

From Properties of Virtual Photon to Wave-Particle Duality

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ABSTRACT

The aim of this work is to show that the wave properties of quantum objects are determined by the wave properties of virtual photons created by these objects: in particular, the frequency of the wave function of quantum object equals the frequency of precession of spin of virtual photon created by the quantum object. The quantum objects called as “entangled” are objects having equal and co-oriented frequencies of precession of spin of virtual photons created by these quantum objects.

The quantum correlations between quantum objects are accomplished by spin supercurrent transferring angular momentum (angles of precession and angles of deflection) between precessing spins of virtual photons created by the objects.

The creation of interference pattern by quantum objects passing through a crystal lattice can be a result of existence of two properties of virtual photons: first, the existence of electric and spin components that might interact with the crystal lattice; secondly, these components perform periodic oscillation and the time between two such interactions is a multiple of the oscillation period.

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Introduction

The main experimental data indicating the existence of wave-particle duality is the emergence of interference pattern while passing quantum objects through a crystal lattice similar to those that emerge as a result of passing photons through this crystal lattice (Figure 1) [1].



Figure 1: The interference pattern

One of the first was an experiment by Clinton Davisson and Lester Germer in 1923-27 [2], in which electrons scattered by the surface of a crystal of nickel metal displayed an interference (diffraction) pattern.

It is remarkable that a similar interference pattern was obtained at using of flow of low-energy quantum objects (for example, electrons) in experiments by L.M. Biberman, V.A. Fabricant and N.G. Sushkin in 1949 [3]. In these experiments, the probability of location at least of two electrons in the crystal lattice simultaneously is negligible.

Note: The quantum correlations are not an experimental proof of wave-particle duality as the single wave function for interacting quantum objects is introduced only for explaining the superluminal speed of this process (without contradiction with postulates of Special Relativity).

The similarity of the interference patterns emerging as a result of passing photons through the crystal lattice and as a result of passing quantum objects through crystal lattice indicates the existence of analogy in the properties of photon and quantum object. Let us consider this question in detail.

The emergence of interference pattern as a result of passing photons through a crystal lattice can be caused by two properties of photons: first, the existence of electric, magnetic and spin components that might interact with the crystal lattice; secondly, these components perform periodic oscillation and time interval T_i between interactions of quantum objects with atoms of crystal lattice can satisfy the condition [1]:

$$T_i = n2\pi / \omega_{ph}, n=1,2,3... \quad (1)$$

where ω_{ph} is the photon precession frequency.

Schematic image of photon in a pure state, that is of a circular-polarized photon is presented in Figure 2. The spin S_{ph} of photon is directed transverse to the light velocity \mathbf{c} [4], that is $S_{ph} \perp \mathbf{c}$, and, consequently, it performs a precession motion with the frequency of the photon ω_{ph} . An electric \mathbf{E}_{ph} and magnetic \mathbf{B}_{ph} components of photon perform precession motion as well [5]; β is the angle of deflection (angle between S_{ph} and $-\omega_{ph}$); \mathbf{c} is the velocity of photon.

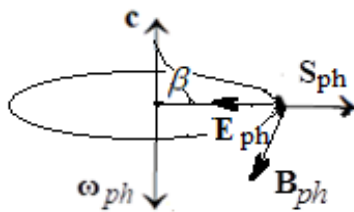


Figure 2: The schema of characteristics of photon: \mathbf{c} is the velocity; ω_{ph} is the frequency of precession of spin S_{ph} ; \mathbf{E}_{ph} and \mathbf{B}_{ph} are, respectively, an electric and magnetic components of photon; β is the angle of deflection.

Let us consider now the properties of quantum object. In 1949, Nobel laureate R. Feynman for the concretization of force fields in his diagrams introduced virtual particles. In particular, electric and magnetic interactions are accomplished by virtual photons consisting of two electric oppositely charged virtual particles [6]. That is, the virtual photon in his diagrams is an electric dipole and, consequently, has an electric dipole moment, $\mathbf{d}_v \neq 0$, and, thus, related to its electric component \mathbf{E}_v .

