The Problem of Creating a Universal Theory of LENR

Vladimir Vysotskii*

Introduction

It is well known that the total probability of nuclear reactions with participation of charged particles is defined as the action of the Coulomb barrier. This fundamental limitation stimulates the use of fast particles in the composition of a thermonuclear plasma, which leads at once to the necessity to solve the extremely complicated technological problems related to the formation and confinement of such a plasma. It is also obvious that the choice of the "thermonuclear" approach makes any attempt of using (under terrestrial conditions) the reactions of synthesis on the base of isotopes heavier than deuterium or tritium absolutely unreal.

The real alternative to hot fusion is LENR. Among numerous LENR problems, the most important one is connected with overcoming the Coulomb potential barrier during the interaction of low energy charged particles. The "standard" approach to nuclear physics leads to a very small probability of the tunnel effect and can't solve this problem. Other problems (*e.g.*, sharp change of ratio of reaction channel probability, suppression of neutron channel, abnormal sensitivity to variable environment, etc.) are directly connected to the "barrier problem."

These problems are considered in the present work. Outlooks and shortcomings of a "chemical" approach to LENR phenomenon, as proposed by Storms,[1] are discussed.

We consider a general and sufficiently universal mechanism of stimulation and optimization of nuclear reactions running at low energy with participation of both light and heavy nuclei. This mechanism can be applied with high efficiency to very different experiments (both the executed and planned ones).

Several successful dynamical correlated-induced LENR experiments are also analyzed.

Outlooks and Shortcomings of a "Chemical" Approach to LENR Phenomenon

It is known that the LENR problem is connected with interdisciplinary researches and needs the efforts of different experts and different points of view.

Storms has declared three basic requirements for LENR phenomena: experimental observation; full prediction and reliability of LENR effects; adequate understanding of LENR mechanisms on the basis of a full theoretical model.

These statements are correct, but there is also a fourth requirement: possibility and efficiency of practical use.

Storms has proposed a "chemical" (phenomenological) means for the analysis of LENR phenomenon. At the first step it is necessary to discover the location of the process and only then to identify the basic characteristics of its mechanism.

In a correct physical model of any phenomenon the absence of clear statement and numerical calculations is admissible in the initial stage of formation of the theory. In the final form such model should be strictly formulated and confirmed by detailed mathematical analysis. This can lead to success in special cases, *i.e.* if LENR is observed only at certain conditions for certain kinds of particles and in certain environments.

These requirements are satisfied, for instance, for the Mössbauer effect: it takes place only in a crystal matrix (1) made of heavy atoms, (2) at low energy of gamma-radiation, (3) and if the temperature of the crystal is less than the Debye temperature. In contrast to this example, LENR phenomenon was observed in different systems and in different environments (loaded crystal matrix, cooled deuterium gas, electric explosion of wire in water, electron beam implosion of metal targets, etc.).

Storms has declared that cracks in solids are chosen as the universal nuclear active environment (NAE) for realization of LENR on the basis of hydrogen isotopes. According to Storms' model, several nuclei of hydrogen (all isotopes) with accompanied joint (collectivized) electrons might be confined in the crack due to the action of charges situated on each wall of the crack.

According to this "voids model," the initial state of interacting particles (*e.g.*, Pd, d or t) corresponds, actually, to a deformed D_2 molecule (in the case of two particles) or hydrogen plasma (for large ensemble of hydrogen atoms) placed in a crack. The equilibrium distance between two nuclei in D_2 molecules equals $r_{dd} \approx 0.84$ A. The distance between nearest d nuclei in the discussed ensemble at usual laboratory condition is not less than r_{dd} because the same distance $r_{dd} \approx 0.84$ A corresponds to compressed D gas at high pressure of $P \approx 12000$ atm in crack volume.

Unfortunately, Storms does not consider the concrete mechanism and efficiency of overcoming the Coulomb barrier in these systems (in the paper there is only general speculation about the potentiality of nuclear transmutation). It is the most important problem for explanation of LENR experiments because in a typical D_2 molecule the rate of pair dd-fusion $\lambda_{dd} \le 10^{-70}$ s^{-1} is very small. Such rate can't explain any of the numerous conducted experiments. This "voids model" does not explain reactions of transmutation with the participation of middle mass and heavy nuclei.

On the other hand, the problem of optimization of nuclear interaction in such cracks (including analysis of the possibility of suppression of Coulomb barrier action in different kinds of cracks, nanowells and voids with the participation of two nuclei or degenerated deuterium gas) has been investigated in many works.[2-10] In several of these works very detailed quantitative analysis of features of interaction between particles has been carried out.

It is necessary to make some essential remarks to the analysis conducted in the Storms paper.

