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Exotic Matter and Propulsion within Maxwell's Equations

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Abstract

Utilizing Maxwell's equations, a negative energy density is derived from the interaction of time-varying Electromagnetic fields and synchronously time-varying Electromagnetic 4-current densities. This form of negative energy density is compared to the negative energy density found in the Casimir effect, as a source of Exotic Matter. It is shown that by choosing the proper phase displacements, negative energy densities may be realized by the interaction of the 4-current densities with the Electromagnetic field, as shown by the canonical Energy-momentum tensor. This coincides with radiated Electromagnetic waves of positive energy density and opposing strong Lorentz forces exerted on the 4-current densities that do positive work to propel them forward. Thereby, creating an Electromagnetic propulsion system. The similarities and differences between the Casimir effect and the negative energy density developed by the propulsion system are discussed. It is found that in both approaches, the negative energy density is realized by the relative potential energy of the system and by the intensity differences of Electromagnetic frequency modes, between one region of space-time and another. This may open the door to developing new technologies for engineering Electromagnetic propulsion devices.

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1 INTRODUCTION

A negative energy density violates all the known energy conditions and averaged energy conditions that are essential to the theorems of classical black hole thermodynamics. [1-3] A few examples are the weak, the strong and the dominant energy conditions, familiar from General Relativity. The term "Exotic Matter" is used to describe negative energy densities that violate these energy conditions.

In this paper a negative energy density is derived from the interaction of time varying Electromagnetic (EM) fields and synchronously time-varying EM 4current densities. The convention $(c = G = 1)$ is used throughout this paper.

Recently, much attention has been given to the Casimir effect [3] as a way of constructing a negative energy density. [4-8] A Casimir region may be constructed as a very small separation between two relatively large, flat conducting plates. A measurable inward force is exerted on the plates by the surrounding EM Zero-Point field, (ZPF). This indicates that there is greater energy density and field pressure outside the plates than there is between them. [8]

The ZPF of the Quantum vacuum does *Work* that pushes the plates together, by exerting what is called the Casimir Force. [7,8] The amount of work done is found by integrating the Casimir Force over the change in separation, in bringing the plates together from infinity. The work done is positive. However, the potential energy stored by this work is negative. As in classical physics, the sign for stored potential energy is negative.

The Casimir energy is the difference between two infinite energy quantities, $U(d) = E(d) - E(\infty)$. [8] Infinite energies such as these are typical in Quantum Electrodynamics (QED), where only their difference has any observable physical significance. For perfectly conducting plates of area L^2 and separation d, this potential may be expressed by,

$$U(d) = -\frac{p^2 \hbar L^2}{720 d^3} \tag{1}$$

The reason the Casimir region contains negative energy density, as explained in [8], is because there are fewer EM frequency modes allowed to exist in this region, relative to the surrounding vacuum. The EM ZPF has a continuum of frequency modes. The conducting plate boundaries act to filter out the low frequency end of the spectrum for frequency modes propagating orthogonal to the plates. [8] This leaves only those modes that have wavelengths shorter than the separation distance d. Longer wavelengths cannot propagate and therefore do not exist in this region.

It has been said that there is nothing exotic about the Casimir region. [7,8] It contains the same EM ZPF energy it had before the plates were introduced. The only difference is that the size and separation of the plates establishes a low frequency cut-off in 1 dimension, reducing the number of frequency modes permitted

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[3] A thorough derivation and interpretation of the Casimir effect may be found in Milonni. [8]

in this region. The ZPF of the surrounding vacuum region is unaffected and there fore has a greater energy density and pressure.

With regards to Exotic Matter, although many interesting proposals involving the Casimir effect have been made, [4-7] none really measure up to what is needed to *engineer* space-time short cuts. [1-3,9,10] Which are the driving motivation behind such proposals.

What is presented herein is an entirely different approach, which permits large quantities of negative energy density, utilizing nothing more than Maxwell's equations and a distributed array of 4-current densities that generate the EM field.

