PHENOMENOLOGICAL ANALYSIS OF DISPERSIVE EFFECTS IN SCALAR ELECTROMAGNETIC COUPLINGS INCLUDING HIGHER POWERS OF THE ELECTROMAGNETIC INVARIANTS

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A discussion of the dispersive effects arising when scalar waves are coupled to plane electromagnetic waves is given. Higher powers of the electromagnetic invariants are included that may arise in strong fields and certain distinct signatures for the number of independent frequency components that occur for particular couplings are found.

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1. Introduction

Scalar fields in physics have widespread application and have become a fashionable representation of scalar particles ever since the Yukawa scalar meson theory [1]. In particle physics the use of a scalar doublet to carry out the mechanism of spontaneous symmetry breaking has prompted many theorists to search for a more fundamental origin of scalars through, perhaps, the technicolour scenario or perhaps from supergravity theory [2, 3]. The axion is a scalar particle that results when the Peccei–Quinn symmetry is broken at a high scale and a pseudo Goldstone boson results as a consequence of the breaking of the global U(1) symmetry [4]. The original motivation for introducing the Peccei–Quinn symmetry was to solve the strong CP puzzle of Q.C.D. by allowing arbitrary adjustment of the vacuum angle (θ) in the topological CP violating term. Along with the axion there are other scalars, so-called majorons and familons that result from neutrino mass-generating mechanisms and horizontal symmetry breaking schemes involved in quark mass generation [5, 6]. To date, none of these particles have been found although they are still being sought after in accelerator experiments. There is also the possibility that scalar partners of the Z are present in nature and have a dynamically generated mass from an underlying preon theory [7]. If we turn toward gravitational theory we find that scalars arise by allowing the gravitational constant to vary to better accommodate Mach's principle in the guise of Brans-Dicke theory, scalars are also present in creation theories such as Barber's theory wherein the scalar field plays the role of both inverse gravitational constant and the creation field [8, 9]. If we examine the structure of supergravity theories we find that both the dilaton and gravi-scalar emerge as necessary components of the supergravity multiplet [10, 11]. Both of these scalars affect cosmological dynamics, and the gravi-scalar can in principle be detected in Eötvös type experiments because of its asymmetric interaction with matter and anti-matter [12]. The couplings of the above fields to electromagnetism although difficult to detect in accelerator experiments may have testable consequences in electromagnetic scalar propagation. In this regard, the axion has a coupling to electromagnetism through quark loops [13], and in principle both the dilaton and the gravi-scalar should couple to the electromagnetic field through supergravity couplings. Another possible coupling of electromagnetism to scalar fields results from Kaluza–Klein theory upon compactification wherein a scalar electromagnetic coupling is a necessary result of the consistency of the theory [14]. Lastly the presence of axial-vector torsion in gravitational theory necessitates the presence of a scalar field that generates torsion and couples to the electromagnetic field through the virtual fermions created by the electromagnetic field. The spin of these virtual fermions generates the torsion electromagnetic coupling by the intervention of virtual fermion loops [15]. In a previous note we have discussed the dispersive effects of this coupling but did not calculate the higher order couplings that we discuss in this note [16]. In what follows we develop a phenomenological analysis of electromagnetic scalar couplings through plane wave propagation. We include higher powers of the electromagnetic invariants that become important with high fields when vacuum polarization effects become relevant. We also discuss possible signatures for certain couplings including the number of dispersive components signaling a certain preferred coupling. With regard to gravitational theory we note, following Gasperini, that in general these couplings violate the equivalence principle [17], and suggest that the discovery of these dispersive effects would open up new avenues of investigation in both gravitational theory and particle theory to ascertain the fundamental origin of these couplings.

2. Phenomenological scalar-electromagnetic couplings and plane wave propagation

We begin our analysis of scalar-electromagnetic propagation by writing down a general gravitational electromagnetic scalar lagrangian in the spirit of Bergmann's original lagrangian [18],