Of course, the standard statement "cold fusion is caused by a process completely different from and in conflict with the one causing hot fusion" is correct. But, the reasons for such difference are not obvious. It is impossible to explain this difference on the basis of the assumption that features of hot fusion are connected only with additional excitation of compound nucleus at accelerated motion of interacting particles with energy $T = p^2/2m$. From simple analysis it follows that in the case of inter-nuclear reactions with the participation of heavy or middle mass nucleus with mass M_n and light particle (*e.g.*, proton of deuteron with mass m) it should not be the essential difference in final products of cold ($T_{CF} \approx 0.025$ eV) and "moderately" hot ("thermonuclear") fusion with $T_{HF} \approx 10$ keV. In both cases the additional energy brought by the light particle into the compound nucleus is very close to large binding energy $Q \approx 6$ - 8 MeV $>> T_{CF,HF}$.

The difference exists only in extranuclear processes:

a) For the case of hot fusion the energy $W_R \approx (m/M_n)T_{HF} \geq 10$ - 100 eV of relative motion of compound nucleus is much greater than the binding energy of this nucleus in a lattice, and in the case of cold fusion it is much lower ($W_R \approx (m/M_n)T_{CF} << 0.025$ eV);
b) For hot fusion the duration of nuclear collision is very small and mutual reorientation of electric dipole momentums of interacting nuclei is impossible; for cold fusion the probability of such reorientation is high.

These reasons can lead to different types of reactions.

For the case of hot fusion the interaction usually leads to the formation of slowly moving compound nucleus and to "standard" multi-channel nuclear decay; for cold fusion (LENR) it leads to the possibility of reaction of incomplete penetration and single-channel reaction.

For the last type of reactions the orientation effects play an important role. They are similar to the Oppenheimer-Phillips reaction that can explain He^4 formation:

$$d+d \equiv \frac{1}{2}\begin{Bmatrix}(p+n)+(n+p)\\(p+n)+(p+n)\end{Bmatrix} \rightarrow (p+n)+(n+p) \rightarrow (p+n+n+p)^* \rightarrow He^4 + N\gamma \quad (1)$$

and absence of free neutrons

$$d+d \equiv \frac{1}{2}\begin{Bmatrix}(p+n)+(n+p)\\(p+n)+(p+n)\end{Bmatrix} \rightarrow (p+n)+(n+p) \rightarrow (p+n+n)^*+p \rightarrow t+p+\Delta E \quad (2)$$

in dd-reactions.

For fast particles (hot fusion) the probability of Reaction 1 is very low because of the necessity of the presence of an additional nearest heavy nucleus for satisfaction of the momentum conservation law. For Reaction 2, the impossibility of mutual reorientation of deuterons leads to identical probability of two reaction channels by formation of compound nuclei

$$d + d \rightarrow He^{4*} \rightarrow \frac{1}{2}\begin{cases}(p+n+n)^* + p = t + p + \Delta E\\(p+n+p)^* + n = He^3 + n + \Delta E\end{cases} \quad (3)$$

and incomplete penetration with the same probability

$$d + d \equiv \frac{1}{2}\begin{cases}(p+n)+(n+p) \rightarrow (p+n+n)^* + p \rightarrow t + p + \Delta E\\(p+n)+(p+n) \rightarrow (p+n+p)^* + n \rightarrow He^3 + n + \Delta E\end{cases} \quad (4)$$

The presence of distant from nucleus neutron potential well for even-odd more heavy nuclei (virtual neutron traps at distance of 10 - 30 fm)[11] also leads to the optimization of reactions of incomplete penetration. For LENR in solids the Mössbauer-like process with transfer of recoil energy to a lattice is also possible.

One more statement made by Storms demands elaboration. The author[1] asserts that mandatory requirement of LENR is the satisfaction of the "Second Law of Thermodynamics that requires energy to always go from where it is greater to where it is less—from hot to cold, from high to low, from light to dark. Consequently energy cannot be increased locally beyond certain very narrow limits, which are controlled by the Laws of Probability." This requirement is correct only for equilibrium systems. For such systems the role of fluctuations is small. In such systems any phase relationships are absent. For density matrix approximation it corresponds to full relaxation of nondiagonal and diagonal matrix elements.

These assumptions are totally incorrect for use of the method of coherent correlated states (CCS)[12-15] for interacting particles in non-stationary LENR (see below).

I also disagree with another "standard" belief that Storms asserts: ". . .attempts to explain cold fusion by proposing to concentrate energy or by forcing the d closer together is a waste of time because the typical hot fusion products would be expected." It is very important that the CCS method can unite both these conditions—the barrier is overcome with high probability during fluctuation with virtual, very high energy and reaction goes as real (stationary) low energy.

It has been shown[12-15] that the use of CCS can lead to such effects. Below we briefly consider the possible methods of formation of such states and their application to real experiments (including LENR in non-stationary cracks).

