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Review

Possible internuclear interaction of atoms

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This work had been devoted to the problem of the nature of forces between molecules of second liquid. A hypothesis of the internuclear interaction of atoms was proposed. But this hypothesis turned out to be suitable also for the interpretation of the chemical covalent bond. It was offered a new model of hydrogen molecule, based on the corpuscular properties of electrons (together with the wave ones). This model did not yield to the interpretation with electromagnetic interaction, but could be explained with internuclear forces. A method of the experimental check-up of the proposed hypothesis was pointed out.

Key words: Second liquid, π-mesons, chemical covalent bond, hydrogen molecule model, proton accelerator.

INTRODUCTION

In the beginning of the 20th century liquid was considered nonstructural (that is, similar to very dense gas). But as it was proved by experiment in 1933, liquid had complicated intermolecular structure (Bernal and Fowler, 1933). This was the first important broadening of our notions of liquid. From that time on, the liquid structure is studying in many scientific laboratories of the world (Turnbull, 1952; Reichert et al., 2000).

The second broadening had been developed for a long time in some stages; it was concerned with phase transitions of the first kind, in particular, with melting. It turned out that, the melting of crystal on its surface begins at the temperature essentially more low than it was considered before. This phenomenon for the first time was noticed and studied by M. Faraday (1850), but the results of his investigations did not gain recognition at that time. The existence of this phenomenon was definitely proved experimentally in 1985 only; it was named “premelting” (Dash et al., 1995).

Premelting of ice enables one to interpret plenty of natural phenomena (the flow of glaciers, ice slippery, heaving of frozen ground etc). Investigations on these subjects were carried out now on a large scale in many countries (Bluhm et al., 2002; Engemann et al., 2004).

Author of this article has made an attempt to extend further our notions of liquid. It is considered now that, sublimation is a direct transition from solid (crystalline) state of matter into gas. The author has propounded and substantiated the principle of least time for first-order phase transition; it is shown by means of this principle that, sublimation goes in two steps through a certain intermediate state in the form of surface film. It is concluded that, this film consists of nonstructural liquid like matter which is a certain antipode of liquid; this liquid like state of matter is named “second liquid” (Mosienko, 2008, 2009).

Subsequently, the mentioned subject is continued and developed. It is assumed from theoretical reasons, that second liquid can exist in all area of ordinary liquid. The point comes to the sizes of liquid objects: if only one dimension of a liquid object does not exceed a certain critical size, it has to consist of second liquid. This conclusion ought to be of important applied significance. It is shown that the second liquid conception could throw light upon the following problems:

1) the cause of uniquity of solid nanomaterial properties;
2) the ion-induced nucleation in atmosphere;
3) some unusual properties of liquid water in nanocavities (particularly, in the cells of living organisms) (Mosienko, 2012).

The notion of second liquid cannot be completed, till the

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problem of the nature of forces between its molecules will be solved. An assumption which contains the appropriate solution is proposed in the paper. However, it turned out that, this solution is suitable for explanation of the chemical covalent bonding. So, we have come up to more important topic (a different interpretation of covalent bond) which became the main subject of the article. The critical remarks of the existent interpretation of covalent bond have been adduced; a new model of hydrogen molecule has been presented.

ASSUMPTION ON INTERNUCLEUS FORCES

As known, the Mechanism M_1 is due to Van der Waals' (London's) forces, that is, to electromagnetic interaction. But which interaction is the Mechanism M_2 to due?

At present, four fundamental interactions of nature are known: gravitational, electromagnetic, strong nuclear and weak nuclear interaction. The gravitational interaction of atoms and molecules is insignificant, one can disregard them. The nuclear interactions display themselves inside atomic nuclei only. There is electromagnetic interaction which is left; it is known that, first of all, the existence of atoms themselves is caused by this interaction. Van der Waals' forces are due to electromagnetic interaction too. Besides, the chemical bond between atoms in molecule is explained by this interaction.

