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The Physical Process Responsible for the Brown Effect (the Biefeld-Brown Effect)

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ABSTRACT

On November 15, 1928, American scientist Thomas Townsend Brown was granted a British patent for discovery of the "Method and apparatus for producing force or motion by the use of electrodes", according to which an electric asymmetric capacitor can move towards the positive pole (the smaller electrode) and maintain this movement until it is discharged. Until recently, there was no experimentally and theoretically grounded explanation of the Brown effect.

It is shown in this work that the Brown effect can be a result of the electric dipole interaction of virtual photons (spin vortices) created by quantum objects of capacitors in physical vacuum, according to the hypothesis by Nobel Prize winner Richard Feynman. As a result of this electric dipole interaction, a repulsive force can emerge between the opposite electrically charged electrodes of a capacitor. As the electrodes of capacitors have different masses, they acquire different acceleration under the action of the repulsive force. Thus, during the same time, the electrode with a smaller mass might move a longer distance. The fact that electric dipole interaction includes the moment allowed Brown to obtain significant results in the creation of electric motors by replacing the rectangular electrodes with disks capable to rotate.

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Introduction

On November 15, 1928, American scientist Thomas Townsend Brown was granted a British patent [1] for discovery of the "Method and apparatus for producing force or motion by the use of electrodes", according to which an electric asymmetric capacitor can move towards the positive pole and maintain this movement until it is discharged. Two diagrams of electric asymmetric capacitors are shown in Figure 1. The diagrams differ in the mutual arrangement of the electrodes of capacitors.

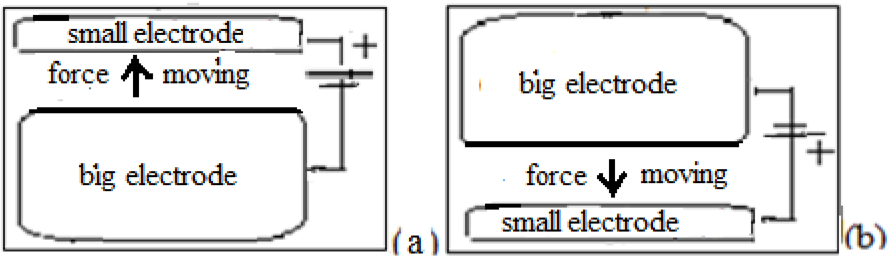

Fig. 1. The variants (a) and (b) of the "moving" electrodes of a capacitor under the action of force.

The Brown effect is characterized by the following experimentally observed features.
1) The force moving the electrodes acts also after turning off the power supply, and it works until the capacitor is charged [1].
2). According to Brown's patent № 3187206 1965 [2], the main condition of the occurrence of force effects is the asymmetric form of electrodes of the capacitor.
3) The Brown force effect is directly proportional to the value of the voltage applied to the electrodes of capacitors [3].
4) The Brown force effect is inversely proportional to the distance between the electrodes of capacitors [3].
5) In addition to the moving force, the electrode may experience a torque. In his experiments, Brown used disks instead of an ordinary capacitor with two charged electrodes. When charged, these disks began to move in a circular path [4].
6) The Brown effect disappears in the Faraday cage shielded from the electric field of the Earth [4].
7) When the electrodes are located along a straight line perpendicular to the Earth's surface, a change in the weight of capacitor is observed: the weight is less if the "small" electrode is above and is greater if it is below [1].

Until recently, there was no experimentally and theoretically grounded explanation of the Brown effect. It is shown in this work that the Brown effect can be a result of the electric dipole interaction of virtual photons (spin vortices) created in physical vacuum by quantum objects of capacitors. This work is based on the experiments by S.J. Barnett on the additional magnetization of a rotating magnet [5] and on the hypothesis by Nobel Prize winner R. Feynman about creating in physical vacuum of virtual photons (spin vortices) by quantum objects that are features in electrical or magnetic fields [6]. Let us consider these phenomena in detail.

