ENERGY INHERENT IN THE PURE GAUGE VACUUM
by

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ABSTRACT

A transition from the pure vacuum to the pure gauge vacuum is considered and shown to generate energy through the covariant derivative for all gauge group symmetries. The source of this energy is space-time curvature. A local gauge transformation of lagrangians made up of components of the four potential of the pure gauge vacuum generates a topological charge g, the electromagnetic field, and a locally gauge invariant and conserved charge current density which acts as the source for the electromagnetic field in the vacuum. Therefore there emerges a vacuum Poynting Theorem. The energy inherent in the vacuum is not bounded above, and in principle can be used as the source of energy for working devices.

1 INTRODUCTION

In this paper the possibility is investigated of extracting energy from the pure gauge vacuum[1]-[3]. The latter is generated from the pure vacuum, defined by $A_\mu = 0$, by a local gauge transformation. It is shown in section 2 that this is equivalent to a space-time translation in which energy is generated through space-time curvature. In section 3 it is shown that a local gauge transformation on the pure gauge vacuum results in kinetic electromagnetic energy (the electromagnetic field) and also a vacuum charge current density which acts as a source for the field in the vacuum. There is therefore a Poynting Theorem for the vacuum and energy inherent in the vacuum which could be used for working devices. The theory is developed for the standard U(1) invariant lagrangian of electrodynamics and also for an O(3) invariant theory of electrodynamics which has been shown recently[4]-[22] to be more self-consistent than the standard U(1) invariant theory. The O(3) invariant theory predicts, for example, the existence[15] of a massive boson which has been detected recently in a LEP collaboration[15].

2 THE PURE GAUGE VACUUM

The transition from a pure vacuum to a pure gauge vacuum is described by the space-time translation generator of the Poincaré group. In the usual U(1) invariant theory[1]-[3] the pure vacuum is described by the field equations:

$$\partial_\mu \tilde{F}^{\mu\nu} := 0 \tag{1}$$

$$\partial_\mu F^{\mu\nu} = 0 \tag{2}$$

with

$$\tilde{F}^{\mu\nu} = 0; \quad F^{\mu\nu} = 0 \tag{3}$$

So the kinetic electromagnetic energy term in the lagrangian:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \tag{4}$$

is zero. In the pure gauge vacuum[1]-[3] the ordinary derivative is replaced by a covariant derivative so the field equations (1) and (2) become:

$$\partial_\mu \tilde{F}^{\mu\nu} = -iA_\mu \tilde{F}^{\mu\nu} \tag{5}$$

$$\partial_\mu F^{\mu\nu} = -iA_\mu F^{\mu\nu} \tag{6}$$

where A_μ is defined by:

$$A_\mu = -\frac{i}{\mathsf{g}}(\partial_\mu \mathsf{S})\mathsf{S}^{-1} \tag{7}$$

Here S is a rotation generator[1]-[3] and g is a conserved topological charge with the units[22]:

$$\mathsf{g} = \frac{\kappa}{A^{(0)}} \tag{8}$$

where κ is the wavenumber and $A^{(0)}$ the magnitude of the vector potential. However, in the pure gauge vacuum the fields are still zero, therefore:

$$F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu = 0 \tag{9}$$

and there is no kinetic electromagnetic energy. However, there occurs an energy change from a pure vacuum to a pure gauge vacuum, an energy change proportional to $\mathsf{g}A_\mu$, and whose origin is topological. The origin of this energy change can be traced to the replacement of the ordinary derivative ∂_μ by the covariant derivative D_μ in the U(1) gauge theory representing vacuum electromagnetism. Essentially this replacement means that space-time changes from one that is conformally flat to one that is conformally curved. In other words the axes vary from point to point whenever a covariant derivative is used for any gauge group symmetry[1, 15]. This variation of the axes introduces energy into a pure gauge vacuum. The covariant derivative in the latter is:

$$D_\mu = \partial_\mu - i\mathsf{g}A_\mu \tag{10}$$

which can be written using the rule $i\partial_\mu = \kappa_\mu$ as:

$$\kappa_\mu \rightarrow \kappa_\mu + \kappa_\mu^{'} \tag{11}$$

an expression which is equivalent to:

$$\mathbf{p}_\mu \rightarrow \mathbf{p}_\mu + \mathbf{p}_\mu^{'} \tag{12}$$

where $\mathbf{p}_\mu$ is the space-time translation generator of the Poincaré group. Within a factor $\hbar$ the space-time translation generator is the energy momentum four vector, so it becomes clear that the covariant derivative introduces energy / momentum into the pure gauge vacuum, essentially through space-time curvature.

3 LOCAL GAUGE TRANSFORMATION OF THE PURE GAUGE VACUUM

It is possible to consider independent scalar components A and A^* of the four potential of the pure gauge vacuum and subject these to a local gauge transformation:

$$A \to \mathsf{exp}\Big(-i\Lambda\big(x^\mu\big)\Big)A \tag{13}$$

$$A^* \to \mathsf{exp}\Big(i\Lambda\big(x^\mu\big)\Big)A^* \tag{14}$$

where $\Lambda\big(x^\mu\big)$ depends on the space-time coordinate x^μ. Two independent scalar components are considered because there is present in the vacuum a topological charge g, which forms part of the covariant derivative. The lagrangian density formed by A and A^* is proportional to:

$$\mathcal{L} \;=\; \partial_\mu A\,\partial^\mu A^* \tag{15}$$

and the fields themselves each have two components:

$$A \;=\; \frac{1}{\sqrt{2}}\big(A_1 + iA_2\big) \tag{16}$$

$$A^* \;=\; \frac{1}{\sqrt{2}}\big(A_1 - iA_2\big) \tag{17}$$

so if we define

$$\mathbf{A} \;=\; A_1\mathbf{i} + A_2\,\mathbf{j} \tag{18}$$

the lagrangian can be expressed as:

$$\mathcal{L} \;=\; \partial_\mu\mathbf{A}\cdot\partial^\mu\mathbf{A} \tag{19}$$

For plane waves for example:

$$A_1 \;=\; \frac{iA^{(0)}}{\sqrt{2}}e^{-i\big(\omega t-\kappa \mathsf{Z}\big)};\quad A_2 \;=\; \frac{A^{(0)}}{\sqrt{2}}e^{-i\big(\omega t-\kappa \mathsf{Z}\big)} \tag{20}$$

Under a global gauge transformation of the type:

$$A \to e^{-i\Lambda}A; \quad A^* \to e^{i\Lambda}A^* \tag{21}$$

Noether's Theorem gives the conserved current (S.I. units):

$$J^\mu \;=\; i\mathrm{g}c\big(A^*\partial^\mu A - A\partial^\mu A^*\big) \tag{22}$$

and conserved charge:

$$Q \;=\; \int J^0 dV \tag{23}$$

For the plane waves (20) the latter is easily shown to be:

$$Q \;=\; \frac{2\,c\,\mu_0}{A^{(0)}}E_n \tag{24}$$

where

$$E_n \;=\; \frac{1}{\mu_0}\int (B^{(0)})^2 dV \tag{25}$$

is a conserved and gauge invariant electromagnetic energy. Therefore it has been shown that a global gauge transformation of the pure gauge vacuum produces electromagnetic energy in the vacuum. For a monochromatic plane wave propagating in the vacuum the quantity g is also conserved because κ and $A^{(0)}$ do not change.

The above is a simple example of the generation of kinetic electromagnetic energy in the vacuum, using a global gauge transformation of the lagrangian of a vacuum initially defined by a finite **A** and a zero **E** and **B**. A local gauge transform of the U(1) invariant lagrangian (15) gives a more complete description of energy generated in the vacuum as shown as follows. It is to be noted however that the conserved quantity Q has the following properties:

1. it is time independent;
2. it does not depend on the charge on the proton;
3. it is a classical quantity;
4. it is not integer valued and when **A** is real it vanishes.