The Lorentz force density produced is then generalized to the array of 4-current densities and shown that it may be used in applications to produce EM propulsion. [10]

A comparison of the Casimir effect to the superimposed EM fields and 4-current array is presented. The similarities and differences between these two approaches are illustrated with regards to Exotic Matter.

2 4-CURRENT DENSITY AND THE ELECTROMAGNETIC FIELD

Consider a macroscopic EM field, F^{ab}. The Electric and Magnetic field 3-vectors are represented by $\mathbf{E}$ and $\mathbf{B}$ respectively and the 4-vector gauge potentials are represented by A^{a}. The EM field is superimposed on to an array of macroscopic 4-current densities J_a that are also the sources of the EM field. Maxwell's continuity equation, $\partial^{a} J_a = 0$ holds within the boundaries of the individual 4-current densities.

The interaction term[4] of the Relativistic Lagrangian density within the boundary of J_a is,

$$L_I = -J_a A^a / g \qquad (2)$$

Where $g = dt/dt$. From (2), the Lorentz force density $f^b = F^{ab} J_a$ and the equations of motion for J_a are derived. [11]

The EM field also has a free field term in the Relativistic Lagrangian density that exists in the vacuum outside the boundary of J_a, defined by,

$$L_F = -\frac{1}{16p} F_{ab} F^{ab} \qquad (3)$$

From this term, the equations of motion of the EM field are derived. [11] These are simply electromagnetic waves in free space.

Both the EM field and the 4-current densities are sources of energy. Work may be done on the 4-current density by the EM field or vise versa. The flow of energy and momentum depends on their relative phase displacement.

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[4] The subscript $_I$ is used for interaction terms and the subscript $_F$ is used for fields in free space.

The conservation laws require that the divergence, $\partial_a T^{ab} = 0$. Therefore, the vacuum part of the EM field outside of J_a , as well as the interaction of J_a with the EM field must be included. It follows that conservation of energy and momentum may be expressed by,

$$\int d^3x\left(\partial_a T_F^{ab} + f^b\right) = \frac{d}{dt}\left(P_F^b + P_I^b\right) = 0 \qquad (4)$$

Where $f^b = -\partial_a T_I^{ab}$ and $\left(P_F^b + P_I^b\right)$ is the 4-momentum of the EM field plus the 4-momentum of the 4-current densities.

The free EM field is radiated into free space along the Poynting vector. The energy density of the free field is always positive. However, the interaction contributions posses negative potential energy density.

The relative potentials between the 4-currents are expressed by the gauge field A^a and are derived by integration of the Lorentz force as mechanical work is done. Similar to what was done in deriving the Casimir energy by integration of the work done by the Casimir Force.

From the canonical Energy-momentum tensor, [11] the energy density and flow of momentum for the EM field in free space are as follows,

$$T_F^{00} = \frac{1}{8p}\left(\mathbf{E}^2 + \mathbf{B}^2\right) \qquad (5)$$

$$T_F^{0i} = \frac{1}{8p}\left(\mathbf{E} \times \mathbf{B}\right)_i \qquad (6)$$

Equation (5) is always positive for the field in free space and equation (6) represents the Poynting vector of the radiated EM field.

The interaction of the EM field with a 4-current density, possessing the relative gauge potential $A^a = \left(f, A_i\right)$ in the Lorentz gauge, [11] is given by the energy density and momentum terms,

$$T_I^{00} = \frac{1}{4p}\nabla\bullet\left(f\mathbf{E}\right) \qquad (7)$$

$$T_I^{0i} = \frac{1}{4p}\nabla\bullet\left(A_i\mathbf{E}\right) \qquad (8)$$

The charge density r_Q is derived from the divergence of the Electric field, $\nabla\bullet\mathbf{E} = 4p r_Q$ and is the time component of the 4-current density defined by Maxwell's equation, $\partial_a F^{ab} = 4p J^b$.

