Quantum Nonlocality - Possible Cosmophysical Effects

S N Mayburov

Lebedev Inst. of Physics, Leninsky Prospect 53, Moscow, Russia, RU-117924

E-mail: mayburov@sci.lebedev.ru

Abstract. Mutiple experimental results indicate the existence of cosmophysical effects which influence parameters of nuclear decays and chemical reactions in lab. conditions. In particular, variations of nucleus decay parameters are detected which amplitudes are of the order 10^{-3} and periods of one year, 24 hours or about one month. Similar influence of solar activity on nuclear decays and chemical reactions also was reported. We argue that such deviations from radioactive decay law and other similar effects can be described by novel quantum nonlocality mechanism, different from standard EPR-Bohm nonlocality. Modified Doebner-Goldin model applied for the description of dynamical nonlocal effects concerned with nuclear decays.

1. Introduction

In the last decades, ample bulk of experimental results provided evidence for the existence of long-distance cosmophysical correlations, which presumably can't be explained by standard quantum physics. First observations of this kind were done in the forties by G. Piccardi, who has shown that parameters of some chemical reactions, in particular, their rates correlate in time with solar activity, in particular, with intense solar flares, observed parameter variations are of the order 10^{-1} [1]. Later, similar correlations of chemical reaction parameters with solar activity and other cosmophysical effects were reported by other groups [2, 3]. In the same vein, some recent experiments have found the periodic modulations of nuclear $\alpha-$ and $\beta-$decay parameters of the order of 10^{-3} and with typical periods of one year, one day or about one month [4-6]. Influence of solar activity on some nuclear decay parameters also was observed [5, 7]. These and other related results reviewed below in more detail.

Until now theoretical discussion of these effects had quite restricted character. In particular, oscillations of β-decay rate was hypothized as anomalous interaction of solar neutrino flux with nuclei or seasonal variations of fundamental constants [5]. Yet, neither of these hypothesis can't explain α-decay parameter oscillations of the same order, because nucleus α-decay should be insensitive to neutrino flux or other electro-weak processes. Really, $\alpha-$ and β-decays stipulated by nucleon strong and weak interactions correspondingly. Therefore, observation of parameter oscillations for both decay modes supposes that some universal mechanism independent of particular type of nuclear interactions induces the decay parameter oscillations. Besides, chemical reactions performed via electromagnetic interactions, so it gives, in fact, additional arguments in favor of such hypothetical mechanism universality.

Nowadays, the acknowledged universal theory is quantum mechanics (QM), so it's worth to start from the analysis of its foundations. In this framework, it's notable that QM axiomatics

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implicates the existence of notorious quantum-mechanical nonlocality. This phenomenon was first formulated as famous EPR-Bohm paradox and later developed as Bell theorem [8, 9]. Now such nonlocal effects confirmed experimentally and applied in quantum communication and computing. In fact, this mechanism permits to realize specific form of nonlocal correlations (NC) or 'action at the distance' between distant parts of quantum system S. Such NC effects obey to strict constraints, in particular, it should not violate causality. NC realization in EPR-Bohm variant demands that initially these S subsystems $S_1, \ldots, S_n$ should interact with each other, after such interaction seized and the subsytems departed, such NC conserve correlations of S_i uncertain parameters even at large distance between subsystems. Obviously, such conditions is impossible to fulfill in cosmophysical situations. Meanwhile, it was argued for long that quantum NC can be more general concept than standard QM formalism admits and, in principle, some other NC effects, beyond EPR-Bohm mechanism, can exist [10-12]. In this paper, we develop phenomenological NC model and discuss its possible application to cosmophysical correlation description.

