

Exchange Interaction of Quantum Entities as Interaction of Spin Vortices Created by the Quantum Entities in the Physical Vacuum

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Abstract The aim of this paper is to show that there is a physical process that underlies the exchange interaction of quantum entities. To this end the features of exchange interaction of quantum entities in the following physical phenomena are discussed: the creation of Cooper pairs in superconductors and superfluids, the covalent (molecular) bond, the interaction of light beams. The explanation of the exchange interaction is based on the concept of quantum mechanics according to which the quantum entity that is a singularity in electric and/or magnetic fields produces in the physical vacuum a pair of oppositely charged virtual particles having precessing spin, that is being essentially a spin vortex in the physical vacuum. The analysis of the above mentioned phenomena allows one to suppose that the exchange interaction of quantum entities in these phenomena may be due to interaction of spin vortices created by these quantum entities in the physical vacuum. It is shown also that the interaction of these vortices may be an electric dipole-dipole interaction. The equations describing the electric dipole-dipole interaction of spin vortices are derived in this work. A possibility of influence of the dipole-dipole interaction of spin vortices created by quantum entities that constitute the medium on viscosity of the medium, that is, on its superconductive and superfluid properties is considered.

Keywords: exchange interaction, spin vortex, virtual particles pair, electric dipole moment of spin vortex, spin, frequency of wave function

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1. Introduction

The exchange interaction between quantum entities in terms of wave characteristics is introduced as follows [1]: if the wave frequencies of the entities are equal and the distance between the entities is less than their wavelengths (that is their wave functions overlap in space), then the entities can be described by a single wave function and therefore there is a coherence in their behavior, which, in particular, manifests itself as the exchange interaction. At present, there is no physical explanation determining the nature of forces underlying the exchange interaction.

In this work the physical interpretation of the exchange interaction is discussed. To this end, a number of physical phenomena in which exchange interaction between two quantum entities takes place are considered: the creation of Cooper pairs in superconductors [2] and in superfluid $^3\text{He-B}$ [3], the formation of a covalent (molecular) σ -bond [4], the interaction of light beams. [5] The analysis conducted results, in particular, in the following conclusions about the characteristics of exchange interaction in these physical phenomena. First, the quantum entities constituting a Cooper pair and covalent σ -bond have

oppositely oriented momenta. Secondly, the motion of Cooper pairs in one direction (electric current in superconductors, the motion of superfluid medium, the thermal motion) may result in destroying the Cooper pairs. Thirdly, the exchange interaction takes place between the quantum entities of equal energies, U_q . It means that these entities have the same wave function frequency. [6]

$$\omega_q = U_q / \hbar \quad (1)$$

(\hbar is Planck's constant. For the nonrelativistic quantum entity of nonzero rest mass the frequency ω_q is the frequency of Schrodinger's wave function).

According to postulates of quantum mechanics, the quantum entities that are singularities in electric or magnetic fields produce in the physical vacuum pairs of oppositely charged virtual particles having spin. [7, 8] (The entity is a singularity in electric and/or magnetic fields if it has an electric charge and/or dipole magnetic moment and/or dipole electric moment). The number of physical phenomena explained by the properties of virtual particles pairs created by quantum entities is continuously being increased. Among such phenomena are the van der Waals force between two atoms, Casimir effect (attraction between a pair of electrically neutral metal plates), Lamb

shift of atomic energy levels, the spontaneous emission of a photon during the decay of excited atom or excited nucleus, the so called near-field of radio antennas. [8,9]

Electric properties and properties of spin of virtual particles are the same as those of real particles. Note that spin of real particles has no definite direction and by the magnitude of spin the magnitude of its projection onto a preferential direction is meant: that can be interpreted as a precession of the spin about the preferential direction. Consequently, the precession motion of the virtual particles pair spin may be introduced and thus a virtual particles pair may be considered as a spin vortex in the physical vacuum. According to conclusion of Boldyreva [10], the precession frequency of the vortex spin ω_v equals frequency ω_q of wave function of quantum entity, that is:

$$\omega_q = \omega_v. \quad (2)$$

Thus the equality of energies of quantum entities at the exchange interaction, according to equations (1) and (2), means the equality of precession frequencies of spins of spin vortices that are created by these quantum entities and consequently the possibility of *constant mutual orientation of these precessing spins*. Thus there is a possibility of interaction of spin vortices depending on the mutual orientation of their spins. As the spin vortex is a pair of oppositely charged virtual particles, it is an electric dipole and according to [11,12] the direction of electric dipole moment \mathbf{d}_v of a spin vortex is related to the orientation of its spin \mathbf{S}_v as:

$$\mathbf{d}_v \uparrow \downarrow \mathbf{S}_v. \quad (3)$$

Thus the exchange interaction of quantum entities may be an electric dipole-dipole interaction of spin vortices created by these entities.

