Foundations of Physics Letters, Vol. 16, No. 1, February 2003 (©2003)

"BREAKTHROUGH" PROPULSION AND THE FOUNDATIONS OF PHYSICS

James F. Woodward

Departments of History and Physics
California State University
Fullerton, California 92834
E-mail:jwoodward@fullerton.edu

Received 2 July 2002; revised 23 August 2002

Hopeful that a way can be found to circumvent the technical problems of conventional advanced propulsion, some have recently initiated investigations into so-called "breakthrough propulsion physics." Speculative conjectures in this area involving alleged unconventional electromagnetic effects, both classical and semi-classical, predating this recent interest, have become a focus of current investigation. Two of these conjectures are examined here in some detail and shown to be untenable since, in addition to violating conservation principles, they lead to the expectation of large effects that are not observed.

Key words: breakthrough propulsion, electromagnetic propulsion, space drives.

1. INTRODUCTION

Nearly 15 years have passed since Kip Thorne and his then graduate students Michael Morris and Uli Yurtsever fundamentally changed the nature of discourse on rapid spacetime transport, indeed, even time travel [1,2]. They did this by pointing out that those possessing an "arbitrarily advanced culture" might be able to engineer "wormholes," fixtures that have since become the backbone of much science fiction and continue to be addressed in serious scientific literature. The work of Thorne *et al.* did more than inaugurate investigations of wormholes, their kin "warp bubbles," and time travel. It created the environment in which serious discussion of "breakthrough propulsion physics" became possible. The "breakthrough" part of this moniker stems from

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the realization that we won't be going anywhere very far very fast with the sort of propulsion technologies now widely accepted as feasible, or even plausible. Given the widespread belief that we already know all propulsion schemes allowed by present physics, the assumption of the necessity of a "breakthrough" to "new physics" to accomplish truly rapid spacetime transport is understandable, though not necessarily correct. Accordingly, when NASA established a program in 1996 to seek "revolutionary" advances in propulsion technology, it was natural to call it the Breakthrough Propulsion Physics (BPP) program [now "project" as its participants have so far managed to avoid the sort of embarrassments that would have led to its cancellation].

Whatever one may think about the prospects of a breakthrough to new physics that might enable rapid spacetime transport, some aspects of physics are so well-known and so well-established that any purported "breakthrough" that calls them into question should be regarded with *very deep skepticism.* For example, several schemes that purport to enable rapid spacetime transport antedate the creation of the BPP project. Almost all of them are based on electrodynamical effects that putatively produce propulsive forces without the ejection of any material propellant. Were such a scheme workable, needless to say, that would be pretty impressive in light of the fact that none of these schemes constitute photon rockets. Although most of these schemes are purely classical, the most heavily hyped scheme is semi-classical in that it alleges that propulsive forces might be created by electromagnetic manipulation of the quantum mechanical electromagnetic zero point fields (EZPFs), the sea of fleeting photons that putatively fills all spacetime. When the BPP project was created, these schemes were natural candidates for examination in the search for the imagined breakthrough. Indeed, quite apart from the modest investments made through the BPP project, some of these schemes have attracted very substantial resource investments. The first (and so far only) workshop sponsored by the BPP project was dominated by those advocating an EZPF scheme. That scheme turns out to be deeply flawed; but one may reasonably ask: What about other schemes based on classical electrodynamics, including the semi-classical quantum vacuum? That is the question addressed in this paper.

2. CONSERVATION PRINCIPLES

If one adheres to Thomas Kuhn's vision of the progress of science, then one would expect that the "breakthrough" needed to enable rapid spacetime transport might well lead to the falsification of some truly fundamental principle lying at the foundations of physics, notwithstanding that Thorne *et al.* explicitly stipulated that this *not* be the case in their investigations. The obvious candidate principle for violation is the conservation of momentum, for if it is violable, then one can imagine that there might be some way, by local operations, without the expulsion of material propellant, to get a craft to accelerate. There are two very general problems with all of these schemes. First, the conservation of momentum, the nonrelativistic counterpart of the conservation of "momenergy", since the work of Emmy Noether back in 1917, is known to be a consequence of the invariance of the laws of physics under infinitesimal space translations, a symmetry principle. (The relativistic counterpart, of course, is the invariance of those laws under infinitesimal transformations of the Poincaré group, which implies the conservation of momenergy.) That is, if you allow violations of momentum conservation, the laws of physics here may be quite different from laws of physics out there. One hears speculation of this sort from time-to-time, but no one takes it at all seriously for no credible evidence that the conservation principle is false has ever been adduced. Not only do the law of physics lose their universality if the conservation law is violated, the principle of relativity (observer independence of the laws of physics), which leads inexorably to the theory of relativity, is violated too. Selling that idea to any sensible physicist makes selling a major public monument, for example, the Brooklyn Bridge, the Eiffel Tower, or the Great Wall of China, trivial by comparison. Experimental corroboration of relativity theory places that theory and its underlying principle beyond serious criticism.

