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FISSION FRAGMENT GAMMA-RAYS ANISOTROPY AND SOME CLASSICAL NUCLEAR PROPERTIES.

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Abstract: The anisotropy of fission fragment gamma rays in the reaction $^{235}U(n_{th},f)$ has been measured for gamma energy band 0.82-0.92 Mev. The anisotropy value was found to be 0.165+0.03. The data is corrected for Doppler effect and background and results were worked according to the theory of Strutinski. As it was found from cluster model, that nuclear viscosity should be zero.from rigidity, anisotropy increases with mass of fissioning nucleus and fragment rotations due to Nix and Swiatski are absent.y. It was also found that there is a minimum rigidity for fissionable nuclei and that hard gamma rays result from clusters in a fissioning nucleus.

Introduction

For heavier elements, the average total gamma ray energy per fission (for both fragments) has been found experimentally to be about 8 Mev[1-4]. Fragment de-excitation calculations made for nonrotating fragment indicate that roughly one-half this amount of gamma-ray energy is expected[5-8]. It has been suggested that this discrepancy is due to the presence of a total fragment rotational energy of several Mev.

Experimental information regarding the distributionof fragment angular momenta is obtainable from at least three different types of experiments. One is a measurement of the distribution of the total prompt gamma ray emitted by each fragment. The distribution of individual fragment angular momentum could then be estimated from a knowledge of the effect of angular momentum on the competition between neutron and gamma-ray emission in the fragment de-excitation process as indicated[9-11]. The second method involves the measurement of the angular distribution of prompt gamma rays emitted from fragments[12-18]. The third method which would yield information only for specific fragment masses, is the study of shielded isomer ratios in the fission products[19-20].

The object of the present work is first to measure the anisotropy in the reaction $^{235}U(n_{th},f)$ for the energy band 0.83-0.92 Mev.

From the measured anisotropy one can calculate the average angular momentum J_{av} by making use of the Strutinsiky formula /21/. Nix and Swiatecki[22] and also Wilets[23] and others have pointed out that fragment rotation along the z-axis is also present. The second aim is to discuss the effect of rigidity of fission fragment on possible gamma-ray anisotropy. This was obtained from the simplified attempt to extend the Strutinsky formula to include fragment rotation along the z-axis.

Experimental

The fission target isotope U-235 (=98%) was electro-deposited (1 mg/cm^2) on an aluminium backing of 0.1 mm thickness. The fragment detector was 15 u thick plastic scintillator. The efficieency of detector to fragment was 98±2% and insensitive to both neutrons and gamma rays (=1%). For gamma-ray detection, Na I(Tl) crystal (40x2o mm) was used and was placed at 73 cm from the target.

A fast coincidence technique was employed to reduce the effect of fission neutrons as a result of their delayed arrival at gamma detector. The change in the resolution time(t=8xNano sec), during four days of operation was in the range 10%. The efficiency of the circuit fluctuated with ±3%. The position of the centre of fast coincidence curve changed within a range of ± 2x Nano sec, indicating a satisfactory stability of the circuit. Reference /17/ should be consulted for the experimental set up and procedure.

Results and discussion

The number of fission fragment gamma-rays per 10^6 fission was measured at angular intervals of 22.5° in the angular range 90° to 180°. The gamma channel width was experimentally set to cover the gamma energy band 0.83-0.92 Mev. The band was selected where the background contributions were least.

The number of gamma quanta in c.m. system $N(\psi)$ is related to $N(\theta)$, the number in laboratory system through the relation[17,18].

$$N(\theta)=\frac{N(\psi)}{2}\left(1+\frac{1+f\,\beta\cos\theta}{(1-\beta\cos\theta)^2}\right)(1-\beta^2)^{1/2} \quad (1)$$

where $\beta=v/c$, v and c are the velocities of fragment and light. The factor f is due to Doppeler attenuation. The result of this transformation is indicated in table 1.

table 1. Number of gamma-rays per 10^6 fission $N(\theta)$ before and $N(\psi)$ after Doppler corrections for energy band 0.83-0.92 Mev

Position	$N(\theta)$	$N(\psi)$
180°	22.9	24.3
157.5°	21.8	23.0
135°	21.5	22.4
112.5°	20.2	21.4
90°	20.2	20.2

The expression for the angular distribution of the gamma rays as obtained by Strutinsky[21]

$$N(\psi)/N(180) = 1 + K \sin^2\psi \qquad (2)$$

Using the values of N(/) in table 1, the value of anisotropy K = 16.5±3 % is obtained by least square fitting procedure as

$$d/dK \quad (N(\psi)/N(180)-1-K \sin^2\psi)^2=0 \qquad \text{...............(2a)}$$

The value of the anisotropy obtained in this work indicates with the previous results[17] that the anisotropy values for different energy bands are close to experimental error ,so that anisotropy and energy are rather independent.

