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Particles and quantum waves diffusion in physical vacuum

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A B S T R A C T

The new quantum waves' diffusion equation based on Heisenberg uncertainties and De Broglie's frequencies of waves is presented. The free movement and quantum diffusion through a rectangular barrier are considered. We find a quantum diffusion coefficient and radii of bound systems. The obtained formula connecting radii and bound energies of simple quantum systems, such as a hydrogen atom, deuteron and mesons, consisted of quarks.

Introduction

Usually, in quantum mechanical investigations of properties of elementary particle systems are provided. Only the quantum field theory of interaction of real particles with virtual particles and antiparticles represents different fields in physical vacuum. Using quantum field interaction with particles we can include generation of particles and antiparticles, and also reactions which can be investigated experimentally. According to Sokolov and Tumanov [1], vacuum oscillations of the quantum field require to introduce for electrons the effective radius what can help to explain Lamb shift of atomic levels $2S_{1/2}$ and $2P_{1/2}$ [2] in hydrogen. The vacuum oscillations can spread the dot-electron in some region with the radius R_e proportional to Compton wavelength [1] λ_e and square root of the fine-structure constant α

$$R_e = \sqrt{\alpha}\frac{\hbar}{m_0 c}, \quad \alpha = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{\hbar c} = 7.29735257\cdot 10^{-3}, \quad \lambda_e = \frac{\hbar}{m_0 c} = 2.42\cdot 10^{-10}\,\text{cm}. \tag{1.1}$$

The presented statistical model of quantum mechanics represents an electron's movement inside atom like Brownian particle [3] interacting with fluctuations of electromagnetic vacuum. Taking into consideration that quantum phenomena have a stochastic character, we propose a new equation of quantum waves' diffusion [3] based on Heisenberg uncertainties and de Broglie waves. The link between uncertainties and non-locality [2] holds for all physical theories. Heisenberg observed that quantum mechanics [4] have restrictions of accuracy of incompatible measurements, such as position and momentum whose results cannot be simultaneously predicted. These restrictions are known as uncertainty relations. Applications of these uncertainties mainly to measurements are misleading because they suggest that the restrictions occur only when one makes measurements, but in our case it is not necessary. Taking into consideration the Lamb shift and Eq. (1.1), we can say that the problem is more general than quantum mechanics suggests. The definition of duality of wave-particle and physical parameters by probabilities require modifying the classical Schrödinger equation based on the wave equation and de Broglie waves. We have proposed the quantum equation connecting stochastic quantum diffusion in physical vacuum and de Broglie waves representing a guiding field for direction of moving quantum particles.

Diffusion of quantum waves

We assume that the equation of quantum mechanics diffusion can be derived from the diffusion equation [5]

$$\frac{\partial \psi_J}{\partial t} = D_C\frac{\partial^2 \psi_J}{\partial x^2} \tag{2.1}$$

applied to the wave function

$$\psi_J = Ae^{-i\omega t+\lambda x}. \tag{2.2}$$

In this case, we obtain

$$\lambda^2 = -\frac{i\omega}{D_C}, \quad \lambda_{1,2} = \pm i\sqrt{\frac{\omega}{2D_C}} \mp \sqrt{\frac{\omega}{2D_C}}. \tag{2.3}$$

Requiring that the solution must represent some kind of linearly independent physical ψ_{J1} and nonphysical ψ_{J2} solutions

$$\psi_{J1} = Ae^{-i\omega t+ikx-k|\Delta x|}, \quad \psi_{J2} = Be^{-i\omega t-ikx+k|\Delta x|}, \quad \Delta x \geqslant x - x_n, \quad k = \sqrt{\frac{\omega}{2D_C}}, \quad x_n = n\frac{\lambda}{2} \quad n = 0, 1, 2 \tag{2.4}$$

