

Enhancement Mechanisms of Low Energy Nuclear Reactions

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1 Introduction

One of the fundamental presentations of nuclear physics since the very early days of its study has been the common assumption that the radioactive process (the half-life or decay constant) is independent of external conditions. Rutherford, Chadwick and Ellis [1] came to the conclusion that:

- «the value of λ (the decay constant) for any substance is a characteristic constant independent of all physical and chemical conditions».

This very important conclusion (still playing a negative role in cold fusion phenomenon) is based on the common expectation (P. Curie suggested that the decay constant is the etalon of time) and observation that the radioactivity is a nuclear phenomenon since all our actions affect only states of the atom but do not change the nucleus states. We cannot hope to mention even a small part of the work done to establish the constancy of nuclear decay rates. For example, Emery G.T. stated [2]:

- «Early workers tried to change the decay constants of various members of the natural radioactive series by varying the temperature between $24^{\circ}K$ and $1280^{\circ}K$, by applying pressure of up to 2000 atm, by taking sources down into mines and up to the Jungfrauoch, by applying magnetic fields of up to 83,000 Gauss, by whirling sources in centrifuges, and by many other ingenious techniques. Occasional positive results were usually understood, in time, as result of changes in the counting geometry, or of the loss of volatile members of the natural decay chains. This work was reviewed by Meyer and Schweider [3], Kohlrausch [4], and Bothe [5]. Especially interesting for its precision is the experiment of Curie and Kamerlingh Onnes [6], who reported that lowering the temperature of radium preparation to the boiling point of liquid hydrogen changed its activity, and thus its decay constant, by less than about 0.05%. Especially of Rutherford and Petavel [7], who put a sample of radium emanation inside a steel-encased cordite bomb. Even though temperatures of $2500^{\circ}C$ and pressures of 1000 atm were estimated to have occurred during the explosion, no discontinuity in the activity of the sample was observed».

It seems (in that time) that this conclusion was supported by the following very simple and strong arguments (Common Sense):

1. Nuclear processes have characteristic energies ≈ 1 MeV, whereas chemistry has a few eV per atom, molecules have a part of eV. The inner atomic shells are bound with many keV in the medium and heavy elements.
2. The localization of electrons in atoms is $\approx 10^{-8}$ cm, whereas the localization of nucleons in nuclei is $\approx 10^{-13}$ cm.

Therefore, the nucleus should be unaffected by superficial atomic changes: nuclear processes should not be influenced by the surroundings. The constancy of nuclear decay rates was firmly established, confirming evidences from experimental studies of α - and β -decays and theoretical estimations.

The constancy of nuclear decay rates acquired the strength as a classical law. Any papers contradicting this law were ignored by all the scientific journals as erroneous ones.

The history of science has own laws. The ground of the β -decay of nuclei was given by E. Fermi in 1934 year. It was very easy to prove that certain processes of radioactive decay should be intimately connected with the presence of atomic electrons and may be affected by the changes in the electronic structure produced by chemical compounds. It took 13 years to understand this very simple phenomenon. The possibility of altering the decay rate of Be^7 was suggested in 1947 by Segre [8] and by Dodel [9, 10]. In the case of electron- capture decays the decay rate is directly related to the density of atomic electrons in the nucleus and the effects of different chemical environments should be measurable. The theoretical foundation was the following [8]:

- «The radioactive decay constant of a substance decaying by orbital electron capture is proportional to $|\psi(0)|^2$ of the electrons. In the case of a light element like 7Be it may be possible to alter this quantity by an appreciable amount by putting the Be in different chemical compounds. We would then have a slight change of the radioactive half-life of the Be in different compounds. The magnitude of the effect may be in the neighborhood of one percent, but it is practically impossible to give quantitative estimate because the total change of $\psi(0)$ is affected by certain factors such as the density of the crystal, nature of the chemical bond, etc. they are both positive and negative, and have comparable magnitudes. To obtain a reliable estimate of the effect we require a more detailed knowledge of the wave functions for various compounds than is at present available. Experiments are in progress to detect the effect by comparing the half-life of 7Be in Be metal with that in BeO or BeF_2 ».

The confirmed altering decay rate for 7Be in different chemical compounds was of the order 0.1% [2]. The 6-hr isomer ${}^{99m}Tc$ decays by internal conversion of a 2.2-keV E3 transition. The observed effects in different chemical forms were of the order 0.3% [2]. The greatest chemically induced half-life changes of the order 3.5% were established in [11].

The half-life of 7Be electron capture was measured [12] in endohedral fullerene ${}^7Be@C_{60}$ and 7Be metal: $T_{1/2} = 52.68 \pm 0.05$ and $T_{1/2} = 53.12 \pm 0.05$ days, respectively. This 0.83% difference between the electron capture in C_{60} and in 7Be metal represents a strong environmental effect on the 7Be EC capture rate, caused by the different electronic wave functions near the 7Be nucleus inside a C_{60} cage and inside Be metal.