Let's consider first the conditions to which such nonstandard NC mechanism should obey in general. Plainly, beside causality demands, such NC should agree with all standard invariance principles i.e. time, space shift and rotation symmetries. In addition, we'll suppose that NC by itself can't transfer the energy, momentum or orbital momentum between distant objects, such transfer can be performed by conventional fields only. Hence the system average energy, momentum and orbital momentum should not change during such communications. Suppose now that the states of two distant objects S_1, S_2 due to their conjugate NC influence, become to differ from S_1, S_2 states expected after their independent evolution during fixed time interval $\{t_0, t_f\}$. Then, from described assumptions it follows that according to QM rules the initial S_1, S_2 states can't be stationary and non-degenerate, because such states possess the minimal possible energy and only some energy transfer can make them to evolve to another excited state. Hence the only possibility is that S_1, S_2 are degenerate systems, i.e. they have several states with the same energy and during time interval $\{t_0, t_f\}$ evolve from one state to another one. The simple example of such system is the particle with energy level E confined in symmetric double well potential divided by potential wall U_0 with $E < U_0$. Such S_1 has two degenerate orthogonal states g_1, g_2 in these wells with the same energy E, let's suppose that at t_0 it's in state g_1 confined in one well. Thereon, due to under-barrier tunneling it would spread gradually into other well [9], so that it will evolve with the time to some g_1, g_2 superposition. In this case, hypothetic S_2 NC influence on S_1, in principle, can change this state parameters, in particular, resulting g_1, g_2 probabilities at t_f. Such state degeneration is typical for many chemical and nuclear reactions, below we'll consider them in more detail. In this paper, model of such NC processes involving quantum tunneling will be considered. We'll assume that such NC effects can be described analogously to QM evolution equations and construct corresponding Hamiltonians.

2. Experimental motivations

Natural radioactivity law is one of most fundamental laws of modern physics, in accordance with it, nuclear decay parameters are time-invariant and practically independent of environment [13]. First results, indicating the deviations from exponential β-decay rate dependence, were obtained during the precise measurement of ^{32}Si isotope life-time by means of decay exponent fit [4]. Sinusoidal annual oscillations with the amplitude $6 * 10^{-4}$ relative to total decay rate and maxima located at the end of February were found during 5 years of measurements. Since then, the annual oscillations of β-decay rate for different heavy nuclei from Ba to Ra were reported, for most of them the oscillation amplitude is of the order $5 * 10^{-4}$ with its maximum on the average at mid-February [5]. Some other β-decay experiments exclude any decay constant modulations as large as reported ones [14]. Life-time of short-living α-decayed isotope ^{214}Po was measured directly, the annual and daily oscillations with amplitude of the order $9 * 10^{-4}$, with annual maxima at mid-March and daily maxima around 6 a.m. were found during 4 years of measurements [6]. The similar dependence on astronomical cycles was found for some biochemical reaction rates [3]. It was shown also that decay rates of ^{53}Mn, ^{55}Fe e-capture and ^{60}Co β-decay correlate with solar activity, in particular, with intense solar flare moments, observed decay variations are of the order 10^{-3} [5, 7]. As was noticed already, the rates of some chemical reactions demonstrate the similar dependence on solar activity [1, 3].

Individual nuclear decay acts normally are independent of each other [13]; such stochastic processes are called Poissonian and described by Poisson probability distribution [15]. For this distribution, at any time interval dT the dispersion of decay count number $\sigma = N^{\frac{1}{2}}$, where N is average count number per dT. However, some recent results show that under particular external influence this relation can be violated, several experiments of this kind reviewed in [16]. In one of them, α-particles from ^{239}Pu decay detected by Geiger counter located at the distance 2 cm from isotope. Glass volume with diameter 8 cm located at the distance of 10 cm from α-particle beam. In this volume, reaction of $C_{12}H_{22}O_{11}$ disaccharide (sucrose) hydrosolvation performed by dissolving 100 g of sucrose in 400 g of water. Effective reaction time at room temperature is about 15 minutes, during this period the observed dispersion of detector counting rate was reduced by a factor 3, whereas average counting rate practically doesn't change. It assumes that the decay process becomes more regular or sub-Poissonian. In quantum physics, the collective quantum states with sub-Poisson event distribution called squeezed states, they were obtained for optical photon ensembles [17]. Of course, it looks quite surprising that chemical reactions can somehow influence nucleus decay parameters, however, they both involve quantum systems and QM universality, in principle, can provide such possibility via quantum nonlocality.