$$L = \begin{bmatrix} \dfrac{C^4}{16\pi G} R + \dfrac{\partial^\mu \phi \partial_\mu \phi}{2} - \dfrac{1}{16\pi} F_{\mu\nu} F^{\mu\nu} - \varrho_0 \phi - \dfrac{f_1(\phi) F_{\mu\nu} F^{\mu\nu}}{4} \\ - \dfrac{f_2(\phi)}{4} \left(\dfrac{\varepsilon^{\mu\nu\alpha\beta} F_{\alpha\beta} F_{\mu\nu}}{\sqrt{-g}} \right) - \dfrac{f_3(\phi)}{4} (F_{\mu\nu} F^{\mu\nu})^2 \\ - \dfrac{f_4(\phi)}{4} \left(\dfrac{\varepsilon^{\mu\nu\alpha\beta} F_{\alpha\beta} F_{\mu\nu}}{\sqrt{-g}} \right)^2 - \dfrac{f_5(\phi)}{4} (F^{\mu\nu} F_{\mu\nu}) \left(\dfrac{\varepsilon^{abcd} F_{cd} F_{ab}}{\sqrt{-g}} \right) \end{bmatrix} \sqrt{-g} \qquad (2.1)$$

We have added the source term $\varrho_0\phi$ to balance out the background electromagnetic field about which we study fluctuations. We have included the pseudo-scalar couplings

$$\frac{f_2(\phi)}{4}\frac{\varepsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}F_{\mu\nu}}{\sqrt{-g}}, \quad f_4(\phi)\left(\frac{\varepsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}F_{\mu\nu}}{\sqrt{-g}}\right)^2, \quad \frac{f_5(\phi)}{4}(F^{\mu\nu}F_{\mu\nu})\left(\frac{\varepsilon^{abcd}F_{cd}F_{ab}}{\sqrt{-g}}\right)$$

to take into account the two fundamental invariants of the electromagnetic field. Actually ϕ in Eq. (2.1) could be either a scalar or pseudoscalar field and we have not restricted the lagrangian to be invariant under reflections since for either choice of scalar or pseudoscalar the lagrangian will have parity violating terms. Our analysis is purely phenomenological and allows for the parity violating terms. In studying the propagation of scalar-electromagnetic waves we discuss a wave with two states of polarization; Gasperini has shown how two states of polarization are necessary to understand the rotation of the plane of polarization of electromagnetic waves by a scalar field [19]. The most general plane wave moving in the x direction is specified by the following field configuration

$$F_{12} = B_z, \quad F_{24} = E_y, \quad F_{13} = -B_0 - B_y, \quad F_{34} = E_z. \tag{2.2}$$

Here B_0 = background magnetic field in the y direction.

Varying equation (2.1) with respect to ϕ gives

$$-\Box\phi - \varrho_0 - f_1'(\phi)\left(\frac{F_{\mu\nu}F^{\mu\nu}}{4}\right) - \frac{f_2'(\phi)\varepsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}F_{\mu\nu}}{4\sqrt{-g}}$$

$$-\frac{f_3'(\phi)(F_{\mu\nu}F^{\mu\nu})^2}{4} - \frac{f_4'(\phi)}{4}\left(\frac{\varepsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}F_{\mu\nu}}{\sqrt{-g}}\right)^2 - \frac{f_5'(\phi)}{4}(F_{\mu\nu}F^{\mu\nu})\left(\frac{\varepsilon^{abcd}F_{cd}F_{ab}}{\sqrt{-g}}\right) = 0. \tag{2.3}$$

Varying equation (2.1) with respect to A_μ gives

$$\frac{1}{4\pi}\frac{\partial}{\partial x^\nu}(\sqrt{-g}\,F^{\mu\nu}) + \frac{\partial}{\partial x^\nu}(f_1(\phi)F^{\mu\nu}\sqrt{-g}) + \frac{\partial}{\partial x^\nu}(f_2(\phi)\varepsilon^{\mu\nu\alpha\beta}F_{\alpha\beta})$$

$$+\frac{\partial}{\partial x^\nu}(2f_3(\phi)F_{\alpha\beta}F^{\alpha\beta}F^{\mu\nu}\sqrt{-g}) + \frac{\partial}{\partial x^\nu}\left(2f_4(\phi)\frac{\varepsilon^{\alpha\beta ab}F_{ab}F_{\alpha\beta}}{\sqrt{-g}}\varepsilon^{\mu\nu cd}F_{cd}\right)$$

$$+\frac{\partial}{\partial x^\nu}\left[f_5(\phi)\left(\frac{\varepsilon^{abcd}F_{cd}F_{ab}}{\sqrt{-g}}\right)F^{\mu\nu}\sqrt{-g}\right] + \frac{\partial}{\partial x^\nu}(f_5(\phi)F^{ab}F_{ab}\varepsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}) = 0. \tag{2.4}$$

