# The theory of electromagnetic field motion
# 9. Interaction mechanism of electrons

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Interaction mechanism between two or more electrons is considered in present paper on the basis of theory of electron core structure. It is pointed out that electrons may be only in two steady states: with parallel or opposite spins. Various cases are considered differed by mutual position of electrons. Basic attention is given to the axially arranged electrons with opposite spins at short distances, when electron cores are partially overlapped. It is shown that in this case electron pairs are generated and the electrons cores are considerably increased in their sizes. Electron pairs can be merged to form more complicated structures or the electron chains which form electron shells of atoms. Two atoms can be bonded to form a molecule by merging their outer shells what forms longer chain. Free electrons in metals can also merge to generate Cooper pairs. In turn, in sufficient cooling, Cooper pairs generate the electronic chains which surface layer is found to be superconductive.

## 9.1. Introduction

In the present paper we consider mechanism of interaction between elementary particles using interaction between electrons as an example. Electron, as it is known, has magnetic moment, electric charge and, as we have found, has a core which is not a point object but distributed in space. We believe that similar properties have all other elementary particles or, anyway, the components of the particles that have complicated structure. In addition, electron is one of the key figures defining the basic properties of substance. For these reasons we consider hereinafter interaction of electrons essentially.

In uniform (in scale of an electron) electric or magnetic field, and also at large distances from other charged particles where their fields also can be considered as uniform, electron behaves itself as a semiclassical particle and it is completely in accordance to quantum representations. As semiclassical particle we understand a particle which generates spherically symmetrical electric field, has a point charge concentrated in the centre, angular and magnetic moments and obeys the laws of classical electrodynamics. However, all is changed if an electron is located at a distance from an electron or other interacting charge that is comparable by size with electron core. Classical representations thus are not held, and quantum approach adequately describes the phenomena, only by introduction the special postulates intended only for given special case.

### 9.2. Interaction between two electrons with opposite spins

Let's consider interaction of an electron with another electron. At distances which are large in comparison to electron core size electrons with magnetic moments inclined to each other at an initial angle will begin to precess. As a result of energy loss due to electromagnetic radiation they occupy one of two positions, depending on initial conditions: on axis line connecting each other (let`s name such a position as axial) or in equatorial plane (such a position let`s accordingly name as radial) in such a manner that the electron magnetic moments coincide by direction with flux lines. This is the known fact which has been established at the initial stage of electromagnetic studies for magnetic needles. However, the situation changes if electrons approach very short distance between them, where appear extended nature of electron charge and presence of dipole magnetic field which is also has extended nature.

For the electron interaction mechanism described below the accuracy and detail of the description of core charge distribution has no principal value, it is enough to know that the electric charge is distributed in core volume, with the total core charge is equal to classical electrons charge, and beyond the core is described by the equation (6.28) [1]. Concerning electron magnetic field it is possible to say similarly that distribution of the magnetic field inside core is not so important, it is important only that it is closed inside the core and this core space is of finite sizes.

Such an approach is, on the one hand, is forced because we actually do not know detailed field and charge distributions inside core. On the other hand, this approach gives a generality to the results obtained: these results will be correct for all elementary particles for which are valid the most general properties of electron core described above.

Let's consider dependence of interaction energy $E$ of two electrons with oppositely directed spins on distance $r$ between them (fig. 9.1). Let`s consider electric and magnetic energy zero level to correspond to the electrons which are infinitely remote from each other.

In consideration of electron interaction let us accept as starting the position where electrons are completely aligned to each other and their magnetic moments are directed oppositely. In figures 9.1 this position corresponds to the point of coordinate origin.

