Measurements of The Wide Value Range of Strong Interaction Coupling Constant

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Abstract - *Determination of the strong interaction coupling constant, α_s, in the wide value range using non - accelerator experimental results is presented for the first time. For this purpose we have measured the isotopic shift of zero phonon line in the low temperature photoluminescence spectra of LiH and LiD crystals which differ only strong interaction in deuterium nucleus. Observation of the isotopic shift phononless line in the photoluminescence spectra of the whole series of LiH_xD_{1-x}mixed crystals is permitted to construct changes α_s in the wide value range. Moreover we have shown the influence of different number of neutrons in nuclei on the strong interaction coupling constant in different substances. Our results open a new avenue in the investigation of the hadron - lepton interaction via study the low temperature characteristics (reflection, photoluminescence) of solids.*

Keywords: *Strong interaction; quarks; gluons, excitons; QED; QCD*

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I. Introduction

One of the fundamental goal of the contemporary physics is understanding of the origin of mass of all everyday objects as well as their interactions starting from first principles. According to modern knowledge most of the mass of everyday objects resides in atomic nuclei: the total of the electron's mass adds up to less than one part in a thousand [1, 2]. The nuclei are composed of nucleons - protons and neutrons - whose nuclear binding energy, though tremendous on a human scale, is small compared to their energy. The nucleons are, in turn, composites of massless gluons and nearly massless quarks (see, e.g. [2]). Indeed, deeply inelastic electron - nucleon scattering measurements (with wide angles) are modeled well with weakly interacting constituents known as partons [3]. To obtain a full appreciation of the interior of the nucleon, however, one must to turn to the modern theory of strong interaction, namely Quantum Chromodynamics (QCD). QCD merges the ideas of the quark model (introduced to account for the plethora of strongly interacting hadrons [4, 5]), the quantum number "color" (introduced to reconcile spin and statistics [6, 7]) and partons into self - contained theory [8]. In modern particle physics, the masses of fundamental particles are incalculable constants, being supplied by experimental values. Therefore, the concept of mass is not really understood, and their numerical values remain a mystery [9]. In this connection it is appropriate to underline that isotope effect is a direct manifestation of the mass effect in microphysics. It should be added that the direct observation of strong nuclear interaction is also seen in solids with isotope effect (see [10] and references quoted therein). We should repeat that nowadays in text books and elsewhere the separation of electromagnetic and strong interactions is tacitly assumed. The results of the paper [11] have shone a new light on some residual interaction (ultimately based in the character of magnetic forces, the electromagnetic or color origin, which by their very nature, are difficult to conceal within the elusive nucleon physical boundary) between both kind of forces which experimentally manifested through isotopic shift of zero phonon line in optical spectra. From the experimental value of the isotopic shift was obtained a residual strong coupling constant equals to 2.4680. This value is quite large in comparison with the normal fine structure constant [11].

It is well - known, that the size of the strong coupling constant, α_s, like other fundamental "constants" of nature (e.g. the mass of fundamental particles), is not given by theory, but must be determined by experiment. According to contemporary physics the QCD has specific features, so - called asymptotic freedom and confinement, which determine the behavior of quarks and gluons in particle reactions at high and at low energy scales. QCD predicts that the strong coupling strength decreases with increasing energy or momentum transfer, and vanishes at asymptotically high energies [12]. Confinement implies that the coupling constant, α_s, become large in the regime of large distance or low - momentum transfer interactions [13]. Conversely quarks and gluons are probed to behave like free particles, for short - time intervals ($\Delta t < 10^{-24}$c [12]), in high - energy or short - distance reactions: they are said to be "asymptotically free", i.e.

$\alpha_s \rightarrow 0$ for momentum transfer $Q \rightarrow 0$ (for more details see [13]). within QCD, the phenomenology of confined and asymptotic freedom is realized by introducing a new quantum number, called "color charge". Quarks carry one of three different color charges, while hadrons are colorless bound states of 3 quarks and antiquarks (baryons like protons), or of a quark and antiquark (meson). Gluons in contrast to photons which do not carry (electrical) charge by themselves, have two color charges. This concepts leads to the process of gluon self - interaction, which in turn, through the effect of gluon vacuum polarization, gives rise to asymptotic freedom, i.e. decrease of $\alpha_s$with increasing momentum transfer [12].

Despite the triumphant success of Standard Model (SM), there exist the one of the most problems, connected with the origin of the mass elementary particles (see, e.g. [14, 15]). In this connection we should pay attention our readers to new low - energy mechanism of the origin of mass of elementary particles [16 - 18], in the first - step the results of the to non - accelerator experiments. Moreover the hierarchy of these mass is one of the biggest puzzles of particle physics [12, 14, 18].