Application of Correlated States of Interacting Particles in LENR Phenomena

2.1. Principles of formation of coherent correlated states of interacting particles at low energy

The presence of wave properties and the possibility of the tunnel effect for microparticles are one of the basic distinctive peculiarities of the quantum mechanical description of Nature. In a concentrated form, these properties are expressed in the form of uncertainty relations which determine, in fact, the limit of the applicability of the classical and quantum descriptions of the same object. This limit is connected with the Planck constant $\hbar$.

The Heisenberg uncertainty relation for the coordinate and momentum,

$$\sigma_q \sigma_p \geq \hbar^2/4 \quad (5a)$$

and its generalization

$$\sigma_A \sigma_B \geq |<[\hat{A}\hat{B}]>|^2/4,\ \sigma_C = <(\Delta\hat{C})^2> \equiv (\delta C)^2,\ \Delta\hat{C} = \hat{C} - <C> \quad (5b)$$

for arbitrary dynamical variables A and B are the base relations of quantum mechanics. In modern interpretation, Equations 5a and 5b correspond to uncorrelated states.

In 1930, Schrödinger[16] and Robertson[17] generalized Equation 5b and derived a more universal inequality called the Schrödinger-Robertson uncertainty relation

$$\sigma_A \sigma_B \geq |<[\hat{A}\hat{B}]>|^2/4\ (1 - r^2),\ r = \sigma_{AB} / \sqrt{\sigma_A \sigma_B}\ , \quad (6a)$$
$$\sigma_{AB} = <\Delta\hat{A}\Delta\hat{B} + \Delta\hat{B}\Delta\hat{A}>/2 = (<\hat{A}\hat{B} + \hat{B}\hat{A}>)/2 - <A><B>$$

where r is the correlation coefficient between A and B with $|r|\leq 1$, σ_{AB} is the mutual variance of A and B corresponding to the mean value of the anticommutator of the error operators $\Delta\hat{K} = \hat{K} - <K>$.[12,18]

The Schrodinger-Robertson uncertainty Equation 6a is an obvious generalization of the Heisenberg-Robertson uncertainty Equation 5b for correlated states and is reduced to it at $r = 0$.

It was shown[12-15,18] that for a model system including a particle with coordinate $q(t)$ and momentum $p(t)$ in the field of a nonstationary harmonic oscillator

$$V(q,t) = \frac{mq^2\omega^2(t)}{2} \tag{7}$$

a decrease in the particle oscillation frequency $\omega(t)$, leads to an increase in the correlation coefficient $|r(t)|$, and a change of the uncertainty relation,

$$\delta q\delta p_q \geq \hbar/2\sqrt{1-r^2},\ r(t) = <q\hat{p} + \hat{p}\,q>/2\delta q\delta p, \qquad \delta q \equiv \sqrt{<q^2>},\ \delta p \equiv \sqrt{<p^2>} \tag{6b}$$

From the formal point of view the change in the correlation coefficient in the uncertainty relation can be taken into account by introducing the variable Planck constant $\hbar^*$

$$\hbar \rightarrow \hbar^* \equiv \hbar/\sqrt{1-r^2} \tag{8}$$

at $|r| \rightarrow 1$ we have $\hbar^* \rightarrow \infty$.

When a strongly correlated particle state with $|r| \rightarrow 1$ is formed, the product of the variances of the coordinate $<q^2>$ and momentum $<p_q^2>$ increases indefinitely. This leads to the possibility of a much more efficient particle penetration into the sub-barrier region $V(q)$ than that for the same particle in an uncorrelated state. It was shown[13-16] that very low barrier transparency (tunneling probability) for the initial uncorrelated state,

$$D_0 \equiv D_{r=0} = \exp\{-W(E)\} << 1, \qquad W(E) = \frac{2}{\hbar}\int_R^{R+L(E)} |p(q)|dq,\ |p(q)| = \sqrt{2M} < \sqrt{V(q)-E} > \tag{9}$$

that corresponds to the conditions $E<<V_{\max}$, $W(E)>>1$ for the formation of CCS can increase to maximal possible value, $D_{|r|\rightarrow 1} \rightarrow 1$ at the same low energy $E<<V_{\max}$. In Equation 9 R is the nucleus radius, $L(E)$ is the "barrier width" and M is the reduced particle mass.

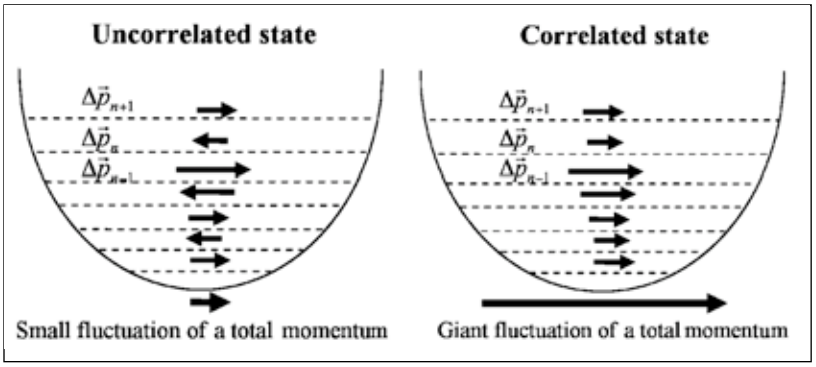

Figure 1. Formation of total fluctuating momentum of a particle in potential well in uncorrelated and correlated superpositional states.