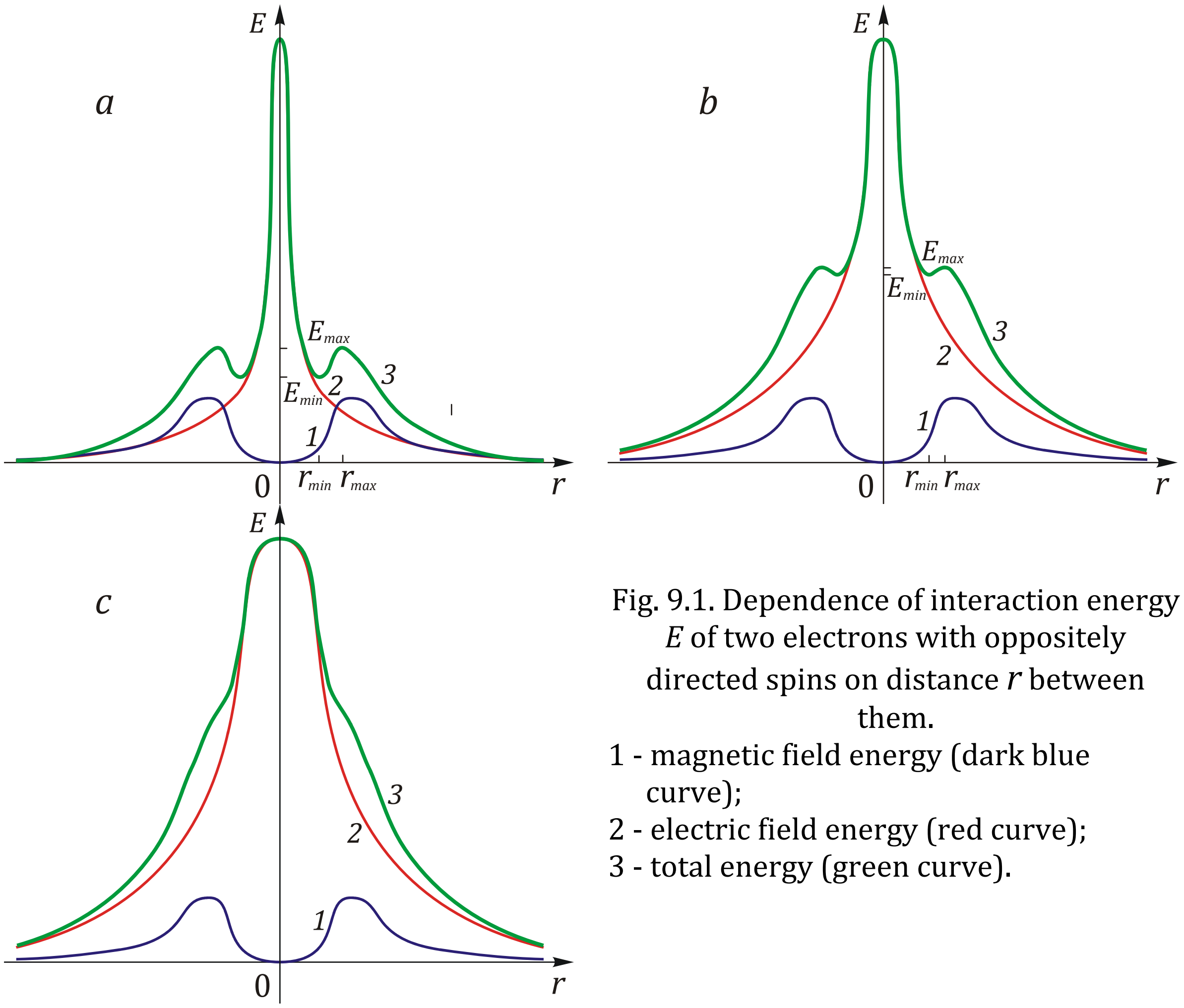

Fig. 9.1. Dependence of interaction energy *E* of two electrons with oppositely directed spins on distance *r* between them.

1 - magnetic field energy (dark blue curve);
2 - electric field energy (red curve);
3 - total energy (green curve).

Let's consider separately magnetic field energy (curves 1, dark blue colour) and electric field energy (curves 2, red colour) at various electric field energy dependences on *r*. Curves of total energy (curves 3) are designated by green colour.

Various character of dependence *E(r)* is found to depend on what direction we move the mobile electron in relation to another, conditionally stationary, electron. We are interested only in two directions of such moving, the axial and radial, because if displaced in any other direction the electron will precess, as it was marked above, what results in that the electron may be found in one of two possible positions, axial or radial.

We consider important only qualitative behaviour of electric or magnetic energy dependence and relative position of these curves to each other. Therefore let`s consider the curves for magnetic field energy to be identical in every considered case in spite of the fact that for axial and radial directions they may really differ a little from each other.

If electric field energy is not taken into account the position of electrons at $r = 0$ with opposite directed magnetic moments is steady because magnetic fields cancel each other in the whole space, magnetic field energy is equal to zero, and any displacement of one of electrons in any direction leads to the increase in this energy. The same occurs if angular position of an electron is changed. In other words, electron is in its stable equilibrium state if electric field influence is disregarded.

This stable equilibrium state is not characteristic only for electrons or other elementary particles. It will be observed for any extended magnetic dipoles, in particular, for coils of any configuration in their opposite switching, from single current carrying coils to long solenoids. To the surprise, we have not found anywhere in the literature any mentions on this fact4; probably, it is necessary to be more diligent in search. Meanwhile, it is obvious from the general physical reasons, easily calculated with digital methods and is verified experimentally without special difficulties. The single difficulty arising in that case consists in that in experimental check physical penetration of coils each other is necessary what for coils of usual configuration is, obviously, impossible. This difficulty may be easily eliminated, if coaxial coils are used to study axial stability with the minimum gap, and sectioned coils are used to research radial stability such that sections of one coil could enter into the gaps between sections of other coil before coils have been aligned together. We would like to emphasize that for point dipoles such character of interaction will not be possible to observe and steady state position is also absent.

The situation changes in some extent if the electron electric field is taken into account. If electrons are completely aligned together the electric field strength is doubled, and the energy is increased quadruples its value as the electric fields and charges do not depend on direction of the magnetic moment. This is unstable balance position as shown in graphs of fig. 9.1. Electrons will tend to go apart, however in axial and radial moving of electron the behavior of electric field energy functions of displacement value $E_e(r)$ are principally differ from each other.

Let's consider the **case of axial interaction of electrons**.

Electric field on electron axis is equal to zero, since in the electric field equations (6.20) - (6.22 [1] factor $\sin\vartheta = 0$. Electrons, when they are in this zone on the axis, practically do not interact according to the equations presented above. Actually electron shell charges start to interact with field because the electron charge is not concentrated completely in its centre but distributed in some area according to (6.28) [1] and, in addition, in approaching of the electrons the electric field loses its uniformity. As a result electric field energy sharply decreases from the maximum value at $r$ = 0 to very low value as electrons move away, though is not equal to zero accurately. This case corresponds to fig. 9.1*a*.

Total energy dependence $E(r)$ (curve *3* of green colour in fig. 9.1*a*) in this case has sharp minimum at the point $r_{min}$. It is the point of steady equilibrium state of electrons with high enough potential barrier of $E_{max}$ - $E_{min}$ in height. Position of the point $E_{min}$ for the reasons considered above, apparently, is more closer to axis *r*, than figure shows.

The case of axial interaction of electrons, in our opinion, underlies structure of all substances and will be considered in detail below in the subsections devoted to electron pairs.

**Case of radial interaction of electrons**.

Electric field in a radial direction of electron, as follows from (6.20) - (6.22) [1], is much more than axial field and decreases with distance much more slowly. For this reason the curve $E_e(r)$, as can be seen from fig. 9.1*c*, is much more wider. Maximum of the curve is at the same point because starting position is identical. As follows from the figure, the minimum on the total energy curve $E(r)$ in this case is absent. Hence, there is no also zone in which repulsive force between electrons is replaced by attraction force.

