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DIRECT PAIRING OF ELECTRONS

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The pairing occurs when electrons tunnel through the Coulomb barrier to the region of the dominant values of their spin-spin interaction energy. In an external electrostatic field the pair rotates in the plane orthogonal to the field strength vector and its centre-of-mass tends to be pushed out from the field along this plane. Applying an *rf* electric field causes an experimentally observed resonance absorption of its energy at a frequency equal to that of the pair's rotation, and is linear in the electrostatic field strength.

About hundred years ago Prof. N.P. Myshkin [1, 2] performed a simple and clear experiment which appeared to challenge Coulomb's law. He discovered an abnormal movement of the stream of several particles issuing from the tip of a solitary metallic point connected to the negative pole of an electrostatic machine (the collinear positive point was separated by a distance of 50 cm). For a distance of up to four metres these particles left in the air a strong trace in the form of a free negative charge which remained on different bodies, i.e. these particles carried this charge. In spite of this they did not obey Coulomb's forces since they moved not along the vector of the electrostatic field strength at the tip, i.e. not along the point axis, but perpendicular to it, along any radial direction within the narrow space region containing the tangent plane orthogonal to the point axis (Fig.1).

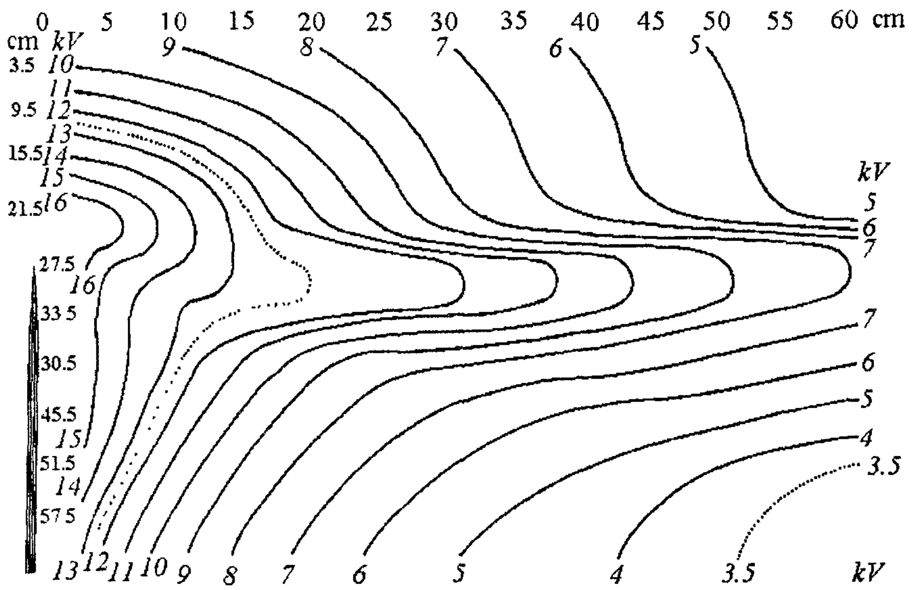

Fig. 1. Potential distribution of a metallic probe in a vertical plane containing the point (from [1])

Only in these directions did the stream cause different mechanical, luminescent and photochemical effects: it set in rapid rotation a light plastic disc, initiated luminosity of a fluorescent screen, and produced blackening of a photoplate. N.P. Myshkin verified that the stream was not caused by air motion, i.e. it was not in any way related to such a well known phenomenon as an electric wind. Nevertheless the thought of an electrical object devoid of its main principle to interact duly with an electric field, appears so absurd that even these easily reproduced experimental observations have remained without worthy attention. The question why the particles carrying a negative charge can move orthogonally to the lines of electric force has been left open for many years.

