Intra-atomic binding energy

Calculation according to the Wave Model, Part 1

Helium

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1. Introduction

Considering elementary particles and, accordingly, atoms as wave formations, pulsating energy bunches of the primary physical vortex field-space (physical vacuum or the so-called ether) [1], and applying for their description the equation that we have obtained for the first time for a pulsating wave shell,

$$\hat{F}_s = \frac{4\pi r^3 \varepsilon_0 \varepsilon_r}{1 + k^2 r^2}(1 - ikr)\hat{\upsilon} i\omega, \qquad (1)$$

and standard wave equation [2],

$$\Delta\hat{\Psi} - \frac{1}{c^2}\frac{\partial^2 \hat{\Psi}}{\partial t^2} = 0, \qquad (2)$$

we have found that atoms have a shell-nodal (molecule-like) structure identical with the structure of the nodes of standing waves in a spherical field-space.

Molecular structures do not have nuclei. Accordingly, since no one doubts the fact that all objects and phenomena in the Universe have the wave nature (which is the axiom of dialectical philosophy), including atoms, they must recognize the reality of a *nuclear-free* molecular-like structure of atoms. The latter directly follows from the solutions of the general ("classical") wave equation (2), which describes the structure and behaviour of wave objects and physical phenomena.

Accordingly, as it is not sad for most physicists, but they must agree with the fact of the fallacy of the *nuclear* model of the atom – the *dominant model* that describes the atom at present in the framework of two independent theories (*atomic* physics and physics of *atomic nuclei*).

The binding energy of nucleons in atoms within the framework of the existing *nuclear atomic model* cannot be calculated directly, in principle, due to lack of knowledge of the basic parameters characterizing the internal structure of atomic nuclei, where, according to the above theory, almost the entire mass of the atom is concentrated. We mean, first of all, ignorance of the mutual spatial arrangement of nucleons in nuclei, etc. Therefore, to determine the binding energy, physicists use the formula of the equivalence of mass and energy of a particle $E = mc^2$, calculating the equivalent energy of mass defect, $\Delta E = \Delta m c^2$.

Parameters of the molecular structure of atoms, determined within the Wave Model (WM) [3] from solutions of the wave equations, (1) and (2), makes it possible to directly calculate the binding energy of nucleons in them without resorting to the mass defect formula [4]. The main characteristic parameters of molecular structures are the geometry of disposition of nodes, distances between them, sizes of nucleons and their masses.

It is also necessary to know the parameters of the behaviour of nucleons (which are dynamic formations) in the nodes, and the law of their interaction at interstitial distances in the atom-molecule. In this case, the Universal Law of Exchange (interaction), describing the three types of fundamental interactions (strong, electromagnetic and gravitational),

discovered also in the framework of the Wave Model, should be applied. It has the following general form,

$$\langle F \rangle = \omega_f^2 \frac{m_1 m_2}{4\pi\varepsilon_0\varepsilon_r r^2} \qquad (3)$$

The frequency ω_f means one of the two fundamental frequencies: ω_e – the fundamental frequency of atomic and subatomic levels, or ω_g – the fundamental frequency of the gravitational wave field [5]. Recall that in equations (1) and (3), as usual in the WM, the parameter denoted by ε_0 is the absolute unit of density, that is, $\varepsilon_0 = 1 g \cdot cm^{-3}$.

In this article (Part 1), we will consider the calculation of the binding energy of the *simplest* atom-molecule - the stable isotope of the *helium atom*, ^{4}He. The second article (Part 2) will be devoted to the *carbon atom*, and the third article (Part 3) – to the *deuteron*.

In the beginning of each article, we will explain the *shell-nodal* structure (a *discovery* of the WM) of the considering atoms, including the *structure* of *all* possible their *isotopes* – the *subsequent discovery*, naturally made as a *consequence* of the above-mentioned *basic*.

2. Shell-nodal structure of a helium atom

The *shell-nodal structure* of *five* from the nine *currently known* helium isotopes, as well as the *hypothetical isotope* helium-14, which has not yet detected, is *shown schematically* in Fig. 1. Such a structure of helium isotopes follows from solutions of the wave equation (2).

