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Photocosmos, Is the Universe Made of Light? Photons, Particles, Gravitation from the Electromagnetic Vacuum

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Abstract

Without stating postulates or making any hypothesis, the quantization of the vector potential amplitude at a single photon level yields naturally the electromagnetic field ground state corresponding to the electromagnetic vacuum having both classical and quantum representations. It is a zero-energy cosmic field with electric nature permeating all of space and composed of real quantum states, called *kenons* (from κενο = vacuum). It overcomes the vacuum energy singularity in quantum electrodynamics without compromising any of the achievements. Photons appear clearly as local oscillations of the electromagnetic vacuum state propagating at the speed of light and having a non-local real wave function. The elementary positive and negative charges derive equally from the electromagnetic vacuum and may correspond to standing photon states in specific topological configurations. Furthermore, it is shown that the masses of all elementary particles-antiparticles derive from the electromagnetic vacuum and are expressed proportionally to the elementary charge. The mass effect results from the charge states and their magnetic moments. All neutral particles are composed of positive and negative charges. The electromagnetic nature of particles implies that Newton's and Coulomb's laws are naturally equivalent. The gravitational constant has also electromagnetic nature and depends on the electromagnetic vacuum density of states entailing that it may not be universal. The electromagnetic vacuum is the source of light, matter, anti-matter and gravitational effects in the universe.

Keywords

Photons, Vector Potential Quantization, Electromagnetic Vacuum, Kenons, Elementary Charge, Mass-Charge Relation, Electromagnetic Gravity, Electromagnetic Vacuum Cosmology, Unified Field Theory

1. Introduction

Following the publication of Maxwell's equations in 1865, the vector potential $\vec{A}(\vec{r},t)$ was considered to be simply a mathematical function, with no physical existence [1] [2]. It permits to calculate the electric $\vec{E}(\vec{r},t) = -\partial\vec{A}(\vec{r},t)/\partial t$ and magnetic $\vec{B}(\vec{r},t) = \vec{\nabla}\times\vec{A}(\vec{r},t)$ fields of the electromagnetic waves, considering generally the scalar potential to be constant in space [3]. In 1949, W. Ehrenberg and R. E. Siday put in evidence experimentally the direct influence of the vector potential on charges [4]. This was also confirmed later by R. G. Chambers (1960) followed by the works of A. Tonomura (1982) and N. Osakabe (1986) [5]-[7]. Hence, the physical reality of the vector potential and its direct influence on charges in absence of electric and magnetic fields has been demonstrated experimentally. It is well established that the electric and magnetic fields derive from the vector potential which is a real field and constitutes the essence of the electromagnetic waves [3] [8]-[10].

Thus, the quantization of the electromagnetic field in QED is based precisely on the vector potential [11]-[13]. In recent years, the vector potential quantization has been enhanced to a single photon level putting in evidence the electromagnetic vacuum, a real field having equivalent representation in classical and quantum theories and overcoming the zero-point energy singularity in QED [14]-[18]. Photons are oscillations of the electromagnetic vacuum. In addition, the electron-positron elementary charge derives naturally during the photon vector potential quantization process. Hence, it has been shown that the photon vector potential is directly related to the elementary charge and mass entailing that the electron and positron may be composed of (standing) states of photons in specific topological configurations.

We advance here the possibility that all the elementary particles are composed of charges, which themselves are states of photons, establishing the mass-charge equivalence relation. It is drawn that the universe may be composed entirely of light issued from the electromagnetic vacuum. In addition, it is put ahead that gravitation is an electromagnetic effect and it is shown that the gravitational constant depends directly on the electromagnetic vacuum density of states entailing that it may not be universal.

2. Photons from the Electromagnetic Vacuum

Before addressing the electromagnetic nature of all elementary particles it is of crucial importance to recall briefly the main features of the photon vector potential quantization leading to the electromagnetic vacuum with the associated cosmological implications.

2.1. Photon *Vector Potential - Energy* Quantum Equation and the Photon Wave Function

The photon wave function $\vec{\Phi}_{k(L,R)}(\vec{r},t)$ for a free k-mode photon with angular frequency ω_k and circular polarization left (L) or right (R), corresponding respectively to spin $\pm\hbar$, is expressed as follows [19] [20]

$$\vec{\Phi}_{k(L,R)}(\vec{r},t)=\left(\frac{\varepsilon_0\omega_k}{\hbar}\right)^{1/2}\left[\alpha_{0k}(\omega_k)\left(\hat{\varepsilon}_{k(L,R)}\mathrm{e}^{i(\vec{k}\cdot\vec{r}-\omega_k t+\theta)}+\hat{\varepsilon}^*_{k(L,R)}\mathrm{e}^{-i(\vec{k}\cdot\vec{r}-\omega_k t+\theta)}\right)\right] \quad (1)$$

where $\hat{\varepsilon}_{k(L,R)}$ is the circular polarization complex unit vector, $\vec{k}$ the wave-vector with amplitude $|\vec{k}|=2\pi/\lambda_k$, λ_k is the wavelength of the mode k and θ a phase parameter.

$\vec{\Phi}_{k(L,R)}(\vec{r},t)$ satisfies Maxwell's propagation equation in vacuum,

$$\vec{\nabla}_k^2\vec{\Phi}_{k(L,R)}(\vec{r},t)-\frac{1}{c^2}\frac{\partial^2}{\partial t^2}\vec{\Phi}_{k(L,R)}(\vec{r},t)=0 \quad (2)$$

Helmholtz equation,

$$\vec{\nabla}_k^2\vec{\Phi}_{k(L,R)}(\vec{r},t)+k^2\vec{\Phi}_{k(L,R)}(\vec{r},t)=0 \quad (3)$$

and the photon *vector potential - energy* quantum equation,

$$i\begin{pmatrix}\xi\\ \hbar\end{pmatrix}\frac{\partial}{\partial t}\vec{\Phi}_{k(L,R)}(\vec{r},t)=\begin{pmatrix}\tilde{\alpha}_{0k}\\ \tilde{H}_k\end{pmatrix}\vec{\Phi}_{k(L,R)}(\vec{r},t) \quad (4)$$

expressing both the first (energy) and second (vector potential) quantization of the electromagnetic field corresponding to k-mode photons with energy $E_k(\omega_k)=\hbar\omega_k$ and vector potential amplitude $\alpha_{0k}(\omega_k)=\xi\omega_k$.

