ENERGETICS OF THE CHARGED PARTICLE-INDUCED FISSION OF Ra^{226}, Bi^{209}, AND Au^{197}

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(Received January 15, 1962)

A back-to-back semiconductor counter system was used to study the energetics of 10.8-Mev and 13.6-Mev deuteron-induced fission of Ra^{226} and 25-Mev He^3-induced fission of Au^{197} and Bi^{209}. The resulting mass ratio distributions and the variation of the average total kinetic energy release, E_K, as a function of mass ratio are shown in Figs. 1 and 2.

The purpose of this Letter is to point out three interesting characteristics of these results which may give further insight on the basic characteristics of the fission process: (1) The Ra^{226} results give further evidence for the presence of two distinct modes of fission as has been previously hypothesized[1,2] and indicate that the scission shapes may be somewhat different for these two modes; (2) all the data are consistent with the hypothesis that for each mode (symmetric or asymmetric) the total kinetic energy release arises from the Coulomb repulsion of the fragments with the scission shape approximately the same for all mass ratios within a given mode; and (3) these results appear to be basically different from previous spontaneous and thermal-neutron-induced fission results,[3] suggesting that the fission process at moderate excitation energies is somewhat different than at very low excitation energies.

The counter system was calibrated by comparison of time-of-flight results[4] for Cf^{252}. The mass distribution for Cf^{252} spontaneous fission obtained with this equipment compared to the "inherent" distribution[4] indicates a mass resolution of 6 ± 2 mass units, which is approximately equal to the dispersion expected from neutron recoils alone. Therefore, no resolution corrections have been made for the present data because of the lack of information on the neutron emission.

The results shown in Figs. 1 and 2 have been fitted by assuming that E_K is given by

$$E_K = CZ_1Z_2/(A_1^{1/3}+A_2^{1/3}), \qquad (1)$$

where C is a constant obtained for each case from a fit to the data (see figures). The most probable nuclear charges, Z_1 and Z_2, are determined from the formula given by Milton.[5] The Bi and Au results can be fitted quite well with this type of dependence. The radium results can be fitted using two such curves, one for the symmetric mode and one for the asymmetric mode. From the fit to the radium E_K values the mass ratio distributions can be obtained for the symmetric and asymmetric modes, and the results in Fig. 2 show the shapes of these distributions to be the same for the two bombarding energies even though the ratio for the probabilities for the two modes is different. Further evidence for the validity of the two-mode hypothesis is given by the widths of the total kinetic energy distribution

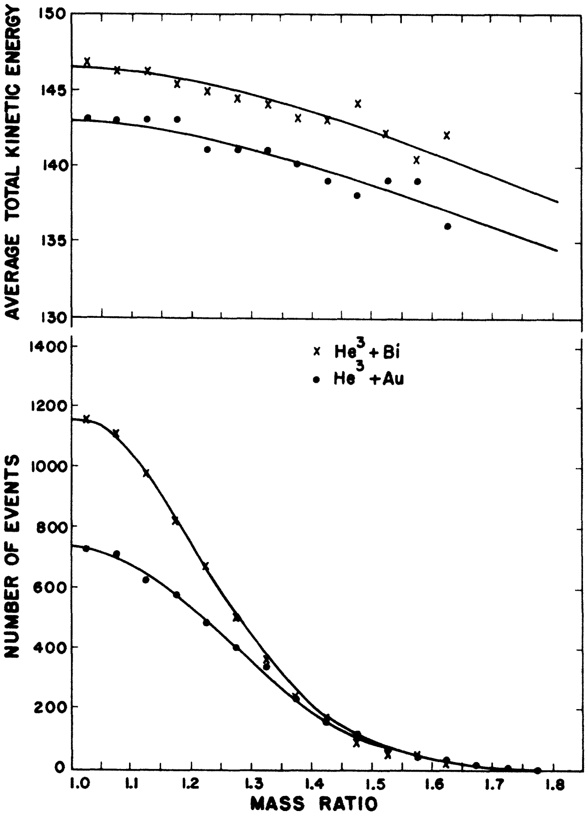

FIG. 1. The mass ratio distribution and the average total kinetic energy released as a function of the mass ratio for the two fragments for the 25-Mev He^3-induced fission of Au^{197} and Bi^{209}. The absolute values for the average total kinetic energy releases are believed to be accurate to ±4 Mev. The solid curves on the total kinetic energy distributions are fits to the data using Eq. (1) (see text) with values for C of 0.77 and 0.81 for the Bi and Au results, respectively.

