

# The Model of Magnetic Field Based on the Concepts of Virtual Particles and Quantum Harmonic Oscillators Possessing Zero-Point Energy

Liudmila B. Boldyreva \*

The State University of Management, Moscow, Russia

\*Corresponding author: boldyrev-m@yandex.ru

**Abstract** The magnetic field model proposed in the paper is based on the two concepts of quantum mechanics: the creation of virtual particles pairs by quantum entities and the possibility of existence in the physical vacuum of quantum harmonic oscillators possessing zero-point energy. The characteristics of magnetism, i.e. the magnetic vector potential and magnetic induction, are shown to be associated with definite types of motion of quantum harmonic oscillators. The magnitude of magnetic vector potential is determined by the oscillation frequency of quantum harmonic oscillators. The magnetic induction is proportional to the speed of translational motion of quantum harmonic oscillators. The energy associated with these types of motion is analyzed. If in a certain region of physical vacuum there is no quantum harmonic oscillators, in particular this takes place in the motion of Cooper pairs of electrons in superconductors, no magnetic field may exist in the region, that is, there takes place the “expulsion” of magnetic field from the superconductor. It is shown that in the physical vacuum containing quantum harmonic oscillators there is a relationship, under definite conditions, between magnetic and electric fields.

**Keywords:** zero-point energy, quantum harmonic oscillator, magnetic induction, magnetic vector potential, virtual particles, Meissner–Ochsenfeld effect, superconductivity

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## 1. Introduction

The following magnetic field characteristics are considered in the paper: the magnetic induction, magnetic vector potential, relationship with electric field. The discussion of these characteristics is based on the following two concepts of quantum mechanics:

*The 1st concept.* In the physical vacuum a quantum entity may produce a pair of oppositely charged virtual particles having the following properties [1]:

1) A pair of virtual particles may be converted into a pair of real particles with the total spin equal to  $\hbar$ , the angular momentum being conserved.

2) A pair of virtual particles has a mass.

3) The electric properties of virtual particles are the same as those of real particles. Consequently, a pair of oppositely charged virtual particles is an electric dipole whose electric properties are the same as those of the electric dipole formed by a pair of oppositely charged real particles.

4) The virtual particle has spin with the same properties as the real particle spin, hence it follows that:

a) the spin of a pair of virtual particles has no definite direction, and by the magnitude of spin the magnitude of its projection onto a preferential direction is meant; this can be interpreted as a precession of the spin about the

preferential direction; the precession is characterized by the precession phase, angle of deflection, and precession frequency;

b) spin correlations may take place between the spins of pairs of virtual particles.

*The 2nd concept.* In the physical vacuum there may exist quantum harmonic oscillators possessing zero-point energy. The concept of zero-point energy was developed in Germany by Albert Einstein and Otto Stern in 1913 [2]. According to this concept, it is the energy of the vacuum, which in quantum field theory is defined not as an empty space but as the ground state of the field whose features are as follows [3,4]:

1) the field consists of oscillators with oscillation frequency  $\Omega$  (the oscillator is called at present “quantum harmonic oscillator”, in this paper the abbreviation QHO is used);

2) the energy of such an oscillator is equal to  $\hbar\Omega/2$ , the energy is referred to as zero-point energy;

3) neighboring oscillators interact with each other.

The model of magnetic field developed in this paper gives reasons for the following:

- Virtual particles created in the physical vacuum by moving quantum entities produce in the physical vacuum, in their turn, the objects whose properties are similar to those of a QHO possessing zero-point energy.

- The magnetic induction is associated with the speed of motion of QHOs in the physical vacuum; the

specific energy of magnetic field is equal to the kinetic energy of the moving QHOs in a unit volume of the physical vacuum.

- The magnetic vector potential is determined by the oscillation frequency of QHO. The energy associated with the magnetic vector potential is equal to the energy associated with the oscillation.