3 EXOTIC MATTER?

Negative energy density (Exotic Matter) may be shown explicitly by using Maxwell's equation, $\mathbf{E} = -\nabla f - \frac{\partial \mathbf{A}}{\partial t}$ and equation (7),

$$
\begin{aligned}
T_I^{00} &= \frac{1}{4p} \nabla \bullet (f \mathbf{E}) \\
&= \frac{1}{4p} \mathbf{E} \bullet \nabla f + r_Q f \\
&= \frac{1}{4p} \left(-\nabla f - \frac{\partial \mathbf{A}}{\partial t} \right) \bullet \nabla f + r_Q f \\
&= -\frac{1}{4p} \left(\left| \mathbf{E}_\Phi \right|^2 + \mathbf{E}_\mathrm{A} \bullet \mathbf{E}_\Phi \right) + r_Q f
\end{aligned}
\tag{9}
$$

Where $\nabla f = -\mathbf{E}_\Phi$ and $\frac{\partial \mathbf{A}}{\partial t} = -\mathbf{E}_\mathrm{A}$.

The first term, $-\left|\mathbf{E}_\Phi\right|^2 / 4p$ is always negative. Considering time-varying EM waves, the second term is made negative when the Electric field vectors, $\mathbf{E}_\mathrm{A}$ and $\mathbf{E}_\Phi$ are *in phase* at the coordinates where they coincide. The third term is made negative when the time-varying scalar charge density r_Q and the scalar potential f, are 180° *out of phase* as the Lorentz force is integrated to determine the work being done. Therefore, the resulting energy density is negative.

Each of these terms is a violation of the energy conditions. [1-3] A similar expression may be derived from (8) for each component A_i, of the vector potential,

$$
\begin{aligned}
T_I^{0i} &= \frac{1}{4p} \nabla \bullet (A_i \mathbf{E}) \\
&= \frac{1}{4p} \mathbf{E} \bullet \nabla A_i + r_Q A_i \\
&= -\frac{1}{4p} \left(\nabla f + \frac{\partial \mathbf{A}}{\partial t} \right) \bullet \nabla A_i + r_Q A_i
\end{aligned}
\tag{10}
$$

By engineering the proper phase relationships in each term of (9) and (10), these expressions may be made to oppose the sign of the free field expressions, (5) and (6). In doing so, EM propulsion may be realized. EM waves are radiated in one direction with an arbitrary positive energy density and momentum P_F^b, as shown in equation (4) and the 4-current densities are propelled in the opposite direction, *forward* by strong Lorentz forces, f^b. These forces and the radiation emitted deplete the potential energy stored and carried by the moving 4-current densities and their relative gauge potentials.

4 ELECTROMAGENTIC PROPULSION

EM propulsion may be illustrated by considering a simple propulsion system consisting of two 4-current densities, J_{1a} and J_{2a} that generate a superposition of two electromagnetic fields, F_1^{ab} and F_2^{ab} respectively. These could be two dipole antennas for example.

The 4-currents and their resulting EM fields need not be equal or symmetrical but may be time-varying and posses a particular frequency and phase relationship. In such a system, the force density exerted on the 4-currents as a whole is then the sum of the two force densities exerted on the individual 4-currents,

$$f^b = F_2^{ab} J_{1a} + F_1^{ab} J_{2a} \tag{11}$$

Maxwell's equations do not require that these forces sum to zero. Reciprocity does not necessarily apply in pulsed control systems for example. A dipole antenna with a ¼ wave reflector is a typical example of an array that falls into this category.

A unidirectional force may be exerted on the system as a whole. This may be used for EM propulsion applications. Such an array of 4-currents used for EM propulsion shall be referred to as an EGM (Electro-Gravi-Magnetics) [5] Array. [10]

Additional sources require additional terms. Equation (11) then becomes a discrete summation over the products of each source and the superposition of N EM fields at its location. The Lorentz force density exerted on J_{1a} by its own field and that of the other $N-1$ sources is,

$$f_1^b = \left(F_1^{ab} + F_2^{ab} + \ldots + F_N^{ab}\right) J_{1a} \tag{12}$$

The total force density on the entire array is,

$$f^b = f_1^b + f_2^b + \ldots + f_N^b \tag{13}$$

This leads to a complicated set of equations for a large, distributed array of 4-currents and the controlled superposition of EM fields. In principle, this is similar to the Radiation Reaction phenomenon, [8] associated with a charged particle interacting with its own radiation field. Here a macroscopic array of 4-current densities is interacting with its own radiation field.

