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Research Article

On Enhancement of Transmission Probability through a High Potential Barrier Due to an Anti-Zeno Effect

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Abstract

We consider a situation in which observations themselves can significantly increase a particle transmission probability through a high barrier compared with the particle tunneling probability (a barrier anti-Zeno effect). This may explain the results of cold fusion experiments that have been reported by other authors for various systems. We examine the anti-Zeno effect as a model of a barrier of a special shape, which is similar to the form of barriers to nuclear fusion in a solid, and moreover, has an analytic solution. We have deduced formulas that demonstrate conditions that increase the barrier permeability. Numerical estimates of the particle flows through the barrier are carried out for the conditions of cold fusion experiments.
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1. Introduction

How can the observation of a process affect its outcome?

The ancient Greek philosopher Zeno of Elea gave the reasoning in his aporia that "a watched arrow never flies". According to Zeno, an arrow cannot move if we observe it in mid-air. Indeed, if we observe an arrow in mid-air, it takes place in a space equal to itself, the same for every point in time. Since this fact is absolutely true for any point in time, it means that this fact is true in general. Thus, according to Zeno, any flying arrow is at rest.

However, a rigorous analysis of this reasoning only confirms the obvious conclusion: in the framework of classical mechanics, observation can in no way influence a process.

But in quantum mechanics, in contrast to the classical frame, there may indeed be situations where an observation may affect the process that is being observed [1]. The quantum Zeno effect can manifest itself in emission of photons by a two-level system in an excited state [2–5]. Usually this influence is manifested in the fact that the more we

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observe, the fewer photons are emitted. Therefore, in the limit of continuous monitoring, when the measurement time is $\Delta t \to 0$, emissions can be stopped completely. However, in some cases, the opposite effect can occur, that is, the observation of a process increases the probability of the process occurring. That is the anti-Zeno effect [6–9]. Since its discovery, the quantum anti-Zeno effect has attracted widespread interest both theoretically and experimentally due to its relevance to the foundations of quantum mechanics (see, e.g., [10] and references therein). Many publications are devoted to the problem of increasing the transparency of potential barriers due to the anti-Zeno effect (see, e.g., references in [10,11]). In [12,13], the problem of the probability of particle tunneling through a barrier was considered in a time-dependent framework using the effective Schrödinger equation with a non-Hermitian Hamiltonian. In [12,13], a slight increase in barrier transparency due to the anti-Zeno effect was obtained for systems with quantum dots. The authors of [14,15] have shown that that the formation of correlated coherent states of protons is accompanied by a sharp increase in short-term fluctuations of proton energy. As a result, the probabilities of tunneling a slow proton through a high potential barrier increases very significantly, and conditions for cold nuclear fusion may be possible.

Recently, in [16], one of the authors of this paper analyzed a process of particle transmission through a barrier accompanied by a transition from an excited state to the ground state (or a lower excited state) of a two-level system in the barrier. In the state of the two-level system, interacting with the particle is detected. It has been shown that in this case, observation increases the probability of a particle passing through the barrier.

In the quantum Zeno effect, the probability of a measurement-affected process varies inversely with a number of observations n_z per unit of time ($n_z = (\Delta t)^{-1}$), but in here, the probability of passage of a particle through a barrier varies directly with n_z. In some cases, the increase in the probability of passing through the barrier may be many orders of magnitude greater than the probability of the "normal" tunneling, which occurs when there is no observation of the particle. In [16], this effect has been called a barrier anti-Zeno effect.

On the qualitative level, the barrier anti-Zeno effect is as follows. Let us observe a system, and detect (indirectly) a particle inside the barrier. However, particle detection within the barrier leads to the fact that the particle proceeds from sub-barrier states to an above-barrier state. Once in the above-barrier state, the particle has a chance to fly freely over the entire barrier, or at least over a part of it (depending on the form of the barrier), going into the region beyond the barrier.

