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Radioactivity of nuclei in a centrifugal force field

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ABSTRACT

Radioactivity of nuclei in a centrifugal force field of an ultracentrifuge is considered for heavy radioactive nuclei, *i.e.*, for the same nuclei, but with a significant virtual mass thousands of times larger than the actual mass and is characterized by an angular momentum. As the nucleus leaves the centrifugal force field, the virtual mass disappears, but the spin number appears and/or changes. The role of centrifugal and gravitational forces in radioactive decay of nuclei is studied. According to the terminology of western researchers, such a virtual mass state is called the dynamic gravitation which is more adequate. The oscillator and possible changes in the nucleus state are considered under conditions of dynamic gravitation and taking into account features of atomic nucleus physics. To a first approximation, the drop model of the nucleus was used, in which shape fluctuations have much in common with geophysical and astrophysical analogues. Shape fluctuations of analogues strongly depend on the gravitational force g defined by their mass (or nucleus mass). Experiments were performed by radiometric measurements of transbaikalian uranium ore (1.5 g) with known composition in a centrifuge at various rotation rates or gravitational forces g. The existence of characteristic times or the effect of rotation frequencies (*i.e.*, g) on atomic nuclei, which, along with the nucleus type itself, controls the nucleus response to perturbation (stability increase or decay), is found statistically significant.

Keywords: Radioactivity; Nuclei; Ultracentrifuge; Increase of Virtual Mass; Stability Increase of Nucleis

1. INTRODUCTION

It is known that the state of the electron shell of heavy radioactive nuclei has an effect on the half-life. For example, more than several decades ago, French researchers showed a minor change in the half-life of a radioactive element, depending on the type of chemical bonds of elements forming a substance with a complex chemical composition. B.A. Mamyrin, Corresponding Member of the Russian Academy of Sciences (St. Petersburg) experimentally showed that the tritium ion is characterized by a shorter half-life which is decreased by 20% - 25% at total ionization. Theorists of the Kurchatov Institute (Filippov *et al.*) studied the role of strong magnetic fields on the electron shell: the half-life of some radioactive elements decreased by a factor of 10^{-7} in this case. Of particular interest are long-term studies of the ά decay by S.E. Shnol. Therefore, the heavy nucleus radioactivity in the centrifugal force field was considered. That is the features of the same nucleus, but with a significant virtual mass exceeding the actual mass by a factor of thousands and characterized by an angular momentum. This means that the virtual nucleus mass disappears without centrifugal forces, but the spin appears and/or changes. Centrifugal forces or dynamic gravitation were widely used in studying the Möossbauer effect and in experiments on testing the general relativity theory (GRT) and equivalence principle [1-5]. According to the equivalence principle, the motion in the gravitational field is indistinguishable from the motion in an accelerated system, e.g., in the centrifugal force field of a centrifuge.

2. CENTRIFUGAL FORCE FIELD AND RADIOACTIVE PROCESSES [1-3]

The energy of γ-ray photons of ^{57}Fe nuclei was shifted in the accelerated system [1-3] in the simplest centrifuge [3]. In this case, the use of various statistical estimates makes it possible, e.g., at the beginning of an increase in the number of revolutions, to obtain an intensity decrease (0 - 100 revolutions per second (rps)) or a zero increase plateau (200 - 300 rps). It is also of interest to estimate the temperature thermal shift of the resonance line in the Mössbauer effect [2], which would allow simultaneous consideration of the role of centrifugal forces or dynamic gravitation [1,2].

The thermal acceleration a_T as a factor affecting the nucleus was estimated. At the lattice vibration frequency $\nu \approx 10^{13}$ Hz and harmonic vibrations, we have $a_T \approx 10^{16}$ g which is insignificant for objects of nuclear scale [2]. The last statement for heavy radioactive and/or unstable deformed nuclei does not seem convincing; however, observations confirm this statement. Therefore, the existence of unexpected physical mechanisms "preserving" the nucleus can be assumed. For example, the electron shell is similar to a damping system at external accelerations of the atom and internal accelerations of the nucleus with respect to the electron shell. At times of $\sim 10^{-12}$ s, the force constant at a relative displacement of neutron and proton components in the ^{57}Fe nucleus is $3 \cdot 10^{23}$ dyn/cm; at an acceleration of 10^{16} g, the maximum displacement in the nucleus is $\sim 10^{-13}$ of the nucleus radius [4]. Even shorter times correspond to the elastic interaction of particles with nucleus. Therefore, the consideration of the nucleus as a purely mechanical system (shell model) determines its mechanical characteristics as a superstrength nuclear matter. In all experiments when a γ-ray source was under conditions of dynamic gravitation, some radiation anomalies were observed, which, unfortunately, were unnoticed by the authors of [1-5].