The dipole-dipole interaction makes it possible to describe a number of physical phenomena connected with exchange interaction: the creation of Cooper pairs and the formation of a covalent (molecular) σ -bond, the destruction of Cooper pairs in superconducting medium under the electric current higher than the critical value, the destruction of Cooper pairs in a superfluid medium at the speed of its motion higher than the critical speed, and destruction of Cooper pairs at the increase of temperature above the critical one. The equations describing electric dipole-dipole interaction of spin vortices are derived in this work. It follows also from the equations derived that the overlapping of the wave functions of interacting quantum entities increases significantly the energy of electric dipole-dipole interaction of spin vortices created by these quantum entities.

The supposition that the exchange interaction of quantum entities is performed as an interaction of spin vortices created by these quantum entities agrees with that the exchange interaction may take place for photons (for example, the transverse optical force between beams of light [5]); the photon itself being a spin vortex.

Since any quantum entity that is a singularity in electric or magnetic fields produces a spin vortex in the physical vacuum, all quantum entities interact with each other due to dipole-dipole interaction of the vortices, and this interaction contributes to the viscosity of the medium. The Cooper pairing of quantum entities may be one of the

factors that causes a decrease in the viscosity, because the total electric dipole moment of spin vortices created by the quantum entities is equal to zero (the latter takes place independent of the type of Cooper pairing of quantum entities, with total spin of the entities being equal to zero or one). No doubt, this decrease in the viscosity influences the superfluid and/or superconductive properties of the medium.

2. The Experimental Data

2.1. Cooper Pairs in Superconductors

The superconductors contain pairs of electrons (Cooper pairs). [2] The main properties of these pairs are the following.

1) It is more favorable energetically to produce pairs by electrons in s -state with total spin equal to zero and with oppositely directed momenta (accordingly $(\mathbf{p}_1)_e$ and $(\mathbf{p}_2)_e$). That is:

$$(\mathbf{p}_1)_e = -(\mathbf{p}_2)_e. \quad (4)$$

2) The electrons of a pair have equal energies and their speed u (at least in metals) is determined as:

$$u \sim 10^5 \text{ m/s}. \quad (5)$$

3) There exists a critical value of electric current in superconductors at which superconductivity disappears.

4) The superconductivity disappears at increasing the temperature above the critical one.

2.2. Cooper Pairs in Superfluid $^3\text{He-B}$

The Cooper pairs that constitute superfluid $^3\text{He-B}$ consist of ^3He atoms whose nuclei are fermions. [3] The main properties of these pairs are the following.

1) The nuclei form pairs in p -state with total spin equal to one and with oppositely directed momenta (respectively $(\mathbf{p}_1)_n$ and $(\mathbf{p}_2)_n$). That is:

$$(\mathbf{p}_1)_n = -(\mathbf{p}_2)_n. \quad (6)$$

2) The atoms of ^3He that constitute a Cooper pair have equal energies and their speed u is determined as [13]:

$$u \sim 10^2 \text{ m/s}. \quad (7)$$

3) The superfluidity disappears at the critical value of speed of motion of superfluid medium.

4) The superfluidity disappears at increasing the temperature above the critical one.

2.3. Covalent σ -bond

The covalent (molecular) bond provides the formation of a molecule from atoms due to collectivization of electrons of those atoms. [4] Either of interacting atoms provides one electron to form the covalent bond, consequently, two atoms share a pair of electrons. The covalent bond is characterized by the following properties.