If a particle reaches the above-barrier state, the probability of penetration in the region behind the barrier is much greater than the tunneling probability, when the particle passes the entire region of the barrier in the sub-barrier state. Accordingly, in many cases, the total probability of passing through the barrier due to the barrier anti-Zeno effect (i.e. the probability of hitting in the above-barrier state, and then passing through the barrier) would be significantly greater than the tunneling probability.

In this paper, we discuss whether the barrier anti-Zeno effect can, at least in principle, increase the penetration probability across a potential barrier in fusion reactions enough to explain the results of cold fusion experiments [17–20]. According to the authors of the papers [17–20], in these experiments, they have observed energy releases which cannot be explained by chemical or any other non-nuclear processes, as well as changes in the elemental and isotopic composition of the samples.

However, in the case of real barriers (as opposed to a simple rectangular barrier model [16]), which could be relevant to cold fusion, it is very difficult to obtain both quantitative and qualitative estimations of the enhanced probability. A particular difficulty lies in the accurate calculation of the matrix elements, which are integrals of rapidly oscillating functions. In this case, small computational errors, associated with the imperfection of the numerical analysis methods or calculating integrands, can completely distort the result. Therefore, in this situation, analytical approaches are of particular importance. Within these approaches, the corresponding integrals can be calculated exactly. Or even if they are calculated approximately, they do not contain errors that completely change the result.

The aim of this paper is to examine the anti-Zeno effect in a model of a potential barrier, which has (at least qualitatively) the form of a potential barrier to nuclear fusion in a solid, and in addition, allows an analytic solution.

We will examine the probability of passing through the barrier due to the anti-Zeno effect, and compare it with the tunneling probability (which can also be calculated analytically). This comparison indicates the conditions under which the contribution of the barrier anti-Zeno effect in the current particle through the barrier exceeds the contribution of the tunneling current by many orders of magnitude.

2. Barrier Anti-Zeno Effect in a One-dimensional Model of Potential Barrier Allowing for an Analytical Solution

Let the potential barrier be described by the expression

$$V\left(x\right)=\begin{cases}\frac{1}{2}V_0\left[1+th\left(\frac{x}{2a}\right)\right]+\frac{U_0x_\alpha}{x_1-x}, & -x_1\le x\le x_1,\\ 0, & x<-x_1, x>x_1.\end{cases} \tag{1}$$

Here, $x_1 \gg a, x_\alpha$; and $U_0 > V_0$, but $V_0x_1 \gg U_0x_\alpha \gg V_0a$.

A particle A is introduced into the region to the left of the barrier. The mass and energy of this particle are m and E_{L}, respectively ($V_0 \gg E_{\mathrm{L}}$). The observation of this particle is carried out using a two-level system B, placed in a point x_0 inside the barrier (Fig. 1). The system B, initially located in a first level $E^{(1)}$, interacts with the particle A and goes over to the second level $E^{(2)}$as a result of this interaction ($E^{(1)} > E^{(2)}$). The transition energy ΔE satisfies the condition

$$V_0 \gg \Delta E. \tag{2}$$

In the case of cold fusion experiments [17–20], multicharged atomic nuclei participate, and the two-level system could be the electron subsystem of the atom. The states of the electron subsystem can change when particle A penetrates the electron shell of an atom. To observe this particle A, we use a device that includes a two-level system in an excited state. The state of a two-level system is observed, that is, after a time step Δt, we check whether it has changed the state from the first to the second one. Such a check can be carried out, e.g., as follows. We split the second level of