Using standard methods a local gauge transform of the lagrangian (15) produces the lagrangian[1]-[3]:

$$\mathcal{L} \;=\; \big(\partial_\mu A + i\mathrm{g}A_\mu A\big)\big(\partial^\mu A^* - i\mathrm{g}A^\mu A^*\big) - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} \tag{26}$$

which is made up basically of **A** and $\mathbf{A}^*$, and an extra potential A_μ introduced[5] by the need to conserve the action under the local gauge transform (13) and (14). This extra four potential A_μ

forms part of the covariant derivative used in the local gauge transform and introduces into the pure gauge vacuum the gauge invariant electromagnetic field:

$$F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu \tag{27}$$

which carries kinetic electromagnetic energy through the vacuum. The source of this field can be found through the Euler Lagrange equation:

$$\frac{\partial \mathcal{L}}{\partial A_\mu} - \partial_\nu \Big(\frac{\partial \mathcal{L}}{\partial(\partial_\nu A_\mu)} \Big) = 0 \tag{28}$$

which in S.I. units gives the inhomogeneous field equation in the vacuum:

$$\partial_\nu F^{\mu\nu} = -i\mathrm{g}c\big(A^* D^\mu A - A D^\mu A^*\big) \tag{29}$$

and the conserved and gauge invariant charge current density (S.I. units):

$$J^\mu = -i\epsilon_0 \mathrm{g}c\big(A^* D^\mu A - A D^\mu A^*\big) \tag{30}$$

first introduced phenomenologically by Lehnert[4]-[6] and developed by Lehnert and Roy[7]. The current J^μ is conserved in the vacuum:

$$\partial_\mu J^\mu = 0 \tag{31}$$

and cannot be gauged away to zero.

Eqn. (29) is an inhomogeneous field equation from which can be constructed a vacuum Poynting Theorem (law of conservation of energy). Since A^μ or $F^{\mu\nu}$ are not bounded above it follows that there must be a term in the vacuum Poynting Theorem which is also not bounded above. An analogy exists in general relativity, in which curvature can become a delta function, producing point mass. The vacuum energy due to the charge current density J^μ is:

$$E_n = \int J^\mu A_\mu dV \tag{32}$$

and its rate of doing work is:

$$\frac{dW}{dt} = \int \mathbf{J}(vac) \cdot \mathbf{E}\, dV \tag{33}$$

The volume V is arbitrary, and standard methods[2, 3] give the Poynting Theorem of the vacuum:

$$\frac{dU(vac)}{dt} + \nabla \cdot \mathbf{S}(vac) = -\mathbf{J}(vac) \tag{34}$$

Here $\mathbf{S}(vac)$ is the Poynting vector of the vacuum, representing electromagnetic energy flow, and is defined by:

$$\nabla \cdot \mathbf{S}(vac) \;=\; -\mathbf{J}(vac) \cdot \mathbf{E} \tag{35}$$

Integrating this equation gives:

$$\mathbf{S}(vac) \quad = \quad \int \mathbf{J}(vac) \cdot \mathbf{E}\, dr + \mathsf{constant} \tag{36}$$

where the constant of integration and the electromagnetic energy flow are not bounded above. This means in theory that there is an unlimited amount of electromagnetic energy flow available for use by devices[20]. Sometimes the constant of integration is referred to as the Heaviside component of the vacuum electromagnetic enegy flow, and the detailed nature of this component in not restricted by gauge theory.

In summary therefore a pure gauge vacuum has been obtained from a pure vacuum and the former subjected to a local gauge transformation to produce the electromagnetic field in the vacuum, and its source, a conserved and gauge invariant vacuum charge current density first introduced phenomenologically by Lehnert[4]-[6] and premultiplied by the topological charge g. Lehnert and Roy[7] have given empirical evidence for the existence of the vacuum charge current density and have linked it to a finite photon mass.

