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The Spin Magnetic Moment of Electron as a Photon Property

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Abstract A fundamentally new approach to definition of spin magnetic moment of electron is given in this paper. In contrast with the existing descriptions of the spin magnetic moment based on accounting for the interaction of electron with the physical vacuum, it is shown in this paper that the principal component of this moment, i.e. the Bohr magneton, is a property of photon. In a photon decay into an electron and positron a “transfer” of magnetic moment from the photon to the emerging electron-positron pair takes place, which is similar, for example, to “transfer” of the spin from a photon to the emerging electron and positron. It is shown also in this work that the so-called radiative correction to the principal component of the electron spin magnetic moment may be determined by magnetic moments of virtual particles in the virtual particles pair (virtual photon) created by the electron in the physical vacuum. Thus both the principal component of spin magnetic moments of electron (the Bohr magneton) and radiative correction to the principal component are essentially determined by the properties of photons: the photon that has created the electron (in the photon decay into an electron-positron pair) and the virtual photon (the virtual particles pair) created by the electron in the physical vacuum.

Keywords: *spin magnetic moment of electron, virtual particle, photon, magnetism, quantum mechanics*

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1. Introduction

The spin magnetic moment of electron, $\left(m_{mag}\right)_e$, is generally expressed [1] as:

$$\left(m_{mag}\right)_e = \mu_B \cdot s \cdot g_e \tag{1}$$

where $s = S_e / \hbar$ ($S_e = \hbar / 2$ is electron’s spin angular momentum); g_e is the electron g-factor; μ_B is the Bohr magneton:

$$\mu_B = \frac{e\hbar}{2m_e c}, \tag{2}$$

where e and m_e are respectively the charge and mass of electron, c is the speed of light, $\hbar$ is the Planck constant. The spin magnetic moment is antiparallel to the spin angular momentum, that is $\left(\mathbf{m}_{mag}\right)_e \uparrow\downarrow \mathbf{S}_e$. The value g_e was derived in experiments on determining the electron g-factors for the $2S_{1/2}$, $2P_{1/2}$ and $2P_{3/2}$ states of sodium and gallium [2], and determining the hyperfine splitting of the ground state of atomic hydrogen [3]:

$$g_e = 2.00231930436153(53). \tag{3}$$

From equation (1) it follows that the ratio of electron spin magnetic moment to electron spin angular momentum (hereafter the term “spin” will be used), $\left(m_{mag}\right)_e / S_e$, is almost twice as great as the ratio of electron orbital magnetic moment to electron orbital angular momentum $\hbar$. Thus the properties of electron spin magnetic moment are purely quantum, having no explanation in classical physics.

The expression for $\left(m_{mag}\right)_e$ most close to equation (1), i.e. $\left(m_{mag}\right)_e = \mu_B$, was derived from the Dirac equation [4] for electron in the external magnetic field in a nonrelativistic approximation. A more precise value of $\left(m_{mag}\right)_e$ determined by equation (1) was derived on the basis of mathematical formulas of quantum electrodynamics by taking into account the interaction of electron with zero fluctuations of electromagnetic vacuum, in particular the absorption and generation of virtual photons by electron, resulting in changing the electron characteristics (for example, mass) [5,6].

In this paper, according to the proposed method of determining the spin magnetic moment of electron, the expression (1) for $\left(m_{mag}\right)_e$ is presented as a sum of two summands:

$$\left(m_{mag}\right)_e = \mu_B + \mu_B\left(g_e s - 1\right). \tag{4}$$

The approach advanced in this paper for determining the first summand in equation (4) differs fundamentally from the method based on Dirac's equations [4] in that the interaction of electron and the physical vacuum is not taken into account. It is shown in this paper that the component of the spin magnetic moment which equals the first summand (the Bohr magneton) is a photon characteristic, in particular it is the magnetic moment of either virtual particle in the virtual particles pair that constitutes the photon. In the decay of photon into an electron-positron pair a "transfer" of the magnetic moment from the photon to the emerging electron and positron takes place, similar to the "transfer" of the spin of photon to the emerging electron and positron.