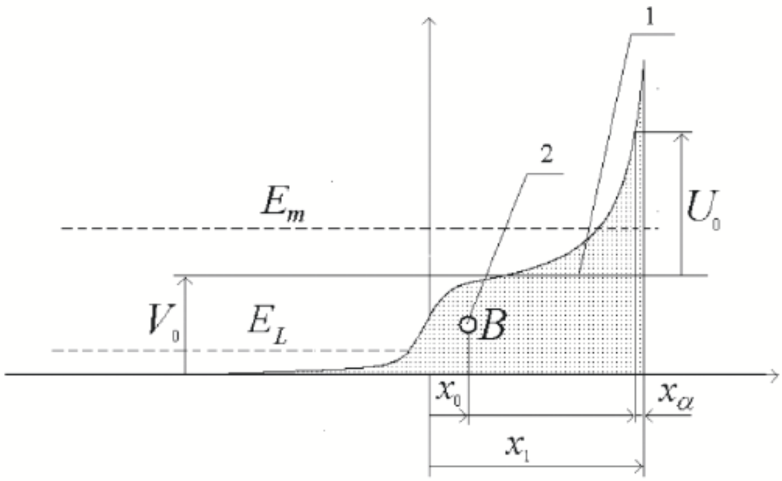

Figure 1. (1) is a potential barrier for a particle A; (2) is a two-level system B.

the two-level system into two sublevels, the energy difference of which is equal to δE (and $\delta E \ll \Delta E$). (Although after such a splitting, the system is already three-level, but in the case of $\delta E \ll \Delta E$, approximately, it can still be considered as a two-level one.) Sequentially through the time interval Δt, we will send quanta, one by one, with the energy $\hbar\omega = \delta E$, and irradiate the two-level system with these quanta. If the two-level system is at the first level, then these quanta will fly through it, practically without dispersion. But if the system is at the second level, its parameters can be chosen so that the quantum dissipates on it with a probability close to unity. After detecting the scattered quantum (e.g., by a photomultiplier), we can thus determine that the system was at the second level when the scattering occurred. If the quantum was not registered, it means that the system was at the first level. Thus, by checking whether the quantum scattering has occurred, or not, we monitor the state of the two-level system.

If condition (2) is satisfied, the energy ΔE is definitely insufficient to excite the particle A directly to the above-barrier state. However, the presence of the system B (whose state is periodically detected) leads to an increased probability of the particle tunneling through the barrier. In order to calculate this probability we need the total wave function of the entire system ψ_p (which includes both the particle A and the two-level system B).

We use the Dicke model [21] for two-level systems to represent the total wave function in the form

$$\psi_\mathrm{p} = \begin{pmatrix} \psi_1(x,t) \\ \psi_2(x,t) \end{pmatrix}, \tag{3}$$

where $|\psi_1(x,t)|^2\,\delta x$ yields a probability of finding the particle Ain an infinitesimal element δx around x at a time t and the system B in an excited state, and $|\psi_2(x,t)|^2\,\delta x$ is probability of finding the particle A in an interval δx around x at a time t and the system B in its lower energy state. The equation for ψ_p has the form

$$\left(\hat{H}_0 + \hat{H}_\mathrm{int}\right)\cdot\psi_\mathrm{p} = i\hbar\frac{\partial\psi_\mathrm{p}}{\partial t}, \tag{4}$$

where

$$\hat{H}_0 = \left(-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x)\right)\hat{I} + \Delta E\cdot\hat{r}_3,$$

$$\hat{H}_\mathrm{int} = 2\hat{g}(x)\cdot\hat{r}_1,$$

and the operators $\hat{r}_1$, $\hat{r}_2$, $\hat{r}_3$, and $\hat{I}$ are expressed in terms of the Pauli matrices and the identity matrix,

$$\hat{r}_1 = \frac{1}{2}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \hat{r}_2 = \frac{1}{2}\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \hat{r}_3 = \frac{1}{2}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \quad \hat{I} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}.$$

$\hat{g}$ describes the short-range interaction of particle A and the two-level system B localized in the barrier near $x = x_0$. A short -range potential is required so that the characteristic region of interaction between the particle A and the two-level system would be concentrated mainly within the potential barrier (in order to register particle A that is in the barrier). We do not select a particular form of the operator $\hat{g}(x)$.

Let us assume that the next check of the system B, it has been found that it is in the first state. Then, neglecting in the zero approximation the interaction of the system B and the particle A, for $t > 0$ (the time is counted from the instant of the inspection), we can write

$$\psi_\mathrm{p}^{(0)} = \begin{pmatrix} \phi_\mathrm{L}(x)\exp\left[-i\left(E_\mathrm{L} + \frac{\Delta E}{2}\right)\frac{t}{\hbar}\right] \\ 0 \end{pmatrix}. \tag{5}$$

Here, $\phi_n(x)$ is the eigen function of the particle A (in the well) which corresponds to the state with the energy E_n (measured from the well bottom) provided the particle does not interact with the system B. In expression (5), we have $n = L$.

