J. Condensed Matter Nucl. Sci. 29 (2019) 348–357

Research Article

Effective LENR in Weakly Ionized Gas Under the Action of Optimal Pulsed Magnetic Fields and Lightning (Theory and Experiments)

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Abstract

The features and mechanism of LENR production in a system of free particles under the action of a weak impulse (e.g., the action of a pulsed magnetic field) are considered. It is shown that in such a system effective formation of coherent correlated states of particles with the accompanying very sharp increase in the energy fluctuations take place. The amplitude of these fluctuations exceeds by many orders the average thermal energy of the particles and can reach 10–50 keV and more. This mechanism fully explains the nuclear reaction both in the atmosphere during a lightning discharge, and laboratory experiments conducted using electric discharges.

Keywords: Coherent correlated states, LENR in gas, Lightning, Nuclear transmutation of isotopes

1. Application of Coherent Correlated States in LENR Processes

Numerous successful LENR experiments, some of which have confidently emerged from the "child" age of laboratory experiments and have manifested themselves at the industrial level, up to now have not been based on a reliable theoretical model that adequately explains non-trivial results that are not consistent with the traditional models of nuclear physics.

This problem has been actively discussed over the past 20 years. There are many different theoretical models that should explain the results of successful experiments. It should be noted that the majority of these models are of a highly specialized nature. Each of them is aimed at explaining a specific experiment in a specific environment involving specific nuclei. As a rule, the theoretical model proposed for one particular experiment (with one set of conditions and parameters) is not applicable to another experiment (with another set). We believe that such approach (the existence of a set of uncoordinated theoretical models) is not correct and has very limited area of application.

Moreover, each of these models is aimed at explaining one unique property of LENR: the anomalously high probability of a tunneling effect at low particle energy. In this case, other unique properties of such reactions (ban on the formation of radioactive daughter isotopes and very strong suppression of concomitant gamma radiation) are not

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actually considered. In our works [1–9] a completely different approach has been proposed and developed: a unified theoretical model (method of formation of coherent correlated states (CCS) of interacting particles), which allows us to explain in details all successful LENR experiments, without exception. The physical basis of this method is related to the Schrödinger–Robertson uncertainty relations [10,11]:

$$\sigma_A\sigma_B \;\geq\; |\langle[\widehat{A}\widehat{B}]\rangle|^2/4(1-r^2) \equiv G^2|\langle[\widehat{A}\widehat{B}]\rangle|^2/4, \tag{1}$$

$$r = \sigma_{AB}/\sqrt{\sigma_A\sigma_B}, \quad \sigma_C \;=\; \langle(\widehat{C}-\langle C\rangle)^2,$$
$$\sigma_{AB} \;=\; (\langle\widehat{A}\widehat{B}+\widehat{B}\widehat{A}\rangle)/2-\langle A\rangle\langle B\rangle,$$

where r is a correlation coefficient determining the degree of mutual coupling of the quantities A and B in a particular superposition state, described by the wave function $\Psi(q)$, and $0\leq|r|\leq 1$, G is the coefficient of correlation efficiency. More clearly, the influence of the correlation at $|r|\to 1$ characterizes a parameter $G=1/\sqrt{1-r^2}$ that varies in the interval $1\leq G<\infty$ and which can be called the coefficient of correlation efficiency [6,9,12–14].

In the case $A=q,\ B=p,\ \langle q\rangle=0,\ \langle p\rangle=0$ relations (1) take the form

$$\delta q\delta p \geq \hbar/2\sqrt{1-r^2}\equiv G\hbar/2,$$

$$r(t)=\langle q\widehat{p}+\widehat{p}q\rangle/2\delta q\delta p, \quad \delta q=\sqrt{\sigma_q}\equiv\sqrt{\langle q^2\rangle}, \ \ \delta p=\sqrt{\sigma_p}\equiv\sqrt{\langle p^2\rangle}. \tag{2}$$

From a formal point of view, the presence of a correlation in the uncertainty relation can be taken into account by replacing $\hbar\to\hbar^*\equiv\hbar/\sqrt{1-r^2}\equiv G\hbar$. In totally uncorrelated state (at $r\to 0$) we have $\hbar^*\to\hbar$ and formula (2) takes the form of standard Heisenberg uncertainty relations $\delta q\delta p\geq\hbar/2$.