If one would suppose that, Mechanism M_2 also is due to electromagnetic interaction, the question would arise: if there is too much demand from electromagnetic interaction? But the great thing is not this quantitative aspect of the problem. The most important point is the following: liquid and second liquid are some antipodes by their physical properties, mechanisms of their intermolecular forces scarcely could be within the framework of the same fundamental interaction. So, we are forced to seek and bring in some new suitable fundamental interaction.

Could one be able to search for a source of these forces? We have a small choice:

i) Atom of any substance consists of a nucleus and surrounding electrons (electron cloud). It is considered that, Van der Waals' forces are due to the configuration of electron cloud as the element which is more light and mobile in comparison with atomic nucleus. Therefore, it is necessary to look for a source of sought-for forces in atomic nuclei.

ii) Atomic nucleus consists of protons and neutrons. It is known that, internuclear distances of molecules hydrogen (H_2) and deuterium (D_2) are equal; it is the experimental fact (Erdey-Grus, 1973). Since the D_2 atomic nucleus contains neutron, and the H_2 atomic nucleus does not contain it we may conclude that, neutrons cannot take part in the formation of sought for forces. So, this source must be found in protons. Protons (together with neutrons) are the source of nuclear forces.

The carriers of the nuclear forces are considered the virtual π-mesons with a mass of about 300 m_e, where m_e is electron mass. The effective range r of the nuclear forces is determined by the mass m of the carriers (π-mesons):

$$r = h/mc,$$

where h is Planck constant and c is the velocity of the light.

It is known that, the size of the atomic nucleus is approximately in 10^5 times less than the size of atom. Let us assume that, protons of atomic nuclei give off (together with virtual π^0-mesons) some light-weight and electroneutral virtual x^0-mesons of the mass $(300m_e)/10^5 = 0.003m_e$. In this case, we would receive a new force analogous with the nuclear force. This force operates between the nuclei of the neighboring (that is, being in contact) atoms. It might be called *internuclear force*.

CHEMICAL COVALENT BOND

It is clear that, now we cannot pass over the problem of chemical bond. Indeed, if atomic nuclei are the source of some internuclear forces, these forces must manifest themselves not only in the mutual attraction of the second liquid molecules, but still to a greater extent in the mutual attraction of atoms in molecules, since in this case, the distances between nuclei are less. Thus, we come to the possibility of existence of another source of the chemical covalent bond.

On the existent notions of covalent bond

As it is known, Schrödinger equation is the wave equation; it takes into account the wave properties of electrons only, but the corpuscular ones remain in the background. Of course, there are considered just such waves which correspond to the electron momentum; none the least, this is the wave question. Meantime, electron, first of all, is a particle and already then it is a wave.

It is considered that, to imagine a movement of electron in atom along a certain trajectory is impossible. W. Heisenberg (1927) especially insisted on this statement. But it is difficult to agree with that; many outstanding physicists (including Einstein, Planck, and Laue) considered it too categorical.

Let us consider that, electron in molecule does not lose its individuality as a particle; we accept this statement by a way of postulate. We know that, the electron trajectory in molecule cannot be determined by real experiments. But we may use this notion in imaginary experiments; moreover, we shall construct a hydrogen molecule model with the aid of this notion. Of course, it will be a

hypothetical model. However, according to Feynman (1965), the great thing is that, the consequences of our hypothesis can be compared with the results of experiments. Electron in atom has a definite wavelength, and this wavelength, according to de Broglie is given by:

$\lambda = h/mv$

where *h* is Planck constant, *m* is the mass of electron, *v* is the electron velocity. The electron wave moves with a definite and constant velocity. If electron is in unexcited state, only one wavelength gets in around the nucleus on the surface of atom. The middle of this configuration can be considered the place where electron (as a particle) is found. So, we fancy the electron trajectory in atom while imagining the uniform motion of the wave on the circumference.

Let us remind of the essence of existent notions of chemical covalent bond. It is considered that, pair of shared electrons is drawn into the space between the two atomic nuclei. Here the negatively charged electrons are attracted to the positive charges of both nuclei. This overcomes the repulsion between the two positively charged nuclei of two atoms; just this overwhelming attraction is the covalent bond.