It is purpose of our paper to advance a description of the manifestation of strong nuclear interaction in solids, using partly published and new non - accelerator experimental results. Our spectroscopic measurement of the low temperature optical characteristics of $LiH_xD_{1-x}$is permitted to quantitative study of the dependence of strong coupling constant, α_s, on the proton - neutron distance in the deuteron nuclei. The another purpose of our communications is to draw the attention of physical society towards the expansion of the Quantum Electrodynamics (QED) boundary via taking into account new experimental non- accelerates manifestation of the residual strong interaction in solids. Below we will briefly describe the results of the optical spectroscopy of isotope - mixed crystals. The uniqness of LiH and LiD crystals consist in difference nucleus of H and D, is firstly the absent strong nuclear interaction and secondly we have strong interaction in deuteron nuclei. We should underline that these crystals differ by term of one neutron from each other (using LiD crystals instead LiH ones). In this paper we shall present all the details of our experimental results which we omitted in the previous paper and in a series of international conference.

II. Experimental

The main experimental results were obtained on a device used already in the investigations [19, 20, 10, 11]. The experimental apparatus including the low temperature technique (homemade immersion helium cryostat), two double grating (prism) monochromators (with reciprocal dispersion 10 Å/mm for the wavelength λ = 220 nm) arranged at right angle. Spectra were exciting by various lines of a 40 W deuterium lamp and a 120 W mercury arc lamp. The excitation light was felt on the entrance slit of the first monochromator and after leaving it passed through quartz windows of the immersion cryostat and irradiated of the crystals. The light of the optical spectra (reflection, luminescence, light scattering) from the samples was dispersion in another double prism (grating) monochromator and photoelectrically detected. A photoelectric registration of the optical signal was realized by a cooled photomultiplier for ultraviolet (UV) range of the spectrum and the subsequent high - sensitivity photon - counting system with a storage facilities (computer). The signal - to - noise ratio was approximately $n \cdot 10^2$, where $n = 2 \div 5$ for different batches of crystals. The experiments were carried for all LiH_xD_{1-x}crystals ($0 \leq x \leq 1$) which differ at x = 0 and x = 1 by a term of one neutron. The single crystals were synthesized from ^{7}Li (^{6}Li) metal and hydrogen of 99.7% purity and deuterium of 99.5% purity (see, e.g. [20, 21]). The X - ray diffraction investigations show that the LiH_xD_{1-x} mixed crystals form a continuos row of the solid solution and testify themselves like a virtual crystal with a variable lattice constant (and exciton radius, respectively) that obeys Vegard's law (for details see [20, 21]). In view of the high hygroscope and therefore high reactivity of the investigated samples, the crystal was cleaved directly in liquid or superfluid helium in the cryostat bath. This made it possible to prepare samples with a clean surface.

III. Results

The modern view of solid state physics is based on the presentation of elementary excitations, having mass, quasi - impulse, electrical charge and so on (see, e.g. [22]). According to this presentation, the elementary excitations of the nonmetallic materials (like LiH and LiD crystals) are electrons (holes), excitons (polaritons) and phonons (see also [23]). The model discussed below forms the basis for the modern theory of electrons in solids [24]. It arises from the consideration of the periodicity of the crystal structure. This periodicity leads to the formation of energy bands (see, e.g. Fig. 1 in [25]). An underlying assumption is that the entire electron - electron interaction can be taken into account via independent electron approximation. The Schrődinger equation for the many - ion many - electron problem of a solid is exceeding complex, but there is well - established knowledge for simplifying such an equation (see, e.g. [24]). The ions are regarded as rigidly fixed at their lattice sites, and any one of the valence electrons is considered to move in potential formed by the ions and all other electrons, this is the essence of one - electron approximations. The effective one - electron potential V(r) is periodic sharing the periodicity of the underlying lattice. The importance of the electronic theory of solids as embodied in band theory is that it provides us with clear means of underlying how solids may be insulators, semiconductors, or metals. This dependence upon whether or not it is a Fermi surface. The existence of a Fermi surface produces metallic behavior, whereas at 0K, if the filled electron levels (valence band) are separated from vacant (conduction band) ones, we have insulating properties. If the separation is large, say ≥ 5 eV, the substance remains an insulator at a temperature above 0K, whereas semiconducting properties arise if the filled and empty bands lie within 0 - 2 eV of one another (for more details see [23, 24]).

