SciFed Journal of Spintronics & Quantum Electronics 2018, 1:2 (11 pages).
SF J Spin Quant Elect, 2018, 1:2 (11 pages).
https://www.scifedpublishers.com/open-access/the-concept-of-spin-in-the-submicroscopic-description.pdf

The concept of spin in the submicroscopic description

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Abstract

A short review of recent studies of the notion of spin is presented, which shows that the spin is not a point property of the particle in question but a characteristic that covers a quite large volume around the particle and also involves the interaction of the particle with the ambient space. A cloud of excitations named *inertons* by the author, which accompany the moving particle, carry out the interaction of the particle with the space and hence the interaction with another particle. The presence of inertons allows us to completely resolve the old problem of spin associated with the reasons that provide the appearance of half-integer angular momentum ½$\hbar$. Besides, it allows one to learn more on the behavior of canonical particles in external fields, such as magnetic, electromagnetic and also inerton.

Key words: spin, electron, angular momentum, wave function, inertons

1. Introduction

There are many works devoted to the study of different aspects associated with the notion of spin (see, e.g. monograph [1] and references herein), which usually is treated as an intrinsic form of angular momentum carried by an electron or another elementary particle. Spin is considered like a vector quantity, which is an inner property of a particle and this characteristic is rather isotropic for a free particle. At the same time, spin has a definite magnitude and orientation, but quantization makes this orientation different from that of an ordinary vector.

The Dirac's theory of the electron seems the most suitable for the description of spin and magnetic moment of the electron and atoms including atoms in condensed media, and such a situation is not in contradiction with Pauli's exclusion principle, which showed detailed experimental and theoretical studies of Oudet and Lochak [2]. In his further work on spin, Oudet [3-8] discussed the Dirac equation for the half integer spin and angular momentum. He notes that according to the solutions of the Dirac equation, it is clear that the *n*s states correspond to just one spin state, contrary to that is generally supposed. The two sub-shells of the *n*p, namely, *n*d and *n*f shells correspond to an additional quantum state to that of the *n*s states with a different number of states, which is exhibited with the Zeeman effect. Besides, Oudet notes that the same situation takes place at the calculation of the magnetic moment of different compounds.

Oudet [3-8] notes that such a behavior of spin is different from the classical notion of spin introduced by Uhlenbeck and Goudsmit [9] who proposed spin just to explain the two subshells

np*:* nd and nf. Recall that according to Uhlenbeck and Goudsmit [9], the spin of a particle behaves like an angular momentum and, therefore, has an associated magnetic moment $\mathbf{M}_\mathrm{s} = g\mu_\mathrm{B}\mathbf{S}/\hbar$ where $\mathbf{S}$ is the spin operator, g is a constant introduced to produce the best fit with experiment. The interaction with a magnetic field is proportional to $\mathbf{M}_\mathrm{s} \cdot \mathbf{B}$ (this is the basis of the NMR technique). It is found that good fits to experimental data are obtained when $g = 2$, which means that the spin gyromagnetic ratio $g\mu_\mathrm{B}/\hbar$ is twice as large as the orbital gyromagnetic ratio $\mu_\mathrm{B}/\hbar$.

Based on his experiments Oudet [3-7] showed that in the Dirac equation all the spinor components ψ_j ($j = \overline{1,4}$) could be regarded as being an exchange by "grains" between the electron and its field, where he understood a "grain" to be an element of the total electron mass. So Oudet's studies insist on involving some intrinsic processes inside the electron, which are responsible for its spin. He reasons that the action associated with rotation of the electron in an hydrogen atom cannot be correctly described by the product of two vectors, the momentum $\boldsymbol{p}$ and displacement $d\mathbf{l}$, which lie in one plane. These two vectors must necessarily have two components in orthogonal planes so that the action results from exchanges in volume, i.e. the plane rotation has been the result of two orthogonal rotations. Thus only when the momentum $\boldsymbol{p}$ is decomposed into two components, Oudet [6] easily derives the half-integer angular momentum $M = ½\hbar$. He [9] further says that there is always the same number of negative and positive values of the angular momentum, but the contribution proportional to $½\hbar$ has always the same direction. This half-integer contribution is associated to the own rotation of the electron and such spin contribution is always positive. Accordingly there is just one kind of spin but two different sub-shells.

Oudet [6] pointed out that half-integer numbers belonging to the model of Dirac consequently consolidated the assumption of spin, however, the Dirac approach describes the properties of a point. Although the studies performed to date show that the property of spin is associated rather with particle's own rotation. Oudet emphasized that the own rotation of the electron is a characteristic of volume and the study of the properties of a point in classical mechanics or special relativity do not reveal the characteristics of this volume. The concept of spin escapes Dirac's theory just as the theory of Sommerfeld.