This result directly corresponds to the approximate formula for the transparency coefficient of the barrier in the presence of CCS

$$D_{r\neq 0}\approx\exp\left\{-\frac{2\sqrt{1-r^2}}{\hbar}\int\limits_{R}^{R+L(E)}\sqrt{2M\{V(q)-E\}}\,\mathrm{d}q\right\}=(D_{r=0})^{\sqrt{1-r^2}}\equiv\sqrt[G]{D_{r=0}}. \tag{3}$$

An estimation of the efficiency of such approximation was carried out in [8–10]. In these works it was shown that it is possible to increase the transparency of the barrier at low energy (e.g., at room temperature) at a real deformation of the potential well (which leads to CCS formation) from a negligible values $D_{r=0}\leq 10^{-100}-10^{-300}$ to an acceptable values $D_{r\neq 0}\approx 10^{-1}-10^{-10}$, which are sufficient for the efficient nuclear fusion of both light and heavy isotopes and elements. A non-trivial physical reason for the sharp increase of the transparency of the barrier for a particle in a CCS is the interference of mutually correlated particle momentum fluctuations corresponding to different components of the non-stationary superposition state in which the particle is located. The result of this interference is the formation of giant fluctuations in momentum and kinetic energy, which leads to a reasonable increase in the transparency of the barrier. This effect clearly follows from a simple analysis.

The total current fluctuation of the momentum of a particle in a potential well with N levels in the superposition state is described by the expression:

$$\Delta\vec{p}(t)=\sum_{n}^{N}\Delta\vec{p}_n(t). \tag{4}$$

The corresponding dispersion of this momentum is determined by the formula

$$\sigma_p = \left\langle \left\{ \sum_n^N \Delta\vec{p}_n(t) \right\}^2 \right\rangle = N \left\langle (\Delta\vec{p}_n)^2 \right\rangle + N^2 \left\langle \Delta\vec{p}_n \Delta\vec{p}_m \right\rangle \tag{5}$$

The average total kinetic energy of a particle in such well is characterized by formula

$$\langle \Delta T \rangle = \langle \Delta\vec{p}(t)^2 \rangle / 2M \; = N^2 \left\langle \Delta\vec{p}_n \Delta\vec{p}_m \right\rangle / 2M + N \left\langle (\Delta\vec{p}_n)^2 \right\rangle / 2M. \tag{6}$$

From the last formulas follows that at the absence of correlation of quantum states of a particle at different levels of quantized motion (for the case $\langle \Delta\vec{p}_n \Delta\vec{p}_m \rangle = \left\langle \Delta\vec{p}_n^{\,2} \right\rangle \delta_{nm}$), we have a "standard" (usual) result: the total average energy of a particle in a system of energy levels is equal to the sum of energies at all levels where a particle can be located

$$\langle \Delta T \rangle = \sum_{n=1}^{N} \left\langle (\Delta\vec{p}_n)^2 \right\rangle / 2M = N \left\langle (\Delta\vec{p}_n)^2 \right\rangle / 2M \equiv N \langle \Delta T_n \rangle \sim N. \tag{7}$$

However, at the presence of such correlation (at $r \neq 0$), we have a fundamentally different result

$$\langle \Delta T \rangle = N \left\langle (\Delta\vec{p}_n)^2 \right\rangle / 2M + N^2 \left\langle \Delta\vec{p}_n \Delta\vec{p}_m \right\rangle / 2\tilde{M} \sim N^2 \tag{8}$$

corresponding to a very significant increase of the mean kinetic energy at $N \gg 1$.

