MASS DISTRIBUTION STUDIES IN NUCLEAR FISSION USING LEXAN DETECTOR

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ABSTRACT. An investigation of the ranges of fission fragments from thermal fission of ^{235}U has been made using "Lexan" polycarbonate detector. A method of sandwiching the Uranium between two layers of "Lexan" enabled a simultaneous measurement on the two fragments. The average ranges of the fragments of the light and heavy groups in Lexan were found to be 20.22 ± 0.027 microns and 16.38 ± 0.021 microns respectively. It is found that from the correlated range measurements, the fragment masses can be estimated fairly accurately using an iteration procedure.

INTRODUCTION

The determination of fragment masses in fission by physical methods requires a simultaneous measurement of the kinetic energies or the velocities of the two fragments. In the past, attempts have been made to obtain the fragment mass distribution by measurement of the ranges of fragments using radiochemical methods (Aras *et al*, 1965) and employing known range-energy relationships. Ranges of fission fragments have also been measured using nuclear emulsions (Manley, 1962). In recent years, solid state track detectors are being used increasingly in the detection of fission fragments (Fleischer *et al*, 1965) especially for recording events of low probability such as in photofission. The present work was undertaken to assess the accuracy with which fragment mass distributions could be determined by measuring fragment ranges in the thermal fission of ^{235}U, with a "Lexan" polycarbonate (Fleischer *et al*, 1964) detector. "Lexan" being a primary ionisation threshold detector, records alpha particles of energy only less than 0.5 MeV (Fleischer *et al*, 1967). The study of fission events in the presence of the background of alpha particles was thus possible. Moreover, the ranges of γfission fragments in this detector are larger than those in nuclear emulsions because the stopping power of the polycarbonate is smaller than that of nuclear emulsion. Simplicity of handling and ease of processing of these detectors are added advantages. In the present work the ranges of the two fragments are found simultaneously by using a sandwich technique and fragment masses are derived from the measured ranges by a method of iteration.

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EXPERIMENT

A sandwich of natural uranium was prepared by pressing a drop of 10% uranium nitrate between two layers of Lexan (density 1.25, composition $H_{18}C_{16}O_3$) joined together at one end. The layers which were held pressed between two perspex plates with screws were exposed to a beam of neutrons in the thermal column of "CIRUS" for about a day where the flux of neutrons is about 3×10^7 $n/cm^2/sec$. After exposure, the sandwich was washed and etched in a 6N solution of NaOH at 70°C for about 30 minutes. The fragment tracks were measured by viewing the sandwich under a microscope with a magnification of 1000×. It was found that a drop of sandal wood oil between the layers kept the surfaces in close contact. A dye, 'Nigrosine' was introduced into the tracks to enhance the contrast characteristics. This enabled better accuracy in the measurements. A track density of between 10 and 25 per field of view was maintained. The two surfaces of the sandwich were found to have a lateral displacement of between 5 and 40 microns. The correlation could be obtained easily here from the similarity in direction because of the low track density. A total of 2000 events were scanned and the data analysis was performed on the computer CDC 3600. Measured ranges were corrected for a slight change in the length by a factor connected with the dip angle of the track (Price).

RESULTS AND ANALYSIS

(a) *Range measurements of fission fragments*

The range distributions of light and heavy fragments were obtained from the measurements on correlated fragments making use of the fact that in general lighter fragment has a longer range. These distributions are shown in fig. (1).

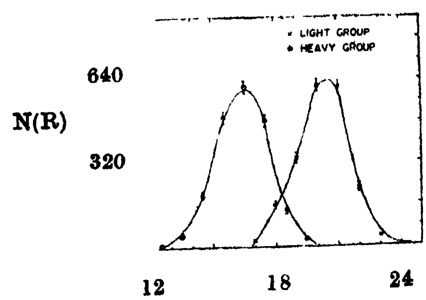

Fig. 1. Range-frequency plot of correlated fragment tracks in Lexan from thermal fission of ^{235}U.

The average ranges of the light and the heavy groups were found to be 20.22± 0.027 microns and 16.38±0.021 microns respectively. These values are about 1.5 times larger than the corresponding ranges in nuclear emulsions (Vigneron,

1950) and about 1.1 times larger than those in the celluloid backing of normal photographic films (Gerhardt *et al*, 1966).

