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A Description of the Properties of Electrons in an Atom without Mathematical Tools of Wave-Particle Dualism

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ABSTRACT

The aim of the work is to show that the study of following properties of electrons in atoms: stability of motion, the Pauli exclusion principle; the effect of electrons state (singlet or triplet) in hydrogen atoms on creating from them of the hydrogen molecule, - can be carried out based on concepts of classical mechanics (forces, moments). The contemporary investigation of topic "The Properties of Electrons in Atoms" is based on concepts of quantum mechanics, in particular on notions of electron wave function having probabilistic character. However, it is very difficult to perform the exact description of deterministic processes from the standpoint of probability theory.

It has been proven in this work that description of properties of electrons in atom may be performed with using the concept of virtual photons created by the considered electrons. The concept of virtual photons was developed by Nobel Prize winner R. Feynman in 1949; one of the main properties of virtual photons is their ability to interact with each other by electric dipole interaction.

The virtual photon is a unique object: except deterministic characteristic-(electric dipole moment) it has one of the attributes of wave function of the quantum object that created the virtual photon: the size of virtual photon equals the wavelength of this quantum object wave function. This is the reason why the description of properties of electrons in atom based on the concept of virtual photon created by atomic electrons is in accordance with some conclusions of quantum mechanical description of those properties.

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Introduction

Let us consider the simplest composition of an atom: electron and nucleus-proton, that is, the hydrogen atom. From the standpoint of classical mechanics, the problem is that an accelerated moving electron radiates electromagnetic oscillations and thus loses kinetic energy and, consequently, speed. Thus, a question arises: "Why doesn't the electron fall on the nucleus?"

Except of stability of motion of electron, the following properties of electrons in atoms are considered in this work: the Pauli exclusion principle (dependence of interaction of electrons on mutual orientation of their spins); the effect of the electrons state (with total unit or zero spin) in hydrogen atoms on a possibility of creation from them of the hydrogen molecule [1]. In these cases, a question arises: "Why does the force interaction between electrons depend on the mutual orientation of their spins?"

The contemporary investigation of interaction of electrons in atom is based on concepts of quantum mechanics, in particular, on characteristics of wave function of these electrons [1]. That is, the explanation of experimental data is produced without introduction of any forces, only by using the characteristics of electron wave function having probabilistic character.

The answers to the above-mentioned questions may be received on condition of using Feynman's hypothesis of virtual photons for explanation of properties of electron in atom. In 1949, Nobel Prize winner R. Feynman proposed a hypothesis according to which electric and magnetic interactions are accomplished by so-called virtual photons consisting of a pair of electric oppositely charged virtual particles having precessing spin [2], that is, being spin vortices.

The size of virtual photon is assumed to be equal to wavelength λ_q of wave function of quantum object that created the virtual photon. This property explains why the description of properties of electrons in atom based on the concept of virtual photons created by those electrons is in accordance with some conclusions of quantum mechanical description of those properties.

In 2020, the investigation by H. Li and others [3] was conducted supporting the hypothesis of Feynman, "We report the quantized superfluid vortex filaments induced by the axial flow effect". Really, the superfluid medium in investigation by H. Li characterized by intrinsic angular momentum is similar to the physical vacuum characterized by "zero-point energy" [4]. Thus, it follows from the investigation by H. Li that the motion (at velocity $\mathbf{u}$) of quantum object can be followed by "quantized superfluid vortex filaments", in particular, by spin vortex (virtual photon). Consequently, the following relation exists:

$$\mathbf{u} \sim \boldsymbol{\omega}_v, \qquad (1)$$

where $\mathbf{u}$ is a velocity of quantum object, $\boldsymbol{\omega}_v$ is a frequency of precession of spin $\mathbf{S}_v$ of spin vortex (virtual photon) created by quantum object.