The determination of the second summand is based on the concept of quantum mechanics concerning the creation of a virtual particles pair (also called the "virtual photon") by a quantum entity. However, unlike the above-mentioned works [5,6], in this paper not the variations of characteristics of electron in the process of absorption and generation of virtual photons are considered, but the properties of those virtual photons. It is shown that the component of electron spin magnetic moment determined by the second summand in the equation (4) may be determined by magnetic moments of virtual particles in the virtual particles pair created by the electron in the physical vacuum.

Thus both components of spin magnetic moments of electron are essentially determined by the properties of photons: the photon that has created the electron (in the photon decay into an electron-positron pair) and the virtual photon (the virtual particles pair) created by the electron in the physical vacuum.

The validity of the equations used for determining the photon characteristics is substantiated by derivation on the basis of these equations of experimentally proven expression for spin-orbit interaction of electron in an atom (see Section 3).

1. The derivation of the first summand (μ_B) in the expression (4) determining the electron spin magnetic moment

In this section it is shown that the first summand in the equation determining the electron spin magnetic moment (the Bohr magneton, μ_B) is one of the characteristics of photon.

According to the quantum mechanical concept, a photon in the physical vacuum can be represented by a virtual particles pair. According to quantum field theory, a pair of virtual particles that constitutes a photon has the following properties [7]:

1) It is produced in the region whose size is of the order of magnitude of the wavelength of the photon of energy U_{ph}, the wavelength $\lambda\!\!\!^{-}_{ph}$ being determined [8] as:

$$\lambda\!\!\!^{-}_{ph} = c \cdot \hbar / U_{ph}. \tag{5}$$

2) It has spin S_{ph}: $S_{ph} = \hbar$.

3) It has a mass which manifests itself, for example, when a photon decays into a pair of real particles of nonzero mass. In this case the mass of virtual particles pair that constitutes the photon is transformed into the real particles mass. Essentially, the mass of virtual particles pair that constitutes a photon equals the so-called relativistic mass of photon, m_{ph}, determined [9] as:

$$m_{ph} = U_{ph} / c^2. \tag{6}$$

4) It is a pair of oppositely charged virtual particles. The pair of virtual particles that constitutes a photon of energy $U_{ph} = 2m_e c^2$ can be transformed into an electron-positron pair with total mass $2m_e$ and electric charge $2e$ (without taking the sign into account), and this makes it possible to introduce the following charge/mass ratio between the total charge $2q_{ph}$ (without taking the sign into account) and mass m_{ph} of virtual particles that constitute the photon:

$$e / m_e = 2q_{ph} / m_{ph}. \tag{7}$$

The electric properties of virtual particles are the same as those of real electrically charged particles; consequently the Coulomb attractive force $\left(F_q\right)_{ph}$ acts between them. Under the assumption that the virtual particle size is much less than the distance between the particles (we shall take it to be equal to photon's wavelength $\lambda\!\!\!^{-}_{ph}$), the force $\left(F_q\right)_{ph}$ is determined in the CGS system [1] as:

$$\left(F_q\right)_{ph} = \frac{q_{ph}^2}{\varepsilon_{ph} \cdot \lambda\!\!\!^{-}{}_{ph}^2}, \tag{8}$$

where ε_{ph} is the relative permittivity of the physical vacuum at the location of the virtual particles pair that constitutes the photon.

(In Section 3 it is shown on the basis of derivation of equation for spin-orbit interaction of electron in the atom of hydrogen that equation (7) and the assumption that the distance between the virtual particles in the virtual particles pair equals $\lambda\!\!\!^{-}_{ph}$ are valid.)

The fact that the electrically charged virtual particles in the virtual particles pair are not annihilated shows that between the virtual particles there exists not only the Coulomb attractive force but also a repulsive force (designated here as $\left(F_c\right)_{ph}$) that compensates force $\left(F_q\right)_{ph}$. That is, for either virtual particle in the pair it holds true that

$$\left(\mathbf{F}_q\right)_{ph} = -\left(\mathbf{F}_c\right)_{ph}. \tag{9}$$

Solving simultaneously equations (6)-(9) we obtain the following expression for $\left(F_c\right)_{ph}$: $\left(F_c\right)_{ph} = \dfrac{e^2 \cdot U_{ph}^2}{4 \cdot \varepsilon_{ph} \cdot c^4 \cdot m_e^2 \cdot \lambda\!\!\!^{-}{}_{ph}^2}$. Using in this expression for $\left(F_c\right)_{ph}$ the equation (2) for the Bohr magneton μ_B and expression (5) for photon's wavelength $\lambda\!\!\!^{-}_{ph}$ we obtain:

$$\left(F_c\right)_{ph} = \frac{1}{\varepsilon_{ph}} \cdot \frac{\mu_B^2}{\lambda\!\!\!^{-}{}_{ph}^4}. \tag{10}$$

