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Research Article

A Possible Signature of Neutron Quarks – Leptons via Gluon Interaction in Solids

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Abstract

The experimental evidence for a macroscopic manifestation of the residual strong interaction in the optical spectra of solids (luminescence and reflection) which differ by term of one neutron from each other (using LiD crystals instead LiH ones) is presented. As far as the gravitation, electromagnetic and weak interactions are the same in both of kind crystals, this only changes the residual strong interaction. Therefore, we conclude that the renormalization of the energy of electromagnetic excitations (electrons, excitons, and phonons) is carried out by the residual strong nuclear interaction. The necessity to take into account the more close relation between quantum chromodynamics and quantum electrodynamics is underlined. In the first step quantum electrodynamics should take into account the residual strong interaction at the description of the dynamics of elementary excitations (electrons, excitons, and phonons) dynamics.

Keywords: Excitons, Leptons, Quantum electrodynamics and chromodynamics, Quarks, Strong interaction

1. Introduction

Recently, the direct dependence of the energy of interband transition E_g in solids (e.g. LiH_xD_{1-x} crystals) on the strong nuclear interaction was demonstrated [1]. The present report is devoted to advance a description of the experimental results demonstrated by the above dependence. According to contemporary physics, the Universe is made up of matter fields, whose quanta are fermions and force fields (whose quanta, in turn, are bosons). Basically, fermions can be classified into two groups: elementary and composite fermions. Elementary fermions are leptons (electron, electron neutrino, muon, muon neutrino, tau, and tau neutrino and quarks (up, down, top, bottom, strange, and charm)). Hadrons (neutrons and protons) containing an odd number of quarks, and nuclei made of an odd number of nucleons (e.g. $^{13}_{6}C$ nuclei contain six protons and seven neutrons) are considered to be composite fermions. Elementary fermions are the fundamental building blocks of matter and antimatter [2,3]. Bosons are identical particles having zero or integer spins. Unlike fermions, bosons do not obey the Pauli Exclusion Principle. The SM [4] only consists of five

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elementary bosons (see Fig. 11 in [5]). They are namely the Higgs boson, gluon, Z and $W^{\pm}$ bosons. The Higgs boson have zero electric charge and zero spin, and is the only scalar boson.

The discovery of the neutron by Chadwick in 1932 [2] may be viewed as the birth of the strong interaction: it indicated that the nuclei consists of protons and neutrons and hence the presence of a force that holds them together, strong enough to counteract the electromagnetic repulsion. In 1935, Yukawa [6] pointed out that the nuclear force could be generated by the exchange of a hypothetical spinless particle, provided its mass is intermediate between the masses of proton and electron – a meson. Yukawa predicted the pion [2,7]. The strong forces do not act on leptons (electrons, positrons, muons, and neutrinos), but only on protons and neutrons (more generally, on baryons and mesons – this is the reason for the collective name hadrons). It holds protons and neutrons together to form nuclei, and is insignificant at distances greater than 10^{-15} m ([6] see below). Its macroscopic manifestations have been restricted up to now to radioactivity and the release of nuclear energy [3,4]. Quantum chromodynamics (QCD) is the theory of the strong interaction, responsible for binding quarks through the exchange of gluons to form hadrons (baryons and mesons).

Our present knowledge of physical phenomena suggests that there exist four types of forces between physical bodies (see, e.g. [8,11]): (1) gravitational, (2) electromagnetic, (3) strong, and (4) weak (see, e.g. Table 8 in [5]).