Fig. 9.1b shows graph of the function $E_e(r)$ with intermediate width. This case is presented to illustrate behavior of the minimum of total curve $E(r)$ in dependence on width of curve $E_e(r)$. It is visible from the figure that if the curve is enough narrow in comparison with that shown in fig. 9.1c the minimum energy appears, but its value is substantially higher in comparison with that in fig. 9.1a.

There is no radial attraction force for electrons, anyway, there are no any experimental facts indicating the existence of such a force. As a result of this circumstance for the radial interaction of electrons the dependence of energy on the distance, presented on fig. 9.1*c* is valid. However, one cannot to exclude possibilities of that the dependence $E(r)$, presented on fig. 9.1*b* is valid for some more difficult cases in comparison with two isolated electrons, in particular, for other elementary particles or nuclear structures.

Radial interaction is responsible, on our opinion, for strong interaction inside hadrons (baryons and mesons) and nucleons in atomic nuclei. However, radial interaction allows to generate only flat configurations of particles, in particular, of three particles. Nuclei represent a volume configuration of nucleons. Possibility of generation of such a configuration provides the axial interaction named in present case as weak, in a combination with radial (strong) interaction.

The **real picture** is much more difficult, than is described above. When electrons arranged initially in axial positions approach each other, the positive electric charges located along electron axes, penetrate into the core central regions of each other, increasing the central positive charge. This additional charge acts on positive and negative charges in vortex wall. Positive charges are located closer to the electron axis and therefore they interact with positive charges of another electron with greater force in comparison with that acting upon wall negative charges. As a result the electron core increases in sizes in relation to initial ones before the new steady equilibrium position will be achieved.

Despite increase in sizes, the general configuration of electron core is conserved, and the conclusion about existence of the minimum on graph in figure 9.1*a*. is also conserved. The scale on $r$ axis and, to a lesser extent, on $E$ axis are only changed. Qualitatively the dependence $E(r)$ remains invariable.

## 9.3. Axial stability of electrons with parallel spins

Interaction of two electrons in a radial position with parallel (i.e. unidirectional) spins are not of any particular interest because function $E(r)$ monotonously decreases with growth of $r$ and has no local minima. In addition, electron in this position is in unstable equilibrium state in the whole range of $r$.

Axial position of an electron with parallel spins is of substantially greater interest. Axially disposed magnetic needles are known to accept the position where magnetic moments are parallel in the absence of influence of the earth magnetic field or magnetic fields of other nature. We remind that in this position the magnetic moments are unidirectional and are directed along a line connecting points where the moments are located. In such a position at large distance between electrons they are in steady angular equilibrium state.

Dependence of interaction energy $E$ of two electrons with parallel spins on distance $r$ between them is presented in fig. 9.2. Zero level of electric and magnetic energy corresponds to the state where the electrons are located at infinitely large distance from each other.

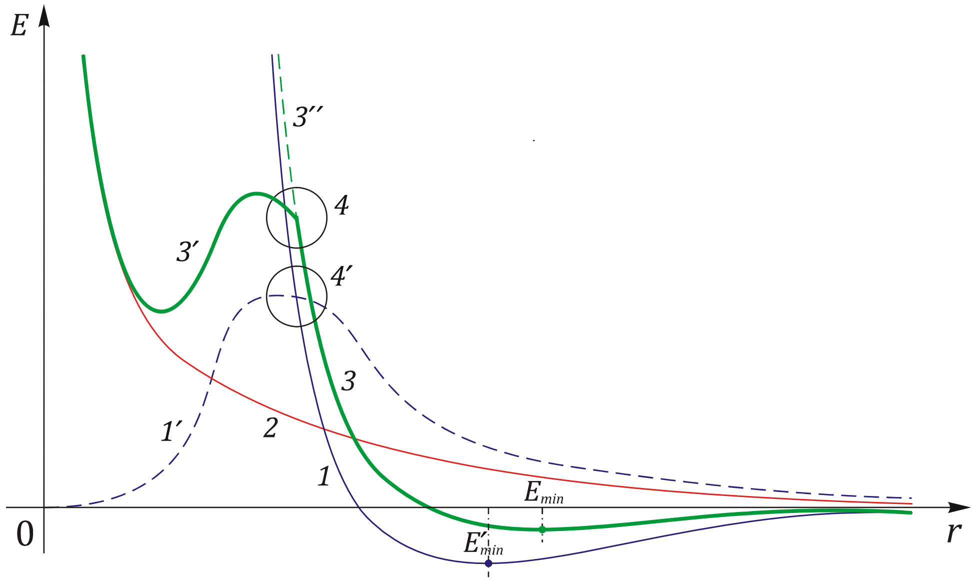

Fig. 9.2. Dependence of interaction energy $E$ of two electrons with parallel spins on distance $r$ between them.
1 - magnetic field energy (dark blue curve); 1′ - magnetic field energy in the case of opposite directed spins (dotted dark blue curve);
2 - electric field energy (red curve); 3 - total energy (green curve); 3′ - total energy at small distances, steady angular equilibrium state (opposite spins);
3′′ - total energy at small distances, unstable angular equilibrium state (parallel spins); 4 - transition area from curve 3 to 3′ and vice-versa; 4′ the same area without electric field energy (transition from a curve 1 on 1′ and vice-versa).

Curve 1 (dark blue curve) is energy of magnetic interaction between electrons (without magnetic field energy). At high $r$ values the curve shows trend from below to $E = 0$ value. As $r$ decreases the energy $E$ tends to area of negative values, and in case of point dipoles the energy $E$ tends to the area of infinite negative values. For real extended dipoles the energy in point $E'_{min}$ reaches the minimum value, and then increases to very high, but finite maximum (located outside of figure).