The operators involved in (4) write

$$\begin{pmatrix}\tilde{\alpha}_{0k}\\ \tilde{H}_k\end{pmatrix}=-i\begin{pmatrix}\xi\\ \hbar\end{pmatrix}c\vec{\nabla}_k \quad (5)$$

where $\vec{\nabla}_k$ merely means that the gradient acts upon the mode k.

The vector potential quantization constant is

$$\xi=\frac{\hbar}{4\pi ec} \quad (6)$$

with $\hbar$ Planck's reduced constant, c the speed of light in vacuum and e the electron-positron elementary charge. Note that ξ can be negative or positive [14]-[16].

The function $\vec{\Phi}_{k(L,R)}(\vec{r},t)$ issues [21] from the photon vector potential function $\vec{\alpha}_{k(L,R)}(\vec{r},t)$ with the quantized amplitude $\alpha_{0k}(\omega_k)=\xi\omega_k$

$$\vec{\alpha}_{k(L,R)}(\vec{r},t)=\xi\omega_k\left(\hat{\varepsilon}_{k(L,R)}\mathrm{e}^{i(\vec{k}\cdot\vec{r}-\omega_k t+\theta)}+\hat{\varepsilon}^*_{k(L,R)}\mathrm{e}^{-i(\vec{k}\cdot\vec{r}-\omega_k t+\theta)}\right)=\omega_k\vec{\Xi}_{k(L,R)}(\vec{r},t) \quad (7)$$

Overcoming the point photon concept, $\vec{\Phi}_{k(L,R)}(\vec{r},t)$ is normalized with respect to the photon quantization volume V_k, an intrinsic topological property issued from both the density of states theory and the energy normalization process of a plane electromagnetic wave to a single photon [19]

$$V_k=\left(\frac{\hbar}{2\varepsilon_0\xi^2}\right)\omega_k^{-3}=4\alpha\lambda_k^3 \quad (8)$$

The normalization condition is satisfied with respect to the quantization volume

$$\int_{V_k}\left|\vec{\Phi}_{k(L,R)}(\vec{r},t)\right|^2\mathrm{d}^3r'=1 \quad (9)$$

Obviously, according to (1) and (7), the photon wave function $\vec{\Phi}_{k(L,R)}(\vec{r},t)$ depends fundamentally on the main function of the vector potential $\Xi_{k(L,R)}(\vec{r},t)$

$$\vec{\Phi}_{k(L,R)}(\vec{r},t)=\left(\frac{\varepsilon_0\omega_k^3}{\hbar}\right)^{1/2}\vec{\Xi}_{k(L,R)}(\vec{r},t) \tag{10}$$

It is straightforward to show that the mean values of the relativistic massless particle Hamiltonian $\tilde{H}_k=-i\hbar c\vec{\nabla}_k$ and the momentum operator $\vec{p}_k=-i\hbar\vec{\nabla}_k$ in the single photon state, respecting the quantization volume V_k, give the single photon energy and momentum respectively [20]

$$\left|\left\langle\Phi_{k(L,R)}(\vec{r},t)\middle|\tilde{H}_k\middle|\Phi_{k(L,R)}(\vec{r},t)\right\rangle_{V_k}\right|=\left|\left\langle\Phi_{k(L,R)}(\vec{r},t)\middle|-i\hbar c\vec{\nabla}_k\middle|\Phi_{k(L,R)}(\vec{r},t)\right\rangle_{V_k}\right|=\hbar\omega_k \tag{11}$$

$$\left|\left\langle\Phi_{k(L,R)}(\vec{r},t)\middle|\vec{p}_k\middle|\Phi_{k(L,R)}(\vec{r},t)\right\rangle_{V_k}\right|=\left|\left\langle\Phi_{k(L,R)}(\vec{r},t)\middle|-i\hbar\vec{\nabla}_k\middle|\Phi_{k(L,R)}(\vec{r},t)\right\rangle_{V_k}\right|=\frac{\hbar\omega_k}{c} \tag{12}$$

The precession of the quantized vector potential around the propagation axis at the angular frequency ω_k with circular polarization gives birth to orthogonal electric $\vec{\varepsilon}_k$ and magnetic $\vec{\beta}_k$ fields whose amplitudes are proportional to $\xi\omega_k^2$ and the corresponding magnitudes, that is the square root of the sum of the squares of the components, are obtained directly from Maxwell's equations [19] [20]

$$\begin{aligned}\left\|\vec{\varepsilon}_k\right\|&=\left\|-\partial\vec{\alpha}_{k(L,R)}(\vec{r},t)/\partial t\right\|=\sqrt{2}\left|\xi\right|\omega_k^2\\ \left\|\vec{\beta}_k\right\|&=\left\|\vec{\nabla}\times\vec{\alpha}_{k(L,R)}(\vec{r},t)\right\|=\sqrt{2\varepsilon_0\mu_0}\left|\xi\right|\omega_k^2\end{aligned} \tag{13}$$

with μ_0 the vacuum magnetic permeability.

In addition, the energy density for a single photon state as a pointless particle is readily obtained and is identical in both classical and quantum representations

$$\begin{aligned}W_k&=\left|\Phi_{k(L,R)}(\vec{r},t)\right|^2\left|\left\langle\Phi_{k(L,R)}(\vec{r},t)\middle|\tilde{H}_k\middle|\Phi_{k(L,R)}(\vec{r},t)\right\rangle_{V_k}\right|\\ &=\frac{1}{2}\left(\varepsilon_0\left\|\vec{\varepsilon}_k\right\|^2+\frac{1}{\mu_0}\left\|\vec{\beta}_k\right\|^2\right)=\frac{\hbar\omega_k}{V_k}=2\varepsilon_0\xi^2\omega_k^4\end{aligned} \tag{14}$$

showing the self-consistency of the developed formalism.