Thus, spin, which gives the half-integer angular momentum, is simultaneously a point-like solution of the Dirac equations and the solution of the complicated motion of the electron in orbit, as shown by Oudet.

We can also mention recent studies of Olszewski [10] who considers the mechanical angular momentum and magnetic moment of the electron and proton spin using the uncertainty principle for energy and time. In his model the spin effect is treated as a consequence of the introduced size of the electron (or proton), which is chosen to be equal to the particle's Compton wavelength. Such a hypothesis then allowed him to reconsider the spin motion on the basis of the old quantum theory, which gave a quantum number $n = ½$ as the index of the spin state acceptable for the electron and proton. However, though the quantum number is suitable with the experimental data, a helical trajectory suggested for the electron in the hydrogen atom looks very disputable (no any reasonable potential has been given to keep the electron in such a path).

In the present paper we consider the spin as it follows from a submicroscopic theory of space developed by the author [1]. The major principles of the motion of a particle in space constructed as a mathematical lattice of primary topological balls is described and it is shown how the particle's wave ψ-fucntion is interpreted in the real space, what are its content and structure. The appearance and properties of the spin are considered in the smallest detail.

2. The electron as an extended object

Recently Hofer [11, 12] examining his own experiments has proposed a theory of extended electrons in which their wave properties are related to some form of density oscillation. In his theory a free electron traveling along the z-axis with a constant velocity υ undergoes a density oscillation, which is described by a plane wave $\rho(z,\ t) = \frac{1}{2}\rho_0 \cdot [1 + \cos(4\pi z/\lambda - 4\pi\nu t)]$ and then the Schrödinger wave function is determined as

$$\psi = \sqrt{\rho_0}\exp[i(2\pi z/\lambda - 2\pi\nu t)]. \tag{1}$$

The spin of an electron is defined as

$$\psi\mathbf{e}_2\psi^+ = \rho_0 \cdot [\mathbf{e}_2 + \sin(2\pi z/\lambda - 2\pi\nu t)\mathbf{e}_1] \tag{2}$$

where the directions of the reference vectors $\mathbf{e}_1$ and $\mathbf{e}_2$ are perpendicular to the direction of electron motion. Thereby the spin vector has the form $\mathbf{s} = \frac{1}{2}\ \psi\mathbf{e}_2\psi^+$ and is oriented under an angle of $\pi/4$ to the direction of the electron velocity vector. Thus Hofer, using geometric algebra, or Clifford algebra determined the spin of an electron with respect to the velocity vector of the electron, i.e. as a property of the electron itself, but not with respect to the external magnetic field. Spin-properties of the electron are referred to intrinsic field components and such description satisfies the measurements of spin in an external field yielding the two possible opposite orientations. Hofer's theory allows the consideration of spin-dynamics of single electrons in terms of a modified Landau-Lifshitz equation, which is in agreement with experimental manifestations of spin. Thus, Hofer's approach demonstrates the importance of the internal structure of the electron in understanding the notion of spin.

Lévy-Leblond [13] (see also Ref. 14) performed an important research – he linearized the Schrödinger equation. He started from the Schrödinger equation written in the operator form

$$\hat{S}\psi = 0, \qquad \hat{S} \equiv i\hbar\frac{\partial}{\partial t} + \frac{\hbar^2}{2m}\Delta = \hat{E} - \hat{\mathbf{p}}^2/(2m). \tag{3}$$

The equation is symmetric with respect to time ($\partial/\partial t$) and space ($\partial/\partial\mathbf{r}$) derivatives, but is quadratic in $\hat{\mathbf{p}}$. To reach the symmetry, Lévy-Leblond constructed a wave equation in the form

$$\widehat{\Theta}\psi = \left(\hat{A}\hat{E} + \widehat{\mathbf{B}} \cdot\ \hat{\mathbf{p}} + \hat{C}\right)\psi = 0 \tag{4}$$

where $\hat{A}$, $\widehat{\mathbf{B}}$ and $\hat{C}$ are linear operators, rather than matrices. This allows him to split the Schrödinger equation to four linear equations

$$\left[-i\begin{pmatrix} 0 & 0 \\ \mathbf{1} & 0 \end{pmatrix}\hat{E} + \begin{pmatrix} \hat{\boldsymbol{\sigma}} & 0 \\ 0 & \boldsymbol{\sigma} \end{pmatrix} \cdot \hat{\mathbf{p}} + 2mi\begin{pmatrix} 0 & \mathbf{1} \\ 0 & 0 \end{pmatrix}\right]\begin{pmatrix} \phi \\ \eta \end{pmatrix} = 0. \tag{5}$$