The answer to this question can be found by the extremely unexpected supposition that these particles are directly paired electrons. Such a pairing occurs due to the attraction of their spin magnetic moments and exceeds Coulomb's repulsion at a short distances between the electrons. The interaction of two electrons separated by a distance **r** from one another can be described by the potential energy V(**r**) taken from Hamiltonian of a charged particle possessing spin [3]

$$V(\mathbf{r}) = e^2A^2/(2M)\,(\mu_e\cdot\mathbf{B}) + e\varphi \qquad (1)$$

where M $\approx$m/2 is the equivalent mass of two-electron system; e, m, μ_e are charge, rest mass, and magnetic moment of an electron; **A** and **B** are vector potential and magnetic flux density of the field created by one electron in the location of another one (we suppose div **A** = 0); $\varphi = e/(4\pi\varepsilon_0 r)$ is the potential of electric field in that place. In this case [4] $\mathbf{A} = \mu_0[\mu_e \times \mathbf{r}]/(4\pi r^3)$ (ε_0 and μ_0 are the permittivity and the permeability of a vacuum).

In the singlet state magnetic moments of electrons are antiparallel, therefore the second term of Eq.(1) becomes

$$-(\mu_e\cdot\mathbf{B}) = -\mu_0\mu_e^2/(4\pi r^3) + 3\mu_0(\mu_e\cdot\mathbf{r})^2/(2\pi r^5). \qquad (2)$$

As long as the system aspires to be at the minimum energy, the second term in Eq.(2) disappears. This corresponds to the mutual orthogonality of vectors μ_e and **r**, hence we can regard all forces as central ones: $A = \mu_0\mu_e/(4\pi r^2)$, $B = \mu_0\mu_e/(4\pi r^3)$. This can be used to express Eq.(1) in the form

$$V(r) = e^2\mu_0^2\mu_e^2/(16\pi^2 m r^4) - \mu_0\mu_e^2/(4\pi r^3) + e^2/(4\pi\varepsilon_0 r). \qquad (3)$$

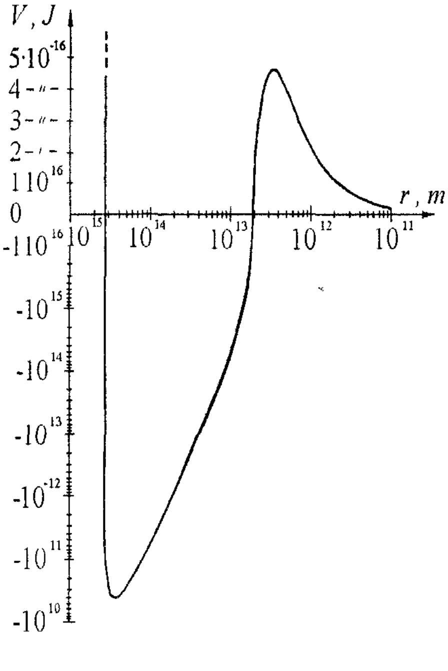

Fig. 2. Potential energy of two electrons with antiparallel spins as a function of a distance between them

The graph of this function looks like a potential well (Fig.1) with a solid repulsive core of radius

$$r_c = \mu_0 e^2/(4\pi m) \qquad (4)$$

which is obtained by equating the first and the second terms of Eq.(3) and coincides with a classic electron radius, whence the possibility of the existence of bound states follows.

Before we convince ourselves of the reality of this possibility it should be noted that Eq.(3) does not include a term describing exchange interaction. For the considered system this term would be determined by exchange integral J [3] Owing to the symmetry of the system we can be sure that the sign of J is obviously determined by the sign of Eq.(3) and coincides with it. Since the sign of V(r) is negative within the potential well so J is negative too, and therefore the exchange forces between paired electrons are the ones attractive, i.e. these forces cannot prevent pairing, but quite the reverse, promote it. This spares us the necessity of taking the exchange interaction into account on the first approaching the problem and attempting to see whether the potential well would appear at all.

Now we can use the method of phase functions [5,6] and solve the equation for the arc tangent of the modified partial scattering amplitude of Dirac's radial equation included Eq. (3) as the potential energy:

$$dY/dX = -(U/L)\{\sinh P\cos Y + \exp P\sin Y\}^2 -$$
$$- UL\{(P^{-1}\sinh P - \cosh P)\cos Y\,(1+P^{-1})\exp(-P)\sin Y\}^2. \qquad (5)$$