3. RELATIVITY, INERTIA, AND ACCELERATION

The second problem – since we're not going to entertain violation of the principle of relativity and the conservation principles that follow from the invariance of the laws of physics under the Poincaré transformation group – is a bit subtler. It is based on the fact of experience that accelerations take place with respect to the chiefly distant matter in the cosmos, not with respect to some "absolute" space, as the notion of absolute space is incompatible with the principle of relativity. For example, when an object is set into rotation, centripetal forces must be provided to keep the object from flying apart. Inverting this observation, we remark that centripetal forces only occur when objects rotate, and rotation accordingly singles out a preferred set of frames of reference: those frames that do not rotate. Rotate with respect to what? Newton would have said "absolute space," but we know that can't be right. The principle of relativity (already built into Newton's first law of motion) tells us that there is no absolute space. If we look around, however, we discover that all non-rotating frames of reference, inertial frames of reference in particular, are those that do not rotate with respect to the chiefly distant matter in the cosmos.

Ernst Mach, notably, remarked on this fact in his critique of Newtonian mechanics [3]. Einstein succumbed to the intuitive obviousness of this observation, and elevated it to principle status: Mach's principle, or equivalently, the principle of the relativity of inertia – the proposition that inertial forces are caused solely by the matter in the universe, relative to which all accelerations ultimately transpire, *not* as a consequence of accelerations with respect to absolute space (or "aether," be it classical or quantum mechanical). How? Through the only truly universal interaction: gravity. Einstein thought he had failed to incorporate "Mach's principle" into general relativity theory (GRT). It wasn't until the mid 1970s that he was shown to have been wrong in this conclusion, at least in the case of the class of model universes that includes ours (so-called Friedmann-Robertson-Walker universes distinguished by their large-scale homogeneity and isotropy) [4].

The gravitational origin of inertial forces, as one might expect, does have some relevance to revolutionary propulsion. But for our purposes here, it can be ignored.

As far as electrodynamical rocket science is concerned, the fact that the inertia of objects is determined by the distribution and gravitational action of chiefly distant matter means, ultimately, that in order to change the velocity of some local object without the expulsion of some material propellant, one must find a way to directly "push off" of the chiefly distant matter in the cosmos. This might be done in one of several ways. For example, one might envision that one could create some field locally which, when aimed at the distant matter in the direction one wanted to go, would couple to the distant matter and cause the desired acceleration. A gravitational "tractor beam" scheme of this sort was seriously proposed by Li and Torr in the 1990s [5]. The physics in this proposal, though debatable on several points, is reasonable and plausible. But when Edward Harris pointed out that an error of roughly 20 orders of magnitude had been made in the computation of the forces created, this scheme quietly passed away [6]. Electromagnetic tractor beam schemes have been proposed too; but none worthy of serious consideration has yet been laid out (though I note that an "in house" BPP investigation, done literally "on a shoestring," recently discredited one of these schemes) [7].

4. UNBALANCED ELECTROMAGNETIC PROPULSION SCHEMES I [STATIC FIELDS]

Other strictly electromagnetic propulsion schemes involve creating "unbalanced" forces within an object that allegedly accelerate it, sometimes by "pushing off" the vacuum. Two are worthy of note, chiefly because of their persistence (both have been around for upwards of fifty years). The first was "created" by a fellow named T. Townsend Brown in the 1920s (references to Brown's "work" can be found in Refs. 8 and 9, critiques thereof). Brown, it seems, learned that the inertial mass of positive charges was greater than the inertial mass of negative charges