Here, the wave ψ-function becomes a 4-component matrix in which

$$\phi = \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}, \quad \eta = \begin{pmatrix} \eta_1 \\ \eta_2 \end{pmatrix}. \tag{6}$$

$\hat{\boldsymbol{\sigma}}$ is the vector whose components are the three Pauli matrices, $\hat{\boldsymbol{\sigma}} = \{\hat{\sigma}_1,\ \hat{\sigma}_2,\ \hat{\sigma}_3\}$ and

$$\mathbf{1} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \tag{7}$$

is the unit matrix. Writing the matrix equations (5) results in the coupled system of equations for two-component spinors $\phi = (\phi_1,\ \phi_2)$ and $\eta = (\eta_1,\ \eta_2)$:

$$\hat{\boldsymbol{\sigma}} \cdot \hat{\mathbf{p}}\, \phi + i2m\eta = 0, \qquad \hat{\boldsymbol{\sigma}} \cdot \hat{\mathbf{p}}\, \eta - i\hat{E}\phi = 0. \tag{8}$$

In the presence of an external electromagnetic field, the gauge invariance of the Schrödinger equation requires the known substitution

$$\frac{i\hbar\partial}{\partial t} \rightarrow \frac{i\hbar\partial}{\partial t} - eV(\mathbf{r},\ t), \qquad -i\hbar\nabla \rightarrow -i\hbar\nabla - e\mathbf{A}(\mathbf{r},\ t) \tag{9}$$

and then the linear equations of motion (8) become

$$\hat{\boldsymbol{\sigma}} \cdot (\hat{\mathbf{p}} - e\mathbf{A})\, \phi + i2m\eta = 0, \quad \hat{\boldsymbol{\sigma}} \cdot (\hat{\mathbf{p}} - e\mathbf{A})\, \eta - i(\hat{E} - eV)\phi = 0. \tag{10}$$

After some transformations equations (10) are finally transferred to the Pauli equation

$$[\hat{E} - eV - \frac{1}{2m}(\hat{\mathbf{p}} - e\mathbf{A})^2 + \frac{e\hbar}{2m}\hat{\boldsymbol{\sigma}} \cdot \hat{\mathbf{B}}]\phi = 0 \tag{11}$$

where $\hat{\mathbf{p}} = -i\hbar\nabla$ and the magnetic induction $\mathbf{B} = \nabla \times \mathbf{A}$.

The last term in equation (11) describes the interaction energy of the intrinsic magnetic moment of the electron with the external magnetic field.

The intrinsic magnetic moment $\hat{\mu} = e\hbar\hat{\sigma}/(2m)$ can be presented via the spin operator $\hat{\mathbf{S}} = \frac{1}{2}\hat{\boldsymbol{\sigma}}$ of the particle studied

$$\hat{\mu} = \frac{e\hbar}{m}\hat{\mathbf{S}} = g\mu_{\mathrm{B}}\hat{\mathbf{S}} = 2\mu_{\mathrm{B}}\hat{\mathbf{S}} \tag{12}$$

where the spin-Landé factor, or the gyromagnetic ratio g, is equal to 2, and μ_{B} is the Bohr magneton. So the linearized theory establishes the correct intrinsic magnetic moment of a spin-1/2 particle.

In such a way, the existence of spin is a consequence of the linearization of the wave equations, i.e. a system of two coupled differential equations of first order, which then are coupled the electromagnetic field. These linear equations coupled with the electromagnetic field arrive at the Pauli equation (11). Besides, the Dirac equation, which is obtained by linearization of the Hamiltonian operator $\hat{H} = \sqrt{\hat{\mathbf{p}}^2c^2 + m_0^2c^2}$, also discloses the presence of spin in the particle.

Recent experimental studies of spin properties of electrons and neutrons have displayed the importance of the structure of the space in their vicinity. The mobility of electrons in the graphene honeycomb lattice indicates that the electron's half-integer spin originates from the nearest space around the particles, rather than from the particles themselves [15].

Some experimental studies (see e.g. Ref. 1, Ch. 3) are interesting because they point to the fact that the spin of neutrons is not local and has an extension in space and the neutron's spin wave function is quite extended and it can influence other neutrons at a distance.

Baeßler [16] reviewed experiments on the gravitationally bound quantum states of neutrons where the lowest neutron quantum states in a gravitational potential were distinguished and characterized by a measurement of their spatial extent. In particular, it was observed an effect of a spin-dependent extra interaction of the ultra-cold neutron with a gravitational potential. One neutron spin-component was treated as attractive, the other repulsive at short distances and even unpolarized neutrons were sensitive to such spin-dependent interactions.