1) Electrons can form a connection in s -state (σ -bond), with total spin equal to zero and with oppositely directed momenta (respectively $(\mathbf{p}_1)_\sigma$ and $(\mathbf{p}_2)_\sigma$). That is, we have:

$$(\mathbf{p}_1)_\sigma = -(\mathbf{p}_2)_\sigma. \quad (8)$$

2) Covalent (molecular) bond is formed between atoms of elements, which are similar in their energetic characteristics, e.g. between two atoms of nonmetals or between two atoms of metals.

3) There is considerable overlapping of wave functions of electrons. For example, for hydrogen atom (electron's energy is 13.6eV) the electron wavelength λ_q is 0.44\AA ; at the same time the size a of electron pair in σ -bond (the most robust bond for the hydrogen molecule) equals 0.6\AA . That is,

$$2\lambda_q / a \approx 1.5. \quad (9)$$

The speed of electrons in σ -bond is determined as:

$$u \sim 2 \cdot 10^6 \text{ m/s}. \quad (10)$$

2.4. The Interaction between Beams of Light

As was shown by experimental data, there is a so-called transverse optical force between parallel beams of light of the same frequency: the beams of light displaced in phase are repulsive; the beams of the same phase are attractive [5].

2.5. Analysis of Experimental Data

Let us determine the common properties of physical phenomena discussed in Section 2.

I. All the objects involved in the exchange interactions are quantum entities.

Any quantum entity which is a singularity in electric and/or magnetic fields creates a pair of oppositely charged virtual particles (spin vortex) in the region whose size is of the order of magnitude of the wavelength λ_q of the quantum entity [7,8], λ_q being determined [6] by momentum p_q of the quantum entity as:

$$\lambda_q = \hbar / p_q. \quad (11)$$

II. The quantum entities involved in exchange interaction have the same energy. Consequently, according to equations (1) and (2), they create spin vortices of equal spin precession frequencies. That is, the difference between the spin precession frequencies, $\Delta\omega_v$, of these vortices is equal to zero:

$$\Delta\omega_v = 0. \quad (12)$$

The equality of the precession frequencies means that spins of virtual particles pairs created by quantum entities may have a *constant mutual orientation*.

III. According to equations (4), (6) and (8), the quantum entities that constitute Cooper pairs and covalent σ -bond have equal and oppositely directed momenta;

we shall generally denote them as $(p_q)_1$ and $(p_q)_2$, that is:

$$(\mathbf{p}_q)_1 = -(\mathbf{p}_q)_2 \quad (13)$$

IV. The following takes place: the destruction of Cooper pairs in a superconductive medium under the electric current greater than the critical one; also in a superfluid medium at its motion at a speed greater than the critical speed and at thermal motion at increasing the temperature greater than the critical value.

The common property for all mentioned cases is the following: the motion of quantum entities constituting the Cooper pair in the same direction. That is, in all these cases the equality (13) does not hold.

3. The Interactions between Spin Vortices Depending on Mutual Orientation of Spins of These Spin Vortices

3.1. Pseudomagnetism

Let us consider the following phenomena.

– At motion of neutrons and protons in a substance with polarized spins of nuclei and at motion of electrons in a substance with polarized spins of substance's electrons, a precession of spins of moving quantum entities relative to the direction of substance's spin polarization takes place. The magnetic field does not affect this interaction and its energy exceeds more than thousand times the energy of magnetic interaction. This interaction is called a pseudomagnetic interaction. [14,15]

– Ferromagnetism is caused by the formation of domains with spins of electrons oriented in one direction. The studies have shown that the ordered orientation of spins in domains is due to a specific type of interaction (in [15] this interaction is referred to as pseudomagnetism, in [16] as exchange interaction). The energy of this interaction between electrons may be thousand times greater than the energy of magnetic interaction between them.

– In passing light through a magnetized medium (that is, through a medium with oriented spins) light polarization twisting may take place. In this case, in contrast to natural optical activity, the sign of rotation angle does not depend on the direction of propagation of light (along the magnetization or against). This phenomenon is called the Faraday effect and it is not a magnetic effect. [17] It is supposed that the Faraday effect is caused by pseudomagnetic interaction between spins of photons, on the one hand, and oriented spins of the medium through which the light passes, on the other hand. [15]

3.2. Spin Supercurrent

Spin supercurrent was discovered in experiments with superfluid $^3\text{He-B}$. The spin supercurrent arises between regions with identically oriented and coherently precessing spins of ^3He atoms. [18] The value of the spin supercurrent is determined by the difference between the precession angles (phases) and/or between the deflection

angles of precessing spins of atoms between which it emerges. The action of this supercurrent results in equalizing of the respective characteristics of spins of their atoms. One of the arguments in favor of possibility of the emergence of spin supercurrents not only between quantum entities but between photons as well (that is between spin vortices that constitute photons) is the existence of correlation of phases of spatially separated (some kilometers) photons of the same frequency. [19] In [10] this correlation is accounted for by emergence of spin supercurrents between spin vortices that constitute interacting photons.