The most optimal method of CCS formation is connected with optimal modulation of non-stationary parabolic potential $V(q,t) = M\omega^2(t)q^2/2$ for discussed particle (in fact, modulation of effective frequency $\omega(t)$). On the basis of solution of non-stationary Schrödinger equation an explicit form of the correlation coefficient for this particle can be found [15]

$$r = \mathrm{Re}\left\{ \varepsilon^* \frac{\mathrm{d}\varepsilon}{\mathrm{d}t} \right\} / \left| \varepsilon^* \frac{\mathrm{d}\varepsilon}{\mathrm{d}t} \right|, \qquad r^2 = 1 - 1 / \left| \varepsilon^* \frac{\mathrm{d}\varepsilon}{\mathrm{d}t} \right|^2. \tag{9}$$

In a similar way it is possible to find the compression coefficient k determining the ratio of the dispersions (variances) of the complex dimensionless coordinates ε and the momentum $\mathrm{d}\varepsilon/\mathrm{d}t$ of the particle

$$k = \sigma_q / \sigma_p = |\varepsilon / (\mathrm{d}\varepsilon/\mathrm{d}t)|^2 \tag{10}$$

and also the values of these dispersions

$$\sigma_q \geq \; (\hbar/2)\sqrt{k/(1-r^2)}, \qquad \sigma_p \geq (\hbar/2)\sqrt{1/k(1-r^2)}. \tag{11}$$

In these formulas $\varepsilon(t)$ is a dimensionless (normalized to $q_0 = \sqrt{\hbar/M\omega_0}$) complex coordinate of the particle, which is a solution of motion equation of a classical oscillator with a variable frequency

$$\frac{\mathrm{d}^2\varepsilon}{\mathrm{d}t^2} + \omega^2(t)\varepsilon = 0, \qquad \varepsilon(0) = 1, \qquad \left.\frac{\mathrm{d}\varepsilon}{\mathrm{d}t}\right|_0 = i, \qquad \omega(0) = 1, \tag{12}$$

$\omega(t)$ is a dimensionless frequency normalized to a characteristic frequency ω_0; t-dimensionless (normalized to ω_0^{-1}) time.

The simplest practical method of CCS formation is associated with different regimes of deformation (modulation) of a non-stationary harmonic oscillator, in the parabolic field (parabolic well) of which the particle under consideration is located. This modulation leads to an optimal mutual phasing of the different eigen states of the particle in this well. Such a formation can be obtained with a monotonic asymptotic decrease or increase of the oscillator frequency [1,2,6,9], with a change of this frequency in a limited interval [3–9] or with its periodic modulation at the absence [6–9, 12–14,17] or at the presence of random force and frequency fluctuations [12], at external pulse action [18,19].

These mechanisms can be produced in different systems: with external irradiation of crystals with a spatial alternation of heavy and light nuclei [4,20], in the process of growth or squeezing of nanocracks on a surface of metal hydrides [5–9], at the orientational motion of particles in crystals and molecular gas [21,22], in biophysical processes [21–26].

2. Formation of Coherent Correlated States and Effective Low Energy Reactions with the Participation of Charged Particles at Action of Pulsed Magnetic Field

In this paper we consider one additional practical method of LENR production based on the formation of CCS in a gaseous or plasma environment under the action of a pulsed magnetic field on free ions. This system is fundamentally different from the usually considered LENR models, which are based on a specific type of interaction in a solid target. The universal method of LENR production using of coherent correlated states, which have been considered for a long time (e.g. [1–20]), makes it possible to successfully solve also such a problem.