In such a manner, the experiments point to the fact that all the information about spin lies in components of the wave function that is the product of a quantum particle. The situation with spin appears as follows. A particle has a dense kernel that moves with a velocity **v** and its motion is featured by four components of its wave function, or four sub wave functions. The named characteristics when coupled with an external electromagnetic field create a new characteristic of the particle (i.e. spin), which is manifested as an intrinsic form of the particle's angular momentum.

The phenomenon of spin can be clarified only when the nature of the wave function and its 4 sub wave functions become complete clear. De Broglie constantly emphasized the need for searching for the physical meaning of the wave ψ-function. Hofer [11, 12] claims that the wave ψ-function represents the density (1) of a particle. In the case of the electron, its wave function additionally receives a Poynting-like vector of the electromagnetic energy flux that also oscillates by the same rule as the density. But why does the density oscillate with this specific frequency? No idea that could lead to the splitting of ψ…

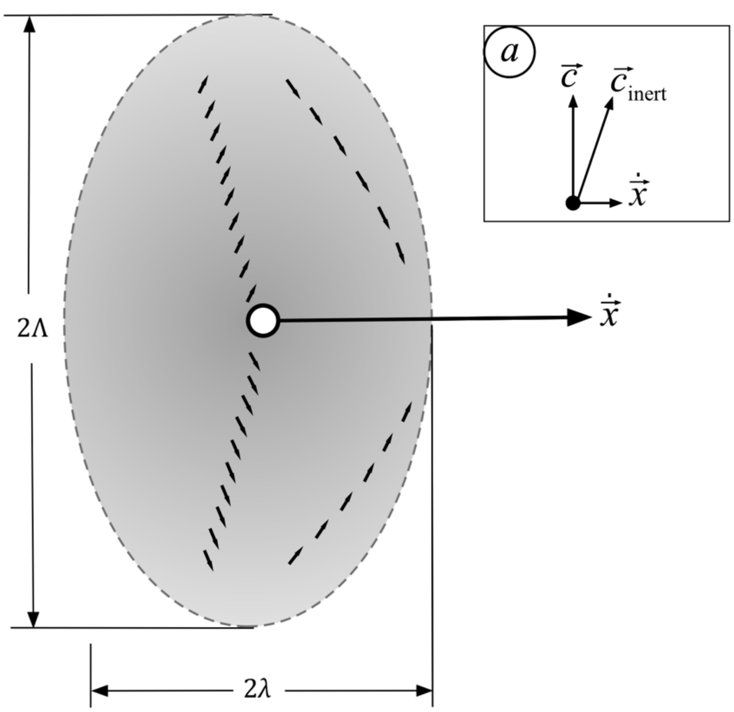

Fig. 1. The wave ψ-function, which in the real space is presented by the core particle moving in the surrounding of its cloud of inertons. a – the vector velocity of inertons $\vec{c}_{\text{inert}}$, which are connected to the particle ($\vec{c}$ and $\dot{\vec{x}}$ are the velocity of light and the particle velocity, respectively [1]).

The inner motion of canonical particles was studied in monograph [1] in detail, which shows that the particle is accompanied with a cloud of spatial excitations named *inertons* (Fig. 1). The radius to which inertons spread from the particle is

$$\Lambda = \lambda c / \upsilon \tag{13}$$

where λ is the particle's de Broglie wavelength $\lambda = h/(m\upsilon)$, υ is the velocity of the particle, c the speed of light, m mass of the particle and h Planck's constant. Nevertheless, we cannot consider the separation of the particle from the system {particle + its inerton cloud} as the first step to the description of spin, because this system as the whole is the primary object whose projection to a phase space is an abstract wave ψ-function that satisfies the Schrödinger equation. Although the particle is travelled as a corpuscle through the tessellattice (a mathematical lattice of primary topological balls) [1], its inertons migrate as excitations in a molecular crystal (i.e. they are hopping from cell to cell of the tessellattice).

A hint to the reasons of the decomposition of ψ is in the inner oscillations of the particle mass is de Broglie's [17] work that considers a dynamics of a particle with a variable mass and the inner oscillations of the particle's deformation coat [1]. Oudet [3-7] also applied this idea to the consideration of the spin of the electron. If mass is variable, we must recognize that mass, as a volumetric fractal deformation of a cell of the tessellattice, is a variable characteristic [1]: the volumetric fractal deformation is periodically transferred to a tense state of the cell, which occurs within a section equals the particle's de Broglie wavelength.

Thereby we admit the variability of the mass: the particle's mass as a local deformation of the cell of space undergoes periodical transformations to another physical state, a state of tension (meaning the physical condition of being stretched or strained). Accordingly in any quantum mechanical Lagrangian/Hamiltonian we shall represent the classical parameter of *mass* as a variable parameter that is periodically substituted by this condition of tension. The frequency of the oscillations of the particle and its inerton cloud is $\nu = E/h$ where E is the particle energy and h is Planck's constant.