Both the gravitational and the electromagnetic forces vary in strength as the inverse square of the distance and so are able to influence the state of an object even at very large distances. When nuclear physics developed, two new short-range forces joined the ranks. These are the nuclear forces, which act between nucleons (proton, neutron, etc.) and the weak force, which manifest itself in nuclear β-decay (see, e.g. [7). The nuclear force is a result of the residual strong force binding quarks to form protons and neutrons. Subatomic physics deals with all entities smaller than the atom. The modern quantum mechanical view of the three fundamental forces (all except gravity) is that particles of matter (fermions neutrons, protons, and electrons) do not directly interact with each other, but rather carry a charge, and exchange virtual particles (gauge bosons photons, gluons, and gravitons) which are the interaction carriers or force mediators. As can be seen from Table 8 in [5], photons are the mediators of the interaction of electric charges (protons, electrons, and positrons); and gluons are the mediators of the interaction of color charges (quarks). In the present day, the accepted view is that all matters are made of quarks and leptons. As can be seen, of the three pairs of quarks and leptons, one pair of each – the quark u and d and the leptons e^{-} and ν^{e} (electrons neutrino) – are necessary to make up the everyday world, and a world which contained only these would seem to be quite possible.

These facts, and a summary of modern nuclear and subatomic physics (see, e.g. [2,7]) allow us to draw several conclusions in regard to nuclear forces, most notably that the binding energy of a nucleus is proportional to the number of nucleons and that the density of nuclear matter is approximately constant. This leads to the conclusion that nuclear forces have a “saturation property” [2,7]. It seems from the last conclusion that it is enough to change the number of neutrons in the nucleus to change the strength of the nuclear force. This constitutes the main ideas of the isotope effect [8].

2. Experimental

The apparatus used in our experiments has been described in several previous publications [9–11]. For clarity, we should mention here that a home-made immersion helium cryostat and two identical double-prism monochromators were used. One monochromator was used for the excitation, and the other, which was placed at right-angle to the first, for analyzing the luminescence and scattering of light. In our experiments we investigated two kinds of crystals (LiH and LiD) which differ by one neutron. The single crystals of LiH and LiD were grown from the melt by a modified Bridgeman–Stockbarger method (see [18,5] and references quoted therein). The crystals were synthesized from 7Li metal and hydrogen of 99.7% purity and deuterium of 99.5% purity. Virgin crystals had a slightly blue–green color, which can be attributed to a nonstoichiometric excess of lithium present during the grown cycle. On annealing for several days (up to 20) at 500°C under $\sim$3 atm of hydrogen or deuterium, this color was almost completely eliminated.

Because of the high reactivity and high hygroscopy of the investigated crystals an efficient protection against the atmosphere was necessary. Taking into account this circumstance, we have developed special equipment which allows us to prepare samples with a clean surface cleaving them in a bath of helium cryostat with normal or superfluid liquid helium [5].

3. Results

We should briefly review electronic excitations in solids. According to the modern concept, the excitons can be considered [12] as the excited N-particles system: An electron from the valence band (see Fig. 1 in [11]) is excited into the conduction band. The attractive Coulomb potential between the missing electron in the valence band, which can be regarded as a positively charged hole, and the electron in the conduction band gives a hydrogen-like spectrum with an infinite number of bound state and ionization continuum (Fig. 71 in [13]). Below we will briefly describe the results of the optical spectroscopy of isotope-mixed solids. In our experiments we have investigated the low-temperature optical spectra (Fig. 1 reflection and Fig. 2 luminescence) of LiH_xD_{1-x} crystals ($0 \leq x \leq 1$) which differ by one neutron from each other. The mirror reflection spectra of mixed and pure LiH and LiD crystals cleaved in liquid helium are presented in Fig. 1. All spectra have been measured with the same apparatus under the same conditions. As the deuterium concentration increases, the long-wave maximum (n = 1S excitons [12]) broadens and shifts towards the shorter wavelengths.

As demonstrated early (see, e.g. review [13]) most low-energy electron excitation in LiH crystals are the large-radius excitons [12]. Exciton luminescence is observed when LiH (LiD) crystals are excited in the midst of fundamental absorption. The spectrum of exciton photoluminescence of LiH crystals cleaved in liquid (superfluid) helium consists of a narrow (in the best crystals, its half-width is $\Delta E \leq 10$ meV) phononless emission line and its broader phonon repetitions, which arise due to radiated annihilation of excitons with the production of one to five longitudinal optical (LO) phonons (see Fig. 2).