2.1. Dynamic Gravitation and Features of Atomic Nucleus Physics

2.1.1. Oscillator under Conditions of Dynamic Gravitation [6,7]

Let us mainly consider only frequency properties. For the classical oscillator, the oscillation frequency is $\omega = \sqrt{k/m}$, where k and m are the oscillator stiffness and mass. For the quantum-mechanical oscillator, the features follow from the solution to the Schrödinger equation, *i.e.*, there exists a discrete set of energy eigenvalues $E_n = \hbar\sqrt{k/m} \times (n + 1/2)$, $n = 0, 1, 2, \cdots$; $\hbar = h/2\pi$, h is Planck's constant; energy levels are arranged at equal distances, the selection rule allows transitions only between adjacent levels, the quantum oscillator emits only at one frequency coinciding with the classical one $\omega = \sqrt{k/m}$. The zero-point energy $\hbar\omega/2$($\omega = 2\pi/T$, T is the oscillation period) exists for the quantum oscillator. The zero-point oscillation amplitude is $l = \sqrt{\hbar/m\omega}$, *i.e.*, under conditions of dynamic gravitation, the quantum oscillator emission frequency and the zero-point oscillation amplitude decrease. The harmonic oscillator Hamiltonian is expressed in terms of creation $\hat{A}^+$ and annihilation $\hat{A}$ operators, $\hat{H} = h\omega\left(\hat{A}^+ \times \hat{A} + 1/2\right)$.

All modern models of the quantum field theory are determined on the multivariate generalization of this expression, *i.e.*, dynamic gravitation can have many effects, including those on the quantum oscillator transitions from one energy level (n) to others (m) under an external force. This is also true for oscillations of elementary particles and selection rules between energy levels of quantum systems (elementary particle, atomic nucleus, atom, molecule, crystal). Let us consider in more detail the behavior of the atomic nucleus.

2.1.2. Atomic Nucleus under Conditions of Dynamic Gravitation [8]

The atomic nucleus 10^{-12} - 10^{-13} cm in size has a positive electric charge multiple of the electron charge e magnitude, $Q = Ze$, Z is the integer number, *i.e.*, the atomic number of the element in the periodic system. The atomic nucleus consists of nucleons. The total number of nucleons is the mass number A, the nucleus charge Z is the number of protons, the number of neutrons characterizes the isotope; isotopes with different Z, but equal N are isotones; isotopes with equal A, but different Z and N are isobars. Nucleons consist of quarks and gluons; the nucleus is a complex system of quarks and interacting gluon and meson fields. (The meson is a complex system constructed of a pair of particles with spin 1/2, *i.e.*, quark and antiquark ($q\,\tilde{q}$) and a small fraction of gluons; the gluon is a neutral particle with spin 1 and zero mass; it is a carrier of the strong interaction between quarks). However, the nuclear state cannot be described within quantum chromodynamics because of significant complexity. At not too high excitation energies or under normal conditions, deviations from the nucleus steady state are minor and manifest themselves as follows. During the interaction, nucleons can transit to excited states (resonances) or nucleon isobars (1% in time). In the nucleus, a quark-gluon matter bunch can arise for a short time due to nonabsolute blocking of quarks in nucleons. Nucleon properties in the nucleus can differ from properties in the free state. In nuclei, (virtual) mesons periodically (10^{-23} - 10^{-24}) appear. The study of non-nucleon degrees of freedom of the nucleus is the problem of relativistic nuclear physics; however, proceeding from the general nature of resonances and instabilities, these processes will be suppressed under conditions of dynamic gravitation.

