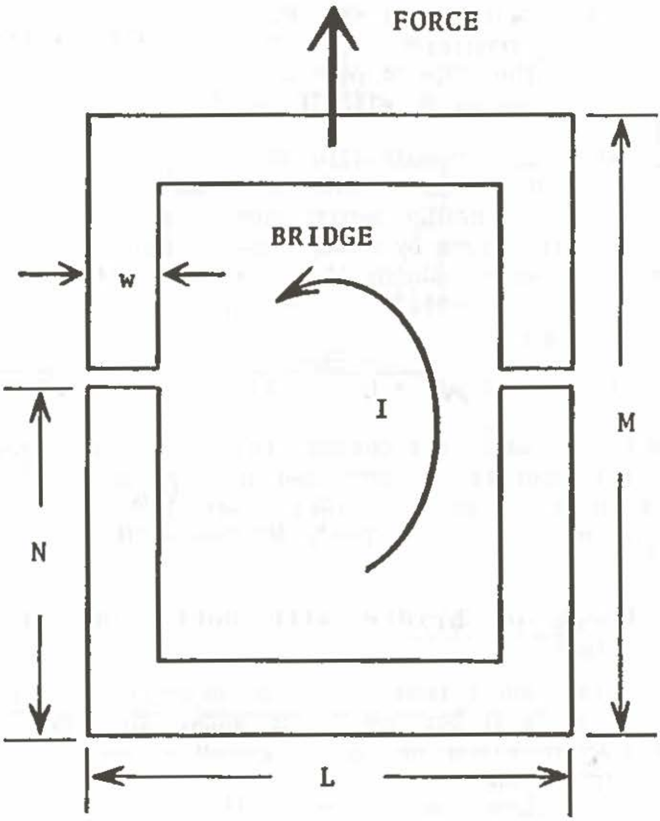

Fig. 2. Diagram of Ampere's bridge with straight ends showing the dimensions L, M, N, and w.

Carrying out the 6 necessary integrations for the Ampere bridge with straight ends as diagrammed in Fig. 2, the Biot-Savart law predicts a force on the bridge, when the width w is equal to the laminar thickness and is small, given by

$$c^2 F_B/2I^2 = -1 + \sqrt{1 + L^2/M^2} - \ln\left[1 + \sqrt{1 + L^2/M^2}\right] + \ln\left[1 + \sqrt{1 + L^2/(M-N)^2}\right]. \qquad (29)$$

This result (29) is quite different from the Ampere result (27); as may be readily seen for the case where L/M and L/(M - N) → 0. In this case the Ampere result is large and varies as $ln(L/w)$; while the Biot-Savart result becomes zero. The strong repulsive force observe [4,25,28-34] is in agreement with the Ampere prediction. The experimental observations do not agree with the weak or zero Biot-Savart prediction.

Actually, this result (29) is *absurd*: From symmetry the lower portion of the circuit diagrammed in Fig. 2 also forms an Ampere's bridge which should also experience a Biot-Savart force given by changing the sign of Eq.(29) and replacing M - N by N. Adding these two forces the net Biot-Savart force on the entire circuit is then suppose to be nonzero and equal to

$$c^2 F_{B\,net}/2I^2 = ln\left[1 + \sqrt{1 + L^2/(M-N)^2}\right] - ln\left[1 + \sqrt{1 + L^2/N^2}\right]. \tag{30}$$

Newton's third law is not obeyed. This force (30) could be used to lift oneself by ones own boot straps, to violate conservation of energy, etc. This result (30) is a specific example of the *absurdity* already demonstrated above by Eqs. (23) and (24).

5.3. Force on bridge with bent ends from the Ampere law

Moyssides and Pappas [35] also measured the force on Ampere's bridge with bent ends, as shown in Fig. 3. Using Ampere's law as given by Eq.(26), the 6 integrations may again be carried out in closed form. When the width w equals the laminar thickness and is small, the force on the bridge is given by