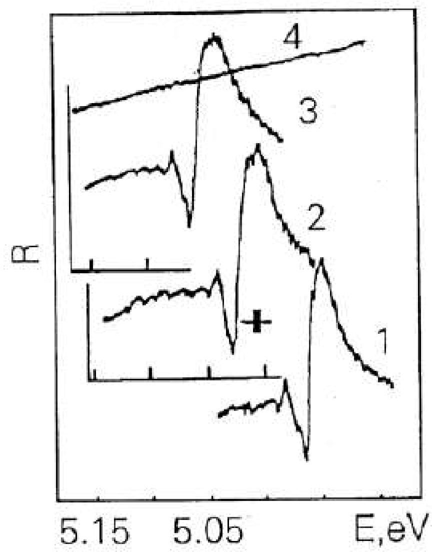

Figure 1. Mirror reflection spectra of crystals: (1) LiH, (2) LiH_xD_{1-x}, (3) LiD at 2 K, and (4) light source without crystals.

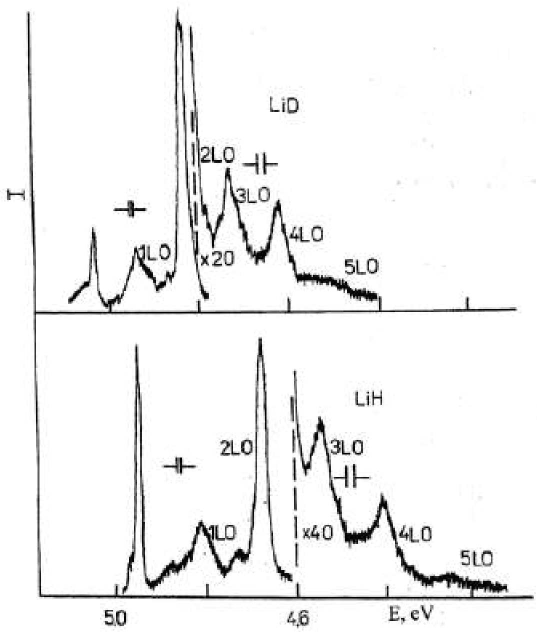

Figure 2. Photoluminescence spectra of free excitons at 2 K in LiH and LiD crystals cleaved in superfluid helium.

The phononless emission line coincides in an almost resonant way with the reflection line of the exciton ground state, which is indication of the direct electron transition X1–X4 of the first Brillouin zone [14]. The lines of phonon replicas form an equidistant series biased toward lower energies from the resonance emission line of excitons.

The energy difference between these lines in LiH crystals is about 140 meV, which is very close to the calculated energy of the LO phonon in the middle of the Brillouin zone [15,16] and which has been measured (see, e.g. [17,18] and references quoted therein). The isotopic shift of the zero-phonon emission line of LiH crystals equals 103 meV. As we can see from Fig. 2 the photoluminescence spectrum of LiD crystals is largely similar to the spectrum of intrinsic luminescence of LiH crystals. There are, however, some related distinctions. First, the zero-phonon emission line of free excitons in LiD crystals shifts to the short-wavelength side on 103 meV. These results directly show the violation of the strong conclusion (see, e.g. [2,7]) that the strong force does not act on leptons. The second difference concludes in less value of the LO phonon energy, which is equal to 104 meV. The simplest approximation, in which crystals of mixed isotopic composition are treated as crystals of identical atoms having the average isotopic mass, is referred to as virtual crystal approximation (VCA) [19]. Going beyond the VCA, in isotopically mixed crystals one would expect local fluctuations in local isotopic composition within some effective volume, such as that of an exciton. As follows from Fig. 1, excitons in LiH_xD_{1-x} crystals display a unimodal character, which facilitates the interpretation of their concentration dependence. Figure 3 shows the concentration dependence of the power of strong nuclear interaction, i.e. dependence on the neutron concentration. In the first approximation the mechanism of isotope shift will be connect with the neutron magnetic field of the deuterium nucleus (neutron) (to be published separately). As can be seen from Fig. 3, the VCA method cannot describe the observed experimental results. As was shown early [18] this deviation from linear low (VCA approximation) is connected with isotope-induced disorder in isotope mixed crystals LiH_xD_{1-x}. According to Lifshitz [20] the isotopic disordering ought to be classified as site disordering of the crystal lattice.