Artificial activation of the strong interacting by adding of one neutron to the hydrogen nucleus causes the global reconstruction of the macroscopic characteristics of solids. The measurements of these global reconstruction of the macroscopic characteristics of solids via optical spectra are devoted present paper. Numerous investigations have shown that binary compounds LiH (and LiD) are insulator with band - to - band transition energy E_g = 4.992 eV (5.095 eV for LiD) at liquid helium temperature (LHeT) and possess the direct electron transition at the X - point of the Brillouin zone (see, e.g. review [20]). Possessing a large oscillator strength the long - wavelength edge structure of the fundamental absorption (see, e.g. Fig. 1 in [10]) is formed by large radius excitons with binding energy E_b= 42 meV (E_b = 52 meV for LiD) [20]. As was shown earlier [10], free exciton photoluminescence is observed when LiH (LiD) crystals are excited in the midst of the fundamental absorption. The spectrum of free exciton photoluminescence of LiH crystals cleaved in superfluid helium consists of a narrow phononless emission line and its broader phonon repetitions, which arise due to radiative annihilation of free excitons with the production of one to five longitudinal optical (LO) phonons [20]. Free exciton photoluminescence at low temperature of LiD crystals is largely similar the spectrum of intrinsic luminescence of LiH crystals. The isotopic shift of the zero - phonon emission line of LiD crystals equals 0.103 eV [10]. When light is excited by photons in a region of fundamental absorption in mixed LiH_xD_{1-x} crystals at low temperature, line emission is observed (Fig. 1), like in the pure LiH and LiD crystals.

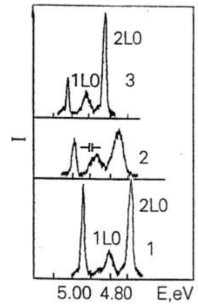

Fig. 1. Photoluminescence spectra of free excitons at 2 K in LiH (1), LiH_xD_{1-x} (2)and LiD(3) crystals cleaved in superfluid helium.

As before [20], the luminescence of crystals cleaved in superfluid helium consists of the relatively narrow phonoless emission line and its wide LO replica. For the sake of convenience, and without scarfing generality, Fig. 1 shows the lines of two LO replicas. In Fig. 1 we see immediately that the structure of all three photoluminescence spectra is the same. The measurements of the low temperature of reflection and luminescence spectra of the whole series of mixed crystals is permitted to obtain the dependence of the interband transition (the value of the strong coupling constant) energy on the deuterium concentration (Fig. 2).

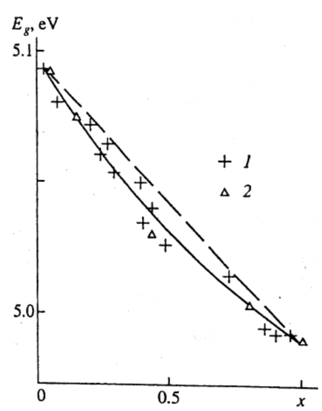

Fig.2.Dependence of the interband transition (strong interaction strength) energy $E_g$in mixed crystals on the concentration x (number of neutrons N). The straight dashed line is the linear dependence of coupling constant strong interaction α_s=f(N) [E_g=f(x)] in the virtual model. The solid line corresponds to calculation using the polynom of second degree $\alpha_s = \alpha_s$ (LiD)+[α_s (LiH)– α_s(LiD)-b]x-bx², where b=0.046 eV is curvature parameter[18]. Points derived from the reflection spectra indicated by crosses,ħand those from luminescence spectra by triangles.

This dependence has a nonlinear character.

IV. Discussion

First of all we should consider the Born - Oppenheimer approximation of the nuclear - electron interaction, so - called the adiabatic approximation [26]. The Schrödinger equation for the molecule

$$H\Psi(r, R) = E\Psi(r, R) \qquad (1)$$

Here Ψ(r, R) is an eigenfunction and E the corresponding eigenvalue, H the Hamiltonian operator of molecule and r is electron and R is nuclear distance. The simplest approximate method for solving the Schrödinger equation (1) uses, as indicated above, the so - called Born - Oppenheime approximation [26, 27]. This approximation is used that the nuclei are much heavier than an electron and, consequently, move very slowly in comparison with the electronic motion.

If the nucleus to be fixed in some configuration for this particular R (distance between nuclei) we get the next differential equation

$$-((\hbar^2)/(2m))\sum_i \Delta_i^2\Psi(r, R) - ((\hbar^2)/2)\sum_\alpha((\Delta_\alpha)/(M_\alpha))\Psi(r, R) + V(r, R)\Psi(r, R) = E\Psi(r, R), \quad (2)$$

where Δ is Laplasian [28], m and M electron and nucleus mass, index i for electrons and α is index for nuclei.

