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The Refractive Index of the Physical Vacuum Modified by a Stochastic Electromagnetic Field

Zoltan Borsos, Ion Simaciu

Universitatea Petrol-Gaze din Ploieşti, Bd. Bucureşti 39, Ploieşti, Catedra de Fizică
e-mail: borsos.zoltan@gmail.com, isimaciu@yahoo.com

Abstract

In this paper there are derived the components of the vacuum permittivity and permeability tensors induced by a background electromagnetic radiation field with random phase in order to establish a limit of stochastic. To achieve this goal we started with the tensors expressions of modified vacuum by an electromagnetic field derived by Euler and Kockel. These relations are customized for a field with continuous spectrum and random phases. The modified vacuum by that field is optically homogeneous and isotropic. The vacuum properties modified by the stochastic field at temperature $T = 0\mathrm{K}$ *(CZPF background) are just free vacuum properties (physical vacuum in a region of space without substance and fields) with* $\varepsilon_{V\,jj} = \mu_{V\,jj} = 1$. *This assumption implies an upper limit of background spectrum. The limit frequency established is higher than the Compton frequency for electron.*

Keywords: *refractive index, vacuum permittivity and permeability tensors, Compton frequency*

Introduction

The paper aim is to establish the expressions for the vacuum permittivity and permeability tensors and permeability induced by a background electromagnetic radiation with random phase in order to establish a frequency limit of stochastic background spectrum with $T = 0\mathrm{K}$.

In the first section, the vacuum permittivity and permeability tensors components are derived in presence of electromagnetic radiation background with continuous spectrum. In the second section the properties of modified vacuum are analyzed by the stochastic field with temperature $T = 0\mathrm{K}$.

The Electromagnetic Radiation Background with Continuous Spectrum

In this section we propose to find out the optical properties of a modified vacuum by the homogeneous and isotropic background radiation with a continuous spectrum and random phases. One such background field is modeled in the quantum electrodynamics as Planck photonic gas (thermal radiation or black body equilibrium radiation) having spectral distribution (spectral density $\rho = \mathrm{d}w/\mathrm{d}\omega$ with energy density w) [5]:

$$\rho_P(\omega, T) = \left(\frac{1}{\pi^2 c^3}\right) \frac{\hbar\omega^3}{\exp\left(\hbar\omega/kt\right) - 1}, \tag{1}$$

or a virtual gas of photons with divergent spectrum (spectrum of zero point fluctuations of quantum vacuum [6]):

$$\rho_Z(\omega) = \frac{\hbar\omega^3}{2\pi^2 c^3} . \quad (2)$$

In stochastic Physics [2], the background radiation field is modeled as a stationary electromagnetic field with spectral distributions given by equations (1) and (2). Stochastic background field in physics with distribution (2) is an electromagnetic radiation at equilibrium with temperature $T = 0\mathrm{K}$ and is called Classical Zero Point Field (CZPF). This fund is a classic model of physical vacuum.

Vectors corresponding to the electromagnetic plane waves of the field, with random directions and phases (random phases) are [8]:

$$\vec{E}_f(\vec{r},t) = \mathrm{Re}\left\{(4\pi\varepsilon_0)^{-1/2})\sum_{\lambda=1}^{2}\int d^3k\,\vec{e}\,A(\omega)\exp\left[-i(\omega t - \vec{k}\vec{r} - \theta_r(\vec{k},\lambda)\right]\right\}, \quad (3)$$

$$\vec{H}_f(\vec{r},t) = \mathrm{Re}\left\{(4\pi\mu_0)^{-1/2}\sum_{\lambda=1}^{2}\int d^3k(\vec{\kappa}\times\vec{e})A(\omega)\exp\left[-i(\omega t - \vec{k}\vec{r} - \theta_r(\vec{k},\lambda)\right]\right\}, \quad (4)$$

with polarization $\lambda = 1, 2$, unit vector of polarization $\vec{e}$, wave vector $\vec{k} = k\vec{\kappa}$, angular momentum ω ($\omega = ck$), amplitude $A(\omega) = c\sqrt{c\rho}/\omega$ of mode $\vec{k}(\omega)$ and $\theta_r(\vec{k},\lambda)$ (proportional to the distribution function) and how the stage is random (random phase).