In the first order of the perturbation theory, the correction to the zeroth-order approximation has the form

$$\delta\psi_{\mathrm{p}}^{(1)}(x,t) = \left(\sum_i^0 \left\{ \exp\left[-i\left(E_i - \tfrac{\Delta E}{2}\right)\tfrac{t}{\hbar}\right] - \exp\left[-i\left(E_{\mathrm{L}} + \tfrac{\Delta E}{2}\right)\tfrac{t}{\hbar}\right] \right\} \frac{g_{i,L}(x_0)\,\phi_i(x)}{E_i - E_{\mathrm{L}} - \Delta E} \right). \tag{6}$$

Here, the matrix element $g_{i,L}(x_0)$ is represented as

$$g_{i,L}(x_0) = \int_{-x_2}^{x_2} \phi_i^*(x)\,\hat{g}(x - x_0)\,\phi_{\mathrm{L}}(x)\,\mathrm{d}x. \tag{7}$$

Now, we shall consider only those states whose energy exceeds V_0. To describe such states, we introduce index m (instead of index i). Using expression (6), we can represent the probability that the particle A will be in a state with energy $E_m > V_0$ after the next test of the system B :

$$P_{m,L}(x_0) = |g_{m,L}|^2 / E_m^2. \tag{8}$$

Let us consider the domain of a few a near the point $x = 0$. In this region, energy E_m is clearly higher than the barrier height. This means that the particle A, having appeared in this region after the next testing of the B, is with a probability of $P_{m,L}$ in the above-barrier state. But in order to overcome the barrier and appear to its right, the particle still need to tunneling through the region of $x \sim x_1$. Thus, the probability, that a particle with the energy of E_m has overcome this region and is to the right of the barrier can be represented as:

$$Z_{m,L} \approx \frac{1}{2}\exp\left\{-2\sqrt{\frac{2mU_0x_\alpha}{\hbar^2}}\left[\int_{x_m}^{x_1}\sqrt{\left(\frac{1}{x_1 - x} - \frac{1}{x_1 - x_m}\right)}\mathrm{d}x\right]\right\}. \tag{9}$$

Here, x_m is defined by $U_0x_\alpha/(x_1 - x_m) = E_m - V_0$. Using (8) and calculating (9), we can represent the particle flow behind the barrier, due to the anti-Zeno effect, as

$$J_{\mathrm{p}} = \left\{\sum_m \frac{|g_{m,L}(x_0)|^2}{2(E_m)^2}\exp\left[-2\pi\sqrt{\frac{2m}{\hbar^2(E_m - V_0)}}\cdot U_0x_\alpha\right]\right\} n_z P_{\mathrm{B}} N_{\mathrm{A}}, \tag{10}$$

where P_{B} is a probability to find the system B in the first (i.e., excited) state, and N_{A} is a number of particles in the well to the left of the barrier.

Now, let us proceed to calculate the matrix element $g_{m,L}(x_0)$. We assume that the action of the operator $\hat{g}(x)$ on the function $\phi_{\mathrm{L}}(x)$ is reduced to multiplication of $\phi_{\mathrm{L}}(x)$ by a function $g(x)$. We consider the case, where $x_0 \sim a$, and the characteristic scale, on which $g(x)$ is changed, is of the order of a. Then, in a region that gives the main contribution to the matrix element (7), we can represent $g(x)$ in the form:

$$g(x) = g(-x_0) + \left(\left.\frac{\mathrm{d}g(x)}{\mathrm{d}x}\right|_{x=-x_0}\right)x. \tag{11}$$

Since the wave functions that correspond to different energy eigenvalues are orthogonal, the contribution to (7) of any terms, that are independent of x is zero, therefore you can save in (11) only one term containing x.