The work contains the following Sections.
1. The Properties of Virtual Photons
2. The Interaction of Electron with Nucleus
3. The Formation of Molecule of Hydrogen
4. Features of Electron Interaction in Atom
4.1. Pauli exclusion principle
4.2. Interaction of electrons in p-state
5. Discussion
6. Conclusion

1. The Properties of Virtual Photons

According to hypothesis of Feynman, a virtual photon consists of two electric oppositely charged virtual particles, essentially, it is an electric dipole (with electric dipole moment $\mathbf{d}_v$) and it is formed in the area the size δ of which is equal to wavelength λ_q of wave function of quantum object creating the virtual photon

$$\delta = \lambda_q . \qquad (2)$$

Thus, $\mathbf{d}_v$ is defined by expression:

$$d_v = q_v \lambda_q , \qquad (3)$$

where q_v is an electric charge of virtual particle – of the virtual photon component.

In quantum mechanics, the wavelength of wave function of quantum object is determined by its momentum p_q [5]:

$$\lambda_q = \hbar / p_q = \hbar / \left(m_q u\right), \qquad (4)$$

where u and m_q are respectively speed and mass of quantum object.

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

$$m_v = U_q / c^2, \qquad (5)$$

where U_q is the energy of quantum object creating the virtual photon.

Based on the results of experiments conducted by Kaufmann [6] on the deflection of beta-rays emitted by radium, which showed that the mass of electron m_e is purely of an electromagnetic nature, we assume that the same is valid for the virtual particles that make up the virtual photon with mass m_v: that is, the following holds: $e/m_e = 2q_v/m_v$ (e is the electric charge of electron). From the latter expression, we obtain the expression for q_v:

$$q_v = em_v/(2m_e). \quad (6)$$

Solving together Eqs (2)-(6) and using the formula for magneton of Bohr $\mu_B = e\hbar/(2m_e c)$, we obtain the following expression for electric dipole moment d_v of virtual photon created by electron:

$$d_v = \mu_B U_q/(cp_q). \quad (7)$$

Taking the energy of the electron equal to its kinetic energy ($U_q = m_e u^2/2$) and taking into account: $p_q = m_e u$ we obtain from Eq. (7):

$$d_v = \mu_B u/(2c). \quad (8)$$

As shown in [7], electric dipole moment $\mathbf{d}_v$ of virtual photon is related to its spin $\mathbf{S}_v$ as:

$$\mathbf{d}_v \uparrow\uparrow \mathbf{S}_v. \quad (9)$$

According to the properties of gyroscopes [8], moment $\mathbf{M}_v$ causing the precession motion of spin $\mathbf{S}_v$ with frequency $\boldsymbol{\omega}_v$ satisfies the condition:

$$\mathbf{M}_v = \boldsymbol{\omega}_v \times \mathbf{S}_v. \quad (10)$$

The electric field of quantum object acts on a virtual photon (as on electric dipole) produced by this object and following it. Consequently, the orientation of electric dipole moment of virtual photon is determined by the sign and by the direction of velocity **u** of the quantum object that creates the virtual photon. Thus, with taking into account the equations (1), (9) and (10) we have:

$$\boldsymbol{\omega}_v \uparrow\downarrow \eta\mathbf{u}, \quad (11)$$

$$\eta = \begin{cases} 1, & \textit{for positively charged quantum object} \\ -1, & \textit{for negatively charged quantum object} \end{cases}; \quad (12)$$

As shown in [7]:

$$\boldsymbol{\omega}_v \uparrow\uparrow \mathbf{S}_q, \quad (13)$$

where $\mathbf{S}_q$ is spin of quantum object creating the virtual photon.

In Figure 1 is given a schematic representation of characteristics (Eqs (9) – (13)) of virtual photon produced by electron.

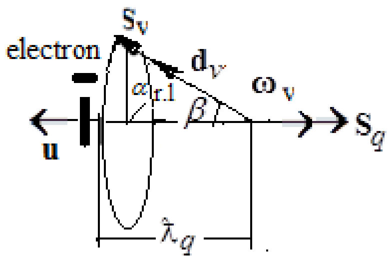

Figure 1: The schematic representation of a virtual photon created by electron. $\boldsymbol{\omega}_v$ is the frequency of precession of spin $\mathbf{S}_v$, β is the angle of deflection, **u** is the velocity, $\mathbf{S}_q$ is spin of electron, λ_q is wavelength of electron's wave function, r.l. is a reference line, α is an angle of precession.