The structure of equation (10) is similar to the structure of equation determining the force of magnetic interaction of two magnetic dipoles having the magnetic moments equal to μ_B and separated by the distance $\bar{\lambda}_{ph}$. Indeed, the expression for the force of magnetic interaction of virtual particles that constitute the photon (provided every particle has magnetic moment μ_B) is determined in the CGS system as:

$$(F_m)_{ph} = \gamma\mu_{ph} \cdot \frac{\mu_B^2}{\bar{\lambda}_{ph}^4}, \tag{11}$$

where μ_{ph} is the relative magnetic permeability of the physical vacuum at the location of the virtual particles pair that constitutes the photon; γ is the factor of proportionality that depends on the mutual orientation of magnetic moments of virtual particles [1]. The repulsive force acts between the magnetic dipoles if magnetic moments of those dipoles are oriented oppositely along one line connecting the magnetic dipoles ($\leftarrow\rightarrow$ or $\rightarrow\leftarrow$) or parallel to each other ($\uparrow\uparrow$). In experiments, the photon does not exhibit the properties of magnetic dipole whose magnetic dipole moment is $2\mu_B$, and we may assume that the magnetic moments of the virtual particles that constitute the photon are oriented oppositely, that is two cases are possible:

$$(m_{mag})^+_{ph} \leftarrow\rightarrow (m_{mag})^-_{ph}, \tag{12}$$

or

$$(m_{mag})^+_{ph} \rightarrow\leftarrow (m_{mag})^-_{ph}, \tag{13}$$

where $(m_{mag})^+_{ph}$ and $(m_{mag})^-_{ph}$ are respectively the magnetic moment of positively and that of negatively charged virtual particles that constitute the photon. The pair of oppositely charged virtual particles that constitutes the photon is an electric dipole whose electric dipole moment $\mathbf{d}_{ph}$ is directed from the negative virtual particle to the positive one. According to [10], the photon spin is in opposition to the photon electric dipole moment, that is $\mathbf{S}_{ph} \uparrow\downarrow \mathbf{d}_{ph}$. Then in case (12) the mutual orientation of magnetic moment $(m_{mag})^+_{ph}$ and the photon spin $\mathbf{S}_{ph}$, and also that of magnetic moment $(m_{mag})^-_{ph}$ and the photon spin $\mathbf{S}_{ph}$ are the following:

$$(m_{mag})^+_{ph} \uparrow\uparrow \mathbf{S}_{ph}, (m_{mag})^-_{ph} \uparrow\downarrow \mathbf{S}_{ph}. \tag{14}$$

Note that relations (14) are appropriate to the mutual orientation of spin magnetic moment and spin angular momentum of positron and electron respectively [1].

Due to the similarity of expressions (10) and (11) and correspondence of expression (14) to the properties of positron and electron we may suppose that the virtual particles that constitute the photon are magnetic dipoles, the magnetic moment of either being equal to μ_B (the moment does not depend on the photon energy), that is:

$$(m_{mag})^+_{ph} = (m_{mag})^-_{ph} = \mu_B. \tag{15}$$

Thus not only spin $S_{ph}/2$, mass $m_{ph}/2$, charge q_{ph}, but also magnetic moment μ_B should belong to the characteristics of the virtual particles that constitute a photon. In the decay of photon into an electron-positron pair, all characteristics of the virtual particles that constitute the photon are "transferred" to the emerging electron and positron. (Observed in experiments the decay of photon in an electric field [8] may be associated with the violation of equality (9) due to action of the electric field on the charged virtual particles that constitute the photon. In the quantum field theory this phenomenon may be classified as so-called bosonization: creation of fermions from bozons [11]).