Experiments of other kind exploited some biochemical and organic-chemical reactions, the example is reaction of ascorbic acid with dichlorphenolindophenol [2, 18]. Authors noticed first that dispersion of these reaction rates can change dramatically from day to day, sometimes by one order of value [19]. Further studies have shown connection of this effect with some cosmophysical factors, like solar activity, solar wind and orbital magnetic field. In particular, reaction rate dispersion becomes maximal during solar activity minima of 11 year solar cycle [2]. Shielding of exploited chemical reactors from external electromagnetic field in steel and permalloy boxes practically don't change these effects, hence such cosmophysical influence can't be transferred by electromagnetic fields. It's notable that such chemical reaction rate distributions aren't Poissonian but rather correspond to flicker-noise regime, for which the dispersion is, in general, essentially larger. If to suppose that all described effects have the same mechanism, then quantum NC seems most reliable candidate for their explanation.

3. Theoretical NC model

Let's discuss possible NC properties for collective systems like the set of noninteracting nuclei or molecules. Experimental results discussed in previous section suppose that NC influence makes their evolution less chaotic and more regular. It's notable that self-ordering is quite general feature of quantum dynamics, examples are crystal lattices or atomic spins in ferromagnetic. Then, it's reasonable to suppose that any large system would gain via NC mechanism its own self-ordering, in particular, making its own evolution more regular and ordered. Besides the self-ordering corresponding to more regular time intervals between events, other forms of system evolution symmetry, in principle, can be induced by NC effects. In particular, enlargement of average time intervals between decay events can be also treated as the self-ordering corresponding to the growth of evolution symmetry, because the event distribution becomes more homogeneous in time. Experimental results reviewed above demonstrate both enlargement and reduction of nucleus life-time induced by cosmophysical factors [1, 6]. Hence under their influence such evolution symmetry can transform in both directions, below only life-time enlargement will be studied.

It's natural to suppose that NC effect for any system of restricted size is proportional to the number of system constituents N_c involved into reactions. For the case of two nearby systems S_1 evolution due to NC effects supposedly results in its own self-ordering and influences S_2 in the similar way and vice versa. It's reasonable to suppose also that the scale of NC effects for decays or chemical reactions will be proportional to the average system process rate. For the case of two nearby systems of which one of them S_1 is large and other one S_2 is small, for them NC effects supposedly realized in master regime, i.e. S_1 can significantly influence S_2 state and make it evolution more ordered, whereas S_2 practically doesn't influence S_1 state evolution. This is characteristic for α-decay experiment described above: for considered set-up the chemical reaction involves about 10^{23} molecules, whereas α-decay isotope contains about 10^{18} unstable nuclei. It can be assumed also that in this case, S_2 self-ordering NC effect is insignificant in comparison with S_1 NC influence. Then, resulting NC effect in S_2 should depend on S_1 evolution properties and S_1, S_2 distance R_{12}.

Here we'll consider simple NC model for the set of N identical, unstable α-decay nucleus $\{A_i\}$. In fact, the similar considerations are applicable to the evolution of arbitrary metastable system, like atom or molecule, yet for nucleus α-decay its description is most simple. Gamow theory of nucleus α-decay supposes that in initial nucleus state, free α-particle already exists inside the nucleus, but its total energy E is smaller than maximal height of potential barrier constituted by nuclear forces and Coulomb potential [20]. Hence α-particle can leave nucleus volume only via quantum tunneling through this barrier. Therefore, alike for double well example, the state energy is the same inside and outside nucleus, and corresponding inside-outside states $\psi_{0,1}$ are degenerate and orthogonal to each other. Hence such degeneration permits, in principle, for some hypothetic NC mechanism to change nucleus decay rate without any energy transfer to α-particle, but just changing the barrier transmission rate. α-particle Hamilton A_i operator