The angle of deflection β (angle between vectors $\mathbf{S}_v$ and $-\boldsymbol{\omega}_v$) is determined as [7]:

$$\sin\beta = u/c. \quad (14)$$

According to results of Weber's experiment [9], β equals $\pi/2$ for photon, that is, in this case $\sin\beta = 1$. It follows from Eq. (14) that when the speed of virtual photon is equal to the speed of light, the irradiation of photon by quantum object takes place. This effect is observed and called

"Cherenkov effect" [10]: radiation of photon by quantum object moving at a speed not less than the speed of light.

Note: It is possible that radiation of photon by atom during its transition from one energetic atom's level to another may be "Cherenkov effect" if this transition is the spatial movement of electron of atom at a speed not less than the speed of light.

2. The Interaction of Electron with Nucleus

Let us consider the simplest atom - hydrogen (electron and nucleus-proton) and prove that formula (8) determining electric dipole moment of virtual photon is in agreement with the properties of electron in atom of hydrogen. Let us consider some properties.

1) The spin-orbit interaction of electron in atom of hydrogen.

Due to the existence of electric dipole moment $\mathbf{d}_v$, there is the spin-orbit interaction of quantum object creating the virtual photon with the electric field in which the object moves. As an example, let us consider the spin-orbit interaction of electron in the atom of hydrogen. In electric field $\mathbf{E}_n$ of nucleus, moment $\mathbf{M}_n$ acts on $\mathbf{d}_v$: $\mathbf{M}_n = \mathbf{d}_v \times \mathbf{E}_n$. The speed u of electron in hydrogen atom is determined as: u=2.2 10^6 m/s [1], that is, $u \ll c$; then from condition (9), (11)-(12) and (14) it follows: $\mathbf{d}_v \uparrow\uparrow \mathbf{u}$. The expression for $\mathbf{M}_n$, with using Eq. (8) and condition $\mathbf{d}_v \uparrow\uparrow \mathbf{u}$, is the same as for the maximum, experimentally tested value of the spin-orbit interaction energy U_{s-o} of the electron: $\left(U_{s-o}\right)_{\max} = \left|\mu_B \left(\mathbf{u} \times \mathbf{E}_n\right) / (2c)\right|$ (the expression was derived by L. Thomas based on the general requirements of relativistic invariance [11]).

2) One of the fundamental properties of an atom is stability of the electron's orbit. In classical mechanics, there is no answer to question: "**Why doesn't an electron fall to the nucleus** under the action of Column force?" In quantum mechanics, stability of the electron's orbit in atom is explained by the multiplicity of the size of an electron's orbit to wavelength λ_q of its wave function. However, the force should be compensated by other force; the condition of the multiplicity of the size of an electron's orbit to wavelength λ_q of its wave function is only a concomitant effect based on the following hypothesis of Feynman: the size of virtual photon equals wavelength $\lambda\!\!\!^-_q$ of electron that created the virtual photon (see Eq. (2)). The motion of an electron relative to the nucleus is accelerated, therefore, the electron during this motion can radiate electromagnetic oscillations and, consequently, it loses kinetic energy gradually approaching the core. Thus, velocity $\mathbf{u}_y$ of electron directed to nucleus emerges, and according to equation (8), it results, under the condition $\mathbf{u}_y \ll c$, in appearance of component of electric dipole moment directed to nucleus: $\mathbf{d}_y \uparrow\uparrow \mathbf{u}_y$. In inhomogeneous electric field $\mathbf{E_y}$ of atom's nucleus, repulsive force $\mathbf{F}_{r\mathbf{y}}$ will act on electric dipole moment $\mathbf{d}_y$. $\mathbf{F}_{r\mathbf{y}}$ is determined by expression [12]:

$$\mathbf{F}_{r\mathbf{y}} = \mathbf{d_y}\left(\partial \mathbf{E_y} / \partial \mathbf{y}\right) = 2\mathbf{d_y} e / y^3, \qquad (15)$$

where e is the charge of hydrogen nucleus: of proton.