The measured anisotropy is related to angular momentum J through eq.(2b)

$$K = k_L (\hbar^2 J/TI)^2 \qquad (2b)$$

where I and T are the moment of inertia and average fragment temperature after neutron evaporation, k_L = 1/8 for L=1 (dipole) ; for L=2 (quadropole) k_L = -3/8.

Assuming[13] T=0.4 Mev and I= 0.5 I_{rig} one gets J_{av} = 5.3. It should be noted that the magnitudes of T and I are not easily determined and are model dependent.

From the clustor theory of fission/26/ the rotation of both clusters is normal to the fission direction. This angular momentum of cluster remains till deexcitation of fragment angular momentum by gamma radiation, confirming the assumptions of Strutinsky.

However Strutinsky equation does not take into account any rotation along the fission axis, which may occur during the later stages of fission. The effect of possible bending, twisting and wirigling was calculated by Nix /22/ and Swiatecki theory by using the expressions:

$$P(J)= \frac{4J}{[(C_{pb}+C_{pw})(C_{pb}+C_{pw}-C_{pt})]^{0.5}} \times$$

$$\times \exp\left(-\frac{2J^2}{C_{pb}+C_{pw}}\right) \operatorname{erf}(x) \quad ...(3)$$

where C_{pb}, C_{pw} and C_{pt} are widths of the bending, wrigling and twisting normal modes (assuming no initial rotation) and

$$x = \left[\frac{2\,(C_{pb}+C_{pw}-C_{pt})}{C_{pt}\,(C_{pb}+C_{pw})}\right]^{\frac{1}{2}} J$$

For $\vec{J}$, a vector, the expression is

$$P(\vec{J}) = \frac{2\sqrt{2}}{\sqrt{\pi}\, C_{pt}\,(C_{pb}+C_{pw})\pi} \times$$

$$\times \exp\left(-\frac{J_x^2+J_y^2}{C_{pb}+C_{pw}} - \frac{J_z^2}{C_{pt}}\right) \quad ..(4)$$

This shows that the bending and wrigling modes are x and y components and the twisting mode a z-component. The width of the latter component is $C_{pt} = M_t \cdot T_{sp}$ where M_t is the effective mass number for twisting and T the width of temperature at the saddle point.

The quantities in equations (3,4) are plotted by Nix as a function of the fissionability parameter/22/. Once the quantities in eqs. (3,4) are calculated the distribution of J could be obtained and plotted. The results for U-336 are shown in Figs.(1,2). Fig. 1 shows the distribution of the angular momentum for fragments with infinite viscosity (dashed line) and zero viscosity (solid line).

Fig. 2 shows the dependence of the average angular momentum J_{av} on excitation energy at scission point for infinite and zero viscosity cases and for moments of inertia one-half the rigid body value and that of a rigid body. The approximate values of average angular momentum J_{av} for both cases of zero and infinite viscosity are 7.62 ($I=I_{rig}$); 5.22 ($I=0.5I_{rig}$) and 13.1 ($I=I_{rig}$); 11.4 ($I=0.5I_{rig}$) respectively. It is clear that when the moment of inertia is lowered to $I=0.5\,I_{rig}$ the J_{av} decreased by a factor $\sqrt{2}$ for the case of zero viscosity and $(2)^{.25}$ for the other case.

The excitation energy at scission point was chosen as E^*=10Mev based on the estimate of Armbruster/24/. There seems to be a possibility to take the non-zero width of the z-component using Strutensky's first order of approximation by introducing a quantity a defined by

$$a = \frac{\sqrt{C_{pt}}}{\sqrt{C_{pb}+C_{pw}}+\sqrt{C_{pt}}} \quad ..(5)$$

which gives a fractional z-component width and when put in eq (2) one gets

$$\frac{N(\psi)}{N(180)} = 1 + (1 - \frac{3}{2} a)\ k\ \sin^2\psi \quad ...(6)$$

The correction factor a is calculated for U-336 and plotted in Fig. 3, for the cases of zero and infinite viscosity.