Using the solutions of the Schrödinger equation with the potential $V(x) = V_0(1 + th(x/(2a)))/2$ (solution to this problem is found, e.g., in [22]) we may represent a solution $\phi_{\mathrm{L}}(x)$, which can be used both in the region to the left of the barrier, and in the region $x \sim 0$, as

$$\phi_{\mathrm{L}}(y) = (2x_2)^{-1/2} y^{v} (1-y)^{\mu} \Big[F(\mu+\nu, \mu+\nu+1, 2\mu+1, 1-y) + (1-y)^{-2\mu} F(-\mu+\nu, -\mu+\nu+1, -2\mu+1, 1-y)\Big]. \tag{12}$$

Here, $F(a,b,c,y)$ is the hypergeometric function,

$$y = (1+\exp(x/a))^{-1}, \quad \mu^2 = -2ma^2 E_{\mathrm{L}}/\hbar^2, \quad \nu^2 = 2ma^2 (V_0 - E_{\mathrm{L}})/\hbar^2 \approx 2mV_0 a^2/\hbar^2,$$

$$C_1 = \frac{\Gamma(\nu-\mu)\Gamma(\nu-\mu+1)}{\Gamma(2\nu+1)\Gamma(-2\mu)},$$

and $\Gamma(x)$ is the gamma function. Now, the expression for $\phi_m(x)$ can be written in the as

$$\phi_m(x) \approx \sqrt{\frac{2}{x_2}} \sin\left[i\sqrt{\frac{2mE_m}{\hbar^2}}(x-x_2)\right] \equiv \phi_m(y) = \sqrt{\frac{2}{x_2}} \frac{1}{2i} \left[\frac{(1-y)^{i\nu(m)}}{y^{i\nu(m)}\beta_m} - \frac{(1-y)^{-i\nu(m)}\beta_m}{y^{-i\nu(m)}}\right], \tag{13}$$

where $\nu(m) = \sqrt{2mE_m} \cdot a/\hbar$, and $\beta_m = \exp(i\nu(m) x_2/a)$.

Formally, the expression (13) is valid under the condition $E_m \gg V_0$, but in fact it can be used even for $E_m > (3 \div 4) V_0$. Using (11)–(13), we can rewrite the expression for $g_{m,L}(x_0)$ as

$$g_{m,L}(x_0) = \left(\left.\frac{\mathrm{d}g(x)}{\mathrm{d}x}\right|_{x=-x_0}\right) \lim_{\gamma\to 0} \left\{\frac{\partial}{\partial y}\left[\int_0^1 a^2 \frac{(1-y)^{\gamma}}{y^{\gamma}} \phi_m^*(y)\phi_{\mathrm{L}}(y) \frac{\mathrm{d}y}{y(1-y)}\right]\right\}. \tag{14}$$

Expression (14) can be calculated analytically, using the formula from [23]:

$$\int_0^1 x^{\rho-1}(1-x)^{\sigma-1} F(\alpha,\beta,\gamma,x)\,\mathrm{d}x = \frac{\Gamma(\rho)\Gamma(\sigma)}{\Gamma(\rho+\sigma)} \cdot {}_3F_2(\alpha,\beta,\rho,\gamma,\rho+\sigma,1), \tag{15}$$

where ${}_3F_2(\alpha,\beta,\gamma,\delta,\varepsilon,x)$ is the generalized hypergeometric series.

However, the exact analytical expressions for $g_{m,L}(x_0)$ are exceedingly long, so it is very inconvenient to use them. It makes sense to obtain an approximate formula for $g_{m,L}(x_0)$, which has adequate accuracy and is relatively compact and convenient. First of all, we note that a considerable contribution to (14) comes from the region $y \sim 1$, and within this region, we can significantly simplify (12). Next, we take into account the inequality $\nu(m) \gg \nu \gg |\mu|$, as well as the fact that we are interested only in the modulus of $g_{m,L}(x_0)$, i.e. the phase of the matrix element is not important. Taking all of this into account, we can write:

$$|g_{m,L}(x_0)| \approx \left|\frac{Z_0}{x_2}\left[\frac{\pi\sqrt{2\pi\nu}}{\nu(m)}\left(\frac{\nu(m)\cdot e}{\nu}\right)^{\nu} \exp(-\pi\nu(m))\right]\right|, \tag{16}$$

where

$$Z_0 = a^2\left(\left.\frac{\mathrm{d}g(x)}{\mathrm{d}x}\right|_{x=-x_0}\right), \tag{17}$$

and e is Euler's number.

