Zero Point Field (ZPF) effects in the interaction of the ultra-short laser pulses with matter

Mirosław Kozłowski[a], Janina Marciak-Kozłowska[b,c]

[a] Institute of Experimental Physics and Science Teacher's College, Warsaw University, Hoża 69, 00-681 Warsaw, Poland

[b] Institute of Electron Technology, Al. Lotników 32/46, 02-668 Warsaw, Poland

[c] Author to whom correspondence should be addressed.

Abstract

In this paper the effects of *zero-point energy* (ZPE) on the heat transport induced by ultra-short laser pulses is investigated. It will be shown that the existence of the *zero-point energy* in the physical vacuum influence the heat transport on the atomic level. The interaction of the building blocks of matter-atoms with the *zero-point fields* (ZPF), which generate the ZPE guarantees the stability of matter. The interaction of the ultra-short laser pulses ($\Delta t \sim 1$ as) with matter can be used as the source of the information on the ZPF.

Key words: Ultra-short laser pulses; Quantum heat transport; *Zero-point energy*; *Zero-point fields*.

1 Introduction

During the 20th century, our knowledge regarding space and the properties of the vacuum has taken a considerable progress. In the popular meaning the vacuum is considered to be a void or "nothingness". This is the definition of a *bare vacuum*. However, with the progress of science, a new and contrasting description has arisen, which physicist call the *physical vacuum*. The *physical vacuum* contains measurable energy. This energy is called the *zero-point energy* (ZPE) because it exists even at absolute zero. The very fruitful theoretical framework in which we can describe the *zero-point energy* is the stochastic electrodynamics (SED) [1, 2, 3, 4]. In the SED approach the *physical vacuum* at the atomic or subatomic level may be considered to be inherently comprised of a turbulent sea of randomly fluctuating electromagnetic field.

These fields exist at all wavelengths longer than the Planck length. At the macroscopic level these *zero-point fields* (ZPF) are homogenous and isotropic.

The atomic building blocks of matter are dependent upon the ZPF for their very existence. This was demonstrated by H. Puthoff [3, 4]. Puthoff started by pointing out the anomaly. According to classical concepts an electron in orbit around the proton should be radiating energy. As a consequence, as it losses energy, it should spiral into the atomic nucleus. But that does not happen. In quantum mechanics it is explained by the *Bohr's quantum conditions*. Instead of the Bohr model of the atom, Puthoff approached this problem with the assumption that the classical laws of electrodynamics were valid and that the electron is therefore losing energy and the loss was exactly balanced by energy gain from the ZPF.

In this paper we adapted the Puthoff's results to the study the heat transport on the atomic level. To that aim we consider the quantum heat transport (QHT) equation [5]. It will be shown that at the atomic level the structure of the QHT is dependent upon the ZPF. The condition for the quantum heat transport limit [5] guarantees the balance of the loss-gain energy on the atomic level. This open new field of investigation for laser scientists and engineers. The interaction of the ultra-short laser pulses ($\Delta\ t \sim$ attosecond) with matter can be used as the source of the information on the ZPF. Maybe that the future engineers will be specialized in "vacuum engineering".

2 The physical vacuum

In the stochastic electrodynamics (SED) [1, 2, 3, 4] the physical vacuum is assumed to be filled with random classical zero-point electrodynamic radiation which is homogenous, isotropic and Lorentz invariant. Writing as a sum over plane waves, the random radiation can be expressed as [3]

$$
\begin{aligned}
E^{\mathrm{zp}}(\vec{r},t) &= \mathrm{Re}\sum_{\delta=1}^{2}\int d^3k\hat{\epsilon}\left(\frac{\hbar\omega}{8\pi^3\epsilon_0}\right)^{1/2}\times e^{i\vec{k}\vec{r}-i\omega t+i\Theta(k,\delta)}, \qquad (1)\\
H^{\mathrm{zp}}(\vec{r},t) &= \mathrm{Re}\sum_{\delta=1}^{2}\int d^3k(\hat{k}\times\hat{\epsilon})\left(\frac{\hbar\omega}{8\pi^3\mu_0}\right)^{1/2}\times e^{i\vec{k}\vec{r}-i\omega t+i\Theta(k,\delta)},
\end{aligned}
$$

where $\delta = 1,2$ denote orthogonal polarizations, $\hat{\epsilon}$ and $\hat{k}$ are orthogonal unit vectors in the direction of the electric field polarization and wave propagation. Vectors, respectivately, $\Theta(\vec{k},\delta)$ are random phases distributed uniformly on the interval 0 to 2π (independently distributed for each $\vec{k},\delta$) and $\omega = kc$. It must be stressed that in the SED the *zero-point field* is treated in every way as a real, physical field.

In the subsequent we will approximate the matter as the ensemble of the one dimensional charged harmonic oscillators of natural frequency ω_0 immersed in the *zero-point field.* For orientation along the x axis the (nonrelativistic) equation of motion for a particle of mass m and charge e, including damping is given by [3]

$$m\frac{d^2x}{dt^2} + m\omega_0^2 x = \left(\frac{e^2}{6\pi\epsilon_0 c^3}\right)\frac{d^3x}{dt^3} + eE_x^{\mathrm{zt}}(0,t), \tag{2}$$

where e is the charge on electron, c is the light velocity and ϵ_0 is the electrical permittivity of the vacuum.