4 O(3) INVARIANT LAGRANGIAN DENSITY

The local gauge transformation of the pure gauge vacuum is not restricted to any particular gauge group. For example one can consider an O(3) invariant lagrangian[4]-[22]:

$$\mathcal{L} \;=\; \partial_\mu \mathbf{A} \cdot \partial^\mu \mathbf{A}^* \tag{37}$$

and the local O(3) invariant gauge transformations:

$$\mathbf{A} \to e^{iJ_i\Lambda_i}\mathbf{A}; \quad \mathbf{A}^* \to e^{-iJ_i\Lambda_i}\mathbf{A}^* \tag{38}$$

under which the original lagrangian becomes:

$$\mathcal{L} \;=\; D_\mu \mathbf{A} \cdot D^\mu \mathbf{A}^* \;-\; \frac{1}{4}\mathbf{G}_{\mu\nu}\mathbf{G}^{\mu\nu} \tag{39}$$

where $\mathbf{G}^{\mu\nu}$ is an O(3) invariant field tensor[4]-[22]. Using the langrangian(39) in the Euler Langrange equation:

$$\frac{\partial \mathcal{L}}{\partial \mathbf{A}_\mu} \;=\; \partial_\nu \Big(\frac{\partial \mathcal{L}}{\partial(\partial_\nu \mathbf{A}_\mu)} \Big) \tag{40}$$

produces the O(3) invariant inhomogeneous field equation of the vacuum:

$$\partial_\nu \mathbf{G}^{\mu\nu} = -\mathsf{g} D^\mu \mathbf{A}^* \times \mathbf{A} \tag{41}$$

The term on the right hand side of eqn. (41) is the O(3) invariant vacuum charge current density[22] and eqn. (41) has the structure of a Yang Mills theory of electromagnetism. Such a theory has been shown recently[4]-[22] to be far more self-consistent, and more consistent with empirical data, than the received view, based on a U(1) invariant lagrangian density in the internal space of the gauge theory.

The presence of a vacuum charge current density in eqn. (41) gives rise to the vacuum energy:

$$E_n = \int \mathbf{J}^\mu(vac) \cdot \mathbf{A}_\mu dV \tag{42}$$

whose source is conformal curvature of space-time introduced by the use of an O(3) covariant derivative containing the rotation generators (J_i) of the O(3) group.

5 DISCUSSION

The empirical basis for the existence of a pure gauge vacuum is well known[1] to be the Aharonov Bohm effect, which is due to a local gauge transform of the pure vacuum. In this paper it has been shown that a local gauge transformation of the pure gauge vacuum produces kinetic electromagnetic energy in the form of the electromagnetic field, and inhomogeneous field equations (29) and (41) in the vacuum. These concepts imply that the electromagnetic field in the vacuum is never in a source free region, the vacuum charge current density acts as a source in the vacuum. Empirical data for this conclusion have been supplied by Lehnert and Roy[7, 21]. Essentially therefore the electromagnetic field is due to space-time curvature. The charge g in the vacuum is topological in nature, and has the units $\frac{\kappa}{A^{(0)}}$. However, it may also have the units $\frac{e}{\hbar}$, where e is the charge on the proton and $\hbar$ the Dirac constant. Therefore, in the presence of matter the charge g becomes proportional to $\frac{e}{\hbar}$. The origin of $\frac{e}{\hbar}$ can be thought of as the space-time curvature that generates $\mathsf{g} = \frac{\kappa}{A^{(0)}}$ in the vacuum as part of the covariant derivative, whose use implies that space-time is conformallly curved for any gauge group, i.e. the use of a covariant derivative means that cartesian axes vary from point to point in space[1]. It follows that if the origin of $\frac{e}{\hbar}$ is space-time curvature then circuits can be driven by the work done by the vacuum. In theory, this property provides an unlimited source of clean energy.

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