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1 Phenomenology of the origin of isotope effect. chromodynamics, quantum electrodynamics Abstract. Our paper describes the macroscopical manifestation of the origin of isotope effect. The experimental evidence of macroscopic manifestation of the strong interaction in optical spectra of solids which are differ by term of one neutron from each other (using LiD crystals instead LiH) has been presented. This evidence is directly seen from luminescence and reflection spectra.

As far as the gravitation, electromagnetic and weak interactions are the same in both of kind crystals, it only changes the strong interaction. Therefore a sole conclusion is made that the renormalization of the energy of electromagnetic excitations (electrons, excitons, phonons) is carried out by the strong nuclear interaction. The last one simultaneously indicates the origin of the isotope effect is caused by the 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 the quantum electrodynamics should be taken into account the strong interaction at the description of elementary excitations (electrons, excitons, phonons) dynamics in solids. I. Introduction.

Recently it was shown the direct dependence of the energy of interband transition E_g in solids (for example LiHxD1_x crystals) on the strong nuclear interaction [1]. The present paper is devoted to advance description of the experimental results demonstrated indicated above dependence. According to contemporary physics, the Universe is made up of matter fields, whose quanta are fermions and force fields, whose quanta 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) (see, Table 1).

Hadrons (neutrons, protons) containing an odd number of quarks, and nuclei made of an odd number of nucleons (for example ^{13}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]. Keywords: strong interaction, quarks, gluons, excitons, phonons, quantum 2 Table 1. Quarks and leptons.

Family	1	2	3	Electric charge (e)	Leptons	e	μ	τ	Quarks	u	c	t	2/3	d	s	b	-1/3
Bosons are identical particles having zero or integer spins. As fermions, bosons can be categorized into two groups: elementary and composite bosons. Unlike fermions, bosons do not obey the Pauli Exclusion Principle. In other words, any number bosons can occupy the same quantum state. Behaviors of bosons are described by the Bose - Einstein statistics.																	

The SM [4] only consists of five elementary bosons (see Fig. 1 in [5]). They are namely the Higgs boson, gluon, Z and W[±] bosons. The Higgs boson have zero electric charge and zero spin 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 [5] pointed out that the nuclear force could be generated by the exchange of a hypothetical spinless particle, provided its mass intermediate between the masses of proton and electron - a meson. Yukawa predicted the pion [2, 7]. The strong forces does 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 however below). Its macroscopic manifestations are restricted up to now to radioactivity and the release of nuclear energy [3,4]. Our present knowledge of physical phenomena suggests that there four types of forces between physical bodies (see, e.g.

[9, 12]): 1) gravitational; 2) electromagnetic; 3) strong; 4) weak (Table 8 in [5]). Both the

gravitational and the electromagnetic forces vary in strength as the inverse square of the distance and so able to influence the state of an object even at very large distances.

Gravitational is important for the existence of stars, galaxies, and planetary systems as well as for our daily life, it is of no significance in subatomic physics, being far too weak to noticeably influence the interaction between elementary particles [3, 4].

Electromagnetism is the force that acts between electrically charged particles (atoms, molecules, condensed matter).

When nuclear physics developed, two new short - ranged forces joined the ranks. These are the nuclear force, which acts between nucleons (proton, neutron, etc.) and the weak force, which manifests itself in nuclear_ - decay (see, e.g. [7]). The nuclear force is a result of the strong force binding quarks to form protons and 3 neutrons.

Due to experimental results of this paper connected to the manifestation of the strong interaction, we should briefly analyze the structure of subatomic particles and the strong interaction. We should underline, that subatomic physics lacks so coherent theoretical formulation that would permit us to analyze and interpret all phenomena in a fundamental way: atomic physics has such a formulation in quantum electrodynamics, which permits calculations of some observable quantities to more than six figures.

Subatomic physics deals with all entities smaller than the atom. Our present knowledge of physical phenomena suggests that there four types of forces between physical bodies (see, e.g. [9, 12]): 1) gravitational; 2) electromagnetic; 3) strong; 4) weak (Table 8 [5]).

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The modern quantummechanical view of the three fundamental forces (all except gravity) is that particles of matter (fermions neutrons, protons, electrons) do not directly interact with each other, but rather carry a charge, and exchange virtual particles (gauge bosons photons, gluons, 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, positrons); and gluons are the mediators of the interaction of color charges (quarks). In our days, the accepted view is that all matter is made of quarks and leptons (see Table 1). 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 $\bar{e}$ (electrons neutrino) - are necessary to make up the every day world, and a world which contained only these would seem to be quite possible.

The facts, summarized in the modern nuclear and subatomic physics (see, e.g. [2, 7]) allow 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 conclude that nuclear forces have a "saturation property".

It seems from the last conclusion it is enough to change the number 4 of neutrons in nucleus to change strength of nuclear force. But the last one constitutes the main ideas of the isotope effect [8]. II. Results. Below we will briefly describe the results of the optical spectroscopy of isotope - mixed solids.