Fig. (2) shows the distribution in the range of one of the fragments for various fixed ranges of the complimentary fragment. It is not necessary here to associate the longer range with the lighter fragment and vice versa. The results are found to be similar to those obtained by Brunton and Hanna (1950) for the kinetic energies

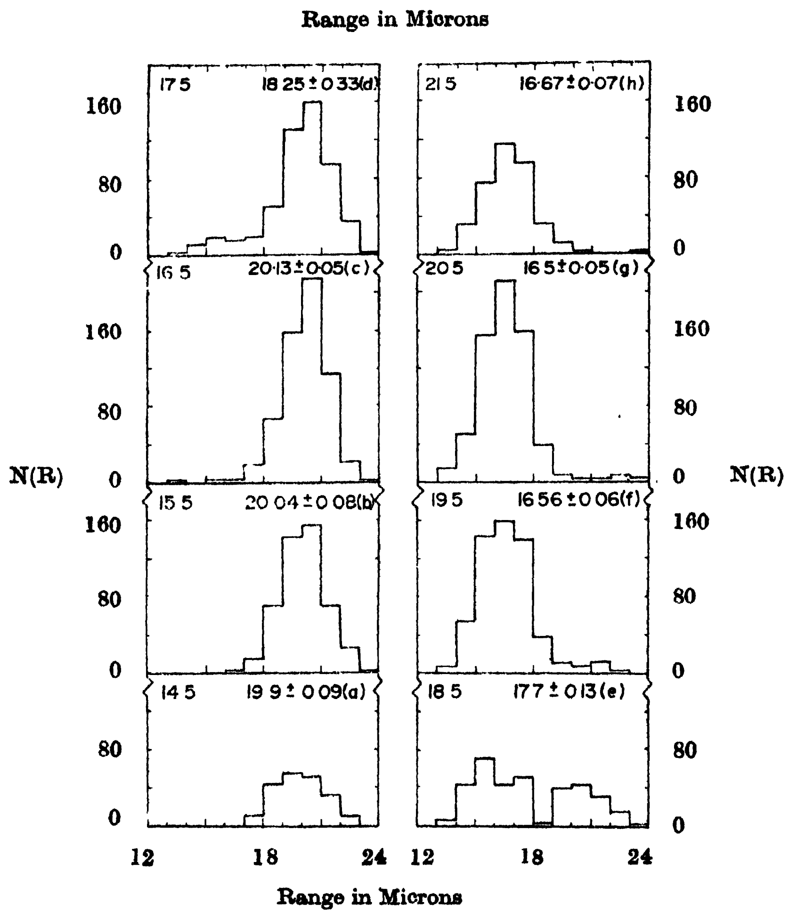

Fig. 2. The distribution in range of one fragment for various fixed ranges of the complimentary fragment. The number on the left hand top corner, of represents the range of the fixed fragment. The mean of the distribution obtained is represented on the right hand top corner. The error given is statistical.

of fission fragments. This suggests the validity of a direct correspondence between range and energy. However, since most of the contribution to the spectra of fig. (2) comes from the most probable masses, any breakdown of the direct correspondence in other mass regions may not be apparent here.

Fig. (3) shows the obtained distribution in the total range of the two fragments. The experimental points have been fitted to a Gaussian distribution by the least square method. The average value of the total range and its variance are found to be 36.62 microns and 3.23 respectively.

(b) *Determination of mass distributions from range measurements*

Lindhard *et al* (1963) have used the Thomas-Fermi model of the atom to calculate theoretically the range energy relationships for heavy ions. These calculations are based on the Bloch's relation $I = I_0.Z_0$, where I is the average ionisation potential, I_0 is the Bloch's constant and Z_0 the charge number of the medium. This relation is not strictly valid for the detector used here (Brandt, 1956). The mass distribution was obtained here using the range-energy relation given by Barkas and Berger (1964) and applying an iteration procedure as described below.

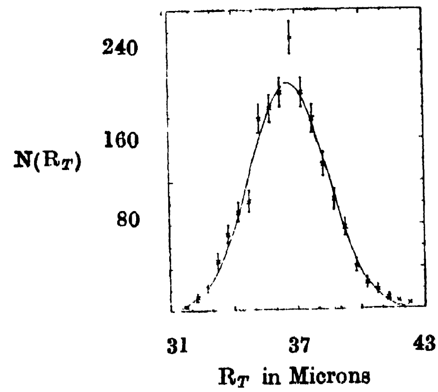

Fig. 3. The distribution in total range of the two fragments. The curve drawn is a gaussian with a mean of 36.62 microns and standard deviation 1.80 microns.