So one pair $\phi = (\phi_1,\ \phi_2)$ of a set of four sub wave functions can be related to the particle's kinetic mass m and corresponding tension $\boldsymbol{\Xi}$. These two sub wave functions have to be presented by two antagonistic components: ϕ_1 is for mass (which is responsible for attraction) and ϕ_2 is for the tension (which is responsible for repulsion). In this case we cover Hofer's idea expressed in relation (2), namely, that spin is in fact related to the density of the particle.

The second pair $\eta = (\eta_1,\ \eta_2)$ of the four sub functions should have a structure similar to that of the $\phi = (\phi_1,\ \phi_2)$. All the sub wave functions spread out to a distance covered by the amplitude Λ (13) of the inerton cloud, which usually far exceeds the particle's Compton wavelength λ_{Com}:

$$\Lambda = \lambda_{\mathrm{Com}} c^2/\upsilon^2. \tag{14}$$

The initial conditions for a fermion are formed when it acquires a new momentum at the point of scattering. Therefore for the $\phi = (\phi_1,\ \phi_2)$-pair of four sub wave functions we have two opposite tendencies: (i) the fermion acquiring the vector velocity **v** occupies the mass state (the sub function ϕ_1); (ii) the fermion acquiring the velocity **v** attends the tension state (the sub function ϕ_2). This is the real physical sense of antisymmetric wave functions of fermions.

Along the particle path in odd sections λ the particle emits inertons and the tension gradually grows in them; in even sections λ the inertons come back to the particle and their tension gradually drops down to the state of mass. So the particle's inerton cloud is a carrier of the deformation potential of the particle. The mass appears as a local deformation, which is responsible for attraction. The tension component has to have an opposite property – it will induce a local repulsive potential.

The described situation immediately finds the confirmation regarding the structure of the four sub wave functions in Baeßler's [16] review paper on properties on neutrons: "one neutron spin-component would be attracted, the other repelled at short distances".

Hence we naturally come to the Pauli exclusion principle declaring that two identical fermions cannot occupy the same quantum state simultaneously. In terms of the submicroscopic concept [1] this means that if two fermions reach the same place they will be attracted if they are characterized by the opposite sub wave functions, ϕ_1 and ϕ_2. However, if they are both are featured by the same sub wave functions (i.e. both by ϕ_1 and ϕ_1 or ϕ_2 and ϕ_2) the particles will be repelled.

Thus we have derived not only the wave ψ-function, which is the ratio $\psi = m(x,\ t)/m_0$. We also have obtained the pair of sub functions $\phi = (\phi_1,\ \phi_2)$, which are responsible for the manifestation of spin [1]

$$\phi_1(x,\ t) = \frac{1}{2}[1 + \cos{(kx - \omega t)}], \tag{15}$$

$$\phi_2(x,\ t) = \frac{1}{2}[1 - \cos{(kx - \omega t)}]. \tag{16}$$

The spinor ϕ_1 describes the state of the particle when in the initial moment the particle emits its inertons, as its mass decreases

$$m(x,\ t) = \frac{1}{2} m_0 [1 - \cos{(kx - \omega t)}], \tag{17}$$

though its tension increases

$$\Xi(x,\ t) = \frac{1}{2}\Xi_{\max}[1 + \cos{(kx - \omega t)}]\ . \tag{18}$$

For the spinor ϕ_2 the situation is opposite:

$$m(x,\ t) = \frac{1}{2} m_0 [1 + \cos{(kx - \omega t)}], \tag{19}$$

$$\Xi(x,\ t) = \frac{1}{2}\Xi_{\max}[1 - \cos{(kx - \omega t)}] \tag{20}$$

where $k = 2\pi/\lambda$ and $\omega = 2\pi/T$. The spinor ϕ_2 describes the state of the particle when in the initial moment it absorbs its inertons, as its mass increases (19). These two situations are depicted in Fig. 1.

The Pauli exclusion principle only works in the case when two fermions are close enough, i.e. when their inerton clouds overlap or at least touch each other, which means they start to interact only when approaching the distance at least of 2Λ (see Fig. 1).