A weak interaction which is responsible for electron capture and other forms of beta decay is of very short range. So the rate of electron capture and emission (internal conversion) is proportional to the density of electrons at the nucleus. It means that we can manage the electron-capture (emission) rate by the change of the total density in the nucleus. It can be carried out in different macroscopic ways by using available environmental effects. These questions were highlighted in different reviews and books [2, 13, 14, 15, 16, 17, 18, 19] at the end of the seventies of the 20th century. The reader should compare the common by accepted conclusions about the decay rates in the thirties and seventies of the 20th century.

Data on pleochroic halos led to the conclusion [20] that these data do not provide a convincing proof that the laws of radioactive decay are constant in time.

Shnol S. and coauthors [21] came to the conclusion that the decay rates of radioactive nuclei change in time with the period of 24 hours, 27, and 365 days. Periodic variations in β -decay rates of ^{60}Co , ^{90}Sr and ^{137}Cs were discovered [22, 23, 24, 25]. The 27-day and 24-hour period in these changes were found.

The aim of this talk is to discuss the possibility of inducing and controlling nuclear reactions at low temperatures and pressures by using different low-energy external fields and various physical and chemical processes. The main question is the following: is it possible to enhance LENR rates by using the low and extremely low energy external fields?

2 Cold fusion and transmutation

In 1989 Fleishmann M. and Pons S. reported about their observation of nuclear products and excess heat on a palladium electrode during the electrolysis of solutions in heavy water. The electrochemical experiments were interpreted by the authors as a result of nuclear fusion reaction (named cold fusion) but the scientific community rejected this interpretation. More than 3000 papers in the field of cold fusion and transmutation (further the low-energy nuclear reaction LENR) were published. Various anomalous results were observed at low temperatures and pressures which are beyond the framework of modern theoretical paradigm. The theoretical models are not able describe these anomalies even qualitatively. The reader can find the history and problems of cold fusion in the Proceedings of the International Conferences on Condensed Matter Nuclear Science, the Russian Conferences on Cold Nuclear Transmutation of Chemical Elements and Ball Lighting, and also in a recent review of the Department of Energy of the USA [26] and books [27, 28]. Russian experimental data on the low-energy nuclear reactions are published in [29, 30, 31, 32] and their new theoretical interpretation was given in [33, 34, 35, 36].

The general important conclusion can be drawn from the studies performed during 15 years:

- The poor reproducibility of experimental results and extreme difficulties of their interpretation in the framework of modern standard theoretical physics are the main reasons of the persistent nonrecognition of cold fusion and transmutation phenomenon.

Recent progress in both directions is remarkable (see Abstracts ICCF-11, Marseille: France: 2004, 31 October - 5 November); in spite of being rejected by physical society, this phenomenon is a key point for further success corresponding fundamental research.

2.1 Reproducibility of Low-Energy Nuclear Reaction Experiments

Reproducibility of experiments within and between laboratories is a fundamental requirement and cornerstone for any scientific investigations. There are many fundamental factors that are relevant to the issue of reproducibility (for details see [37]).

Everybody with a perfect ear will say that, for example, on the viola play will have never be reproducible: it depends on too many factors (resonance conditions) which are impossible to repeat. The semiconductor effect in a transistor is extremely sensitive to damages and impurities of crystal which were impossible to control in the initial experiments. The degree of reproducibility was increasing over the years when the properties of used materials were improved and standardized, and the process was optimized and controlled with high accuracy. The same would happen for reproducibility of LENR [27]. We will show that expectation for

LENR is correct only partly¹.

The targets in standard nuclear physics using accelerators are the substances in the ground states: the gases, amorphous solids or crystalline solids. The projectile particle interaction with target nuclei has taken place in vacuum. Therefore, the influence of the surrounding matter (say, atomic electrons) on the velocity of such nuclear processes (especially at high energies) should be negligible. It seems that these expectations supported by estimations of energy and size differences ($10^{-5} - 10^{-6}$) of atoms and nuclei and experiments show almost a full reproducibility.

We come to the following conclusion:

- A greater part of processes in nuclear physics takes place in closed systems. Reproducibility of such experiments should be independent of the place and time of measurements - a cornerstone of the modern scientific method.

LENRs occur in the surroundings (gases, condensed mater, water, solutions,...) which are induced by low-energy external fields as ultrasounds, electromagnetic fields, lasers,... So atoms, molecules in the surroundings and atoms of interacting nuclei are in excited states or ionized. Nuclei, atoms, the surrounding medium, and external fields representing interacting subsystems are form a dynamical open system. Frequencies and phases of subsystem motions may be coordinated according to the universal resonance synchronization principle (see Appendix) and the result may be a creation of a collective (coherence) state for the whole system. We will call such a system an auto-oscillation system in which the frequencies of an external field and frequencies of the all subsystems are commensurable. The demand for frequency commensurability means that all motions in a system are in co-ordination (in resonance), which is difficult to fulfil. This is the cause of poor reproducibility of LENR.