$$\mathbf{E}_v \uparrow \downarrow \mathbf{d}_v. \quad (2)$$

The virtual photon is created in the area whose size δ_v equals wavelength λ_q of quantum object creating the virtual photon:

$$\delta_v = \lambda_q. \quad (3)$$

According to the hypothesis of Feynman, the properties of virtual photon are similar in many ways to the properties of photon transferring electromagnetic interaction as well: it has spin S_v precessing with frequency ω_v , the angles of precession α and deflection β . That is, a virtual photon, similar to photon, is a spin vortex in the physical vacuum characterized by “zero-point energy” [7], i.e. having an internal angular momentum [8]. The following takes place in a spin vortex [8]:

$$\mathbf{E}_v \uparrow \downarrow \mathbf{S}_v. \quad (4)$$

The schematic image of characteristics of virtual photons created by negative electric charged quantum objects is given in Figure 3. The spin S_v precesses with frequency ω_v ; α is the precession angle; r.l. are reference lines; \mathbf{E}_v is the electric component of virtual photon connected with electric dipole moment \mathbf{d}_v ; β is the angle between S_v and $-\omega_v$ (deflection angle); \mathbf{u} is the velocity of quantum object creating the virtual photon.

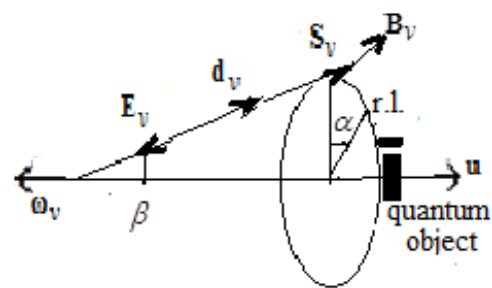


Figure 3: The schematic image of characteristics of virtual photon created by negative electric charged quantum object. β is the deflection angle; ω_v is the precession frequency; α is the precession angle; r.l. is a reference line; S_v is spin; \mathbf{d}_v is the electric dipole moment; \mathbf{u} is the velocity of quantum object; \mathbf{E}_v is the electric component.

As follows from Figure 3, the passing of virtual photons created by quantum objects through a crystal lattice can cause the emergence of interference pattern as a result of existence of two properties of virtual photons: first, the existence of electric and spin components, Eqs (2) and (4), that might interact with the crystal lattice; secondly, these components perform periodic oscillation and time interval T_i between interactions of quantum objects with atoms of crystal lattice can satisfy the condition analogous to condition (1):

$$T_i = n2\pi / \omega_v, n=1,2,3... \quad (5)$$

Thus, the wave properties of quantum objects are a consequence of creating virtual photons by these quantum objects.

It should be noted that the conclusion is in accordance with the assumption of de Broglie that the wave properties of particles are analogous to similar properties of the photon [9] and with the Feynman hypothesis that the properties of virtual photon are similar to the properties of photon spreading the electromagnetic interaction as well [6]. Consequently, the wave properties of quantum object are the wave properties of virtual photon created by the quantum object. That is, the frequency ω_v of precession of spin S_v , angle of precession α , size λ_v of virtual photon (as of electric dipole) respectively equal to the frequency, phase and wavelength of the wave function of the quantum object creating the virtual photon. Thus, the wave properties of quantum object are a consequence of precession motion of spin of virtual photon created by the quantum object and the consequence can be described by the following system of equations [8]:

$$\left. \begin{aligned} (S_v \sin \beta)_y &= (S_v \sin \beta)_0 \exp(i\omega_v t - i\mathbf{x} / (2\lambda_q)) \\ (S_v \sin \beta)_z &= in(S_v \sin \beta)_0 \exp(i\omega_v t - i\mathbf{x} / (2\lambda_q)) \end{aligned} \right\},$$

where \mathbf{x} , \mathbf{y} , \mathbf{z} are Cartesian coordinates; $n=1$ at $\omega_v \uparrow \uparrow \mathbf{u}$; $n=-1$ at $\omega_v \uparrow \downarrow \mathbf{u}$; and β is the angle of deflection (see Figure 3). The angle of precession of spin, $\alpha = \omega_v t$, is responsible for the phase of the wave function of the quantum object.

The creation of virtual photon allows us not only to describe the corpuscular-wave dualism but to explain the physical phenomena known as “quantum correlations” as well. It is shown in Section 2 that quantum correlations between quantum objects are accomplished by the process transferring angular momentum (angles of precession, angles of deflection) between virtual photons created by the quantum objects.