In a very simplified form, this effect can be taken into account by the formal (not quite correct) substitutions

$$W_{r=0}(E) \rightarrow W_{r\neq 0}(E,\hbar) \equiv W_{r=0}(E,\hbar^*) = W_{r=0}(E,\hbar)\sqrt{1-r^2}, \qquad D_{|r|\neq 0}(E) = (D_{|r|=0}(E))^{\sqrt{1-r^2}} \tag{10}$$

In this case the barrier transparency for a particle in a correlated state increases by a factor of

$$D_0^{\sqrt{1-r^2}}/D_0 = 1/D_0^{1-\sqrt{1-r^2}} >> 1 \tag{11}$$

which is close to the result of exact barrier clearing calculations at different r using rigorous quantum mechanical methods.[12] Although these estimates with the substitution $\hbar \rightarrow \hbar^*$ are not quite correct (they are made just for illustration of order of the effect) and must be justified every time, they clearly demonstrate a high efficiency of the use of CCS in solving applied tunneling related problems in the case of a high potential barrier and a low particle energy.

The physical reason for the huge increase in barrier transparency for a particle in coherent correlated superposition state is related to the fact that the formation of a coherent correlated state leads to the cophasing and coherent summation of all fluctuations of the momentum $\Delta\vec{p}(t) = \sum_n^N \Delta\vec{p}_n(t)$ for various eigenstates forming the superpositional correlated states. This leads to great dispersion of the momentum of correlated state

$$\sigma_p = <\left\{\sum_n^N \Delta\vec{p}_n(t)\right\}^2> = N\left\langle(\Delta\vec{p}_n)^2\right\rangle + N^2\left\langle\Delta\vec{p}_n\Delta\vec{p}_m\right\rangle \tag{12}$$

and very great fluctuations of kinetic energy

$$<\Delta T> = <(\Delta\vec{p}(t))^2>/2M = N^2\left\langle\Delta\vec{p}_n(t)\Delta\vec{p}_m(t)\right\rangle/2M + N\left\langle(\Delta\vec{p}_n(t))^2\right\rangle/2M \sim N^2 \tag{13}$$

of the particle in the potential well and increasing of potential barrier penetrability. This situation is presented in symbolic form in Figure 1.

A CCS can be formed in various quantum systems. The most easy way to form such state is when the particle is in a nonstationary parabolic potential well (Equation 7). The formation mechanism in such system was considered.[13-15]

The coefficient of correlation $r(t)$ can be obtained by analyzing the equation of motion for a classical oscillator with a variable frequency that in dimensionless form is

$$\frac{d^2\varepsilon}{dt^2} + \omega^2(t)\varepsilon = 0,\ \varepsilon(0) = 1,\ \frac{d\varepsilon}{dt}\Big|_0 = i,\ \omega(0) = \omega_0 \tag{14}$$

where $\varepsilon(t) = \varepsilon^{\varphi(t)}$ is the complex amplitude of the harmonic operator normalized to $x_0 = \sqrt{\hbar/M\omega_0}$; $\varphi(t) = \alpha(t) + i\beta(t)$.

The correlation coefficient is defined by the expression[12-15,18]

$$r = Re\left\{\varepsilon^*\frac{d\varepsilon}{dt}\right\} / \left|\varepsilon^*\frac{d\varepsilon}{dt}\right|,\ r^2 = 1 - \omega_0^2 / \left|\varepsilon^*\frac{d\varepsilon}{dt}\right|^2 \tag{15}$$

Equations 14-15 are equivalent to equations for the real functions $\alpha(t)$ and $\beta(t)$

$$\frac{d^2\alpha}{dt^2} + \left(\frac{d\alpha}{dt}\right)^2 - \exp(-4\alpha) = -\omega^2(t) \tag{16a}$$

$$\beta(t) = \int_0^t \exp\{-2\alpha(t')\}dt' \quad (16b)$$

$$|r| = \sqrt{(d\alpha/dt)^2\exp(4\alpha)/[1+(d\alpha/dt)^2\exp(4\alpha)]} \quad (16c)$$

The problem of influence of both damping and presence of additional fluctuation force was solved and discussed.[15]

It is very important that the CCS can be formed, at least in principle, within any system of levels of quantized motion that are not subjected to an external intense dephasing action, provided that a certain coherent action is superimposed on it.