We formulate as a working hypothesis the following assumption:

- LENRs take places in open systems in which all frequencies and phases coordinated according to the universal resonance synchronization principle – the main reason for poor reproducibility. Poor reproducibility and unexplained results do not mean that the experiment is wrong.

2.2 The Bound State β^- Decay

Bound state β^- decay (β_b), in which the decay electron remains in an electron bound state of the daughter atom and the monochromatic antineutrino carries the total decay energy Q , was first predicted by R. Daudel, M. Jean, and M. Lecoïn [38] in 1947 and discussed in [39, 40, 41, 42, 43].

This new decay mode, the bound state β^- decay, was for the first time experimentally observed for bare ^{163}Dy [44] (Bare means that the atom ^{163}Dy is ionized fully. We will use the designation for this case as $^{163}\text{Dy}^{66+}$) and ^{187}Re [45]. Nucleus ^{163}Dy is stable as a neutral atom ($Q_\beta = -2.565$ keV) and become radioactive when fully ionized atoms (bare nucleus $^{163}\text{Dy}^{66+}$) decay to $^{163}\text{Ho}^{66+}$ ($Q_{\beta_b}^K = +50.3$ keV) via the bound state β_b decay with a half-life of 47 days. Nucleus ^{163}Ho is unstable and it is transferred to ^{163}Dy by electron capture with a half-life of $4.6 \cdot 10^3$ yr. Difference of masses $m(^{163}\text{Ho}) - m(^{163}\text{Dy}) = 2.6$ keV; therefore, the electron capture is only possible from M- or higher orbits. Unstable nuclei ^{163}Ho become practically stable due to ionization of atoms ^{163}Ho up to these orbits because the electron capture in these cases is only possible from continuum states which have an extremely small probability. The ionization of

¹References to original and review cold fusion literature are not given in our talk. They are available in the Proceedings of ICCF.

atoms changes the beta decay direction of nuclei: in neutral atoms ^{163}Ho (^{163}Dy) the electron capture leads to the transition $^{163}\text{Ho} \rightarrow ^{163}\text{Dy}$ (^{163}Dy are stable), in fully ionized atoms bare nuclei $^{163}\text{Ho}^{67+}$ ($^{163}\text{Dy}^{66+}$) are stable (unstable).

- General conclusion: in neutral atoms some ground state nuclei decay via orbital electron capture, for bare nuclei (fully ionized atoms) the electron capture branches are blocked. In these cases (if in addition the positron decays are lacking) bare nuclei become stable. This conclusion is very strong and well-known in nuclear society.

For neutral $^{187}\text{Re}^{0+}$ only a unique, first forbidden transition to the ^{187}Os ground state is energetically possible. The small matrix element and the small Q_β value of $Q_\beta=2.663(19)$ keV lead to the long half-life of 42 Gyr. The measured half-life [45] for bare $^{187}\text{Re}^{75+}$ ($Q_{\beta b}^K=+72.97$ keV) of $T_{1/2} = (32.9 \pm 2.0)$ yr is billion times shorter than that for neutral ^{187}Re .

- The ground state β decay properties of nuclei cardinaly change when all electrons of the atomic shells are removed: stable (unstable) nuclei become unstable (stable) and a half-life may decrease up to billion times - 9 orders of magnitude. The interpretation is very simple: magnitude of Q_β and phase volume increase for the ionized atoms rather than for neutral ones.

2.3 Nuclear Decay of Coulomb Excited and Isomeric States for Fully Ionized Atoms

The half-lives of isomeric states of fully ionized $^{144m}\text{Tb}^{65+}$, $^{149m}\text{Dy}^{66+}$ and $^{151m}\text{Er}^{68}$ were measured [46]. The increase was observed of the half-lives of bare isomers by factors of up to 30 to their neutral counterparts. The authors [46] give the correct and evident interpretation of experimental results:

- This is due to the exclusion of the strong internal conversion and electron-capture channels in the radioactive decay of these bare nuclei.

Experiments with highly-ionized $^{57}\text{Fe}^{q+}$ ($q = 19 - 25$) projectiles at 6 MeV [47] and $^{125}\text{Te}^{q+}$ ($q = 46 - 48$) projectiles at 27 MeV/u [48] have demonstrated a growth (ranging from a few 10% up to 670%) of nuclear half-lives of Coulomb excited levels due to the direct influence of the electronic configuration on the internal-conversion coefficients.

2.4 The Effect of Host on the Half-life of ^7Be

Norman E.B. et al. [49] measured ^7Be decay rates in gold (Au), graphite, boron nitride and tantalum (Ta). Among these materials, they found that the ^7Be half-life was the longest in Au and the shortest in graphite. According to their experiments, the decay rate of ^7Be in Au is lower than that in graphite by $(0.38 \pm 0.09)\%$.

Ray A. [51] measured the difference of ^7Be decay rates in Au and Al_2O_3 and found that the decay rate in Au was lower than that in Al_2O_3 by $(0.72 \pm 0.07)\%$.