The first works introducing the process of transfer of angular momentum in descriptions of physical phenomena were works by J. C. Maxwell describing a model of luminiferous ether in 1861-1873 [10- 11].

In hundred years, the investigation of the process of transfer of angular momentum was continued (with taking into account the quantum object characteristic discovered in the 20th century - spin) by M. Vuorio [12], in his experiments this process was called “long transport of spin polarization”. In the following years the process was studied in experiments with superfluid $^3\text{He-B}$ by A. Borovic-Romanov, Yu. Bunkov, V. Dmitriev, I. Fomin, et al [13-15]; in the latter investigations the process of transfer of angular momentum is called “spin supercurrent”. (It should be noted that Bunkov, Dmitriev, and Fomin were awarded the Fritz London Memorial Prize in 2008 for the studies of spin supercurrents in superfluid $^3\text{He-B}$.) The main properties of spin supercurrent are the superluminal speed, independence from electromagnetic shielding, slight dissipation; for more details see Section 2.1.

2. The Quantum Correlation

2.1. The properties of spin supercurrent

Let us consider the main properties of spin supercurrent J_z emerging between virtual photons, using as an example two virtual photons with uniformly oriented (along axis \mathbf{z}) frequencies of precession $(\omega_v)_1$ and $(\omega_v)_2$, α_1 and α_2 are precession angles determined from reference lines (r.l.); β_1 and β_2 are deflection angles; S_v are spins.

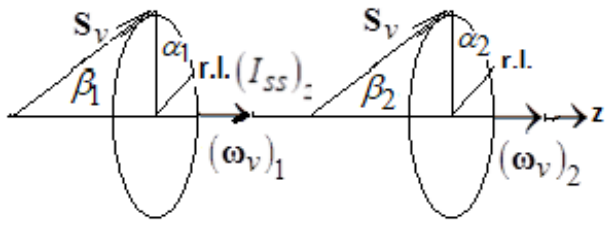


Figure 4: Schematic images of two virtual photons with the following characteristics: β_1 and β_2 are deflection angles; $(\omega_v)_1$ and $(\omega_v)_2$ are precession frequencies oriented along axis z ; α_1 and α_2 are precession angles; r.l. are reference lines; \mathbf{S}_v are spins, J_z is a spin supercurrent.

1) The spin supercurrent tends to equalize the values of respective characteristics of spins of interacting virtual photons: angles (phases) of precession and angles of deflection. For example, the value of spin supercurrent J_z in the direction of orientation of precession frequencies (axis z) of spins \mathbf{S}_v is determined as follows:

$$J_z = -g_1(\alpha_2 - \alpha_1) - g_2(\beta_2 - \beta_1), \quad (6)$$

where $g_1 > 0$ and $g_2 > 0$ are coefficients depending on deflection angles and the properties of the medium where spin supercurrent emerges.

2) As a result of the action of spin supercurrent, according to its definition as transforming angular momentum, at arbitrary moment t the following holds:

$$|\alpha_1 - \alpha_2| \geq |\alpha'_1 - \alpha'_2|, \quad (7)$$

$$|\beta_1 - \beta_2| \geq |\beta'_1 - \beta'_2|, \quad (8)$$

where: α'_1 and α'_2 are respectively the values of precession angles α_1 and α_2 of precessing spins of interacting virtual photons after the action of spin

supercurrent; β'_1 and β'_2 are respectively the values of deflection angles β_1 and β_2 of precessing spins of interacting virtual photons after the action of spin supercurrent. Let us assume that before the action of spin supercurrent at time t the angles of precession α_1 and α_2 were determined as $\alpha_1 = (\omega_v)_1 t + \alpha_{01}$ and $\alpha_2 = (\omega_v)_2 t + \alpha_{02}$, where α_{01} and α_{02} are the values of angles of precession respectively α_1 and α_2 at $t=0$. If $\alpha_{01} = \alpha_{02} = 0$, then we have:

$$\alpha_1 - \alpha_2 = ((\omega_v)_1 - (\omega_v)_2)t. \quad (9)$$

It follows from Eq. (7):

$$((\omega_v)_1 - (\omega_v)_2) \geq ((\omega'_v)_1 - (\omega'_v)_2), \quad (10)$$

where $(\omega'_v)_1$ and $(\omega'_v)_2$ are the values of spin precession frequencies $(\omega_v)_1$ and $(\omega_v)_2$ after the action of spin supercurrent.