It is well known that the state of a charged particle in a magnetic field $H(t)$ is analogous to the state of a particle in a harmonic oscillator with the appropriate energy spectrum and characteristic frequency.

$$E_n = \hbar\omega(t)(n + 1/2), \qquad \omega(t) = |q|H(t)/Mc \tag{13}$$

and the wave functions $\Psi_n = C_n H_n(\varepsilon)\,\mathrm{e}^{-\varepsilon^2/2}$, where $H_n(\varepsilon)$ is Hermite polynomial. Under the action of a pulsed magnetic field

$$H(t) = H_0(1 + f(t)), \qquad f(t) = g\,\mathrm{e}^{-(t-t_0)^2/2\tau^2}, \quad t_0 \gg \tau \tag{14}$$

on a charged particle, the characteristic cyclotron frequency has the similar form

$$\omega(t) = \omega_0(1 + f(t)). \tag{15}$$

For the convenience it is assumed that the particle is situated in a weak permanent magnetic field H_0 (e.g., the Earth's magnetic field) before the impulse action starts and after its completion. The results of calculation of correlation coefficient $r(t)$ and formation of a CCS using a pulsed magnetic field (14) and the system of equations (9)–(12), (14), and (15) are shown in Figs. 1 and 2.

Figure 1 shows the dependence of the current $r(t)$ value of the correlation coefficient versus time t and maximum $|r(t)|_{\max}$ value versus duration of pulse τ for relative amplitude $g = 5$ of the magnetic field pulse. From these data it can be seen that under such influence a large values of the current $|r(t)|_{\max} = 0.9972$ and averaged over time $\langle|r(t)|\rangle = 0.952$ correlation coefficient are achieved at a specific pulse duration $\tau_{\text{opt}} = 0.112/\omega_0$. If the pulse duration is longer or shorter, both values ($|r(t)|_{\max}$ and $\langle|r(t)|\rangle$) very rapidly decreases.

From these data it can be seen that under such influence great values of the current $|r(t)|_{\max} = 0.9972$ and averaged over time $\langle|r(t)|\rangle = 0.952$ correlation coefficients are achieved at a specific pulse duration $\tau_{opt} = 0.112/\omega_0$.