From the theory of packed clusters in a fissioning nucleus, the equal angular motion of clusters carries energy few Mev (for U-235). From the definition of packed clusters, the energy of motion of the smaller cluster is found to be $\frac{2}{5}$ E $\simeq$ 1 Mev. The error in locating cluster motion r > nuclear radius.

But the viscous motion of clusters requires a velocity gradient defined by an inter nucleon separation distance far less than nuclear radius. As the error in locating cluster motion is more than the nuclear radius, therefore the velocity gradient cannot be defined for cluster mostion in the nucleus. Hence the degree of viscosity may have an indefinite value which is either zero or infinity. As clusters are only a part of the nucleus, the rest of the nucleus cannot unify with cluster rigidity, therefore infinite viscosity cannot be defined as well. Hence the nuclear viscosity should be zero.

Experimentally/25/ determined direct methods of J_{av} gives 6.4 for U-236 and 6.3, 6.9 for U-234, Pu-240.

Effect of Rigidity:

The presence of clusters in nuclei U-233, U-236 and Pu-239 require that the nuclear rigidity may be more than 30%. The moment of inertia I and the average angular momentum J_{av} of fission fragment are affected by rigidity factor R_g where

$$I = mr^2 R_g = \sum mr^2_{eff} = I'_o R_g \quad ..(7)$$

from which

$$R_g = \sum\left(\frac{r_{eff}}{r}\right)^2$$

As

$$J_{av} = \int \ddot{\theta}\ \frac{I\ dt}{h} = \sum m\ v\ r_{eff} / \hbar$$

Therefore

$$J_{av} = \sum m\ v\ r\ R_g^{\frac{1}{2}} / \hbar = J'_o\ R_g^{\frac{1}{2}} \quad ..(8)$$

The measured anisotropy values related to angular momentum through eq (6)

$$K = k_L\ (1 - \frac{3}{2} a)\ \left(\frac{h J'_o}{I'_o T}\right)^2 \frac{1}{R_g} \quad ...(6a)$$

The relation between the anisotropy and the rigidity eqs (2a, 6a) is plotted in Fig. 4. In the limitting case of no twisting a = 0 one obtains fig. 4A and Fig. 4B is obtained for a = 0.32 (zero viscosity).

From anisotropy values for U-234, U-236 and Pu-240 the fragment rigidity decreases with increasing masses of the fissioning nucleus (Fig. 4).

From experiments higher nuclear excitation temperature yields harder gamma and from equation (6a) higher nuclear excitation temperature yields lower anisotropy, it follows that harder gamma may get lower anisotropy. As from eq. (6a) higher rigidity gets lower anisotropy it follows that the hard gamma is emitted from deecixitation of angular momentum of clusters which have higher rigidity.

As the rigidity of fragment should be at least equal to rigidity from presence of cluster in fragment, it follows that nuclei with higher anisotropy values require too low rigidity values when calculated from Nix and Swiatski' asumptions.

It follows that nuclei of Pu-239, U-235, U-233 may have no twisting and wirggling modes.

The average anisotropy from the light and heavy fragment is $\frac{1}{2}(K_L + K_H)$, as in eq. (9). We assume that clusters carrying angular momentum remain till deexcitation by gamma emission from fragments

As the ratio $J'/I'_o \propto \omega$ angular rotation of cluster which is the same for both clusters. ∴ from eq (6a), the average anisotropy of both fragments

$$\frac{1}{2}(K_L + K_H) = k_L\ (1 - \frac{3}{2} a)\ \left(\frac{\hbar\omega}{T}\right)^2 \left(\frac{M_L + M_H}{2 M_c}\right) \quad ..(9)$$

where M_c = final state cluster mass

and $M_L + M_H = M_o$ = initial nuclear mass

From eq (9), the average anisotropy increases with the mass of the fissioning nucleus, as seen in Fig. 4.