– as is in fact the case with electrons and protons. Evidently, this suggested to him that capacitors should accelerate toward their positive electrodes, especially if the putative effect in operation were "concentrated" by making the positive electrode smaller than the negative electrode. The asymmetry of the capacitor produces a strong gradient in the electric field, but nothing more. Now, it should be *obvious* that this scheme is *nonsense*. It is easy to understand how an untutored student in the 1920s might entertain such a scheme, but given its clear violation of momentum conservation and lack of any explanation of the alleged force generation, how anyone else could take it seriously remains a mystery. Wishful thinking seems the only possible motivator. Nonetheless, this scheme has been extensively investigated, repeatedly, since it first surfaced in the '20s. It was convincingly discredited in 1952 by a theoretical investigation carried out at the Naval Research Labs [8]; and again in the late 1980s when the Air Force commissioned a careful experimental investigation which also yielded convincing null results [9]. These and other experimental falsifications notwithstanding, patents continue to be granted (as recently as 2001) for devices justified in terms of the so-called Biefeld-Brown effect. (Biefeld was a teacher of Brown's who was snookered into taking his "experiments" seriously.)

Part of the obvious lunacy of the putative Biefeld-Brown effect is a consequence of the fact that, allegedly, it is produced by *static* high voltages. Since the only electromagnetic fields present in one of these "asymmetrical capacitor" systems are non-propagating induction fields (after static conditions have been achieved), and since there is no net electric charge out there (on average) at a distance for the induction fields to couple to, plainly such a system will not accelerate – no matter what field gradients may be present in the system itself. There can be no question that this is true for any classical electrodynamical system. But what if the vacuum really is seething with the ZPFs of quantum lore? What if the vacuum really does behave as a *virtual* polarizable medium because of all of the evanescent electron-positron (e-p) pairs constantly flitting into and out of existence? It would seem that along with any material dielectric present in an asymmetrical capacitor, the vacuum must also be polarized when the plates of the capacitor are charged. Like the dipoles induced in any *real* material dielectric, the polarized vacuum must experience a "volume" force owing to the presence of the electric field gradient.

In material dielectrics, the effect we are talking about is electrostriction, a well-known, small effect that causes dielectrics in the presence of a non-uniform electric field to move to the region of highest field strength, because of the interaction in the dielectric between the induced polarization and the external field gradient. (This effect is quadratic in the field strength, for the resulting force is always toward higher field strengths irrespective of the direction of the field.) If the dielectric is a solid confined between the plates of a capacitor, however, it does not move. The electrostrictive "body" or "volume" force in the dielectric is balanced by the "surface" forces on the dielectric at the plates, as demanded by momentum conservation. But *if* the vacuum e-p ZPF carries energy and momentum, *as it is not confined by material structures like capacitor plates,* that accelerating force will cause a momentum flux in the vacuum that conservation laws dictate must be compensated by equal and opposite momentum acquired by the asymmetrical capacitor. So, it would seem that *if the e-p ZPF really exists*, asymmetrical capacitors might produce "unbalanced" forces and accelerate more-or-less as claimed by Brown and his aficionados. Note that this is true even if the total energy density of the vacuum is essentially zero (as observed in fact), for only electrically charged ZPFs respond to the induced electric field, and their energy density, and thus mass density, presumably is not zero (indeed, according to standard quantum field theory, it is ridiculously large). Moreover, it makes no difference whether you take the e-p ZPF to be simple random fluctuations that behave as a fluid, or transient bound state positronium that behaves as a solid (like the luminiferous aether of yesteryear). Either one is unconstrained by the solid structures that confine any real dielectric present, and accordingly will be accelerated by any electric field gradient present – yielding the unbalanced reaction force on the asymmetrical capacitor.

ZPFers might look for reasons to believe that there may be something to all this (like the Lamb shift and so on). We, instead, look for some reason to set all this aside (before troubling to engage in a calculation of the magnitude of the putative semi-classical effect). As it turns out, there is a simple argument that should suffice to put "asymmetrical capacitors" in static charged conditions beyond the pale for propulsive purposes. It depends on energetic considerations. We posit that statically charged asymmetric capacitors really do create a momentum flux (though a surface that encloses the capacitor) in the e-p ZPF of the vacuum in the direction of the induced field gradient. If such a momentum flux is in fact created by the electric field gradient in the capacitor, it must be accompanied by an energy flux, for the "effective" mass of the substance in the momentum flux has acquired an "effective" mechanical energy by virtue of its acceleration by the electric field gradient in the capacitor. We now ask: where does the energy conveyed to the vacuum e-p ZPF come from? New agers might suggest that it comes from "another dimension," or a "parallel universe," or that it is simply created *ex nihilo* by the electric field gradient. But were that the case, we should expect to see energy flows out of atoms and other structures of elementary particles where strong electric field gradients are commonplace. No such energy flows are observed. We are thus left with the energy stored in the field between the plates of the capacitor as our only plausible energy source. So if there is an energy/momentum flux in the e-p ZPF out of the capacitor, it must deplete the energy stored in the field of the capacitor. That is, the capacitor should spontaneously discharge at a rate consistent with the putative energy flux carried away by the e-p ZPF. (But note that symmetrical capacitors should not so discharge.) No credible evidence whatsoever for such behavior exists. So we can't push, off the vacuum (or anything else) by statically charging asymmetric capacitors; they aren't the "flux capacitors" of science fiction that we seek.