It should be noted that in all above considered phenomena (see sections 3.1 and 3.2) the interaction of quantum entities appears as a moment acting on spins of these entities. At the same time the exchange interaction appears in general as a force action. Consequently, we need to consider a different nature (not pseudomagnetism and not spin supercurrents) of exchange interaction.

According to equation (3), the spin vortex (a pair of oppositely charged virtual particles) created by a quantum entity is an electric dipole and the direction of electric dipole moment \mathbf{d}_v of spin vortex is related to the orientation of its spin \mathbf{S}_v . Consequently, the electric dipole-dipole interaction of spin vortices may be as well an interaction depending on the mutual orientation of their spins. Thus the exchange interaction of quantum entities may be an electric dipole-dipole interaction of spin vortices created by these entities.

Note. It is noteworthy that in a discussion in 1930 of covalent bond F. London introduced an intermolecular electric dipole interaction, the so-called London Dispersion Force (LDF). London supposed that it is a weak intermolecular force arising from quantum-induced instantaneous polarization multipoles in molecules. [20]

3.3. The Electric Dipole-dipole Interaction

3.3.1. The Electric Dipole Moment of Spin Vortex

Taking into account that the size of a spin vortex equals the wavelength λ_q of the quantum entity that creates this pair, the electric dipole moment \mathbf{d}_v of the spin vortices may be determined [21] as:

$$d_v = q_v \lambda_q, \quad (14)$$

where q_v is the charge of virtual particle that constitutes the spin vortex. For determining q_v of virtual particle we assume that the specific charge of the virtual particle produced by an electron or positron is equal to the specific electron charge (note that the experiments conducted by W. Kaufmann on deflection of beta-rays emitted by radium make one believe that the mass of electron is purely of electromagnetic nature [22]), that is,

$$e / m_e = 2q_v / m_v, \quad (15)$$

where e and m_e are the electric charge and mass of electron, respectively; factor 2 in the right-hand side of the equation is due to the fact that the mass m_v is the mass of

the spin vortex, that is of the whole virtual particles pair but not only one virtual particle. Let us determine m_v , similar to defining the mass m_{ph} of spin vortex that constitutes the photon ($m_{ph} = U_{ph} / c^2$, where U_{ph} is the photon energy, c is the speed of light [12]), as $m_v = U_q / c^2$. Then, using the expression for the Bohr magneton $\mu_B = e \cdot \hbar / (2 \cdot m_e c)$, we obtain from equation (15):

$$q_v = \frac{\mu_B \cdot U_q}{\hbar \cdot c}. \quad (16)$$

Using equations (11) and (16) in equation (14) we obtain for electric dipole moment d_v of electron:

$$d_v = \frac{\mu_B \cdot U_q}{c \cdot p_q}. \quad (17)$$

Let us prove the validity of expression for \mathbf{d}_v , using as an example the electric dipole moment of spin vortex created by electron of hydrogen atom. The energy of electron in a hydrogen atom equals its kinetic energy (i.e. $U_q = m_e \cdot u^2 / 2$, and besides, $p_e = m_e u$, where u is the electron speed). In this case, the equation (17) can be rewritten as:

$$d_v = \frac{\mu_B \cdot u}{2 \cdot c}. \quad (18)$$

In the electric field \mathbf{E} a moment \mathbf{M} will act on the spin vortex as on electric dipole [21]:

$$\mathbf{M} = \mathbf{d}_v \times \mathbf{E}. \quad (19)$$

If for the virtual particles pair created by electron moving at speed

$$u \ll c \quad (20)$$

(as it takes place in a hydrogen atom: $u \sim 10^6$ m/s), it holds that [12]

$$\mathbf{d}_v \uparrow \uparrow \mathbf{u}, \quad (21)$$

then from equations (18)-(19) and also (21) it follows that the moment acting on the spin vortex created by electron of hydrogen atom is determined as: $\mathbf{M} = \frac{\mu_B}{2 \cdot c} (\mathbf{u} \times \mathbf{E})$.