Dotted dark blue line in fig. 9.2 represents dependence of magnetic field energy in case of oppositely directed spins (a curve 1′), coinciding with similar curve 1 in figures 9.1. As $r$ decreases after crossing of dependences 1 and 1′ inside circle 4′ (we remind that we do not consider electric field energy) electron will pass with some delay from curve 1 to curve 1′, in other words it will occupy the state with lower energy and change its orientation into the opposite. In reverse movement of the electron all will be repeated but in reverse sequence: electron in a circle 4′ from curve 1′ with some hysteresis will pass in state with lower energy on the curve 1. Causes of hysteresis are described below. All these reasonings are valid also for the case in figure 9.1*a*, however, for simplification we believed that electron is forced to keep its orientation. Such an approach, when the real behaviour of the object being studied is ignored, is quite admitted when purely theoretical dependences and phenomena are discussed.

If electric field energy contribution is taken into account (curve 2, red line) the dependence 3 (green line) is obtained which passes into curve 3″ (dotted green line), or into curve 3′ in the case where electron orientation is considered to be changed into opposite inside circle 4. The circle 4 is the circle 4′ but with electric field energy taken into account.

There is minimum on the section of curve 3′, it is the same minimum, as on the curve 3 in figure 9.1*a*. This minimum can also be absent as on curve 3 in figure 9.1*c*. On curve 3 also there is minimum at point $E_{min}$. Both minima correspond to positions of two electrons when they can generate pair being bonded to each other. However, there are substantial differences between these two cases.

The first difference consists in that at minimum point of curve 3′ electrons have magnetic moments oppositely directed and, accordingly, have spins. At the same time at the point $E_{min}$ the magnetic moments, as well as spins, are parallel.

The second difference consists in that the energy levels and potential barriers in both cases are substantially separated. At the point $E_{min}$ energy level and potential barrier are much less than at the minimum point on curve 3′. According to said above the temperatures at which electron pairs can be observed at the point $E_{min}$, are much lower than for minimum on curve 3′.

It is this mechanism that possibly underlies the electron pair generation in strontium ruthenate, $Sr_2RuO_4$. This is indicated by the fact that spins of electron pairs in this material are unidirectional unlike other superconductors what has been shown experimentally. In addition, critical temperature is equal approximately to 1,5 K what much more lower than for other superconductors. Numerous publications are devoted to the superconductivity of strontium ruthenate (see, for example, [2]).

Other consequences of the considered above interaction mechanism between electron and, more widely, between any simple and complicated charged particles we consider in more detail hereinafter in the subsections devoted to electron pairs. And now we concern one more question which cannot be bypassed in consideration of interaction mechanism between elementary particles.

### 9.4. Angular stability of electron

Let's consider energy $E$ of electron located near central region of the core of another electrons (that is when the cores are partially overlapped) depending on angle $\vartheta$ between directions of electron magnetic moments (figure 9.3).

Let's simplify problem by considering that one of electrons is only the source of electric and magnetic field, with the electric field is the field of point spherical charge, and the magnetic field is the field of extended magnetic dipole described in [3] which axis is directed along line, connecting both electrons. The second electron, the probe one, has just the same magnetic field, and electric field is described by the equations (6.20) - (6.21) and by electric charge distribution (6.28) [1]. Such simplification would be absolutely inadmissible at quantitative calculations, however is quite suitable in qualitative consideration of the problem.

The curve 1 on fig. 9.3 shows dependence of magnetic field energy on angle $\vartheta$. Since we consider case with partially overlapped cores the energy reaches maximum when the directions of both magnetic moments electrons coincide ($\vartheta = 0$, generally this position is the unsteady equilibrium state), and is minimum, when these directions are opposite ($\vartheta = \pi$, position of steady equilibrium state). It should be noted that if distance between electrons is large the maximum and minimum positions changes into opposite, i.e. the curve 1 in figure 9.3 in this case is necessary to displace by $\pi$. The curve 1 corresponds to the energy of magnetic dipole in magnetic field, depending on rotation angle relative to the field lines.

Electron energy, defined by mutual position of point source of electric field and angular position of probe electron, is shown by curve 2. According to (6.21), as appears from known trigonometrical relation, this curve has the doubled frequency by angle $\vartheta$ in comparison with a curve 1. Therefore, as follows from figure 9.3, the total energy (curve 3) in favorable concurrence (in enough high amplitude of curve 2 in relation to curve 1) has the second minimum at $\vartheta = 0$. This minimum is metastable in relation to the basic minimum at the point where $\vartheta = \pi$.

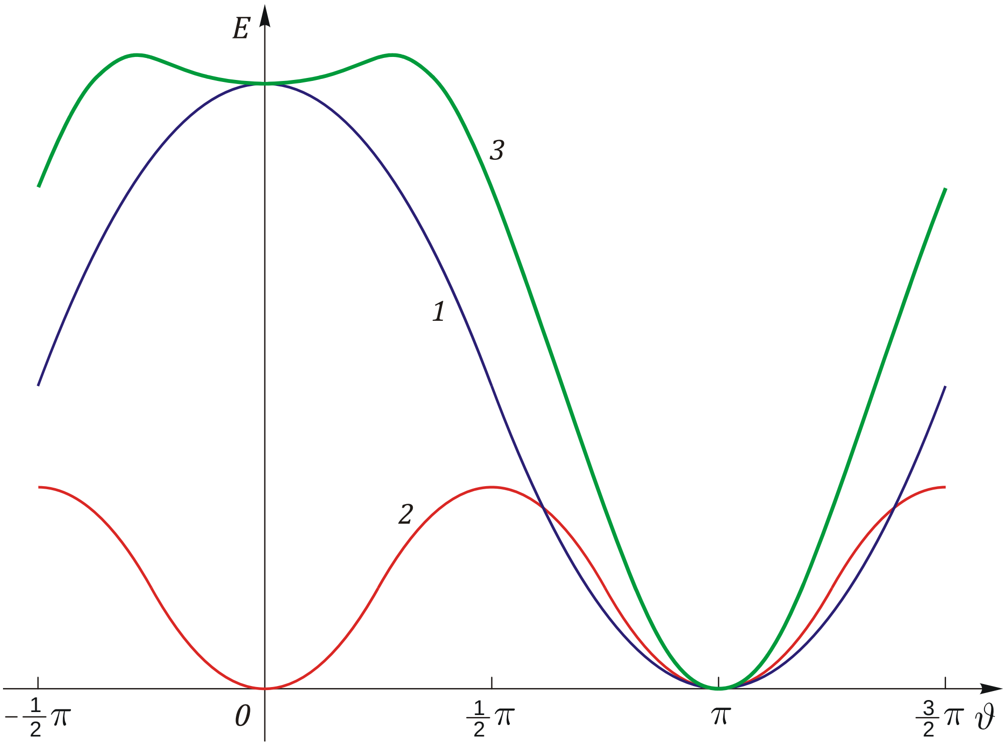

Fig. 9.3. Dependence of electron energy $E$ on angle $\vartheta$ between directions of the electron magnetic moments