$$H_i = \frac{\vec{P}_i^2}{2m} + U_N(r_i), \tag{1}$$

where m is α-particle mass, $\vec{P}_i$ is its momentum operator, U_N is nucleus barrier potential, r_i is the distance from nucleus center [21]. If at t_0 α-particle was in initial state ψ_0, then the solution for its state $\psi(t)$ in WKB approximation gives for decay probability at given decay moment t for nucleus A_i

$$p_i(t) = \lambda \exp[-\lambda(t - t_0)]. \tag{2}$$

Here p_i is, in fact, the time derivative of total decay probability from t_0 to t; resulting nucleus life-time is proportional to λ^{-1} . Hence at $t \to \infty$ nucleus state evolves to final state ψ_1 [20]. Typical experimental accuracy of decay time measurement Δt is several nanoseconds [13]. Formally, such measurement described as the sequence of two consequent nucleus state measurements divided at least by Δt interval. If first one shows that nucleus is in ψ_0 state, and next one that it's in the state ψ_1, it means that nucleus decay occurred during this time interval [22]. In QM formalism, a general state of quantum system S described by density matrix ρ, for pure states $\rho = |\psi><\psi|$. If A_1, A_2 nuclei are its components, the partial $A_{1,2}$ density matrixes $\rho_{1,2}$ can be defined. For each A_i it turns out that if some other S components are also measured, then its decay probability would differ from eq. (2) and becomes

$$\gamma_i(t) = \frac{\partial}{\partial t} Tr \rho_i(t) P_1^i, \tag{3}$$

where P_1^i is projector on A_i final state [22].

Formal solution of QM evolution equation for system state prepared at t_0

$$\psi(T) = W(T)\psi(t_0),$$

where integral operator of evolution

$$W(T) = \exp[-\frac{i}{\hbar}\int_{t_0}^{T} H(\tau)d\tau]. \tag{4}$$

Consider now the case $N = 2$, for the system of two independent nuclei A_1, A_2 its initial state $\psi_A = \psi_0^1\psi_0^2$ where formally $\psi_0^{1,2} = \psi_0$. If their evolution is independent, then operator $W(T)$ will be just the product of two right side terms of eq. (4), but it can be also formally written as

$$W(T) = C_t \exp\{-\frac{i}{\hbar(T-t_0)}\int_{t_0}^{T}\int_{t_0}^{T}[H_1(t_1) + H_2(t_2)]dt_1dt_2\}, \tag{5}$$

where $H_{1,2}$ are $A_{1,2}$ Gamow Hamiltonians with corresponding notations $r_{1,2}$, C_t is time-ordering (chronological) operator [23]. In a sense, here the second integration for each term is dummy giving just multiplier $T - t_0$, yet such ansatz is used here because below NC effects will be treated via time-dependent Hamiltonians for which multiple time parameters is routine approach [23]. Note that here $H_{1,2}$, in fact, don't depend on time, their time parameter just indicates on which of time parameters t_1 or t_2 $H_{1,2}$ integration was truly performed.

4. Nonlinear QM formalism

As was supposed, NC effects should not change the system average energy, however, if the corresponding evolution terms are linear operators, then for α-decay this condition can be violated [24]. It will be shown here that some nonlinear operators satisfy much better to this condition. Interest to nonlinear QM can be dated back to the early days of quantum physics, but at that time it was applied in effective theories describing collective effects. Now it's acknowledged that nonlinear corrections to standard QM Hamiltonian can exist also at fundamental level [25]. In nonlinear QM, particle evolution described by nonlinear Schroedinger equation of the form

$$i\hbar\partial_t\psi = -\frac{\hbar^2}{2m}\bigtriangledown^2\psi + U(\vec{r},t)\psi + F(\psi,\bar{\psi})\psi, \tag{6}$$

where m is particle mass, U is system potential, F is arbitrary functional of system state. Currently, the most popular and elaborated nonlinear QM model is by Doebner and Goldin (DG) [26, 27]. In its formalism, simple variant of nonlinear term is $F = \frac{\hbar^2\Gamma}{m}\Phi$ where

$$\Phi = \bigtriangledown^2 + \frac{|\bigtriangledown\psi|^2}{|\psi|^2} \tag{7}$$

is nonlinear operator, Γ is real or imaginary parameter which, in principle, can depend on time or other external factors, here only real Γ will be exploited. With the notation

$$H^L = -\frac{\hbar^2}{2m}\bigtriangledown^2 + U(\vec{r},t) \tag{8}$$

we abbreviate (6) to $i\hbar\partial_t\psi = H^L\psi + F\psi$ where in our case, H^L is Gamow Hamiltonian.