The apparatus used in our experiments has been described in several previous publications [9, 10, 11]. For clarity, we should mention here that immersion home-made 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 a term of one neutron. We should remind very briefly about the electronic excitations in

solids. According to modern concept, the excitons can be considered [11] as the excited of the 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 infinitive number of bound state and ionization continuum (Fig. 71 in [13]).

In our experiments we have investigated the low - temperature optical spectra (reflection - Fig. 1 and luminescence Fig. 2) of $\text{LiH} \times \text{D}_2$ crystals ($0 \leq x \leq 1$) which differ by term of 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 condition. As the deuterium concentration increases, the long - wave maximum (n_15 excitons [12]) broadens and shifts towards the shorter wavelengths. 5 Fig. 1. Mirror reflection spectra of indicated crystals. Light source without crystals indicates by lamp. 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 the 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 ~ 10 meV) phononless emission line and its broader phonon repetitions, which arise due to radiative annihilation of excitons with the production of one to five longitudinal optical (LO) phonons (see Fig. 2). Fig. 2. Photoluminescence spectra of free excitons at 2 K in LiH and LiD crystals cleaved in superfluid helium.

6 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 $X_1 - X_4$ 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 was measured in (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 distinctions one is related. Firstly the zero - phonon emission line of free excitons in LiD crystals shifts to the short - wavelength side on 103 meV.

The second difference concludes in less value of the LO phonon energy, which is equal to 104 meV. When light is excited by photons in a region of fundamental absorption in mixed LiH x D $1-x$ crystals at low temperature, line luminescence is observed (Fig. 3), like in the pure LiH and LiD crystals.

As before [18], the luminescence spectrum of crystals cleaved in superfluid liquid helium consists of the relatively zero - phonon line and its wide LO replicas. For the sake of convenience, and without scarfing generality, Fig. 3 shows the lines of two replicas. Usually up to five LO repetitions are observed in the luminescence spectrum as described in detail in [18]. In Fig.

3 we see immediately that the structure of all three spectra is the same. The difference is in the distance between the observed lines, as well as in the energy at which the luminescence spectrum begins, and in the half - width of the lines. Fig. 3.

Photoluminescence spectra of free excitons in LiH (1), LiH x D $1-x$ (2) and LiD 7 (3) crystals cleaved in superfluid helium at 4.2 K.

Spectrometer resolution is shown. 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 an exciton. As follows from Fig. 1, excitons in LiH x D $1-x$ crystals display a unimodal character, which facilitates the interpretation of their concentration dependence. Fig. 4 shows the concentration dependence of the power of strong nuclear interaction, i.e. dependence on the neutron concentration. Fig. 4.

Dependence of the interband transition (strong interaction) energy E_g in mixed crystals on the concentration x (number of neutrons). As can be seen from Fig. 4, VCA method cannot describe observed experimental results was shown early [18] this deviation from linear law (VCA approximation) is connected with isotope - induced disorder in isotope mixed crystals LiH x D $1-x$.

According to Lifshitz the isotopic disordering ought be classified as site disordering of the crystal lattice. Comparison the experimental results on the luminescence and

reflection in the crystals which differ by a term of one neutron only is allowed to the next conclusions; 1. At the adding one neutron (using LiD crystals instead LiH ones) is involved the increase exciton energy on 103 meV. 2.

At the addition one neutron the energy of LO phonons is decreased on the 36 meV, that is direct seen from luminescence and scattering spectra. Both characteristics are macroscopic. III. Discussion. Nucleus is central part of an atom consisting of A - nucleons, Z - protons and N - neutrons. The atomic mass of the nucleus is equal $Z + N$ (see Fig. 1 in [4]).

A given element can have many different isotopes, which differ from one other 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 source of isotopic effect (see, also [18]).

LiH (LiD) crystals with a lattice of NaCl type, whose parameters are close to cubic crystals, are dielectrics with band gap of $E_g \approx 4.992$ eV ($E_g \approx 5.090$ eV for LiD) at 2 K [22]. These crystals have an identical electronic structure. The energy band structure of these substances is also identical. All three kinds of forces - gravitational, electromagnetic and weak are also the same for compounds above.

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 deuteron. Nucleons can combine to make four different few - nucleon systems, the deuteron ($p + n$), the triton ($p + 2n$), the helion ($2p + n$) and the α - particle ($2p + 2n$).

These particles are grouped together because they are all stable (apart from triton which has a half - life of about twelve years and so may be treated as a stable entity for most practical purposes), have no bound excited states (except the α - particle which has two excited states at about 20 and 22 MeV [7]), and are frequently used as projectively in nuclear reactions. Few - nucleon systems provide the simplest systems to study nuclear structure (see, e.g. [23]).

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 deuteron to be approximately the sum of the magnetic moments of the proton and neutron, namely $\mu_p - \mu_n = (2.793 - 1.913) \mu_N = 0.880 \mu_N$ ($\mu_N = e\hbar/2m_p$) [7]. If however, the spins are anti-parallel, we expect it to be $(2.793 + 1.913) \mu_N = 4.706 \mu_N$. Experimentally it is $0.857 \mu_N$ [7, 24] 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 $\mu_d = 0.857 \mu_N$ and $\mu_p - \mu_n = 0.880 \mu_N$ is due, as will be shown below, to the tensor character of strong forces in the deuteron. We thus conclude that the ground state of the 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 contradicts experiments.