1 - magnetic field energy (dark blue curve); 2 - electric field energy (red curve); 3 - total energy (green curve).

In the previous subsection we noticed that inside circle 4 in figure 9.2 electron should pass from curve 3 to curve 3` and vice-versa with hysteresis. This hysteresis is explained by that in such a transition electron appears in metastable state and only then is translated by thermal movement to the basic stable state after some delay.

Presence of the basic angular minimum at $\vartheta = \pi$, along with the axial minimum represented on fig. 9.1*a*, is the necessary state for the electron pairs with opposite directed spins to appear. At the same time transition into metastable state with parallel spins is possible in certain cases.

Presence of metastable level at $\vartheta = 0$ on fig. 9.3 leads to important consequences in the magneto-optical physics. One of such consequences, apparently, is the splitting of radiation spectral lines in magnetic field. The same can be said about electron paramagnetic resonance and, in particular, about spin echo. Availability of electron pair metastable state can also play appreciable, though minor, role in the superconductivity phenomena.

### 9.5. Electron pair and covalent bond

Electrons, as shown above, can generate steady pairs where they are arranged along an axis. Increase in electron core size is a consequence and, most likely, necessary condition of this arrangement. Let`s consider only electron pairs with opposite directed spins since the pairs with unidirectional spins can be generated only in very limited range of materials (strontium ruthenate) and only at very low temperatures as it was noted above. Electron pairs with opposite directed spins, on the contrary, play key role in the nature since they compose atoms and are responsible for molecular bonds and, in addition, account for superconductivity.

Image of electron core (fig. 8.2 [3]) is enough complicated, though it precisely corresponds to representations about core as much as possible. Schematic image in the form of arches is used to simplify this image, as shown in figure 9.4.

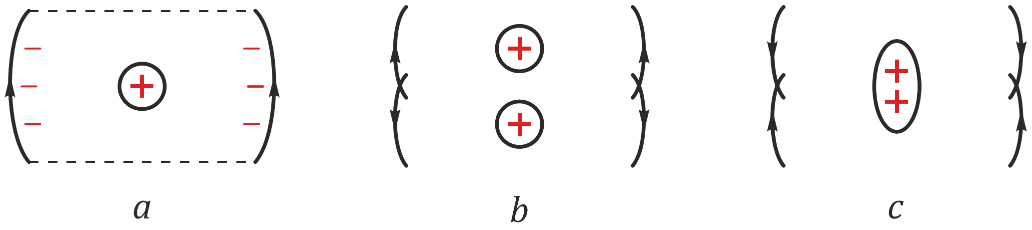

Fig. 9.4. The schematic image of electron shell configurations

In figure 9.4*a* the hydrogen atom as considered in [3] is schematically shown. Here the arches symbolically display magnetic field in electron core wall, and the arrows designate field flux direction. In the centre of electron (electron shell) hydrogen atom nucleus is located, designated by «+» sign. Signs «-» designate negative charges of core wall since total wall charge is negative. Dotted lines are the conditional core (or electron shell) vertical borders. The designation of a magnetic field by arches is used only for convenience and does not reproduce the real flux lines.

Even more simplified schematic image of hydrogen molecule is presented in figure 9.4*b*. Common electron shell is generated here by electron pair with opposite directed magnetic moments (and hence opposite directed spins). Cores of both electrons are partially overlapped that is symbolically displayed in figure by crossed arches. Vertical arrangement of hydrogen nuclei is absolutely conditional, actually it can be both more and less than is represented in figure.

Figure 9.4*b* shows crossed field, instead of the total magnetic field because in certain cases, according to a relativistic superposition principle, this difference may be important. It is obvious that if spin directions change into opposite, as it is represented in figure 9.4*c*, it nothing is changed, it is only important that spin directions in electron pair be opposite.

Figure 9.4*c* shows helium atom represented schematically. The atom nucleus has the doubled charge in relation to hydrogen atom, and electron shell configuration of helium coincides with electron configuration of hydrogen molecule.

More heavy elements than helium have more than one electron in its shell. It is caused by that the internal electron shell can contain only two electrons. From the point of view of the stated theory this is explained by that in attempts to join additional electrons the influence of core electric field on the internal positively charged core wall surface appears insufficient owing to large distance between them for the influence to be efficient. This, in turn, leads to that the increase in core sizes appears insufficient to generate electron pair with additional electron.

For the helium where shell is constructed of two electrons all comes to an end. However, if the nucleus charge exceed that for helium for additional third and subsequent electrons role of atomic nucleus will play an ion consisting of a nucleus and an internal electron shell. Electron core will increase so that formation of following in the order electron shell will be initiated as it is shown for oxygen as an example (fig. 9.5).

Figure 9.5 shows two oxygen atoms forming $O_2$ molecule. The outer electron shell of the upper atom initially contains 6 electrons: two pairs on section *a* (blue colour) and one pair, the top one, on section *b* (dark blue colour). The lower atom also contains 6 electrons: two pairs on section *c* (purple colour) and one pair, in the bottom, on section *b* (dark blue colour). On the other hand, each of atoms can hold, as it is known, 8 atoms. Thus, the upper atom holds electrons on sections *a* and *b*, and the lower holds electrons on sections *b* and *c*. Section *b* thus is appeared to be common.