1. The properties of physical vacuum

1) In quantum field theory [7, 8], a physical vacuum free from magnetic and electric fields (without regard to gravitational energy) is defined not as an empty space but as the ground state of a field that consists of some "quantum oscillators" with "zero-point energy" determined by oscillations of angular momentum $\mathbf{S}_{qo}$. The existence in physical vacuum of quantum oscillators having angular momentum explains the conservation of angular momentum in the Cherenkov effect [9]: radiation of photon (having spin) by a quantum object moving with the speed of light while saving its own spin.
2) In physical vacuum with the above-considered properties, an effect similar to that of the S. J. Barnett effect [5] can take place. In the Barnett effect, the rotation of magnet with the angular velocity $\mathbf{\Omega}$ results in emerging of precession frequency $\boldsymbol{\omega}_e$ of electrons' spins $\mathbf{S}_e$ in the following way: $\mathbf{\Omega} \uparrow\uparrow \boldsymbol{\omega}_e$ (see Figure 2).

Spin $\mathbf{S}_q$ of a quantum object may lead to analogous phenomena in physical vacuum consisting of quantum oscillators with angular momenta (spins) $\mathbf{S}_{qo}$. They will precess with frequency $\boldsymbol{\omega}_{qo} \uparrow\uparrow \mathbf{S}_q$, (see Figure 3).

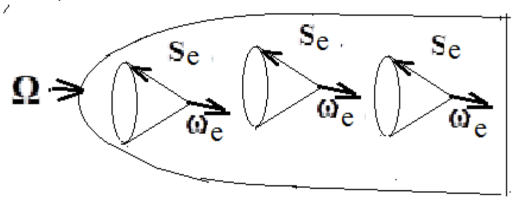

Fig. 2. The characteristics of rotating magnet in the Barnett effect. $\boldsymbol{\omega}_e$ - frequency of precession of electrons' spins $\mathbf{S}_e$. $\mathbf{\Omega}$ - angular velocity of rotating magnet.

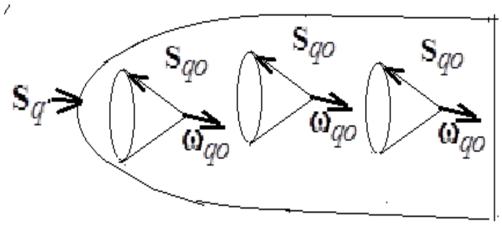

Fig. 3 The characteristics of physical vacuum under the action of spin $\mathbf{S}_q$ of quantum object. $\boldsymbol{\omega}_{qo}$ is frequency of precession of spins $\mathbf{S}_{qo}$ of quantum oscillators.

It follows from Figure 3 that area of physical vacuum with total spin $\mathbf{S}_v = \sum \mathbf{S}_{qo}$ and with averaged frequency $\boldsymbol{\omega}_v \approx \boldsymbol{\omega}_{qo}$ may be classified as a spin vortex and condition $\mathbf{S}_q \uparrow\uparrow \boldsymbol{\omega}_{qo}$ may be rewritten in the form:

$$\mathbf{S}_q \uparrow\uparrow \boldsymbol{\omega}_v . \tag{1}$$

As the spin vortex with precessing spin $\mathbf{S}_v$ possesses the properties of gyroscope, the following holds [10]:

$$\mathbf{M}_v = \boldsymbol{\omega}_v \times \mathbf{S}_v , \tag{2}$$

where $\mathbf{M}_v$ is a moment causing spin precession.

The electric field of a quantum object acts on a spin vortex (as an electric dipole) produced by this object and following it. Consequently, the orientation of the electric dipole moment of a spin vortex is determined by the sign and direction of velocity **u** of the quantum object that creates the spin vortex. Thus, with taking into account the equations (1) and (2) and Fig. 3, we have:

$$\boldsymbol{\omega}_v \uparrow\uparrow \eta \mathbf{u} , \tag{3}$$

where
$$\eta = \begin{cases} 1, & \textit{for positively charged quantum object} \\ -1, & \textit{for negatively charged quantum object} \end{cases} . \tag{4}$$