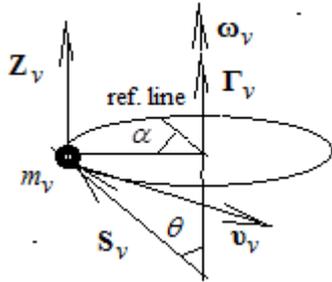
- In the physical vacuum containing QHOs possessing zero-point energy, at certain conditions there is a relationship between magnetic and electric fields.

The equations derived in the paper provide explanation to experimentally established effect: the expulsion of magnetic field from a superconductor (in particular, the Meissner–Ochsenfeld effect) [5].

## 2. Propagation of Spin Precession in the Physical Vacuum

Every moving quantum entity produces a pair of oppositely charged virtual particles in the physical vacuum. According to the properties of virtual particles mentioned in Introduction, the pair has a precessing spin and a mass associated with it. In Fig. 1 are shown the following characteristics of a virtual particles pair: spin  $\mathbf{S}_v$ ; precession frequency  $\omega_v$ ; precession angle (phase)  $\alpha$ ; angle of deflection  $\theta$ ; mass  $m_v$  performing a circular motion at speed  $\mathbf{v}_v$  and having angular momentum  $\mathbf{Z}_v$ ,  $\mathbf{Z}_v \uparrow \uparrow \omega_v$ . The circulation of  $\mathbf{v}_v$ ,  $\Gamma_v$ , is determined as:

$$\Gamma_v = \frac{2\pi\mathbf{Z}_v}{m_v} = \frac{2\pi\mathbf{Z}_v}{m_v} \frac{\omega_v}{\omega_v}. \quad (1)$$



**Figure 1.** The characteristics of a pair of virtual particles:  $\mathbf{S}_v$  is spin;  $m_v$  is the mass;  $\omega_v$  is the precession frequency;  $\mathbf{Z}_v$  is the angular momentum of  $m_v$ ;  $\mathbf{v}_v$  is the speed of the circular motion of  $m_v$ ;  $\theta$  is the deflection angle;  $\alpha$  is the precession angle (phase);  $\Gamma_v$  is circulation of  $\mathbf{v}_v$ ; ref. line is the reference line

Energy  $U_S$  is associated with the precession of spin  $\mathbf{S}_v$  and is a function of deflection angle  $\theta$  [6]. The maximum value of  $U_S$ ,  $(U_S)_{\max}$ , is defined as:

$$(U_S)_{\max} = S_v \omega_v. \quad (2)$$

The energy associated with the circular motion of  $m_v$  is defined [6] as:

$$U_m = Z_v \omega_v / 2. \quad (3)$$

According to the properties of pairs of virtual particles mentioned in Introduction, a pair of virtual particles may be converted into a pair of real particles with the total spin

equal to  $\hbar$ , the angular momentum being conserved. Consequently, the total spin  $S_v$  of a virtual particles pair, at least while converting into real particles, must not be equal to zero. But a virtual particles pair may be created by the quantum entity whose spin equals  $\hbar/2$  and while creating the virtual particles pair the quantum entity preserves this spin. Hence this may suggest that the physical vacuum has an intrinsic degree of freedom, i.e. spin, which manifests itself in the creation of virtual particles. That is,  $S_v$  is the total spin that determines the intrinsic degree of freedom of the physical vacuum in the region where the virtual particles pair is created.

According to the property 4b of pairs of virtual particles mentioned in Introduction, spin correlations may take place between the spins. Experiments conducted with superfluid  $^3\text{He-B}$  showed that the spin correlations may be effected by spin supercurrent [7,8,9]. The spin supercurrent may emerge between the spins of the virtual particles pairs and the spins that determine the intrinsic degree of freedom of the physical vacuum. The spin supercurrent makes equal the respective characteristics of precessing spins (the deflection and precession angles), between which the spin supercurrent emerges, and thus the “propagation” of the spin precession of the virtual particles pairs may take place in the physical vacuum. Let us assume that the frequency  $\omega_v$  and frequency  $\Omega_v$ , which arises as a result of the “propagation” of the spin precession are mutually related by the equation:

$$\Omega_v = \omega_v f(r), \quad (4)$$

where  $f(r)$  is a function determining the dependence of  $\Omega_v$  on distance  $r$  between the virtual particles pair with precession frequency  $\omega_v$  and the point where the spin precession with frequency  $\Omega_v$  arises.