The vacuum permittivity and permeability tensors components in presence of radiation zero point field radiation is obtained through mediation by a random phase relationship (7) and (8) obtained in paper [1]:

$$\left\langle\varepsilon_{ik}\right\rangle_{\theta_r} = \delta_{ik} + 7a\left(\mu_0\left\langle H_{fi}H_{fk}\right\rangle_{\theta_r}\right), \quad (5)$$

$$\left\langle\mu_{ik}\right\rangle_{\theta_r} = \delta_{ik} + 7a\left(\varepsilon_0\left\langle E_{fi}E_{fk}\right\rangle_{\theta_r}\right), \quad (6)$$

with a given by expression $a = 4e^4\hbar\big/\left(45m^4c^7\right)$.

According to the methods developed in works [2, 8], the average random phase is defined

$$\left\langle E_{fj}E_{fk}\right\rangle_{\theta_r} = \frac{1}{8\pi\varepsilon_0}\left\{\sum_{\lambda=1}^{2}\int \mathrm{d}^3k\left(e_je_k\right)A^2(\omega)\right\}.$$

Replacing equation (7) $\mathrm{d}^3k = k^2\mathrm{d}k\sin\theta\mathrm{d}\theta\mathrm{d}\varphi = k^2\mathrm{d}k\mathrm{d}\Omega$ and $\sum_{\lambda=1}^{2}\left(e_je_k\right) = \delta_{jk} - \kappa_j\kappa_k$, results

$$\left\langle E_{fj}E_{fk}\right\rangle_{\theta_r} = \frac{1}{8\pi\varepsilon_0}\left\{\int k^2\mathrm{d}k\,A^2(\omega)\left[\int\sum_{\lambda=1}^{2}\left(e_je_k\right)\mathrm{d}\Omega\right]\right\} = \frac{1}{8\pi\varepsilon_0}\left\{\int k^2\mathrm{d}k\,A^2(\omega)\left[\int\left(\delta_{jk} - \kappa_j\kappa_k\right)\mathrm{d}\Omega\right]\right\} \quad (8)$$

Replacing equation (8) the expression for $\vec{\kappa}$ vector components ($\kappa_x = \sin\theta\cos\varphi$, $\kappa_y = \sin\theta\sin\varphi$, $\kappa_z = \cos\theta$) and integrated, results:

$$\left\langle E_{fj}E_{fk}\right\rangle_{\theta_r} = 0, \quad j \neq k ; \quad (9a)$$

$$\left\langle E_{fj}E_{fj}\right\rangle_{\theta_r} = \frac{1}{3\varepsilon_0 c^3}\int \omega^2\mathrm{d}\omega\,A^2(\omega) = \frac{1}{3\varepsilon_0}\int \rho(\omega)\mathrm{d}\omega = \frac{w}{3\varepsilon_0} . \quad (9b)$$

Through same method, the averaged $\left\langle H_{fi}H_{fk}\right\rangle_{\theta_r}$ values are obtained:

$$\left\langle H_{fj} H_{fk} \right\rangle_{\theta_r} = 0, \quad j \neq k \; ; \quad \left\langle H_{fj} H_{fj} \right\rangle_{\theta_r} = \frac{w}{3\varepsilon_0}. \tag{10}$$

With these values of the random phase averages the vacuum permittivity and permeability tensors components (5) and (6) become

$$\left\langle \varepsilon_{ik} \right\rangle_{\theta_r} = 0, i \neq k; \left\langle \varepsilon_{ii} \right\rangle_{\theta_r} = 1 + \frac{7a}{3} w \; ; \; \left\langle \mu_{ik} \right\rangle_{\theta_r} = 0, \; i \neq k; \; \left\langle \mu_{ii} \right\rangle_{\theta_r} = 1 + \frac{7a}{3} w \; . \tag{11}$$

Refractive index of vacuum corresponding expressions (11) and (12) is identical to that given by expression (24) from paper [1].The permittivity and permeability tensors (11) and (12) of the vacuum in the presence of a electromagnetic random field have the same characteristic as permittivity and permeability tensors determined by gravitational field $\varepsilon_{ij} = \mu_{ij}$ [4, 9].