We also have the condition on the potential

$$\frac{\partial F_{\mu\nu}}{\partial x^\sigma} + \frac{\partial F_{\sigma\mu}}{\partial x^\nu} + \frac{\partial F_{\nu\sigma}}{\partial x^\mu} = 0. \tag{2.5}$$

For the electromagnetic invariants we have

$$F_{\alpha\beta}F^{\alpha\beta} = 2\vec{B}^2-2\vec{E}^2 = 2[B_z^2+(B_0+B_y)^2]-2(E_y^2+E_z^2)$$

$$= 2B_z^2+2B_y^2+4B_0B_y+2B_0^2-2E_y^2-2E_z^2. \tag{2.6}$$

$$\frac{\varepsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}F_{\mu\nu}}{\sqrt{g}} = -8\vec{B}\cdot\vec{E} = -8E_zB_z-8E_y(B_0+B_y). \tag{2.7}$$

We keep only terms linear in the fluctuating fields and neglect quadratic terms such as B_z^2, E_y^2 ... .

Thus, to first order

$$F_{\alpha\beta}F^{\alpha\beta} = 2B_0^2+4B_0B_y$$

$$\frac{\varepsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}F_{\mu\nu}}{\sqrt{-g}} = -8E_yB_0. \tag{2.8}$$

We now choose the scalar coupling to be linear in the scalar fields and given by

$$f_1(\phi) = \varepsilon_1\phi, \quad f_2(\phi) = \varepsilon_2\phi, \quad f_3(\phi) = \varepsilon_3\phi, \quad f_4(\phi) = \varepsilon_4\phi, \quad f_5(\phi) = \varepsilon_5\phi. \tag{2.9}$$

In conventional C.G.S. units, the scalar field has dimensions $\left(\frac{\text{erg}}{\text{cm}}\right)^{1/2}$, the couplings $\varepsilon_1, \varepsilon_2$ have dimensions $\left(\frac{\text{cm}}{\text{erg}}\right)^{1/2}$, where as $\varepsilon_3, \varepsilon_4, \varepsilon_5$ have dimension $\frac{(\text{cm})^{7/2}}{(\text{erg})^{3/2}}$. After the calculation of the dispersion in the frequencies of plane electromagnetic scalar waves we comment briefly on the possible origin of these couplings as generated by a symmetry breaking mechanism at the electroweak and Planck scales. For the present, however, we just treat them as phenomenological constants.

When we insert the fields from Eq. (2.2) and the scalar coupling from Eq. (2.9) in the field Eq. (2.3) and Eq. (2.4) we have

$$-\frac{1}{C^2}\frac{\partial^2\phi}{\partial t^2}+\frac{\partial^2\phi}{\partial x^2}-\varrho_0-\frac{\varepsilon_1}{4}(2B_0^2+4B_0B_y)-\frac{\varepsilon_2}{4}(-8E_yB_0)-\frac{\varepsilon_3}{4}(4B_0^4+16B_0^3B_y)$$

$$-\frac{\varepsilon_5}{4}(2B_0^2)(-2E_yB_0) = 0, \tag{2.10}$$

$$-\frac{1}{4\pi}\frac{\partial B_z}{\partial x}-\frac{1}{4\pi C}\frac{\partial E_y}{\partial t}-\frac{2\varepsilon_2B_0}{C}\frac{\partial\phi}{\partial t}-\frac{\varepsilon_5}{C}\frac{\partial\phi}{\partial t}(4B_0^3) = 0, \tag{2.11}$$

$$\frac{1}{4\pi}\frac{\partial B_y}{\partial x}-\frac{1}{4\pi C}\frac{\partial E_z}{\partial t}+\varepsilon_1\frac{\partial\phi}{\partial x}B_0+4B_0^3\varepsilon_3\frac{\partial\phi}{\partial x} = 0. \tag{2.12}$$

The condition on the source ϱ_0 follows from the unperturbed fields in Eq. (2.10).

$$-\varrho_0-\frac{\varepsilon_1 B_0^2}{2}-\varepsilon B_0^3=0. \tag{2.13}$$

We now use the condition in Eq. (2.5) or equivalently

$$\frac{\partial E_z}{\partial x}=\frac{1}{C}\frac{\partial B_y}{\partial t}, \quad \frac{\partial E_y}{\partial x}=-\frac{1}{C}\frac{\partial B_z}{\partial t}$$

to simplify Eq. (2.11) and Eq. (2.12) after differentiating Eq. (2.11) with respect to t and Eq. (2.12) with respect to X. This gives in combination with Eq. (2.10) after extracting the source condition and leaving the fluctuating fields.