The range R of a fragment of mass M and charge Z, moving with a velocity βC is given by

$$R = \frac{M}{Z^2}\,(\lambda + B_z) \tag{1}$$

where λ is the range of a proton of velocity βC and the term B_z takes into account the range extension caused by the capture of electrons by a positive ion of charge Ze. For the case of "Lexan" used, the value of λ was obtained by a numerical integration of the stopping powers, of the constituent atoms as given by Whaling

(1958) and the value of B_z was evaluated according to Barkas and Berger (1964). These values of λ and B_z are given by

$$\lambda = 84.1264 \times \beta^{10/3} \text{gms/cm}^2 \quad \ldots (2)$$

$$B_z = 7.717 \times 10^{-4} \times M^{5/3} \times \beta \text{ gms/cm}^2 \quad \ldots (3)$$

A constant charge density of 0.394, equal to that of the parent nucleus, was used in arriving at the value of B_z given by equation 3. Assuming a linear relation between energy and range of the fission fragment, approximate fragment masses were first calculated from the relationships

$$M_1 . R_1 = M_2 . R_2 \quad \ldots (4)$$

and

$$M_1 + M_2 = M, \quad \ldots (5)$$

where M is the mass of the fissioning nucleus. These masses M_1 and M_2 were fed back in equations 1, 2 and 3 and the values of β_1 and β_2 were estimated. Better estimates of M_1 and M_2 were then obtained using the rigorous relationship

$$M_1\beta_1 = M_2\beta_2 \quad \ldots (6)$$

These new values of M_1 and M_2 were again fed into equations 1, 2 and 3 and three such iterations were made using the computer. In all the cases the results of the last two iterations were found to be converging to within five mass units. The resultant mass ratio distribution is shown in fig. 4. For the sake of comparison, the mass ratio distributions derived from measurements of fragment

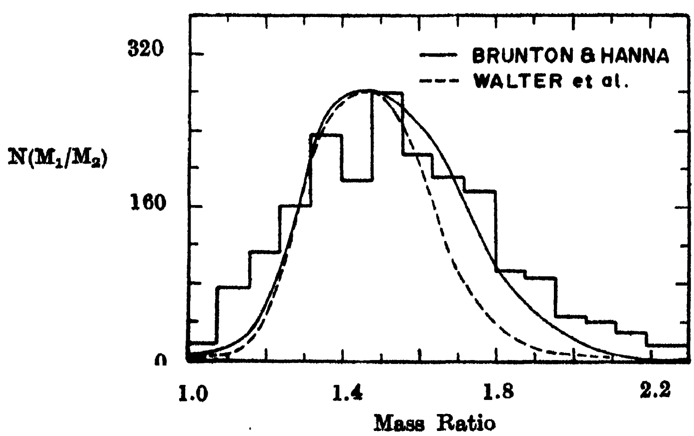

Fig. 4. Plot of mass ratio versus frequency. The histogram refers to the present experiment. The dotted curve is computed from the data of Walter *et al* (1963) and the continuous curve is from Brunton and Hanna (1950)

energies by double ionisation chamber method (Brunton *et al*, 1950) and slid-state detectors (Walter *et al*, 1963) are also shown. It is seen that the present data compare favourably with the results of Brunton and Hanna (1950) except for the region of near symmetry. The agreement of the present results with that of Walter *et al* (1963) is not, however, very good. This discrepancy could be due to not including in our calculations the effect of nuclear stopping also termed "Ionisation defect" (Lamphere, 1960). It must be mentioned here that while Brunton and Hanna (1950) did not correct for the ionisation defect in their results, Walter *et al* (1963) have corrected for the same by an elaborate method of calibration (Schmitt *et al*, 1965) for the solid-state detectors. In any case, the present results show that the range measurements on correlated fragments can be used for approximate fragment mass ratio determinations and therefore this method can be applied to the cases where low counting rates prohibit the use of conventional methods. The method could be improved further by using a better range-energy relationship which takes into account atom-atom elastic collisions as well as experimentally observed fragment charge distributions in fission (Reisdorf *et al*, 1967).

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