The mass, mass angular momentum  $\mathbf{Z}_{\Omega_v}$ , energy  $W_m$  of circular motion of mass are associated with frequency  $\Omega_v$ , as well as they are associated with frequency  $\omega_v$  (see Eq. (2)). Energy  $W_m$  is determined by the relation  $W_m = Z_{\Omega_v} \cdot \Omega_v / 2$ . If  $Z_{\Omega_v} = \hbar$ , then

$$W_m = \hbar \cdot \Omega_v / 2. \quad (5)$$

Equation (5) is the same as that determining the zero-point energy of a QHO. In addition to similarity in the equations determining the energy, the objects created in the physical vacuum due to the “propagation” of spin precession possess as well other properties of QHO that were given in Introduction: an oscillatory process (precession) with frequency  $\Omega_v$  takes place, and neighboring objects can interact with each other (for example, by spin supercurrents). Because of the above-mentioned similarity, these objects can be referred to as QHO as well.

## 3. The Magnetic Induction

A pair of oppositely charged virtual particles is an electric dipole,  $\mathbf{d}_v$ . If the quantum entity that created a virtual particles pair has an electric charge, then the

entity's electric field,  $\mathbf{E}_v$ , exerts a moment  $\mathbf{M}_v$  on the virtual particles pair as an electric dipole,  $\mathbf{M}_v = \mathbf{d}_v \times \mathbf{E}_v$ . Since the direction of electric dipole moment of virtual particles pair is associated with the orientation of  $\omega_v$  as  $\mathbf{d}_v \uparrow \downarrow \omega_v$  [10,11], the direction of precession frequency  $\omega_v$  depends on the direction of  $\mathbf{E}_v$ , that is on the sign of the moving quantum entities. It is shown in [10, 11] that the direction of precession frequency  $\omega_v$  of spin of virtual particles pair created by the charged quantum entity is determined as:

$$\omega_v \uparrow \uparrow \mathbf{I}. \quad (6)$$

The electric current  $I$  may be looked upon as a flow of virtual particles pairs created by moving electrically charged quantum entities. Taking into account Eq. (6), that is, the same direction of spin precession frequencies of all virtual particles pairs created by the charged quantum entities that form the current, the total circulation  $\Gamma_I$  of the mass velocity of these virtual particles pairs is determined as  $\Gamma_I = z \cdot \Gamma_v$ , where  $z$  is the number of the quantum entities (having electric charge  $q$ ) whose motion forms current  $I$ .

$$z = I / q. \quad (7)$$

Using Eqs. (1), (6) and (7) in the expression for  $\Gamma_I$  we obtain:

$$\Gamma_I = \frac{2\pi Z_v \mathbf{I}}{m_v q} \quad (8)$$

It is shown in [6] that there is a complete analogy between the structures of formulas describing the magnetic interactions of current-carrying wires and the structures of formulas describing the interactions of vortices in an ideal incompressible liquid with positive density and negative pressure. The sign of the pressure  $p$  in a medium depends on the nature of internal stresses in it. If the internal stresses are like "omniradial tensions", the pressure will be negative [6]. The virtual particles pair is a pair of oppositely charged particles, thus there exists a repulsive force between the particles that compensates the electric attractive force between them. The existence of repulsive forces between virtual particles suggests that the medium consisting of virtual particles pairs has negative pressure, i.e. the following may be valid:

$$\rho u^2 / 2 - p = const, \quad (9)$$

where  $u$  and  $\rho$  are respectively the speed and density of the physical vacuum with QHO;  $\rho$  is positive because it is associated with the QHO mass. The dissipation free motion of celestial bodies, such as the planets of the solar system allows one to look upon the physical vacuum as a medium without shear (linear) viscosity.