Substituting (17) into (10) and carrying out the summation over E_m, we obtain finally the expression for the particle flow J_p behind the barrier:

$$J_\mathrm{p} \approx \frac{\pi^2}{\sqrt{2}}\left(\frac{Z_0 a}{U_0 x_\alpha}\right)^2\left(\frac{\hbar^2}{2mU_0x_\alpha a^5}\right)^{1/4}\sqrt{e}\left(\frac{U_0x_\alpha}{V_0 a}e\right)^{2\nu-1/2}\exp\left(-4\pi\sqrt{\frac{2mU_0x_\alpha a}{\hbar^2}}\right)n_z P_\mathrm{B} n_\mathrm{A}, \tag{18}$$

where n_A is the particle density in front of the barrier.

As the expression (18) shows, the dependence of J_p on the barrier parameter is determined mainly by the exponent. At the same time, the particle flow J_p depends much weaker on the parameters before the exponent. Therefore, to analyze the dependence of J_p on the barrier parameters, we can confine ourselves to the consideration of the exponential term, and treat all the prefactors as constant. In particular, this analysis shows that J_p is increased when the barrier becomes steeper with decreasing a.

For comparison, we write the expression for the "ordinary" tunneling current J_T through the same barrier:

$$\begin{aligned}J_\mathrm{T} &= \frac{n_\mathrm{A}}{2}\sqrt{\frac{2E_\mathrm{L}}{m}}\exp\left\{-2\sqrt{\frac{2m}{\hbar^2}}\left[2\int_0^{\sqrt{x_1}}\sqrt{(U_0x_\alpha+V_0z^2)}\,\mathrm{d}z\right]\right\}\\ &= \frac{n_\mathrm{A}}{2}\sqrt{\frac{2E_\mathrm{L}}{m}}\exp\left\{-2\sqrt{\frac{2m}{\hbar^2}}\left[\sqrt{x_1\left(U_0x_\alpha+V_0x_1\right)}+\frac{U_0x_\alpha}{\sqrt{V_0}}\ln\left(\frac{\sqrt{V_0x_1}+\sqrt{U_0x_\alpha+V_0x_1}}{\sqrt{V_0x_1}}\right)\right]\right\}\\ &\approx \frac{n_\mathrm{A}}{2}\sqrt{\frac{2E_\mathrm{L}}{m}}\exp\left\{-2\left[\sqrt{\frac{2mV_0}{\hbar^2}}x_1\left(1+\left(\frac{1}{2}+\ln(2)\right)\frac{U_0x_\alpha}{V_0x_1}\right)\right]\right\}.\end{aligned} \tag{19}$$

Here, as well as in the situation with the particle flow J_p in formula (18), the dependence of the particle flow J_T on the barrier parameters is determined mainly by the exponential function, entering into formula (19).

Comparing the expressions for J_p and J_T, we see that formula (18), in contrast to (19), does not contain x_1. Consequently, for sufficiently large values of x_1, which can be estimated as

$$x_1 \gg 2\pi\sqrt{\frac{U_0x_\alpha a}{V_0}}, \tag{20}$$

an inequality $J_\mathrm{p} \gg J_\mathrm{T}$ is satisfied. This means that the current through the barrier due to the anti-Zeno effect will probably be dominant in these cases.

Let us give comparative estimates of flows J_P and J_T for the conditions of the cold fusion experiment. Various authors (including the authors of Refs. [17–20]) interpret their observations as cold fusion in which multicharged atomic nuclei participate, and a new heavier multicharged atomic nucleus is formed. Here we estimate the penetration probability of a nucleus (proton) through a potential barrier of a many-electron atomic shell to form a new atomic nucleus.