$$-\frac{1}{C^2}\frac{\partial^2\phi}{\partial t^2}+\frac{\partial^2\phi}{\partial x^2}+B_y(-B_0\varepsilon_1-4B_0^3\varepsilon_3)+E_y(2B_0\varepsilon_2+4\varepsilon_5B_0^3)=0, \tag{2.14}$$

$$\frac{C}{4\pi}\frac{\partial^2 E_y}{\partial x^2}-\frac{1}{4\pi C}\frac{\partial^2 E_y}{\partial t^2}-\frac{2\varepsilon_2 B_0}{C}\frac{\partial^2\phi}{\partial t^2}-\frac{\varepsilon_5 4B_0^3}{C}\frac{\partial^2\phi}{\partial t^2}=0, \tag{2.15}$$

$$\frac{1}{4\pi}\frac{\partial^2 B_y}{\partial x^2}-\frac{1}{4\pi C^2}\frac{\partial^2 B_y}{\partial t^2}+\varepsilon_1 B_0\frac{\partial^2\phi}{\partial x^2}+4B_0^3\varepsilon_3\frac{\partial^2\phi}{\partial x^2}=0. \tag{2.16}$$

Substituting the plane wave solutions in Eqs (2.14), (2.15) and (2.16)

$$\begin{aligned}\phi&=\bar{\Phi}_0 e^{i(kx-\omega t)},\\ B_y&=\bar{B}_0 e^{i(kx-\omega t)},\\ E_y&=\bar{E}_0 e^{i(kx-\omega t)},\end{aligned} \tag{2.17}$$

$$\bar{\Phi}_0\left(\frac{\omega^2}{C^2}-k^2\right)+\bar{B}_0(-B_0\varepsilon_1-4B_0^3\varepsilon_3)+\bar{E}_0(2B_0\varepsilon_2+4\varepsilon_5B_0^3)=0, \tag{2.18}$$

$$\bar{\Phi}_0(8\pi\varepsilon_2B_0+16\pi\varepsilon_5B_0^3)\frac{\omega^2}{C^2}+0+\bar{E}_0\left(\frac{\omega^2}{C^2}-k^2\right)=0, \tag{2.19}$$

$$\bar{\Phi}_0(-4\pi\varepsilon_1B_0-16\pi B_0^3\varepsilon_3)k^2+\bar{B}_0\left(\frac{\omega^2}{C^2}-k^2\right)+0=0, \tag{2.20}$$

we define

$$A=B_0\varepsilon_2+2B_0^3\varepsilon_5, \quad B=\varepsilon_1B_0+\varepsilon_3(4B_0^3),$$

and insisting that the determinant of the coefficients vanish in order to ensure a solution for $\bar{\Phi}_0$, $\bar{E}_0$, $\bar{B}_0$ we have

$$\left(\frac{\omega^2}{C^2}-k^2\right)(-1)\left[\left(\frac{\omega^2}{C^2}-k^2\right)^2-16\pi A^2\left(\frac{\omega^2}{C^2}\right)\right]-4\pi B\left[(-Bk^2)\left(\frac{\omega^2}{C^2}-k^2\right)\right]=0. \tag{2.21}$$

Equation (2.21) factors to give

$$\left(\frac{\omega^2}{C^2} - k^2\right)\left[-\frac{\omega^4}{C^4} + \frac{2\omega^2 k^2}{C^2} - k^4 + \frac{16\pi A^2 W^2}{C^2} + 4\pi B^2 k^2\right] = 0, \tag{2.22}$$

the solution for ω^2 are

$$\omega^2 = C^2 k^2 \tag{2.23}$$

which is the normal branch, and

$$\omega^2 = \frac{2k^2C^2 + 16\pi A^2 C^2 \pm \sqrt{(2k^2C^2 + 16\pi A^2 C^2)^2 - 4k^4C^4 + 16\pi B^2 k^2 C^4}}{2}$$

or

$$\omega^2 = k^2C^2 + 8\pi A^2 C^2 \pm \sqrt{16\pi A^2 k^2 C^4 + 64\pi^2 A^4 C^4 + 4\pi B^2 k^2 C^4} \tag{2.24}$$

for the shifted dispersion relations due to the scalar electromagnetic coupling.