The electric polarization of physical vacuum in the electric field indicates the existence of electric properties of quantum oscillators, in particular, it can be the electric dipole moment of a quantum oscillator, $\mathbf{d}_{qo} \neq 0$. Consequently, a spin vortex has electric dipole moment $\mathbf{d}_v = \sum \mathbf{d}_{qo}$. Thus, it follows from Eqs. (1)-(4) that electric dipole moment $\mathbf{d}_v$ of spin vortex is related to its spin $\mathbf{S}_v$ as:

$$\mathbf{d}_v \uparrow\uparrow \mathbf{S}_v . \tag{5}$$

Note. In this case, the results of the investigation by H. Li and others can be used [11]:" We report the quantized superfluid vortex filaments induced by the axial flow effect". Indeed, the superfluid medium in the investigation by H. Li characterized by intrinsic angular momentum is similar to the physical vacuum characterized by "zero-point energy". Thus, it follows from the investigation by H. Li that the motion (at velocity **u**) of a quantum object can be followed by "quantized superfluid vortex filaments", in particular, by spin vortex (virtual photon). One of the main properties of spin vortex is the precession motion (with frequency $\boldsymbol{\omega}_v$) of its spin $\mathbf{S}_v$. Consequently, the following relation exists: $\mathbf{u} \sim \boldsymbol{\omega}_v$. This relation is in accordance with Condition (3)-(4).

2. The properties of virtual photons

The properties of virtual photons in the hypothesis by Feynman [5] are similar to the properties of spin vortices emerging in physical vacuum (discussed in Section 1). According to this hypothesis, quantum objects that are features in electric and magnetic fields create virtual photons having precessing spin $\mathbf{S}_v$, electric dipole moment $\mathbf{d}_v$ and size equal to wavelength $\lambda\!\!\!^{-}_q$ of wave function of a quantum object. The characteristics of virtual photons created by positively and negatively charged quantum objects are shown in Figure 4.

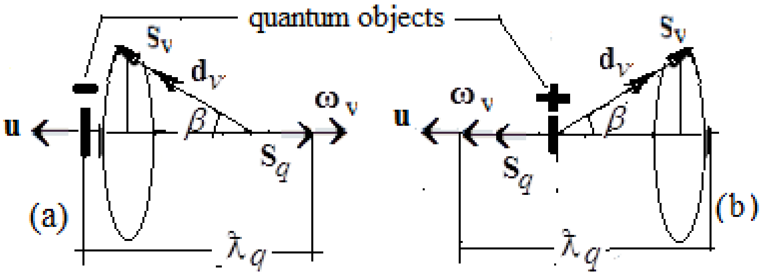

Fig. 4. Diagrams of virtual photons created by a negatively charged quantum object (case (a)) and positively charged quantum object (case (b)). $\mathbf{S}_q$ are spins of quantum objects; $\boldsymbol{\omega}_v$ are frequencies of precession of virtual photons' spins $\mathbf{S}_v$; β are angles of deflection; $\mathbf{d}_v$ are electric dipole moments; **u** are velocities of quantum objects; $\lambda\!\!\!^{-}_q$ is the size of a virtual photon (equal to the wavelength of wave function of an object that creates a virtual photon).

The angle of deflection β is determined [12] by the speed u of the virtual photon (or, which is the same thing, by the speed of the quantum object which creates this virtual photon) and by the speed of light:

$$\sin\beta = u/c. \tag{6}$$

It follows from equation (6) that at $u=c$ a virtual photon converts into a "real" photon. The existence of the Cherenkov effect [9] proves the validity of equation (6).

The existence of the electric dipole moment and a spin of virtual photons causes the existence of two types of interaction of virtual photons.
1) The electric dipole-dipole interaction.
2) The transmission of precession and deflection angles by spin supercurrent.

Let us consider these types of interactions in detail.

2.1. The electric dipole-dipole interaction of virtual photons.

The determination of the electric dipole moment of a virtual photon created by a quantum object.