Main properties of eq. (6) were studied in [26, 28], for constant Γ they can be summarized as follows: (a) The probability is conserved. (b) The equation is homogeneous. (c) The equation is Euclidian- and time-translation invariant for $U = 0$. (d) Noninteracting particle subsystem remain uncorrelated (separation property). (e) For $U = 0$, plane waves $\psi = \exp[i(\vec{k_0}\vec{r} - \omega t)]$ with $\omega = E\hbar$, $|\vec{k}_0|^2 = 2mE/\hbar$ are solutions both for real and imaginary Γ. Writing $< Q >= \int\bar{\psi}\hat{Q}\psi d^3x$

for operator expectation value, in particular, since $\int \bar{\psi} F \psi d^3x = 0$, the energy functional for solution of (6) is $< i\hbar\partial_t > = < H^L >$. Hence the average system energy would change insignificantly if not at all if F added to initial Hamiltonian, therefore, it advocates DG ansatz application in NC models.

It's notable that nonlinear term F in particle Hamiltonian can modify the particle tunneling through the potential barrier effect. In particular, exact solution of this problem was obtained for rectangular potential barrier, it was shown that the barrier transmission rate depends exponentially on Γ [28]. To calculate corrections to Gamow model, WKB approximation for nonlinear Hamiltonian of (6) can be used [28]. In this ansatz, 3-dimensional α-particle wave function reduced to $\psi = \frac{1}{r}\exp(i\sigma/\hbar)$; function $\sigma(r)$ can be decomposed in $\hbar$ order $\sigma = \sigma_0 + \sigma_1 + ...$ [9, 23]. Given α-particle with energy E, one can find the distances R_0, R_1 from nucleus centre at which $U(R_{0,1}) = E$. Then, for our nonlinear Hamiltonian the equation for σ_0 is

$$(\Lambda - \frac{1}{2m})(\frac{\partial \sigma_0}{\partial r})^2 = E - U(r), \tag{9}$$

where $\Lambda = \frac{2\Gamma}{m}$ for $R_0 \leq r \leq R_1$, $\Lambda = 0$ for $r < R_0$, $r > R_1$. Its solution for $R_0 \leq r \leq R_1$ can be written as

$$\psi = \frac{1}{r}\exp(i\sigma_0/\hbar) = \frac{C_r}{r}\exp[-\frac{1}{\hbar}\int\limits_{R_0}^{r} q(\epsilon)d\epsilon],$$

where C_r is normalization constant,

$$q(r) = \frac{1}{\hbar}\{\frac{2m[U(r) - E]}{1 - 4\Gamma}\}^{\frac{1}{2}}.$$

Account of higher order σ terms doesn't change transmission coefficient which is equal to

$$D = \exp[-\frac{2}{\hbar}\int\limits_{R_0}^{R_1} q(\epsilon)d\epsilon] = \exp[-\frac{\phi}{(1 - 4\Gamma)^{\frac{1}{2}}}] \simeq \exp[-\phi(1 + 2\Gamma)]. \tag{10}$$

Here ϕ is constant, whereas Γ, in principle, can change in time, assuming that its time scale is much larger than the barrier transition time. To calculate nucleus life-time, D multiplied by the number of α-particle kicks into nucleus potential wall per second n_d, so it gives $\lambda = n_d D$ [20], for DG model n_d doesn't depend on F term presence [28].