3) Spin supercurrent is not an electric or magnetic process and consequently it is not shielded by electromagnetic screens.

4) It is not discovered that the effectivity of action of spin supercurrent between interacting objects depends on the distance between them. For example, the action of spin supercurrent in superfluid $^3\text{He-B}$ is limited only by the volume of superfluid.

5) At a definite nonzero difference in the values of angles of precession $\Delta\alpha_c = \alpha_1 - \alpha_2$ a phase slippage, that is, the drop in the value and change in the sign of spin supercurrent J_z may take place (see Figure 5). With taking into account Eq. (9), $\Delta\alpha_c$ can be determined as:

$$\Delta\alpha_c = \alpha_1 - \alpha_2 = ((\omega_v)_1 - (\omega_v)_2)t = \Delta\omega_v \cdot t. \quad (11)$$

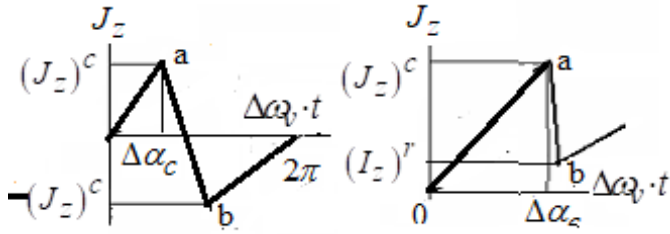


Figure 5: The variants of character of the dependence of the spin supercurrent I_z between two virtual photons on the hypothetical difference in the precession angles $\Delta\alpha_\nu \cdot t$ (respectively, with a change in sign and without change in sign of spin supercurrent). $(I_z)^c$ is the critical spin supercurrent, $(I_z)^r$ is the residual current. The line a–b corresponds to the phase slippage at phase difference $\Delta\alpha_c$.

In the case of phase slippage, Eq. (6) does not hold. Taking into account that, according to Eq. (6), the action of spin supercurrent is effective at $(\omega_\nu)_1 \uparrow \uparrow (\omega_\nu)_2$ and that, according to Eq. (11), the phase slippage is absent at $\Delta\alpha_\nu = 0$, the interaction of virtual photons will be effective at condition:

$$\Delta\omega_\nu = 0. \quad (12)$$

6) In experiments with superfluid $^3\text{He-B}$, the spin supercurrent equalizes the parameters of the wave function of superfluid $^3\text{He-B}$ [13-15], consequently, theoretically spin supercurrent must possess the following properties: the absence of dissipation and infinite speed. In reality, spin supercurrent must have slight dissipation and superluminal speed y_{SS} that is:

$$y_{SS} \gg c. \quad (13)$$

7) It should be noted that in case of slight dissipation the sum of angles of precession and sum of angles of deflection of interacting photons (or virtual photons) does not change during the action of this current. That is, Eqs. (7)-(8) can be presented in the form:

$$\alpha_1 + \alpha_2 = \alpha'_1 + \alpha'_2, \quad (14)$$

$$\beta_1 + \beta_2 = \beta'_1 + \beta'_2. \quad (15)$$

2.2. Results of experiments with quantum correlations

Quantum correlations belong to the category of phenomena that are collectively called “quantum non-locality”. The essence of the phenomenon can be described using the following example. Let two quantum objects (Figure 6) a and b , which are emitted by the same source and have the same wave function at the initial moment of time, move in different directions.

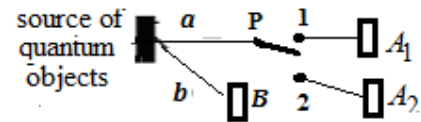


Figure 6: Schematic diagram of the experiment that illustrates the quantum correlations between quantum objects. a and b are quantum objects; A_1 , A_2 , and B are detectors; and P is a switch with positions 1 and 2.

Object a is directed, depending on the position (1 or 2) of switch P , towards either detector A_1 or detector A_2 (these detectors have different characteristics), while object b is directed towards detector B . According to the postulates of quantum mechanics and experimental data, the properties of object b being detected will depend on which detector detects a .

Let us consider the properties of quantum correlations and compare them with the properties of spin supercurrent [8, 16].