Here U=V(r)/(Mc^2), X=rMc/$\hbar$, P=κr, Y=arctang_0(r,κ), $L=\{(1-W^2)/(1+W^2)\}^{1/2}$, $\kappa=(Mc/\hbar)(1W^2)^{1/2}$, $W=W_0/Mc^2$, $g_0(r,\kappa) = -if_0(r,k)$, k=i$\kappa$, $i=(-1)^{1/2}$; W_0 is the bound state energy of the system when the motion of its centre-of-mass was separated; f_0(r,k) is the partial scattering amplitude without a multiplier 1/k ; ħ is Plank constant divided by 2π; c is the velocity of light. One difficulty connected with singularity of potential V(r) in this case can be avoided by choosing $Y(r_c)=0$ as the initial condition. From the view of V(r) it is clear that the basic change of the phase function can only be within the potential well. As our calculation has an estimated character we can cut the potential at a certain distance G: V(r>G)=0.

For the formation of only one bound state it is enough that function Y reaches the value of $\pi/2$ within the potential well. We can obtain the numerical solution of Eq. (5) at values $W\leq 1$, $G=10^{-11}$m using the Runge-Kutta-Felberg calculational techniques [7]. This solution is shown in Fig. 3a.

The possibility of the coupling becomes clear from the stepped character of the graph. By approximately halving V(r) we can choose the conditions when only one bound state exists (see Fig. 3b). Parameters of the potential well are thus quite enough to bind electrons at the bond energy close to the rest energy in the centre-of-mass frame. It should be noted that none of the above calculations were created to find wave functions and energies of bound states: this purpose cannot be achieved at the potential energy shown in Fig. 2. These calculations are provided only to answer whether any bound states do exist or not, and the method of phase functions can just do it.

Owing to the strong coupling we may expect that electron interaction forces undergo saturation like nuclear ones: paired electrons cannot interact with other charged particles in an ordinary manner. Hence, a proper electric field distribution of the pair must differ from that of free electrons, so that this field seems to be concentrated only into the pair's volume and reduces to vanishing values outside of it.

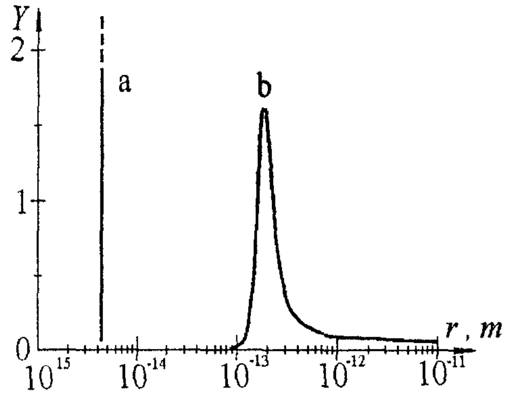

Fig. 3. Results of the solution of Eq. (5) at W = 0.999999:
a) for the initial defined value V(r);
b) for the value V(r) multiplied by 0.4690731335

Since the energy of the pair can change only discretely, the pair loses its normal sensitivity to an external electric field, but does not remain entirely unaffected it. In order to sustain the conditions of existence of the bound state in the presence of the external electric field $\mathbf{E}_e$ this field must be completely compensated near each electron. Compensation can be executed by the intrinsic electric field $\mathbf{E}_\imath$ appearing due to the rotation of the pair around its centre-of-mass in the plane orthogonal to the vector $\mathbf{E}_e$ with the angular frequency ω, so that $\mathbf{E}_e \| \omega$, and also due to the slope of the vectors μ_{e1} and μ_{e2} to the rotation axis at the angle γ. The velocities of paired electrons are antiparallel at any moment, thus, their fields in the locations of each other have only transversal components. According to the Lorentz transformation at $v \ll c$, the magnetostatic field $\mathbf{B}_1'$ (or $\mathbf{B}_2'$) produced by the spin magnetic moment μ_{e1} (or μ_{e2}) of each electron in the location of another one is seen by this electron as an additional electric field $\mathbf{E}_{\imath 1} = [\mathbf{v}_2 \times \mathbf{B}_1'] = [\mathbf{v}_1 \times \mathbf{B}_2'] = \mathbf{E}_{\imath 2} = \mathbf{E}_\imath$ having the same direction for each paired electron ($\mathbf{v}_1 = -\mathbf{v}_2$ is the velocity of one electron relative to another one). We can imagine this pair as a rigid system and suppose that all vectors μ_{e1}, μ_{e2}, $\mathbf{B}_1'$, $\mathbf{B}_2'$, and $\mathbf{E}_\imath$ are situated in the same rotating plane shown in Fig. 4, where $\omega \uparrow\downarrow \mathbf{E}_e$