But why are the shared electrons are drawn into the internuclear space? As known, the sharing of electrons means only that, electrons are on the same energy level (that is, they move on the same orbit); of course, by this they must repel each other in accordance with Coulomb law and, therefore, to be on the utmost distance from each other. Or else, their movement must be uniform and mutually coordinated. The drawing of electrons into internuclear space (that is, their mutual attraction) contradicts Coulomb law. However, one could agree with this, taking into account that, the mutual approach of electrons leads to a decrease of the potential energy of two atomic system on the whole. Much the worse is another thing: in such a case, the uniformity and mutually coordination around nuclei would be broken. Indeed, in order to create an abundant negative charge in the space between nuclei, electrons must slow down the movement in this space. One can see from de Broglie formula that, a decrease of the electron velocity must lead to an increase of their wavelength. Such behavior of electrons seems unnatural.

The arguments adduced above, concern the corpuscular properties of electrons in molecule. Meantime, the conclusion about electrons, which are drawn into the space between two atomic nuclei, is received from Schrödinger equation which takes into account the wave properties of electrons only. Emphasize that, corpuscular-wave dualism is not ignored by this. But corpuscular properties of electrons are considered on the stage of the interpretation of Shrödinger equation solution. In our variant, they are considered on the stage of the model constructing (see the following section). This is just the significant difference of the proposed approach from the existent one.

A proposed model of hydrogen molecule

We know that molecules are very stable constructions. One could put a question: why does it happen? The completed external electron shell of atom contains two electrons with opposite spins. Helium atoms have just such shells; that's why they have high strength and practically do not deform by collisions. It is quite naturally, that electrons behave in accordance with Coulomb law (that is, are on the greatest distances from one another) and with de Broglie formula. Such behavior of electrons corresponds to minimum of its potential energies.

As known, the nature is simple in its own way: it does not make with much, what can be made with one. So, it is reasonable to expect that if, we take into account the said in the preceding paragraph, it will be received a stable and strong construction of hydrogen molecule.

Let us consider this in detail. The only electron of H_2 on the lower energy level (in a unexcited state) moves around his nucleus so that the length of his wave is equal $2\pi r_0$, where r_0 is the atomic radius (Figure 1). As the electron shell is not closed, it is highly pliant and so easily deforms by collisions of atoms. Let atoms bring together (by collision) at a distance r_0 (that is, in the two times nearer than at the quiet state) and let electrons have opposite spins. In this case, each electron can begin to move along a trajectory which embraces the both nuclei; this trajectory has a form of the eight. So, atoms find themselves connected in molecule (Figure 2). Incidentally, the wavelengths of electrons (and, consequently, their velocities) do not alter; but the form of each electron orbit turns into figure-of-eight. As to the coordination of electrons movement, it consists in the following: electrons move uniformly on the same orbit and in the same direction with the relative phase shift of $\lambda/4$. One could easily understand with Figure 3 that, electrons in any time are in diametrically opposed points in respect of one another, that is, on the greatest distance from one another in accordance with Coulomb law (the distance here must be understood in an integral meaning). This transition happens spontaneously with an emission of energy 435 kJ/mol; just this value determines the bond strength of hydrogen molecule.

It is easy to understand that, a half of electron wavelength cannot form the closed construction around nucleus of individual atom: the beginning and the end of such construction cannot joint as they are in the different (opposite) phases. But this is possible for molecule: there is one half of the wave around each of atoms; besides, the beginning of the second half is in phase with the end of the first half, and the end of the second half is in phase with the beginning of the first one. Indeed, these halves