Let us determine the distance y_v between virtual photon, created by electron, and nucleus, in which case repulsive force $\mathbf{F}_{r\mathbf{y}}$ between electron and nucleus is equal to attractive force $\mathbf{F}_{a\mathbf{y}} = \mathbf{y} e^2 / y^3$ between them. From equality $\mathbf{F}_{r\mathbf{y}} = \mathbf{F}_{a\mathbf{y}}$, with using equation (15), we obtain:

$$y_v = 2 d_y / e. \qquad (16)$$

Taking into account equations (2), (4), (8) and (16) we obtain the following expression for radius R of electron orbit: $R = \lambda\!\!\!^-_q + y_v = \hbar / \left(m_e u_y\right) + \mu_B u_y / (ce)$.

Assume that u_y equals the value of electron speed u in atom of hydrogen (in an undisturbed state) [1]

$u = 2.1857\ 10^6 m/s$, we obtain the following value R: $R = \bar{\lambda}_q + y_v = \hbar/(m_e u) + \mu_B u/(ce)$.

$$= (0.529\ 10^{-10} + 0.14110^{-14})m. \qquad (17)$$

Thus, calculated value R is almost equal to an experimentally and theoretically proven value $0.529\ 10^{-10} m$ [1], that is, equal to the wavelength of wave function of electron, which corresponds to the principles of quantum mechanics.

A diagram illustrating the interaction of virtual photon created by electron with nucleus is given in Figure 2.

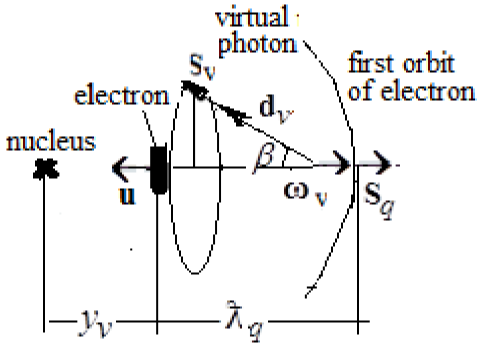

Figure 2: A diagram illustrating the interaction of virtual photon created by electron with nucleus. $\boldsymbol{\omega}_v$ is the frequency of precession of spin $\mathbf{S}_v$, β is the angle of deflection, **u** is the velocity, $\mathbf{S}_q$ is spin of electron, $\bar{\lambda}_q$ is the wavelength of electron's wave function; $\mathbf{d}_v$ is the electric dipole moment; y_v is the distance between virtual photon created by electron and nucleus.

3. The Formation of Molecule of Hydrogen

Hydrogen atoms form hydrogen molecules if electrons, that make up these atoms, have antiparallel spins $\mathbf{S}_q$ (↑↓), that is, they are in singlet state [1]. Hydrogen atoms do not form hydrogen molecules if electrons, that make up these atoms, have parallel spins $\mathbf{S}_q$ (↑↑), that is, they are in triplet state [1]. According to Eqs (9)-(10) and (13) the mutual orientation of electrons spins influences mutual orientation of electric dipole moments of virtual photons created by these electrons. That is, electric dipole moments $\mathbf{d}_v$ of virtual photons created by electrons in singlet state are oriented as (↑↓); electric dipole moments $\mathbf{d}_v$ of virtual photons created by electrons in triplet state are oriented as (↑↑).

The schematic images of a virtual photons created by electrons in singlet and triplet states are given, respectively, in Figure 3 and in Figure 4.

