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191

COMPARISON OF THE PROBABILITIES OF THE TRIPLE FISSION OF U^{233}, U^{235}, *AND* Pu^{239}

V. N. DMITRIEV, L. V. DRAPCHINSKIĬ, K. A. PETRZHAK, and Yu. F. ROMANOV

Radium Institute, Academy of Sciences, U.S.S.R.

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RECENTLY there has been a considerable increase in the interest in nuclear fission accompanied by the emission of long-range α particles. A study of this phenomenon yields more information on the fission mechanism, since the emission of the α particle is connected with the initial stage of the process and characterizes the state of the nucleus during the instant of fission.

One of the most important characteristics of nuclear fission with emission of long-range particles is the probability of the given process relative to the fission into two fragments. The determination of the probability of triple fission of U^{235} induced by slow neutrons has been the subject of many investigations,[1-9] but U^{233} and Pu^{239} have not been sufficiently investigated in this respect. Thus, data on the relative probabilities of triple fission of Pu^{239} and U^{235}, determined by Farewell et al.[4] and Allen and Dewan,[6] do not agree with each other — whereas it follows from reference 4 that the probability of triple fission of Pu^{235} is half that of U^{235}, reference 6 yields a probability that is 1.14 times greater. It is therefore interesting to obtain more exact values for the relative probabilities of triple fission of U^{233}, U^{235}, and Pu^{239}, induced by slow neutrons.

We used for this purpose a setup intended for the investigation of the energy distribution of triple-fission fragments.[10] The triple fissions were identified by the coincidences of the pulses from the fragment chamber and from the α-particle chamber. The fraction of registered triple fissions depended on the solid angle of the α chamber relative to the target of the fissioning substances, on the argon pressure in the chamber, and on the degree of pulse discrimination in the α channel. Under the condition of the present experiment, a calculation of this fraction is subject to great errors, and therefore the determination of the absolute probabilities of triple fission does not seem advisable. The apparatus used can measure, with great accuracy, the ratios of probabilities of triple fission of different nuclei. The geometry of the chamber and the chosen argon pressure resulted in maximum pulses from the α particles with the most probable energies. It is known that the energy spectra of long-range α particles, emitted upon fission of the investigated nuclei, are nearly equal.[6] The measurement conditions in experiments with different nuclei remained unchanged. Consequently, the sought ratio of probabilities of triple fission of nuclei 1 and 2 is

$$\eta_1 / \eta_2 = (N_{tr} / N_d)_1 / (N_{tr} / N_d)_2,$$

where N_{tr} is the number of triple fissions and N_d is the number of double fissions registered per unit time.

The targets were irradiated with slow neutrons in the experimental reactor of the U.S.S.R. Academy of Sciences. The measurement results are listed in the table, and the background of random coincidences, which amounted to 3% of N_{tr}, was taken into account. The statistical errors are indicated.

Nucleus	N_{tr}, pulse/min	N_d, pulse/min
U^{233}	7.45 ± 0.15	28600 ± 140
U^{235}	8.86 ± 0.18	41600 ± 200
Pu^{239}	18.53 ± 0.37	74000 ± 400

The resultant data were used to determine the ratios of triple-fission probabilities:

$$\eta(U^{233})/\eta(U^{235}) = 1.22 \pm 0.06,$$

$$\eta(Pu^{239})/\eta(U^{235}) = 1.18 \pm 0.06.$$

According to the results of Allen and Dewan,[6] these values are 1.25 ± 0.22 and 1.14 ± 0.23 respectively.

Thus, the probability ratios obtained in the present work agree with those calculated from the data of Allen and Dewan. The use of the method of relative measurements ensured a higher accuracy of the results.

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192

LONGITUDINAL RELAXATION OF NUCLEAR SPINS IN A PARAMAGNETIC CRYSTAL AT VERY LOW TEMPERATURES

B. I. KOCHELAEV

Kazan' State University

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It is well known that at sufficiently low temperatures, the specific heat associated with the lattice of a paramagnetic crystal becomes negligible compared with the specific heat of spin systems. In this case, the spin system of paramagnetic atoms will be the thermostat determining the equilibrium population distribution among nuclear spin levels, and the longitudinal nuclear relaxation time T_1 will be the time required to establish thermodynamic equilibrium between the electronic and nuclear spin systems. It is the purpose of this note to describe some calculations of this time.

At low temperatures, the energy levels of most paramagnetic atoms in an external magnetic field can be described by an effective spin $S = \frac{1}{2}$ with an anisotropic g factor, i.e., with the magnetic moment of an atom being given by $\mu = \beta \mathbf{g}\mathbf{S}$, where $\mathbf{g}$ is a tensor of the second rank and β is the Bohr magneton. We assume that the electric field inside the crystal has axial symmetry and that the Zeeman energy is much greater than either kT or the mean interaction energy of magnetic dipoles. In this case Bogolyubov's approximate method for second quantization can be used to find the energy spectrum of the interacting electron spins. This spectrum turns out to be equivalent to the spectrum of a system of non-interacting Bose particles with Hamiltonian

$$\mathscr{H} = E_0 + \sum_{\mathbf{k}} E_{\mathbf{k}} N_{\mathbf{k}},\quad N_{\mathbf{k}} = b_{\mathbf{k}}^{+} b_{\mathbf{k}},$$

$$E_0 = g_{\parallel}\beta H N,\quad E_{\mathbf{k}} \approx \frac{10\pi}{a} g_{\perp}^2 \beta^2 (k^2 - 3k_z^2), \tag{1}$$

where $b_{\mathbf{k}}^{+}$, $b_{\mathbf{k}}$ are creation and destruction operators for Bose particles with wave vector $\mathbf{k}$, N is the number of paramagnetic atoms, a is the shortest distance between them and $g_{\parallel}$, $g_{\perp}$ are the principal values of the tensor $\mathbf{g}$. In our calculations we used the fact that to find the spectrum of a spin system in a strong magnetic field it is only necessary to consider the diagonal and semi-diagonal parts of the operator for the dipole-dipole interaction.[2] It was also assumed that the paramagnetic atoms were arranged in a simple cubic lattice, that the magnetic field $\mathbf{H}$ is directed along the symmetry axis of the crystal field, and the lattice sums can be approximated by integrals.

Suppose the nuclear spins are coupled to the paramagnetic atoms only through the dipole-dipole interaction. We shall find the probability of a transition in which one boson is created, another destroyed, the energy difference between them being equal to the energy required to re-orient a nuclear spin in the external field, $E_{\mathbf{k}_1} - E_{\mathbf{k}_2} = 2g_N\beta_N H$ (where g_N is the nuclear magnetic moment in nuclear magnetons β_N). Assuming that $2g_N\beta_N H \ll \beta^2 g_{\perp}^2/a^3$ and using the standard formulas of perturbation theory, we find that the probability of a transition is

$$P(m+1, m) = \frac{9}{20\pi^2\hbar}\left(\frac{g_{\parallel}}{g_{\perp}}\right)^2 g_N^2\beta_N^2 \frac{a^3}{r^6}\sin^2 2\theta$$

$$\times \exp\left(\frac{2g_{\parallel}\beta H}{kT}\right)(I+m+1)(I-m), \tag{2}$$

where $\mathbf{r}$ is the radius vector from a paramagnetic atom to a nuclear spin $\mathbf{I}$; θ is the angle between the direction of the magnetic field and $\mathbf{r}$, and m is the magnetic quantum number of the nucleus.

Experimentally, the method of a saturated nuclear magnetic resonance has been used to meas-