Ray A. et al. [50] pointed out that the apparent disagreement between the two sets of experimental results was most likely due to the choice of different reference samples with which the comparisons were carried out. Indeed, Norman E.B. et al. [49] used the ^7Li beam for their implantation studies, whereas Ray A [51] used the proton beam. The radiation damage by

${}^7\text{Li}$ on gold lattice sites, where ${}^7\text{Be}$ nuclei stop, would be much larger [52] ($3 * 10^{-4}$ vacancies/Angstrom/ion) than the corresponding damage (10^{-5} vacancies/angstrom/ion) for proton. Therefore, the radiation damage effects on lattice due to heavy ion irradiation might also be partly responsible for apparent discrepancies. It means that to speak about reproducibility in this case we should take into account at least atomic physics effects that are usually ignored.

The ratio of L to K -shell electron capture in ${}^7\text{Be}$ bare nucleus shows [53] that the measured ratio is less than half of the existing data for free ${}^7\text{Be}$.

- These discrepancies are most likely due to the distortions of L and K -shell orbitals by the host medium.

2.5 Controlled Gamma-Decay of Excited Nuclei

According to the modern theory, the spontaneous gamma-decay of excited nuclei in free space without any material bodies is a noncontrolled process. Probability A_{eg} of this decay

$$A_{eg} \equiv \frac{1}{\tau} = \frac{4\pi^2\omega_{eg} |\vec{d}_{eg}|^2 \rho(\omega_{eg})}{3\hbar} = \frac{4\omega_{eg}^3 |\vec{d}_{eg}|^2}{3\hbar c^3}$$

is fully determined by the matrix element \vec{d}_{eg} of the nucleus dipole moment and energy of the nuclear transition $\hbar\omega_{eg} = E_e - E_g$.

The total lifetime $\tau_{tot} = \tau/(1 + \alpha)$ and radiative lifetime τ of this excited nucleus in free space are the constants. Here α is the coefficient of internal electron conversion for the nuclear transition $E_e - E_g$.

Problems become very complicated in the important case when material bodies are present in the surrounding space. Vysotskii V.I. [54] considered the general system which included the excited atom nucleus, the system of atom electrons, the system of zero-energy (in vacuum state) electromagnetic modes, and the screen – the system of N resonant or nonresonant atoms situated at the distance $d \gg \lambda_{eg} = 2\pi c/\omega_{eg}$. The authors of [55] concluded that

- It is usually stated that in all cases with the presence of any material bodies at a macroscopic distance $d \gg \lambda_{eg} = 2\pi c/\omega_{eg}$ from the excited nucleus the expression for the lifetime τ and τ_{tot} remains the same or changes by an unmeasurable small value. Such a supposition is erroneous. It was shown [54] that a spontaneous gamma-decay was a process of an excited nucleus relaxation, the phase promise of which was caused by interaction with a fluctuating state of the thermostat at the distance $d \gg \lambda_{eg}$ from the nucleus. The phenomenon of a controlled nucleus gamma-decay is a result of interaction of the nucleus with zero-energy modes, interaction of these modes with the atoms of controlled (and controlling) screen, and interaction of the nucleus with the system of atom electron.

The increase in radiative lifetime τ of an excited nucleus by 10 – 40% and total lifetime τ_{tot} by 1% was observed in the experiments [55, 56, 57] with gamma-source ${}^{57}\text{Co}({}^{57*}\text{Fe})$ and with gamma-absorber made of stable ${}^{57}\text{Fe}$ isotope. So these results prove the possibility of controlled essential influence of a thin resonant screen on the amplitude, space and temporal characteristics of a spontaneous decay and excited nuclei radiation.

2.6 Okorokov Effect

Let us consider the interaction of an incoming particle (atom or nucleus having the ground state E_g and the excited state E_e) with the crystal target. It is possible to choose the conditions

[58, 59] when the frequency of a collision particle with the atoms of crystal $\nu_{col} = V_0/a_0$ (the velocity V_0 of a particle motion a_0 is the distance between the atoms in the crystal) will be commensurable with the transition frequency ν_{tr} of the particle

$$\nu_{tr} = \frac{E_e - E_g}{h} = \frac{n_1}{n_2} \nu_{col},$$

where n_i - integer numbers. It is clear that at such conditions the interaction between the particle and atoms of the crystal should have a resonance character.

If the particle interacts with the n atoms of the crystal, then the probability to excite the particle is equal to

$$W(n) = W(1)n^2,$$

where $W(1)$ is the probability of excitation of the particle by one atom of the crystal.

This is a collective (coherent) amplification mechanism of the excitation for the projectiles in the periodic field of the crystal predicted first by Okorokov V.V. [58, 59] and observed experimentally by Okorokov V.V. too [60, 61, 62].

The resonance and coherent amplification of atoms and nuclei excitations by the periodic fields of crystals is now well established and recognized by the physical society and is used in different applications but is not known for the cold fusion society.

From a modern point of view water has a very complicated geometrical structure as a collection of quasicrystal clusters (see [63] and references in it). The hydrogen atom, atoms and molecules, water and solutions, solid states and condensed matter have the same homology in the geometric structure, where the de Broglie wave length of electron in the ground state of hydrogen atom plays the role of the standard one [64].

