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Влияние гравитационного потенциала небесных тел на скорость радиоактивного распада атомных ядер

The influence of the gravitational potential of celestial bodies on the rate of radioactive decay of the atomic nuclei

Alexander P. Trunev (Toronto, Canada)

Alexander P. Trunev, Ph.D

В статье рассмотрена система фермионов атомных ядер во внешнем гравитационном поле. Сезонные вариации скорости радиоактивного распада для ^{32}Si и ^{226}Ra объясняются как реакция системы фермионов на сезонные вариации гравитационного поля солнечной системы

The nuclear fermions system in an external gravitation field is described in the paper. The seasonal variations of the radioactive decay rate recently reported for ^{32}Si and ^{226}Ra could be explained as reaction of the nuclear fermions system on the seasonal variations of the solar system gravitation field.

Ключевые слова: альфа-распад, бета-распад, система фермионов, внешние поля, гравитационное поле

Keywords: alpha decays, beta decays, system of fermions, external fields, gravitational field

The seasonal variations of the radioactive decay rate have been reported by several research groups /1-3/. In the article /3/ is discovered the dependence of the rate of radioactive decay on the number of astrophysical factors, including daily, 27 day and annual periods. The authors /4/ via the comparison of the rate of the beta decay of ^{32}Si /1/ and rate of the alpha decay of ^{226}Ra /2/ proved that the relative rate for these two processes correlate between themselves and with the Earth-Sun distance. They assume that the Sun generates the unknown scalar field (or even two), which influences the rate of radioactive decay. Meanwhile analogous seasonal dependence was obtained for the electric inductance and the resistance with the measurement in the thermostat according to bridge schema in the experiments /5/ - see Figures 1-2. In our article /6/ it was shown that data /5/ for the inductance and the resistance correlate between themselves and with the Earth-Sun distance. The theory of this phenomenon, based on the Fermi-Dirac statistics of conduction electrons, is given in our report /7/. As it was established the seasonal variations of resistance (and an inductance) could be presented as a linear function of the universal parameter as follows (see Figures 3-4):

$$(R-R_0)/R_0 = -1.3216\Delta K_2 - 0.0125$$
$$(L-L_0)/L_0 = -0.9888\Delta K_2 - 0.0002$$
$$\Delta K_2 = -5m_e(\varphi-\varphi_0)/3kT = -5m_e\varphi/3kT - 0.3284443$$

Here R_0=2.69 K ohms; L_0=151.64 mH, $m_e = 9.1093826 \cdot 10^{-31} kg$ - the mass of electron, $k = 1{,}3806505 \cdot 10^{-23} J/K$ - the Boltzmann constant, T - absolute temperature, φ - the potential of gravitational field,

$$(1) \qquad \varphi = -\gamma \sum_i \frac{M_i}{R_i}$$

$\gamma = 6{,}6742 \cdot 10^{-11} Nm^2 kg^{-2}$ - Gravitational constant, M_i, R_i - the mass of celestial body and distance to it respectively.

Let us examine the application of the theory /7/ to the rate of radioactive decay.