These equations may be modeled by conventional EM Modeling software and shall be presented in a forthcoming publication.

5 COMPARISON TO THE CASIMIR EFFECT

[5] The methodology of Electro-Gravi-Magnetics is defined and utilized in earlier publications by dgE, [12-14].

The negative energy density associated with the Casimir effect is simply a difference in the intensity of EM waves at particular frequency modes, between the surrounding vacuum region and the confined Casimir region, as explained in [8]. There is nothing *exotic* about the energy density within the Casimir region. It is typical EM energy, consisting of photons like those found in any EM field and it is not unique to the ZPF. [7,8]

The negative energy density in the Casimir region is also explained by the negative potential energy stored. This was derived by integrating the Casimir Force over the change in separation to bring the two plates together from infinity, to a separation d .

The Casimir region is unique in that it excludes all modes orthogonal to the plates with wavelengths longer than the separation distance between the plates. This means that the number of photons per cubic wavelength is, $k = 0$ at these frequency modes and in this region. [15]

Since there are no negative energy photons known to exist, then at the excluded frequencies, this is the lowest possible energy state of the EM ZFP. It represents a lack of photons in the relatively low frequency end of the EM spectrum, whereas in the surrounding vacuum ZPF, the number of photons per cubic wavelength is normalized to $k = 1$. [15]

The energy difference between the vacuum ZPF and the Casimir region, at any individual frequency mode is very tiny, limited to only $E = \hbar w$. Therefore the Casimir effect is incapable of providing a large quantity of negative energy density at any one particular frequency mode. It is the sum of the contributions of a wide range of frequency modes that permits the Casimir Force to be measured. [8]

The negative energy density in the Casimir region results from the reduction of photons relative to the surrounding ZPF. Therefore, in order to produce a large negative energy density in this way, a relatively high cut-off frequency must be used. This is problematical because there is no known way to eliminate a wide range of frequency modes over a large volume of space-time. The Casimir region between the plates is far too small to be of any practical use.

In general, the Casimir effect is a relatively low frequency, non-relativistic EM phenomenon. [8] The frequency modes of the ZPF are manipulated in essentially the same way that EM waves are manipulated by wave-guides in modern optics and telephony.

The Casimir effect is made possible by the fact that the EM frequency modes used cannot pass through the conducting boundaries. A simple thought experiment shows that if there is any connection between the EM ZPF and gravity, it must be at frequency modes that are not reflected by conducting surfaces. For example, a heavy object placed inside a closed metal box does not experience any appreciable loss of weight. Therefore, the connection to gravitational fields should be looked for at EM frequency modes that pass through all known materials, such as the sub-atomic frequency spectra. [12-15]

The EGM Array is a propulsion system that works by constructively interfering EM fields behind the array and destructively interfering the fields in front of the array via synchronously controlled 4-currents and the EM fields they produce. Thereby, a unidirectional, coherent Poynting vector field is established behind the array and strong Lorentz forces are exerted on the 4-currents to propel them forward.

The Lorentz force is derived from the gradients in the EM field potentials acting on the charged 4-current densities. The integration of the Lorentz force results in positive work and negative potential energy density, as expressed by T_I^{00} and T_I^{0i} in equations (9) and (10).

The potential energy of the individual 4-current densities is measured with respect to the other 4-currents in the array and not with respect to a preferred "grounded" reference frame. Therefore, the momentum of the EGM array T_I^{0i} is considered to be a *vector field* possessing negative energy density. This is clearly a violation of the energy conditions. [1-3]

By comparison, in both the Casimir effect and the EGM Array propulsion system, there is a difference in the intensity of the frequency modes present in one region of space-time relative to another. There is nothing special about these energy differences and there are no new or *exotic* particles of any kind.