It is worth noting that the question of the sense of rotation (Is ω aligned with the external field $\mathbf{E}_e$ or opposed to it) remains open. Perhaps this question can be cleared up in future by using a circularly polarized *rf* electric field. Nevertheless, all results described above and below remain valid at either sense of rotation relative to $\mathbf{E}_e$.

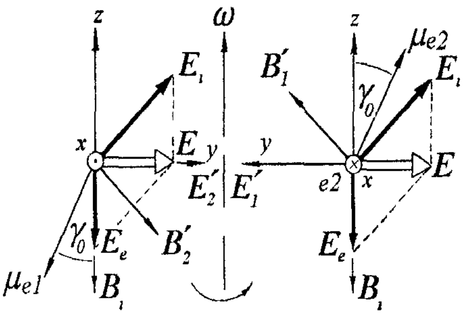

Fig. 4. Intrinsic compensation of the external electric field by the rotation of an electron pair

This rotation may also look like the equivalent precession of the spin magnetic moments μ_{e1} and μ_{e2} in the additional magnetic field $\mathbf{B}_\imath = \mathbf{B}_{\imath 1} = -c^{-2}[\mathbf{v}_2 \times \mathbf{E}_1'] = c^{-2}[\mathbf{v}_1 \times \mathbf{E}_2'] = \mathbf{B}_{\imath 2}$ created by the electrostatic fields $\mathbf{E}_1'$ and $\mathbf{E}_2'$ of each electron in the location of another one, the more so as the gyromagnetic ratio of this precession is the well known value $\omega/B_\imath = e/m$..

Consequently each electron is acted upon by the additional electric field $\mathbf{E} = \mathbf{E}_\imath + \mathbf{E}_e$ Assuming the distance between electrons is equal r_c and using explicit expressions for r_c, B_y', and B_z' one can obtain $E_{\imath z} = 2E_{\imath y} \tan\gamma$, $E_{\imath y} = \mu_0\mu_e\omega\cos\gamma/(4\pi r_c^2) = 4\pi\mu_e m^2\omega\cos\gamma/(\mu_0 e^4)$.

To compensate the external field E_e by the component $E_{\imath z}$ and to conserve volume energy density it is necessary that $E_e = E_{\imath z} = E_{\imath y} = E$. It can be achieved at $\gamma = \arctan(1/2) = \gamma_0$ and

$$\omega = \mu_0 e^4 E_e/(4\pi\mu_e m^2 \cos\gamma_0) \approx 5{,}50\ E_e. \qquad (6)$$

So as

$$\gamma_E^{theor} = \omega/(2\pi E_e) \approx 0{,}88\ \text{Hz m/V}. \qquad (7)$$

This means that the stipulation $v = \omega r_c \ll c$ is satisfied in a whole range of practically achieved values of E_e As a result the external electric field is completely compensated, all forces due to the fields $\mathbf{B}'$, $\mathbf{E}'$, $\mathbf{B}_\imath$ are balanced relative to the centre-of-mass, and both paired electrons are only acted upon by the translational force $e\mathbf{E}$, which causes their equally probable movement in all radial directions lying on the equipotential surface orthogonal to the vector $\mathbf{E}_e$. Therefore paired electrons push themselves out from the external electric field and at long last seek to occupy such areas where the electric field strength is minimized and best suited to their own stability. This phenomenon can be regarded as an electrical analogy to the Meissner – Ochsenfeld effect. This particular movement was detected by N.P. Myshkin from observations of decaying electron pairs in the air.

The decay happens under collisions with normal charged particles when paired electrons can find themselves in fields which are capable of influencing the bound state. Then an outer part of the interaction potential may change so that there appears the possibility of a pair tunnelling through the potential barrier, shown in Fig. 1, «from left to right». A reverse tunnelling «from right to left» forms a pair, this becomes possible at high enough values of volume or surface charge density enriched, of course, on metallic points.