As was noticed, the growth of average time intervals between events can be considered as the growth of system evolution symmetry. For example, the event distribution of eq. (2) on time half-axe $\{t_0, \infty\}$ becomes maximally homogeneous for $\lambda \to 0$, hence the evolution symmetry rises in this limit. Consider two nucleus systems S_1, S_2 with the average distance between S_1, S_2 elements equal to R_{12}. S_1 is the set of N_0 unstable nuclei $\{A_l\}$ prepared at t_0 with decay probability described by eq. (2). S_2 includes just one unstable nuclide B prepared also at t_0, its evolution normally described by Gamow Hamiltonian H^L ansatz of (8). Its decay constant λ_b, in principle, can differ from λ of eq. (2) if for B $U \neq U_N$ of eq. (4). In such set-up, the system S_1 of N_0 nuclei presumably would induce NC effect in B evolution and also change its own evolution as well. Suppose that all geometric factors of such NC influence on B for given S_1 described by real coefficient $\chi(R_{12})$ which absolute value grows with N_0 and diminishes with R_{12}. Resulting corrections to H^L are supposed to be small and so can be accounted only up to first order of χ . Basing on assumptions discussed above, in particular, that resulting NC effect proportional to S_1 total decay rate, it follows that if no measurements of S_1 states performed, then corrected B Hamiltonian becomes

$$H^d(t) = H^L + \frac{\hbar^2}{m}\chi(R_{12})p_i(t)\Phi, \tag{11}$$

where p_i is of eq. (2), Φ is nonlinear operator of (7) for B α-particle. It means that in this case, $\Gamma = \frac{\hbar^2}{m}\chi p_i(t)$, substituting it in eq. (10), in WKB approximation, it gives B decay probability

$$p'(t) = C_b \exp\{-[(t - t_0)\xi(t)]\}. \tag{12}$$

Here C_b is normalization constant

$$\xi(t) = \exp\{[1 + 2\frac{\hbar^2}{m}\chi(R_{12})p_i(t)] \ln \lambda_b\}. \tag{13}$$

Hence for such ansatz, B Hamiltonian and consequently B life-time depends on S_1 nuclei decay probability at given time moment. Namely, under NC influence resulting B nucleus life-time for $\chi > 0$ becomes larger than initial one. Note that kinematic parameter n_d practically doesn't change in this case. Assuming now that $N > 1$ i.e. S_2 includes not one but many identical B nuclei, on which proposed S_1 NC effect influences independently, then average time intervals between S_2 decays would enlarge. Such S_2 evolution modification can be interpreted as the growth of S_2 evolution symmetry such that resulting decay probability $p'(t)$ becomes more homogeneous in time in comparison with initial B decay probabilty $p_b(t)$.

Now this NC effect can be considered on more fundamental level beyond master regime. Let's suppose that for system S $N_0 = N = 1$ and nuclei A_1, B states described by wave functions ψ_1, ψ_b correspondently. Then for the same initial conditions as above, the system initial wave function $\psi_s = \psi_1\psi_b$, S Hamiltonian in first χ order

$$H_s(t) = H^L + \frac{\hbar^2}{m}\chi(R_{12})p_1(t)\Phi + H_1 + \frac{\hbar^2}{m}\chi(R_{12})p_b(t)\Phi_1, \tag{14}$$

where Φ_1 is is nonlinear operator of (7) for A_1. Solution of evolution equation for such Hamiltonian would give probabilities for A_1, B decays. Resulting A_1, B states are correlated but aren't entangled, so that system state $\psi_s = \psi_1\psi_b$ at any time. Plainly, resulting NC effects will be quite small. Exploited approach to Hamiltonian formulation is, in fact, analogue of well-known Hartry-Fock approximation for electromagnetic interactions in atoms [23].