We now study three cases for the above shifted dispersion formula in Eq. (2.24). Case I: If $B = \varepsilon_1 B_0 + \varepsilon_3(4B_0^3) = 0\ (\varepsilon_1, \varepsilon_3 = 0)$, and $16\pi A^2 k^2 C^4 > 64\pi^2 A^4 C^4$, where $A = B_0\varepsilon_2 + 2\varepsilon_5 B_0^3$, giving $k^2 > 4\pi A^2$, or,

$$\frac{\pi^{1/2}}{\lambda} > \varepsilon_2 B_0 \text{ if } \varepsilon_5 = 0 \tag{2.25}$$

and

$$\frac{\pi^{1/2}}{2\lambda} > \varepsilon_5 B_0^3 \text{ if } \varepsilon_2 = 0. \tag{2.26}$$

Under these conditions Eq. (2.24) gives

$$\omega^2 = k^2C^2 \pm kC^2 4\pi^{1/2} A, \tag{2.27}$$

with

$$\frac{\Delta(\omega^2)}{\omega_0^2} = \frac{4\pi^{1/2}(\varepsilon_2 B_0)}{k} \quad \text{for} \quad \varepsilon_5 = 0 \tag{2.28}$$

and

$$\frac{\Delta(\omega^2)}{\omega_0^2} = \frac{4\pi^{1/2}(2\varepsilon_5 B_0^3)}{k} \quad \text{for} \quad \varepsilon_2 = 0. \tag{2.29}$$

Here $\omega_0^2 = k^2C^2$. For a field of $B_0 = 10^4$ gauss and a shift of 1% in ω^2 we have

$$\frac{\Delta(\omega^2)}{\omega_0^2} = \frac{4\pi^{1/2}(\varepsilon_2 B_0)}{k} = 10^{-2}, \text{ or } \varepsilon_2 = \frac{10^{-6}}{\lambda}\left(\frac{\pi^{1/2}}{2}\right) \text{ for } \varepsilon_5 = 0, \tag{2.30}$$

$$\frac{\Delta(\omega^2)}{\omega_0^2} = \frac{4\pi^{1/2}}{k}(2\varepsilon_5 B_0^3) = 10^{-2}, \quad \varepsilon_5 = \frac{10^{-14}\pi^{1/2}}{\lambda(4)} \text{ for } \varepsilon_2 = 0. \tag{2.31}$$

We see in both these cases that the above limits in Eqs (2.25) and (2.26) are satisfied to justify the approximation.

Case II: For $A = 0$, $(\varepsilon_2, \varepsilon_5 = 0)$ and

$$\omega^2 = k^2C^2 \pm 2(\pi)^{1/2}kC^2B, \tag{2.32}$$

where $B = \varepsilon_1 B_0 + 4B_0^3\varepsilon_3$ if $B_0 = 10^4$ gauss and if we look for a dispersion of 1% we have

$$\frac{\Delta(\omega^2)}{\omega_0^2} = \frac{kC^2(2\pi^{1/2})B}{k^2C^2} \text{ giving } \frac{\Delta(\omega^2)}{\omega_0^2} = \frac{2(\pi^{1/2})(\varepsilon_1 B_0)}{k} = 10^{-2} \tag{2.33}$$

or, $\varepsilon_1 = \dfrac{10^{-6}}{\lambda}(\pi^{1/2})$ if $\varepsilon_3 = 0$, and

$$\frac{\Delta(\omega^2)}{\omega_0^2} = \frac{2\pi^{1/2}}{k}(4\varepsilon_3 B_0^3) = 10^{-2} \tag{2.34}$$

or,

$$\varepsilon_3 = \frac{10^{-14}}{\lambda}\left(\frac{\pi^{1/2}}{4}\right) \text{ if } \varepsilon_1 = 0.$$

Case III: For $B \doteq 0$ $(\varepsilon_1, \varepsilon_3 = 0)$ and high fields;

$$64\pi^2A^4C^4 > 16\pi k^2A^2C^4 \quad \text{or} \quad \text{if} \quad B_0\varepsilon_2 > \frac{\pi^{1/2}}{\lambda} \text{ if } \varepsilon_5 = 0, \tag{2.35}$$

and

$$\varepsilon_5 B_0^3 > \frac{\pi^{1/2}}{2\lambda} \text{ if } \varepsilon_2 = 0 \tag{2.36}$$

we have from Eq. (2.24):