The right side of expression for \mathbf{M} is the same as that for maximum value of the spin-orbit interaction energy U_{s-o} of the electron in a hydrogen atom:

$$(U_{s-o})_{\max} = \left| \frac{\mu_B}{2 \cdot c} (\mathbf{u} \times \mathbf{E}) \right|. \quad (\text{The obtained expression for}$$

$(U_{s-o})_{\max}$ coincides with the expression for the energy of electron in a hydrogen atom derived by L. Thomas with due account of general requirements of relativistic invariance [23]). One may consider this coincidence as a proof of validity of expression (17).

3.3.2. The Force of Dipole-dipole Interactions of Spin Vortices

Let us consider interaction of two spin vortices created by electrons of equal energies, respectively $(U_q)_1$ and $(U_q)_2$, and equal but oppositely directed momenta, respectively $(\mathbf{p}_q)_1$ and $(\mathbf{p}_q)_2$. According to Eqs. (1)-(2), (11), (17) and (21), these equalities mean the following for electric dipole moments (respectively $(\mathbf{d}_v)_1$ and $(\mathbf{d}_v)_2$) of the virtual particles pairs (spin vortices):

$$(\mathbf{d}_v)_1 = -(\mathbf{d}_v)_2. \quad (22)$$

In this case, an attractive force acts between electric dipoles. [19]

The characteristics of virtual particles pairs in this case are given in Figure 1: L is the distance between the virtual particles pairs; q_v is the electric charge of a virtual particle; λ_q is the wavelength of quantum entity; $(\mathbf{d}_v)_1$ and $(\mathbf{d}_v)_2$ are electric dipole moments of the pairs; \mathbf{F}_1 and \mathbf{F}_2 are forces acting on each virtual particle in pairs; \mathbf{F}_r is the resulting attractive force acting on a pair.

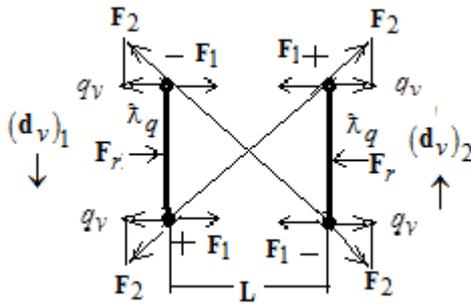


Figure 1. The characteristics and mutual orientation of virtual particles pairs that constitute two spin vortices

L is the distance between pairs; q_v is the electric charge of a virtual particle, \mathbf{F}_1 and \mathbf{F}_2 are forces acting on each virtual particle; λ_q is the wavelength of quantum entity; $(\mathbf{d}_v)_1$ and $(\mathbf{d}_v)_2$ are electric dipole moments of the pairs. \mathbf{F}_r is the resulting attractive force acting on a pair.

Taking into account condition (22), force F_r is expressed as: $F_r = 2 \left(F_1 - F_2 \cdot L / \sqrt{L^2 + \lambda_q^2} \right)$, where F_1 and F_2 are determined respectively as: $F_1 = k \cdot q_v^2 / L^2$ and $F_2 = k \cdot q_v^2 / (L^2 + \lambda_q^2)$ (k is a proportionality factor, in the CGSE system of units $k=1$). Using expression for F_1 and F_2 in F_r we obtain:

$$F_r = \frac{2 \cdot k \cdot q_v^2}{L^2} \left(1 - \frac{1}{(1 + \lambda_q^2 / L^2)^{3/2}} \right). \quad (23)$$

If $L \ll \lambda_q$, the Eq. (23) with due account of Eq. (16) takes the form:

$$F_r = \frac{2k \mu_B^2 U_q^2}{\hbar^2 c^2 L^2}. \quad (24)$$

If $L \gg \lambda_q$, the equation (23) with an accuracy of $(\lambda_q / L)^2$ with regard for Eqs. (11) and (16) may be written as:

$$F_r = \frac{3k \mu_B^2 U_q^2}{p_q^2 c^2 L^4}. \quad (25)$$

4. The Dipole-dipole Electric Interaction Between Spin Vortices Created by Quantum Entities that Take Part in Exchange Interaction