According to the hypothesis by Feynman, the virtual photon (with mass m_v) consists of two virtual particles with charge q_v and mass $m_v/2$; the distance between virtual particles equals wavelength $\lambda\!\!\!^{-}_q$ of wave function of a quantum object which creates the virtual photon. Then electric dipole moment d_v of a virtual photon is determined by the expression:

$$d_v = q_v \lambda\!\!\!^{-}_q, \tag{7}$$

where $\lambda\!\!\!^{-}_q$ is determined by the momentum of a (d_v ıntum object p_q [13]:

$$\lambda\!\!\!^{-}_q = \hbar / p_q. \tag{8}$$

Let us determine the electric dipole mc d_v nt of a virtual photon created by an electron. Based on the results of experiments conducted by W. Kaufmann [14] on the deflection of beta-rays emitted by radium, which showed that the mass of an electron is purely of the electromagnetic nature, we assume that the specific charge of any of the two particles that constitute the virtual photon created by the electron is proportional to the specific electron charge: that is, the following holds:

$$(q_v)_e = e(m_v)_e/(2m_e), \tag{9}$$

where e and m_e are electric charge and mass of an electron, respectively; $(q_v)_e$ and $(m_v)_e/2$ are electric charge and mass of one of the two particles that constitute the virtual photon created by an electron. According to [12], the mass of a virtual photon created by an electron with energy U_e is determined by the expression $(m_v)_e = U_e/c^2$. If an electron has only kinetic energy, that is: $U_e = m_e u_e^2/2$ and $p_e = m_e u_e$ (p_e and u_e are respectively momentum and speed of electron) then, taking into account Eqs. (7)-(9), we have:

$$(d_v)_e = \mu_B u_e/(2c), \tag{10}$$

where μ_B is Bohr magneton in the Gauss system.

Note. Electric dipole moment may determine spin-orbit interaction of a quantum object when it moves in the electric field. For example, the maximum value $(U_{s-o})_{\max}$ of energy of the electron in a hydrogen atom, when using Eq. (10), is described by expression: $(U_{s-o})_{\max} = \left|\mu_B(\mathbf{u}\times\mathbf{E}_n)/(2c)\right|$, where $\mathbf{E}_n$ is electric field strength at the point where the electric dipole is located. The expression for $(U_{s-o})_{\max}$ is the same as for the maximum value of the spin-orbit interaction energy of the electron in a hydrogen atom which was derived by L. Thomas based on the general requirements of relativistic invariance [15]. It should be noted that the possibility of explanation of spin–orbit interaction of the electron in a hydrogen atom, with using Eq. (10), can serve as a proof of validity of this equation for determining electric dipole moment of a virtual photon created by the electron.

If the above-considered mathematical relations (7)-(10) are applied to the proton, we obtain:

$$(d_v)_p = \mu_N u_p/(2c), \tag{11}$$

where $\mu_N = \hbar e/(2cm_p)$ is nuclear magneton in the Gauss system, m_p is the proton's mass, u_p is the proton's speed.

The following energy characteristics are related to electric dipole moments ($\mathbf{d}_{v1}$ and $\mathbf{d}_{v2}$ **) of virtual photons: force** $\mathbf{F}_v$**, moment** $\mathbf{M}_v$ [16].

$$\mathbf{F}_v = \begin{cases} k\mathbf{d}_{v1}\mathbf{d}_{v2}/r^4 - \textit{attractive at } \mathbf{d}_{v1}\uparrow\downarrow\mathbf{d}_{v2}(k{=}3) \textit{ or } \mathbf{d}_{v1}\rightarrow\rightarrow\mathbf{d}_{v2}(k{=}6) \\ k\mathbf{d}_{v1}\mathbf{d}_{v2}/r^4 - \textit{repulsive at } \mathbf{d}_{v1}\uparrow\uparrow\mathbf{d}_{v2}(k{=}-3) \textit{ or } \mathbf{d}_{v1}\leftarrow\rightarrow\mathbf{d}_{v2}(k{=}-6) \end{cases}. \tag{12}$$

$$\mathbf{M}_v = \left[\mathbf{d}_{v2}\cdot\left(\left(3\mathbf{r}(\mathbf{d}_{v1}\mathbf{r}) - \mathbf{d}_{v1}r^2\right)/r^5\right)\right], \tag{13}$$

where r is the distance between virtual photons, $r >> \lambda_q$.

2.2. Interaction of virtual photons by spin supercur d_v t

Besides the electric dipole-dipole interaction, the spin supercurrent transferring the angular momentum between spins of spin vortices in physical vacuum can emerge between virtual photons.