The puzzle of poor reproducibility of experimental data of LENR is now evident:

- Electrolysis in solutions, discharge in gases and any external influence on atoms leads to
 1. The atoms are ionized, thus changing radioactive rates by bound state β_b -decay of nuclei.
 2. The ions can be accelerated in a such way that they come to resonance conditions to intensify excitation of nuclei, atoms,...
 3. Even small external fields can induce large responses as an avalanche in the mountains is stimulated, say, by an accident cry.

A mechanical analogue of the observed phenomenon is the synchronization of oscillations of the pendulum clock suspended from the moving girder – the Huygens synchronization principle [65]. The universal resonance synchronization principle for a microsystem (for nuclei, atoms, molecules for living and nonliving cells,...) was established in [66].

The decrease and increase radioactivity of tritium with increasing temperature in small titanium particles was observed [67] whereas current experiment and theory overlooked this effect.

2.7 Nuclei and Atoms as Resonators

In 1953 Schwartz H.M. in 1953 [68] proposed the nuclear and the corresponding atomic transitions be considered as a unified whole process. This process contains the β decay which represents the transition of nucleon from one state to an other with emission of electron and antineutrino and, simultaneously the transition of atomic shell from the initial state to the final one. A complete and strict solution of this problem is still waiting for its time (see, for example, a review paper [69]).

The division of decay energy into nuclear and atomic energies has only a conditional sense, especially, in the resonance case. The process has a resonance character and its probability is large when energy differences of nuclear and atomic transitions become close to zero. The drastic acceleration of decay time in H -like ions of ^{229m}Th may be up to 10^5 [69], the electron shell serves as a trigger, reducing the lifetime of the isomer by up to five orders of magnitude. The fantastic acceleration of decay time for the case $E3$ -transition in ^{235}U may be up to 20 orders of magnitude.

The probability of the resonance transfer of energy by electrons from the nuclei can be increased by application of laser, which compensates the defect of resonance. The corresponding enhancement factor in some cases may be 10^3 . It is important to note that the knowledge of isomer energy is not necessary, the laser should be synchronized on the atomic frequency.

- This is a real phenomenon of resonance synchronization (see Appendix) of nuclear, atomic, and laser frequencies to control the decay processes.

It is also predicted [70] that the lifetime of the hindered photo-fission can be reduced up to $10^3 - 10^4$ by application of laser. Laser in a such case changes the angular momentum of a decaying state by unity practically without altering its energy.

- Low-energy external fields in LENR can play a role of a trigger changing the quantum numbers of the hindered or forbidden processes so that the first should be enhanced and the second should be allowed. This mechanism inducing LENR may be the main reason for poor reproducibility of LENR experiments and main mechanism of geo- and biotransmutations.

2.8 Geo-, Bio- and Alchemical Transmutations

All the above-described mechanisms of LENR are grounded on the universal resonance synchronization principle (see Appendix). The main requirement of this principle is that the frequencies $\nu_i(ext)$ of external fields should be *commensurable* with the frequencies $\nu_j(in)$ of subsystems making a whole system: $\nu_i(ext) = \nu_j(in)n(j)/n(i)$. We strongly emphasize that the frequencies of an external field can be *infinitely small* in comparison with the corresponding frequencies of subsystems. The frequencies $\nu_i(ext)$ are as triggers starting emission of internal energy. The enhancement (resonance) effect on LENR induced by external fields can be extremely large (small) when maximal values of density distributions for external fields and the corresponding distributions of a subsystem coincide (do not coincide). It means that:

- Even extremely low-energy external fields may induced nuclear transmutations with emission of internal high energies, according to the universal resonance synchronization principle.

Natural geo-transmutations in the atmosphere and earth occur at the points of strong change in geo- and electromagnetic fields [71, 72, 73]. V.I. Vysotsky and A.A. Kornilova published an excellent book: «Nuclear Fusion and Transmutation of Isotopes in Biological System» [74], we refer a reader to this book.

It seems (for F.A.Gareev) that the fact that some alchemists may [75] «change base metals into noble ones, silver or gold» does not contradict the mechanisms of LENR described above.

2.9 Ball lightning as a macroscopic low energy nuclear reactor

All internal contradictions of the previous theories of a ball lightning were based, by default, on an assumption that the ball lightning is a plasmoid. In order to maintain the macroscopic volume of air (the mixture of nitrogen, oxygen, water vapour, etc.) in ionized condition, it is necessary to provide a great amount of energy from some kind of a source. Many experimenters, among them are such well-known experts as P.L. Kapitsa, made repeated attempts to create a long-living spherical plasmoid in laboratory conditions. However, no efficient ways of supplying the isolated plasma clots with energy and maintaining them in a stationary condition for a few minutes (that is the lifetime of a natural ball lightning) could be found.

The purpose of this paper is to substantiate a hypothesis that the natural ball lightning is an area of space where the chain nuclear reaction of the bound-state β -decay of radioactive phosphorus nuclei takes place. It is shown that the analyzed phenomenon is related to the physics of electrical discharge in gases indirectly. Therefore, the term globular lightning is not sufficiently correct.