Figure 1: Seasonal variations of inductance /5/

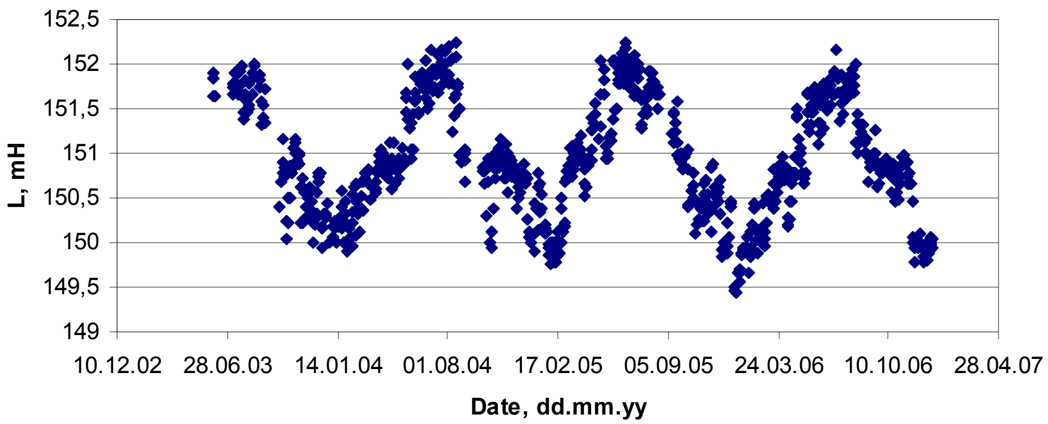


Figure 2: Seasonal variations of resistance /5/

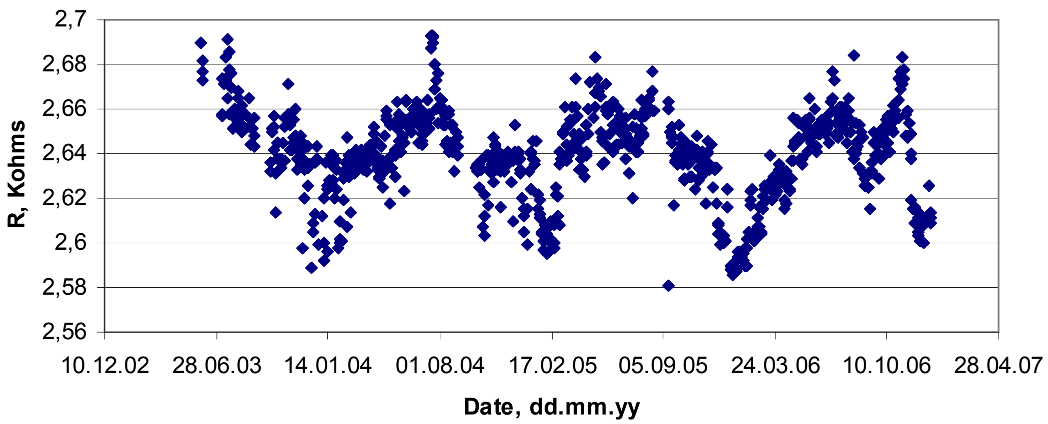


Figure 3: The relative seasonal variations of an inductance vs. the universal parameter K_2

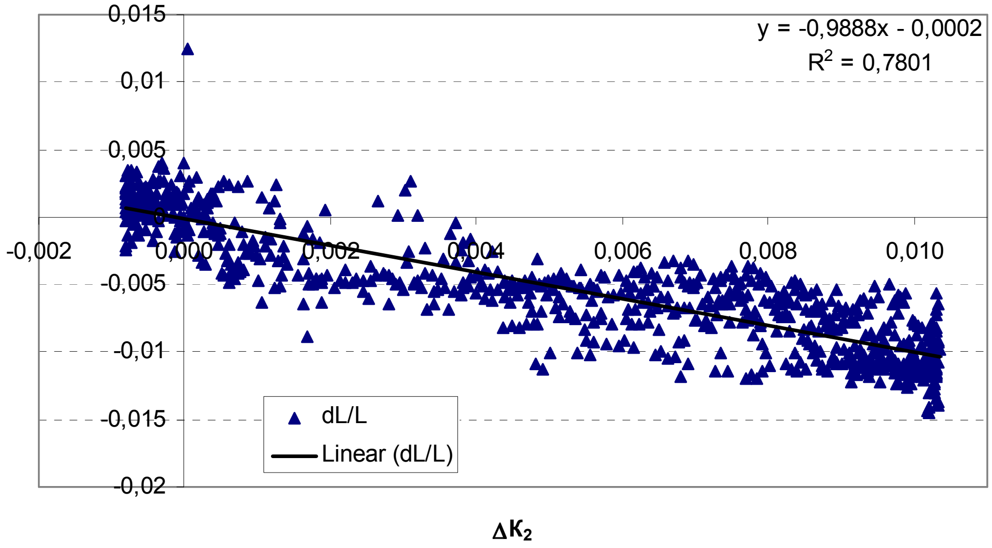
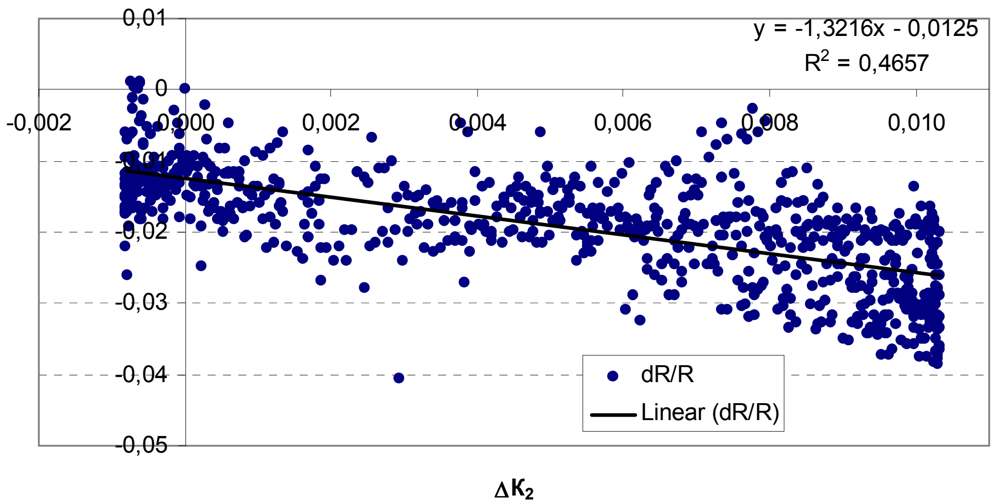