Thus, the concept of directly paired electrons gives us the agreed qualitative description of formation, decay, and the strange movement of these structural objects. Besides that it predicts a new resonance phenomenon which can be expected from the above described rotation of a pair in an external electric field. If together with this permanent field one also applies to paired electrons a weak alternating electric field, whose frequency is about the value satisfied in Eq. (7) they cannot remain unaffected by this subjection. Experiments [8] performed on corona discharge in the negative point-to-plane gap clearly show the resonance absorption of *rf* electric field energy at the frequency equal to, or divisible to that of Trichel pulses. Moreover, the initial portion of dependence between resonance values of frequency and of electrostatic field strength in the greater part of the gap is linear, and although it is displaced from zero (this displacement is apt to be caused by space charge and depends on the gap length) it has the same factor of proportionality for different gap lengths. This factor is estimated as

$$\gamma_E^{experim} \approx (1{,}0 \pm 0{,}2)\ \text{Hz m/V} \qquad (8)$$

and by analogy with well-known magnetic resonance phenomena can be named as «gyroelectric ratio». This value of Eq. (8) is so close to that predicted by Eq. (7) that it cannot be accidental, so the theory developed above should be treated as being in perfect agreement with the experiment.

Furthermore this experiment also showed the possible multiplicity of energy levels of the pair, because it was found that not only a single resonance with the frequency obeyed to Eq. (6) exists but also the family of resonances whose frequencies were multiples of it.

Because of their unexpectedly subtle properties, bound electrons have been beyond an understandable reality threshould up untill now, in spite of numerous observations of them in their indirect manifestations. The considerable complex of such manifestations was investigated by N.P. Myshkin, who could not suspect this, and his work was ahead of its time.

Conclusions

1. Two electrons with opposing spins are capable of direct pairing by tunnelling through the Coulomb barrier to the region of the dominant values of their spin-spin interaction energy. The most favourable conditions for this pairing are obtained at high surface densities of the negative charge, particularly on metallic points at high negative potentials. The pair dimensions are determined by the geometry of the potential well in electron-electron interaction energy and are about classical electron radius, i.e. $2.8\ 10^{-15}$m.

2. The response of the pair to an external permanent electric field is that the pair executes a rotation in the plane which is orthogonal to the vector of the electric field strength. The factor of proportionality («gyroelectric ratio») between the pair rotation frequency and the electric field strength is theoretically estimated by Eq. (7). The rotation of the electron spin magnetic moments brings into existence the additional internal electric field, which completely compensates the external field and causes the translational movement of the centre-of-mass of the pair at right angles to the external electric field, so that the pair tends to be pushed out from this field along the equipotential surface. Such movement is an electrical analogy of the Meissner — Ochsenfeld effect and its indirect evidence was first observed by N.P. Myshkin in 1899.

3. The fundamental experimental proof of the concept of directly paired electrons (DPE) is the phenomenon of resonance absorption of alternating electric field energy by structural products of the corona discharge on the negative point, revealed recently. It occurs at the frequency connected with the permanent electric field strength (at its low values) by the linear dependence. The factor of proportionality in this linear dependence (Eq. (8)) was found to be almost equal to that in Eq. (7). Consequently, experimentally measured frequency of the resonance absorption of the alternating electric field energy is very close to the theoretical frequency of the electron pair rotation in the applied permanent electric field. The

proximity between theoretical and experimental γ_E-values is strong evidence in favour of the presented theory. It means, on the one hand, that directly paired electrons do exist among the structural products formed by the negative corona and on the other hand, that the developed theory describing their behaviour is proved by this experiment.

4. It seems reasonable to say that «selfconcealment» of directly paired electrons impedes estimation of their possible importance in a lot of natural processes and phenomena. Among them first of all appears to be ball lightning whose electrical peculiarities and, in particular, charge confinement, can acquire the most uncontradicted explanation. Inasmuch as the size of the pair is the same order with those of nuclei it will not be unexpected if further studies show the ability of directly paired electrons to take part in «cold» nuclear reactions, which can occur slow and unnoticed in different media, including, possibly, even living matter.

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