The Shell-Nodal Structure of the Carbon Atom and Graphene

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Main peculiarities of the discovery [1] of a shell-nodal structure of atoms, including carbon, are presented in this report. A new method [2] allowing the controlled use of graphene in high tech for fabrication of graphene nanodevices with strictly prescribed parameters was invented on the basis of the discovery.

Recognizing without any doubts the wave nature of the Universe, we have come to the conclusion that all phenomena and objects in the Universe at all levels, including subatomic, atomic, and molecular, have to exhibit behavior subjected to the general wave equation

\[ \Delta \Psi + \frac{1}{c^2} \frac{\partial^2 \Psi}{\partial t^2} = 0 \]

Taking this statement into account, we have analyzed some purely mathematical solutions of the equation. In result of the analysis [1], it turned out that the well-known particular solutions of the equation de facto, as we have assumed, contain information about the structure of matter and some regularities in nature unknown earlier [3]. With regard to the structure of atoms, we have found the following.

- Atoms are wave formations.
- Atoms have a quasi-spherical shell-nodal structure coincident with the nodal structure of standing waves localized in a three-dimensional wave space-field.
- Every potential polar-azimuthal node in spherical shells of stable atoms contains two nucleons.
- Along the z axis of the atom (in spherical polar coordinates), there are polar potential-kinetic nodes not completed with nucleons in the most abundant and stable atoms.
- Interaction between completed nodes inside and outside of the atoms is realized on the fundamental frequency of pulsating of the spherical shells of constituent particles [4],

\[ \omega = 1.869162559 \times 10^{18} \text{ s}^{-1} \]

Exchange (interaction) is realized by exchange charges. The latter are defined as the product of the associated mass of a particle and the fundamental frequency \( \omega \),

\[ q = m \omega g \times \text{s}^{-1} \]

Above enumerated features cardinally change the common view on the structure of matter. They are in violent discrepancy with present-day concepts in atomic physics which did not call doubts up to now.

We verified the obtained solutions by different ways and all they completely confirmed correctness and validity of the solutions. Graphene, one-atom-thick layers of graphite, having a two dimensional hexagonal lattice, gives us a new unique possibility for the direct verification of one of the predictions, originated from the solutions. It is very important because by this way we can examine once more new basic theoretical concepts on the structure of matter.

Which prediction is we mean? According to modern notions, the hexagonal lattice of graphene, a two dimensional crystal, has a high order symmetry axis, six-fold. Hence, the electrical conductivity of graphene must be isotropic in a plane perpendicular to this axis, in full agreement with the basic symmetry theory [5] as having more than two-fold symmetry. This is why an examination of feasible conductivity anisotropy in pristine unstrained graphene has never been undertaken, and a question about such tests has never been raised among researchers.

Thus, an existence of natural anisotropy of graphene was not only unknown, but even is not discussed a possibility itself of this phenomenon, as completely unacceptable, craze. Really, at first glance a talk about an existence of natural conductivity anisotropy in graphene seems nonsensical. However, according to the shell-nodal structure of the carbon atom, it makes sense. If one takes into account the position of all atomic nodes, completed and empty (potential and kinetic polar-azimuthal, and polar potential-kinetic [6, Fig. 23]), graphene has not a six fold axis, but only two fold [6, Figs. 29, 37]. Polar potential-kinetic nodes along the z axis (empty and, therefore, invisible in structural analysis) form together an empty channel allowing the ballistic motion of electric charges in graphene. They divide the hexagonal cell formed of potential nodes filled with nucleons (and, hence, visible in structural analysis) onto two symmetrical halves. Accordingly, the conductivity anisotropy conditioned by the existence of the ballistic channel must be observed in such a case. The fact that we do not see empty polar nodes forming the ballistic channel does not quite mean that these nodes do not exist.
means are too imperfect at present to observe all peculiarities of the structure of matter at the atomic level.

The laboratory tests conducted quite recently, have confirmed the existence of conductivity anisotropy, i.e., the validity of theoretical solutions, and, hence, the correctness of the shell-nodal structure of carbon atoms and their specific ordering in the hexagonal lattice as shown schematically in Fig. 37 and other figures in [6]. A polar diagram of conductivity anisotropy of graphene has a characteristic elliptical form. Along the major axis of anisotropy, coincident with the ballistic channel, graphene behaves like a metal; in a direction perpendicular to the major axis (along the minor axis) graphene exhibits semiconducting properties.

On the basis of shell-nodal atomic model, specific features of graphene are naturally explained, logically and noncontradictory, for example, such properties of graphene nanoribbons (GNRs) as: "length and width dependent resistance scaling in GNRs", "the averaging hopping length between localized states", why "the charge transport is dominated by hopping through localized state", what are "localized states" themselves [7, 8]. The new atomic model uncovers also, why "graphene is...an interesting mix of a semiconductor...and a metal..." [9]; and so on.

Graphene anisotropy explains logically the fact that graphene nanotubes, rolled-up form of graphene, have either conductivity, metallic or semiconducting. The rolling-up of graphene is realized mainly along two crystallographic directions [8]: along the major axis (we called it the Z-axis) and in perpendicular to it direction. Obtained nanotubes have the minimal energy of state in these cases. The rolling-up of graphene sheets runs spontaneously at the high temperature conditions; it is not yet controlled process. The rolling-up in other directions is thermodynamically unfavourable unstable process, which does not provide the minimal energy of state for the formed systems (graphene nanotubes).

Ignorance about an existence of the anisotropy conditions a random orientation of graphene sheets in experiments conducted to present and, as a result, leads to diversity, jumble, lack of coordination in numerous experimental data obtained in different laboratories (see, for example Fig. 44 in [6]).

Thus, as follows from the particular solutions of the general wave equation, atoms do not correspond to the Rutherford-Bohr model. They have the shell-nodal structure and resemble molecules composed of coupled nucleons that fill up potential wave nodes of atomic spherical shells. Accordingly, atoms are not one-center.

The validation of new theoretical concepts has been proved in all cases. To present time we have reconsidered and explained from a new point of view all those physical phenomena which we were able physically to review during the last two decades.

References