$$\begin{aligned} c^2 F_A/2I^2 &= ln\left[(L-P)/P\right] + ln\left[Q/(Q-P)\right] + \sqrt{1 + Q^2/N^2} \\ &- \sqrt{1 + Q^2/M^2} + \sqrt{1 + Q^2/(M-N)^2} - \sqrt{1 + (L-Q)^2/N^2} \\ &+ \sqrt{1 + (L-Q)^2/M^2} - \sqrt{1 + (L-Q)^2/(M-N)^2} - \sqrt{1 + P^2/N^2} \\ &- \sqrt{1 + (Q-P)^2/(M-N)^2} + \sqrt{1 + (L-Q-P)^2/(M-N)^2} \\ &+ \sqrt{1 + (L-P)^2/N^2} - ln\left[(L-Q)/(L-Q-P)\right] \qquad (31) \\ &+ ln\left[\frac{1 + \sqrt{1 + (L-Q)^2/N^2}}{1 + \sqrt{1 + Q^2/N^2}}\right] - ln\left[\frac{1 + \sqrt{1 + (L-Q)^2/M^2}}{1 + \sqrt{1 + Q^2/M^2}}\right] \\ &- ln\left[\frac{1 + \sqrt{1 + (L-P)^2/N^2}}{1 + \sqrt{1 + P^2/N^2}}\right] - ln\left[\frac{1 + \sqrt{1 + Q^2/(M-N)^2}}{1 + \sqrt{1 + (Q-P)^2/(M-N)^2}}\right] \\ &+ ln\left[\frac{1 + \sqrt{1 + (L-Q)^2/(M-N)^2}}{1 + \sqrt{1 + (L-Q-P)^2/(M-N)^2}}\right]. \end{aligned}$$

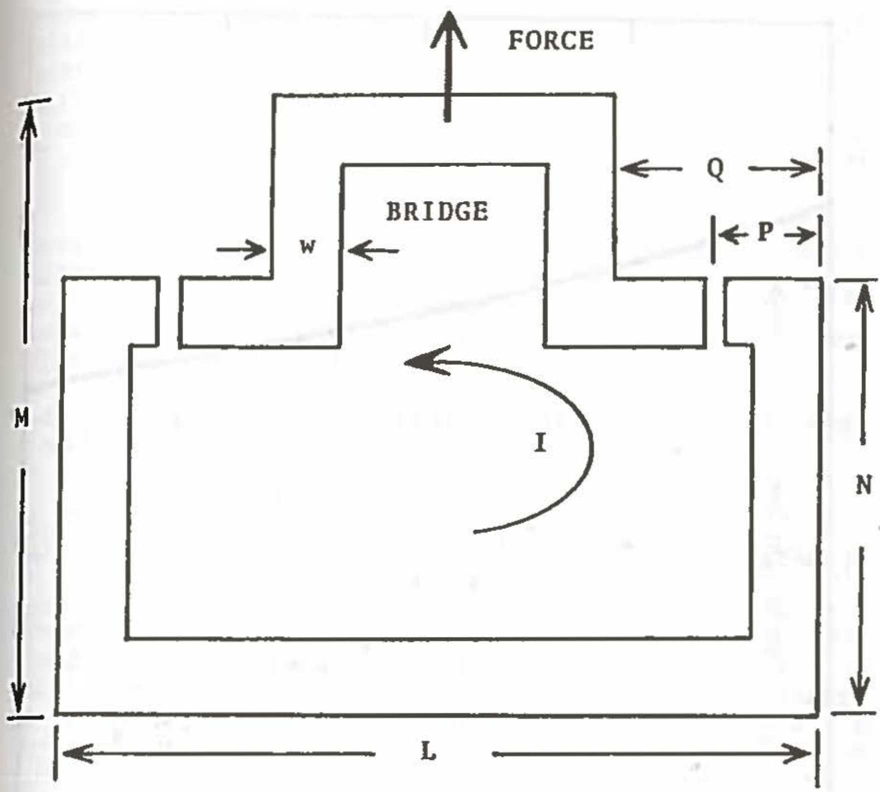

Fig. 3. Diagram of Ampere's bridge with bent ends showing the dimensions L, M, N, P, Q, and w.

Although this result (31) is lengthy with 5 parameters; numerical results may be readily computed to compare with experiment.