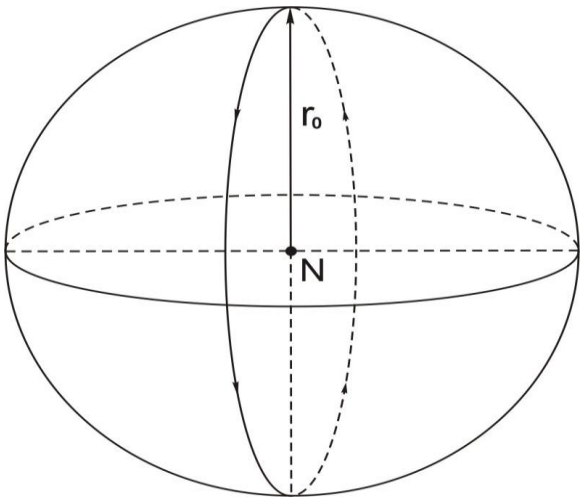

Figure 1. The model of hydrogen atom. Here, N is the nucleus of the atom, the electron orbit plane changes its disposition in the space by chance; therefore, the average density of the electron cloud on the surface of sphere is the same.

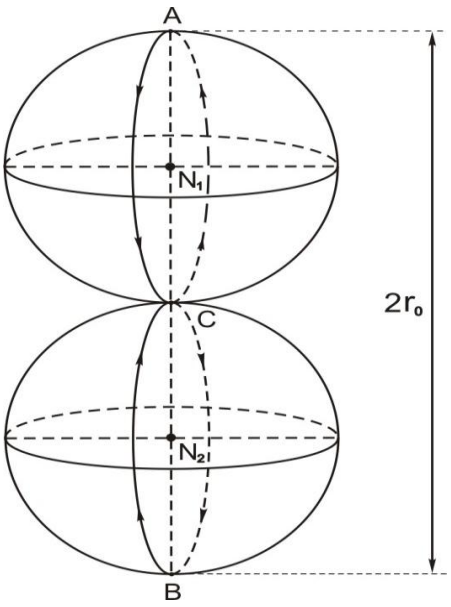

Figure 2. The model of hydrogen molecule. It is as if the two globes which are put on the same axle, here N_1 and N_2 are the nuclei of the molecule. If electron orbit plane (which has the form of an eight) rotates around the axis AB, the average density of the electron cloud must have an axial symmetry. Using by geographic terminology, one may say that this density does not depend on a meridian, but essentially depends on a latitude: it is minimal on the equators and maximal on the poles. (Pay attention, that the scales of Figures 1 and 2 are the same.)

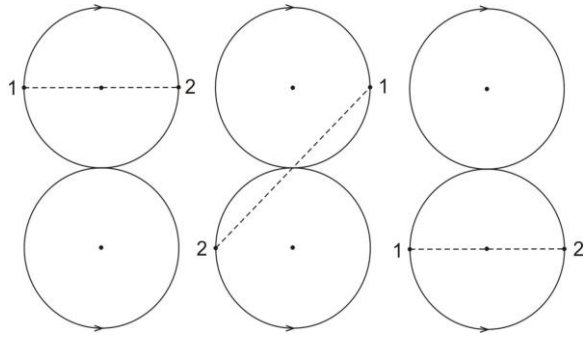

Figure 3. The scheme of electrons movement along the hydrogen molecule orbit in the form of an eight. They are represented as the three electrons positions being at the quarter of an orbit period from each other.

belong to the same wave, which at first was around atom but now is stationed in a different way (Figure 2).

The eight-form of the electron trajectories of hydrogen molecule is a principal link of the proposed model. Such closed construction is a simple and reliable mechanism which connects the two identical atoms in molecule. It is suitable for all atoms having only one electron on the external orbit. Such successful finding of nature (a peculiar molecular lock), apparently, is realized also in more complicated cases.

Note that, there are none of some intermediate stages between the states represented in Figures 1 and 2; otherwise, it is a typical quantum jump (analogous to the electron transition from the second energy level to the first one).

Every one of the hydrogen molecule halves in the given model is analogous to helium atom in some respects: each electron shell of the both molecular halves consists of the two shared electrons and is closed. These shells cannot overlap because this contradicts to Pauli principle. Consequently, they have the high strength and, practically, do not deform by collisions. It is clear that, the traditional interpretation of covalent bond is unacceptable for the proposed model.