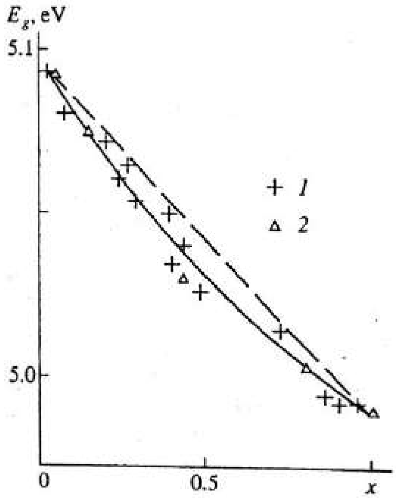

Figure 3. Dependence of the interband transition (strong interaction) energy E_{g} in mixed crystals on the concentration *x* (number of neutrons N). The straight dashed line is the linear dependence of coupling constant strong interaction $\alpha_{\mathrm{s}} = f(N)(E_{\mathrm{g}} = f(x))$ in the virtual model. The solid line corresponds to the calculation using the polynomial of second degree $E_{\mathrm{g}} = E_{\mathrm{g}}$(LiD) $+\{E_{\mathrm{g}}$(LiH) - E_{g}(LiD) - $b\}x$ - bx^2, where $b = 0.046$ eV is curvature parameter [18]. Points derived from the reflection spectra indicated by crosses, and those from luminescence spectra by triangles.

A comparison of the experimental results with luminescence and reflection in the crystals which differ by one neutron allows the following conclusions:

(1) Adding one neutron (using LiD crystals instead LiH ones) is caused in the increase of exciton energy to 103 meV.
(2) At the addition of one neutron, the energy of LO phonons is decreased on the 36 meV, that is directly seen from luminescence and scattering spectra.

Both characteristics are macroscopic. These experimental results can open an avenue for new nuclear physics. Moreover, our results demonstrate very important information that high energy physics could obtain via the rather simple and inexpensive equipment of experimental physics.

A comparison of the dependence of the residual strong nuclear force in different substances shows that the residual strong nuclear force has a nonlinear character on the number of neutrons (Fig. 4). We should stress that in all experimental results we have, the case where the perturbation theory works very well – the isotope shift 0.103 eV is much smaller than interband transition energy E_{g} and more less than nuclear energy (results which will be published separately).

4. Discussion

The nucleus is the central part of an atom consisting of A – nucleons, Z – protons, and N – neutrons. The atomic mass of the nucleus is equal to $Z + N$(see Fig. 1 in [5]). A given element can have many different isotopes, which differ from one another by the number of neutrons contained in the nuclei [2,7,21]. Modern physics distinguishes three fundamental properties of atomic nuclei: mass, spin (and related magnetic moment), and volume (surrounding field strength) which are the sources of the isotopic effect (see, also [18]).

