http://shpenkov.janmax.com/GrapheneAnisotropy.pdf

Anisotropy of Unstrained Pristine Graphene

George P. Shpenkov

g.shpenkov@firmus.mc

We present here very briefly, as far as possible in an understandable manner, the main peculiarities of the discovery [1] on the basis of which it was invented method [2] allowing the controlled use of graphene crystals in high tech for fabrication of graphene nanodevices with strictly prescribed parameters.

All in the Universe at all its levels, including micro- and mega-, is in incessant oscillatory-wave motion and, hence, has the wave nature. Wave fields of all objects are overlapped therewith. All in the Universe is undergone the law of rhythm and is in natural harmony. Accordingly, a natural harmonic bond exists between all fields, including electromagnetic and gravitational, like between any objects and phenomena.

Recognizing without any doubts the wave nature of the Universe, it is not so difficult to 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

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

Taking this statement into account, accepting it fully, we have decided to analyze some purely mathematical solutions of the equation to find there most likely existent, but uncovered up to now (as we believed) information about the structure and behavior of matter. We were assured in an achievement undertaking this task for many reasons. One of them is the fact that the physical meaning of some particular solutions of the wave equations was a white spot in science. Intellects of most physicists were/are focused just on controversial “solutions” of the Schrödinger equation and nobody thought either it is viable alternative or not. As it turned out in time, the latter were/are unable to withstand the critics, and in point of fact were finally found erroneous [3-5].

In result of our analysis carried out profoundly enough [1], it turned out that the well-known particular solutions of the general wave equation de facto, as we have assumed, contain information about the structure of matter and about some regularities in nature unknown earlier [6]. 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 formed in local regions of a three-dimensional wave space-field.
- Every potential polar-azimuthal node in spherical shells of stable atoms contains by 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 elementary particles [7], which at the same time is the fundamental frequency of exchange,

$$\omega_e = 1.869162559 \times 10^{18}\ s^{-1},$$

by exchange charges of nucleons and electrons, respectively. Exchange charge is defined as the product of associated mass of a particle and fundamental frequency ω_e,

$$q = m\omega_e \; g \times s^{-1}$$

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 layer 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, in respect to physical properties of graphene. It is very important because by this way we can examine once more basic theoretical concepts of dialectical physics [1] related to 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 [8] 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 [9, Fig. 23]), graphene has not a six fold axis, but only two fold [9, 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, in full agreement with a new atomic theory, shell-nodal, originated from the particular solutions of the wave equation [1].

The fact that we do not see empty polar nodes forming the ballistic channel does not quite mean that these nodes do not exist. Modern technological 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 [9]. 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 [9].

We would like to emphasize once more the fact that the discovery in question is not a result of an invention, or a fruit of our imagination, it is a result of profound analysis of well-known particular solutions of the wave equation. They have crucial importance for the entire foundation of physics. The discovery changes our view on the structure of atoms and, in particular, uncovers the reason of unusual properties observed in graphene.

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 [10, 11]. The new atomic model uncovers also, why "*graphene is...an interesting mix of a semiconductor...and a metal*..." [12]; 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 [11]: 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 (confusion) in numerous experimental data obtained in different laboratories (see, for example Fig. 44 in [9]).

The main conclusion is rather stunning. And we are aware of the situation. As follows from the particular solutions of the general wave equation, atoms do not correspond to the Rutherford-Bohr model. They have the shell-node structure and resemble molecules composed of coupled nucleons that fill up potential nodes of atomic spherical shells. Accordingly, atoms are not mononuclear.

Thousands years people thought about, what is atom? Now scientists must come back to this topic and carefully analyze an uncovered physical meaning of the well-known particular solutions of the general wave equation, deeply hidden from us up to now and, fortunately, found at last.

Validity of new theoretical concepts reported here has been verified from different sides. To present time (see References in [13]), basing on the shell-nodal atomic model and also on the dynamic model of elementary particles [7], we have reconsidered and explained from the new point of view, logically and noncontradictory, all those physical phenomena which we physically were able to review during the period beginning from the date of the discovery (1995) [1].

Thus, anisotropy of unstrained pristine graphene is the effect, confirmed experimentally, of the well-known pure mathematical particular solutions of the general wave equation. The property of anisotropy of two dimensional hexagonal lattice of graphene is one of the new properties already found in the framework of a new approach; they are enumerated in the comparative table in [6].

References

[1] L. Kreidik and G. Shpenkov, Atomic Structure of Matter-Space, Geo. S., Bydgoszcz, 2001, 584 p. http://shpenkov.janmax.com/atom.asp

[2] METHOD FOR MANUFACTURING NANO ELECTRONIC DEVICES MADE FROM 2D CARBON CRYSTALS LIKE GRAPHENE AND DEVICES OBTAINED WITH THIS METHOD. International Application Published under the Patent Cooperation Treaty (PCT). International Application No.: PCT/EP2010/052298. International Publication No.: WO/2010/097393. Author: G. Shpenkov.

https://register.epo.org/application?number=EP10707863&lng=en&tab=main

http://www.wipo.int/pctdb/en/wo.jsp?WO=2010097393&IA=EP2010052298&DISPLAY=STATUS

[3] L. G. Kreidik and G. P. Shpenkov, *Important Results of Analyzing Foundations of Quantum Mechanics*, GALILEAN ELECTRODYNAMICS & QED-EAST, Vol. 13, SI No. 2, 23-30, (2002); http://shpenkov.janmax.com/QM-Analysis.pdf

[4] G. P. Shpenkov and L. G. Kreidik, *Schrodinger's Errors of Principle*, GALILEAN ELECTRODYNAMICS, Vol. 16, No. 3, 51 - 56, (2005); http://shpenkov.janmax.com/Blunders.pdf

[5] G. P. Shpenkov, *Conceptual Unfoundedness of Hybridization and the Nature of the Spherical Harmonics*, HADRONIC JOURNAL, Vol. 29. No. 4, p. 455, (2006); http://shpenkov.janmax.com/HybridizationShpenkov.pdf

[6] George P. Shpenkov, *A Comparison of Two Models in Physics: DM (new) and SM (used currently)*; http://shpenkov.janmax.com/dmds.asp

[7] Leonid. G. Kreidik and George P. Shpenkov, *Dynamic Model of Elementary Particles and the Nature of Mass and "Electric" Charge*, REVISTA CIENCIAS EXATAS E NATURAIS, Vol. 3, No 2, 157-170, (2001); http://www.unicentro.br/editora/revistas/recen/v3n2/trc510final.pdf

[8] Robert E. Newnham, *Properties of Materials: Anisotropy, Symmetry, Structure*, Oxford University Press, 2005.

[9] Carbon and Oxygen; http://shpenkov.janmax.com/CarbonOxygen.pdf

[10] Melinda Y. Han, Juliana C. Brant, and Philip Kim, *Electron Transport in Disordered Graphene Nanoribbons*, Phys. Rev. Lett. **104**, 056801 (2010).

[11] Graphene Nanoribbons; http://shpenkov.janmax.com/nanoribbons.pdf

[12] A.H. Castro Neto, F. Guinea, N. M. R. Peres, K. S. Novoselov and A. K. Geim, *The electronic properties of graphene*, Rev. Mod. Phys. **81**, 2009.

[13] George P. Shpenkov; http://shpenkov.janmax.com/selectedpub.asp

George P. Shpenkov
21.12.2010