5.4. Experimental results for force on bridge with straight ends

The theory assumes a rectangular cross section for the wire used; whereas Moyssides and Pappas [35] actually used wires of circular cross section. To an adequate approximation the small cross-sectional areas may be equated; or

$$w = \sqrt{\pi}\, d/2, \tag{32}$$

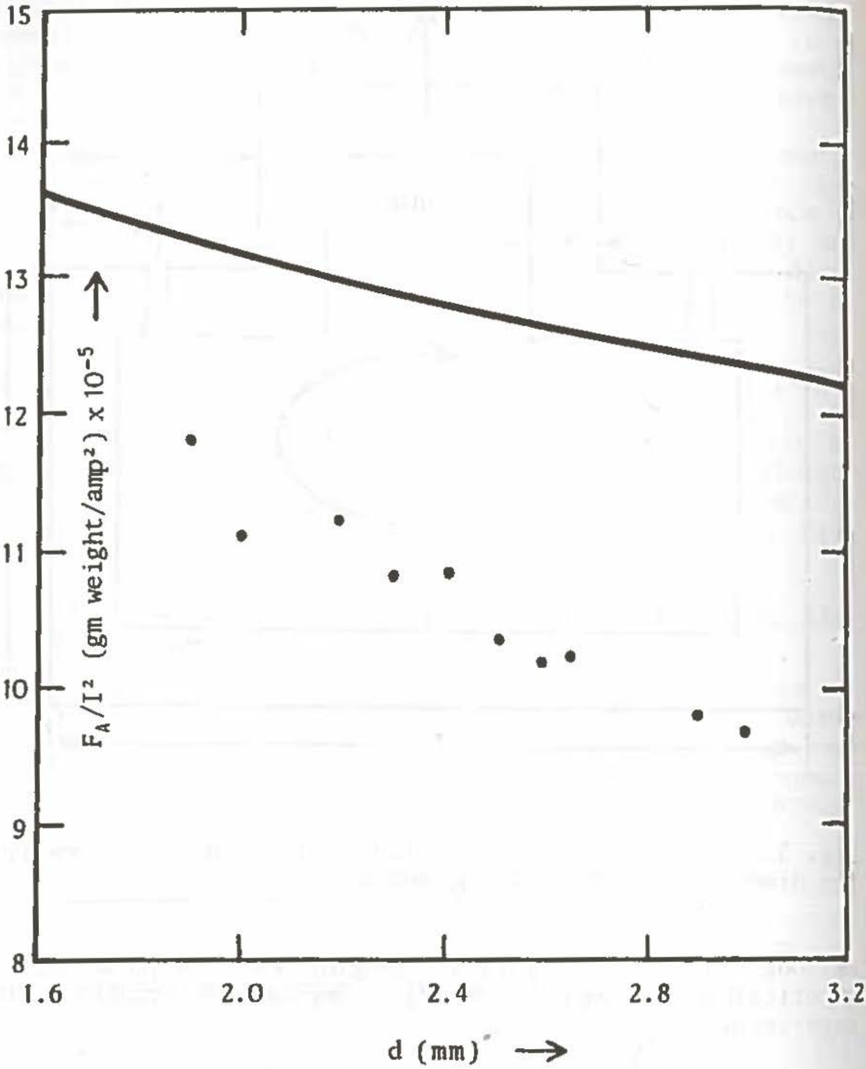

Fig. 4. Force on Ampere's bridge with straight ends, the theory (solid curve), Eq.(33), compared with experimental points.

where d is the diameter of the circular wire used. Moyssides and Pappas used L = 48 cm and M = 120 cm. They used units of gram weight for the force F_A; so Eq.(27) must be divided by the acceleration of gravity 980.0 cm/sec². They used units of ampere for the current instead of electrostatic units; so Eq.(27) must also be multiplied by $c^2/100$. Using Eq.(32) and the above facts, Eq.(27) yields the theoretical formula

$$F_A/I^2 = (14.569 - 2.0408\, ln\, d) \times 10^{-5}, \qquad (33)$$

where F_A is the force in gram weight units, I is the current in amperes, and d is the wire diameter in millimeters. This theoretical result (33) is plotted in Fig. 4, where it is compared with the experimental points of Moyssides and Pappas [35] (as presented in their Fig. 3).

5.5. Experimental results for force on bridge with bent ends

For the case of 1 cm bent ends Q - P = 1 cm, L = 52 cm, P = 1 cm, M = 120 cm, and N = 43 cm Moyssides and Pappas [35] report a force on the Ampere bridge per current squared of $7.04 \pm 0.14 \times 10^{-5}$ gm weight/amp², where the error has been estimated from their Fig. 11. Substituting the dimensions reported by Moyssides and Pappas into Eq.(31) yields the theoretical prediction of 9.500×10^{-5} gm weight/amp². Similarly for the case of 2 cm bent ends where Q - P = 2 cm, L = 54 cm, P = 1cm, M = 120 cm, and N = 43 cm Moyssides and Pappas report a force per current squared of $6.06 \pm 0.12 \times 10^{-5}$ gm weight/amp². The theoretical prediction in this case from Eq.(31) is 9.019×10^{-5} gm weight/amp². Results are summarized in Table 1.