2. The derivation of the second summand, $\mu_B(g_e s - 1)$, of the expression (4) determining the electron spin magnetic moment

As shown in Section 2, the first summand in equation (4) for the electron spin magnetic moment determines essentially the property of virtual particles that constitute a photon. Since the second component of the electron spin magnetic moment determined by the second summand in equation (4) exhibits the same properties in the magnetic field (the directions of forces and momenta acting on the electron) as the first component, it is not unreasonable to assume that the second component is a property of virtual particles as well. In this section a proposition is discussed that the second component of the electron spin magnetic moment may be determined by properties of virtual particles pair (virtual photon) created by electron in the physical vacuum.

By analogy with the properties of virtual particles pair that constitutes the photon the properties of virtual particles pair created by electron are determined as follows.

1) It is produced in the region whose size is of the order of magnitude of the photon wavelength $\bar{\lambda}_e$ determined by the electron momentum p_e as [8]:

$$\bar{\lambda}_e = \hbar / p_e. \tag{16}$$

2) It has spin S_v.

3) It has a mass. By analogy with the photon mass (equation (6)), we shall define the virtual particles pair mass m_v through the energy of the entity that created the pair, in the case in question through electron's energy U_e (other than the rest mass energy) as following:

$$m_v = U_e / c^2. \tag{17}$$

4) The virtual particles in the pair have charge. By analogy with the charge of a virtual particle that constitutes the photon (equation (7)), the charge q_v of the virtual particle created by the electron is determined as:

$$q_v = \frac{e \cdot m_v}{m_e \cdot 2}. \tag{18}$$

(Equation (18) is essentially based on the results of experiments conducted by W. Kaufmann on deflection of beta-rays emitted by radium: the mass of electron may be purely of electromagnetic nature [12]. This is in accordance with the conclusion of work [13]: the electron is not an elementary object but a system including, in particular, the classical electromagnetic field as well.)

Like in the case of photon the attractive Coulomb force $\left(F_q\right)_v$ between oppositely charged virtual particles in a pair is compensated by the repulsive force $\left(F_c\right)_v$, that is for either virtual particle in the virtual particles pair it holds true:

$$\left(\mathbf{F}_q\right)_v = -\left(\mathbf{F}_c\right)_v. \tag{19}$$

On the assumption that the size of virtual particles created by electron is much less than the distance between the particles (we shall take it to be equal to electron's wavelength $\lambda\!\!\!^{-}_e$), force $\left(F_q\right)_v$ is determined in the CGS system [1] as:

$$\left(F_q\right)_v = \frac{q_v^2}{\varepsilon_v \cdot \lambda\!\!\!^{-}_e{}^2}, \tag{20}$$

where ε_v is the relative permittivity of the physical vacuum at the location of the virtual particles pair created by the electron.

Using equations (17)-(20), $\left(F_c\right)_v$ can be expressed as $\left(F_c\right)_v = \dfrac{e^2 \cdot U_e^2}{4 \cdot \varepsilon_v \cdot c^4 \cdot m_e^2 \cdot \lambda\!\!\!^{-}_v{}^2}$. If the electron moving at speed u has only kinetic energy, that is:

$$U_e = m_e u^2 / 2, \tag{21}$$

then using equation (16) for $\lambda\!\!\!^{-}_e$ (taking into account that in this case $p_e = m_e u$) and equation (2) for the Bohr magneton in the latter expression for $\left(F_c\right)_v$ we obtain:

$$\left(F_c\right)_v = \frac{1}{\varepsilon_v}\left(\frac{\mu_B \cdot u}{2 \cdot c}\right)^2 / \lambda\!\!\!^{-}_e{}^4. \tag{22}$$

The structure of equation (22) is similar to the structure of equation

$$\left(F_m\right)_v = \gamma \cdot \mu_v \left(\frac{\mu_B \cdot u}{2 \cdot c}\right)^2 / \lambda\!\!\!^{-}_e{}^4, \tag{23}$$

determining (in the CGS system) the force $\left(F_m\right)_v$ of the magnetic interaction of two entities separated by distance $\lambda\!\!\!^{-}_e$ and having magnetic moment $\mu_B u / (2 \cdot c)$; μ_v is the relative magnetic permeability of the physical vacuum at the location of virtual particles pair created by the electron.