2.2. The Electromagnetic Vacuum

We recall that the zero-point energy in QED issues from the harmonic oscillator Hamiltonian and represents a constant. Therefore, it commutes with all quantum mechanics Hermitian operators corresponding to observables and consequently is not responsible for the vacuum effects such as the Lamb shift and the spontaneous emission. In fact, the last effects are calculated in QED by using the photon creation and annihilation operators [22]. In addition, it has been demonstrated that the Casimir effect is due to Lorentz's forces of source fields and not to the zero-point energy [23]-[26]. Finally, the density of the zero-point energy conflicts with recent well-validated astrophysical observations by 120 orders of magnitude leading to the well-known vacuum catastrophe riddle, a real cosmological problem [27]-[30].

In fact, the zero-point energy of the electromagnetic field issues from the fundamental mathematical ambiguity consisting of replacing commuting classical canonical variables of position and momentum by the non-commuting corresponding quantum mechanics operators [12] [15]. Consequently, the zero-point energy cannot represent a real physical state and the question arises how to complement the normal ordering Hamiltonian of the electromagnetic field with a realistic vacuum description.

For that purpose, let us analyze what happens to the photon functions at zero frequency. For $\omega_k = 2\pi c/\lambda_k \to 0$, that is for $\lambda_k \to \infty$, the photon energy, vector potential, electric and magnetic fields vanish. However, the final state does not correspond to a perfectly empty space since the fundamental function $\vec{\Xi}_{k(L,R)}(\vec{r},t)$ of the vector potential (7) still subsists and is expressed in both classical and quantum formalisms [16]-[18] [20] [31]

$$\vec{\Xi}_{0(L,R)} = \xi\left[\hat{\varepsilon}_{(L,R)}\mathrm{e}^{i\theta} + \hat{\varepsilon}^{*}_{(L,R)}\mathrm{e}^{-i\theta}\right] \tag{15a}$$

$$\tilde{\vec{\Xi}}_{0(L,R)} = \xi\left[\hat{\varepsilon}_{(L,R)}a_{k(L,R)}\mathrm{e}^{i\theta} + \hat{\varepsilon}^{*}_{(L,R)}a^{+}_{k(L,R)}\mathrm{e}^{-i\theta}\right] \tag{15b}$$

where in the quantum expression (15b) we have used the creation $a^{+}_{k(L,R)}$ and annihilation $a_{k(L,R)}$ non-Hermitian operators respectively for a single *k*-mode photon with circular polarization.

The expressions (15) represent the electromagnetic field ground state corresponding to the electromagnetic vacuum, a zero-energy field with electric potential nature filling all of the space.

For the first time, the classical electromagnetic theory is endowed with a vacuum state and QED with a vacuum representation depending on the photon creation and annihilation operators, complementing the normal ordering Hamiltonian.

Obviously, the phase parameter θ in the expressions (15) may take any value and consequently the electromagnetic vacuum is composed of all possible states $\vec{\Xi}_{k(L,R)}(\vec{r},t)$

$$\vec{\Xi}_{k(L,R)}(\vec{r},t) = \xi\left(\hat{\varepsilon}_{k(L,R)}\mathrm{e}^{i\left(\vec{k}\cdot\vec{r}-\omega_k t+\phi\right)} + \hat{\varepsilon}^{*}_{k(L,R)}\mathrm{e}^{-i\left(\vec{k}\cdot\vec{r}-\omega_k t+\phi\right)}\right) \tag{16a}$$

$$\tilde{\vec{\Xi}}_{k(L,R)}(\vec{r},t) = \xi\left(\hat{\varepsilon}_{k(L,R)}a_{k(R,L)}\mathrm{e}^{i\left(\vec{k}\cdot\vec{r}-\omega_k t+\phi\right)} + \hat{\varepsilon}^{*}_{k(L,R)}a^{+}_{k(L,R)}\mathrm{e}^{-i\left(\vec{k}\cdot\vec{r}-\omega_k t+\phi\right)}\right) \tag{16b}$$

The electromagnetic vacuum states $\vec{\Xi}_{k(L,R)}(\vec{r},t)$, which can be called *kenons* (from κενο = vacuum), involve all the characteristic physical parameters for any *k*-mode of the electromagnetic field, that is wave vector, frequency and spin (helicity, corresponding to circular polarization).

It is extremely important noting that the *kenons* result naturally from the quantized vector potential without stating any postulates or advancing any hypothesis.

From the fundamental photon *vector potential - energy* quantum Equation (4) we obtain the equation governing the *kenons* [31]

$$i\frac{\partial}{\partial t}\begin{bmatrix}\vec{\Xi}_{k\lambda}(\vec{r},t)\\ \tilde{\vec{\Xi}}_{k\lambda}(\vec{r},t)\end{bmatrix} = \begin{pmatrix}\omega_k\\ \tilde{\omega}_k\end{pmatrix}\begin{bmatrix}\vec{\Xi}_{k\lambda}(\vec{r},t)\\ \tilde{\vec{\Xi}}_{k\lambda}(\vec{r},t)\end{bmatrix} = \begin{bmatrix}\vec{\alpha}_{k\lambda}(\vec{r},t)\\ \tilde{\vec{\alpha}}_{k\lambda}(\vec{r},t)\end{bmatrix} \tag{17}$$

where the angular frequency operator acting upon each mode k is $\tilde{\omega}_k = -ic\vec{\nabla}_k$.

The physical interpretation of Equation (17) is that real photons with vector potential $\vec{\alpha}_{k(L,R)}(\vec{r},t)$ are generated by the action of the angular frequency operator $\tilde{\omega}_k$ upon the *kenons*. In other words, photons are oscillations (precessions) of the electromagnetic vacuum states. Hence, the electromagnetic vacuum is composed of an infinite sea of *kenons* involving all modes k with circular polarizations.