We shall derive equations that establish a relationship between the characteristics of magnetic field and kinematic characteristic of the vortex line in the medium with the above mentioned properties (Eq. 9), assuming that the density  $\rho$  of the physical vacuum with QHO is constant.

*Interaction of infinite vortex lines and interaction of two infinite current-carrying wires.* The force acting on the unit length of either of the two infinite mutually parallel vortex lines having the same values of circulation  $\Gamma$  is  $F = \rho \Gamma^2 / (2\pi r_w)$ , where  $r_w$  is the distance between the vortex lines with circulation  $\Gamma$  [6]. The force on the unit length of either of the two infinite mutually parallel current-carrying wires (in the CGSE system of units):  $F = 2I^2 / (r_w c^2)$ , where  $I$  is the current,  $r_w$  is here the distance between the current-carrying wires,  $c$  is the speed of light [12]. By equating the above expressions for the forces and taking into account that the forces are attractive if the currents as well as velocity circulations around the vortex lines have the same direction, we obtain:

$$\Gamma = I 2\sqrt{\pi} / (c\sqrt{\rho}). \quad (10)$$

Note that using Eqs. (8) and (10) it is possible to relate density  $\rho$  to the characteristics of the virtual particles pair created by the quantum entity having electric charge  $q$ :  $\rho = m_v^2 q^2 / (\pi c^2 Z_v^2)$ .

*The field of velocities generated by a closed vortex line and the magnetic induction around a current loop.* The field of velocities  $\mathbf{u}$  generated by a closed vortex line having circulation  $\Gamma$  along an arbitrary loop enclosing the

vortex line is defined [6] as  $\mathbf{u} = \frac{\Gamma}{4\pi} \int_L \frac{d\mathbf{l} \times \mathbf{r}}{r^3}$ , where  $d\mathbf{l}$  is

an infinitesimal vector element of the vortex line,  $L$  is the length of the line,  $\mathbf{r}$  is a radius vector from  $d\mathbf{l}$  to the point of observation. Outside the vortex line,  $\text{curl} \mathbf{u} = 0$ . The structure of equation for  $\mathbf{u}$  is the same as the structure of equation for the Biot-Savart law in the CGSE system of units, defining the magnetic induction  $\mathbf{B}$  generated by a loop with current  $I$ :  $\mathbf{B} = \frac{I}{c} \int_L \frac{d\mathbf{l} \times \mathbf{r}}{r^3}$  ( $L$  is the length of the loop,  $d\mathbf{l}$  is the wire element) [12]. Having solved simultaneous equations for  $\mathbf{B}$ ,  $\mathbf{u}$  and Eq. (10), we obtain an equation relating the magnetic induction  $\mathbf{B}$  to the velocity  $\mathbf{u}$  of the medium:

$$\mathbf{B} = \mathbf{u} 2\sqrt{\pi\rho}. \quad (11)$$

*The specific energy of the physical vacuum and the specific energy of magnetic field.* The kinetic energy  $U_u$  of a unit volume of the medium moving at speed  $u$  is:

$$U_u = \rho u^2 / 2. \quad (12)$$

Taking into account Eq. (11), energy  $U_u$  in Eq. (12) can be represented in the form:  $U_u = B^2 / (8\pi)$ . This expression is the same as that for the specific energy of magnetic field  $B$  [12].

*Notes:*

1) The speed  $u$  of the motion of the physical vacuum with QHO specifying the magnetic induction in Eq. (11) is determined relative to the same frame as the speed of the charges, which determines the electric current  $I$ .

2) Equations determining the magnetic forces between the current-carrying wires and the magnetic induction

produced by electric current are written, first, for the vacuum whose permeability  $\mu = 1$ , and, secondly, they are written in the CGSE system of units in order to maintain the constant  $c$  in these equations to show a relation of magnetic field characteristics to the properties of the physical vacuum.