Further we put

$$\Psi(r, R) = \chi(r, R)\phi(R) \qquad (3)$$

Here ϕ(R) is the nuclear wavefunction, which depends on nuclear distance R and on electronic state.

After substitution (3) in (2) we have

$$-((\hbar^2)/(2m))\phi(R)\sum_I \Delta_i\chi(r, R) - ((\hbar^2)/2)\sum_\alpha((\Delta_\alpha)/(M_\alpha))\chi(r, R)\phi(R) + V(r, R)\chi(r, R)\phi(R) = E\,\chi(r, R)\phi(R). \quad (4)$$

Further we neglect the next members in (4)

$$L\Psi(r, R) = -(\hbar^2)/2)\sum_\alpha(1/(M_\alpha))[\phi(R)\Delta_\alpha\chi(r,R) +$$

$$2\nabla_\alpha\phi(R)\nabla_\alpha\chi(r, R)]. \qquad (5)$$

Operator L is call the non - adiabatic operator, which describe the nuclear - electron interaction. After the last operation the equation (4) splits on two equations:

$$-((\hbar^2)/(2m))\sum_i\Delta_i\chi(r, R) + V(r, R)\chi(r, R) = E_l(R)\chi(r, R); \quad (6)$$

And

$$-((\hbar^2)/2)\sum_\alpha((\Delta_\alpha)/(M_\alpha))\phi(R) + E_l(R)\phi(R) = W\phi(R). \quad (7)$$

Where E_l (R) is electronic energy and W is the nuclear energy. Every equation have the view of the Schrödinger equation. The first equation (6) describes the electron stationary state in adiabatic approximation. Equation (7) is an equation for a wavefunction of the nuclei alone. Note, please that Equation (6) contains the nuclear charges through the Coulomb potential, but is doesn't include any reference to nuclear mass. Thus E_l(R), the eigenvalue (energy) of the electronic Schrödinger equation (6) is the same for all isotopes, and consequently, is isotopically independent. The independent E_l(R) on isotopic substitution is the essence of the Born - Oppenheimer approximation. However, we must repeat, that the Born - Oppenheimer approximation [26, 27] is the standard anzatz to the description of the interaction between electrons and nuclei in solids (see, e.g. [24]). The last result forces us to search for new models and mechanisms of nuclear - electron interaction including the results of subatomic physics, e.g. hadron - lepton interaction.

Out of four known interactions, three are described by SM - the electromagnetic, weak and strong ones. The first two of them have a common electroweak gauge interaction behind them. The symmetry of this interaction $SU(2)_L$ X $U(1)_Y$ manifests itself at energies higher than ∼ 200 GeV. At lower energies, this symmetry is broken down to $U(1)_{EM} \neq U(1)_Y$(the electroweak symmetry breaking): in SM this breaking is related to the vacuum expectation value of a scalar field [12]. The strong interaction in SM is described by the QCD, a theory with the gauge group $SU(3)_C$. The effective coupling constant of this theory grows when the energy decreased. As a result, particles which feel this interaction cannot exist as free states and appear only in the form of bound states called hadrons (see, also [9]). Most of modern methods of quantum field theory work at small values of coupling constant,α_s, [13], that is, for QCD, at high energies. Quarks and leptons, the so - called SM matter fields, are described by fermionic fields. Quarks take part in strong interactions and compose observable bound state hadrons. Both quarks and leptons participate in the electroweak interaction. The matter fields constitute three generation: particles from different generation interact identically but have different masses (see, e.g. [2]). For the case of neutrino, Yukawa interactions are forbidden as well, so neutrinos are strictly massless in SM (see, however [17]). The gauge bosons, which are carriers of interactions, are massless for unbroken gauge groups $U(1)_{EM}$ (electromagnetism - photons) and $SU(3)_C$(QCD - gluons), masses of $W^{\pm}$ and Z^0 bosons are determined by the mechanism of electroweak symmetry breaking. It should note that the forces between the quarks must be long rang, because the gluons have zero mass. This does not imply that forces between hadrons are also long range, because hadrons have zero color charges overall. The forces between the colorless hadrons are the residues of the forces between their quark constituents, and cancel when the hadrons are far apart.

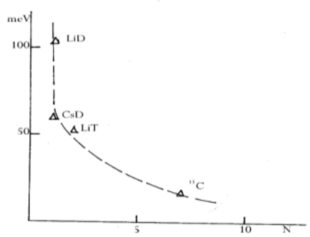

Fig. 3. The dependence of the strong force on the number of neutrons in different substances.