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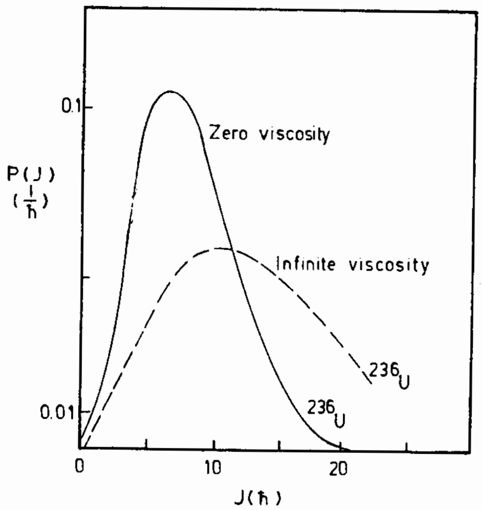

Fig.1; Angular momentum magnitude distribution calculated by expression(3) for infinite and zero viscosities.

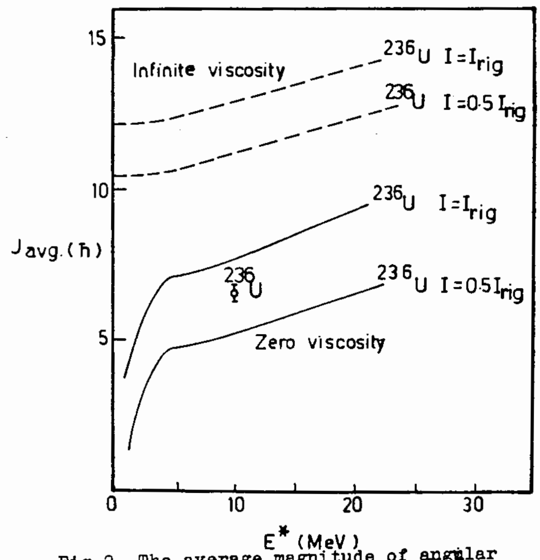

Fig.2 The average magnitude of angular momentum J_{av} against excitation energy E^*. The experimental values(at E^*=10 MeV)are from reference (20).

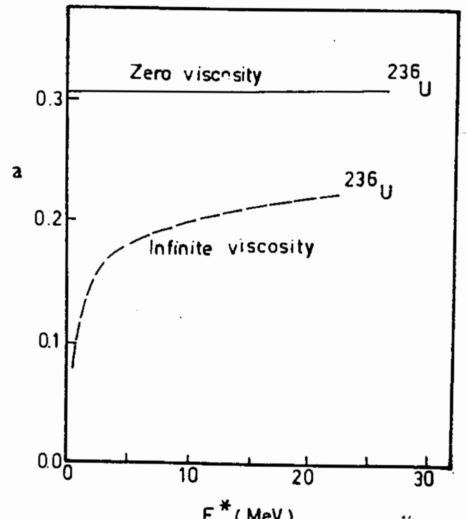

Fig.3 Correction factor $a = \frac{(C_{pt})^{1/2}}{(C'_{pw}+C'_{pb})^{1/2}+C_{pt}}$
Upper curve(solid line) for zero viscosity and lower for infinite viscosity.

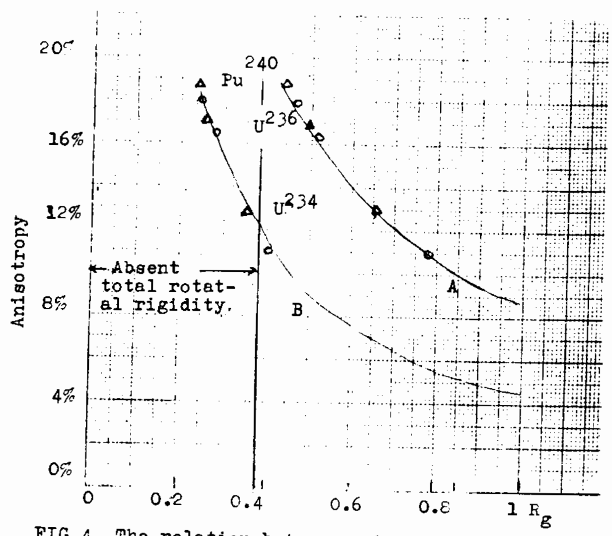

FIG.4. The relation between anisotropy and rigidity using Strutinsky formula(A) and modified formula (B),for two energy bands _ 0.49-0.65 MeV and O 0.38-0.92 MeV