#### 4. The Magnetic Vector Potential

In classical electrodynamics the magnetic field of strength  $\mathbf{B}$  is determined by the equation [12]  $\mathbf{B} = \text{curl}\mathbf{A}$ , where  $\mathbf{A}$  is a magnetic vector potential. The potential  $\mathbf{A}$  created by element  $dy$  of a wire carrying current  $\mathbf{I}$  is determined at the distance  $r$  from the wire (Figure 2), provided that  $dy \ll r$ , as [13]:

$$\mathbf{A} = \frac{\mathbf{I} \cdot dy}{4\pi r \cdot c}. \quad (13)$$

There are a great number of experiments which suggest that magnetic vector potential has a physical meaning of its own [14]. In general, these experiments were as follows: the beam of quantum entities emitted by a source is split into two beams: one of them passes through the region where  $\mathbf{B} = 0$  and  $\mathbf{A} \neq 0$ , the other through the region where  $\mathbf{B} = 0$  and  $\mathbf{A} = 0$ ; after that both beams arrive at an interferometer. The interference rings obtained suggest that there is a change in the wave function phase of quantum entities passing through the region where  $\mathbf{B} = 0$  and  $\mathbf{A} \neq 0$ .

Let us analyze the physical process that could cause a change in the wave function phase of the quantum entities passing through the region of the physical vacuum where  $\mathbf{A} \neq 0$ . For this purpose let us consider the passage of a quantum entity through point  $P$  of the physical vacuum, which is located at a distance  $r$  from the wire carrying current  $I$ . Because of "propagation" of the precession of spin of virtual particles pairs created by the charges that form the current  $I$  (see Section 2) at point  $P$ , there is QHO with spin precession frequency  $\Omega_I$  determined as  $\Omega_I = z \cdot \omega_v$ . Using (4) and (7) in the expression for  $\Omega_I$ , we obtain:

$$\Omega_I = \omega_v f(r) \mathbf{I} / q. \quad (14)$$

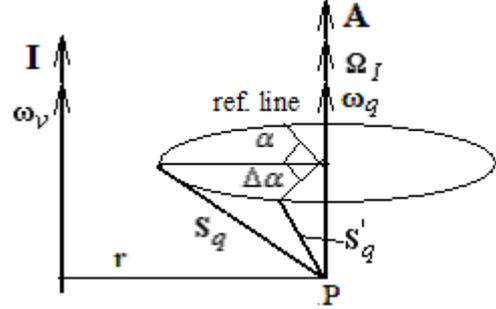
The QHO spin precession (with frequency  $\Omega_I$ ) causes a change in the spin precession frequency  $\omega_q$  of the virtual particles pair created by the quantum entity at the point  $P$ . The nature of the change depends on the mutual orientation of  $\omega_q$  and  $\Omega_I$ . If  $\omega_q \uparrow \uparrow \Omega_I$  or  $\omega_q \downarrow \downarrow \Omega_I$ , the magnitude of spin precession frequency will change by:

$$\Delta\omega_q = \Omega_I. \quad (15)$$

The change in the spin precession frequency will lead to a change in the spin precession phase. The value of change in spin precession phase  $\Delta\alpha$  during time  $t$  is expressed as  $\Delta\alpha = \Delta\omega_q \cdot t$ , or in view of Eq. (15), as follows:

$$\Delta\alpha = \Omega_I \cdot t. \quad (16)$$

Figure 2 shows as an example the relative direction of  $\Omega_I$  and  $\omega_q$ , and also the change in the precession phase,  $\Delta\alpha$ , of spin  $\mathbf{S}_q$  of the virtual particles pair created by a quantum entity ( $\mathbf{S}'_q$  is the position of spin  $\mathbf{S}_q$  after the action of vector potential).