1) Correlations take place between quantum objects of zero or non-zero rest mass.

Both types of objects produce spin vortices (photons or virtual photons) in a physical vacuum and consequently are characterized by angular momentum. According to the first property of spin supercurrent (Eqs (6)-(8) and (10)), this current can emerge in this case.

Note: It follows from this supposition that quantum correlations cannot take place between quantum objects producing groups of spin vortices with total zero spin in the physical vacuum. For example, there will be no quantum correlations in superconductors between Cooper pairs because the total spin of the

virtual photons created by the quantum objects, constituting the Cooper pair, equals zero [8].

2) Correlations take place between quantum objects not only at the moment of simultaneous registration of the objects.

Experimentally, it is verified that correlations between two quantum objects can take place when one quantum object is detected and another quantum object is still in the physical vacuum [17]. It can mean that the quantum correlations are not a result of interaction of source and detector of quantum objects. They are a result of interaction of quantum objects.

3) It follows from experiments that quantum correlations are of non-electric and non-magnetic nature.

This property is in accordance with property 3 of the spin supercurrent: the spin supercurrent is not screened by electromagnetic screens.

4) Correlations take place independent of the distance between the interacting spin structures [18, 19].

This property is in accordance with property 4 of the spin supercurrent.

5) It is known in quantum mechanics that effective quantum correlations are possible between so called “entangled” quantum objects. These objects have equal frequency of their wave function. According to experimental data, “entangled” objects can be quantum objects generated in an atomic cascade or photons of the same frequency emitted by the same or different sources and not having crossed polarization [20].

It should be noted that the properties of “entangled” quantum objects satisfy conditions of effective action of spin supercurrent between virtual photons: Eq. (12) (the property 5 of spin supercurrent).

6) The possibility of correlations of photons separated in space and simultaneously emitted indicates that the speed of quantum correlations is greater than the speed of light. Experiments exist [21] in which it is shown that the speed of quantum correlations is greater by a factor of 10^4 than the speed of light.

This property is in accordance with property 6 of the spin supercurrent: condition (13).

7) The two-photons interference with “initial values” of phases (angles of precession of photons spins) x_1 and x_2 [20] can be a result of appearance at the output of experimental setup of photons with phases y_1 and y_2 obeying the condition $x_1 + x_2 = y_1 + y_2$. This condition is in accordance with property 7, Eqs (14)-(15), of spin supercurrent. That is two-photons interference can be accomplished by spin supercurrent.

Thus, the characteristics of the spin supercurrents emerging between virtual photons created by quantum objects describe the properties (observed in experiments) of quantum correlations between these quantum objects.

3. The Force Interaction of Virtual Photon with Crystal Lattice

As was pointed in Introduction, one of the conditions of formation of interference pattern by virtual photons created by quantum objects passing through a crystal lattice is a possibility of force interaction of the virtual photons with atoms of the crystal lattice. According to Feynman’s model, the virtual photon consists of two electric oppositely charged virtual particles, and, consequently, it has electric dipole moment \mathbf{d}_v and related to its electric component \mathbf{E}_v (Eq. (2)). Thus, the electric interaction of virtual photons with atoms of the crystal lattice is possible. The validity of the Feynman supposition about the existence of virtual photon electric dipole moment is proved by possibility of explanation on this basis of spin-orbit interaction of electron in an atom and the Casimir effect.

Let us consider these phenomena in detail, beginning from the definition of the electric dipole moment of virtual photon.

3.1. Electric dipole moment

By definition, d_v is determined by size δ_v of virtual photon and electric charge q_v of virtual particle constituting the virtual photon:

$$d_v = q_v \delta_v. \quad (16)$$

In Feynman's model, the virtual photon is created in the area whose size equals wavelength λ_q of wave function of quantum object creating this virtual photon, Eq. (3). In quantum mechanics, λ_q is determined by momentum p_q of quantum object [5]: $\lambda_q = \hbar / p_q$, thus, from Eq. (16) it follows:

$$d_v = q_v \hbar / p_q. \quad (17)$$

Based on the results of experiments conducted by Kaufmann [22] on the deflection of beta-rays emitted by radium, which showed that the mass of the electron m_e is purely of an electromagnetic nature, we assume that the same is valid for the virtual particles that constitute the virtual photon with mass m_v : that is, the following holds: $e / m_e = 2q_v / m_v$ (e is the electric charge of electron). From the latter expression, we obtain the expression for q_v :