The Electromagnetic Properties of Vacuum

In quantum electrodynamics, the vacuum is modeled as a background field derived from the virtual particle fluctuations to zero [6]. Virtual particles are not observed directly - they are manifested only through interactions to the systems quantum states. As we shown, the stochastic physical vacuum is modeled as a field of random electromagnetic waves with temperature $T = 0$ and spectral density given by expression (2). As it is known, the relative permittivity and relative permeability of vacuum are equal to unity $\varepsilon_{V\,jj} = \mu_{V\,jj} = 1$. Because, according to results from previous section, these tensors are determined from the radiation field with temperature $T = 0$, with density w_f, it results:

$$\varepsilon_{V\,jj} = \mu_{V\,jj} = \frac{7aw_{fZ}}{3} = 1 \; . \tag{13}$$

The background radiation field, with temperature $T = 0$ can be formed from both the electromagnetic (CZPF) and the gravitational field (Gravitational CZPF - CZPFG):

$$w_{fZ} = w_{CZPF} + w_{CZPFG} \; . \tag{14}$$

In electrodynamics theory of gravity [4, 9], the two fields are superposed $w_{fZ} = w_{CZPF}$. In this case,from the relations (13) and (14), the limit frequency (cutoff frequency ω_c) for electromagnetic radiation can be expressed as

$$\frac{7a}{3} \int_0^{\omega_l} \frac{\hbar \omega^3}{2\pi^2 c^3} \mathrm{d}\omega = 1 \; , \tag{15a}$$

or, taking into account the constant term a,

$$\omega_l = \left(\frac{24\pi^2 c^3}{7\hbar a} \right)^{1/4} = \frac{mc^2}{\hbar} \left(\frac{\hbar c}{e^2} \right)^{1/2} \left(\frac{2 \cdot 3^3 \cdot 5\pi^2}{7} \right)^{1/4} = (51,73) \frac{mc^2}{\hbar} \; . \tag{15b}$$

Expression and the value of frequency limit given by (15b) is close to those obtained in references [3] and [7].

Conclusions

Starting from the assumption of modern physics that the vacuum have a structure and acts as a physical medium, the paper tries to demonstrate that we can estimate the parameters of this subquantum structure. The estimates are consistent both with models of the quantum vacuum and the classical models developed by stochastic physics. If modeling vacuum as a background field of electromagnetic waves with random phases and continuous spectrum, vacuum is homogeneous and optically isotropic. The components of vacuum permittivity and permeability tensors and are identical, same with the vacuum tensors in the presence of a gravitational field, in electrodynamics theory of gravity. The vacuum as properties modified by the CZPF background are just the free vacuum properties (physical vacuum in a region of space without substance, and fields) with $\varepsilon_{V\,jj} = \mu_{V\,jj} = 1$. This assumption implies an upper limit of CZPF spectrum. The limit frequency established in the paper is higher than the electron Compton frequency $\omega_l > \omega_C = mc^2 / \hbar$. Limit is consistent with assessments of other known works.

In a future work we intend to evaluate the parameters of modified vacuum by the gravitational background field and to determine the consequences on the physical-mathematical models of vacuum.

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Indicele de refracție al vacuumului fizic modificat de un fond electromagnetic stocastic

Rezumat

În lucrare se deduc expresiile componentelor tensorilor permitivității şi permeabilității vacuumului induse de un fond de radiație electromagnetică cu faza întâmplătoare, cu scopul de a stabili o limită pentru frecvența fondului stocastic cu temperatura $T = 0\mathrm{K}$. *Pentru a realiza acest scop se pleacă de la expresiile tensorilor vacuumului modificat de un câmp electromagnetic deduse de Euler şi Kockel. Aceste relații sunt particularizate pentru un fond de unde cu spectru continuu şi fazele întâmplătoare. Vacuumul modificat de un asemenea fond este omogen şi izotrop optic. Proprietățile vacuumului modificat de fondul cu temperatura* $T = 0\mathrm{K}$ *(fondul CZPF) sunt tocmai proprietățile vacuumului liber (vacuumul fizic într-o regiune a spațiului fără substanță şi câmpuri) cu* $\varepsilon_{V\,jj} = \mu_{V\,jj} = 1$. *Această presupunere implică o limitare superioară a spectrului fondului. Frecvența limită stabilită în lucrare este mai mare decât frecvența Compton pentru electron* $\omega_l > \omega_C = mc^2 / \hbar$.