Let us write the particle flow due to the anti-Zeno effect as $J_\mathrm{p} = A_\mathrm{P}\exp(\beta_\mathrm{p})$, and the ordinary tunneling current as $J_\mathrm{T} = A_\mathrm{T}\exp(\beta_\mathrm{T})$, where

$$\beta_\mathrm{p} = -4\pi\sqrt{\frac{2mU_0x_\alpha a}{\hbar^2}}, \qquad \beta_\mathrm{T} = -2\left[\sqrt{\frac{2mV_0}{\hbar^2}}\cdot x_1\cdot\left(1+1.2\cdot\frac{U_0x_\alpha}{V_0\cdot x_1}\right)\right].$$

Here, *m* is the proton mass, U_0 is a height of the potential barrier (fusion barrier), V_0 is the potential of electron shells. The value x_α is the characteristic distance at which nuclear forces act, x_1 is the atomic radius.

In experiments [20], nucleosynthesis was observed at the interaction of slow protons with lithium. We carried out numerical estimates of β_{p} and β_{T} for the case of proton penetration to the lithium nucleus. We take $m = 1.67 \times 10^{-24}$ g, $U_0 = 2.1 \times 10^6$ eV, $V_0 = 1.22 \times 10^2$ eV, $x_\alpha = 1.77 \times 10^{-13}$ cm, and $x_1 = 10^{-8}$ cm for estimates and β_{p} and β_{T}.

In the expression for β_{p}, which determines the particle flow due to the barrier anti-Zeno effect, the specified values of $U_0, V_0, x_\alpha, x_1 x_\alpha$, only a is a model parameter. The above condition $V_0 x_1 \gg U_0 x_\alpha \gg V_0 a$ (for the potential (1)) is obviously satisfied for $a \leq 10^{-11}$cm.

Figure 2 shows the value of $\beta_{\mathrm{P}}/\beta_{\mathrm{T}}$ depending on the parameter a in the range of parameter values from 10^{-12} to 10^{-11} cm. We have the ratio $\beta_{\mathrm{P}}/\beta_{\mathrm{T}} = 0.05$ at $a = 10^{-11}$ cm, and $\beta_{\mathrm{P}}/\beta_{\mathrm{T}} = 0.016$ at $a = 10^{-12}$ cm. We have obtained the values of $\beta_{\mathrm{T}} = -860$ and $\beta_{\mathrm{P}} = -14$ at $a = 10^{-12}$ cm.

According to our estimates, both J_{p} and J_{T} are small, but even in this case, the inequality $J_{\mathrm{p}} \gg J_{\mathrm{T}}$ is satisfied. Thus, the current through the barrier due to the anti-Zeno effect can significantly exceed the tunnel current, and will be dominant in the situation under consideration.

However, there are many factors that may prevent an accurate quantitative estimate of the current, which is caused by the barrier anti-Zeno effect. In particular, the current significantly depends not only on the barrier form, but also on the parameters characterizing this form. The parameter which describes the barrier shape on the left is included in an exponent in the expression for the particle flow. This parameter can change the value of the particle flow by orders of magnitude.

In general, even small variations in barrier parameter can significantly affect the current caused by the barrier anti-