In Figure 1 there is a diagram of relative orientation of the respective characteristics of an electron and the virtual particles pair created by the electron. The orientation takes into account the action of electron's electric field on the virtual particles of the pair as on electric charges, and the action of electron's magnetic field on the virtual particles of the pair as on magnetic dipoles, and also that force $\left(F_m\right)_v$ acting between the magnetic dipoles must be a repulsive force.

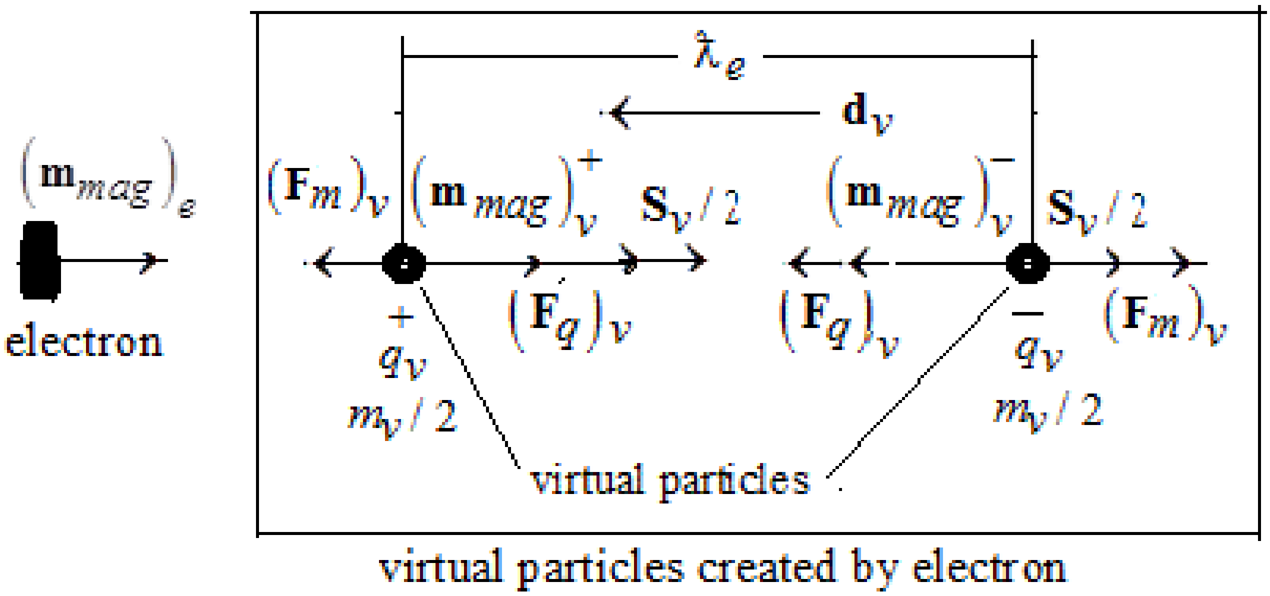

Figure 1. The characteristics of the electron and those of the virtual particles pair created by the electron. m_v is mass; $\mathbf{S}_v$ is spin; q_v is the charge; $\left(\mathbf{F}_q\right)_v$ is the force of electric interaction; $\left(\mathbf{F}_c\right)_v$ is the force of magnetic interaction; $\left(\mathbf{m}_{mag}\right)_v^+$ and $\left(\mathbf{m}_{mag}\right)_v^-$ are respectively the magnetic moment of positively and that of negatively charged virtual particle; λ_e is the distance between the virtual particles; $\mathbf{d}_v$ is the electric dipole moment of the virtual particles pair; $\left(\mathbf{m}_{mag}\right)_e$ is the spin magnetic moment of electron

According to [10] (as well as in the case of photon), the spin $\mathbf{S}_v$ of virtual particles pair created by an electron is in opposition to the electric dipole moment $\mathbf{d}_v$ of the pair, that is $\mathbf{S}_v \uparrow\downarrow \mathbf{d}_v$. From the diagram in **Figure 1** of characteristics of the pair of virtual particles created by the electron it follows:

$$\left(\mathbf{m}_{mag}\right)_v^+ \uparrow\uparrow \mathbf{S}_v, \left(\mathbf{m}_{mag}\right)_v^- \uparrow\downarrow \mathbf{S}_v \tag{24}$$

where $\left(\mathbf{m}_{mag}\right)_v^+$ and $\left(\mathbf{m}_{mag}\right)_v^-$ are respectively the magnetic moment of positively and that of negatively charged virtual particle in the virtual particle pair created by electron.