5. UNBALANCED ELECTROMAGNETIC PROPULSION SCHEMES II [TIME VARYING FIELDS]

When we allow for time-variation of electromagnetic fields, however, the static electromagnetic situation changes. At the very least, electromagnetic radiation is now possible, and the emission of the radiation will necessarily be accompanied by (incredibly minute) radiation reaction forces on the generating circuit, the source of the "push" in photon rockets. Photon rockets, though, are just plain old propellant based rockets, albeit the propellant is now photons rather than fermions. As in the static field case, what we really want here is a scheme that will let us push off of the vacuum; a scheme, however, that doesn't lead to obviously wrong physical predictions as in the case of "asymmetrical capacitors." The "Slepian space drive" purports to be precisely what we are looking for. It is based on the simple series LC circuit shown schematically in Fig. 1 [after Corum, *et al.* [10]]. The action, so to speak, takes place between the plates of the capacitor where time-varying electric and magnetic fields are present when the circuit is driven with an AC power supply. We ask a simple question: What is the force present between the plates of the capacitor due to the presence of the time-varying fields? If we assume that the region between the plates is a vacuum, the straight-forward answer to this question might seem to zero.

But if the force is computed by taking the divergence of the Maxwell stress tensor between the plates, even in a vacuum and even ignoring electrostriction (and magnetostriction), this turns out to be wrong. In addition to the usual Lorentz force (which, at least classically, is zero in a vacuum since it allegedly only acts on "real" electric charges) we recover another term – labeled by the aficionados of the Slepian scheme the "Heaviside force." Although it time-averages to zero, contrary to what one might reasonably expect, instant-by-instant it is non-zero.

The idea that one might actually be able to exert a force on empty space, thus producing a reaction force on the circuit that generates the force, seems utterly counterintuitive. Should one consult most texts on electrodynamics, such a possibility is not even mentioned, much less discussed. But there is at least one exception: the classical electrodynamics text by Panofsky and Phillips, chapter ten, section

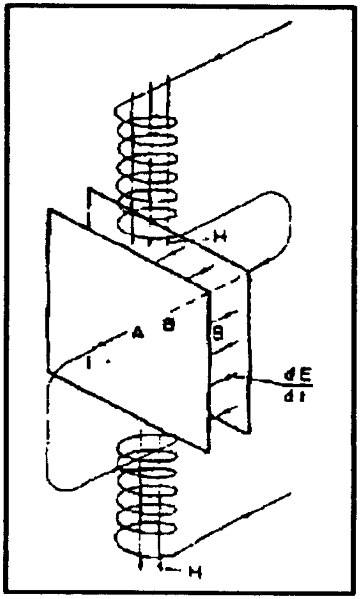

Fig. 1. The Slepian space drive circuit where the time-varying E and B fields between the plates of the capacitor allegedly produce a "Heaviside" force on the vacuum.

six [11]. They compute the divergence of the Maxwell stress tensor $T_{\alpha\beta}$ to recover the body force on a region containing matter and fields, obtaining:

$$\partial T_{\alpha\beta}/\partial x_\beta = [\mathbf{F}_{ev} + \partial(\mathbf{D} \times \mathbf{B})/\partial t]_\alpha = [\mathbf{F}_{ev} + \mu\varepsilon\partial(\mathbf{E} \times \mathbf{H})/\partial t]_\alpha, \quad (1)$$

where, following the conventions and notation of Panofsky and Phillips, $\mathbf{F}_{ev}$ is the volume force acting on material particles in the region, that is, the Lorentz force, and the second term is the time derivative of the Poynting vector. As they remark (on pages 182 and 183), "the second term in [this equation] does not vanish even *in vacuo*, and therefore it would superficially suggest the idea of a volume force on the vacuum. This term has evoked a great deal of speculation. It fits into an ether theory in which vacuum possesses various mechanical properties that enable it to transmit elastic waves and also to sustain body forces .... If we therefore adopt the point of view that the only volume force which has a place in physical theory is a force derivable from the Lorentz force, ... , it follows that the second term in [this equation] must be subtracted out ... " This allows them to write the integrated total body force on the region as the surface integral of $T_{\alpha\beta}$ (via the divergence theorem, without any subtracted terms) minus the volume integral of the subtracted term, now interpreted as the momentum density of the electromagnetic field within the region. That is, the "subtracting out" procedure leads to the now standard view and momentum conservation as commonly understood.