**Figure 2.** The characteristics of physical vacuum with QHO:  $\Omega_I$  is the QHO precession frequency;  $r$  is the distance between the wire and point  $P$ ;  $\mathbf{A}$  is the magnetic vector potential;  $\omega_v$  is the spin precession frequency of the virtual particles pair created by a charged quantum entity that is a constituent of current  $\mathbf{I}$ ;  $\mathbf{S}_q$ ,  $\omega_q$  and  $\alpha$  are respectively the spin, spin precession frequency and precession angle (phase) of the virtual particles pair created by the moving quantum entity;  $\Delta\alpha$  is a change in spin precession phase  $\alpha$ ;  $\mathbf{S}'_q$  is the position of spin  $\mathbf{S}_q$  after the action of vector potential; ref. line is a reference line

It is shown in [11,15] that the quantum entity wave function phase  $\phi_w$  is essentially the precession angle (phase) of spin of the virtual particles pair created by a quantum entity in the physical vacuum; thus

$$\Delta\alpha = \Delta\phi_w, \quad (17)$$

where  $\Delta\phi_w$  is a change in the wave function phase  $\phi_w$ .

Taking into account Eq. (17), the quantity  $\Delta\alpha$  as specified by Eq. (16) may determine the result of the above-described experiments with the two beams of quantum entities.

Therefore, the creation of QHO in the physical vacuum may be assumed to be the physical process that is responsible for the existence of magnetic vector potential. Using Eqs. (13) and (14), the magnitude of the magnetic vector potential  $\mathbf{A}$  created by electric current  $\mathbf{I}$  at the point  $P$  lying at distance  $r$  from the wire may be associated with the quantity  $\Omega_I$  at this point.

$$\mathbf{A} = \Omega_I \frac{q \cdot dy}{4\pi \cdot c \cdot \omega_v \cdot r \cdot f(r)}. \quad (18)$$

A change in the precession frequency of virtual particles pair spin results in a change of virtual particles pair energy and consequently in a change in the energy of the quantum entity that created this pair. The maximum change  $\Delta U_q$  in the virtual particles pair energy associated with precessing spin  $S_q$  is determined according to Eq. (2) as follows:  $\Delta U_q = S_q \cdot \Delta\omega_q$ . Using Eqs. (15) and (18), we obtain for  $\Delta U_q$ :  $\Delta U_q = A \cdot 4\pi \cdot S_q \cdot c \cdot \omega_v \cdot r \cdot f(r) / (q \cdot dy)$ .

A certain amount of energy is associated with frequency  $\Omega_I$ . According to Eq. (2), the maximum value

of this energy,  $(U_{\Omega})_{\max}$ , is determined by equation  $(U_{\Omega})_{\max} = S_{\Omega_I} \Omega_I$ , where  $S_{\Omega_I}$  is the value of QHO precessing spin at the point  $P$ . Using Eq. (18) in this expression we obtain:

$$(U_{\Omega})_{\max} = A \frac{4\pi \cdot c \cdot \omega_v \cdot r \cdot f(r)}{q \cdot dy} S_{\Omega_I}. \quad (19)$$

*Note.* The motion of a quantum entity in the physical vacuum with QHO is equivalent to the exposure of the entity to a magnetic field. Thus the quantum entities that in the above-described experiment pass through the region where  $\mathbf{B} = 0$  in the laboratory frame, while  $\mathbf{A} \neq 0$ , are as well in a magnetic field in the *entities' frame*. The magnetic induction of this field,  $\mathbf{B}_q$ , according to Eq. (11),

is determined by the relation  $\mathbf{B}_q = -\mathbf{v}_q 2\sqrt{\pi\rho}$ , where  $\mathbf{v}_q$  is the quantum entity velocity. According to the Schrödinger equation, the exposure of a quantum entity to a magnetic field changes the wave function phase of the entity (we denote that change as  $(\Delta\varphi_{\psi})_{B_q}$ ). Therefore,

the total change in the wave function phase  $(\Delta\varphi_{\psi})_{\Sigma}$  of a quantum entity, when it is moving in the region where  $\mathbf{B} = 0$  in the laboratory frame and  $\mathbf{A} \neq 0$ , is determined as  $(\Delta\varphi_{\psi})_{\Sigma} = \Delta\varphi_{\psi} + (\Delta\varphi_{\psi})_{B_q}$ , where  $\Delta\varphi_{\psi}$  is determined by Eqs. (15)-(18).