2.2. Methods of formation and effectiveness of application of coherent correlated states at low energy of interacting particles

In our works[12-15] the method of formation of coherent correlated states of a particle at monotonic $\omega(t) = \omega_0 \exp(-t/T)$[12,13] and periodical[13-15] changing in the frequency $\omega(t)$ of a nonstationary harmonic oscillator was investigated.

The first regime can be provided, for example, at a constant depth of the potential well V_{max} in which the particle is located and for monotonous increase its width $L(t)$

$$L(t) = L_0\exp(t/T),\ L_0 = \sqrt{8V_{max}/M\omega_0^2} \quad (17)$$

The efficiency of excitation of the correlated states greatly depends on time (see Figure 2).

The fast increase of correlation coefficient $|r(t)|\to 1$ at such deformation of width $L(t)$ leads to a "giant" increase of barrier transparency (Equation 10) $D_{|r|\neq 0}(E) \to 1$ at low energy. Such effect is possible at monotonic deformation ("growing") of mechanical cracks with deuterium gas in solids, *e.g.* or into nonstationary microwells[1-4] at growth of biological objects.[19,20]

A more realizable situation takes place for a harmonic law of change in $\omega(t)$ in the case of a full-scale change of the oscillator frequency,

$$\omega(t) = \omega_0\,|\cos\Omega t| \quad (18)$$

or a change of this frequency in a limited range,

$$\omega(t) = \omega_0\,(1 + g_\Omega \cos\Omega t) \quad (19)$$

where $|g_\Omega|<1$ is the modulation depth.

This regime can be provided, for example, at a constant depth of the potential well V_{max} in which the particle is located and for a periodic change in its width in the interval

$$L(t) = L_0(1+g_\Omega\cos\Omega t),\ L_0 = \sqrt{8V_{max}/M\omega_0^2} \quad (20)$$

The efficiency of excitation of the correlated states greatly depends on a ratio of ω_0 and Ω.

Figure 3 presents the time dependences of the correlation coefficient for a periodic and limited change in the oscillator frequency (Equation 19) at $\Omega = 2\omega_0$.

It follows from these results that the duration of formation of CCS decreases with the increase of frequency modulation depth, *e.g.* for the case presented in Figure 1b, we have $|r|_{max} \geq 0.999998$ at $t \geq 500/\omega_0$. For such value of $|r|_{max}$ the probability of tunneling effect for reactions d + d and Pd^A + d at room temperature increases from $D_{r=0} \approx 10^{-100}$ (for non-correlated state of interacting deuterons) to $D_{r=0.999998} \approx 0.8$ (for correlated state of d) and from $D_{r=0} \approx 10^{-4600}$ (for non-correlated state of interacting particles d and Pd^A) to $D_{r=0.999998} \approx 10^{-8}$ (for correlated state of d) in potential well of nearest Pd^{A+} ions).

From the detailed analysis it follows that the process of formation of CCS with $|r|_{max} \to 1$ at action of limited periodic modulation (Equation 19) is possible only at any of two conditions: $\Omega = \omega_0$ (resonant formation) or Ω is close to $2\omega_0$ and lies inside the interval $(2 - g_\Omega)\omega_0 \leq \Omega \leq (2 + g_\Omega)\omega_0$ (parametric formation).

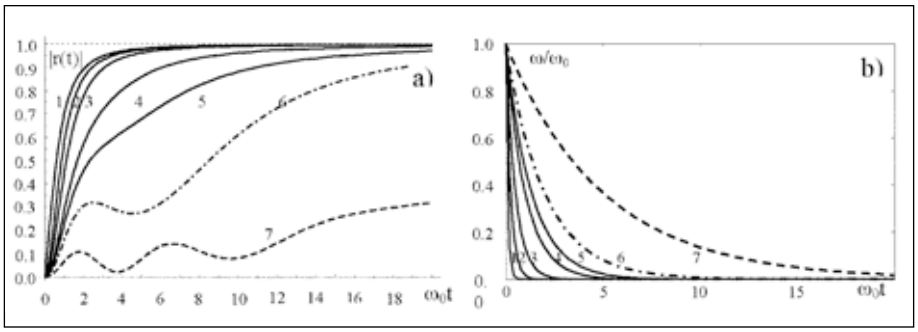

Figure 2. Time dependences of the correlation coefficient $r(t)$ (a) at various rates of monotonic decrease in the harmonic oscillator frequency $\omega(t) = \omega_0\exp(-t/T)$ (b). Curves 1-7 correspond to T = $0.1/\omega_0$, $0.25/\omega_0$, $0.5/\omega_0$, $1.0/\omega_0$, $1.33/\omega_0$, $2/\omega_0$, $5/\omega_0$.