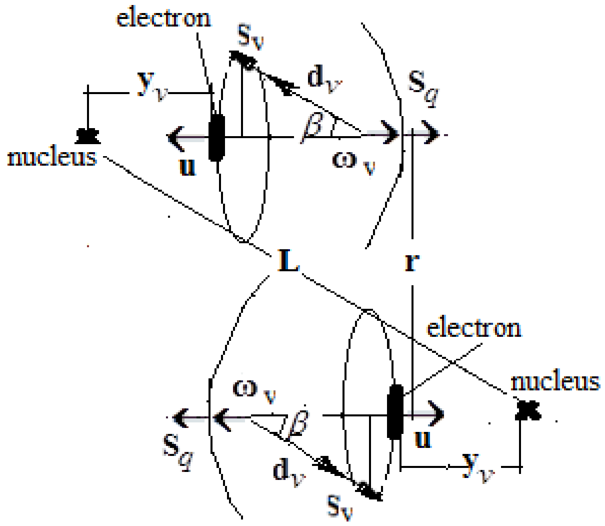

Figure 3: The schematic image of virtual photons created by electrons of atoms. $\boldsymbol{\omega}_v$ are the frequencies of precession of spins $\mathbf{S}_v$, β are the angles of deflection, **u** are the velocities, $\mathbf{S}_q$ are spins of electrons. L is the distance between nuclei of molecule, r is the distance between electrons, y_v is the distance between virtual photon and nucleus.

Note that in the considered case, according to Eqs (9)-(13), spins of electrons $\mathbf{S}_q$ also as spins of virtual photons $\mathbf{S}_v$ created by these electrons are oriented antiparallel. The attractive force F acting in this case between virtual photons is a result of interaction of their electric dipoles and is determined by expression [12]:

$$F = \left| 3d_v^2 \cos^2 \beta / r^4 \right|. \qquad (18)$$

The energy of this interaction is determined as:

$$W = -d_v^2 \cos^2 \beta / r^3. \qquad (19)$$

Using Eqs (8) and (14) in Eq. (19) we obtain the following expression:

$$W=-\mu_B^2u^2(1-u^2/c^2)/\left(4c^2r^3\right). \quad (20)$$

According to Figure 3, $r=\sqrt{L^2-R^2}$. Using the following data in expression for W: Eq. (17) for R, the value of distance L between nuclei of hydrogen molecule [1] $\left(L=0.7416 \cdot 10^{-10}m\right)$, the value of speed u of electron in atom of hydrogen (in undisturbed state) $u=2.1857\ 10^6 m/s$, the values of constants μ_B and c, we obtain from Eq. (20): $W\sim-10^{-9}eV$. Thus, the energy of interaction of electrons in atom increases the negative energy of hydrogen molecule (see Figure 5).

If spins of atom's electrons are parallel ($\uparrow\uparrow$) (electrons are in triplet state [1], Figure 4) the repulsive force acts between virtual photons created by electrons of these atoms. Consequently, in this case the molecule of hydrogen is not formed.

The value of force between virtual photons created by atom's electrons with parallel spins is described by formula (18). The energy of interaction of virtual photons in this case is described by the expressions (19) and (20), but with positive signs.

Schematic image of virtual photons created by atoms electrons in triplet state is shown in Figure 4.

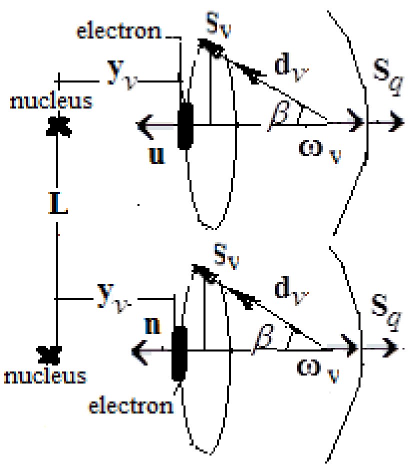

Figure 4: The schematic image of virtual photons created by electrons of two atoms. $\boldsymbol{\omega}_v$ are the frequencies of precession of spins $\mathbf{S}_v$, β are the angles of deflection, **u** are the velocities, $\mathbf{S}_q$ are spins of electrons, L is the distance between nuclei of molecule, y_v is the distance between virtual photon and nucleus, $\mathbf{d}_v$ are electric dipole moments.

Figure 5 contains a graph of dependence of energy W of interaction of two hydrogen atoms on distance $\boldsymbol{r}$ between them; they are considered singlet (red line) and triplet states (black line). Respectively, in singlet state hydrogen molecule is formed, in triplet state the hydrogen molecule is not formed [1].

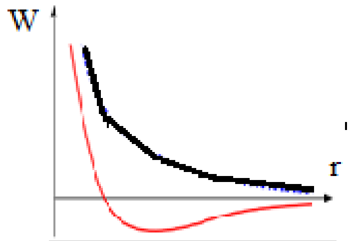

Figure 5: The graph of dependence of energy W of interaction of two hydrogen atoms on distance $\boldsymbol{r}$ between them; red line for singlet state; black line for triplet state.