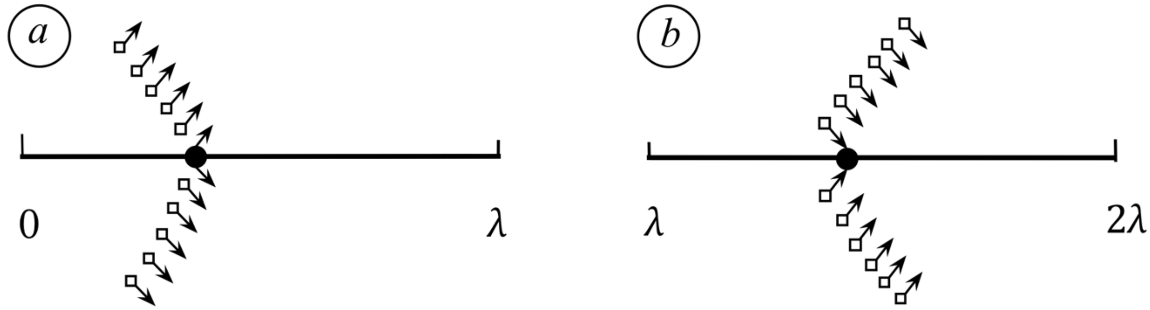

Fig. 2. Particle with inertons. a – the particle emits inertons; its mass disintegrates in the accordance with the solution (15). b – the particle absorbs inertons, or by de Broglie: inertons guide the particle; the particle's mass is restored, which shows the solution (16).

3. The half-integer angular momentum

Now let us consider how the half-integer angular momentum appears when we deal with the described system of {particle + its inerton cloud}.

If a classical particle rotates around a stationary axis with an angular velocity Ω, then its linear velocity is $\upsilon = \Omega r$ where r is the radius of the orbit. For such a motion the angular momentum is

$$M = mr^2\Omega = m\upsilon r = pr \tag{21}$$

where p is the momentum of the particle under consideration.

In the case of a canonical elementary particle such as an electron the situation will be the same if the radius of the orbit exceeds the amplitude (13) of the particle's inerton cloud. That is, if Λ at least several times larger than the radius r of the orbit, the system {particle + its inerton cloud} can be considered as a typical classical particle and its angular momentum will be equal to M as the expression (21) presents.

The realm of quantum mechanics comes when the inequality $\Lambda < r$ holds. What is really happening? First of all the orbit becomes quantized, i.e. its length becomes equal to the particle's de Broglie wavelength λ, namely, $2\pi r = \lambda$. But what does this wavelength actually mean? The submicroscopic concept [1] explains this as shown in Fig. 2: The particle when moving rubs against cells of space and owing to the interaction the particle emits inertons. Hence the particle gradually loses its velocity and also mass because emitted inertons are really carriers of mass. Since the particle loses its velocity and mass synchronously, we may say that the particle loses its momentum p within a section equal to the particle's de Broglie wavelength λ. Finally the particle must stop. But the real space is elastic. That is why the space returns the emitted inertons back to the particle, which happens within the next section λ. Thus along the entire particle path, in each odd section the particle emits inertons, then in each even section the particle again absorbs its inertons restoring the initial values of the velocity υ, the mass m and the momentum p.

How the particle's angular momentum should look like at such motion? The expression (21) clear points out that along the path $2\pi r$ only two parameters are preserved, namely, the radius of the orbit r and the angular velocity Ω. The momentum p of the particle decays to zero (in each odd section of the path) and increases again to p (in the next even section of the path). Hence for the one circle, which equals the particle's de Broglie wavelength, i.e. $2\pi r = \lambda$, we shall take the average value of the momentum $< p >= p/2$. Then the magnitude of the particle's angular momentum becomes $M = pr/2$. Multiplying the left and right hand side of this expression by 2π we obtain $2\pi M = p\lambda/2$ from which we immediately derive for the particle's angular momentum:

$$M = \hbar/2. \quad (22)$$

4. Interactions with external fields

So, the phenomenon of spin includes two possible initial states of the particle: the mass state (m) and the tension state (Ξ), which are described by the two sub wave functions ϕ_1 and ϕ_2, respectively (15) and (16). The Pauli equation (11) imposes an additional condition – spinors should provide the interaction with an applied magnetic field.

The phenomenon of electric and magnetic properties of particles and the photon was elucidated [1] in the smallest detail. Namely, if the notion of mass is associated with the volumetric fractal deformation of a cell of space, the notion of the electric polarization ($\nabla\Phi$) is related to the surface fractal of the cell studied. The magnetic property of the cell appears at the motion of this deformed polarized cell; namely, the magnetic property (**A**) is a tension of the electric state of the surface of the cell studied.

The submicroscopic consideration [1] of the Maxwell equations allows us to conclude that the spinor sub wave functions have to relate to two states of vorticity of the particle: left and right, which are clearly illustrated in Fig. 3. Each charged moving particle is accompanied with its inerton cloud in which inertons additionally possess the surface polarization, i.e. inertons carry also electromagnetic properties – their surface are covered with electric fractals (the electric field generate by the gradient of the appropriate surface potential, $\nabla\Phi$), which periodically change to the tension state (i.e., magnetic property, the potential **A**).