An interaction Hamiltonian between *kenons* and electrons can be readily defined [14] [15] [20]

$$H_{int} = \frac{\hbar e}{m_e c}\tilde{\Xi}_{k(L,R)}\tilde{\omega}_k = -i\hbar\frac{e}{m_e}\tilde{\Xi}_{k(L,R)}\vec{\nabla}_k \tag{18}$$

characterizing the spontaneous emission effect following which a *kenon* state is transformed to a real photon under the action of the angular frequency operator.

As about the Lamb shift, it is estimated exactly with the well-known method in QED since the calculation is based on the photon creation operator $a^+_{k\lambda}$.

In addition, it is straightforward to demonstrate that every particle accelerated in the electromagnetic vacuum with an acceleration γ experiences the Fulling-Davies-Unruh temperature [18]

$$T_H = \frac{\hbar}{2\pi c k_B}|\vec{\gamma}| \tag{19}$$

where k_B is Boltzmann's constant.

Finally, it has been shown that the fluctuations of the electromagnetic vacuum yield an energy density ~10^{-10} J·m^{-3}, compatible with the astrophysical observations [30]. This result issues from the fact that the photon electric field magnitude is proportional to the square of the frequency [17] [20] [32].

Thus, the electromagnetic vacuum (16) is expressed in both classical and quantum formalisms complementing the quantum representation by associating a zero-energy vacuum field to the normal ordering Hamiltonian overcoming the zero-point energy singularity.

3. The Elementary Charge from the Electromagnetic Vacuum

We will show now that the elementary electron-positron charge is directly related to the photon quantized vector potential.

The photon volume V_k expands longitudinally along the propagation axis and corresponds to the volume in which the precession of the vector potential quantized amplitude takes place. We may now consider a closed loop in which the photon is curved. The mean electric field can be expressed by considering the photon electric field amplitude (13) weighed by the ratio of the total volume in all directions ($4\pi V_k$) to the characteristic volume λ_k^3

$$\langle \varepsilon \rangle \simeq \frac{4\pi V_k}{\lambda_k^3}|\vec{\varepsilon}_k| = 16\pi\alpha\xi\omega_k^2 \tag{20}$$

On the other hand, according to Coulomb law, the mean electric field created by a point charge considered at the center of the configuration writes

$$\langle \varepsilon \rangle \simeq \frac{q}{4\pi\varepsilon_0 r_0^2} \tag{21}$$

where $r_0 = \lambda_k / 4\pi$ is the mean distance value in this topological configuration [33].

Equating the last equations, we draw the charge of this bounded photon state

$$q = (4\pi)^2 \alpha \frac{\xi}{\mu_0} \simeq \pm 1.602 \times 10^{-19}\,\mathrm{C} \tag{22}$$

which is that of the electron-positron charge *e*.

It is extremely important to underline here that the same exactly charge issues naturally from the energy normalization of a plane electromagnetic wave over a wavelength to a single photon energy [16] [19] [34]. This fundamental result formally signifies that, as the neutrino structure of photons [35] [36] has not been accepted, it is quite plausible physically either the electrons and positrons to be standing states of photons [33], or the photons to be composed of electron-positron pairs [37] [38].

Now, using the classical electromagnetic theory formalism the spin writes

$$\begin{aligned} \vec{S} &= \int_{V_k} \varepsilon_0 \vec{r}_0 \times \left(\vec{\varepsilon}_{k\lambda} \times \vec{\beta}_{k\lambda}\right) \mathrm{d}^3 r \\ &= \pm \varepsilon_0 \left(c/2\omega_k\right)\left(\sqrt{2}\omega_k \alpha_{0k}\right)\left(\sqrt{2}\omega_k \alpha_{0k}/c\right) V_k \left(\hat{r}_0 \times \hat{k}\right) \\ &= \pm \frac{\hbar}{2}\left(\hat{r}_0 \times \hat{k}\right) \end{aligned} \tag{23}$$

with $\hat{r}_0, \hat{k}$ unit vectors.

Furthermore, it can be shown [18] [31] that the electron-positron mass m_{e^-,e^+} depends directly on the vacuum constant ξ and the elementary charge *e*

$$m_{e^-,e^+} = 2\pi c e^2 \frac{\xi}{\mu_B} \tag{24}$$

where $\mu_B = 9.274 \times 10^{-24}\,\mathrm{J \cdot T^{-1}}$ is the Bohr magneton.

We have considered here the plausible case that electrons and positrons may be standing states of photons, that is of *kenons*. Following the relations (22) and (24), the electron-positron charge and mass are directly related to the photon vector potential and consequently to the electromagnetic vacuum. Pairs of electrons-positrons can be created spontaneously and annihilate in the *kenon* sea. Hence, it seems that the *kenons* fluctuations may be at the origin of the vacuum polarization. With the same token photons are spontaneously created and annihilated in the *kenon* sea. The pic of the residual electromagnetic vacuum spontaneous emission should lie in the THz frequencies and consequently, the JWST might give an answer to that issue [30].

Finally, the vacuum physical characteristics, that is the electric permittivity ε_0 and magnetic permeability μ_0 are expressed through the fundamental physical constants $\alpha, \xi, \hbar$ and the elementary charge *e* showing that they are intrinsic properties of the *kenons*

$$\mu_0 = (4\pi)^2 \alpha\xi / e \quad \varepsilon_0 = \xi e^3 / \alpha\hbar^2 \tag{25}$$

It is straightforward to verify that the last expressions give directly the velocity of light in vacuum

$$\varepsilon_0\mu_0 = \left(4\pi e\xi/\hbar\right)^2 = 1/c^2 \tag{26}$$

Thus, from the electromagnetic vacuum, the *kenon* sea, emerges the fundamental intrinsic vacuum properties as well as the vacuum polarization.