$$q_v = em_v / (2m_e). \quad (18)$$

As, according to Feynman's hypothesis, the properties of virtual photon are similar to the properties of photon, the mass of virtual photon m_v will be defined similar to kinetic mass of photon: $m_{ph} = U_{ph} / c^2$, where U_{ph} is photon energy. Consequently, mass of virtual photon will be defined as:

$$m_v = U_q / c^2. \quad (19)$$

where U_q is the energy of quantum object creating the virtual photon. Solving together Eqs (17)-(19) and using expression for magneton of Bohr $\mu_B = e\hbar / (2cm_e)$, we obtain:

$$d_v = \mu_B U_q / (p_q c). \quad (20)$$

If energy U_q of quantum object (with mass m_q and speed u) equals kinetic energy $U_q = m_q u^2 / 2$, then expression (20) is transformed as:

$$d_v = \mu_B u / (2c). \quad (21)$$

Let us prove the validity of Eqs (20)-(21), getting with their help the experimentally tested expression for the spin-orbit interaction of electron in the atom of hydrogen [23] and expression for Casimir force [24-25, 27].

3.2. Spin-orbit interaction

Due to the existence of electric dipole moment \mathbf{d}_v , there is the spin-orbit interaction of quantum object creating the virtual photon with the electric field where the object moves. As an example, let us consider the spin-orbit interaction of electron in the atom of hydrogen. In electric field \mathbf{E}_n of nucleus, moment \mathbf{M}_n acts on \mathbf{d}_v : $\mathbf{M}_n = \mathbf{d}_v \times \mathbf{E}_n$. The expression for \mathbf{M}_n with using Eq. (21), at condition $\mathbf{d}_v \uparrow \uparrow \mathbf{u}$, is the same as for the maximum, experimentally tested value of the spin-orbit interaction energy U_{s-o} of the electron: $(U_{s-o})_{\max} = |\mu_B (\mathbf{u} \times \mathbf{E}_n) / (2c)|$ (the expression was derived by L. Thomas based on the general requirements of relativistic invariance [23]).

3.3. The Casimir effect

The Casimir effect – the existence of attractive force between two parallel uncharged metal plates. The current explanations of the Casimir force are based on taking the energy of the fluctuation of physical vacuum into account. In this section, it will be shown that the force emerges owing to the existence of the electric dipole moment of the virtual photons created by the conduction electrons of these plates.

In Figure 6 there is presented a schematic image of interacting plates. If the total electric dipole moments of the first and the second plates, respectively \mathbf{d}_{p1} and \mathbf{d}_{p2} satisfy the following condition:

$$\mathbf{d}_{p1} \uparrow \downarrow \mathbf{d}_{p2}, \quad (22)$$

and for the distance r_p between the plates the following holds: $\mathbf{r}_p \perp \mathbf{d}_{p1} (\mathbf{d}_{p2})$, then the force of interaction F_{pd} of the plates is determined to be:

$$F_{pd} = 3d_{p1}d_{p2} / r_p^4. \quad (23)$$

The sign of F_{pd} depends on the mutual orientation of vectors \mathbf{d}_{p1} and \mathbf{d}_{p2} : at $\mathbf{d}_{p1} \uparrow \downarrow \mathbf{d}_{p2}$ force F_{pd} is an attractive force (Figure 6(a)). This force has the name: Casimir force [24]. At $\mathbf{d}_{p1} \uparrow \uparrow \mathbf{d}_{p2}$ force F_{pd} is a repulsive force (Figure 6(b)). This force has the name: Casimir-Lifshitz force [25].

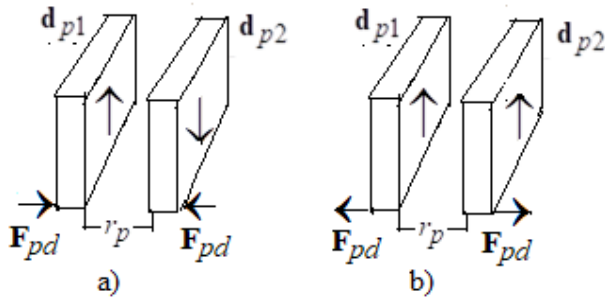


Figure 6: Schematic image of interacting plates. r_p is the distance between plates; \mathbf{d}_{p1} and \mathbf{d}_{p2} are electric dipole moments, respectively, of the first and second plates. The variant (a): \mathbf{F}_{pd} are attractive forces. The variant (b): \mathbf{F}_{pd} are repulsive forces.