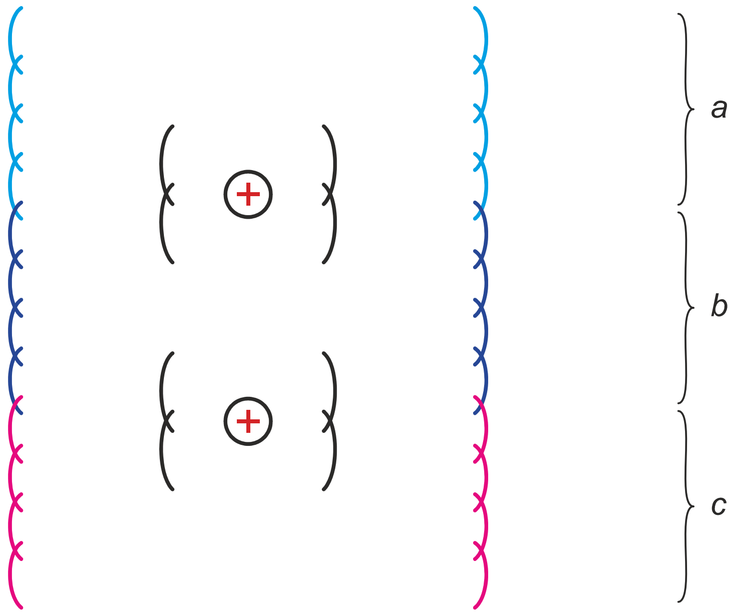

Fig. 9.5. Oxygen molecule

It should be noted that any two neighbor electrons in the oxygen molecule common shell form electron pair with spins directed opposite. The shell does not split into separate pairs, any neighbor pairs of electrons also are connected with each other, forming single chain. The forces bonding electrons and atoms in a molecule are described above and their mechanism is shown in figures 9.1*a* and 9.2. This mechanism underlies formation not only electronic shells, but also nonpolar molecules, in particular hydrogen and oxygen. This bonding mechanism is known as covalent bond.

## 9.6. Electron pair and superconductivity

As we saw, if positively charged nucleus is placed inside an electron the electron sharply increases in sizes. The relative size ratio of electron core does not remain constant. For this reason electron, increasing to certain size, then stops to increase. Such electrons tend to form pairs, as shown above.

The similar phenomenon can occur also with free electrons in metals as it is shown in figures 9.6*a* and 9.6*b*. Figures *a* and *b* differ by magnetic moment directions in pair only, formation of such pairs is equiprobable.

Let's consider that in formation of an electron pair in metal the electron core size is more or much more greater than the period of metal lattice. Then lattice ions are located not only outside of core, but also inside it. The internal area is appeared to have positive charge because the part of negative charge has passed from internal area to the electron core wall. Since ions in internal area of the core are located more close to the internal positively charged core wall surface, than to the outer negatively charged wall surface the net force acting upon the wall will be directed outside, and the size of electron will increase until the forces, acting upon inner and outer surfaces, become equal to each other.

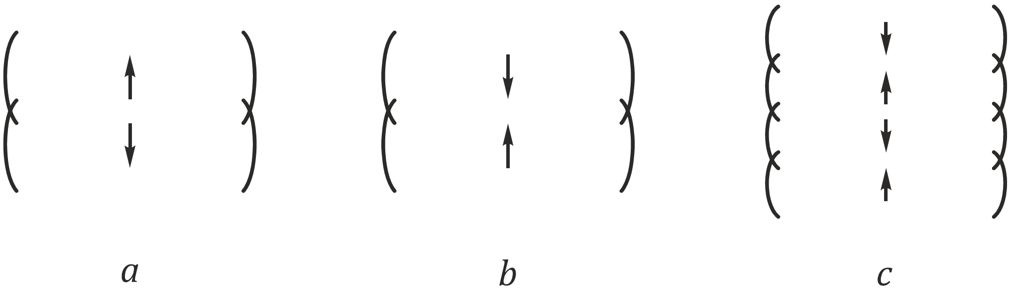
*a* *b* *c*

Fig. 9.6. Electron pairs in metals

Arrows↑ designate direction of the electron magnetic moments.

In addition, it is impossible to exclude also other mechanisms of ionic lattice influence on electron pair. The volume occupied by electron pair is electrically neutral only on the average, in its various separate parts there are local electric fields directly or indirectly influencing core wall due to deformation of the ionic lattice. We consider only general characteristic of mechanisms of ionic lattice influence, despite their possible importance.

Electron pairs can associate to form more complicated structure as it is shown in figure 9.6*c*. Here two pairs associated, but, as well as in electronic shells of the atoms, two middle electrons also form a pair. However, communication in this inner pair is appeared to be less strong, than in isolated pair because of influence outer electrons. In other words binding energy between electron pairs is less than binding energy of separate isolated pair. It leads to that the association of pairs among themselves as it is represented in figure 9.6*c*, is possible only at very low temperatures and not for all metals and alloys. In further temperature decreasing, even rather small, the electronic chain represented in figure 9.6*c*, can be indefinitely increased from both ends of the chain since influence of additional outer electrons sharply decreases due to increase with distance. In addition opposite magnetic fields of remote electrons almost completely cancel each other.

These chains can reach the ends of the metal conductor switched in an electric circuit, or become closed themselves as ring structures what takes place for the ring closed conductors as shown in fig. 9.7.