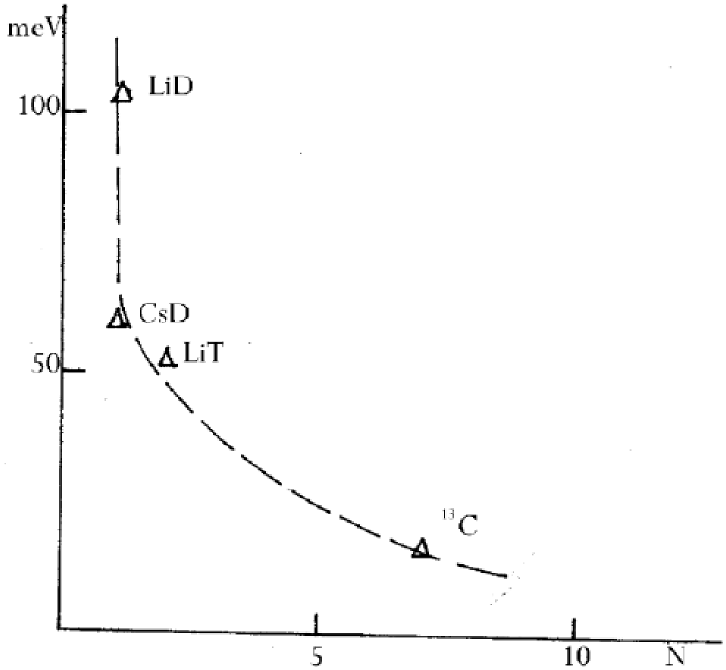

Figure 4. The dependence of the strong force on the number of neutrons in different substances.

LiH (LiD) crystals with a lattice of NaCl type, whose parameters are close to cubic crystals, are dielectrics with a band gap of $E_g = 4.992$ eV ($E_g = 5.090$ eV for LiD) at 2 K [22]. These crystals have an identical electronic structure. The energy band structure of these substances is also identical [13,23]. All three kinds of forces – gravitational, electromagnetic, and weak are also the same for the above compounds. The difference between these substances consists out at one neutron in the nucleus of deuteron. Below we should briefly consider some peculiarities of the physics of deuterons. Nucleons can combine to make four different few-nucleon systems, the deuteron (p + n), the triton (p + 2n), the helion (2p + n), and α-particle (2p + 2n). These particles are grouped together because they are all stable (apart from the triton which has a half-life of about 12 years and so may be treated as a stable entity for most practical purposes). They have no bound excited states (except the α-particle which has two excited states at about 20 and 22 MeV [7]), and they are frequently used as projectile in nuclear reactions. Few-nucleon systems provide the simplest systems to study nuclear structure (see, e.g. [24]). The deuteron provides important information about the nucleon –nucleon interaction. As was noted, the deuteron consists of a proton and a neutron and is the only bound state of two nucleons. Its binding energy is 2.2245 MeV and its total angular momentum J and parity are 1^+ [7]. Since the intrinsic parities of the neutron and the proton are positive parity of the deuteron implies that the relative orbital angular momentum of the neutron and the proton must be even. If the orbital angular momentum L is a good quantum number, states with lower orbital angular momentum generally have lower energy than states with higher angular momentum, and so we expect the ground state of the deuteron to have orbital angular momentum $L = 0$, so that it is in an S state. Then, if the spins of the proton and the neutron in the deuteron are parallel, we expect the magnetic moment of the deuteron to be approximately the sum of the magnetic moments of the proton and neutron, namely $\mu_p + \mu_n$ = (2.793 –1.913) μ_N = 0.880 μ_N (μ_N = e $\hbar$/2m$_p$) [7]. If, however, the spins are anti-parallel , we expect it to be (2.793 + 1.913)μ_N = 4.706 μ_N. Experimentally it is 0.857 μ_N [7,25] so the spins of the proton and neutron are parallel and so the total spin S of the deuteron is one, since $J = L + S$, $J = 1$. The small but definite difference between μ_d = 0.857 μ_N and $\mu_\mathrm{p} + \mu_\mathrm{n}$ = 0.880 μ_N is due, as will show below, to tensor character of strong forces in deuteron. We thus conclude that the ground state of deuteron is a triplet S state. However, this cannot be the whole story because S states are spherically symmetrical and thus have no quadrupole moment. This is contradicted by experiments. Experimentally the deuteron has a positive quadrupole moment of 0.29 fm^2 [25]. The deviation of the actual deuterium moment from the S state moment can be explained if it is assumed that the deuteron ground state is a superposition of S and D states. Part of the time, the deuteron has orbital angular momentum $L = 2$. Independent evidence for this fact comes from the observation that, as was shown above, the deuteron has a small, but finite, quadrupole moment (see, also [26]). As is well-known, the electric quadrupole moment measures the deviation of a charge distribution from sphericity [8]. The quadrupole moment of a disk shaped (oblate) nucleus Q is negative. A positive quadrupole moment of $Q = 0.29$ fm^2 according experiment indicates that the deuteron is slightly elongated on the z-axis, like an olive (prolate). Quantum mechanical definition of quadrupole moment for a single proton [25] is described by:

$$eQ = e\int (3z^2 - r^2)\,\mathrm{d}t. \tag{1}$$

Thus, if the quadrupole moment is not equal to zero then the eigenfunction of the ground state of the deuteron assigns a probability of 0.04 to finding a ^{3}D1 state and a probability of a 0.96 to finding a ^{3}S1 state. The last one points to the tensor character of the nucleon–nucleon interaction (for more details see, e.g. [2,7]). Nuclear magnetic dipole and electric quadrupole have a similar importance in helping us to interpret the deuteron structure (see, also [23]).

The motion of the electrons produces a magnetic field $\mathrm{B_I}$ at the nucleus, which interacts with the electron magnetic moment μ (see, e.g. [27]):

$$E = \mu \cdot B_\mathrm{I}. \tag{2}$$

Typical energy differences of hyperfine multiplets are only about 10^{-7} eV (in case of the deuteron it is 3.16 $\times 10^{-7}$ eV (see also [28])). This value is more than seven orders less than we observe in experiments: the isotopic shift of the n = 1s excitons is equal to 0.103 eV.

The short range character of the strong interaction does not possess a direct mechanism for elementary excitation energy renormalization, which was observed in the experiments. Nevertheless, our results were very close of the isotope shift exciton energy in the case $^{12}\mathrm{C}_x\,^{13}\,\mathrm{C}_{1-x}$ diamond crystals to the indicated value above in LiH crystals. Indeed, in such experiments we have isotope shift in $^{12}\mathrm{C}_x\,^{13}\,\mathrm{C}_{1-x}$ diamond crystals approximately 15 meV (see, e.g. [8] and references therein) per one neutron and on seven neutrons we get 15 ·7 = 105 meV. This value is very close to the observed one (103 meV) in LiH crystals.

However, at present time, we can distinguish the following mechanisms of this renormalization:

(1) Electric field of the neutron's quarks – this mechanism is limited by the boundary of the neutron.
(2) The possible new structure of the quarks and leptons – the so-called preons [29–34].
(3) The most likely mechanism is connected to the magnetic-like field of the neutron quarks.

For the solution of this new task we need more experimental as well as theoretical investigations.

We should underline that the experimental observation of the manifestation of residual strong nuclear interaction in the optical spectra of solids opens an avenue to nuclear and elementary particle physics.

5. Conclusion

The artificial activation of the strong nuclear interaction by adding one (or two, or more) neutrons to atomic nuclei leads it to the direct observation of the strong interaction in low-temperature optical spectra of solids. This conclusion opens a new avenue in the investigation of the strong nuclear interaction by means the condensed matter alike traditional methods (including accelerating technique). Experimental observation of the renormalization of the elementary excitation energy of solids by the strong nuclear interaction stimulates its count in the process of describing the elementary excitations dynamics in quantum electrodynamics. The present article continues to develop the connection between nuclear and condensed matter physics.