Let us estimate the value of \mathbf{F}_{pd} using Eqs (20) and (23). It should be noted that Eq. (23) only applies, if the size of the dipoles is much less than the distance between them. According to Eq. (17), the size of the electric dipole emerging in the spin vortex (virtual photon) created by a quantum object equals its wavelength. For conduction electrons in metals, the wavelength is about $\approx 10^{-7} \text{ cm}$. In the most experiments $r_p \sim 10^{-6} \text{ cm}$. If the total electric dipole moment of either plate can be determined by mere addition of the electric dipole moments of the virtual photons created by individual electrons without the addition of the sizes of the dipoles, then the use of Eq. (23) is quite in order.

Let us consider the plates of the unit area, taking only the electrons present in the ζ thick layer of the plate surface into account. Let us assume that the plates are identical: that is $d_1 = d_2$. We shall make a rather strong assumption that the electric dipole moments of the virtual photons created by the electrons in the ζ thick layer in either plate are oriented in the same direction and, consequently, can be added together as scalar variables. (Note that this assumption is similar to that used in the current explanation of the Casimir force: the energies of all virtual photons in vacuum, which are associated with the conducting plates, are added together.) Then, based on Eqs (20) and (23) we have $F_{pd} = 3 \left(\mu_B U_q \zeta N_0 / (r_p^2 c p_q) \right)^2$, where N_0 is the conduction electron concentration in metals. The

energy of a conduction electron in metals equals the Fermi energy: that is $U_q = \varepsilon_F$. The momentum p_q for the electron is $p_q = \sqrt{2m_e \varepsilon_F}$. Using these relations in the latter expression for F_{pd} we obtain:

$$F_{pd} = \frac{3\mu_B^2 \varepsilon_F}{r_p^4 c^2 2m_e} \zeta^2 N_0^2. \quad (24)$$

The conduction electron concentration in metals N_0 , is of the order of 10^{22} , and the Fermi energy is determined by the following equation: $\varepsilon_F = \hbar^2 (3\pi^2 N_0)^{2/3} / (2m_e)$ [26]. Substituting the right-hand side of the latter equation for ε_F in Eq. (24), as well as substituting the values of all constants and assuming ζ equal to the atom size, that is, $\zeta \approx 10^{-8} \text{ cm}$, we obtain $F_{pd} \approx 4 \cdot 10^{-23} / r_p^4 \text{ (N)}$.

The obtained expression for F_{pd} is very close to the one determining the Casimir force F acting on a unit area of two parallel electrically neutral metallic plates, with the distance between them being not greater than some atomic diameters: $F = \hbar c \pi^2 / (240 r_p^4) \approx 10^{-23} / r_p^4 \text{ (N)}$ [24].

Note: If electric dipole moments \mathbf{d}_{p1} and \mathbf{d}_{p2} of conducting plates satisfy the condition $\mathbf{d}_{p1} \uparrow \rightarrow \mathbf{d}_{p2}$ then moment acts between those plates. This phenomenon is observed in experiments and called “Casimir torque effect” [27].

4. Conclusion

1. The wave properties of quantum objects are determined by the properties of virtual photons created by these objects. The frequency of the wave function of quantum object equals the frequency of precession of spin of virtual photon created by the quantum object. The phase of the wave function of quantum object equals the precession angle of spin of virtual photon created by the object. The wavelength of the wave function of quantum object equals the size of virtual photon (as electric dipole) created by the object.

2. The “entangled” quantum objects are objects having

equal and uniformly oriented frequencies of precession of spin of virtual photons created by these quantum objects.

3. The quantum correlations between quantum objects are accomplished by means of spin supercurrent transferring angular momentum (angles of precession and angles of deflection) between virtual photons created by the objects.

4. The creation of interference pattern by quantum objects after passing through the crystal lattice can be a consequence of interaction of precessing electric dipole moments of virtual photons created by these quantum objects with the atoms of crystal lattice.

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