The motion of such electromagnetic core particle and its inerton-photon cloud can be treated as a vortex in which the surface fractals are subject to libration, left or right. Let the sub wave function ϕ_1 describes the left libration of the surface spikes of the particle (the unit polarization vector $\mathbf{e}_{\text{left}}$) and ϕ_2 is responsible for the right libration (the unit polarization vector $\mathbf{e}_{\text{right}}$). Then the spinor components ϕ_1 (15) and ϕ_2 (16) become

$$\phi_1(x,\ t) = \frac{1}{2}\mathbf{e}_{\text{left}}[1 + \cos{(kx - \omega t)}], \quad (23)$$

$$\phi_2(x,\ t) = \frac{1}{2}\mathbf{e}_{\text{right}}\,[1 - \cos{(kx - \omega t)}]. \quad (24)$$

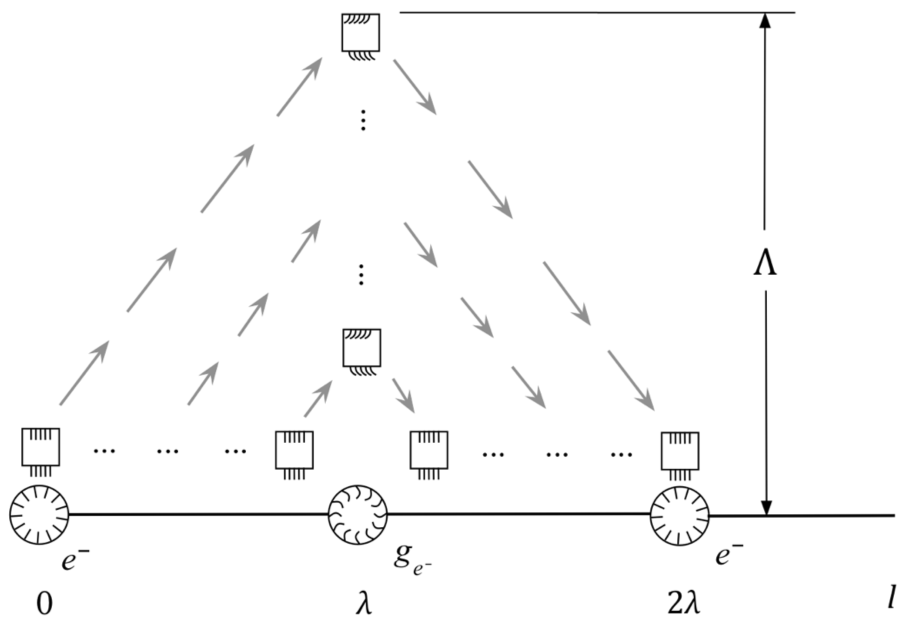

Fig. 3. Motion of the negatively charged particle (i.e. the electron) that creates inerton-photons in its surrounding. Tangential state of spikes of the surface fractals, which is related to the creation of the magnetic field, appears on inerton-photons at the distance Λ from the electron in transverse directions to the line of the electron path. Λ is the amplitude of the electron's inerton-photon cloud.

When the particle comes the odd section of its de Broglie wavelength λ, the particle's electric charge state e^- is transferred to the monopole state g_{e^-}. After coming the even section λ, the particle again acquires its initial state of the electric charge. In the case of the particle with the positive charge (i.e. the positron), all the surface spikes are oriented outward of the particle.

In such a manner we may completely clarify the hidden mechanism of the Pauli exclusion principle. Two particles, whose separation is close to their de Broglie wavelengths $\lambda_1 + \lambda_2$ along the line of the sum of their vector velocities or is closer than the amplitudes of their inerton clouds $\Lambda_1 + \Lambda_2$, will interact through their inertons. In other words, the inerton clouds of these particles must overlap. The particles will be attracted if their sub wave functions are in counter phase, namely, if one particle is characterized by the mass state and the left vorticity and the other one by the tension state and the right vorticity. If the two characteristics in two different particles are the same, they will be repelled. For example, two particles shall be repelled if each of them is in the mass state (or in the tension state) and has the same vorticity.

Usually in particle physics researchers use the term 'helicity' – a combination of the spin and the linear motion of a subatomic particle. Besides, in electrodynamics, particularly in optical physics, researchers use the term 'polarization' (left, right, circular, etc.) in application to photons. Here, we use the term 'vorticity' just to demonstrate the origin of the phenomenon, though all three characteristics – vorticity, helicity and polarization – work together (though the term 'polarization' is generally the most universal).