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References

[1] V.G. Plekhanov, Deposit in VINITI, N202– B2012 (in Russian).
[2] B. Povh, K. Rith, Ch. Scholz and F. Zetsche, *Particles and Nuclei,* Springer, Berlin, 2006.
[3] D.H. Perkins, *Introduction to High Energy Physics*, Cambridge University Press, Cambridge, 2000.
[4] W.N. Cottingham and D.A. Greenwood, *An Introduction to the Standard Model of Particle Physics,* Cambridge University Press, Cambridge, 2007.
[5] V.G. Plekhanov, *Isotope Effect – Macroscopical Manifestation of Strong Interaction,* LAMBERT Academic Publishing, Saarbrücken, Germany, 2017 (in Russian).
[6] Y. Yukawa, *Proc. Phys. Math. Soc*. Jap. **17** (1935) 48.
[7] E.M. Henley and A. Garcia, *Subatomic Physics,* World Scientific, Singapore, 2007.
[8] V.G. Plekhanov, *Isotopes in Condensed Matter,* Springer, Heidelberg, 2013.
[9] V.G. Plekhanov, *Phys. Rev*. B **53** (1996) 9558.
[10] V.G. Plekhanov, *Prog. Mat. Sci*. **51** (2006) 287.
[11] V.G. Plekhanov, *J. Astrophys. and Aerospace Technol*. **5** (2017) 46.
[12] R.S. Knox, *Theory of Excitons,* Academic Press, New York, London, 1963.
[13] V.G. Plekhanov, *Phys. Rep*. **410** (2005) 1.
[14] S. Baroni, G. Pastori Parravicini and G. Pezzica, *Phys. Rev.* B **32** (1985) 4077.
[15] J.L. Verble, J.L. Warren and J.L. Yarnell, *ibid* **168** (1968) 980.
[16] H. Dammak, E. Antoshchenkova, M. Hayoum and F. Finocchi, *J. Phys.: Condensed Matter* **24** (2012) 435402.
[17] V.G. Plekhanov and A.A. O'Konnel, Bronin (Moscow) *JETP Lett*. **27** (1978) 413.
[18] V.G. Plekhanov, *Giant Isotope Effect in Solids,* Stefan University Press, La Jola, CA, 2004.
[19] I. Nordheim, *Ann. Phys*. (Leipzig) **401** (1931) 641.
[20] I.M. Lifshitz, *Selected Works,* Science, Moscow, 1987 (in Russian).
[21] F.E. Close, *An Introduction to Quarks and Partons,* Academic Press, London, New York, 1979.
[22] V.G. Plekhanov, *Phys.* – Uspekhi **40** (1997) 553.
[23] V.G. Plekhanov, *Modern View of the Origin of Isotope Effect,* LAP, LAMBERT Academic Publishing, Germany, 2018.
[24] J. Carlson and R. Schivalia*, Rev. Mod. Phys*. **70** (1998) 743.
[25] A.R. Edmonds, *Angular Momentum in Quantum Mechanics,* Princeton University Press, Princeton, New Jersey, 1957.
[26] H. Kopferman, *Kernomomente,* Acedemische, Verl - Ges., 1956.
[27] V.G. Plekhanov*, Phys. Sci. Intern. J.* **18** (2018) 1.
[28] V.G. Plekhanov, in *Proc. ISINN*, Dubna, Russia, 2018, p. 49.
[29] O.W. Greenberg, A new level of structure, *Phys. Today* 38 (1985) 22–30.

[30] B. Robson, *The Generation Model of Particle Physics*, in *Particle Physics*, E. Kennedy (Ed.), In Tech. Open Access Publisher, Rijeka, Croatia, 2012.
[31] M. Aghirescu, *The Cold Genesis of Matter and Fields*, Science Publishing Group, New York, 2015.
[32] C.S. Kalman and I. D'Souza, *Preons: Models of Leptons, Quarks and Gauge Bosons as Composite Particles,* World Scientific, Singapore, 1992.
[33] C.S. Kalman, Why quarks cannot be fundamental particles, *Nuclear Phys*. B: *Proceedings Supplements* **142** (2005) 235–237.
[34] O. Consa, The helicon: a new preon model, *Progr. Phys*. **14** (2019) 215–219.