Now let's consider NC model, which results in sub-Poissonian self-ordering symmetry growth. Let's take two systems S_1, S_2 of N_0, N nuclei, correspondently, with $N \ll N_0$ and the average distance between S_1, S_2 elements equal to R_{12}. As was supposed, due to conjugal NC influence between S_1 elements, its evolution becomes more regular and self-ordered and it induces similar NC influence on S_2 evolution. Due to it, S_2 evolution can differ from the case of independent nuclei and would result in the temporary correlation between S_2 decays. Modified S_2 evolution operator can be chosen from the analogy with squeezed photon production in atomic resonance fluorescence [17]. In that case, the photon production rate is suppressed if the time interval between two consequently produced photons is less than some fixed ΔT. Due to it, the resulting photon registration becomes more regular, and their distribution is sub-Poissonian. Let's start from the simplest case $N = 2$ and A_1, A_2 nuclei prepared at t_0. Let's suppose that S_1 NC influence rate on S_2 elements characterized by some scalar function $k(R_{12})$, which absolute value supposedly diminishes as R_{12} grows and enlarges as N_0 grows. For the simplicity, we assume that NC correlation of A_1, A_2 decay moments is such that their evolution ansatz can be factorized into A_1, A_2 terms. For example, if no measurement of A_1 state is done, then resulting phenomenological A_2 Hamiltonian supposedly becomes

$$H_2^c(T) = H_2 + \frac{\hbar^2}{m}\int_{t_0}^{T} k(R_{12})\varphi(T - t)p_1(t)dt\Phi_2 \tag{15}$$

with $p_1(t)$ is of eq. (2), $\Phi_{1,2}$ are $A_{1,2}$ nonlinear operators of (7) with corresponding notations. φ is causal Green function

$$\varphi(\tau) = \eta(\tau - \nu) - \eta(\tau)$$

its possible dependence on A_1, A_2 distance supposedly accounted in $k(R_{12})$. Thus, corresponding NC time dependence described as the difference of two step functions $\eta(\tau) = \{0, \tau < 0; 1, \tau \geq 0\}$ which is simplest variant of such ansatz [15]. $\nu > 0$ is NC parameter, it corresponds to the time range in which A_1, A_2 decay acts are correlated; ν supposed to be much larger than the barrier transition time [21]. Hence A_2 Hamiltonian H_2^c is time-dependent, at given time moment T it depends on A_1 decay probability during time interval ν previous to T. Analogous modification occurs for A_1 Hamiltonian with corresponding index change. In general, such S_1 NC influence on A_1, A_2 Hamiltonians supposedly results in $W(T)$ nonlinear modification in comparison with eq. (5)

$$W(T) = C_t exp\{-\frac{i}{\hbar(T - t_0)} \int_{t_0}^{T}\int_{t_0}^{T} [H_1(t_1) + H_2(t_2) + (T - t_0)G(t_1, t_2)]dt_1 dt_2\}. \tag{16}$$

Third term in this equality is NC dynamics term, its simple ansatz which supresses nucleus decays at small time intervals between them can be taken as

$$G(t_1, t_2) = \frac{\hbar^2}{m} k(R_{12})[\varphi(t_1 - t_2)\gamma_2(t_2)\Phi_1 + \varphi(t_2 - t_1)\gamma_1(t_1)\Phi_2].$$

Note that the second right-side term corresponds to H_2^c Hamiltonian of eq. (15), γ_i is of eq. (3). If no measurement of A_i state was performed for $t_f < T$, then $\gamma_i(t_i) = p_i(t_i)$ of (2). Otherwise, if such measurement was done at some t_f and A_i was found to be in the final state, then for $t_a > t_f$ it follows that $\gamma_i(t_a) = 0$. Thus, for $i = 1, 2$ the nucleus A_i NC term is supposedly proportional to decay rate of neighbour nucleus A_{2-i} of eq. (2). Under these conditions, kinematic factor n_d for α-particle motion inside nucleus changes insignificantly. Then, in WKB approximation for our nonlinear evolution operator the joint $A_{1,2}$ decay probability p_s for $k > 0$ will differ from independent case $p_s(t_1, t_2) = p_1(t_1)p_2(t_2)$ and is equal to

$$p_s(t_1, t_2) = C\lambda^{2+4\theta} \exp[-g(t_1, t_2)(t_1 + t_2 - 2t_0)],$$

where C is normalization constant, analogously to eq. (13)

$$g(t_1, t_2) = \exp[(1 + 2\theta) \ln \lambda], \tag{17}$$

where λ is from eq. (2)

$$\theta = \frac{\hbar^2}{m} k(R_{12})[\eta(t_1 - t_2)\varphi(t_1 - t_2)\gamma_2(t_2) + \eta(t_2 - t_1)\varphi(t_2 - t_1)\gamma_1(t_1)].$$