Note. The investigations of spin supercurrent were conducted from 1976 [17-18]; in 2008, Russian scientists Yu. Bunkov, V. Dmitriev and I. Fomin were awarded the Fritz London Memorial Prize for the studies of spin supercurrents in superfluid ^{3}He-B [19-20]. Figure 5 illustrates the example of occurrence of spin supercurrent between virtual photons created by positively charged quantum objects.

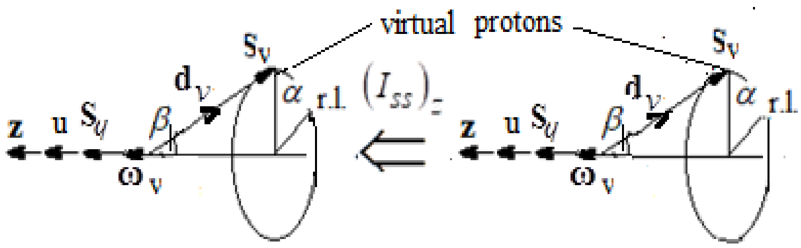

Fig. 5. The characteristics of virtual photons created by quantum objects with spins $\mathbf{S}_q$; $\boldsymbol{\omega}_v$ are frequencies of precession of spins of a virtual photon $\mathbf{S}_v$; β are angles of deflection; $\mathbf{d}_v$ are electric dipole moments; α are angles of precession; r. l. are lines of reference; **u** – velocities. $(I_{ss})_z$ is spin supercurrent oriented along **z.**

The spin supercurrent oriented along **z** is determined by expression $(I_{ss})_z = -g_1 \partial\alpha / \partial z - g_2 \partial\beta / \partial z$, where g_1 and g_2 are proportionality coefficients depending on characteristics of virtual photons.

Due to the action of spin supercurrent, angles of precession (α) and angles of deflection (β) of precessing spins of virtual photons will acquire the same values and, consequently, their summary action on other objects may be replaced by the action of a single (total) virtual photon. From this point of view, let us consider the interaction of virtual photons created by quantum objects of the "big" electrode with virtual photons created by quantum objects of the "small" electrode.

3. The interaction of virtual photons created by quantum objects of the "big" electrode with virtual photons created by quantum objects of the "small" electrode.

As it is specified in the patent by Thomas Townsend Brown [1], the force moving the positively charged electrodes in the capacitor acts also after turning off the power supply, and it works until the capacitor is charged. Consequently, in the absence of the power source, the motion of the positively charged electrode is determined only by the existence of an electric charge on the electrodes of the capacitor. The interaction of these electric charges controls the direction of velocities and, according to Eqs. (2)-(5), the direction of electric dipole moments of the virtual photons created by charged quantum objects. Under a certain mutual orientation of electric dipole moments of these virtual photons, the force emerges that moves the capacitor's electrodes. The electric interaction of these electric dipoles disappears when using the Faraday cage screening the capacitor from the electric field of the Earth [4].

Thus, two types of electric fields take part in the Brown effect: the electric field created by charged quantum objects of electrodes and electric field emerging in physical vacuum as electric components of virtual photons.

The validity of this conclusion is confirmed by the studies listed below.

These studies are based on the investigation of the properties of virtual photons (spin vortices) created by electrically charged quantum objects of the electrodes. In the negatively charged electrode (the "big" electrode in Fig. 1) of the electrically charged capacitor, virtual photons are created by the electrons moving towards the positively charged electrode (the "small" electrode in Fig. 1). Total electric dipole moment $(\mathbf{d}_v)_{be}^t$ of virtual photons created by these moving electrons is determined as:

$$(\mathbf{d}_v)_{be}^t = n(\mathbf{d}_v)_{be}, \tag{14}$$

where n is the number of virtual photons (in the "big" electrode) having electric dipole moment $(\mathbf{d}_v)_{be}$ and created by electrons moving with velocity $\mathbf{u}_{be}$ towards the "small" electrode.