Since electrons of our model move around nuclei on the same orbit (in the shape of an eight) with a constant speed, the average linear density of negative charge on the orbit is constant. If the orbit plane rotates uniformly around the axis AB, the electron cloud of molecule can be considered symmetric about AB. One can see that, the electron cloud of each half of hydrogen molecule is symmetric also about its equator plane; this means that, an interaction force of each nucleus with its electron cloud is equal zero.

Let us appeal to the simplest molecular construction - ion H_2^+. Electrostatic interaction of the electron clouds (shells) of its halves also is equal to zero; indeed, there is only one electron on the orbit, therefore there is nothing to interact with it. So, electrostatic interaction of the halves of this construction consists of a nuclei mutual

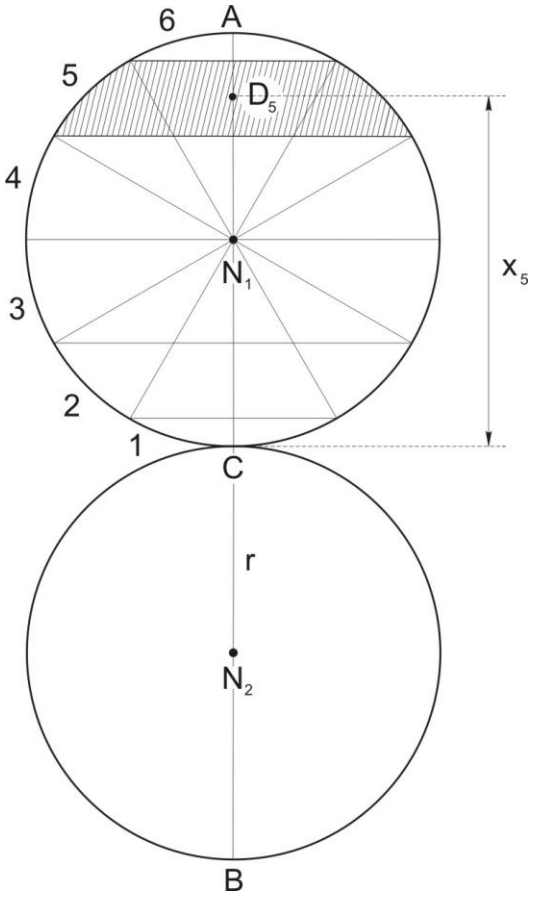

Figure 4. The scheme of an interaction of nucleus of ion H_2^+ with the electron shell of another nucleus (aspect from the side); the electron shell is divided in 6 latitude zones, numbers of which are pointed at the left side, the point D_5 is the centre of the fifth zone; x_5 is the distance from the centre C of ion to the point D_5.

repulsion with a force F_1 and an attraction of each nucleus to the electron shell of other half with a force F_2.

Let us produce the results of such calculation (in the conditional units). Each nucleus is repelled from other one with Coulomb force:

$$F_1 = \frac{e^2}{(2r)^2} = 0{,}25\frac{e^2}{r^2} = 0{,}25\ cond.un.$$

Here, *r* is the radius of sphere of the construction half.

The force F_2 can be calculated with the method of successive approaches; for this, it is a necessary preliminary to divide the spherical surface of the molecule half in several latitude rings of the same charge (Figure 4). Let us replace the charge of each latitude ring (zone) by equal point charge situated at the centre of this zone. The force of interaction of nucleus with this charge of one zone is:

$$F_{2k} = e \cdot \frac{e}{2n} \cdot \frac{1}{(r+x_k)^2},$$

where, x_k is the distance from the centre C of ion to the centre of the given zone. (The size of x_k can be measured on figure similar to Figure 4.) So:

$$F_2 = \frac{e^2}{r^2} \cdot \frac{1}{2n}\sum_{k=1}^{n} \frac{1}{\left(1+\frac{x_k}{r}\right)^2} = \frac{1}{2n}\sum_{k=1}^{n} \frac{1}{\left(1+\frac{x_k}{r}\right)^2}\ cond.un.$$

The calculation is fulfilled with four approaches by n = 3, 6, 12, and 24. The results are presented in Table 1.