Nucleons as hadrons exhibit the strong interaction (nuclear forces) which confines them in the nucleus (the result of the interaction between quarks and gluons; the theory is not completed). The interaction via meson exchange is characterized by the interaction radius, *i.e.*, the Compton wavelength $\lambda_c = h/\mu c$, μ is the meson mass. During the μ-meson exchange, $\lambda_c = 1.41$ Φ_M (1 Φ_M = 10^{-13} cm). In the case of heavier mesons (ρ, ω, and others), the interaction of nucleons is affected at shorter distances, repulsion between them occurs at $\leq 0.4\ \Phi_M$. Under conditions of dynamic gravitation, the interaction radius increases due to an increase in λ_c; however, repulsion of nucleons can strengthen due to the dynamic meson mass. It is important to note that the structure of rotational spectra of nuclei changes during centrifugal effects (an increase in the nucleus moment of inertia as the angular momentum increases, Coriolis forces, and others) [9,10]. In particular, this is true for deformed nuclei where the gravitation effect can also manifest itself. These effects are simpler explained by the drop and superfluid models of the nucleus. In general, the nucleus model choice is associated with the general quantum formalism of the nucleus state description, and the strict criterion does not exist up to now.

It seems that a simpler criterion can be used, *i.e.*, characteristic frequencies of perturbations; the cutoff frequencies for the shell model ($\leq 10^{-12}$), below which the drop model is preferable, are known. An analogy from megascale effects can be presented. For the Earth, in the case of perturbations with characteristic times of 10^5 - 10^6 s, the matter characteristics are close to those of steel; at times 10^8 - 10^{10} s, seismotectonic flows are observed. That is, the atomic nucleus at characteristic times of $\ll 10^{-12}$ under quasi-static perturbations can exhibit properties of liquid. In this case, perturbations of the heavy deformed nucleus surface have the form of standing surface waves, and its oscillation description includes g in the first power. As the simplest estimates show, the acceleration on the nucleus surface does not exceed $\sim 10^{-6}$ g. Therefore, we will consider nucleus oscillations under conditions of dynamic gravitation.

2.2. Vibrational Excitations of Nuclei [11,12]

In the case of dynamic gravitation, to a first approximation, it is easy to consider excitations within the drop model; nucleus shape fluctuations are much in common with geophysical and astrophysical analogues (**Figures 1(a)** and **1(b)**), where the role of g is significant. For the quantum description, for each vibrational mode (L, M), vibrational quanta, *i.e.*, photons, are introduced.

In deformed nuclei, the equilibrium shape has axial symmetry. The photon energies depend on |K|; therefore, the modes longitudinal and transverse to the symmetry axis have different frequencies (**Figure 1(b)**).

Under strong deformations, oscillations are unstable and the nucleus split. The strongest deformations are observed for quadrupole and octupole modes of nucleus oscillations (**Figure 1(a)**). At the same time, an increase in the nucleus mass due to dynamic gravitation even by a factor of 10^3 first of all suppresses these vibrational modes, and reduces them to the monopole mode with much smaller amplitude. Therefore, the nucleus stability

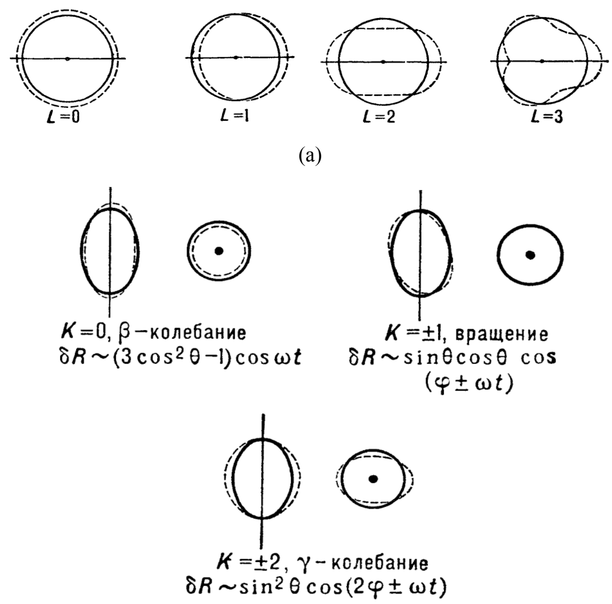

Figure 1. (a) Monopole (L = 0), dipole (L = 1), quadrupole (L = 2), and octupole (L = 3) vibrational modes of the spherical nucleus with the angular momentum L projection onto the motion axis M = 0. The dipole mode is "false" (displacement without changing the shape). The monopole mode (L = 0) corresponds to density fluctuations while retaining the spherical symmetry. The dipole mode (L = 1) corresponds to the nucleus centroid displacement and is not realized as the shape fluctuation. In the quadrupole (L = 2) and octupole (L = 3) modes, the oscillating nucleus is spheroid- and pear-shaped, respectively; (b) The simplest nucleus shape fluctuations with axially symmetric quadrupole deformation (nucleus shape projections in the directions perpendicular and parallel to the symmetry axis are shown); δR (θ, φ, t) is the surface radius variation in the (θ, φ) direction with time. The mode with K = ±1 is "false" (rotation without changing the shape). Key: колебание --> oscillation; вращение --> rotation.