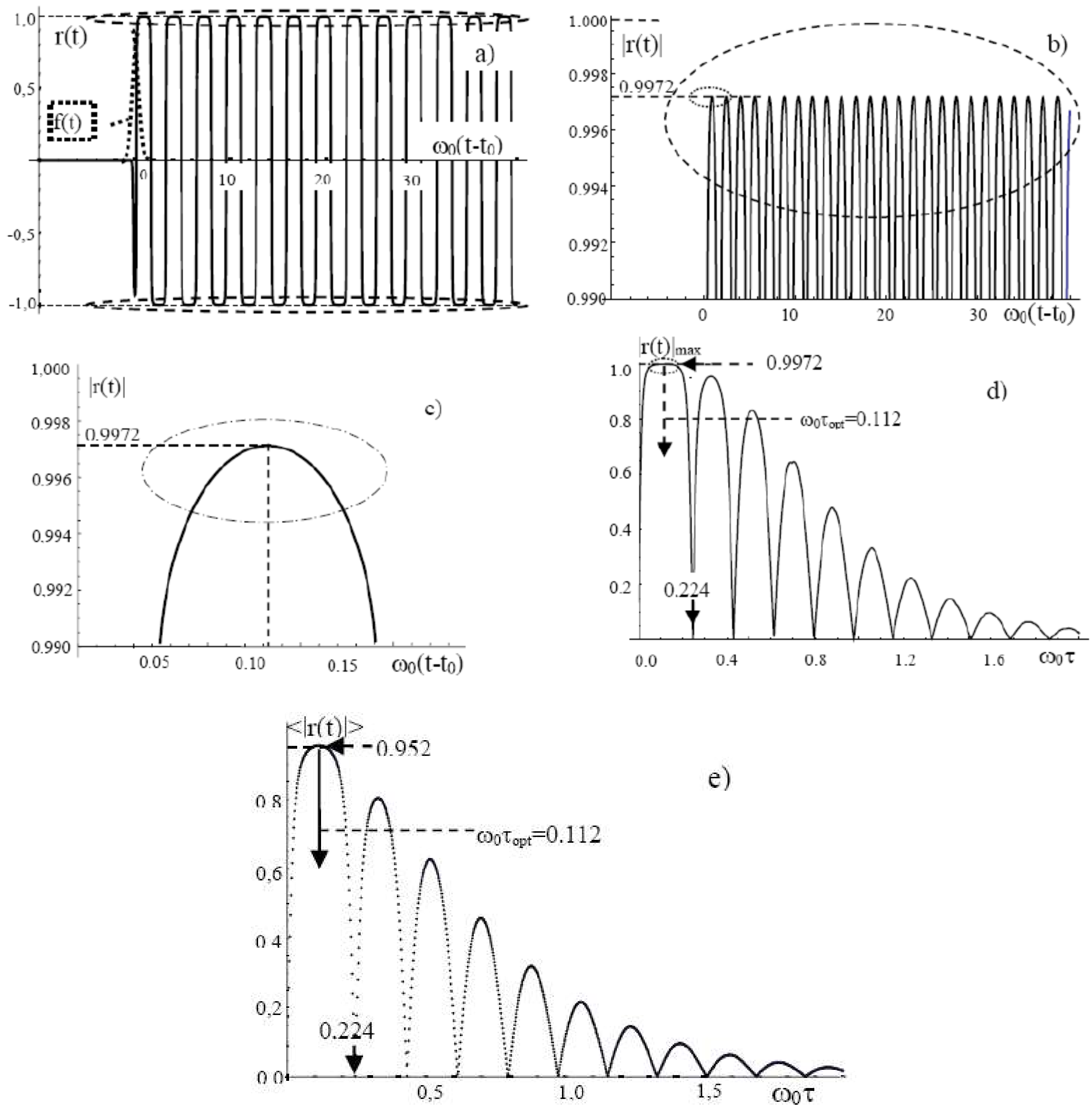

Figure 1. Dependence of the correlation coefficient $r(t)$ versus time t and duration τ of the frequency modulation pulse $f(t)$ (18) at the relative amplitude of magnetic field pulse $g = 5$: (a) general view of $r(t)$ together with $f(t)$; (b) and (c) fragments of $|r(t)|$ in the area $|r(t)| \approx 1$; (d) and (e) dependence of $|r(t)|_{\max}$ and $\langle|r(t)|\rangle$ versus τ.

If the pulse duration is longer or shorter, the both values ($|r(t)|_{\max}$ and $\langle|r(t)|\rangle$) rapidly decreases. To determine the general trend of such effect, the process of formation of a CCS with a different relative amplitudes of the magnetic