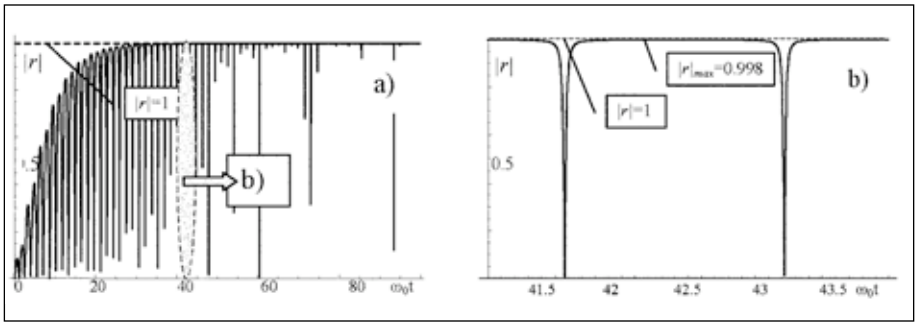

Figure 3. a) Time dependences of the correlation coefficient r for a limited change in the oscillator frequency $\omega(t) = \omega_0\,(1 + g_\Omega\cos\Omega t)$ at $g_\Omega = 0.1$, $\Omega = \omega_0$; b) Increased fragment of (a).

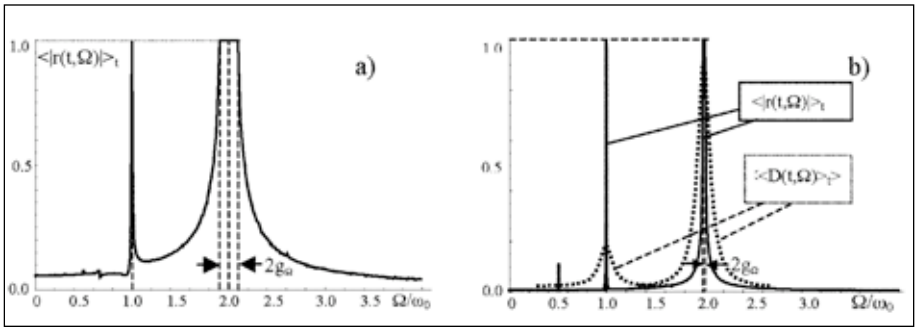

Figure 4. Dependences of averaged correlation coefficient $<|r(t,\Omega)|>$ and normalized averaged coefficient of barrier transparency on frequency Ω at $|g_\Omega| = 0.1$ (a) and $|g_\Omega| = 0.01$ (b).

The results of calculation of averaged correlation coefficient

$$<|r(t,\Omega)|>_t \equiv \frac{1}{\Delta t}\int_{t_0-\Delta t/2}^{t_0-\Delta t/2} |\, r(t,\Omega)|dt \qquad (21)$$

are presented in Figure 4a-b for $\Delta t = 10^3/\omega_0$ and different values of modulation depths $g_\Omega = 0.1$ ($t_0 = 1500/\omega_0$) and $g_\Omega = 0.01$ ($t_0 = 10^4/\omega_0$).

In Figure 4b the results of calculation the averaged coefficient of barrier transparency

$$<<D(t,\Omega)>_t>= \frac{1}{\sqrt{\pi\delta\Omega}} \int \left\{\frac{1}{\Delta t}\int_{t_0-\Delta t/2}^{t_0-\Delta t/2} D(t,\Omega')dt \right\} \qquad (22)$$

$$\exp[-(\Omega - \Omega')^2/(\delta\Omega)^2]d\Omega'$$

at non-monochromatic periodic modulation of $\omega(t)$ are also presented.

From these results follows a very important statement: in any experiments with the use of external periodic modulation with limited frequency interval, the suppression of action of potential barrier on the effectiveness of nuclear reaction with the participation of charged particles is possible only for frequencies $|\Omega - \omega_0| \le \delta\Omega$ or $|\Omega - 2\omega_0| \le |g_\Omega\omega_0 + \delta\Omega|$.

This statement is in very good correlation with "terahertz" laser experiments[21,22] on the stimulation of nuclear reaction at joint action of two laser beams with variable beat frequency on a surface of PdD cathode during electrolysis in D_2O. Figure 5 shows the experimental frequency dependencies of thermal energy release[21] in these experiments.