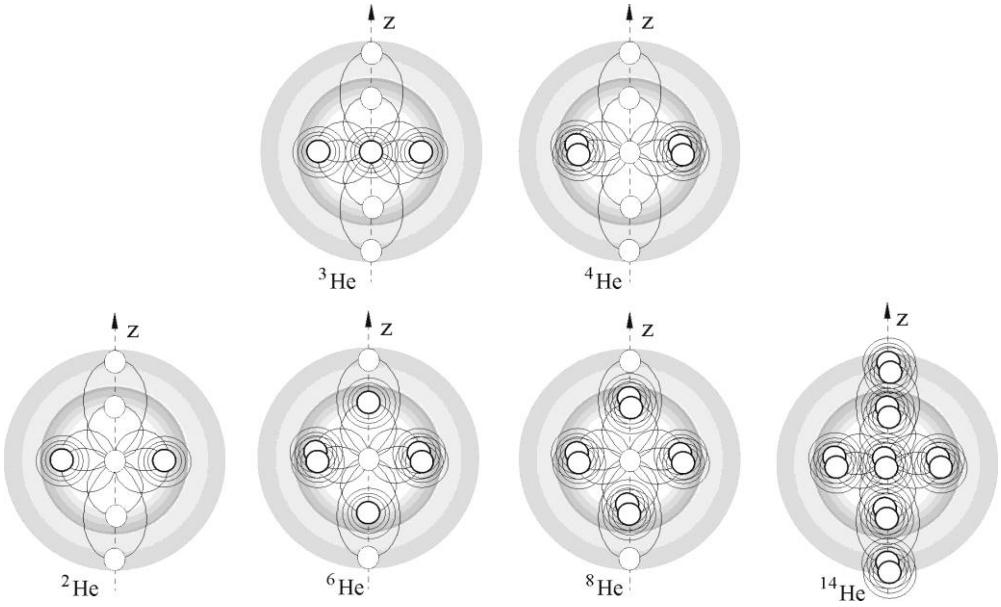

Fig. 1. Simplified drawings of the structure of six helium isotopes: the arrangement of nodes and filling them with nucleons [6].

Two isotopes, existed in nature, helium-3 and helium-4, are *stable*. Two *unstable* isotopes (helium-6 and helium-8) have a *relatively big half-life* (806.7(15) *ms* and 119.0(15) *ms*, respectively). While helium-2 is an *extremely unstable* helium isotope. These three unstable isotopes shown in Fig. 1 (as known unstable isotopes helium-5, helium-7, helium-9, and helium-10, not shown here) were detected as a result of particle collisions in accelerators.

Judging by the number of all nodes (except kinetic, not shown in Fig. 1) in the nodal structure of helium, the helium-11, helium-12, helium-13, and helium-14 isotopes (the latter is shown in Fig. 1), can be produced in experiments on accelerators. The possibility of

observing such an event (of course, for a very short period of time, as, for example, in the case of helium-2) is unknown for physicists who adhere to the Standard Model.

As you can see, the structure and number of isotopes depends on the degree of filling with nucleons (maximum two per node) of all the nodes: principal *potential* polar-azimuthal and polar *potential-kinetic* (located along the z-axis) [6].

From the nodal structure of helium, it follows that the heaviest helium isotope that can be obtained on accelerators is helium-14.

Polar potential-kinetic nodes, situated along the polar axis z, are nodes of rest and movement at the same time. Therefore, they are places of nonequilibrium states. Hence, the structures with forcibly (in accelerators) filled polar nodes are not stable. They are characterized by a short period of existence depending on the geometrical configuration (symmetry) of the location of the filled nodes and the degree of their filling (one or two per node).

In this regard, it should be noted that the united chains of empty polar nodes inside atoms in some compounds forms something like a channel for motion of charges in them without obstacles. This feature was discovered by us, in particular, in studying the conductivity of graphene [2].

The structure of the lightest helium isotope, helium-2, with half-filled nodes, as shown in Fig. 1, is extremely unstable. Such a structure with one nucleon per every node can appear and exist only for an instant, like helium-14 and other similar nonequilibrium formations.