Advocates of the Slepian space drive scheme, in effect, argue that the "subtracting out" procedure used to recover the standard interpretation of electrodynamics is fudging to get the "right" answer. If one does not so fudge, however, and we still attribute momentum to the electromagnetic field (as the existence of radiation pressure suggests we must), then momentum conservation goes by the boards, for we are left with an extra term involving the Poynting vector that louses up momentum balance. As long as one takes the vacuum to be the true void of post special relativity theory classical physics, the standard interpretation is easy to accept as the correct one. But if we take the semi-classical quantum vacuum interpreted to be seething with an e-p ZPF that might be acted upon electromagnetically, then the existence of $\mu_0\varepsilon_0\partial(\mathbf{E}\times\mathbf{H})/\partial t$ "Heaviside force" doesn't seem quite so preposterous. (The zero subscripts indicated vacuum values of the permeability and permittivity.) Even should this be right, however, we're still not out of the woods (vertically one assumes). The Heaviside force between the plates of the capacitor in the Slepian circuit in Fig. 1 with an applied AC voltage is periodic and time-averages to zero. So, even if the Heaviside force acting on the vacuum exists, we're not going anywhere with it unless we can find a way to "rectify" it. Slepianistas have suggested that the inclusion of ferroelectric materials in the capacitor might produce such rectification. Before addressing this issue, we digress to consider the action of time-varying electromagnetic fields on electric charges, for we'll need this in the subsequent discussion.

6. A DIGRESSION ON ELECTROMAGNETIC FORCES

Inspection of the Slepian circuit in Fig. 1 indicates that we are going to be interested in the action of mutually perpendicular electric and magnetic fields on any substance that lies between the plates of the capacitor. Since electromagnetic fields *only* act on electric charges, whatever that substance may be – nothing whatsoever (the vacuum) plus some dielectric material in the standard classical view; and for other views of the vacuum, a polarizable solid dielectric in the case of the aether, the evanescent charges of the e-p ZPF in the case of the semi-classical vacuum, or something yet more exotic – we will need to know what the action of time-varying, mutually perpendicular electric and magnetic fields on electric charges is. In particular, we want to know in what conditions secular momentum transfer from the fields to the charges takes place. The action of a plane electromagnetic wave on a free charge turns out to be a special case of these conditions that is easily generalized to the circumstances of the Slepian system. So we will start with this case and build from there.

Keeping things simple, we consider a lone electrically charged particle initially at rest (at the origin of some convenient coordinate system) imminently to be acted upon by a single frequency, plane electromagnetic wave. When the wave acts on the charge, at the outset the charge only responds to the electric field part of the wave, for it has no velocity and thus is not acted upon by the magnetic field part of the wave. As soon as the charge starts to move under the action of the electric field, of course, this situation changes and the magnetic field part of the wave now acts on the moving charge as the moving electric charge has become an electric current. We will approximate all this by assuming that the action of the electric and magnetic parts of the wave can be treated separately and then added together to get the total action of the wave on the charge. (This is a common practice, for the magnetic contribution to the equation of motion is formally quite small and can therefore be treated as a perturbation.) The equation of motion for the electric part of the wave is

$$|m\mathbf{a}| = eE_0 \sin(\omega t), \tag{2}$$

where m and e are the mass electric charge of the particle respectively, and $\mathbf{a}$ its acceleration in the direction of the electric field $\mathbf{E} = E_0 \sin(\omega t)$ with angular frequency ω. To get the action of the magnetic part of the wave, we integrate this equation to get the velocity of the particle due to the action of the electric field and then use the $e(\mathbf{v} \times \mathbf{B})$ part of the Lorentz force to compute the action of the magnetic field. Integrating Eq. (2), we get

$$|\mathbf{v}| = -(e/\omega m)E_0 \cos(\omega t), \tag{3}$$

in the direction of $\mathbf{E}$. Initial conditions have been chosen so as to suppress the constant of integration.