4. Elementary Particles from the Electromagnetic Vacuum. The Mass-Charge Equivalence

From a historical point of view, we recall that Planck's constant $\hbar$ was initially related experimentally to the energy of light quanta, considered as fundamental parts of the electromagnetic waves. However, although the characteristic physical origin of Planck's constant lies to the quantization of the electromagnetic field it is quite intriguing to realize that the same constant is used in quantum physics for the description of all the other particles. This particular fact probably witnesses the inherent electromagnetic nature of the elementary particles.

In fact, the mass m_i of any particle-antiparticle *i*, other than the electron-positron, writes through the electromagnetic vacuum constant ξ and the electron-positron charge *e* [18] [31]

$$m_i = 2\pi c e^2 \frac{\xi}{\mu_i} \tag{27}$$

where μ_i is the magneton of the particle *i*.

Note that from (22), *e* is the electron charge for $\xi < 0$ while it corresponds to the positron charge for $\xi > 0$. Using the same sign convention and on the condition that magnetons are positive quantities the relation (27) implies that the masses of particles and antiparticles bear naturally opposite signs. This is in agreement with previous studies on matter and antimatter [39].

We also recall that from the very first experiments, the electron charge was considered conventionally as negative and consequently the particle masses appear also here as negative and those of the antiparticles as positives.

An approximate formalism for μ_i related to the Bohr magneton writes

$$\mu_i \simeq \left(\frac{16\alpha}{n_i}\right)\mu_B \tag{28}$$

where α is the fine structure constant and n_i is simply a positive integer [31].

Using the relations (6) and (28) the Equation (27) becomes

$$m_i \simeq n_i \sigma_\xi \xi = n_i \sigma_e e \tag{29}$$

with the constants $\sigma_\xi = \pi c e^2/8\alpha\mu_B$ and $\sigma_e = \hbar/32\alpha\mu_B$.

The last relation means that the masses of all particles-antiparticles derive from the electromagnetic vacuum and are multiples of the vacuum constant ξ or multiples of the elementary charge *e*.

Hence, (29) expresses both the electromagnetic vacuum origin of the mass and the mass-charge equivalence.

The numerical application of (29) writes simply [31]

$$m_i \simeq n_i \; 4.3767 \; \mathrm{MeV}/\mathrm{c}^2 \tag{30}$$

The last relation reproduces the masses of the known elementary particles, presented in **Table 1**, augmented and updated with respect to that published in [31].

Table 1. Elementary particle masses in MeV/c² calculated using the relation (30) and comparison to the experimental values.

n_i	m_i calculated	m_i experimental	$\lvert\delta(\%)\rvert$	Particle
24	105.0	105.65	0.57	Muon (lepton), μ^-
31	135,6	134.97	0.46	Pion (meson), π^0
32	140.0	139.57	0.30	Pion (meson), π^+, π^-
113	494.5	493.68	0.17	Kaon (meson), K^+, K^-
114	498,9	497.70	0.24	Kaon (meson), K^0_s, K^0_L
125	547.1	547.75	0.11	Eta (meson), η^0
177	774.7	775.4	0.11	Rho (meson), ρ^0, ρ^+, ρ^-
179	783.4	782.65	0.10	Omega (meson), ω
204	892.8	891.66	0.08	Kaon (meson), K^{*+}, K^{*-}
205	897.2	896.0	0.12	Kaon (meson), K^{*0}
214	936.6	938.27	0.17	Proton (baryon), p^+
215	940.9	939.56	0.15	Neutron (baryon), n^0
219	958.4	957.66	0.07	Eta prime (meson), η'
233	1019.7	1019.44	0.01	Phi (meson), φ
255	1116.0	1115.68	0.03	Lambda (baryon), Λ^0
271	1186.0	1189.37	0.28	Sigma (baryon), Σ^+
272	1190.4	1192.6	0.18	Sigma (baryon), Σ^0
274	1199.2	1197.45	0.14	Sigma (baryon), Σ^-
282	1234.2	1232 ± 2	0.17	Delta (baryon), Δ^-, Δ^0, Δ^+, Δ^{++}
300	1313.0	1314.8	0.13	Xi (baryon), Ξ^0
302	1321.7	1321.7	0.00	Xi (baryon), Ξ^-
316	1383.0	1382.8; 1383.7	0.00	Sigma (baryon), Σ^{*+}, Σ^{*0}
317	1387.4	1387.2	0.00	Sigma (baryon), Σ^{*-}
350	1531.8	1531.8	0.00	Xi (baryon), Ξ^0 resonance
351	1536.2	1535.0	0.07	Xi (baryon), Ξ^- resonance
382	1671.9	1672.45	0.03	Omega (baryon), Ω^-
406	1776.9	1777.0	0.00	Tau (lepton), τ^-
426	1864.5	1864.8	0.01	D Meson, D^0
450	1969.5	1968.4	0.05	Ds Meson, D_s^+
458	2004.5	2006.97	0.12	D Meson, D^{*0}
459	2008.9	2010.27	0.06	D Meson, D^{*+}