can increase, the decay process will be suppressed, and the nucleus will get the property of the quasi-static one. In the case of dynamic gravitation, the transition to the monopole vibrational mode stabilizes the excited nucleus state, but simultaneously lowers its frequency. However, if we assume that the introduction of dynamic gravitation is analogous to an increase in the number of neutrons, we will obtain a decrease in the nucleus stability. It is difficult to represent the complexity and ambiguity of radioactivity processes under conditions of dynamic gravitation without experimental study.

3. RADIOMETRIC STUDIES OF RADIOACTIVITY UNDER CONDITIONS OF DYNAMIC GRAVITATION

Radiometric measurements of transbaikalian uranium ore (1.5 g) with known composition (see **Figures 2(a)** and **2(b)**) were performed in a centrifuge with various rotation rates.

The sample was fixed at an aluminum rod at a distance of 25 cm from the rotation center.

Preliminarily, radiometric measurements of the background were performed using a SOSNA ANRI-01-02 radiometer in γ and β modes (see the table, the first column); then radiation of rapid rotation (4000 - 5000 rpm) was measured. The distance from the source to the radiometer is 0.05 m at the nearest point during rotation. Accelerations (g-forces) during rotation were determined by the formula: $a = (2\pi N)^2 \cdot R$, where N is the number of revolutions per minute and R is the distance from the rotation center. At 50 rpm, accelerations were on the order of unity; at 4000 rpm, accelerations were 4400 g, (g = 9.8 m/s^2 is the gravitational acceleration on the Earth). The measurement unit was microroentgen. The results are listed in the table. The second column contains background values, the third and fourth columns correspond to rates of ~50 rpm and ~4000 - 5000 rpm, respectively.

The difference between the background average and the average for slow rotation exceeds four standard deviations and is 8.072; the difference between averages for slow and rapid rotation is 6.858 which exceeds the standard deviation by a factor of 3.46. Thus, the probability of the random effect is very low (P < 0.99). That is, for rapid rotation, we observe a decrease in γ-radiation below the background level.