The magnetic field in our plane wave is perpendicular to the $\mathbf{E}$ field and satisfies $\mathbf{B} = B_0 \sin(\omega t)$. So, after a little algebra, we find for the magnetic part of the Lorentz force in this case:

$$|\mathbf{F}_{\text{mag}}| = e|(\mathbf{v} \times \mathbf{B})| = -(e^2/2\omega m)E_0 B_0 \sin(2\omega t). \tag{4}$$

Note that, since $\mathbf{v}$ lies in the direction of $\mathbf{E}$, and $\mathbf{E}$ and $\mathbf{B}$ are perpendicular to the direction of motion of the wave, $\mathbf{F}_{\text{mag}}$ lies in the direction of motion *of the wave.* Inspection of Eq. (4) reveals that the motion induced by the magnetic part of the incident wave is periodic with a frequency twice that of the wave itself and that at this level of approximation, there is no secular momentum transfer from the wave to the charged particle. That is, the action of the wave does not cause the particle to recoil with steadily increasing momentum in the direction of the wave. The combined action of the $\mathbf{E}$ and $\mathbf{B}$ fields is a figure-eight, and it is fixed in space. Actually, notwithstanding the approximations used, this turns out to be a fairly accurate representation of the action of the wave on the charged particle. Indeed, not long ago this was confirmed in an experiment where a strong monochromatic laser beam irradiated a plasma. The second harmonic produced by $\mathbf{F}_{mag}$ was sought and found in the scattered radiation [12].

While this model of the wave/particle interaction may be quite good as a first approximation, we know it cannot be complete, for the motion of the particle induced by the wave is accelerated, and accelerating charged particles radiate. The scattered secondary radiation carries away energy and momentum that originated in the incident wave, but the pattern of the scattered radiation has no net momentum flux in the direction of the incident wave. Conservation of momentum, thus requires that the charged particle recoil in the direction of the incident wave to compensate for the momentum carried away by the scattered radiation. How we can include this effect in our model? By introducing a phase lag between $\mathbf{v}$ and $\mathbf{E}$ that we can attribute to the action of radiation damping of the motion of the particle by the scattered radiation. That is, we replace Eq. (3) with

$$|\mathbf{v}| = -(e/\omega m)E_0 \cos(\omega t + \delta), \tag{5}$$

where δ is the phase lag caused by radiation damping. Computing $\mathbf{F}_{mag}$ with this expression for $\mathbf{v}$, instead of that in Eq. (3), yields

$$|\mathbf{F}_{mag}| = e|(\mathbf{v} \times \mathbf{B})| = -(e^2/2\omega m)E_0 B_0[\sin(2\omega t - \delta) - \sin\delta]. \tag{6}$$

Now, in addition to the periodic response already computed, we have a stationary component of $\mathbf{F}_{mag}$ in the direction of the incident wave that produces momentum transfer to the particle that depends on the phase lag δ induced by radiation damping. Note that the time-independent part of $\mathbf{F}_{mag}$ is a maximum when $\delta = \pi/2$; that is, when $\mathbf{E}$ and $\mathbf{B}$ are 90 degrees out of phase. (This is precisely the relationship between $\mathbf{E}$ and $\mathbf{B}$ that arises when an electromagnetic wave is reflected at the surface of a good conductor. It does not arise, however, because the conduction electrons, acted upon by the Lorentz force, are "pushed" into the lattice ions, thereby effecting momentum transfer from the wave to the material as is sometimes claimed. The Lorentz force induced motion, being a figure eight, is just as likely to cause momentum transfer via this process in the opposite direction as in the forward direction.) Radiation damping in essentially all circumstances, however, is a small, higher order process with very small δ that can safely be ignored. But it, and the phase lag it produces, is the source of secular momentum transfer from the incident wave to the affected charged particle. This suggests that should we be looking for secular momentum transfer in the Slepian circuit, we should be looking for processes analogous to that we've just considered.