The shell-nodal structure of a stable isotope of a helium atom, ${}^{4}_{2}He$, the calculation of the binding energy of which we show here, has two *potential polar-azimuthal* nodes *filled* with *coupled nucleons*, and five *empty polar* potential-kinetic nodes (see Fig. 1). *Kinetic* polar-azimuthal nodes, not shown in the figure, are of no interest to us. They are antinodes of standing waves [3], where intense movement occurs; therefore nucleons cannot be located there.

3. The binding energy of helium ${}^{4}_{2}He$

The binding energy of nucleons in helium-4 is *conditioned* by the following *three* components, listed in order of increasing contribution:

1. The *binding energy* of *paired nucleons* located in *potential polar-azimuthal* nodes, that is, the *energy* of d*euterons*.

2. The *binding energy* of nucleon *nodes* with the atomic *wave shell*, to which these nodes belong. In essence, this is the *oscillation energy* of nucleons in a *node*.

3. The *energy* of *internodal exchange* (interaction) of nucleons.

1) Calculation by the *WM* of the value of the *first* relatively small component of the binding energy of helium-4, the *energy of two deuterons*, we will not consider here. The calculation of the *deuteron binding energy* is not so simple, because it requires knowledge of the *internal structure* of the *nucleons* themselves. We devote to this issue Part 3 of this article.

Therefore, we will use here the value of the deuteron binding energy obtained by usual way from the mass defect formula:

$$\Delta E = c^2 \Delta m \qquad (4)$$

A deuteron is the basis of a deuterium atom. It consists of one proton and one neutron. The sum of the masses of the nucleons of which the deuteron is composed is

$$m_p + m_n = 1.007276 + 1.008665 = 2.015941 amu\,. \qquad (5)$$

The atomic mass of the deuteron D (^{2}H) is 2.013553 *amu*; hence, the mass difference is $\Delta m = 0.002388\, amu$. Thus, according to (4), the deuteron binding energy is

$$E_D = c^2 \Delta m = 2.224\, MeV\ . \qquad (6)$$

Recall that the calculation of the deuteron binding energy in another way (within WM) will be described in Part 3.

2) The *second* component of the binding energy is determined from the following conditions. In a *spherical wave field* of an atom, the radial amplitudes of *nucleon* oscillations in the nodes of the *n*-th atomic shell are determined by the expression,

$$\hat{A}_s = A\hat{e}_l(kr)/kr\,, \qquad (7)$$

obtained from solutions of equation (2) for the radial function $\hat{R}_l(kr)$ [1]. Then the oscillation energy takes the form:

$$E_s = \frac{m_p \omega^2 A_s^2}{2} = \frac{1}{2} h\nu = \frac{m_p \omega^2}{2}\left(\frac{A}{kr}\right)^2 e_l^2(kr) = \frac{m_p c^2 A^2}{2r^2} e_l^2(kr)\,, \qquad (8)$$

where

$$e_l(kr) = \left|\hat{e}_l(kr)\right| = \sqrt{\frac{\pi kr}{2}\left(J^2_{l+½}(kr) + Y^2_{l+½}(kr)\right)}\,, \qquad (9)$$

m_p is the nucleon mass, $J_{l+½}(kr)$ and $Y_{l+½}(kr)$ are Bessel functions.

The radial action *h* in equation (8) is equal to

$$h = 2\pi m_p \upsilon_s A_s\,, \qquad (10)$$

or

$$h = 2\pi m_p \omega\left(\frac{A}{kr}\right)^2 e_l^2(kr) = \frac{2\pi m_p c A^2}{kr^2} e_l^2(kr) \qquad (11)$$

At $l = 0$, in the wave zone ($kr = 1$), we have

$$h = 2\pi m_p c A^2 / r_0\,. \qquad (12)$$

From this equality we determine the constant *A*:

$$A = \sqrt{\frac{h r_0}{2\pi m_p c}}\,. \qquad (13)$$

In the wave zone, $r_0 = ƛ_e$, then assuming that the radial action for the mass m_p is $h = 2\pi m_p \upsilon ƛ_e$, we arrive at the following equality

$$A = \sqrt{\frac{h r_0}{2\pi m_p c}} = ƛ_e \sqrt{\frac{\upsilon}{c}}\,. \qquad (14)$$

If we further assume that the speed υ is equal to the Bohr speed, the constant A takes the value of

$$A = 1.370113189 \cdot 10^{-9}\, cm. \qquad (15)$$

Accepted assumptions lead to the following nucleon energy in a node, at $m_p = m_u$ (where m_u is the atomic mass unit) and the fundamental frequency ω_e:

$$E_s = \frac{m_u \omega_e^2 A_s^2}{2} = \frac{m_u \omega_e^2 A^2}{2(kr)^2} e_l^2(kr) = \frac{w_u}{z_{l,s}^2} e_l^2(z_{l.s}). \qquad (16)$$

where

$$w_u = \frac{m_u \omega_e^2 A^2}{2} = 3398.72\ keV \qquad (17)$$

and $z_{l,s} = kr$ is the root of Bessel functions [7] .