Due to the similarity between expressions (22) and (23) and correspondence of expression (24) to the properties of positron and electron we may suppose that the virtual particles in the virtual particles pair created by electron are magnetic dipoles, the magnetic moment of either being equal to $\mu_B \dfrac{u}{2c}$, that is:

$$\left(m_{mag}\right)_v^+ = \left(m_{mag}\right)_v^- = \mu_B \frac{u}{2c}. \tag{25}$$

As $\left(\mathbf{m}_{mag}\right)_v^+ = -\left(\mathbf{m}_{mag}\right)_v^-$ at the distance from the virtual particles pair much greater than the pair size, $\lambda\!\!\!^{-}_e$, the total magnetic moment $\left(m_{mag}\right)_v^t$ of the pair equals zero. However, the electron creates a virtual particles pair in the region whose size is of the order of magnitude of its wavelength $\lambda\!\!\!^{-}_e$, consequently for electron $\left(m_{mag}\right)_v^t \neq 0$.

As follows from Figure 1, the value $\left(m_{mag}\right)_v^t$ can be expressed as:

$$\left(m_{mag}\right)_v^t = k_1\left(m_{mag}\right)_v^+ - k_2\left(m_{mag}\right)_v^-, \tag{26}$$

where k_1 is a proportionality factor determining the proportion of magnetic moment $\left(m_{mag}\right)_v^+$ of positively charged virtual particles in $\left(m_{mag}\right)_v^t$; k_2 is a proportionality factor determining the proportion of magnetic moment $\left(m_{mag}\right)_v^-$ of negatively charged virtual particles in $\left(m_{mag}\right)_v^t$. According to the relative orientation of magnetic moments $\left(\mathbf{m}_{mag}\right)_v^+$, $\left(\mathbf{m}_{mag}\right)_v^-$ and $\left(\mathbf{m}_{mag}\right)_e$ (see **Figure 1**), $k_1 =< 1$ and $k_2 > 0$, consequently $k_1 - k_2 < 1$. Then according to equations (25) and (26) we have:

$$\left(m_{mag}\right)_v^t < \mu_B \frac{u}{2 \cdot c}. \tag{27}$$

For example, for the electron in a hydrogen atom in the ground state ($U_e = m_e u^2 / 2 = 13.59$ eV) we have:

$$\left(m_{mag}\right)_v^t < \mu_B \cdot 0.003643972.... \tag{28}$$

According to equation (2), the experimentally obtained value of the second summand, $\mu_B\left(g_e s - 1\right)$, while determining the hyperfine splitting of the ground state of atomic hydrogen, is $\mu_B \cdot 0{,}001159652...$ which does not contradict the condition (28). This allows us to assume that $\left(m_{mag}\right)_v^t$ is equal to the second summand, $\mu_B\left(g_e s - 1\right)$, of the expression (4) determining the electron spin magnetic moment.

Thus taking into account the equality (15) and inequality (27) the equation (4) for electron's magnetic moment, $\left(m_{mag}\right)_e$, may be equivalent to the following equation:

$$\left(m_{mag}\right)_e = \left(m_{mag}\right)_{ph}^- + \left(m_{mag}\right)_v^t.$$

That is the electron's magnetic moment can be seen as a sum of two summands: the first one, the magnetic moment of either virtual particle in the virtual particles pair that constituted the photon whose decay resulted in the creation of the electron in question, and the second one, magnetic moments of virtual particles in the virtual particles pair (virtual photon) created by the electron in the physical vacuum.

3. Electron spin-orbit interaction

In this work, for determining the virtual particle charge (q_{ph} for the virtual particles that constitute a photon and q_v for the virtual particles created by an electron) the respective equations (7) and (18) were introduced. Besides, the assumption was made that the distance between the virtual particles in the virtual particles pair equals the wavelength of the quantum entity creating this pair. The validity of those equations and of this assumption is substantiated by that on the basis of these equations and the above assumption it is possible to derive the experimentally proven equation for spin-orbit interaction of electron in an atom.