7. FORCE "RECTIFICATION" IN THE SLEPIAN CIRCUIT

Were we making a real Slepian circuit to test the conjectures that follow, instead of using two coils ranged on opposite sides of the capacitor where the force we seek to "rectify" is located, we might employ a toroidal coil with a gap for the capacitor. If the core material in the coil and the dielectric in the capacitor are simple linear materials, then **D** and **B** in the "Heaviside force" term in Eq. (1) will differ by $\pi/2$ in phase (as the current in the coil is zero when the charge on the plates of the capacitor are at a maximum) and we can write:

$$|\mathbf{D}| = D_0 \sin \omega t, \tag{7}$$

$$|\mathbf{B}| = B_0 \cos \omega t. \tag{8}$$

Since **D** and **B** are perpendicular, we have

$$|\mathbf{D} \times \mathbf{B}| = D_0 B_0 \sin \omega t \cos \omega t = (D_0 B_0/2) \sin 2\omega t. \tag{9}$$

Taking the time-derivative to get the "Heaviside force" yields

$$|\partial(\mathbf{D} \times \mathbf{B})|/\partial t = \omega D_0 B_0 \cos 2\omega t, \tag{10}$$

which time-averages to zero, as noted above.

We now ask: Can we create conditions by inclusion of non-linear ferroelectric (or ferromagnetic) materials in the Slepian circuit that will lead to a time-independent term in the "Heaviside force"? The hysteresis of such materials will cause the sort of phase shifts that produce time-independent forces in the case of the action of electromagnetic waves on free charges as discussed above. This, alas, will not work in this case. If we introduce an (arbitrary) phase lag (for the purposes of argument) into either **D** or **B**, when we take the cross-product we recover a time-independent term, just as in the action of the wave on the free charged particle. But the Heaviside force is the time-derivative of the cross-product, so any time-independent term in the cross-product becomes zero when the derivative is taken. *This means that even if the Heaviside force term actually exists, it cannot be rectified to produce a time-independent force.* No one is going to the stars by pushing off of the vacuum with a Heaviside force that likely doesn't exist in the first place. This scheme won't even work if we put some material stuff between the plates of the capacitor and try to accelerate it as propellant employing this putative force.

If our aim were simply to show that the Slepian scheme cannot work as claimed, we could quit right here. But the proper scope for our investigation should extend a little farther – to the semi-classical quantum vacuum e-p ZPF. We ask: Is it possible that the electromagnetic fields between the plates of the capacitor in the Slepian circuit might act on the e-p ZPF, taken as really existing, and by exerting a force on the e-p ZPF create a reaction (accelerating) force on the circuit? We remark that the analysis of the asymmetrical capacitors of the Biefeld-Brown effect suggests that the answer to this question should be no, for if the e-p pairs of the e-p ZPF carried real energy and momentum (as allegedly they do), then asymmetrical capacitors should, contrary to experience, accelerate. But the un-observed Biefeld-Brown effect depends on the e-p ZPF being polarizable, and perhaps – unlikely though it may be – the e-p ZPF isn't polarizable. So we investigate a little farther.

We ignore the "Heaviside force" term in our investigation, for, as shown above, stationary forces cannot be recovered from it by adjusting the phase of the **E** and **B** fields in the capacitor because of the time-derivative. Normally, one doesn't let the Lorentz force act on the vacuum, for it is supposed to only act on real electric charges. However, if the e-p pairs of the ZPF are really out there – however fleetingly in individual cases – then one might reasonably expect them to experience Lorentz forces produced by externally generated electromagnetic fields. At any rate, that's what we are going to posit for investigation. As in the case of the plane wave incident on a free charged particle, any secular momentum transfer that might take place will be a consequence of the $e(\mathbf{v} \times \mathbf{B})$ part of the Lorentz force, so this is what we must calculate for the electrons and positrons of the ZPF between the plates of the capacitor. The calculation parallels that for the case of the incident plane wave given above.

We start by computing **v** for the electrons and positrons from the equation of motion for a charged particle due to the **E** present in the capacitor which, assuming that $E = E_0 \sin(\omega t)$, as before, turns out to be Eq. (3):

$$|\mathbf{v}| = -(e/\omega m)E_0 \cos(\omega t). \tag{3}$$

If the material substances in the capacitor and coil (if any) are simple, linear, and do not produce any phase lag between **v** and **B**, then $B = B_0 \cos(\omega t)$ in this case. So,

$$\mathbf{e}|(\mathbf{v} \times \mathbf{B})| = -(e^2/\omega m)E_0 B_0 \cos^2(\omega t). \tag{11}$$

Or

$$\mathbf{e}|(\mathbf{v} \times \mathbf{B})| = -(e^2/2\omega m)E_0 B_0[\cos(2\omega t) + 1]. \tag{12}$$

Introducing a phase lag between the **E** and **B** fields (due, say, to non-linear core or dielectric materials) by adding a phase angle δ to the expression for **B** leads us to:

$$\mathbf{e}|(\mathbf{v} \times \mathbf{B})| = -(e^2/2\omega m)E_0 B_0[\cos(2\omega t + \delta) + \cos \delta]. \tag{13}$$

Evidently, the stationary part of $\mathbf{F}_{\text{mag}} = \mathbf{e}(\mathbf{v} \times \mathbf{B})$ is a maximum when $\delta = 0$. So, while the use of a highly permeable core material in the coil may be desirable to maximize the value of **B** in the gap where the capacitor is located, in some measure there is a trade-off if a significant phase lag is introduced as a result, for the phase lag reduces the size of the effect sought.