## 5. The Relationship of Magnetic Field and Electric Field

A pair of virtual particles may be converted into a pair of real particles, with the energy and total spin of virtual particles pair being equal respectively to the energy and total spin of the pair of real particles produced. Thus in the vacuum with QHO the laws of energy and angular momentum conservation are valid. The Einstein-de Haas effect [16] holds in such a medium: a change in the polarization of spin  $\mathbf{S}$  of a volume of medium results in the rotation of the medium. That is the following is valid:

$$\partial\mathbf{S} / \partial t = -k_1 \cdot \text{curl}\mathbf{u}, \quad (20)$$

where  $t$  is time,  $k_1$  is a proportionality factor;  $k_1 > 0$ . Under the property 3 of virtual particles described in Introduction, a pair of oppositely charged virtual particles is an electric dipole, that is between the oppositely charged virtual particles there is electric field  $\mathbf{E}$ . If to introduce a proportionality factor  $k_2$ :  $\mathbf{E} = k_2\mathbf{S}$ , then using Eqs. (11) and (20) we obtain:

$$\frac{\partial\mathbf{E}}{\partial t} = -\frac{k_1 k_2}{2\sqrt{\pi\rho}} \text{curl}\mathbf{B}.$$

The structure of this equation is the same as that of one of the Maxwell equations. Note that the dimension of factor  $k_1 k_2 / (2\sqrt{\pi\rho})$  is the same as that of velocity.

## 6. The Expulsion of Magnetic Field from a Superconductor

This section provides an explanation to the fundamental property of superconductors: the so-called effect of expulsion of magnetic field from a superconductor. The effect takes place both in the case where the superconductor is exposed to an external magnetic field  $B$ ,  $B < B_c$ , at  $T < T_c$  ( $B_c$  is the critical value of magnetic induction at arbitrary  $T$ ,  $T_c$  is the critical temperature) and in the case where the superconductor is exposed to magnetic field  $B$  at  $T > T_c$ , the superconductor being cooled down to the temperature of  $T < T_c$  after that (the so-called Meissner–Ochsenfeld effect [5]). The effect shows that superconductivity cannot be treated as a mere loss of electric resistance by the conductor. If a regular conductor exposed to field  $B$  became superconducting at  $T < T_c$ , the magnetic field that was present in the conductor at the time of transition into the state of superconductivity would persist in the conductor.

In a superconducting substance, electrons form pairs (Cooper pairs). The momenta of the electrons in a pair are oppositely directed; thus according to Eq. (6) the precession frequencies of virtual particles pairs created by the electrons of a Cooper pair are directed oppositely to each other and consequently their sum is zero. Therefore, according to Eq. (4), in the vicinity of a Cooper pair no QHO will be produced in the physical vacuum. In such a physical vacuum without QHO the equation (9) is not valid, and no magnetic field will be formed there.

With QHO is associated the energy determined by Eq. (19). The absence of QHO implies that the motion of Cooper pairs will not be accompanied by energy losses due to formation of QHO.

*Note.* According to the properties of virtual particles pair (see Introduction), the pair has an electric dipole moment. The moment causes the interaction between the electrons due to dipole-dipole interaction between the virtual particles pairs created by the electrons. It is shown in [10,17] that the total electric dipole moment of a Cooper pair is equal to zero, which diminishes the interaction of the assembly of Cooper pair electrons in comparison with the interaction of a similar assembly of unpaired electrons.