Continued

483	2113.9	2112.3	0.07	Strange D (meson), D_s^{*+}
522	2284.6	2286.46	0.08	Lambda c (baryon), Λ_c^+
560	2451.0	2452.9; 2453.7	0.08	Sigma c (baryon), Σ_c^+, Σ_c^0
561	2455.3	2453.9	0.05	Sigma c (baryon), Σc^{++}
564	2468.4	2467.9	0.02	Xi c (baryon), Ξ_c^+, Ξ_c^0
565	2472.8	2471.0	0.07	Xi c (baryon), Ξ_c^+, Ξ_c^0
588	2573.5	2575.7	0.08	Xi c (baryon), Ξ_c^+ resonance
589	2577.9	2578.0	0.00	Xi c (baryon), Ξ_c^0 resonance
616	2696.0	2697.5	0.06	Omega c (baryon), Ω_c^0
632	2766.0	2765.9	0.00	Omega charm(baryon) Ω_c^{*0}
681	2980.5	2980.3	0.00	Charmed Eta(meson), η_c
707	3094.3	3096.9	0.08	J/ψ (meson)
804	3518.9	3518.9	0.00	Xi cc (baryon), Ξ_{cc}^+
827	3619.5	3621.4	0.05	Xi cc (baryon), Ξ_{cc}^{++}
1206	5278.3	5279.34; 5279.65	0.02	B Meson, B^+, B^0
1217	5326.4	5325.1	0.02	B* Meson, B^{*+}, B^{*0}
1226	5365.8	5366.3	0.00	Bs Meson, Bs0
1284	5619.7	5620.2	0.00	Lambda b0 (baryon), Λ_b^0
1327	5807.9	5810	0.04	Sigma b (baryon), Σ_b^+
1329	5816.6	5815.2	0.02	Sigma b (baryon), Σ_b^-
1332	5829.8	5830.3	0.00	Sigma bottom (baryon), Σ_b^{*+}
1333	5834.1	5834.7	0.00	Sigma bottom (baryon), Σ_b^{*-}
1356	5934.8	5935.0	0.00	Xi' b (baryon), Ξ_b'
1360	5952.3	5952.3	0.00	Xi* b (baryon), Ξ_b^*
1361	5956.6	5955.3	0.02	Xi* b (baryon), Ξ_b^{*0}
1381	6044.2	6046.0	0.02	Omega b (baryon), Ω_b^-
1423	6228.0	6226.9	0.01	Xi b (baryon), Ξ_b
1434	6276.1	6276 ± 4	0.00	Charmed B Meson, B_c^+
2125	9300.5	9300 ± 40	0.00	Eta bottom (meson), η_b
2161	9458.0	9460.3	0.02	Ypsilon (meson), Y

The integer n_i characterizing the particle masses in (29) entails that the electromagnetic vacuum must be endowed with a complex structure involving specific quantum states that might be related to the string theory.

In addition, quarks and antiquarks are characterized by fractional elementary charges, $e/3$ and $2e/3$, and could also correspond to particular states of the electromagnetic vacuum. Therein, it is interesting to underline that the value 4.3767 MeV/c^2 in the relation (30) corresponds to the mass of the down quark which is estimated to be roughly 4.7 ± 0.6 MeV/c^2.

Pairs of particles-antiparticles can be created spontaneously and annihilated in vacuum due to the *kenons* fluctuations. However, the probability for this mechanism to occur is much weaker than that of electrons-positrons pairs for which the energy involved in the fluctuation process is much lower. The residual spontaneous generation-annihilation of matter-antimatter in space by the electromagnetic vacuum fluctuations may be in thermodynamic equilibrium at the temperature ~3 K and consequently at the origin of the cosmic microwave background.

Finally, the overall conclusion of the above is that the electron-positron charge derives from the electromagnetic vacuum and is directly related to photons through the vector potential. The particles-antiparticles masses are quantum states of the vacuum field originating from the elementary charges and their magnetic moment.

5. The Gravitational Constant and the Electromagnetic Vacuum

It is well-known that Planck's length $l_P = 1.616 \times 10^{-35}$ m corresponds physically to the shorter possible wavelength of a single photon. Consequently, it characterizes the "granularity" of the electromagnetic vacuum. Considering l_P it has been shown that the gravitational constant G is expressed exactly through the electromagnetic vacuum constants ξ, α and ε_0 [17] [18] [31]

$$G = \frac{1}{4\pi\varepsilon_0\alpha}\left(\frac{l_p}{4\pi\xi}\right)^2 \tag{31}$$

Assuming that Newton's gravitational law is valid at the elementary particle scale, the equivalence between Coulomb's electrostatic law and Newton's gravitational law is straightforward [31]

$$U_{Newton} = G\frac{m_i m_j}{r_{ij}} = \frac{1}{4\pi\varepsilon_0}\frac{e_i e_j}{r_{ij}}\eta_{ij} = U_{Coulomb} \tag{32}$$

where $\eta_{ij} = \frac{\pi\hbar c l_P^2}{\mu_0\mu_i\mu_j}$ is a dimensionless parameter depending on the magnetons of the interacting particles. A similar result has also been obtained adopting a different approach [38].

The gravitational potential between a large number of particles is expressed uniquely through the QED constants $\hbar$, e and the magnetons μ_i, μ_j showing the electromagnetic nature of the gravitational interaction

$$U = \frac{\hbar^2}{4}G\sum_{i,j(i<j)}\frac{e_i e_j}{r_{ij}\mu_i\mu_j} \tag{33}$$

Now, the factor $4\pi\xi/l_p$ in (31) corresponds to the linear density of the vacuum states with respect to the granularity of the electromagnetic vacuum in 4π steradiants.

Consequently, a fundamental concept arises straightforward related to the gravitational constant dependence on the electromagnetic vacuum density. In fact, the relation (31) writes in a more general expression

$$G = \frac{1}{4\pi\varepsilon_0\alpha}\frac{1}{\rho(\xi)^2} \tag{34}$$

where $\rho(\xi)$ is the density of states of the electromagnetic vacuum.

We draw that the gravitational constant G is expressed through electromagnetic constants and derives from the electromagnetic vacuum density of states. Consequently, according to the variation of the *kenons* density in space it may not be a universal constant. This could provide a direct explanation of the gravitational anomalies observed on a quite large numbers of galaxies, which conflict with Newtonian dynamics and general relativity [40]. On the other hand, following many detailed studies over 193 high-quality disk galaxies it also well-established today with a high degree of statistical accuracy that the modified Newtonian dynamics models are not valid [41]. Consequently, the local variation of the gravitational constant due to the electromagnetic vacuum density could give an explanation for those astrophysical anomalies. Furthermore, the radiation pressure of the electromagnetic vacuum might be at the origin of gravitation (*Electromagnetic Push Gravity*) and would be interesting to be investigated experimentally [31] [42]. In addition, the opposite mass signs corresponding to matter and antimatter following relation (29) may easily interpret Hubble's law as well as the cosmic acceleration in agreement with recent astrophysical simulations [43].