4. Features of Electrons Interaction in Atom

4.1. Pauli exclusion principle

Pauli exclusion principle declares that two electrons in atom may not have similar values of their quantum numbers: at least one value must be different [13]. For example, if two electrons are in the same orbital and the values of three quantum numbers: n(main), l(orbital), m(magnetic) — are equal, the values of quantum numbers ms(projection of spin) should be different. That is, electrons must have opposite values of spins: 1/2 and −1/2.

Essentially, Pauli exclusion principle is a result of interaction of virtual photons created by electrons of atom. As shown in Figure 6, attractive force $\mathbf{F}_a$ acts between electrons with oppositely oriented spins (Figure 6a) and repulsive force $\mathbf{F}_r$ acts between electrons with parallel oriented spins (Figure 6b). The values of both forces are determined by formula (18). The value of energy associated with these forces is determined by formula $W = \left| d_v^2 \cos^2 \beta / r^3 \right|$. For attractive force $\mathbf{F}_a$ $W < 0$; for repulsive force $\mathbf{F}_r$ $W > 0$

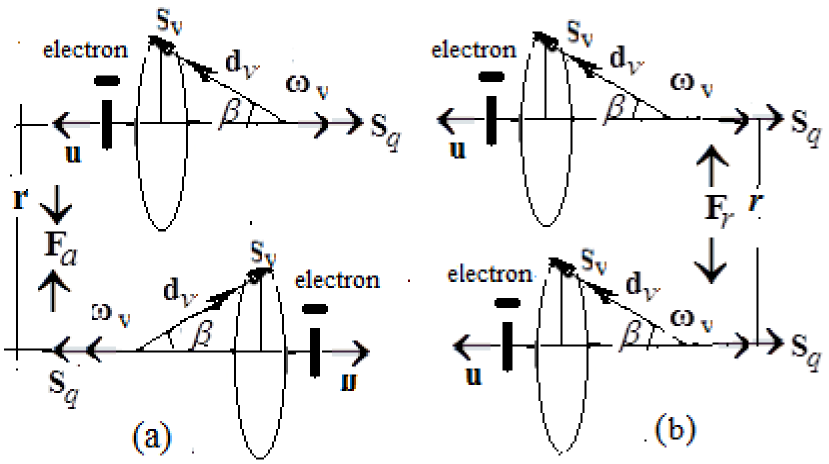

Figure 6: The schematic image of virtual photons created by electrons of two atoms. Between these electrons, attractive force $\mathbf{F}_a$ acts in case (a) and repulsive force $\mathbf{F}_r$ acts in case (b).

Pauli exclusion principle is valid for any quantity of atomic electrons, see (Figure 7)**.**

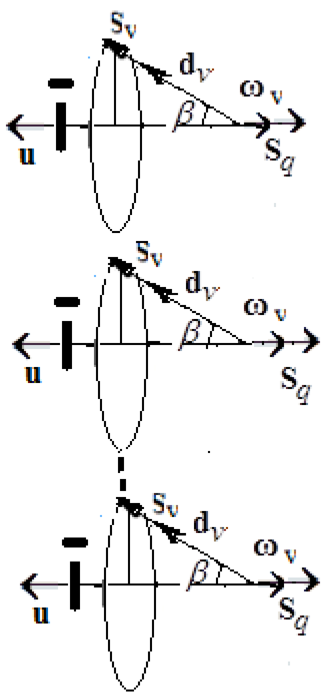

Figure 7: The ensemble of virtual photons created by electrons with spins $\mathbf{S}_q$; $\boldsymbol{\omega}_v$ are frequencies of precession of spins $\mathbf{S}_v$ of virtual photons; $\mathbf{d}_v$ are electric dipole moments of virtual photons; **u** are velocities of virtual photons (consequently, of electrons as well); β are angles of deflection.

A repulsive force acts between any two virtual photons presented in this Figure.