Formation of CCS in this system is connected with the direct or indirect (by plasmon excitation or phonon mode modulation) action of electromagnetic radiation with frequencies Ω on optical phonon modes $\omega_0^{(k)}$ of deuterons in PdD compound. Four resonances of energy release $\Omega_1 \approx 7.8...8.2$ THz, $\Omega_2 \approx 10.2...10.8$ THz, $\Omega_3 \approx 15.2...15.6$ THz, $\Omega_4 \approx 20.2...20.8$ THz in Figure 5 are the result of averaging of about 30 experiments and subsequent statistical processing of experimental data.[21]

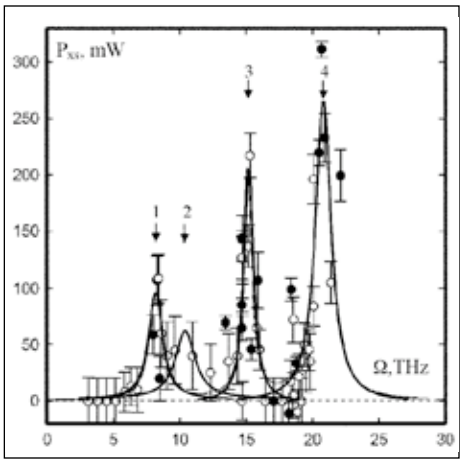

Figure 5. Frequency dependencies of energy release at joint action of two different lasers with beat frequency Ω and monochromaticity $\delta\Omega \approx 1$ THz on a surface of PdD cathode during electrolysis in D_2O.[21]

Comparison of frequencies of all four resonances shows that the ratios between these frequencies are $\Omega_3 \approx 2\Omega_1$ and $\Omega_4 \approx 2\Omega_2$ with good accuracy. By the way, from the given experiments it follows that the amplitude of high-frequency maxima in each of these pairs (accordingly Ω_3 and Ω_4) greatly excided the amplitudes of the maxima corresponding to the "basic" frequencies Ω_1 and Ω_2. Such relation directly follows from comparison of Figure 4b and Figure 5. These experimental results completely correspond to the theoretical model of CCS.[23]

This model also explains the presence of a resonance of nuclear reactions (d + d and Pd^A + d) on frequency $\Omega_4 \approx 20.2...20.8$ THz (at action of beat frequency Ω_4). It is known that in the region $\omega_0^{(k)} > 16$ THz there are no optical phonon modes for PdD compound (see analysis in Hagelstein *et al.*[22]). So, the resonance of these nuclear reactions at action of beat frequency Ω_4 is connected (by parametric interaction at formation of coherent correlated state) with the optical phonon mode in PdD with the frequency $\omega_0^{(2)} = \Omega_4/2 = \Omega_2$.

A different situation takes place if there is a full-scale (maximally possible) change of the oscillator frequency $\omega_0(t)$ (Equation 18). In this case the process of formation of a totally correlated state is possible at various actions on the system (including the use of low frequency $\Omega << \omega_0$). It was shown[13,14] that at $\Omega = \omega_0/100\pi \approx 0.03\omega_0$ we have $|r|_{max} \ge 0.999993$ at $t \ge 4000/\omega_0$.

Obtained results can also explain Rossi-Focardi experiments at action of RF-irradiation to hot NiH nano-powder situated in a closed chamber with the presence of compressed H_2 gas.[24-25] In this case the action of irradiation on the surface of nano-particles leads to modulation $\omega(t) = \omega_{0n}(1 + g_\Omega \cos \Omega t)$ of acoustic phonon and plasmon modes ω_{0n} of these nano-particles. Such modulation leads to formation of CCS, a sharp increase of Coulomb barrier transparency and stimulation of nuclear reactions $Ni^A + p \rightarrow Cu^{A+1} + \nu$ (A = 58,60,61,62,64). Barrier transparency for these reactions at temperature $T \approx 400...600$ C increases from $D_{r=0} \approx 10^{-1000}$ (for non-correlated states of interacting p and Ni^A nuclei) to $D_{r=0.999993} \approx 10^{-6}...10^{-4}$ (for correlated state of p).

The similar effect of formation of CCS and stimulation of effective nuclear dd-fusion (including generation of neutron bursts) takes place in cooled D_2 gas at changing of strong external magnetic field in interval 8...10 kOe.[26]

References

1. Storms E.K. 2013. "Cold Fusion from a Chemist's Point of View," *Infinite Energy*, 18, 108.

2. Vysotskii V.I. and Kuz'min R.N. 1991. "The Theory of Non-Threshold Cold Fusion in Solids," Int. Progress Review, *AIP Conf. Proc: Anomalous Nuclear Effects in Deuterium/Solid Systems*, ed. S.E. Jones and F. Scaramuzzi, 228, 900-928.

3. Vysotskii V.I. and Kuz'min R.N. 1994. "On Possibility of Non-Barrier dd-Fusion in Volume of Boiling D_2O During Electrolysis," *Proc. ICCF4*, Vol. 4, 6-1 - 6-3.

4. Vysotskii V.I. 1994. "Conditions and Mechanism of Non-Barrier Double-Particle Fusion in Potential Pit in Crystals," *Proc. ICCF4*, Vol. 4, 20-2 - 20.5

5. Vysotskii, V.I. and Kornilova A.A. 2009. *Nuclear Transmutation of Stable and Radioactive Isotopes in Biological Systems*, Pentagon Press, Chapter 4.