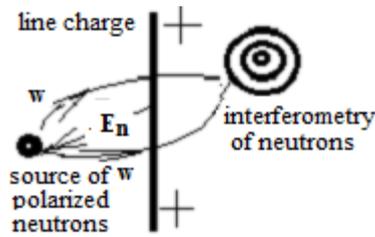
Thus in the electric current formed by Cooper pairs there will be no energy losses of two types: energy losses due to creating QHO in the superconducting region and losses due to electric dipole-dipole interaction of virtual particles pairs produced by electrons of Cooper pairs. Superconductivity may be assumed to be caused by the absence of those two types of energy losses.

## 7. Discussion

*The observation of the topological Aharonov-Casher phase shift by neutron interferometry.*

Figure 3 presents a schematic diagram of the experiment that demonstrates the Aharonov-Casher topological phase shift [18]. Spin-polarized neutrons emitted by a source are divided into two beams. Neutrons of different beams pass on different sides of the line

charge and arrive at the interferometer entrances. The electric field strength in the region where the neutrons propagate is  $\mathbf{E}_n$ .



**Figure 3.** Diagram of the experiment that demonstrates the Aharonov-Casher topological effect.  $\mathbf{E}_n$  is the electric field strength produced by the line charge in the region where the neutrons propagate;  $\mathbf{w}$  is the neutron velocity

Interference fringes were observed in the experiment, which suggests that there is a difference in the wave function phases of the neutrons that passed on different sides of the line charge. The difference in the phases is such as if a magnetic field acted upon a neutron in the reference frame of the neutron, the magnetic induction  $\mathbf{B}_n$  being equal to  $(1/c)\mathbf{E}_n \times \mathbf{w}$ . In the model developed in this paper, for the existence of magnetic field in the frame of neutron it is necessary that the physical vacuum in the region where neutrons propagate contained QHO in the same frame. However, the line charge, which is at rest (relative to the physical vacuum), does not create QHO in the physical vacuum. Therefore, in the model there is no magnetic field in the frame of reference of neutron.

To explain the topological Aharonov-Casher phase shift, let us consider the electric dipole moment  $\mathbf{d}_v$  of virtual particles pair created by a neutron in the physical vacuum. In the electric field of the line charge, the moment  $\mathbf{M}_n$  defined as  $\mathbf{M}_n = \mathbf{d}_v \times \mathbf{E}_n$  will affect the characteristics of the precession of spin of virtual particles pair created by the neutron in the physical vacuum. These characteristics, according to [11,15], are essentially the characteristics of the neutron wave function. In more detail the effect of electric field on a quantum entity due to the existence of the electric dipole moment of the virtual particles pair created by a quantum entity in the physical vacuum is discussed in works [10,11].

## 8. Conclusion

According to the model advanced in this paper, magnetic field may exist in the physical vacuum containing quantum harmonic oscillators possessing zero-point energy. Such characteristics of magnetic field as the magnetic vector potential and magnetic induction are associated with definite types of motion of the quantum harmonic oscillators possessing zero-point energy. The magnitude of magnetic vector potential is determined by the oscillation frequency of quantum harmonic oscillators. The magnetic induction is proportional to the speed of translational motion of quantum harmonic oscillators. The kinetic energy of translational motion of quantum harmonic oscillators in a unit volume of the physical vacuum is equal to the specific energy of magnetic field.

Quantum harmonic oscillators are produced in the physical vacuum by moving quantum entities, in particular by quantum entities that form electric current. Energy is consumed for the maintenance of quantum harmonic oscillators in the physical vacuum. There may be a situation where in the motion of an assembly of quantum entities no quantum harmonic oscillators emerge. For example, this takes place in the motion of Cooper pair electrons in a superconductor. In this case, no energy of Cooper pair electrons is consumed for the maintenance of quantum harmonic oscillators and, besides, no magnetic field may exist in the region. The first property accounts for the phenomenon of superconductivity, the second one underlies the effect of expulsion of magnetic field from a superconductor.

In the physical vacuum containing quantum harmonic oscillators possessing zero-point energy, at certain conditions there is a relationship between magnetic and electric fields.

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