It is clear that, successive approaches are quickly converged to the value which is approximately equals to 0.19 cond. un. To sum up we have: $F = F_1 - F_2 = 0.25 - 0.19 = 0.06$ cond. un. Thus, the halves of such construction are repelled from one other, that is, electrostatic interaction (in the given model) cannot explain the existence of ion H_2^+. Meantime, this ion exists, the energy of its chemical bond is equal 256 kJ/mol; so, it is a very strong compound. But if one supposes that the nuclei of neutral atoms (or of the hydrogen molecule halves) are mutually attracted, everything falls into place.

As one can see, electrons in the proposed model play "an administrative" role: they define on which minimal distance could bring together atomic nuclei. The source of interaction forces of atoms (or of the molecule parts) is in atomic nuclei. Emphasize, that just the imaginary experiment, where the notion of the electron trajectory in atom is considered quite reasonable and acceptable, has led to the hydrogen molecule model described above. However, it is the very case when the consequence of the hypothesis can be compared with the results of experiments (Feynman, 1965).

ON A POSSIBLE EXPERIMENTAL VERIFICATION

The energy of the π-meson at rest is equal about 150 MeV. As is known, π^0-mesons are got with the aid of the charged particles accelerator during the collisions of protons. A necessary minimal energy of the moving proton (by his collision with the motionless proton) is about 300 MeV. Note that, π-mesons are unstable particles. The lifetime of the real π^0-meson is about 10^{-16} sec; it breaks down into the two photons with the energy of which is about 75 MeV.

Each of these photons, travelling through the substance of the register apparatus (counter), generates the electron pair (electron plus positron). But positron cannot exist a long time in the substance; it annihilates by a collision with the first approaching electron. As a result, there are formed two photons, which again generate electron pairs (with the energy less than that at he preceding stage). And so on, till a photon energy

Table 1. The results of the four approaches.

n	3	6	12	24
F2	0.1860	0.1875	0.1885	0.1890

becomes less than 1 MeV (such photons cannot generate electron pairs). The appearance of electron pairs is surely registered with the counter; their tracks make it possible to restore the picture of the break-up. With the aid of analogy between nuclear and internuclear interactions, we come to the following scheme. The energy of the hypothetical resting x^0-mesons must be about (150 MeV)/10^5=1500 eV. The minimal energy of the moving proton must be 3000 eV. Let us consider that, x^0-meson (similarly to π^0-meson) is unstable and breaks down into the two photons with the energy 750 eV each. At this point, the process comes to its close since the energy is less than 1 MeV.

Imagine that, the energy of protons in the beam of proton-proton accelerator increases, and by 3000 eV suddenly photons with energy about 750 eV appear. (This energy corresponds to the wavelength 2.0×10^{-10} m, that is, we have Röntgen rays.) Hence, one may deduce that, the collisions of protons have led to the origin of x^0-mesons. So, the existence of x^0-mesons can be checked up experimentally. As this prediction is rather approximate, it would be able to carry out the search in the sufficiently broad range of the proton energy (for example, from 1000 to 9000 eV).

Emphasize, that analogy gives only the hint on a certain possible solution; it is necessary to have in mind the probability of existence of some other unknown mechanism.

Conclusion

One could ask: why the traditional version of covalent bond does not generate the doubts of researchers in spite of some its artificiality? Let us attempt to answer to it.

The doubts, apparently, take place; but they do not exceed a certain psychological barrier. Strange as this may seem, the principle of simplicity plays a part of such barrier: it turned out that, the covalent bond between atoms may be explained in the framework of well-known fundamental interaction, namely with electromagnetic forces. Of course, such understanding leads to some difficulties; physicists and chemists well know about this. But there had been no a special necessity to go out of the limits of the existing paradigm. This presented itself reasonable and logical.

The new approach to the problem came up from an unexpected side and somewhat by chance: to explain the forces between the molecules of the second liquid, we were forced to assume the existence of an internuclear interaction. This enabled to come up to the problem of the chemical covalent bond from a different angle.

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