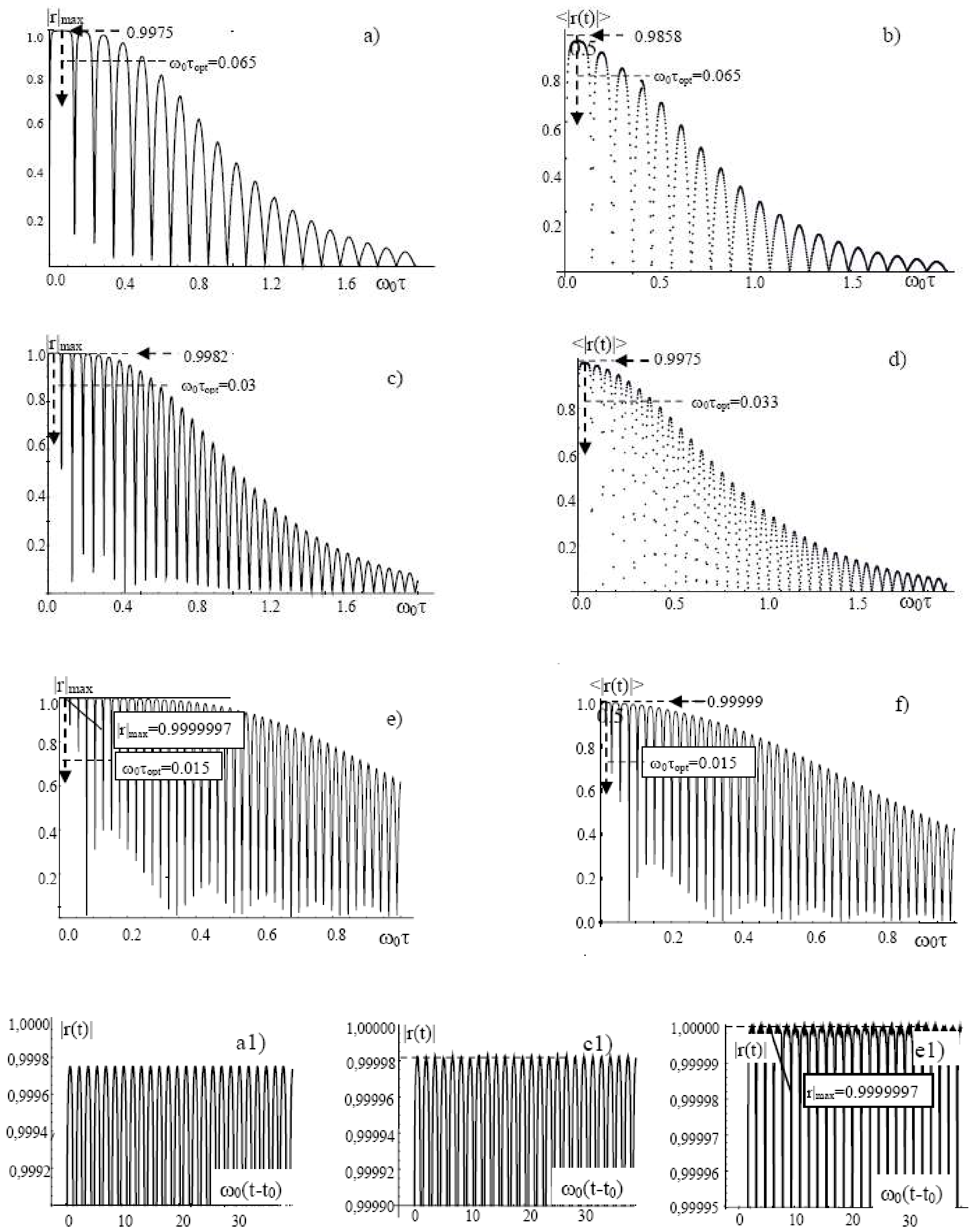

Figure 2. Dependence of the maximum $|r(t)|_{\max}$ (a, c, e) and time-averaged $\langle|r(t)|\rangle$ (b, d, f) correlation coefficient versus duration of the pulse of the frequency modulation (18) for different amplitude of this pulse: $g = 10$ (a), (b); 20 (c), (d); 50 (e), (f). The lower row is the time-dependent structure of the correlation coefficient $|r(t)|$ that correspond to the main (first) maximum of values $|r(t)|_{\max}$ and $\langle|r(t)|\rangle$ at different *g* and τ: $g = 10$ and $\tau = 0.065/\omega_0$(a1); $g = 20$, $\tau = 0.033/\omega_0$(c1); $g = 50, \tau = 0.015/\omega_0$(e1).

field pulse ($g = 10, 20, 50$) were considered. These results are presented in Fig. 2.