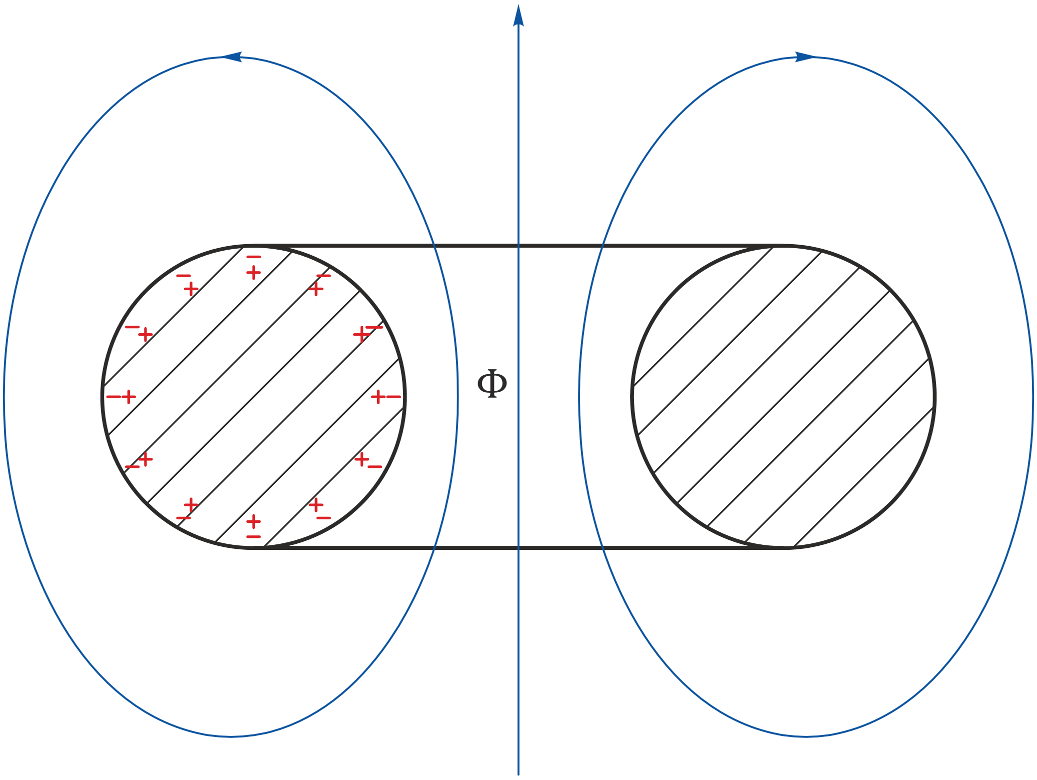

Fig. 9.7. Superconductive toroid

In formation of long electronic chains core borders extend up to the conductor borders. This is due to the interaction forces between charges for isolated electron pair with very rough approach are proportional to $\sim 1/r^2$, as for point charges, whereas in electron pairs bonding in a chain the forces are proportional to $\sim 1/r$ as for linear charges. Here $r$ is the distance between charges. On conductor surface the vortex wall and double electric layer are generated as shown for the left section of toroid in figure 9.7. Unlike single electrons, the magnetic field is equal to zero since oppose directed fields of electrons cancel each other. At the same time electric charges of various electrons, are summarized to form double electric layer according to relativistic superposition principle.

It is thus essential that the bound charges, as well as charges within wall outer surface of the core of the separate electron, are the free charges within this core surface. Inside electron core wall the charges coupled to electric flux lines move together with electric field under the influence of electron magnetic field. As opposed to it in the wall of our metal conductor the magnetic field is absent, therefore charges in initial state are stationary. However if we bring a conductor in an external magnetic field the charges will start moving, and there will be currents on the conductor surface. These currents, as well as in any conductor, obstruct change in magnetic flux.

Let's use the general expression for current density:

$$\mathbf{i} = \rho_e \mathbf{V}_e, \tag{9.1}$$

where $\mathbf{i}$ - current density, $\rho_e$ - density of electric charges, $\mathbf{V}_e$ - the velocity of charges equal to the electric field velocity.

Substituting in (9.1) expression for $\rho_e$ from (7.1) [4] and relation for $\mathbf{V}_e$ from (2.8) [5], we obtain expression for current of bound charges:

$$\mathbf{i} = \frac{[\mathbf{EH}]}{E^2} \operatorname{div} \mathbf{E}. \tag{9.2}$$

Here $\mathbf{E}$ is the vector of electric field strength, $\mathbf{H}$ is the vector of magnetic field strength.

Here is also considered that $\varepsilon_0 c^2 \mathbf{B} = \mathbf{H}$, where $\varepsilon_0$ and $c$ are electric constant and velocity of light respectively. In the denominator of (9.2) the perpendicularity sign is omitted because in the case under consideration electric field and its velocity are always perpendicular to each other.

It should be noted that the numerator (9.2) is none other than Poynting vector. Thus, the currents caused by entering of our metal conductor in a magnetic field, are connected with energy transfer.

It is known from electrodynamics theory that the variable magnetic field of sufficient frequency cannot penetrate into hollow metal body. It is superficial conductivity that is important because in thin wall of a body there are no any currents perpendicular to it. This known property of conductive bodies of high conductivity is used in fabrication of electromagnetic screens. Lower frequency at other equal conditions is defined by material conductivity. If conductivity is increased infinitely the frequency of screened field decreases to zero, i.e. even permanent magnetic field cannot penetrate into such screen.

It is such properties that has metal body under consideration. Surface layer of this body has superconducting properties. The currents in the surface layer, as follows from (9.2), are not due to movement of free discrete charges, electrons or ions. Movement of the bound charges within surface layer occurs without energy losses, i.e. superficial resistance is equal to zero with all the ensuing consequences.

When superconductor is switched to current source by means of usual conductors the current in superconductor flows in the form of bound electric field and charges, positive and negative. Negative charges, however, prevail, as on electron core wall and, thus, the negative charge is transferred as a whole. At the end of a superconductor connected to the current source positive pole, electrons are deposited from this electric field, including positive and negative charges coupled to the field. Accordingly, at the negative pole free electrons are absorbed by the general electronic circuit.