Finally, the Breit-Wheeler effect [44], according to which high energy photons collisions give birth to electron-positrons pairs, has been confirmed [45] [46] while advanced experiments [47] [48] managed to create a high number of electron-positrons pairs using γ photon collisions.

Thus, the experimental evidence has demonstrated that matter-antimatter can be created from photons opening new perspectives for further investigations in order to understand whether the universe is entirely composed of light.

6. Epilogue

The electromagnetic vacuum is a real universal field, composed of *kenons* states with electric potential nature. It has both classical and quantum representations and is at the origin of the fundamental intrinsic vacuum properties, such as the electric permittivity, magnetic permeability and vacuum polarization.

The electromagnetic waves, photons in quantum theory, are simply *kenons* oscillations.

Electrons and positrons are bound topological configurations of photons, that is of *kenons*.

The elementary charge (positive and negative) results precisely from the *kenons* and is proportional to the electromagnetic vacuum amplitude ξ.

The masses of all the elementary particles can be expressed as multiples of the vacuum quantization amplitude ξ and thus of the elementary charge e.

It is drawn that matter and antimatter in the universe issue from *kenons* and are composed of standing states of light.

The electromagnetic nature of particles implies the electromagnetic nature of gravitation and yields the equivalence of Newton's gravitational to Coulomb's electrostatic law.

Considering Planck's length as the fundamental granularity of the electromagnetic vacuum, we have shown that the gravitational constant has electromagnetic nature, it's inversely proportional to the square of the *kenons* density in space and consequently might not be a universal constant.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Ronchi, V. (1970) The Nature of Light: An Historical Survey. Harvard University Press.

[2] Read, F.H. (1980) Electromagnetic Radiation. John Wiley & Sons.

[3] Jackson, J.D. (1998) Classical Electrodynamics. Wiley.

[4] Ehrenberg, W. and Siday, R.E. (1949) The Refractive Index in Electron Optics and the Principles of Dynamics. *Proceedings of the Physical Society. Section B*, **62**, 8-21. https://doi.org/10.1088/0370-1301/62/1/303

[5] Chambers, R.G. (1960) Shift of an Electron Interference Pattern by Enclosed Magnetic Flux. *Physical Review Letters*, **5**, 3-5. https://doi.org/10.1103/physrevlett.5.3

[6] Tonomura, A., Matsuda, T., Suzuki, R., Fukuhara, A., Osakabe, N., Umezaki, H., *et al*. (1982) Observation of Aharonov-Bohm Effect by Electron Holography. *Physical Review Letters*, **48**, 1443-1446. https://doi.org/10.1103/physrevlett.48.1443

[7] Osakabe, N., Matsuda, T., Kawasaki, T., Endo, J., Tonomura, A., Yano, S., *et al.* (1986) Experimental Confirmation of Aharonov-Bohm Effect Using a Toroidal Magnetic Field Confined by a Superconductor. *Physical Review A*, **34**, 815-822. https://doi.org/10.1103/physreva.34.815

[8] Feynman, R. (1988) The Strange Theory of Light and Matter. Princeton University Press.

[9] Heitler, W. (1954) The Quantum Theory of Radiation. Clarendon Press.

[10] Mittleman, M.H. (1982) Introduction to the Theory of Laser-Atom Interactions. Plenum Press.

[11] Weissbluth, M. (1988) Photon-Atom Interactions. Academic Press, Inc.

[12] Garrison, J. and Chiao, R. (2008) Quantum Optics. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198508861.001.0001

[13] Grynberg, G., Aspect, A. and Fabre, C. (2010) Quantum Optics. Cambridge University Press.

[14] Meis, C. (2014) Vector Potential Quantization and the Quantum Vacuum. *Physics Research International*, **2014**, Article ID: 187432.

https://doi.org/10.1155/2014/187432

[15] Meis, C. (2017) Light and Vacuum. 2nd Edition, World Scientific. https://doi.org/10.1142/10450

[16] Meis, C. (2020) Quantized Field of Single Photons. In: Xia, K.Y., Ed., *Single Photon Manipulation*, IntechOpen, 15-36. https://doi.org/10.5772/intechopen.88378

[17] Meis, C. (2018) The Electromagnetic Field Ground State and the Cosmological Evolution. *Journal of Physics: Conference Series*, **1141**, Article ID: 012072. https://doi.org/10.1088/1742-6596/1141/1/012072

[18] Meis, C. (2020) Primary Role of the Quantum Electromagnetic Vacuum in Gravitation and Cosmology. In: Smith, M.L., Ed., *Cosmology* 2020—*The Current State*, IntechOpen, 77-93. https://doi.org/10.5772/intechopen.91157

[19] Meis, C. (2023) Photon Structure and Wave Function from the Vector Potential Quantization. *Journal of Modern Physics*, **14**, 311-329. https://doi.org/10.4236/jmp.2023.143020

[20] Meis, C. (2025) Reappraisal of QED Fundamentals. *International Journal of Quantum Foundations*, **11**, 42-56.

[21] Meis, C. and Dahoo, P.R. (2017) Quantized Vector Potential and the Photon Wavefunction. *Journal of Physics: Conference Series*, **936**, Article ID: 012004. https://doi.org/10.1088/1742-6596/936/1/012004

[22] Milonni, P.W. (1994) The Quantum Vacuum. Academic Press Inc.

[23] Schwinger, J., DeRaad, L.L. and Milton, K.A. (1978) Casimir Effect in Dielectrics. *Annals of Physics*, **115**, 1-23. https://doi.org/10.1016/0003-4916(78)90172-0

[24] Milonni, P.W. (1982) Casimir Forces without the Vacuum Radiation Field. *Physical Review A*, **25**, 1315-1327. https://doi.org/10.1103/physreva.25.1315

[25] Ezawa, H., Nakamura, K. and Watanabe, K. (1998) The Casimir Force from Lorentz's. In: Lim, S.C., Abd-Shukor, R. and Kwek, K.H., Eds., *Frontiers in Quantum Physics*, Springer, 160-169.