Returning to our non - accelerator experimental results, we should underline that in this paper we measure the strong coupling strength in crystals which differ by term of one neutron from each other. When we add one neutron in the hydrogen nucleus, we artificial activation of the strong interaction. As far as the gravitation, electromagnetic and weak interactions are the same in both kind crystals (LiH and LID), it only changes the strong interaction. Therefore a logical conclusion is made that the renormalization of the energy of electromagnetic excitations (isotopic shift equals 0.103 eV) is carried out by strong nuclear interaction [25]. The short range character of the strong interaction of nucleons does not possess direct mechanism of the elementary excitation (electrons, excitons, phonons) energy renormalization, which was observed in our low temperature experiments. Second reason that the interpretation of our experimental results is very difficult task because they are first demonstration of the violation of the strong conclusion in nuclear and particles physics that the strong nuclear force does not act on the colorless leptons (see, e.g. [2, 9]). Moreover we have some contradictions taking into account that the forces between quarks must be long range, because the gluons have zero mass. But as was mentioned above, the short range when forces between the colorless hadrons are the residues of the forces between their quark constituents, and cancel when the distance between hadrons is more than nuclear size [12]. We can see that the nuclear size transforms long range interaction in the short range strong one. It is very old question which up to present time has not any theoretical explanation.

In spite of above discussion, at present time we can distinguish the following mechanisms of the isotopic shift zero phonon line:

1. Long range electric field of the neutron's quarks. This mechanism owing to the confinement quarks is limited by the boundary of the neutron.

2. The possible new structure of the quarks and leptons - so - called preons [29 - 34].

3. The most likely mechanism of the neutron - lepton interaction is connected to the magnetic - like strong field of neutron 's quarks. Taking into account anomalous magnetic moment of the neuron in the paper [11] was obtained the value of strong coupling constant α_s = 2.4680. Quite large value in comparison with the accelerator technique value α_s (M{Z}) = 0.1198 [13]. The large value α_s is thus justified to think that residual strong forces acting beyond nucleon could exist. A possible interpretation is to assume that in addition to the 8 gluons predicted by QCD $SU(3)_C$ group there is a ninth gluon color singlet [12]

$$g_9 = (1/(\sqrt{3}))\ (rr\ +\ gg\ + bb) \qquad (8)$$

This massless photon - like gluon may be strongly interacts between nucleons (neutrons) and leptons (electrons) (see, also [2, 9]. Returning to Fig. 2 we can note that our measurements permit to obtain value of strong coupling constant from α_s = 2.4680 (pure LiD crystals) to α_s = 0 (pure LiH crystals). Moreover, in Fig. 3 we show the dependence of α_s on neutron's number in different substances. We can see as early in the case of pure LiD crystals we have non - linear dependence of α_s on the neutron's number in different substances.

Thus, the tentative interpretation of describing non - accelerator experimental results does not find consisted explanation at the change of strong interaction leaving to another mystery of SM. We should remind that intrinsic contradiction of Standard Model is already well - known. Really, the Lagrangian of QCD has the next form (see, e.g. [16, 35]):

$$L = i\sum_q \Psi_q^a(\nabla_\mu\gamma_\mu + im_q)\Psi_q^a - (1/4)G_{\mu\nu}^n G_{\mu\nu}^n, \quad (9)$$

where

$$\nabla_\mu = \partial_\mu - ig((\lambda^n)/2)A_\mu^n,$$

$$G_{\mu\nu}^n = \partial_\mu A_\mu^n - \partial_n A_\mu^n + gf^{nm}lA_\mu^n A_\nu^l \qquad (10)$$

Ψ_q^a and A_μ^n are quark and gluon fields, a=1,2,3,...8 are color indices , λ^n and f^{nml}} are Gell - Mann matrices and f symbols, m_q- are bare (current) masses, q = u, d, s, c, ... different quarks [13]. It is common place [9, 12] that the Lagrangian (9) contains the members which describe both free motion and interaction between quarks and gluons, which is defined by the strength couple g. Spacing of which it is necessary to remark that although the Lagrangian (9) possesses rather attractive peculiarities (see, also [13, 14, 35]), its eigenstates are the quarks and the gluons which are not observed in free states [2, 36]. 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.

V. Conclusion

The artificial activation of the strong nuclear interaction by adding one (two or more) neutrons in atomic nuclei leads it to the direct observation of the strong interaction in low - temperature optical spectra of solids. This conclusion opens new avenue in the investigation of the constant of strong nuclear interaction in the wide value range by means the condensed matter alike traditional methods. Experimental observation of the renormalization of the elementary excitation energy of solids by the strong nuclear interaction stimulates its count in the process of description of the elementary excitations dynamics in quantum electrodynamics. Present article continuous to develop between nuclear and condensed matter physics.

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