The main hypothesis which is asserted hereinafter was formulated for the first time in [76]. The logic of the creation of this hypothesis is as follows:

1. Ball lightning always leaves a smell of sulphur, ozone, and nitrogen oxide after itself [77].
2. Sulphur can be generated only as a result of phosphorus β -decay [78].
3. Rate constant of β -decay depends on a lot of the ionization degree of decaying radionuclide [33]. The half-life of ionized radiophosphorus is approximately 1-2 minutes and is comparable with the lifetime of ball lightning in natural conditions.
4. Radiophosphorus is abundant in nature. It is found in rain-water in macroscopic amounts [79]

This model was proved in [76] and we can say that it is now confirmed. Thus, it is a type of a natural low-energy nuclear reactor.

2.10 Demkov and Meyer super-focusing

The ion flux transmission through a monocrystalline medium is accompanied by many interesting and unexplained phenomena (see a review papers [93, 94]). Among them we indicate the effect of "channeling" in crystals: the enhancement and reduction of flux near crystallographic directions. Yu.N. Demkov and J.D. Meyer [95] propose to use a "channeling" effect in the stimulation and enhancement of LENR by following way:

"A highly collimated beam of protons (≈ 1 MeV) entering the channel of a monocrystal film forms at a certain depth an extremely sharp (≈ 0.005 nm) and relatively long (some monolayers of the crystal) focusing area where the increase of the flux can reach thousand times. Impinging atoms in this focusing area can undergo nuclear reactions with proper foreign dopants which disappear if the crystal is tilted from this position by only radians. This effect can be called super-focusing in the channels, in contrast to the ordinary flux peaking where the increase of flux reaches only few times. Results are confirmed by the Monte Carlo calculations accounting for several properties of the real lattice."

3 Conclusions

We have concluded that LENR is possible in the framework of the modern physical theory - the universal resonance synchronization principle and based on it different enhancement mechanisms of reaction rates are responsible for it². Investigation of this phenomenon requires the knowledge of different branches of science: nuclear and atomic physics, chemistry and electrochemistry, condensed matter and solid state physics,... The results of this research field can provide a new source of energy, substances, and technologies.

The puzzle of poor reproducibility of experimental data is due to the fact that LENR occurs in open systems and is extremely sensitive to parameters of external fields. Poor reproducibility and unexplained results do not mean that the experiment is wrong³.

4 Appendix

The Universal Resonance Principle of Synchronization

Many objects in Nature - elementary particles, nuclei, atoms, molecules,...., DNA, proteins, etc. are built as self-consistent hierarchical systems and have the same homological constructions in the sense that they are found by the same fundamental physical laws: energy-momentum conservation law and sectorial conservation law (the second Kepler law). Schrodinger [81] wrote that an interaction between microscopic physical objects is controlled by specific resonance laws. According to these laws, any interaction in a microscopic hierarchic wave system exhibits the resonance character. The difference between eigenenergies (eigenfrequencies) in one system should be equal to each other

$$h\nu_1 - h\nu'_1 = h\nu'_2 - h\nu_2, \quad \nu_1 - \nu'_1 = \nu'_2 - \nu_2. \quad (1)$$

Therefore, eigenfrequencies are additive. In other words, the resonance condition is formulated in the following way: oscillations participating in an interaction process should be constituents of the same frequencies. Thus, we come to the important conclusion: in the whole interacting self-consistent wave system the hierarchy of frequencies is established. So the sum of all partial frequencies is the integral of motion. Due to the above-said, the corresponding partial motions are determinate. This determinism arises as a consequence of the energy conservation law. As the resonance condition arises from the fundamental energy conservation law, the rhythms and synchronization of the majority of phenomena to be observed are the reflection of the universal property of self-organization of the Universe. The resonance synchronization principle is substantiated at the microscopic level (see, for details [82]) as the consequence of energy conservation law and resonance character of any interaction between wave systems. In this paper, we have demonstrated the universality of the resonance synchronization principle independent of substance, fields and interactions for microsystems. Thereby, we bring some arguments in favor of the mechanism - ORDER from ORDER, declared by Schrodinger in [83], fundamental problem of contemporary science. We come to a conclusion [84] that a stable proton and a neutron play the role of a standard for other elementary particles and nuclei. They contain all necessary information about the structure of other particles and nuclei. This

²Intensification of LENR using superwave excitation [80] is based on this principle.

³Solutions of salts, electrolytes and living systems contain a large amount of ions. In these cases the bound state β_b -decay and other described above enhancement mechanisms of LENR can play an essential role. Unfortunately, we do not know the works devoted to this problem.

information is used and reproduced by simple rational relations, according to the fundamental conservation law of energy-momentum. We originated the principles of commensurability and self-similarity [85]. The commensurability and self-similarity result in the very unity of the world. The principle of commensurability is displayed in phenomena in different branches of science [85].