[26] Gründler, G. (2013) The Casimir Effect: No Manifestation of Zero-Point Energy. arXiv: 1303.3790v5

[27] Frieman, J.A., Turner, M.S. and Huterer, D. (2008) Dark Energy and the Accelerating Universe. *Annual Review of Astronomy and Astrophysics*, **46**, 385-432. https://doi.org/10.1146/annurev.astro.46.060407.145243

[28] Padmanabhan, T. (2003) Cosmological Constant—The Weight of the Vacuum. *Physics Reports*, **380**, 235-320. https://doi.org/10.1016/s0370-1573(03)00120-0

[29] Bengochea, G.R., León, G., Okon, E. and Sudarsky, D. (2020) Can the Quantum Vacuum Fluctuations Really Solve the Cosmological Constant Problem? *The European Physical Journal C*, **80**, Article No. 18. https://doi.org/10.1140/epjc/s10052-019-7554-1

[30] Meis, C. (2020) The Vacuum Electromagnetic Energy Density—Towards a Physical Comprehension of the Vacuum Energy Scale Problem. *International Journal of Modern Physics A*, **35**, Article ID: 2050153. https://doi.org/10.1142/s0217751x20501535

[31] Meis, C. (2022) The Electromagnetic Nature of Gravitation and Matter-Antimatter Antigravity. Surmise on Quantum Vacuum Gravitation and Cosmology. *Journal of Modern Physics*, **13**, 949-968. https://doi.org/10.4236/jmp.2022.136054

[32] Meis, C. and Dahoo, P.R. (2017) Vector Potential Quantization and the Photon Intrinsic Electromagnetic Properties: Towards Nondestructive Photon Detection. *In-*

ternational Journal of Quantum Information, **15**, Article ID: 1740003. https://doi.org/10.1142/s0219749917400032

[33] Williamson, J.G. and van der Mark, M.B. (1997) Is the Electron a Photon with Toroidal Topology? *Annales de la Fondation Louis de Broglie*, **22**, 133-160.

[34] Meis, C. (1999) Zero-point Radiation Field Revisited. *Physics Essays*, **12**, 174-181. https://doi.org/10.4006/1.3025361

[35] Perkins, W.A. (1965) Neutrino Theory of Photons. *Physical Review*, **137**, B1291-B1301. https://doi.org/10.1103/physrev.137.b1291

[36] Perkins, W.A. (1972) Interpreted History of Neutrino Theory of Light and Its Future. *Physical Review D*, **5**, 1375-1384. https://doi.org/10.1103/physrevd.5.1375

[37] Gauthier, R. (2019) Quantum-Entangled Superluminal Double-Helix Photon Produces a Relativistic Superluminal Quantum-Vortex Zitterbewegung Electron and Positron. *Journal of Physics*: *Conference Series*, **1251**, Article ID: 012016. https://doi.org/10.1088/1742-6596/1251/1/012016

[38] Clague, I. (2022) Examination of the Electromagnetic Force and Gravity through the Composite (Couplet) Photon. *Advanced Studies in Theoretical Physics*, **16**, 41-66. https://doi.org/10.12988/astp.2022.91843

[39] Villata, M. (2011) CPT Symmetry and Antimatter Gravity in General Relativity. *EPL* (*Europhysics Letters*), **94**, Article ID: 20001. https://doi.org/10.1209/0295-5075/94/20001

[40] Fairbairn, M. (2022) Galactic Anomalies and Particle Dark Matter. *Symmetry*, **14**, Article 812. https://doi.org/10.3390/sym14040812

[41] Rodrigues, D.C., Marra, V., del Popolo, A. and Davari, Z. (2018) Absence of a Fundamental Acceleration Scale in Galaxies. *Nature Astronomy*, **2**, 668-672. https://doi.org/10.1038/s41550-018-0498-9

[42] Danilatos, G. (2020) Novel Quantitative Push Gravity/Electricity Theory Poised for Verification. https://zenodo.org/record/5806899#.YdLL6GjMKUk

[43] Dimopoulos, C., Stamokostas, G.L., Gkouvelis, L. and Trigger, S. (2023) Hubble Law and Acceleration Curve Emerges in a Repulsive Matter-Anti Matter Galaxies Simulations. *Astroparticle Physics*, **147**, Article ID: 102806. https://doi.org/10.1016/j.astropartphys.2022.102806

[44] Breit, G. and Wheeler, J.A. (1934) Collision of Two Light Quanta. *Physical Review*, **46**, 1087-1091. https://doi.org/10.1103/physrev.46.1087

[45] Bula, C., McDonald, K.T., Prebys, E.J., Bamber, C., Boege, S., Kotseroglou, T., *et al.* (1996) Observation of Nonlinear Effects in Compton Scattering. *Physical Review Letters*, **76**, 3116-3119. https://doi.org/10.1103/physrevlett.76.3116

[46] Bamber, C., Boege, S.J., Koffas, T., Kotseroglou, T., Melissinos, A.C., Meyerhofer, D.D., *et al.* (1999) Studies of Nonlinear QED in Collisions of 46.6 GeV Electrons with Intense Laser Pulses. *Physical Review D*, **60**, Article ID: 092004. https://doi.org/10.1103/physrevd.60.092004

[47] Pike, O.J., Mackenroth, F., Hill, E.G. and Rose, S.J. (2014) A Photon-Photon Collider in a Vacuum Hohlraum. *Nature Photonics*, **8**, 434-436. https://doi.org/10.1038/nphoton.2014.95

[48] Adam, J., *et al.* (2021) Measurement of e^+e^- Momentum and Angular Distributions from Linearly Polarized Photon Collisions. *Physical Review Letters*, **127**, Article ID: 052302.