Substitution of formula (1) to formula (2) gives the following expression for displacement and velocity:

$$\begin{aligned} x &= \frac{e}{m}\mathrm{Re}\sum_{\delta=1}^{2}\int d^3k(\hat{\epsilon}\cdot\hat{x})\left(\frac{\hbar\omega}{8\pi^3\epsilon_0}\right)^{1/2}\frac{1}{D}\times e^{i\vec{k}\vec{r}-i\omega t+i\Theta(k,\delta)}, \\ v &= \frac{dx}{dt} = \frac{e}{m}\mathrm{Re}\sum_{\delta=1}^{2}\int d^3k(\hat{\epsilon}\cdot\hat{x})\left(\frac{\hbar\omega}{8\pi^3\epsilon_0}\right)^{1/2}\times\left(-\frac{i\omega}{D}\right)e^{i\vec{k}\vec{r}-i\omega t+i\Theta(k,\delta)}, \end{aligned} \tag{3}$$

where

$$\begin{aligned} D &= -\omega^2 + \omega_0^2 - i\Gamma\omega^3, \\ \Gamma &= \frac{e^2}{6\pi\epsilon_0 mc^3}. \end{aligned} \tag{4}$$

From (1) and (3) the average power absorbed by oscillator from ZPF can be calculated [3], viz.:

$$\langle P^{\mathrm{abs}}\rangle = \langle eE^{\mathrm{zp}}\cdot\vec{v}\rangle = \frac{e^2\hbar\omega_0^3}{12\pi\epsilon_0 mc^3}. \tag{5}$$

We now recognize that for "planetary" motion of electrons in the atom the ground state circular orbit of radius r_0 constitutes a pair of one dimensional harmonic oscillator in a plane

$$\begin{aligned} x &= r_0 \cos \omega_0 t, \\ y &= r_0 \sin \omega_0 t. \end{aligned} \tag{6}$$

Therefore the power absorbed from the background by the electron in circular orbit is double of (5) or

$$\langle P^{\text{abs}} \rangle_{\text{circ}} = \frac{e^2 \hbar \omega_0^3}{6\pi\epsilon_0 m c^3}. \tag{7}$$

The power radiated by charged particle in circular orbit with acceleration A is given by the expression [6]

$$\langle P^{\text{rad}} \rangle_{\text{circ}} = \frac{e^2 A^2}{6\pi\epsilon_0 c^3} = \frac{e^2 r_0^2 \omega_0^4}{6\pi\epsilon_0 c^3}. \tag{8}$$

3 Quantum heat transport equation in the presence of ZPF

In monograph [5] the quantum heat transport equation for electrons in matter was formulated:

$$\frac{\lambda_B}{v_h} \frac{\partial^2 T^e}{\partial t^2} + \frac{\lambda_B}{\lambda_m} \frac{\partial T}{\partial t} = \frac{\hbar}{m_e} \nabla^2 T. \tag{9}$$

In Eq. (9) T is the temperature, λ_B and λ_m are the reduced de Broglie wavelength and mean free path (for electron) respectively

$$\lambda_B = \frac{\hbar}{p}, \qquad \lambda_m = v\tau, \tag{10}$$

where v is the electron velocity and τ is the relaxation time for electrons.

In the following we will study the quantum limit of the heat transport in the fermionic system [5]. We define the quantum heat transport limit as follows

$$\lambda_B = \lambda_m. \tag{11}$$

In that case Eq. (9) have the form

$$\tau \frac{\partial^2 T}{\partial t^2} + \frac{\partial T}{\partial t} = \frac{\hbar}{m} \nabla^2 T, \tag{12}$$

where

$$\tau = \frac{\hbar}{m_e v^2}. \tag{13}$$

Having the relaxation time τ one can define the pulsation ω [5]

$$\omega = \tau^{-1} = \frac{mv^2}{\hbar}. \tag{14}$$

For an electron in atom, $\omega = \omega_0$ (formula (6)) i.e.

$$\omega_0 = \frac{mv^2}{\hbar}. \tag{15}$$

Considering that for circular orbit $v = \omega_0 r_0$, formula (15) gives

$$r_0^2 = \frac{\hbar}{m\omega_0}. \tag{16}$$

Substituting formula (16) to formula (8) one obtains

$$\langle P^{\rm rad} \rangle_{\rm circ} = \frac{e^2 \hbar \omega_0^3}{6\pi\epsilon_0 mc^3} = \langle P^{\rm abs} \rangle_{\rm circ}. \tag{17}$$

We conclude that in the SED framework the QHT equation (12) describes the heat transport on the atomic level where the τ is the relaxation time for the electron-*zero point field* interaction. It is quite interesting to observe that formula (15) is the Bohr formula for the ground state of hydrogen atom. It means that the ground state of the hydrogen atom is the result of the balance between radiation emitted due to acceleration of the electron and radiation absorbed from the zero-point background. For the first time the balance between two forms of radiation in hydrogen atom was hypothesed by Boyer [7].

4 Conclusion

In this paper, the quantum heat transport (QHT), formulated in our monograph, was considered in the framework of stochastic electrodynamics (SED). It was shown that the structure of QHT on the atomic level reflects the fact that the energy radiated by the accelerated charged particle in circular motion equals the energy absorbed from the *zero-point field.* It means that hypothetical ZPF is as real as the real are atoms, i.e. matter.

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