The EGM Array is unique in that it constructively interferes with one or more frequency modes in the region behind the array and destructively interferes with these modes in the region ahead of the array. The destructive interference does not permit these modes to exist with any *significant amplitude* in this region. Therefore, the energy density in this region relative to the region behind the array is negative, in the same sense that the energy density within the Casimir region is negative relative to the surrounding ZPF.

The term "significant amplitude" means that, assuming large EM fields can be generated by constructive interference behind the array, then the ZPF at these frequency modes is insignificant. Therefore, the destructive interference in front of the array need not be a total lack of photons. It only needs to be significantly less than the energy density to the rear of the array, in order to produce a relatively large negative energy density ahead of the EGM Array.

6 CONCLUSION

An energy condition violating negative energy density can be interpreted to exist in the Casimir region. Where relatively low frequency EM field modes that are naturally present in the surrounding ZPF, are not permitted to propagate within the Casimir region. Thereby leading to an intensity difference at these modes, between these two regions.

The negative energy density in the Casimir region is interpreted as the potential energy stored by the Casimir Force, by bringing the two plates together from infinity, to a separation d. [7]

The Casimir region is unique in that it possesses less energy density than the surrounding ZPF, at the excluded frequency modes. In the Casimir region, the number of photons per cubic wavelength at the excluded frequency modes is, $k = 0$ and in the surrounding ZPF, $k = 1$ for all frequencies. [15]

An energy condition violating negative energy density can also be interpreted to occur in the superposition of EM fields with an array of 4-current density sources. The appropriate phase displacement between the 4-currents and the EM field potentials permits the energy density of the interaction terms T_I^{0b} to be large and negative, relative to the energy density of the surrounding EM field and relative to the ZPF.

The phase displacements are exactly those that are required to produce constructive interference in the region behind the EGM Array and destructive interference in the region ahead of the array. They are also the proper phase displacements to produce *forward rectified* Lorentz forces, exerted on the 4-current densities and necessary for EM propulsion. [10]

The flow of energy and momentum in a particular reference frame of an outside observer may be bi-directional as expressed by $\frac{d}{dt}\left(P_F^b + P_I^b\right) = 0$. Producing EM waves in free space propagating off in one direction, whilst the Lorentz forces propel the array of 4-current densities forward in the opposite direction. A generalization of the force density that propels the EGM Array forward was presented in equations (11) and (12).

Note that equation (4) is not the equation typically considered for EM propulsion, that is $force = power / c$. This is a very week force because there is no Lorentz force coupled to the radiation emitter. For example, it's like using a flashlight for EM propulsion.

The EGM Array produces EM propulsion that is derived from the exertion Lorentz forces on the 4-currents, not simply by the exhaust of EM radiation. This is the same principle that moves *electric motors*, in which the current carrying conductors are coupled to magnetic flux linkages. [16] Gradients in the flux exert Lorentz forces on the conductors to turn the motor. Reciprocity between the forces acting on each source is suppressed by engineering considerations such as proper phase control and by purposeful design.

For example, compare the thrust produced by a 1 watt flashlight to the torque produced by a 1 watt electric motor. The coupling of the 4-currents to the EM field to produce Lorentz forces does mechanical work that a radiated EM field alone cannot do.

The EGM Array is comparable to a linear electric motor and may be described as *a linear Rotor with a holographic Stator*. [10,16] Holographic referring to the time-varying superposition of EM fields surrounding the EGM Array, from which the Lorentz forces emerge.

More research shall be conducted by modeling the EGM Array in 4-D EM Modeling software, to estimate the practicality of building such propulsion devices with existing technologies. Delta Group Engineering, P/L and Delta Group Research, LLC have many innovative ideas and are currently seeking collaboration with other firms or individuals who have the capability to model these devices accurately.

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