6. Godbole, V. 2012. "Low-energy Electroweak (EW) Physics (in cavities) in Lattices and Fluids," *Proc. ICCF17*.

7. Frisone, F. 2009. "Theoretical Model of the Probability of Fusion Between Deuterons within Deformed Crystalline Lattices with Micro-Cracks at Room Temperature," *Proc. ICCF15*, 312-318.

8. Frisone, F. 2001. "Deuteron Interaction within a Microcrack in a Lattice at Room Temperature," *Fusion Technology*, 39, 2, 260.

9. Frisone, F. 2004. "Theoretical Model of the Probability of Fusion Between Deuterons within Deformed Lattices with Microcracks at Room Temperature," *Proc. ICCF11*, World Scientific, 612.
10. Bockris, J.O.M. and Minevski, Z. 2000. "The Mechansim of the Evolution of Hydrogen on Palladium and Associated Internal Damage Phenomena," *J. Hydrogen Energy*, 25, 747.
11. Vysotskii V.I. and Vysotskyy, M.V. 2010. "Abnormal Features of Neutron-Nucleus Low-Energy Interaction and the Mechanism of Inhibition of Neutron-Induced Reactions," *European Phys. Jour. A*, A44, 279-285.
12. Vysotskii V.I. and Adamenko, S.V. 2010. "Correlated States of Interacting Particles and Problems of the Coulomb Barrier Transparency at Low Energies in Nonstationary Systems," *Technical Physics*, 55, 5, 613-621.
13. Vysotskii, V.I., Vysotskyy, M.V. and Adamenko, S.V. 2012. "Formation and Application of Correlated States in Nonstationary Systems at Low Energies of Interacting Particles," *Journal of Experimental and Theoretical Physics*, 114, 2, 243-252.
14. Vysotskii V.I. and Adamenko, S.V. 2012. "Low Energy Subbarrier Correlated Nuclear Fusion in Dynamical Systems," *Journal of Condensed Matter Nuclear Science*, 8, 91-104.
15. Vysotskii, V.I., Vysotskyy, M.V. and Adamenko, S.V. 2012. "The Formation of Correlated States and the Increase in Barrier Transparency at a Low Particle Energy in Nonstationary Systems with Damping and Fluctuations," *Journal of Experimental and Theoretical Physics*, 115, 4, 551-566.
16. Schrödinger, E. 1930. Ber. Kgl. Akad. Wiss., Berlin, S.296.
17. Robertson, H.P. 1930. "A General Formulation of the Uncertainty Principle and Its Classical Interpretation," *Phys. Rev. A*, 35, 667.
18. Dodonov, V.V., Klimov, A.B. and Man'ko, V.I. *Transactions of FIAN*, 200, 56.
19. Vysotskii V.I. and Kornilova A.A. 2003. *Nuclear Fusion and Transmutation of Isotopes in Biological Systems*, MIR Publ. House.
20. Vysotskii, V.I. and Kornilova A.A. 2010. *Nuclear Transmutation of Stable and Radioactive Isotopes in Biological Systems*, Pentagon Press.
21. Letts, D., Cravens, D. and Hagelstein, P.L. 2009. "Dual Laser Stimulation and Optical Phonons in Palladium Deuteride, in Low-Energy Nuclear Reactions and New Energy Technologies," *Low-Energy Nuclear Reactions Sourcebook* (ACS), Vol. 2, 81-93.
22. Hagelstein, P.L., Letts, D.G.and Cravens, D. 2010. "Terahertz Difference Frequency Response of PdD in Two-Laser Experiments," *J. Cond. Mat. Nucl. Sci.*, 3, 59-76.
23. Vysotskii, V.I., Vysotskyy, M.V. and Adamenko, S.V. 2012. "Application of Correlated States of Interacting Particles in Nonstationary and Periodical Modulated LENR Systems," *Proc. ICCF17*.
24. Michell, J. 2011. *Rossi's ECat: Free Energy, Free Money, Free People*, Xecnet.
25. Rossi, A. 2011. "Method and Apparatus for Carrying Out Nickel and Hydrogen Exothermal Reaction, United States Patent Application Publication (Pub. No.: US 2011/0005506 A1, Pub. Date: Jan. 13, 2011).
26. Mizuno, T., Akimoto, T., Takahashi, A., and Celani, F. 2006. "Neutron Emission from D_2 Gas in Magnetic Fields Under Low Temperature," *Proc. ICCF11*, World Scientific, 312-323.

About the Author
Dr. Vladimir Vysotskii has a Ph.D. (1975) from Bogolyubov Institute for Theoretical Physics (Kiev, Ukraine) and D.Sci. (1992) from National Shevchenko University for Theoretical Physics and Solid State Physics (Kiev, Ukraine). Since 1976, he has been employed by the National Shevchenko University, currently as head of the Theoretical Radiophysics Department. Vysotskii has authored about 300 papers and eight books.

*Email: vivysotskii@gmail.com