In the positively charged electrode (the "small" electrode in Fig. 1) of the electrically charged capacitor, the virtual photons are created by atoms' protons moving towards the negatively charged electrode, and by electrons moving together with these protons. Then the total electric dipole moment of virtual photons is determined by two components: $(\mathbf{d}_v)_{sp}^t$ - the total electric dipole moment of virtual photons created by moving protons, and $(\mathbf{d}_v)_{se}^t$ - the total electric dipole moment of virtual photons created by electrons moving together with protons of atoms. These components are determined by the following expression:

$$(\mathbf{d}_v)_{se}^t + (\mathbf{d}_v)_{sp}^t = m\left((\mathbf{d}_v)_{se} + (\mathbf{d}_v)_{sp}\right), \tag{15}$$

where m is the number of virtual photons (in the "small" electrode) having electric dipole moment $(\mathbf{d}_v)_{sp}$ and created by atoms' protons moving with velocity $\mathbf{u}_{sp}$ towards the "big" electrode. At the same time, m is the number of virtual photons (in the "small" electrode) having electric dipole moment $(\mathbf{d}_v)_{se}$ and created by electrons moving together with atoms' protons with velocity $\mathbf{u}_{se}$, that is:

$$\mathbf{u}_{se} \sim \mathbf{u}_{sp}. \tag{16}$$

Thus, the interaction of "big" and "small" electrodes of a capacitor may be implemented by the interaction of virtual photons with total electric dipole moments: $(\mathbf{d}_v)_{sp}^t$, $(\mathbf{d}_v)_{se}^t$, $(\mathbf{d}_v)_{be}^t$. The schematic representation of these total virtual photons (accordingly: **1**, **2**, **3**) is shown in Figure 6.

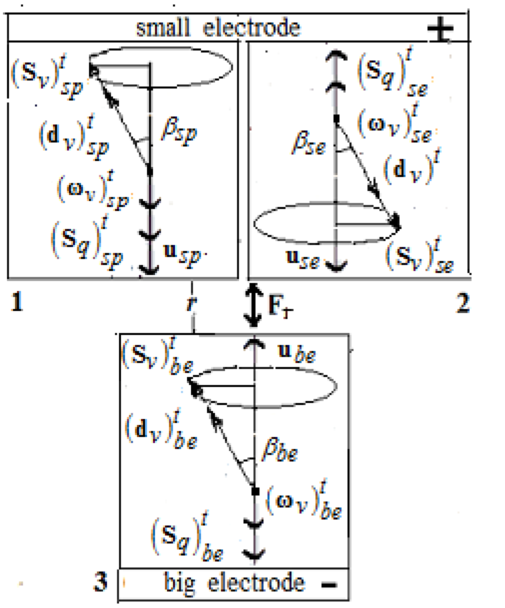

Fig. 6. The characteristics of total virtual photons (v.p.) created by proton (p) and electron (e) in "small" (s) and "big" (b) electrodes. $\left(\mathbf{S}_q\right)_{sp}^t$, $\left(\mathbf{S}_q\right)_{se}^t$, $\left(\mathbf{S}_q\right)_{be}^t$ - spins of proton and electrons; $\left(\mathbf{S}_v\right)_{sp}^t$, $\left(\mathbf{S}_v\right)_{se}^t$, $\left(\mathbf{S}_v\right)_{be}^t$ - spins of v.p.; $\left(\boldsymbol{\omega}_v\right)_{sp}^t$, $\left(\boldsymbol{\omega}_v\right)_{se}^t$, $\left(\boldsymbol{\omega}_v\right)_{be}^t$ - frequencies of precession of spins of v.p.; $\left(\mathbf{d}_v\right)_{sp}^t$, $\left(\mathbf{d}_v\right)_{se}^t$, $\left(\mathbf{d}_v\right)_{be}^t$ - electric dipole moments of v.p.; $\mathbf{u}_{sp}$, $\mathbf{u}_{se}$, $\mathbf{u}_{be}$ - velocities of v.p.; β_{sp}, β_{se}, β_{be} - angles of deflection; $\mathbf{F}_r$ - force; r – distance between electrodes.