All material objects (micro- and macrosystems), which are described by standing waves, know all about each other. Each object is the scaled one of the other and it is not possible to say which is more «fundamental». In this work, we have demonstrated that the structure of DNA and cell molecules can be calculated with some structure of a hydrogen atom. The interatomic distances in cell molecules are quantized according to the quantization rule of the fractional Hall effect. Therefore, we can conclude that the structure of DNA and cell molecules can be established from the analysis of hydrogen spectra using the quantization rule of the Hall effect and vice versa [86]. The bridge between the structure of a hydrogen atom, cell molecules and the Hall effect exists! It is very surprising that there are phenomena in Nature that are really described by simple rational relations. Only the fundamental conservation law of energy – momentum is responsible for this harmonic movement.

The resonance principle of synchronization became a fruitful interdisciplinary science of general laws of self-organized processes in different branches of physics. It is intriguing to speculate that many questions can now be formulated as a result of universality of the resonance synchronization principle independent of substance, fields, matter and interactions for micro- and macrosystems [86]. Information concerning important details of an ecosystem's evolution is contained in frequency spectra. Therefore, matter turns out to be a form of organized information. The Universe was arranged according to number, harmony, and perfect forms.

A new concept in evolution is robustness. One suggests simulating evolution of complex organisms constrained by the sole requirement of robustness in their expression patterns. Robustness in biophysics is defined as the ability to function in face of substantial changes in components. Robustness is implemented by constraining subsequent patterns to have similar expression patterns. Key properties of biochemical networks are robust, i.e., they are insensitive to precise values of the biochemical parameters [87]. Robustness is an important ingredient in simple molecular networks and, probably, also an important feature of gene regulation. S. Bornhold and K. Sneppen [88] suggest considering robustness as an evolutionary principle. We came to the conclusion that the robustness principle can be understood in the framework of the universal resonance synchronization principle.

We have concluded that the homology of atom and molecule structures exists. It means that the de Broglie wave length λ_e of electron in the ground state of a hydrogen atom plays the standard role – all interatomic distances in molecules could be commensurable with λ_e . There are huge examples of commensurable ratios between the interatomic distances and λ_e in superconducting, nanomaterials, DNA, protein, . . . , living molecules [86].

A molecule is an aggregate of atoms in a distinct three dimensional arrangement. Distances between atoms fix the structure of the molecules, as was so forcefully emphasized by L. Pauling. These interatomic distances depend on the resonance interactions between atoms and also on the sizes of atoms. We come to the conclusion that each object in the hierarchical system is scaled one of the other and it is impossible to say which is more «fundamental». We assume now, as a working hypothesis, that the De Broglie electron wave length in a hydrogen atom in the ground state can be considered as a standard of dimensions for atoms and interatomic distances in molecules. So interatomic distances and radii of atoms can be written in the

following way:

$$R = \frac{n_1}{n_2} \lambda_e, \quad (2)$$

where $\lambda_e = 0.33249185$ nm is the de Broglie electron wave length in a hydrogen atom in the ground state and $n_1(n_2) = 1, 2, 3, \dots$

- Note that the quantization conditions for the fractional Hall effect [86] are the same as (2). It means that the fractional Hall effect demonstrates only the commensurable velocities of electrons in hydrogen atoms and *GaAs*-type heterostructures (two-dimensional electron gas). So there is no room for interpretation of the fractional Hall effect in terms of the fractional charge. Nobody observed the fractional charge in Nature.

It is well known in optics (in quantum mechanics too) that the transition coefficient of light through the layer is equal to one if the following relations between the thickness R of the layer and wave length λ_e exist

$$R = \frac{n}{4} \lambda_e, \quad n = 1, 2, 3, \dots \quad (3)$$

It is interesting to note that: 1) the Bohr quantization conditions $\lambda_N = N\lambda_e$ for a hydrogen atom and the quantization conditions $\lambda_N = N\lambda_{He}$ for superfluid 4He coincide with (3) if $N = n/4$; 2) the Tomasch quantization conditions for tunneling are the same as (3).

We have carried out a systematic analysis of interatomic distances for a huge number of systems, using (3), in which $\lambda = \lambda_e$ is the electron wave length in the ground state of a hydrogen atom. We came to the conclusion that the superconductivity can be explained by the assumption: channel motions in systems like that and electron motion in the ground state of a hydrogen atom are exactly synchronous. Therefore, superconductivity systems represent a coherent synchronized state – complex of coupled resonators with the commensurable frequencies.

- It means that we have in principle found out the possibility to achieve superconductivity at room temperature [86].

The parameter-free formula for interatomic distances in biomolecules, superconductors, and size of nanostructures has been obtained. This establishes some bridge between the structures of different phenomena (conductivity, superconductivity, insulator-metal transmission, quantum Hall effect, superfluidity, quantization of nanostructure cluster size, size of biomolecules). This connection can be considered as an indication of existence of some physical phenomena in the structures of the superconducting and living systems.

We have shown [86] only a small part of our calculations by formula (3) and the corresponding comparison with experimental data for interatomic distances in some molecules. One can be surprised by a high accuracy description of the existing experimental data.