Table 1. Force on Ampere's bridge with bent ends (gm weight/amp²) $\times 10^{-5}$

length of bent ends	experiment	theory, Eq.(31)
1 cm	7.04 ± 0.14	9.500
2 cm	6.06 ± 0.12	9.019

5.6. Discussion concerning the measurement of the force on Ampere's bridge

Examining Fig. 4 and Table 1, it may be seen that the predicted force exceeds the force reported by Moyssides and

Pappas by about 2.4 x 10^{-5} gm weight/amp^2 or 20 percent. Considering the well established success of the original Ampere law (6) or (26) in accurately predicting a vast amount of experimental data where the force on a closed current loop is involved (the Maxwell case), a reason must be sought for the discrepancy. The discrepancy is found to behave in a very regular way. For all 11 observations of the force on Ampere's bridge as a function of the wire diameter for the case of straight ends, as well as for the case of bent ends, the discrepancy Δ = (theory) - (experiment), is given quite accurately to within the experimental error by

$$\Delta = 4.57 - 0.2(F_A/I^2)(\text{theory}), \tag{34}$$

in (gm weight/amp^2) x 10^{-5} . Since this result (34) is independent of the many independent variables, the shape and dimensions of the circuit and the diameter of the wire; there must be a systematic error involved in the measurement of the force F_A and or else the current I. Since it seems unlikely that there could be any systematic error involving the current I; only the measurement of the force F_A comes into question. The systematic error might arise from phenomena in the mercury cup. The current may spread out in the cup, thereby reducing the force. Surface tension of the mercury may restrain the free motion of the bridge, resulting in apparent smaller forces. The fractional effect of surface tension should be greater the smaller the forces, as is observed.

Since the discrepancy, Eq.(34), does not depend upon the expression used, Eq.(27) or (31), nor upon the variation of the parameters; it may be legitimately used as a correction. Making this correction, it is concluded that Moyssides and Pappas [35] confirm Ampere's force law (6) or (26) quantitatively to within about 2 percent. Even without the correction they confirm Ampere's law quantitatively to within about 20 percent error.

Peoglos [36] (analyzed by Wesley [37]) reports observing the force on Ampere's bridge in agreement with Ampere's law to within 2 percent accuracy.

6. AMPERE REPULSION AND GRANEAU'S EXPLODING WIRES

Graneau [21,22] reports the breaking of wires (and liquids [23]) when loaded with large currents. He attributes this explosion of wires (and liquids) to the Ampere repulsion between colinear current elements. He was unable to obtain a valid theoretical estimate of the tension, as he used the linear form of Ampere's law (6) and had to introduce an arbitrary nonvanishing distance. The present paper derives for the first time a valid theoretical estimate of the Ampere tension available to rupture a current carrying wire using the three dimensional form of Ampere's law (26). This valid theoretical estimate supports Graneau's claim that the wires rupture due to Ampere repulsion between colinear current elements.

The force on Ampere's bridge due to the remainder of the circuit obtained by integrating Eq.(26) for the geometry shown in Fig. 2 is given by Eq.(27). This force is independent of where the mercury cups occur along the sides of length M (shown as gaps in Fig. 2). To estimate the Ampere tension T for Graneau's setup a square circuit (without mercury cups) may be considered, where L = M; thus, from Eq.(27)

$$T = (I^2/c^2)\left[C' + ln(L/w)\right], \tag{35}$$

where $C' = 13/12 + \sqrt{2} - \pi/3 + (2/3)\, ln\, 2 - ln\,(1 + \sqrt{2}) = 1.0311...$. The tension in a circular loop may then be approximated by a square circuit of the same area. A wire of circular cross section may be approximated by a wire of square cross section of the same area, Eq.(32). The tensile stress created by Ampere repulsion in a circular loop of diameter D carrying a current I in a wire of circular cross section of diameter d may then be approximated as

$$S = 4T/\pi d^2 = (4I^2/c^2\pi d^2)\left[1.0311 + ln(D/d)\right]. \tag{36}$$

6.1. Ampere stress needed to break the wire

Graneau [21] considers the case of the breaking of a current carrying straight wire of diameter d = 1 mm and length L = 150 cm carrying a current of $I = 10^4$ amp. Approximating this case by a circular circuit of diameter $D = 2L/\sqrt{\pi} = 169$ cm, Eq.(36) yields the estimate of the Ampere tension in the wire as 8.64 kgm, or an Ampere tensile stress of 11.0 kgm/mm². This is about 1/4th the tensile stress needed to break cold copper; but it is undoubtedly sufficient to impulsively break copper weakened by Joule heating.