From the data $\omega_0\tau_{opt} \approx 0.112$; 0.065; 0.03; 0.015 presented in Figs. 1 and 2 and corresponding to different relative amplitudes of the magnetic field pulse g =5;10;20;50 for realization of the maximum values of $|r|_{\max}$ and $\langle|r(t)|\rangle$ for a given initial frequency ω_0, it can be seen that the functional dependence of the optimal duration τ of magnetic pulse and the maximum frequency $\omega_{\max} = \omega_0(1+g)$ can be written in the form of a universal relation

$$g\omega_0\tau \approx \omega_{\max}\tau \equiv \tau|q|H_{\max}/Mc \approx 0.6 - 0.7, \tag{16}$$

which is convenient for the analysis of real experiments. It is easy to understand the reason for this condition.

It was shown in [6,9,13] that the maximum efficiency of CCS formation in a non-stationary harmonic oscillator and the possibility of achieving large values of the magnitudes $|r|_{\max}$, $\langle|r(t)|\rangle$ and $G_{\max}$ corresponds to the situation when the frequency Ω_M of the controlled periodic change of the parameters of this oscillator (modulation frequency) in equal to double to the natural frequency of this oscillator during the formation of the CCS. Under this condition, the requirement of optimal synchronization of the phases of the eigenfunction of the particle in the potential well is satisfied. If we apply this result to the problem under consideration, is corresponds to the condition $\Omega_{\max} = 2\omega_{\max}$.

On the other hand, the Fourier spectrum of the pulse (14), (15) has the form

$$f(\Omega) = \tau g \exp(-\Omega^2\tau^2/2), \tag{17}$$

it remains almost constant at $\Omega \le \sqrt{2}/\tau$ and sharply decreases at $\Omega > \sqrt{2}/\tau$.

Comparison of the last two formulas leads to a relation $\omega_{\max}\tau \approx 1/\sqrt{2}$, which completely coincides with [16]. In other words, the condition for optimal CCS formation coincides with the requirement of the maximum spectral density of the function of modulation (14) at the optimum modulation frequency, which leads to synchronization of all fluctuations of momentum and energy. It can be seen from these data that with an increase of the pulse amplitude and, accordingly, with a decrease of its duration, the correlation coefficient and the transparency of the potential barrier increase very rapidly.

If we use, for example, the actual duration of electric discharge pulses $\tau \approx 10^{-7}$s, then, in order to form the CCS of free hydrogen ions (protons) with mass M_p , the optimum value of the maximum strength of the pulsed magnetic field produced by the electric discharge, according to (17), should be equal to $H_{\max}^{(p)} \approx 600$ Oe. For the case of shorter magnetic field pulses, a corresponding increase of the amplitude of these pulses is needed. It should be noted that the use of shorter pulses is the most optimal option, since the effect of dephasing of the CCS due to the accidental collisions in the gas is substantially weakened. This question is considered in detail in the papers [12,18]. From the calculation follows that with such action of magnetic field with $g = 50$ on free protons or deuterons a short-term CCS formation with a very high correlation coefficient $|r|_{\max} = 0.99999997$ and correlation efficiency coefficient $G_{g=50} = 1290$ takes place. Even more impressive results can be obtained with the additional magnification $g \gg 50$ taking into account a corresponding decrease of the duration and increase of the amplitude of the magnetic field pulse. Such increase of $|r(t)|$ and G leads to a very substantial increase in the transparency of any Coulomb barrier and the possibility of nuclear fusion at low energy during the interaction of considering particle (proton) with closely spaced nuclei. This, in particular, can be similar nuclei, which are moving in the same magnetic field, or nuclei of different atoms and molecules, which are situated near the considered moving nucleus. With such a value of the coefficient of correlation efficiency, there is an increase of the transparency of the barrier from very small value $D_{r=0} \le 10^{-100} - 10^{-300}$ to an acceptable values $D_{r\neq 0} \approx 10^{-1} - 10^{-10}$ at which the probability of nuclear reactions is very large.