Figure 4: The relative seasonal variations of a resistance vs. the universal parameter K_2



As it is known atomic nucleus consists of protons and neutrons - particles, which possess half-integral spin. Such particles are subordinated the Fermi-Dirac statistics; therefore the nucleus of heavy elements in a certain approximation can be considered as the system of fermions /8/. The fundamental characteristic of this system is the Fermi energy, which can be calculated using the average energy, which falls to one nucleon:

(2) $$\varepsilon_F = \frac{5}{3} E_{ave} = \frac{5E}{3A}$$

Here A is the total number of nucleons in the volume of nucleus, E - total energy of all nucleons. Note, there is a difference in the electric charge of proton and neutron (+e and 0 respectively), and also they have a different mass (938.271998 and 939.565530 MeV respectively) therefore they are not identical particles as it assumed in the Fermi-Dirac distribution law (see ref. /8/ for instance). Nevertheless some average characteristics of nucleons in the volume of nucleus could be calculated like for identical nucleons. For example, the nuclear spin is half-integer if *A* is odd and integer if *A* is even. It means that spins of protons and neutrons are strong correlated in the volume of nucleus like in a case of identical particles.

In the external gravitational field general energy of particles changes to the value

(3) $$\Delta E = A m_a \varphi$$

Where m_a - average mass of nucleons in the nucleus,

With the fixed number of particles the change in the total energy leads, accordingly (2), to the change of the Fermi energy scale, i.e.

(4) $$\Delta\varepsilon_F = 5 m_a \varphi / 3$$

The number of fermions per unit energy range is given by the Fermi-Dirac distribution law:

(5) $$\frac{dn}{dE} = \frac{8\sqrt{2} V m_a^{3/2}}{h^3} \frac{\sqrt{E}}{e^{(E-\varepsilon_F)/\theta} + 1}$$

where *h* is the Planck constant, V – the volume of nucleus, θ - some constant calculated below.

At the upper level with $E = \varepsilon_F$ we find from the equation (5):

(6) $$\frac{dn}{dE} = \frac{3A}{4\varepsilon_F}$$

If the energy level of Fermi experiences fluctuations in accordance with (4), then we have at the upper level:

(7) $$\frac{dn}{dE} = \frac{3A}{4\varepsilon_F} \frac{2}{e^{-\Delta\varepsilon_F/\theta} + 1}$$

Subtracting from this equation expression (6), we find the change in the density of the distribution function at the level $E = \varepsilon_F$, correlated with the presence of nucleons in the external field:

(8) $$\delta \frac{dn}{dE} = \frac{3A}{4\varepsilon_F} \frac{1 - e^{-\Delta\varepsilon_F/\theta}}{e^{-\Delta\varepsilon_F/\theta} + 1}$$