Free solutions can be presented by introduction [2] of maximum $x = x_0$ or minimum $|x-x_0| = \pi/\Delta k$ of amplitude for a wave pack or the following superposition of quantum oscillations (2.4)

$$\psi_J(x) = Ae^{ikx-k|x-x_0|} + Be^{-ikx+k|x-x_0|}, \tag{2.5}$$

where we can take for the coordinates $x = x_0$ at the maximum $x_{n0\max}$ or

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minimum $x_{n0\min}$ oscillations

$$kx_{n0_{\max}} = n\pi, \quad n = 0, 1, 2... \; |x - x_{n0_{\max}}| = 0, \tag{2.6}$$

$$kx_{n0\min} = (2n+1)\frac{\pi}{2}, \quad n = 0, 1, 2..., \quad k|x_{n0\min} - x_{n0\max}| = \frac{\pi}{2}. \tag{2.7}$$

of the real parts of wave function (2.5). We can represent this wave function in the point x by decreasing oscillations generated in maximum point $x_{n0\max}$. Here we have some train of decreasing waves such as in a wave packet.

Now we will try to consider the spreading wave in x direction

$$\psi_J(x, t) = Ae^{-i\omega t + ikx - k|x - x_0|} = A\exp\left[\frac{i}{\hbar}(-Et + px + ip|x - x_0|)\right] \tag{2.8}$$

This plain wave can be rewritten in the following way as follows

$$\psi_J(x_0, t) = Ae^{-i(\omega \cdot t - kx_0) - k|x_0 - x|} \tag{2.9}$$

which satisfies the simple quantum wave Eq. (2.1)

$$\psi_J(x_0, t) = Ae^{-i(\omega \cdot t - kx_0)} \tag{2.10}$$

when $x = x_0$. We can represent this wave function for the point x_0 by spreading oscillations generated in maximum point (2.6) $x_{n0\max}$ where we can find a moving particle with maximum probability in point x_0. Here we have some train of decreasing waves like in a wave packet where proposed wave function (2.9) can be normalized by integrating probability density $\psi^*\psi$

$$dP = A^2 e^{-2k|x - x_0|} d|x - x_0|, \quad P = 2A^2 \int_0^\infty e^{-2ky} dy = A^2 \frac{1}{k} = 1, \quad A = \sqrt{k}. \tag{2.11}$$

The probability of a freely moving particle to be in interval $d|x - x_0|$ is a proportional to $k = \frac{2\pi}{\lambda}$ which is an important result of the scattering theory in quantum mechanics [2]. If a low energy beam of particles is incident on a sphere with radius $r_0 = d|x - x_0|$, then from (2.11) we obtain $k \cdot r_0 < 1$ or $\hbar k \cdot r_0 < \hbar$. Only partial waves with orbital quantum numbers $l = 0$ take part in interaction with a sphere and freely moving particle represented by wave function (2.9) also located in this region. The velocity of the spreading of these waves can be evaluated requiring

$$-Et + px + ip|x - x_0| = -Et_1 + px_1 + ip|x_1 - x_0| \tag{2.12}$$

of equally complex phases when

$$t_1 = t_0 + \Delta t, \quad x_1 = x_0 + \Delta x. \tag{2.13}$$

Substituting (2.13) in (2.12) we obtain

$$E\Delta t - p\Delta x - ip|\Delta x| = 0. \tag{2.14}$$

For maximum movement $\Delta x_m > 0$ of the waves packet connected with particles generated by quantum diffusion in physical vacuum at wave maximum point x_0, we have $\Delta x_m = \frac{1}{2}\Delta x = \frac{1}{2}|\Delta x|$. Then from the last equation for a nonrelativistic case $E = p^2/2m$, we obtain

$$v_J = \frac{\Delta x_m}{\Delta t} = \frac{2E}{p + ip} = \frac{v}{2}(1 - i). \tag{2.15}$$

Calculating the square of modulus, $v_J^* v_J$, we obtain that quantum diffusion stochastic waves train free spreading

$$v_J^* v_J = \frac{v^2}{2} \tag{2.16}$$

satisfies the conservation of kinetic energy

$$mv_J^* v_J = \frac{mv^2}{2} \tag{2.17}$$

and momentum mv for a freely moving quantum particle with the average velocity v and mass m. From here, we can define an assumption that

$$vt \approx x_{n0\max} = n\frac{\lambda}{2}, \quad |\Delta x_n| = |x - x_{n0\max}| = \left|x - n\frac{\lambda}{2}\right| \tag{2.18}$$

Finding the minimum difference $\Delta x_n = vt - n\frac{\lambda}{2} = x - n\frac{\lambda}{2} < \frac{\lambda}{2}$ from (4.15), we can determine n, $x_{n0\max}$ and $|\Delta x_n|$. Also, the free solutions (2.8) and (2.5) of the quantum diffusion Eq. (2.1) are defined.