If the closed superconductor like a toroid is placed in magnetic field while transferring in superconducting state the magnetic flux $\mathbf{\Phi}$ (see fig. 9.7) will remain infinitely long period. The electronic chain is thus closed in a ring. It should be noted that schematically such superconducting magnet reminds electron core, and in addition the magnetic flux of a magnet is quantized and is multiple of electron magnetic flux. We do not have explanation to this magnetic flux quantization.

Besides free electrons in metals electron pairs forming electron shell of helium atoms can also associate in chain at very low temperature. These pairs form chain like a tube, apparently of small cross-section, isolating helium nuclei from external atoms. Uniform or strictly periodic field is generated inside the tube. In such conditions if nuclei move inside the tube synchronously they do not meet any resistance. This phenomenon is named as superfluidity. Together with nuclei the electric field coupled with positive and negative bound charges must move, as well as in electronic superconductor circuit. As in superconductor at the chain ends there is absorption and deposition of electrons, in chain of helium atoms there is absorption and deposition of helium atoms. If chain is closed in ring infinitely long circulation of helium atoms (nuclei) on the ring is possible.

## 9.7. Conclusion

Interaction mechanism of electrons is considered in present paper. It is shown that interaction is caused by counteraction of two forces: electrical repulsive forces and weaker magnetic attraction forces. Conditions for metastable state to occur at which enough stable bonds of two electrons and longer chains of several or many electrons are generated are considered in the work. In particular, radial and axial forces are considered with the last is shown to generate electron pairs with opposite spins. These pairs are the basis in forming of electronic shells of atoms and formation of covalent bonds in nonpolar molecules.

It is noticed that attraction forces at opposite directed magnetic moments may exist also in laboratory conditions by their modeling with current carrying coils.

It should also be noted that electrons in pair are in the same conditions, being overlapped only partially, and have all identical physical characteristics, except for opposite directed spins. This is in the full agreement with Pauli principle.

Free electrons in metals may also be united in pairs under the influence of crystal ionic lattice, which in this case named as Cooper electron pair. Formation of electron chains (electron pairs) underlies the superconductivity phenomenon. Electrons in such a chain are completely collectivized and when the electric current flows in a circuit there are no moving isolated electrons, moves only electric field in the wall of the circuit generated by walls of isolated electron cores. In such movement transmission of energy from electric field to atoms of the lattice is impossible because all fields remain invariable at any moment. The electric current in a superconductor arises only due to the external magnetic field, otherwise the Poynting vector is equal to zero at the chain wall (all magnetic fields of electrons cancel each other). Electronic chains can occupy whole superconductor volume, or a part of its volume in the case of type II superconductors.

Similar chains also form helium atoms at ultralow temperatures, however, chain diameter in this case is commensurable, apparently, with the diameter of helium electron shell. Helium nuclei inside chain become isolated from external atoms and from each other and can slide along chain without energy loss to form helium II phase. External atoms in relation to the chain form usual, nonsuperfluid, phase helium I.

The purpose of present chapter was not to discover the new phenomena and laws, they are already known and explained for a long time on the basis of quantum mechanics. Our purpose was to explain the same phenomena from non quantum basis, but using the theory of electromagnetic field motion.

## Summary

1. Interaction of two electrons with opposite spins is considered. It is shown that in axial arrangement of electrons and their sufficient approaching the potential holes are generated, where electrons after they have been caught there can generate pairs which are steady to some extent.

2. Radial interaction is most likely responsible for strong interaction inside hadrons (baryons and mesons) and nucleons in an atomic nuclei and is not manifest itself in interaction between electrons.

3. If a positive charge is entered inside electron, atomic ion, the electron sharply increases in sizes. This relates to the atomic electron shells and to the free electrons in metals at low temperatures when electrons unite to form pairs, and the role of the introduced charges play the ions of the metal atomic lattice.

4. In axial arrangement of electrons with parallel spins the electrons are in steady angular equilibrium state. When distance between electrons decreases the total energy of electrons reaches minimum, and electrons can generate pair in spite of the fact that their spins are parallel. Since minimum is very small these pairs can exist only at ultralow temperatures and only in few materials. Apparently, this case is realized in strontium ruthenate.

5. Conditions of angular stability of electron pair are considered. It is shown that electrons in electron pair with opposite directed spins are in steady angular equilibrium state, but formation of metastable state of electrons with parallel spins in pair is also possible.

6. It is shown that electron pairs underlie covalent bond. Being increased in a chain, they form electronic shells of atoms. Incomplete external atomic electron shells can unite to form nonpolar molecules, thus external shells of atoms form single chain, completely filling shells of both atoms at the expense of collectivized electrons.

7. Free electrons in some metals and alloys under the influence of lattice ions can form Cooper electron pairs which, in turn, when cooled sufficiently, unite and form electronic chains. Walls of these chains actually

are the walls of the electron cores and possess superconductivity properties.

8. Shells of helium atoms at ultralow temperatures also unite to form chain but with smaller cross-sections. Atomic nuclei inside chain are appeared to be isolated and therefore possess superfluidity property.

## References

1. L.N. Voytsehovich, Theory of electromagnetic field motion. 6. Electron, 2, (2013), p. 3. *www.science.by/electromagnetism/rem6eng.pdf*.
2. Julien Garaud, Daniel F. Agterberg, Egor Babaev. Vortex coalescence and type-1.5 superconductivity in $Sr_2RuO_4$, *Phys. Rev. B* 86, 060513 (R) (2012).
3. L.N. Voytsehovich, Theory of electromagnetic field motion. 8. An electron core, 2, (2013), p. 34. *www.science.by/electromagnetism/rem8eng.pdf*.
4. L.N. Voytsehovich, Theory of electromagnetic field motion. 7. Electromagnetic field and charges, 2, (2013), p. 23. *www.science.by/electromagnetism/rem7eng.pdf*.
5. L.N. Voytsehovich, Theory of electromagnetic field motion. 2. The principle of motion of electromagnetic field components, 1, (2013), p. 12. *www.science.by/electromagnetism/rem2eng.pdf*.

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