4.1. The Energy of Interaction

According to Eqs. (5), (7) and (10), speed u of the quantum entities constituting Cooper pairs or covalent σ -bond is much less than the speed of light, that is condition (20) holds true. The quantum entities constituting a Cooper pair as well as those constituting a covalent (molecular) σ -bond have equal energies. Consequently, taking into account equations (13), (17) and also (20)-(21), for electric dipole moments $(\mathbf{d}_v)_1$ and $(\mathbf{d}_v)_2$ of spin vortices created by quantum entities of pair as well as by those that constitute σ -bond the equality (22) holds. Thus attractive force F_r between spin vortices created by these entities is determined by Eq. (23).

Let us consider the condition under which the energy (associated with force F_r) of electric dipole-dipole interaction of the spin vortices may have the same order of magnitude as the energy of exchange interaction of quantum entities creating these spin vortices. As an example, the interaction of electrons constituting σ -bond in a hydrogen molecule (see Section 2.3) is considered. As a quantum entity creates a spin vortex in the area whose size equals the wavelength λ_q of this quantum entity, the equality (9) means that spin vortices created by electrons that constitute σ -bond overlap in space. It follows from condition (9) that distance L between spin vortices created by these electrons satisfies the condition: $L < \lambda_q$. Consequently, in determining force F_r it is necessary to use Eq. (24). Then energy W_r associated with force F_r may be determined by expression $W_r = 2k \mu_B^2 U_q^2 / (\hbar^2 c^2 L)$. Using the value of energy U_q from Section 2.3, we obtain that W_r equals the energy of σ -bond in a hydrogen molecule (4.5eV [6])

at $L \approx 10^{-17} m$. The calculated value L is consistent with equality (9), which testifies the considerable overlapping of wave functions of electrons that constitute the σ -bond.

Thus the condition under which the energy of dipole-dipole interaction of spin vortices may have the same order of magnitude as the energy of exchange interaction of quantum entities creating the pairs is an overlapping of wave functions of these quantum entities.

4.2. The Motion of the Pairs of Interacting Quantum Entities

Let us consider such effects as disappearance of superconductivity at the critical value of speed of motion of electrons constituting Cooper pairs (that is at the critical value of emerging electric current), disappearance of superfluidity at the critical value of speed of motion of superfluid medium, destruction of Cooper pairs at their thermal motion at increasing the temperature. In all the cases, the motion of quantum entities that constitute a Cooper pair occurs in the same direction. That is, the quantum entities of a Cooper pair acquire respective velocities, \mathbf{v}_1 and \mathbf{v}_2 , such as

$$\mathbf{v}_1 = \mathbf{v}_2; \quad (27)$$

the respective electric dipole moments $(\mathbf{d}_v)_1^v$ and $(\mathbf{d}_v)_2^v$ of virtual particles pairs created by these quantum entities are associated with these velocities. According to (21) and (27), $(\mathbf{d}_v)_1^v \uparrow\uparrow (\mathbf{d}_v)_2^v$. In this case, the electric dipole repulsive force acts between virtual particles pairs created by quantum entities of Cooper pair [21], which may lead to destruction of the pair.

Note. Increasing the temperature of medium results not only in emerging of $(\mathbf{d}_v)_1^v \uparrow\uparrow (\mathbf{d}_v)_2^v$, but also in changes in energy U_q and momentum p_q of either quantum entity of Cooper pair; however, the influence of these changes on the interaction of the quantum entities of Cooper pair is self-contradictory. On the one hand, according to Eq. (24), an increase in the energy of quantum entity as a result of increasing the temperature leads to a higher value of force of electric dipole-dipole interaction of virtual particles pairs created by the entities. On the other hand, according to Eq. (11), an increase in the momenta of the quantum entities of Cooper pairs at increasing the temperature decreases the wavelengths λ_q of the entities, and consequently decreases the degree of overlapping of wave functions of the quantum entities. The latter results in decreasing of force of interaction F_r (in the analysis of force F_r the equation (25) must be used instead of equation (24)).