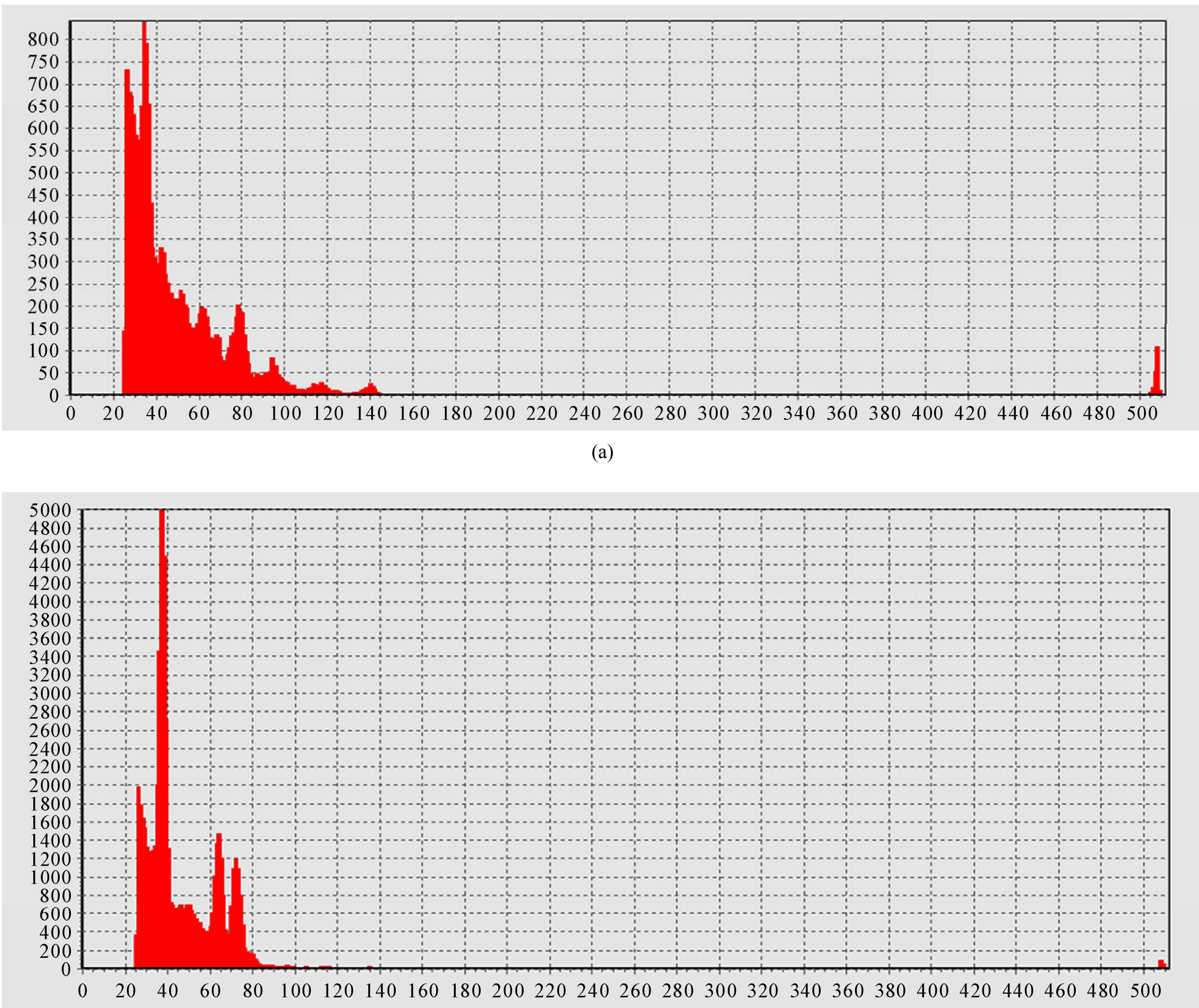

Figure 2. (a) Non-calibrated source by the authors; (b) Calibrated source by the Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, containing the following radioactive elements: ^{40}K (78th channel, 1420 keV), ^{137}Cs (37th channel, 662 keV), ^{60}Co (64-72th channels, 1.17 and 1.33 MeV); 510 channel = 9.5 MeV.

Table 1. Comparison of radioactivity of nuclei under conditions of dynamic gravitation with background level.

No.	μR (backgr.)	μR (50 rpm)	μR (4000 rpm)
1	7	22	10
2	10	17	11
3	11	19	11
4	8	18	12
5	12	16	15
6	8	18	13
7	14	15	11
8	10	16	11
9	13	19	11
10	12	18	15
11	10	17	10
12	11	18	11
13	10	20	8
14	5	21	9
Averages	10.071	18.142	11.285
Standard deviations	2.432	1.955	1.97

4. DISCUSSION AND CONCLUSIONS

As follows from the above consideration, there are characteristic times or frequencies of the influence on atomic nuclei, which, along with the nucleus type itself, define the nucleus response to a perturbation (stability increase or decay). The elastic and inelastic interaction processes and the efficiency of the nucleus shell model point to times of $\sim 10^{-10}$ s. Longer times or threshold perturbations can be expected, depending on the nucleus state and type, from 10^{-8} s and larger. Centrifuge experiments point to effective perturbations at $\sim 10^{-2}$ s. Processes with a pulsed increase in inertial forces (an impact of a depleted uranium rod on an armored plate) cause nucleus radioactivity at times of $\sim 10^{-4}$ s. As the experiments showed, at a *g*-force duration (~5000.0 g) of 10^{-4} s, nuclei can be only stabilized; for ^{238}U, this means that strongly deformed nuclei will take a spherical shape due to dynamic gravitation. A *g*-force of 50000 g disappears in $\sim 10^{-7}$ s and is controlled by the uranium rod end configuration. A pulse 10^{-7} s long is not short for the nucleus; however, as the dynamic gravitation is relieved, quadrupole and octupole nucleus oscillations can be excited for this time interval. Under such conditions, excitation of nucleus oscillations results in instability and the appearance of radioactivity.

We also note that the formalism of dynamic quantum chaos is most appropriate to describe the above processes [13]. Thus, there exist still approximately determined time parameters for acceleration (perturbation) durations for atomic nuclei, when (radioactive) processes occur in nuclei at a certain acceleration. These phenomena can be most easily studied under conditions of dynamic gravitation

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