Experimentally the deuteron has a positive quadrupole moment of 0.29 fm^2 [24]. 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 [25]). 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 $Q = 0.29 \text{ fm}^2$ according to experiment indicates that the deuteron is slightly elongated along the z -axis, like an olive (prolate).

Quantum mechanical definition of quadrupole moment for a single proton [24] is described by: $eQ = e \int (3z^2 - r^2) \rho(r) d\tau$. (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 $3D1$ state and a probability of 0.96 to finding a $3S1$ state.

The last one points to the tensor character of the nucleon-nucleon interaction (the 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 B_e at the nucleus, which interacts with the nuclear magnetic moment I (see, e.g. [26]): $E \sim I \cdot B_e$.

(2) Typical energy differences of hyperfine multiplets are only about 10^{-7} eV (in case of the deuteron it is $3.16 \cdot 10^{-7}$ eV (see also [27])). This value is by more than seven order 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 doesn't possess direct mechanism of the elementary excitation energy renormalization, which was observed in the experiments.

However, there is one not very convincing possible hypothesis of the strong interaction mechanism - this is residual long range electromagnetic interaction of the electric charge quarks [28]. The non - zero value of electric quadrupole moment in deuteron indicates in favour of this hypothesis, for example, in deuterium. Such hypothesis doesn't contradict to the conclusion of the papers [4, 29, 30] about the mass difference origin between the neutron and proton connected with electric charged u and d quarks (see, also [31]).

Moreover, the neutron mass diminishing in nuclei in comparison to the free state of neutron independently shows the actual residual electromagnetic interaction in nucleons between quarks (see, also [32, 33]). Naturally, the origin of Van der Waals or new type forces are in need of more quantitative not only experimental but also theoretical investigations of observed effects. Nevertheless, we have very close of the isotope shift exciton energy in the case $^{12}\text{C}/^{13}\text{C}$ diamond crystals to the indicated value above in LiH crystals.

Indeed, in such experiments we have isotope shift in $^{12}\text{C}/^{13}\text{C}$ diamond crystals approximately 15 meV (see, e.g. [8]) per one neutron and on seven neutrons we get $15 \cdot 7 = 105$ meV. This value is very close to the observed one (103 meV) in LiH crystals. Thus, the tentative interpretation of describing experimental results don't find consistent explanation at the change strong interaction leaving it to be another mystery of SM (see, also [30]). We should remind that intrinsic contradiction of SM is already well - known.

Really, the Lagrangian of QCD (theory of the strong interaction) describes both free motion and interaction between quarks and gluons, which is defined by the strength couple g , its 10 eigenstates are the quarks and the gluons which are not observed in free states [4, 34]. The observed hadrons in the experiment don't eigenstates in quantum chromodynamics.

It is obvious to expect that the modern theory of QCD should finally overcome these difficulties [34]. We should add that the current theoretical and experimental evidence for the existence of electronic objects with a fractional of electron charge ($e/2$, $e/3$, etc.) is reviewed in paper [35].

One more possible mechanism the influence of the strong interaction on the dynamics of elementary excitation connects with the zero - point vibration [7, 8]. Moreover it is necessary to take into consideration anomalous magnetic moments of nucleons. According to contemporary physics, the Universe is made up of matter fields, whose quanta are fermions and force fields, whose quanta are bosons.

All these fields have vacuum fluctuation and zero - point energy. Experimental observation of the manifestation of strong nuclear interaction in the optical spectra of solids opens an avenue to new physics. Conclusion. The experimental evidence of the macroscopic manifestation of strong nuclear interaction in optical spectra of solids which are differ by term of one neutron from each other has been presented for the first time.

This evidence is based on two independent experimental results, which is directly seen from luminescence and reflection spectra. As far as the gravitation, electromagnetic and weak interactions are the same in both of kind crystals, it only changes the strong interaction. Therefore a sole conclusion is made that the renormalization of the energy of electromagnetic excitations (excitons, phonons) is carried out by the strong (nuclear) interaction. There is underlined the necessity consideration the strong (nuclear) interaction in quantum electrodynamics.

—————- *) More than the half - century ago Foldy [36] was shown that the neutron - electron interaction energy equals approximately 1.4 eV (see, also [37]) . The last value is on the one order more than the value observed in experiments equals 0.103 eV. In the case of the Coulomb electromagnetical neutron - electron interaction the neutron (quark) must have only approximately 1.3 % of necessary electron charge.

The availability of the electrical charge of neutron is small in our estimation, though not equal to zero and does not contradict the papers results [28, 38] where was shown that $GE_{n_0} = 0$. References. 1.V.G. Plekhanov, Deposit in VINITI, N202 - B2012 (in Russian). 2. B.Povh, K. Rith, Ch. Scholz, 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.

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