According to Eq. (12), resulting force F_r acting between virtual photons created by "small" and "big" electrodes shown in Fig. 6 is determined by expression:

$$F_r = 6\left[\left(\left(d_v\right)_{se}^t \cos\beta_{se} - \left(d_v\right)_{sp}^t \cos\beta_{sp}\right)\left(d_v\right)_{be}^t \cos\beta_{be}\right] / r^4 .$$

Using Eqs. (6), (10)-(11) and (14)-(16) in equation for F_r, we get:

$$F_r = 6\left[\left(m\mu_B u_{se}\sqrt{1-u_{se}^2/c^2} - m\mu_N u_{sp}\sqrt{1-u_{sp}^2/c^2}\right)n\mu_B u_{be}\sqrt{1-u_{be}^2/c^2}\right] / \left(4c^2 r^4\right).$$

Assuming that the speed of quantum objects in a capacitor is significantly less than the speed of light, expression for F_r can be rewritten in the form:

$$F_r = 6\left[m\left(\mu_B u_{se} - \mu_N u_{sp}\right)n\mu_B u_{be}\right] / \left(4c^2 r^4\right). \qquad (17)$$

Taking into account Eq. (16), inequality $\mu_B >> \mu_N$ and Eq. (12), the following conclusion can be made: force $\mathbf{F_r}$ is a repulsive force.

Note. The change in the character of force acting between the capacitor's electrodes from the Coulomb attractive force at the beginning of charging the capacitor to the repulsive force due to electric dipole interaction can result in the inversion of direction of velocities $\mathbf{u}_{se}$, $\mathbf{u}_{be}$ and $\mathbf{u}_{sp}$. However, based on the definition of electric dipole interaction of virtual photons (Eq. (12)), force $\mathbf{F_r}$ remains to be a repulsive force.

In other words: if as a result of action of force $\mathbf{F_r}$ the inversion of the total virtual photons shown in **Fig. 5** takes place, force $\mathbf{F_r}$ will remain to be a repulsive force and the motion of capacitor electrodes will continue in the same directions.

4. The determination of amount of the electrode's displacement in the capacitor.

Let us consider two versions of the capacitor structure.

The first version. The capacitor with electrodes does not form a rigid structure. That is, the electrodes can move independently inside the capacitor.

According to Newton's second law, acceleration $\mathbf{A}_1$ of motion of the "small" electrode with mass M_1 is determined as: $\mathbf{A}_1 = \mathbf{F}_r / M_1$; acceleration $\mathbf{A}_2$ of motion of the "big" electrode with mass M_2 is determined as: $\mathbf{A}_2 = \mathbf{F}_r / M_2$. The electrodes are moving under the action of force $\mathbf{F}_r$ and their total displacement $\Delta\mathbf{Y}$ in time *T* is determined as:

$$\Delta\mathbf{Y} = \mathbf{Y}_1 - \mathbf{Y}_2 = T^2\left(\mathbf{F}_r / M_1 - \mathbf{F}_r / M_2\right)/2, \tag{18}$$

where $\mathbf{Y}_1$ is the amount of the "small" electrode's displacement, $\mathbf{Y}_2$ is the amount of the "big" electrode's displacement. The expression (18) is justified as well when the locations of the "small" and "big" electrodes in the capacitor are interchanged while maintaining their polarity and size (see Figure 7a and Figure 7b).

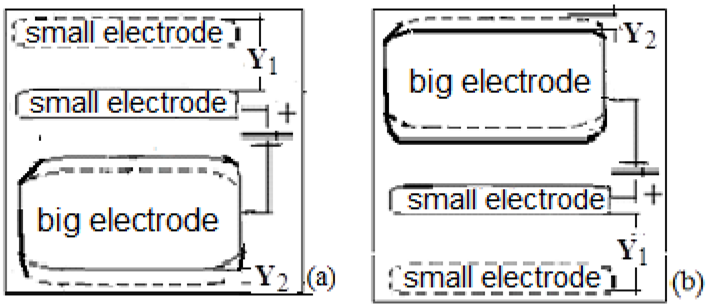

Fig. 7. The schematic representation of the two variants ((a) and (b)) of space arrangement of "big" and "small" capacitor's electrodes, moving from the initial state marked with continuous borders into the state marked with dashed borders. Y_1 - the displacement of the "small" electrode. Y_2 - the displacement of the "big" electrode.