In order to make a crude estimate of the magnitude of the force we might expect as a result of this putative semi-classical effect, we note that Eq. (13) gives the force on each particle of the e-p ZPF between the plates of the capacitor in the Slepian circuit, and that the forces on the electrons and positrons are in the same direction (as the force is quadratic in the electric charge). To get the total force exerted on the e-p ZPF we need merely multiply Eq. (13) by N, the number of e-p ZPF particles present. (We're making an approximation here that the electrons and positrons of the ZPF, aside from their annihilation, do not interact with each other. Arguably, this is a reasonable proposition for a calculation of this sort.) By Newton's third law, this will produce an equal reaction force, F_T on the circuit, presumably at the capacitor. That is,

$$F_T = (e^2/2\omega m) N E_0 B_0 \cos\delta. \tag{14}$$

Curiously, given that ω appears in the denominator of the RHS of Eq. (14), it would appear that this effect should be largest for very low frequencies. (And infinite for static fields. This brings to mind another improbably propulsion scheme. It won't be discussed here, for it's even less likely than pushing off the vacuum.) Had we an estimate of the density of e-p pairs in the ZPF, we could compute N, and since the rest of the quantities on the right hand side of Eq. (14) are experimental parameters, F_T could be calculated.

Even without knowing the value of N, we can make a rough estimate of the force expected, for the value of N will presumably be fairly large. We take $\cos\delta = 1$ and compute the value of e^2/m, finding 2.8×10^{-8}. E_0 we take that to be found in a multiplate high voltage capacitor; say, a thousand volts with a plate separation of a tenth of a millimeter. So E_0 will be on the order of 10^7 volts per meter (or perhaps more). B_0, with modest assumptions about the coil used to generate it, can be taken as lying in the range of a few webers per square meter, so we arrive at $(e^2/m)E_0 B_0 \cos\delta$ being of order unity. That means that if $N/2\omega$ is also of order unity, we should expect to see a vacuum reaction force on the Slepian circuit in the posited circumstances on the order of a Newton. If the number density of e-p pairs in the vacuum is anything like the density of, say, molecules of air at atmospheric pressure, then N is enormous and we are led to expect *ludicrously large* reaction forces on electronic circuits that long since would have been observed. *We therefore conclude that electromagnetic fields produced in electronic circuit elements do not act on the e-p ZPF and that all propulsion schemes based on the action of such fields on the vacuum are patently wrong.*

8. CONCLUSION

What are we to conclude from all of the above? Well, perhaps the obvious remark to make is that the "virtual" electron-positron pairs that allegedly fleetingly exist in the quantum mechanical vacuum really are *virtual*. That is, they are not *real*. *They aren't really there at all.* While it may be helpful as a heuristic to visualize the vacuum as populated by evanescent electron-positron pairs when dealing with certain phenomena, it is important to remember that this is a mental model, not the physical reality. *For, were the electron-positron pairs really there, however fleetingly, they would be acted upon by real electric and magnetic fields via the Lorentz force, and the semi-classically predicted propulsive forces described above would actually exist. In fact they do not.* This should be a cautionary message for those convinced that the electron-positron pairs of vacuum polarization are really out there.

The second remark to make is that even were it possible to push off the vacuum, as in one of the semi-classical schemes described here, this would not be evidence for an exclusively local process because the particles of the vacuum would be coupled gravitationally to the chiefly distant matter in the universe, just as normal propellant in any type of rocket is. In other words, since inertia is a gravitational effect (a la Mach's principle), no "revolutionary" electromagnetic propulsion scheme, be it classical or quantum mechanical, that fails to take gravity explicitly into account is likely to have any chance whatsoever of working.

Acknowledgment. I thank Harold White for reading an earlier version of this paper and making several suggestions for its improvement. Several referee comments have led to improvements in the exposition.

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