4.2. Interaction of electrons in p-state

The two electrons in p – state have spins $\mathbf{S}_q$ oriented along one straight line ($\rightarrow\rightarrow$) and their total spin equals one. According to Eqs (9)-(10) and (13), the mutual orientation of electrons spins influences mutual orientation of electric dipole moments of virtual photons created by these electrons. That is, electric dipole moments $\mathbf{d}_v$ of virtual photons created by electrons in p – state are oriented as ($\rightarrow\rightarrow$).

The schematic image of characteristics of virtual photons created by electrons in p – state is given in Figure 8.

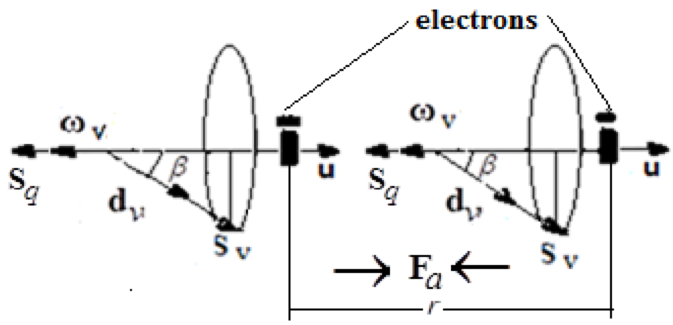

Figure 8: The schematic image of virtual photons created by two electrons in p-state. $\boldsymbol{\omega}_v$ are the frequencies of precession of spins $\mathbf{S}_v$, β are the angles of deflection, **u** are the velocities, $\mathbf{S}_q$ are spins of electrons, r is the distance between nuclei of molecule, $\mathbf{d}_v$ are electric dipole moments, $\mathbf{F}_a$ is an attractive force.

According to [12], between electric dipoles there is force F, which for the versions of mutual orientation of electric dipole moments presented in Figure 8 is determined by expression $F = \left|6d_v^2 \cos^2 \beta / r^4\right|$. The energy of this interaction is as follows:

$$W = -2d_v^2 \cos^2 \beta / r^3. \qquad (21)$$

It follows from equations (20) and (21) that the value of energy of attraction of virtual photons produced by electrons in p-state may be greater than the value of energy of attraction of virtual photons produced by electrons in singlet state (s-state).

5. Discussion

1) It follows from the above-considered examples that description of physical phenomena with using the conception of virtual photons created by quantum objects that make up an atom leads to the same results as those of quantum-mechanical description of phenomena based on wave-particle dualism.

This coincidence is based on a well-founded theoretical proposition [7,14]: the wave properties of quantum object (wavelength is $\lambda\!\!\!^{-}_q$, frequency is ω_q and phase is α_q) are respectively the characteristics of virtual photon created by this quantum object (size of virtual photon is $\lambda\!\!\!^{-}_q$, frequency of precession of its spin is ω_v, angle of precession of its spin is α ; see Figure 1).

Therefore, the wave associated with a quantum object is the precessional fluctuations of spin of virtual photon created by this quantum object.

2) It is possible that the radiation of photon during energy-level transition is a result of Cherenkov effect [10], if this transition is the spatial movement of electron of atom with the speed greater than the speed of light.

3) It follows from [15] that using the Schrodinger equation from the point of view of stability theory, the ensemble of possible precession frequencies of spins of virtual photons created by electrons of an atom can be interpreted as an emission and absorption spectrum of an atom.

6. Conclusion

1. The electron moving in atom radiates electromagnetic oscillations and thus it loses kinetic energy. Under these conditions, the stability of electron orbit can be explained by existence of interaction between virtual photon created by this electron and atom nucleus.

2. The molecule of hydrogen emerges as a result of action of attractive force between virtual photons created by electrons of the atoms that make up the hydrogen molecule.
3. The Pauli exclusion principle is due to existence of repulsive force between virtual photons created by electrons with total unit spins $(\uparrow\uparrow)$.

4. The description of properties of atom based on the concept of virtual photons created by atomic electrons leads to the same results as quantum mechanical description of those properties. The reason is that the wave properties of quantum objects are simultaneously the characteristics of virtual photons created by those quantum objects.

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