It should be noted that the daughter products of such reactions (including fast neutrons and alpha particles) were recorded many times during the experiments with a gas discharge. In particular, the results of neutron detection experiments at a level of 2200 neutrons/pulse in a nanosecond electric discharge in gaseous deuterium at low pressure are presented in [27]. Such regime corresponds to the reaction d(d,He^3)n in the volume of the deuterium. The structure of the discharge pulse in this experiment is very close to the Gaussian function (18) with parameters $\tau \approx 1$ns, $J_{\max} \approx 11$ kA . In this work, the accelerator mechanism was considered under assumption that neutron generation occurs due to the acceleration of deuterons and their interaction with deuterated cathode. However, in this work it is noted that at a deuterium pressure of about 1 Torr, neutron generation is observed when using not only deuterated cathodes, but also cathodes that do not contain deuterium. In this case, the authors assumed the possibility of a reaction due to strong heating of the gas medium by the means of a shock wave. Such an argument is rather questionable, since a shock wave can not heat the gas to a thermonuclear temperature.

This result is explained very well on the basis of the formalism of coherent correlated states, which are formed under optimum impulse action. If we compare the parameters of this experiment with the optimal condition (25), which ensures large values of the quantities, $|r|_{\max}$, $\langle |r(t)| \rangle$ and $G_{\max}$ accordingly, the greater probability of tunneling and the production of the nuclear reaction, it is clear that this condition will be satisfied near the tip of an acute electrode at a small distance from its axis or in region $R \leq 1$ mm of local electronic explosive emission. The small size of these regions leads to a relatively small total neutron yield. We note that when the amplitude or duration of the discharge current pulse is increased by about 10 times, this condition will be satisfied even near the outer surface of the cylindrical tubular electrode used in this work, with a radius , that should lead to a sharp increase of the yields of the reaction. An even greater number of neutrons (at a level of 6000 neutrons/pulse) was recorded in experiments [28] with an electric discharge in ordinary air. The authors did not propose a valid model of the observed effect. This effect is well explained if it is assumed that it is caused by the formation of coherent correlated states of deuterons and protons in air. We note that deuterium enters the air in the form of molecules D_2, and, in a larger amount, in the composition of water vapor with a total concentration $n_D \geq 10^{12} - 10^{13}\,\mathrm{cm}^{-3}$. Such particles, which are in a correlated state, can stimulate in the air many reactions of the type

$$\begin{gathered} \mathrm{d}+\mathrm{d}=\mathrm{T}+\mathrm{p}, \qquad \mathrm{d}+\mathrm{d}=\mathrm{He}^3+\mathrm{n}, \qquad \mathrm{C}^{12}+\mathrm{n}=3\mathrm{He}^4+\mathrm{n}', \\ \mathrm{C}^{13}+\mathrm{p}=\mathrm{N}^{14}, \qquad \mathrm{C}^{12}+\mathrm{d}=\mathrm{N}^{14}, \qquad \mathrm{N}^{15}+\mathrm{p}=\mathrm{O}^{16}, \\ \mathrm{N}^{14}+\mathrm{d}=\mathrm{O}^{16}, \qquad \mathrm{O}^{18}+\mathrm{p}=\mathrm{F}^{19}, \end{gathered} \tag{18}$$

part of the products of which (in particular, He^4) were registered in this experiment.

Based on the parameters of the whole pulse ($J_{\max} \approx 10 - 15\,kA, \tau \approx 100\,\mathrm{ns}$), the criterion (16) was satisfied at a distance $R \approx 1.5\,\mathrm{cm}$ from the current axis. At the same time, in this experiment, a short pulse of neutron generation with a duration 20–30 ns was synchronized with the concomitant X-ray radiation and was observed at the leading edge of the current pre-pulse at $\tau \approx 220\,\mathrm{ns}$ and $J_{\max} \approx 550\,A$, which agrees with (16) at $R \approx 0.2$ cm and predicts the possibility of the reactions (18) proceeding directly near the outer surface of the discharge cord. The similar effects of the self-similar formation of the CCS can also explain the mechanism of neutron generation in air during a lightning discharge [29,30] due to the synthesis with the participation of deuterium, which is part of water vapor.

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