Graneau [21] also considers the case of a curved circuit which may be approximated by a circle of diameter D = 50 cm of 99% pure aluminium wire of diameter d = 1.2 mm carrying a current of $I = 5 \times 10^3$ amp. According to Eq. (36) the Ampere tensile stress in the wire is 2.29 kgm/mm². This is about 1/9th the tensile stress needed to break cold aluminum; but it is undoubtedly sufficient to impulsively break aluminum greatly weakened by Joule heating.

6.2. Discussion concerning exploding wires

The microscopic appearance of the clean right angle breaks that Graneau obtains indicate that rupturing occurs as a result of impulsive tensile loading and that no radial pinch effect, which would have yielded a necking-down, could be responsible for the observed ruptures.

It is sometimes speculated that the explosion of wires carrying large currents is due entirely to Joule heating of occluded gases on grain boundaries of the metal. Although this mechanism may contribute to the weakenning of the tensile strength of metals; it cannot account for the explosion. No alternative methods of heating, such as microwaves, even to melting, have ever been observed to produce such explosions in metals. If it were merely a matter of Joule heating, rupturing in the radial direction should also be observed; and radial rupturing providing less resistance to expansion would seem to be preferred. If the effect were due to Joule heating, the ends of the broken wires should be ragged and should show signs of melting instead of showing clean right-angle breaks indicating impulsive tensile loading. In addition, Graneau's [23] observation of ruptures in liquids due to Ampere tnesion cannot be attributed to Joule heating of occluded gases on grain boundaries.

Ampere tension is the only force available to give rise to the observed tensile ruptures. The magnitude of the Ampere tension estimated here is of the correct order of magnitude to account for the ruptures observed. If some weakenning by Joule heating is assumed, the match between theory and experiment is adequate. The absence of data on the rupture strength of metals as a function of temperature and the absence of the temperature of the wires when exploding make it impossible to check this point. In conclusion, Graneau's claim that his wires carrying large currents break due to Ampere tension is undoubtedly correct.

7. GRANEAU-HERING SUBMARINE AND HERING'S PUMP

Hering [25] performed a number of interesting experiments that he claimed could not be adequately explained by traditional Maxwell theory. Among these experiments is the propulsion of a wedge-shaped piece of copper, or "submarine", when laid in a trough of current carrying mercury. Graneau [24] repeated this experiment and ascribed the propelling force to the repulsion between colinear current elements given by Ampere's original force law (6) or (26). Graneau did not derive a theoretical expression for the force on the submarine; nor did he measure the force quantitatively. The present paper derives for the first time an estimate of the force on the Graneau-Hering submarine from Ampere's original force law.

Hering [25] also performed an experiment in which mercury is pumped uphill from a central reservoir into a narrow current carrying channel where the mercury then flows in two opposite directions into large reservoirs at either end of the narrow channel. The electric current flows in only one direction down the narrow channel; the effect is independent of the direction of the current flow. In principle, this experiment again demonstrates the propulsive force on a current carrying metal wedge. In this case the wedge is formed by the mercury from the narrow channel toward the large reservoirs. The theory derived here for the Graneau-Hering submarine is, thus, equally applicable to Hering's pump.