Let us note that if energy of some nucleon exceeds the Fermi energy level, this nucleon can change its state, for example by mode of decay to the proton, the electron and the antineutrino (beta decay) or even leave nucleus in the composition of alpha particle (alpha decay). Whatever there was the mechanism of radioactive decay, a change in the number of atoms in the course of time is described by the equation:

$$\frac{dN_i}{dt} = -\lambda N_i$$

Here λ - decay constant. According to ref. /1-4/, the decay constant has periodic fluctuations correlated with the daily, 27 day and annual periods. In order to characterize these periodic fluctuations, authors /4/ proposed to investigate relative decay rate:

$$U(t) = \frac{dN/dt}{dN(0)/dt} e^{\lambda_0 t}$$

where λ_0 is the average value of decay constant, i.e., time-independent constant. As it was established /4/, relative decay rate of ^{32}Si correlates with the relative decay rate of ^{226}Ra, and in both cases relative decay rate depends on the Earth-Sun distance. In order to explain this effect let us be turned to the equation (8), according to which a change of the number of excited nucleons in the external gravitational field can be characterized by two complexes:

$$K_1 = -\Delta\varepsilon_F / \varepsilon_F = -5m_a\varphi / 3\varepsilon_F,$$

(9) $$K_2 = -\Delta\varepsilon_F / kT = -5m_a\varphi / 3\theta$$

The first of these complexes characterizes the relative contribution of a change in a level of the Fermi energy into seasonal variations in the decay rate, the second complex characterizes the statistical effects, caused by the motion of nucleons.

Thus the relative effect of seasonal variations in the relative decay rate can be presented in the form:

(10) $$(U - U_0)/U_0 = f(K_1, K_2)$$

where *f* is the universal dimensionless function.

Generally speaking, for the nuclei the parameters K_1, K_2 coincide with an accuracy to constant; therefore with the simulation of the effect of gravity it is possible to select one of them, for example, K_2 as for as in the case of seasonal variations in the resistance and inductance (see ref. /7/). In the case of radioactive decay the function in the right part of the equation (10) is, apparently, nonlinear, since in the report /4/ was discovered the phase shift between the data on the relative decay rate and the distance. This means that the predominant influence on the rate of radioactive decay renders the parameter K_2, which describes statistical effects.

The gravitational potential of the Sun periodically changes inversely proportional to the Earth-Sun distance and it gives the main contribution to the gravitational potential of the celestial bodies of the solar system; therefore in the paper /4/ was discovered precisely the effect, connected with the influence of the Earth-Sun distance. In this case the authors /4/ used for finding the correlation a square of distance, assuming that one of the reasons for a change in the rate of radioactive decay can be a change in the neutrino flux.

The gravitational potential of the Sun has seasonal variations, with amplitude of about 0.0167 from the average value (about 8.87826 $\cdot 10^8$ m^2/s^2). Thus, the amplitude of the seasonal variations of the gravitational potential of the Sun composes of 1.482669 $\cdot 10^7$ m^2/s^2. The second largest contribution is own gravitational field of the Earth, which also changes very weakly. Planets periodically moving because of the motion of the Earth and the proper motion; therefore their total potential varies near the average value - 210631.0031 m^2/s^2 (calculated during the period of 100 years, since September 27, 1971), the contribution of planets is 100 times less, and the contribution of the Moon is 1000 times less (note that for the tidal forces there are others numbers).

The typical value of Fermi energy for the atomic nuclei is 35-38 MeV, but the average value of the mass of nucleon it does not exceed the mass of the neutron of, i.e., 939,5731 MeV. Calculating the parameter K_1, we find that its value is approximately 2.5 $\cdot 10^{-7}$. From the other side, the parameter K_2 even in the case of conduction electrons varies within the limits of 0,3276-0,3387 (see /7/). However, in the case of nucleons, taking into account the fact that the ratio of the mass of proton to the mass of electron is about 1836.15152, this parameter can be more than one. If the temperature of nucleons inside the nucleus is proportional to ambient temperature, then for the nucleons the parameter K_2 varies from 601 to 622. Let us note that the temperature inside the nucleus can to three or four orders exceed ambient temperature, since the nucleus does not have any mechanism of heat exchange with the environment, except the channels of radioactive decay. Let us examine solution of problem for $K_2 \ll 1$.