The difference in displacement of "big" and "small" electrodes is determined by difference $Y_1 - Y_2$. Using Eqs. (17)-(18), we obtain:

$$Y_1 - Y_2 = 3T^2\left[m\left(\mu_B u_{se} - \mu_N u_{sp}\right)n\mu_B u_{be}\right]\left(1/M_1 - 1/M_2\right)/\left(4c^2 r^4\right). \tag{19}$$

The second version. The capacitor with electrodes forms a rigid structure (as in the Brown effect).
If the capacitor with electrodes forms a rigid structure with size equal to size of electrodes, the displacement of electrodes is transmitted to the entire capacitor. Consequently, the entire capacitor moves a distance $Y_1 - Y_2$ in the direction of positive ("small") electrode. It is important to note that force $\mathbf{F}_r$ is arising in physical vacuum and is an external force for the capacitor.

From the expression (19), the experimentally confirmed properties of the Brown effect are the following (see Introduction).

1) The value of speed of protons (u_{sp}) and speed of electrons (u_{se}, u_{be}) contained in the electrodes of the capacitor is determined by the electrical voltage on the electrodes of the capacitor.

2) According to Eqs. (17) and (18), the total amount of displacement of electrodes (ΔY) is inversely proportional to the distance between the electrodes (see Fig. 6).

3) According to Eqs. (17) – (18), the total amount of displacement of electrodes (ΔY) is proportional to the difference of masses $|M_1 - M_2|$ of the capacitor's electrodes.

4) According to Eqs. (17) - (18), the total amount of displacement of electrodes (ΔY) is proportional to a number of protons (*n*) in the "big" electrode of a capacitor and a number of electrons (*m*) in the **"**small" electrode of a capacitor; that is the value of ΔY depends on the properties of the substance that makes up the electrodes.

5) The Brown effect disappears in the Faraday cage shielded from the electric field of the Earth. This phenomenon is in accordance with a theoretical explanation of the Brown effect as a consequence of the electric dipole interaction of virtual photons (spin vortices) created by quantum objects of a capacitor's electrodes in a physical vacuum.

Discussion. The use of disks instead of rectangular electrodes in a capacitor

In his experiments, Brown investigated the possibility of changing the form of a capacitor's electrodes: rectangular electrodes are replaced with disks [1]. The disks began moving along a circular path when they were electrically charged.

The circular motion of disks can be explained by the interaction of virtual photons. According to Eq. (13), a moment may act between virtual photons created by quantum objects of the disks. This moment may cause rotation of the disks.

Note. The action of force F_r as a centripetal force is not considered here.

Conclusion

1) Two forces act between electrically charged electrodes of a capacitor: the "ordinary" Coulomb attractive force and force due to the interaction of virtual photons (spin vortices) created by quantum objects of a capacitor's electrodes in a physical vacuum. It is shown in this work that the Brown effect (Biefeld-Brown effect) can be caused by the interaction of virtual photons.

2) As follows from the experiments of S. J. Barnett and the hypothesis by R. Feynman, the virtual photon (spin vortex) has the precessing spin and electric dipole moment. Thus, there are two types of interaction related to virtual photons: spin supercurrent arising between spins of virtual photons and equalizing their characteristics (angles of precession and angles of deflection), and electric dipole-dipole interaction.

3) The equalization of spin characteristics lets us replace the action of many virtual photons with equal values of characteristics with the action of a single (total) virtual photon with total electric dipole moment of combined virtual photons.

4) As a result of the interaction of electric dipole moments of virtual photons (spin vortices) created by quantum objects of capacitor's electrodes, a repulsive force emerges between them. According to Newton's second law, the acceleration of an electrode is inversely proportional to its mass. Consequently, the "small" electrode of a capacitor under the action of a repulsive force can move a significantly greater distance than the "big" electrode under the action of the same force during the same time.

5) Besides the force, a moment may act between virtual photons (spin vortices) created by quantum objects. Therefore, the charged electrodes of a capacitor may be not only rectangular electrodes but also disks performing circular motion.

Note. The Brown effect is not a single physical phenomenon whose explanation requires an appeal to the Feynman's hypothesis of creation of virtual photons (spin vortices) by quantum objects. For example, such phenomena include: the origin of the force of inertia in the First law of Newton and the change in the weight of rotating bodies and/or bodies having vertical (relative to the Earth) acceleration [21].

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