The result (27) or (35) yields the Ampere tension as proportional to the logarithm of the ratio of the size or diameter of the circuit to the size or diameter of the wire. The size of the wire enters in from the integration of Eq. (26) only in the neighborhood of the point where the tension is calculated. Away from this point the size of the wire is a matter of indifference in the integrations when the size of the wire is small compared with the other dimensions of the circuit. For the Graneau-Hering submarine, assuming that all of the current is funnelled through the higher conducting copper submarine, the tension, or force, T_1 at the rear end of width w_1 of the submarine is

$$T_1 = (I^2/c^2)\left[C'' + ln(L/w_1)\right], \tag{37}$$

where c" is a constant, which may be obtained from Eq.(27). The tension or force at the forward end of width $w_2 > w_1$ is

$$T_2 = (I^2/c^2)\left[C'' + ln(L/w_2)\right]. \tag{38}$$

Assuming w_2 and w_1 are small compared with the other dimensions of the circuit, the net force F to propel the submarine is simply

$$F = T_1 - T_2 = (I^2/c^2)\, ln(w_2/w_1). \tag{39}$$

This force propels the submarine in the direction of the broader end as observed.

This result (39) may also be used to obtain the force on the mercury in Hering's pump.

8. AMPERE TENSION IN PHIPPS' MERCURY WEDGE

The observed results of Graneau [24] and Hering [25] for the force on the Graneau-Hering submarine and the force to drive the Hering pump have only been qualitative. An appropraite quantitative prediction of this force (suggested by Wesley [38]) using Ampere's law, as given by Eq.(27) or by Eqs.(37) and (38), should be possible by measuring the pressure difference between the ends of a wedged shape container of current carrying mercury as indicated in Fig. 5. The difference in tension per unit area, the pressure, can be determined by the difference in the height Δh to which the mercury rises in the two columns indicated in Fig. 5. Since the static pressure in the mercury must be the same throughout; the mercury will rise on the end of width w_2, where the internal Ampere pressure is less to match the higher Ampere pressure at the other end of width w_1; thus,

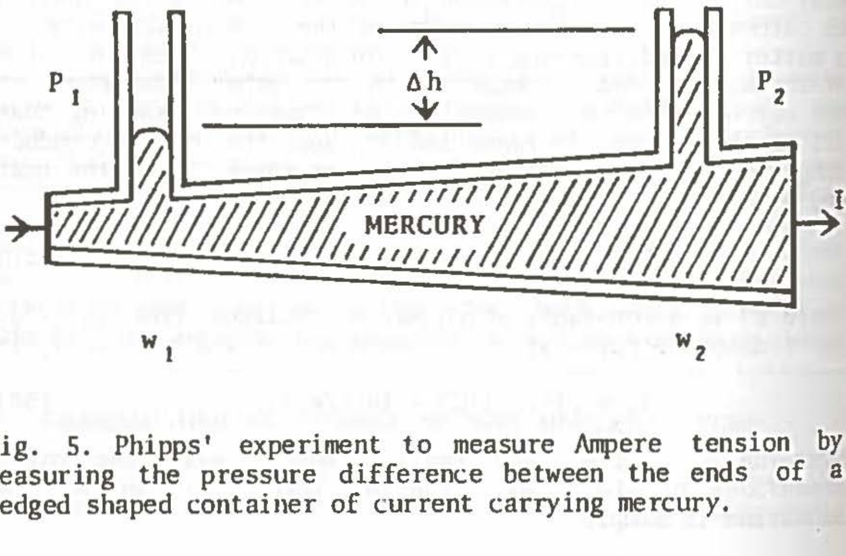

Fig. 5. Phipps' experiment to measure Ampere tension by measuring the pressure difference between the ends of a wedged shaped container of current carrying mercury.

$$\rho_{Hg} g \Delta h = (I^2/c^2 w_1^2)[C'' + ln(L/w_1)] - (I^2/c^2 w_2^2)[C'' + ln(L/w_2)], \tag{40}$$

where ρ_{Hg} is the density of mercury, g is the acceleration of gravity, and C" is a constant that can be obtained from Eq.(27).

Phipps [26] has performed this experiment using a slowly alternating current to set the mercury columns into oscillation. He observes mechanical oscillations of twice the electrical excitation, as would be expected from the Ampere driving tension varying as the current squared I^2. A rocking mode, one column up when the other is down, is observed, as would also be expected from the Ampere on-off tension. A satisfactory approximate quantitative confirmation of Eq.(40) is obtained under the assumptions that: 1) About one-third of the mercury mass present participates in mechanical oscillations. 2) For the micron-sized oscillations observed the restoring force of gravity is augmented (two or three-fold) by surface stretching forces associated with the surface tension of mercury. And 3) the "Q" of the mechanical resonance is lowered by some unidentified form of energy dissipation much greater than that attributable to mercury viscous friction against the vessel walls.

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