The disturbance of the density of the distribution function (8) generates the proportional disturbance of the density of nucleons. Since the scale of energy in this task corresponds to the Fermi energy level, the disturbance of density can be represented in the form

$$\delta n = a\varepsilon_F \delta \frac{dn}{dE} = \frac{3an}{4} \frac{1 - e^{-\Delta\varepsilon_F/\theta}}{e^{-\Delta\varepsilon_F/\theta} + 1} = \frac{3an}{4} \operatorname{th}\left(\frac{\Delta\varepsilon_F}{2\theta}\right) \approx -\frac{3}{8} anK_2 \quad (11)$$

a - some numerical coefficient.

The disturbance of the density of nucleons produces a proportional change in the decay probability, thus a relative change in the decay constant is described by the linear equation:

$$\delta\lambda / \lambda_0 = -\frac{3a}{8} K_2(t) \quad (12)$$

Let us assume in the equation of the radioactive decay $\lambda = \lambda_0 - \frac{3a\lambda_0}{8} K_2(t)$ and integrate it, as a result we have:

$$N = N(0)\exp(-\lambda_0 t + \frac{3a\lambda_0}{8} \int_0^t K_2 dt) \quad (13)$$

Finally, calculating relative decay rate, we find:

$$U(t) = \frac{dN/dt}{dN(0)/dt} e^{\lambda_0 t} = \frac{1 - 3aK_2(t)/8}{1 - 3aK_2(0)/8} \exp\left(\frac{3a\lambda_0}{8} \int_0^t K_2 dt \right) \quad (14)$$

According to data /4/ the amplitude of seasonal variations of relative decay rate is identical for ^{32}Si and ^{226}Ra and it is about 0,003. This amplitude can be utilized for estimation the temperature of nucleons in the nuclei of these isotopes:

$$\Delta U \approx -\frac{3a}{8}\Delta K_2 = \frac{3a}{8}(622 - 601)\frac{kT}{\theta} \approx 0{,}003 \quad (15)$$
,

And therefore the temperature of nucleons is about $\theta \approx 2625kTa = a66{,}3121\,\text{eV}$.

Unknown numerical coefficient was established according to the data of the seasonal variations of resistance and inductance (see ref. /7/):

a=3.5246 for resistance data, and a=2.6368 for inductance data.

Let us note the similarity of the task about the influence of gravitation on the rate of radioactive decay and task about the influence of gravitation on the conductivity, which was explained in our paper /7/. In these tasks we discus the behavior of the system of fermions in the external fields. Therefore, on the basis of this analogy, it is possible to utilize the value of numerical coefficient a for evaluating the temperature of nucleons in the nucleus, therefore we find that its value varies in a range from 1.5 10^6 to 2 10^6 ^oK.

In conclusion let us give the formula for the relative decay rate, convenient for experimental studies. For this let us simplify the right side of the expression (14), in which let us hold only gravitational potential of the Sun, then we obtain:

$$U(t) = 1 + \frac{5am_a}{8\theta}[\varphi(t) - \varphi(0)] = 1 + \frac{5am_a}{8\theta}\frac{\gamma M}{R(t)R(0)}[R(t) - R(0)] \quad (16)$$

M, R - mass of the Sun the Earth-Sun distance respectively.

Separate attention deserves the question of why gravitational potential has an effect on the system of fermions, although, it would seem, the forces, which act on it, are balanced. It must be noted, that the potential of gravitational field in the nonrelativistic approximation is described by Laplace's equation:

$$\nabla^2 \varphi = 0$$

But this equation does not change upon transfer to the noninertial coordinate system, connected with the observation point on our planet (in contrast to Newton's equation, which consists of the fictitious inertial forces). The quantum system of fermions feels gravitational potential, but it does not feel the inertial forces, which are, generally speaking, small in comparison with the forces of nuclear interaction or the forces, caused by spin-spin interaction. Thus, the system of fermions reacts to a variation in the gravitational potential, but it does not react to the system of the forces, whose sum is equal to zero in the laboratory coordinate system. Due to equation (16) the relative rate of decay depends on the Earth-Sun distance, that was established by authors /4/.

Finally note this theory makes it possible to predict existence of 12 year cycle of fluctuations of radioactive decay rate, caused by the motion of Jupiter, 27 day cycle caused by the motion of the Moon, daily cycle and other cycles, corresponding to the motion of the planets of the solar system.

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