$$\omega^2 = k^2C^2 + 16\pi A^2C^2, \tag{2.37}$$

thus we only get one shifted frequency branch which gives a total of two branches including the normal branch in Eq. (2.23). We estimate the shift in ω^2 as follows

$$\frac{\Delta(\omega^2)}{\omega_0^2} = \frac{16\pi C^2(\varepsilon_2 B_0)^2}{k^2C^2} = \frac{4}{\pi}\varepsilon_z^2 B_0^2\lambda^2 > 1$$

if $\varepsilon_5 = 0$;

$$\frac{\Delta(\omega^2)}{\omega_0^2} = \frac{16\pi C^2(2\varepsilon_5 B_0^3)^2}{k^2C^2} = \frac{16}{\pi}\varepsilon_5^2 B_0^6\lambda^2 > 1 \text{ if } \varepsilon_2 = 0.$$

The fact that both of these ratios are greater than 1 follows from Eq. (2.35) for the condition on the values of $B_0, \lambda, \varepsilon_2$ and $B_0, \lambda, \varepsilon_5$. We thus see that high fields with the absence of the couplings $\varepsilon_1, \varepsilon_3$ generate a single dispersive branch in addition to the normal case, (2.23). Both Case I and Case II generate three branches including the normal branch.

3. *Conclusion*

We see from the above analysis that a signature for the couplings of ε_2 or ε_5 for high fields would be two dispersive branches including the normal branch, with a large dispersion in (ω^2) of $\frac{\Delta(\omega^2)}{\omega_0^2} > 1$. The other two cases would produce three dispersive branches and have the calculated couplings for a deviation of 1% away from the normal branch. In a previous note, we discussed just the couplings $\varepsilon_1, \varepsilon_2$ and did not consider the additional invariants discussed in this paper. If we inquire into the origin of these couplings, we may with certain assumptions regarding their dependence on the fundamental constants h, G and C, speculate on their possible generic origin from a symmetry breaking mechanism at the Planck scale and the electroweak scale possibly rooted in supergravity theory. Suppose we study the microwave region with $\lambda \approx 1$ cm, then from Case I and II above, with a 1% shift in ω^2 we have $\varepsilon_1, \varepsilon_2 \approx 10^{-6}$ and dimensionly $\varepsilon_1, \varepsilon_2$ have units $(\text{cm/erg})^{1/2}$. Thus in terms of h, G, C we may write (K_0 = dimensionless constant) $10^{-6} = \left(\frac{G^{1/2}}{c^2}\right) K_0$ giving $K_0 \approx 10^{18}$, which is approximately the ratio of the Planck breaking scale to the electroweak scale. For $\varepsilon_3, \varepsilon_5$ we have assuming a 1% shift in ω^2 from Case I and Case II above, $\varepsilon_3, \varepsilon_5 \approx 10^{-14}$ for microwaves of $\lambda \approx 1$ cm.

The dimensions of $\varepsilon_3, \varepsilon_5$ are $(\text{cm}^{7/2}/\text{erg}^{3/2})$ which gives in terms of the three fundamental constants h, G, C — and the dimensionless constant $\bar{K}$, $\varepsilon_3, \varepsilon_5 \approx 10^{-14} \approx \bar{K}\left(\frac{hG^{5/2}}{c^9}\right)$ which gives $\bar{K} \approx 10^{126} = \left(\frac{\phi Pl}{\phi EW}\right)^8$.

Thus the constants ε_3 and ε_5 would emerge from a symmetry breaking mechanism that leaves a phenomenological coupling constant proportional to the ratio of the Planck scale and the electroweak scale to the eighth power. Though the above numbers are all dependent on a 1% shift in a 10^4 gauss external field, if these dispersive effects are discovered it would be interesting to see if there is a correlation in the coupling constants $\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_5$ with respect to the ratio of the Planck scale to the electroweak scale. If there were, it would certainly suggest that these couplings have an origin based on supergravity or superstring theory with a symmetry breaking mechanism leaving the phenomenological couplings that depend on the Planck scale and the electroweak scale in the above manner. The last point to be made is that these dispersive shifts would have to be separated out from other spectral shifts such as cosmological shifts, Doppler shifts due to local galactic motion and gravitational shifts due to inhomogenities in the universe. Spectral splittings due to possible atomic transitions would also have to be eliminated as possible competitive effects. In closing we hope that this investigation will encourage a closer look at the microwave spectrum as well as other regions of the spectrum to ascertain the presence of scalar electromagnetic couplings.

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