As the virtual particles in the virtual particles pair have unlike electric charges, the pair is an electric dipole. Under the assumption that the distance between the virtual particles in the virtual particles pair equals the wavelength of the quantum entity creating this pair, the electric dipole moment d_v of the virtual particles pair created by electron is defined as:

$$d_v = q_v \lambda\!\!\!^{-}_e. \tag{29}$$

Using equations (16)-(18) in (29) we have:

$$d_v = \frac{e \cdot \hbar \cdot U_e}{2 m_e c^2 p_e}. \tag{30}$$

As follows from [10] for the virtual particles pair created by electron moving at velocity **u** ($u \ll c$) it holds that $\mathbf{d}_v \uparrow\uparrow \mathbf{u}$. Assuming that the energy of electron is equal to its kinetic energy (i.e. equation (21) holds and $p_e = m_e u$) and using expression (2) for the Bohr magneton μ_B, the expression (30) can be rewritten as:

$$\mathbf{d}_v = \frac{\mu_B \cdot \mathbf{u}}{2 \cdot c}. \tag{31}$$

In the electric field $\mathbf{E}$ a moment $\mathbf{M}$ will act on the electric dipole: $\mathbf{M} = \mathbf{d}_v \times \mathbf{E}$. Using equations (31) we obtain the expression for moment $\mathbf{M}$:

$$\mathbf{M} = \frac{\mu_B}{2 \cdot c}(\mathbf{u} \times \mathbf{E}). \tag{32}$$

The right side of the expression (32) is the same as that for the spin-orbit interaction energy for the electron in a hydrogen atom: $U_{s-o} = \mathbf{n}\frac{\mu_B}{2c}(\mathbf{u} \times \mathbf{E})$ if $\mathbf{n} \uparrow\uparrow (\mathbf{u} \times \mathbf{E})$, the unit vector $\mathbf{n}$ is aligned with electron's spin magnetic moment. In this case, $\mathbf{E}$ is the electric field strength produced by the nucleus at the location of the electron. The equation for U_{s-o} was derived by L. Thomas with due account of general requirements of relativistic invariance [14]. Note. In this paper, only the electron electric dipole moment connected with the virtual particles pair created by electron is considered, but there are works in which the electron itself is invested with the properties of electric dipole [15].

2. Discussion

From equations (25) and (31) it follows that the electric dipole moment of virtual particles pair created by electron equals the magnetic dipole moment of either virtual particle in the pair. A similar conclusion can be made as well for the virtual particles pair that constitutes a photon. From equation (8) it follows that the electric dipole moment of this pair d_{ph} is determined as $d_{ph} = q_{ph}\lambda_{ph}$ and, using equations (2) and (5)-(7), we obtain $d_{ph} = \mu_B$. According to equation (15), d_{ph} equals the magnetic dipole moment of either virtual particle in the virtual particles pair that constitutes the photon.

Thus we may draw the following conclusion. For the virtual particles pair created by any quantum entity, the magnitude of electric dipole moment of the pair is equal to the magnitude of magnetic moment of either virtual particle in the pair.

3. Conclusion

I. The spin magnetic moment of electron may be represented as a sum of two summands: $\mu_B + \mu_B(g_e s - 1)$ (μ_B is the Bohr magneton, g_e is the electron g-factor, $s = S_e / \hbar$, where $S_e = \hbar / 2$ is electron's spin angular momentum).

The first component of spin magnetic moment of electron (μ_B) is a property of photon, particularly it is the magnetic moment of either virtual particle in the virtual particles pair that constitutes the photon. In the photon decay into an electron-positron pair there takes place a "transfer" of the magnetic moment from the photon to the emerging electron and positron.

The second component of spin magnetic moment of electron $\mu_B(g_e s - 1)$ may be determined by magnetic moments of virtual particles in the virtual particles pair (virtual photon) created by the electron in the physical vacuum.

Thus both components of spin magnetic moments of electron are essentially determined by the properties of photons: the photon that has created the electron (in the photon decay into an electron-positron pair) and the virtual photon (the virtual particles pair) created by the electron in the physical vacuum.

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