Formally a stationary magnetic field is generated by a current, as the fourth Maxwell equation prescribes, $\nabla \times \mathbf{B} = \mu_0 \mathbf{j}$. From the submicroscopic view point [1] the situation looks as follows. In a flow of charged particles each of the particles creates its proper inerton-photon cloud that spreads up to a distance provided by the amplitude of the inerton cloud (in the present case, the inerton-photon cloud) $\Lambda = \lambda c/v$ (13). In the cloud, the state of inerton-photons gradually changes from pure electrical polarization (near the particle) to pure magnetic polarization (at the distance Λ in transverse directions to the particle path). Fig. 3 accounts for the mechanism of the formation of magnetic field. The vector potential **A** is the origin of the magnetic field, which is evident from the fourth Maxwell equation written in terms of the vector potential **A** and the magnetic monopole g:

$$\nabla \times (\nabla \times \mathbf{A}) = g\mathbf{v}, \quad \text{or} \quad \nabla(\nabla \cdot \mathbf{A}) - \nabla^2 \mathbf{A} = g\mathbf{v}. \tag{25}$$

Hence the magnetic monopole g is the source for the vector potential **A** and, therefore, for the magnetic field **B**.

It is interesting to consider at the submicroscopic level how a stationary magnetic field interacts with the particle spin. For the electron it is obvious: its inerton-photons induce the stationary magnetic field around the electron (these inerton-photons are shown in Fig. 3 as cells with bending spikes). These field carriers coming back to the electron touch it when it is in the monopole state g, which turns the electron to one of the two possible paths. Namely, the energy of the electron changes by the value of $E_{\uparrow(\downarrow)} = \hat{\mu}_z B_z$, where $\hat{\mu}_z$ is the z-projection of the electron's intrinsic magnetic moment and B_z is the stationary magnetic field directed along the z-axis. In the explicit form

$$E_{\uparrow(\downarrow)} = \pm \frac{1}{2} e\hbar B_z/m. \tag{26}$$

If the orientation of B_z corresponds to the vorticity of g, then in expression (26) we shall choose the sign "+"; if the orientation of B_z is opposite to the vorticity of g, we choose the sign "–".

Fig. 3 accounts for why the moving electron experiences a magnetic field but not an electric one. This is because a shell of the electron's inerton-photon cloud is characterized by magnetically polarized inerton-photons. This automatically means that the cloud's shell is able to significantly screen the core cell, i.e. the electron of an external electric polarization.

Nevertheless, magnetic moments of electrons can be controlled also with the help of electrical signals, which is an important task in spintronics (see, e.g. Ref. 18). The electron can be subjected to an oscillating electric field and as a result the electron periodically changes its position. A change in the spatial coordinate leads to a change in the spin-orbit interaction and the appearance of an effective alternating magnetic field, which, in turn, causes the spin of the electron to rotate (the Rabi oscillations).

One more filed that can influence electrons and their magnetic moments is an inerton field. Inerton signals, as carriers of mass, can easily be absorbed by the electron's inerton-photon cloud because inertons in the cloud have the same physical properties as inertons of the inerton signal. Especially actively inerton signals can be absorbed when their frequency is in a resonance with the frequency ν of the electron as this frequency also is responsible for the exchange of inertons between the core cell (i.e. the electron itself) and its inerton cloud. An absorbed inerton may provoke slow motion of the electron whereas the electron has become heavier. Such an excited state may relax through the emission of a photon, which for example [19, 1] takes place in the phenomenon of sonoluminescence.

5. Summary

So, a set of the following characteristics of a canonical particle are responsible for its spin-1/2:

- The motion of the particle is associated with its rubbing against the real space, which is an actual substrate, and due to such interaction a cloud of inertons having a radius, or amplitude Λ appears around the particle;
- The particle together with inerton cloud are projected as the particle's wave ψ-function to the formalism of conventional quantum mechanics;
- The moving particle periodically comes from the mass state (m) to the tension state (Ξ) and the particle's de Broglie wavelength λ acts as the spatial period in this oscillating process;
- The wave ψ-function is a four component spinor: (ϕ_1, ϕ_2) and (η_1, η_2) related to the mass m and corresponding tension Ξ of the system {particle + its inerton cloud};
- The particle has to be charged (e), which at the motion periodically is periodically transferred (with the spatial period of λ) to the monopole state (g) that can be right or left.

If particles are either combined (bosons) or a quasi-particle (photon), then their spin is integral, since it is associated with a real vorticity of these particles.

Thus, basic properties of the spin-1/2 are the presence of the charged state on the surface of a particle and the direction of polarization of the monopole state – left or right. Spin-1/2 is an integral property of a moving particle, which is associated with a libration of the surface fractals, i.e. spikes, which is given by the initial conditions – to the left or right. The half-integer angular momentum $\hbar/2$ of a spin-1/2 particle is caused by the periodical decay of the particle momentum, which is oscillated between the magnitudes p and 0 within each odd and even sections of the particle path.

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