From this, for a free space [2], when $\omega = ck$, $E = \hbar\omega$, we can obtain wave function

$$\psi_{J1} = A\exp\left[-i\omega \cdot t + \frac{1}{c\hbar}(iEx - E|\Delta x_n|)\right], \tag{2.19}$$

which include oscillations in physical vacuum. The free particle with mass m moving with velocity v by action of classical forces and quantum forces [6] depending on wave function or in our case on stochastic waves' packet generated in physical vacuum at points $n\frac{\lambda}{2}$ whose maximums of amplitudes are spreading with velocity v.

Comparing a standard formula $E = \frac{k^2\hbar^2}{2m}$ and (2.4)

$$k^2 = \frac{2mE}{\hbar^2} = \frac{\omega}{2D_C}, \quad E = \hbar\omega \tag{2.20}$$

we obtain the quantum stochastic wave diffusion equation [3]

$$\frac{\partial \psi_J}{\partial t} = D_C \frac{\partial^2 \psi_J}{\partial x^2}, \quad D_C = \frac{\hbar}{4m} = \frac{\omega}{2k^2}. \tag{2.21}$$

For free moving particles $k^2 = \frac{2mE}{\hbar^2}$ from the last formula, we obtain the standard nonrelativistic expression

$$E = \hbar\omega = \frac{p^2}{2m}, \quad p = \hbar k. \tag{2.22}$$

From the expression of the quantum diffusion coefficient we can get that a photon is reducible to virtual particles and antiparticles [7]. When an important expressions (2.4), (2.21) are satisfied, a connection with relativistic virtual processes [7] in physical vacuum

$$m = \frac{\hbar k^2}{2\omega} = \frac{h\nu}{2c^2}, \quad h\nu = 2mc^2 \tag{2.23}$$

can be obtained. The last equation shows that a photon can produce both particle and antiparticle with common mass $2m$ or annihilation by virtual processes.We also can obtain the expression of diffusion coefficient D_C from Heisenberg uncertainties for oscillations in physical vacuum [3]

$$2mc \cdot \Delta r = \hbar, \quad 2mc^2 \cdot \Delta t = \hbar, \tag{2.24}$$

$$D_C = \frac{1}{2}\Delta r^2 \frac{1}{\Delta t} = \frac{\hbar}{4m}, \quad \Delta t = D_C \frac{2}{c^2} \tag{2.25}$$

From (2.23) we get

$$\omega\psi_{J1} = \frac{\hbar k^2}{2m}\psi_{J1}. \tag{2.26}$$

Multiplying the last equation for $\hbar$, if de Broglie equation $\lambda = h/p$ is satisfied, we obtain

$$E\psi_{J1} = \frac{p^2}{2m}\psi_{J1}, \; p = \hbar k. \tag{2.27}$$

After introducing operators to wave processes

$$\hat{E} = i\hbar\frac{\partial}{\partial t}, \quad \hat{p} = -i\hbar\nabla \tag{2.28}$$

and including the potential energy $V(r)$ and new functions, depending on wave $\vec{r_v}$ and diffusion $\vec{r_d}$ coordinates

$$\psi_{JS}(\vec{r} = \vec{r_v} + \vec{r_d}) = \psi_{JS}(\vec{r_v}, \vec{r_d}) = \psi_S(\vec{r_v})\psi_J(\vec{r_d}), \tag{2.29}$$

we obtain the Schrodinger equation [1,2] for bound states:

$$i\hbar\frac{\partial \psi_S}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi_S + V(r)\psi_S \tag{2.30}$$

Free solutions (2.4) did not satisfy the Schrödinger equation when $V(r) = 0$ and for a coincidence free solution of (2.5) and (2.30), we must separate the diffusion processes with different diffusion waves'