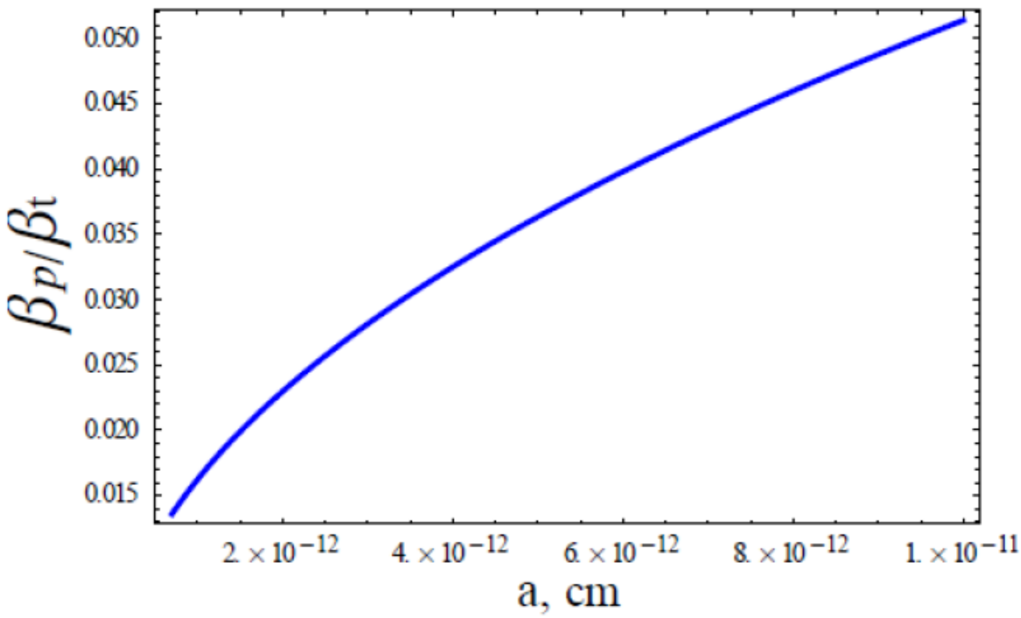

Figure 2. Dependence of $\beta_{\mathrm{P}}/\beta_{\mathrm{T}}$ on parameter a. The particle flow $J_{\mathrm{p}} = A_{\mathrm{P}} \exp(\beta_{\mathrm{p}})$ due to the anti-Zeno effect, and the ordinary tunneling flow $J_{\mathrm{T}} = A_{\mathrm{T}} \exp(\beta_{\mathrm{T}})$ are determined mainly by the values of β_{P} and β_{T}, respectively. (Pre-exponential factors A_{P} and A_T do not differ by many orders of magnitude.)

Zeno effect. Hence, it may be expected that the current could increase dramatically under special conditions. If we assume that in a cold fusion experiment, the nuclear flow through the potential barrier is indeed due to the anti-Zeno effect, could we increase the maximum current by targeted changes in the experimental set-up? We certainly cannot make any noticeable change in the shape of the potential barrier as it is determined by inner electron shells of atoms. But we cannot exclude that the system can be affected, e.g., by various additives to the test substance. The observation of the particles interacting with the barrier is influenced by these additives. For example, in the problem discussed in this paper, to influence the system, which carries out the process of observation, means to change the function $g(x)$, e.g., to change its characteristic scale, etc.

We cannot be sure that the barrier anti-Zeno effect can explain the experimental results on cold nuclear fusion. However, we believe that it is impossible to exclude such a possibility *a priori*, and we can give a number of arguments in support of it. (a) Using the anti-Zeno effect, it is possible to qualitatively explain the need to pre-heat the test substance to temperatures that are very small compared with the usual temperatures of nuclear fusion reactions. However, these temperatures are comparable with the energy difference between the ground and excited states of a measuring two-level system (this can be the electron atom subsystem). And preheating is necessary so that the probability of the initial finding of a two-level system in an excited state is not too small. (b) The observing system is in a metastable state. (If the observing system were completely stable, it would be impossible to carry out any measurements, and the anti-Zeno effect would be impossible [24].) The metastable system is unstable to relatively large perturbations. Since the duration of the experiments is long, relatively large perturbations can destroy the metastable state. As a result, a partial or complete failure of the regime can occur. Thus, the instability of processes in cold fusion experiments can be explained by the barrier anti-Zeno effect.

3. Conclusion

In this paper, we have calculated the particle current through the potential barrier of a special form which is similar to that of the barrier preventing fusion of nuclei in a solid. It is shown that under certain conditions, part of the current, which is caused by the barrier anti-Zeno effect, can significantly exceed (in some cases even by many orders of magnitude) the tunneling current. Accordingly, it can be assumed that in the case of cold fusion a barrier anti-Zeno effect could make a considerable contribution to the nuclear current through the barrier.

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