The binding energy (16) is only an estimation of the bond of the atomic wave shell with the *n*-node, because it was obtained on the basis of a number of assumptions, which should be considered as preliminary axioms.

A transition from one *n*-shell into another is determined by the transition energy:

$$\Delta E_s = w_u \left(\frac{e_p^2(z_{p,m})}{z_{p,m}^2} - \frac{e_q^2(z_{q,n})}{z_{q,n}^2} \right). \qquad (18)$$

The root $z_{l,s} = y_{0,1} = 0.89357697$ determines the following equilibrium distance

$$r_{He} = y_{0,1} \lambda\!\!\!^{-}_e = 1.433196073 \cdot 10^{-8}\, cm \qquad (19)$$

between two potential polar-azimuthal nodes of the external atomic wave shell of a helium atom ^4_2He (Fig. 2).

Therefore, according to (16), the binding energy of the nucleon node with the atomic wave shell in the helium atom is

$$E_{shell} = \frac{w_u}{y_{0,1}^2} e_0^2(y_{0,1}) = 3.92109\, MeV\ . \qquad (20)$$

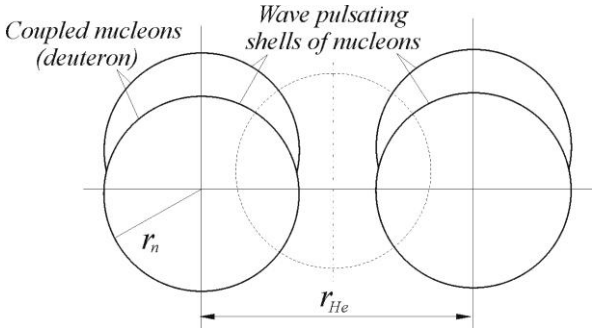

Fig. 2. The mutual disposition of the coupled (overlapped) nucleons in the potential polar-azimuthal nodes of the helium-4 atom; r_n is the radius of the wave pulsating shell of a nucleon, r_{He} is the distance between the centers of the nodes (pairs of nucleons).

3) The *third* constituent of the binding energy of helium is the *energy* of *exchange* (interaction) of *internodal nucleons*, that is, nucleons located in different nodes spaced at a distance *r*. This energy is determined by the equation,

$$E = \omega_e^2 \frac{m_1 m_2}{8\pi\varepsilon_0 r}, \tag{21}$$

which follows from the Law of Central Exchange (discovery of the DM),

$$F = \omega^2 \frac{m_1 m_2}{4\pi\varepsilon_0 r^2} \tag{22}$$

where ω is the *fundamental frequency* of exchange (ω_e or ω_g), m_1 and m_2 are *associated masses*, $\varepsilon_0 = 1 g \cdot cm^{-3}$ is the absolute unit of density. The law (22) lies at the foundation of nature. If $\omega = \omega_e$, this law describes exchange (interactions) at the atomic and subatomic levels.

The product $\omega m = q$ is the *exchange charge* of interacting objects. The *quantum* of *internodal nucleon exchange* is $q = m\omega_e$. Exchange (interaction) at the formation of *internodal bonds* is realized by two such quanta - by one quantum per node: $q_1 = m_1\omega_e$ and $q_2 = m_2\omega_e$.