Understanding of the origin and evolution of the genetic code must be the basis for a detailed knowledge of the relationship between the basic building blocks of DNA and environment. As is widely accepted today, essentially all the DNA in an eukaryotic nucleus are formed of histones and different chromatin structures folded hierarchically. At least five orders of DNA and chromatin organization and folding (nucleotide, helix, nucleosome, solenoid and chromatin fibre loop) have been described in literature. A DNA chain is a long unbranched polymer composed of only four types of subunits. These are nucleotides containing the basis adenin (A), cytozine (C), guanin (G), and thymine (T). These nucleotides form complementary flat pairs and the distances between these plains are equal to λ_e .

- It means that the structures, formed in DNA molecules by nucleotides, produce the two- and three-dimensional waveguide.

All proteins look like dimers in which the two copies of the recognition helix are separated by exactly one turn of the DNA helix: $3.4 \text{ nm} \Leftrightarrow 10\lambda_e = 3.325 \text{ nm}$.

The DNA is packaged with histones into regularly repeating nucleosomes that are packed into 30 nm (it's diameter) fibers; $30 = 90\lambda_e = 29.92 \text{ nm}$, it is also elaborated folded and organized by other proteins into a series of subdomains of distinct character. This higher-order packing is the most fascinating and also most poorly understood aspect of chromatin.

Molecules of DNA, amino acids, proteins, ... contain tetrahedral blocks $H_3C - C$ with the angles $\angle HCH = \angle HCH = 109.47^\circ$, with the bond length $3d(H - C) = \lambda_e = 0.3325 \text{ nm}$ and $3d(H - C) + d(C - C) = 3/2\lambda_e = 0.4987 \text{ nm}$. Note that these molecules of amino acids and DNA have planar blocks $H_2N - C$, whose bond length is equal to $2d(H - N) + d(N - C) = \lambda_e = 0.332 \text{ nm}$. Pentagonal rings in adenin and guanin have the bond length equal to 0.668 and 0.666 nm, respectively, which is close to $2\lambda_e = 0.665 \text{ nm}$.

Many distances in living molecules are commensurable with the de Broglie wave length λ_e of an electron in the ground state of a hydrogen atom. This means that λ_e play the role of the standard distance in molecules, especially in living molecules. Hence, the electron motions in a hydrogen atom and in living molecules are synchronized and self-consistent. A hydrogen atom represents radiating and accepting antennas swapping the information with the surrounding substance.

M. Gryzinski [90, 91, 92] has proved that atoms are the quasi-crystal structure with definite angles: $90^\circ, 109^\circ$ and 120° , which are the well-known angles in crystallography.

- We have proved the homology of atom, molecule, and crystal structures.

So the resonance synchronization principle is substantiated at the microscopic level as the consequence of the energy conservation law and resonance character of any interaction between wave systems. The commensurability and self-similarity result in the very unity of the world.

It means that our method can be used in different fields of fundamental researches and also in applications: construction of new materials, say, high-temperature superconductors, new drugs in medicine, new methods in diagnostics of diseases, and new devices by analogy with biomolecules.

Atoms as open systems

The conservation laws fulfill for a closed systems. Therefore, the failure of parity in week interactions means that the corresponding systems are the open systems. Periodic variations (24 hours, 27, and 365 days [21, 22, 24, 25]) in β -decay rates indicate that failure of parity in week interactions have a cosmophysical origin. The charged particles moving with acceleration should radiate (absorb) electromagnetic waves - the fundamental classical electrodynamics law. The stable orbits of electrons in atoms are exist, but electrons do not radiate on them according to third Bohr's postulate (third Bohr's postulate in 1913 - "Despite the fact that it is constantly accelerating, an electron moving in such an allowed orbit does not radiate electromagnetic energy. Thus, its total energy E remains constant."). Why electrons do not radiate on the stable state of atoms - nobody knows it. We formulate as a working hypothesis the following assumptions:

- The classical laws of physics are valid for macro- and microsystems. Contradiction between classical electrodynamics and quantum theory should be solved a very simple way. Proton and electron in hydrogen atom move with the same frequency, their motions are synchronized. A hydrogen atom represents radiation and accepting antennas (dipole) interchanging of energy with the surrounding substance. This energy is the relict radiation energy.
- The relict radiation ($T=2.725$ K) should play a role of conductor for proton and electron motions in the hydrogen atom due to the universal resonance synchronization principle. The external field - relict radiation field and hydrogen atom form an auto-oscillation system in which the frequencies of an external field and frequencies of the whole subsystem are commensurable. The demand for frequency commensurability means that all motions are in a co-ordination (in resonance).
- The sum of radiate and absorb energies by electron and proton moving in an allowed orbit is equal to zero. **THUS, ITS TOTAL ENERGY E REMAINS CONSTANT** - only the last part of the third Bohr's postulate is correct.
- The relict radiation is a result of the selforganization of stable hydrogen atom according to the universal resonance synchronization principle.

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