5. The Dipole-dipole Electric Interaction between Spin Vortices that Constitute Photons

Using the expression for electric dipole moment of spin vortex created by electron (see equation (17)) electric

dipole moment d_{ph} of spin vortex that constitutes a photon may be determined as: $d_{ph} = \mu_B U_{ph} / (c p_{ph})$, where U_{ph} and p_{ph} are respectively energy and momentum of photon. Taking into account that $U_{ph} = p_{ph}c$, d_{ph} is determined as $d_{ph} = \mu_B$.

From condition (3) it follows that polarization of photon may be determined not only by the direction of electric polarization of photon but by the direction of electric dipole moment \mathbf{d}_{ph} as well. The electric dipole interaction of photons of the same frequency may result both in phase correlations of these photons and in emerging of traverse force between them. At mutual orientation of electric dipole moments (respectively $(\mathbf{d}_{ph})_1$ and $(\mathbf{d}_{ph})_2$) of two photons as $(\mathbf{d}_{ph})_1 \rightarrow \rightarrow (\mathbf{d}_{ph})_2$ the attractive electric dipole force acts between these photons. At mutual orientation of electric dipole moments of photons as $(\mathbf{d}_{ph})_1 \rightarrow \leftarrow (\mathbf{d}_{ph})_2$, the repulsive electric dipole force acts between these photons. These features of the force acting between photons are consistent with experimentally observed properties of traverse force acting between parallel beams of light. [5]

6. Discussion

From the point of view of classical mechanics, superconductivity and superfluidity is a motion of Cooper pairs in the medium without viscosity. The viscosity in the medium can be accounted for in particular by the electric dipole-dipole interaction of spin vortices created by quantum entities that constitute the medium. The Cooper pairing of quantum entities may be one of the factors that causes a decrease in the viscosity, because the total electric dipole moment of spin vortices created by the quantum entities that constitute the Cooper pair, according to equality (22) is equal to zero (the latter takes place independent of the type of Cooper pairing of quantum entities, with total spin of the entities being equal to zero or one). This decrease in the viscosity influences the superfluid and/or superconductive properties of the medium.

Note. It is a feature of a Cooper pair that not only the total electric dipole moment of spin vortices created by the quantum entities that constitute the Cooper pair is equal to zero, but, according to Eq. (3), the total spin of these spin vortices equals zero as well. Consequently, spin supercurrent cannot emerge between these vortices

7. Conclusion

The analysis of a number of physical phenomena in which exchange interaction between two quantum entities takes place (Cooper pairs in superconductors and superfluids, the covalent bond, the interaction of photons) leads to important insights in the physical processes underlying the exchange interaction in these phenomena.

I. The exchange interaction of quantum entities is an interaction of spin vortices (pairs of oppositely charged virtual particles) created by these entities, the interaction depending on mutual orientation of spins of these vortices.

The constant mutual orientation of spins of spin vortices may be in the case only when the precession frequencies of spins are equal. As the value of precession frequency of spin of a spin vortex is determined by the energy of quantum entity creating this vortex, the exchange interaction between the quantum entities arises only in the case when these entities have equal energies.

II. The interaction of spin vortices depending on mutual orientation of spins of these vortices may be an electric dipole-dipole interaction (the electric dipole moment of spin vortex is directed opposite to spin of the vortex). The equations describing the electric dipole-dipole interaction of spin vortices are derived in this work.

From these equations it follows that the destruction of Cooper pairs in superconductive medium under the certain electric current, the destruction of Cooper pairs in a superfluid medium at the certain speed of its motion, and destruction of Cooper pairs at the increase in temperature above the critical one takes place as a result of motion of quantum entities that constitute these pairs in the same direction.

III. The viscosity of a medium can in particular be determined by the electric dipole-dipole interaction of spin vortices created by quantum entities that constitute the medium. The Cooper pairing of quantum entities may be one of the factors that causes a decrease in the viscosity because the total electric dipole moment of spin vortices created by the quantum entities that constitute the Cooper pair is equal to zero (the latter takes place independent of the type of Cooper pairing of quantum entities: with total spin of the entities equal to zero or equal to one). No doubt, this decrease in the viscosity influences the superfluid and/or superconductive properties of the medium.

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