Thus, at $r = r_{He}$ (19), $\omega_e = 1.869162505 \cdot 10^{18}\, s^{-1}$, and the proton exchange charge $q_p = m_p\omega_e$, where

$$m_1 = m_2 = m_p = 1.67262171 \cdot 10^{-24}\, g \tag{23}$$

is the associated mass of a *proton*, we arrive at the following *energy* of *exchange between two nodes filled* with *coupled* nucleons *(energy* of *double* internodal nucleon bond):

$$E_{exch} = \omega_e^2 \frac{m_p^2}{8\pi\varepsilon_0 r_{He}} = 16.9599375\, MeV. \tag{24}$$

Hence, the exchange binding energy per nucleon is

$$E_{exch/n} = E_{exch} / 4 = 4.239984375\, MeV, \tag{25}$$

and per nucleon pair (*single* internodal nucleon *bond*),

$$E_{exch/b} = E_{exch} / 2 = 8.47996875\, MeV. \tag{26}$$

For estimation, we take into account the *double bond* between nodes in helium-4 realized by two *elementary quanta* of internodal nucleon exchange. Thus, two pairs of nucleons participate in the internodal bond, so that the whole value (24) must be taken in this case.

As a result, the binding energy of the *helium atom* ${}_2^4He$, obtained as the sum of three constituents: (5), (20), and (24), is determined by the expression

$$E_{He,atom} = 2E_D + 2E_{shell} + E_{exch} \tag{27}$$

and equal to

$$E_{He,atom} = 2 \cdot 2.224 + 2 \cdot 3.92109 + 16.9599375 = 29.250\, MeV. \tag{28}$$

The contribution of two electrons to the binding energy (28) is insignificant. The binding energy of an electron with a proton (ionization energy) and the energy of inter-electron exchange (interaction) are very small compared to the energy of inter-nucleon exchange. Actually, according to the formula of exchange (21), we have

$$E_{e-exch} = \omega_e^2 \frac{m_e^2}{8\pi\varepsilon_0 r_{He}} \approx 5.24\,eV\,, \qquad (29)$$

where $\omega_e m_e = e = 1.702691627 \cdot 10^{-9}\ g \cdot s^{-1}$ is the *exchange charge* of an *electron*. The energy (29) determines, naturally, the difference between the two energies of ionization of the helium atom:

$$E_{e-bond} = E_{ion}^{(2)} - E_{ion}^{(1)} = (54.42 - 49.18)\,eV = 5.24\,eV\,. \qquad (30)$$

Thus, finally, when subtracting from (28) the internal (dynamic) energy of two electrons, $2E_e = 2m_e c^2$ (determined from the mass-energy equivalent formula), we come to the *binding energy* of the *helium ion* ${}_2^4He^{-2}$ - the "nucleus" of helium, according to modern concepts of physics:

$$E_{He,ion} = E_{He,atom} - 2E_e = 29.250 - 2 \cdot 0.510998902 \approx 28.2281\,MeV\,. \qquad (31)$$

Recall, in the shell-nodal atomic model there is no such thing as a "nucleus".

If we replace the neutron mass $m_n = 1.67492728 \cdot 10^{-24}\ g$ in (24) with the proton mass m_p, then we obtain the energy of the helium ion,

$$E_{He,ion} \approx 28.23\,MeV\,. \qquad (32)$$

The values, (31) and (32), practically coincide with the binding energy of helium "nucleus", obtained by the formula of mass defect,

$$\Delta E_{He} = c^2 \Delta m \approx 28.3\,MeV \qquad (33)$$

Conclusion

A direct calculation of the binding energy of the helium atom became possible thanks to a series of discoveries made in the framework of the Wave Model, here they are:

1) The internal shell-nodal (nucleus-free) structure of atoms and the main parameters characterizing such a structure, in particular, the spatial arrangement of nucleons in them.

2) Dynamic finite-infinite structure of elementary particles and an equation describing the pulsations of their wave shells.

3) Fundamental frequency of the atomic and subatomic levels ω_e determining inter- and intra-atomic interactions (strong and electromagnetic).

4) Universal Law of the central exchange (interaction).

5) Exchange charges q_{ex} as the product of the associated mass m of a particle and the fundamental frequency ω_e.

Truthfulness of the shell-nodal (molecular-like) structure of atoms, following from solutions of the wave equation (2), is confirmed by the discovery of the nature (structure) of

all possible isotopes of atoms, both known and not yet detected; some helium isotopes are shown here.

So, all the data obtained within the WM, including presented in this article, confirm the validity of the wave shell-nodal (molecule-like, nuclear-free) structure of atoms.

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