Due to it, if the time interval between two decay acts is less than ν, the nucleus decay rate will be suppressed, and resulting decay event distribution will become more regular. For independent nucleus decays with $N = 2$ described by eq. (5) their joint decay probability corresponds to Poissonian process, whereas NC dynamics term in eq. (16) would transform it to sub-Poissonan one, resulting in less stochastic and more ordered event distribution. Note that in the considered case, A_1, A_2 states are correlated, but aren't entangled. For $N > 2$ the considered NC dynamics term in $W(T)$ would change to $G(t_1, \ldots, t_N)dt_1 \ldots dt_N$ with corresponding integration over N independent time parameters. As the result, for analogous G ansatz the joint decay probability of two arbitrary consequent decays will be suppressed for small time intervals between them, and the decay time distribution of the event sequence will be sub-Poissonian. For all considered effects it can be supposed that analogous metastable system description is applicable also to chemical reactions and other atomic and molecular effects. It's possible also that two considered evolution symmetrization mechanisms, in principle, can coexist and act simultaneously for some systems.

Proposed models exploits NC dynamics based on nonlinear α-decay Hamiltonian, which, in fact, is used as effective Hamiltonian demonstrating how the decay rates can change under NC influence. It was assumed above that NC doesn't change any subsystem average energy, but in our particular model, in fact, it can change slightly. However, it doesn't exclude the possibility that further model development would permit to avoid this difficulty.

5. Conclusion

Considered experimental results and theoretical analysis evidence that novel communication mechanism between distant quantum systems can exist. It's based on new form of QM nonlocality, principally different from well-known EPR-Bohm mechanism. In this paper, such NC effect was studied for the system of metastable states, in particular, unstable α-decay nuclei described by Gamow model. Application of nonlinear Hamiltonian terms for NC description permits to construct consistent dynamical model. Concerning with causality problem for NC communications, at the moment it's still possible to assume that such NC can spread between systems with velocity of light. But even if this spread is instant, it's notable that usually superluminal signalling in QM discussed for one bit yes/no communications [29]. In our case, to define the resulting change of some parameter expectation value or dispersion, one should collect significant event statistics which makes causality violation quite doubtful possibility. In addition, NC dependence on the distance between two systems can be so steep that it would suppress effective superluminal signalling. Note that some nonlinear models by themselves permit superluminal signalling, but that's untrue for our ansatz [27].

Considered QM nonlocality has universal character, so beside nucleus decays, such temporary variations of system parameters can be observed, in principle, for other systems in which metastable states and tunneling play important role. In particular, it's well known that development and functioning of biological systems performed quite consistently even at relatively large distances between their parts. For example, the kidney and liver cells, blood erythrocytes identify and attract the proper partner cells and reject wrong ones at the distance of several microns, which are much larger than the range of chemical forces [30]. Another notorious example is morphogenesis problem, i.e. proportional and optimal growth of plants and organisms. Up to now the mechanism which regulates spontaneous cell division in optimal way at significant distances between them is poorly understood. It's difficult to admit that such long-distance effects can be achieved via chemical messengers only, so it was argued long ago that some other physical mechanism can be responsible for that. Some authors proposed already that such long-distance correlations can be induced by QM nonlocality [31, 32]. However, standard EPR-Bohm mechanism can't transfer signals effectively in dense and warm media, which is characteristic for biological systems. It isn't obvious how NC model considered here can be extended on biological systems which are quite complex, yet there is no direct obstacles for that as well, some possible options discussed in [24].

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