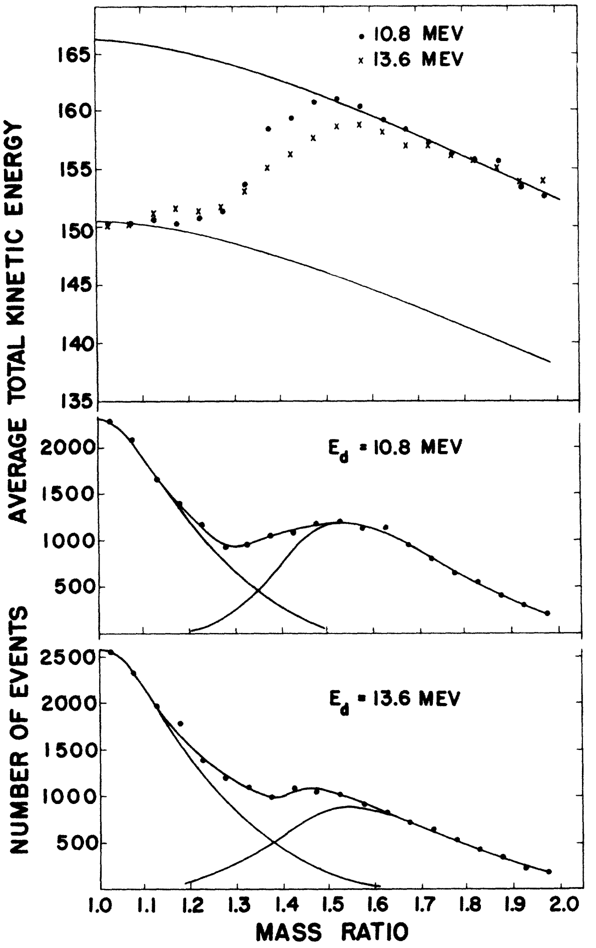

FIG. 2. The mass ratio distributions and the average total kinetic energy released as a function of the mass ratio for the two fragments for the 10.8- and 13.6-Mev deuteron-induced fission of Ra^{226}. The solid curves in the mass ratio distributions are a decomposition into symmetric and asymmetric modes from the average total kinetic energy results. The absolute values for the average total kinetic energy releases are believed to be accurate to ±2 Mev. The solid curves on the total kinetic energy distributions are fits to the data using Eq. (1) (see text) with values for C of 0.74 and 0.81 for the symmetric and asymmetric modes, respectively.

for different mass ratios. For mass ratios near 1.0 or greater than 1.7, where the fission is predominantly from either the symmetric or asymmetric modes, the total kinetic energy distributions have a full width at half maximum of approximately 19 Mev. However, for a mass ratio of 1.35, in the transition region, the width was 29 Mev which is consistent with approximately equal contributions from the symmetric and asymmetric modes with average total kinetic energies separated by 15 Mev.

The fact that E_K can be described by Eq. (1) indicates that for a given mode the shapes of the scission nuclei are approximately the same for all mass ratios. Therefore, the lower total kinetic energies for the symmetric radium mode may indicate that the scission shape for this mode is more elongated than for the asymmetric mode. These two modes may be evidence for the existence of two fission barriers and two saddle-point shapes as predicted from the liquid drop calculations of Cohen and Swiatecki.[6]

Time-of-flight results[7] for the dependence of E_K on mass ratio in the alpha-particle-induced fission of Th^{232} and U^{233} can similarly be fitted by two modes with Eq. (1), but with a smaller C difference than for radium fission.

Previous thermal-neutron and spontaneous fission results[3] show a decrease in E_K with increasing mass ratio that is more rapid than the Coulomb dependence of Eq. (1). It has been shown that these thermal-neutron and spontaneous fission results can be fitted if the dependence of the fragment excitation energy on the mass of the emitted fragment is the same for all fissioning nuclei.[3] The variation of the fragment excitation energy with the mass number of the fragment has been determined from the dependence of the average number of neutrons emitted as a function of mass number.[8] From this variation in excitation energy it appears that the fragment excitations are strongly influenced by the effect of the rigidity of the closed shell configurations $Z = 50$ and $N = 50$ in the emitted fragments.[8]

For these spontaneous and thermal-neutron-induced fission reactions the excitation energies in the fissioning nucleus are near the fission barriers while for the charged-particle-induced reactions, which are fitted by the Coulomb dependence of Eq. (1), the excitations are of the order of 10 Mev or more above the barrier. The difference in the total kinetic energy dependence for these two types of reactions suggests that at moderate excitation energies the closed-shell effects may not be as important as at the lower excitations, and, therefore, the fissioning nucleus may appear more like a charged liquid drop at high excitations.

We are indebted to Dr. R. B. Leachman and Dr. J. J. Griffin for many helpful suggestions concerning the interpretation of these results.

[†] Work performed under the auspices of the U. S. Atomic Energy Commission.

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ANOMALOUS $E2$ INTERNAL CONVERSION COEFFICIENTS FOR ROTATIONAL TRANSITIONS*

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(Received December 18, 1961)

Experiments[1-3] along with theoretical considerations[4,5] have shown that it is possible to have significant contributions to internal conversion coefficients which are due to dynamic effects and depend on the wave functions of the nuclear states. The usefulness of these contributions to the internal conversion process in obtaining new information about the nucleus has been pointed out by Church and Weneser.[4] The theoretical calculations[4,5] indicate that these effects should be appreciable only when the gamma-ray transition rate is hindered. However, the experiments of McGowan and Stelson[2] indicated significant deviations of the conversion coefficients for several highly enhanced $E2$ transitions between rotational states. The purpose of this note is to point out that experimental evidence exists which indicates that many of the conversion coefficients for enhanced $E2$ transitions between rotational states are not in agreement with the theoretical values[6] and also that the discrepancies can be correlated with the ratio of neutrons to protons in the nucleus.

Experimental values of the conversion coefficients can be obtained from a comparison of the cross section for Coulomb excitation of a level with the measured lifetime of the level. Rather accurate values of both of these quantities exist[7] for a large number of rotational transitions in deformed even-even nuclei. The most accurate Coulomb excitation cross sections are obtained by measuring the inelastically scattered projectiles. Previously the lifetime and Coulomb excitation data were analyzed from the point of view of comparing the reduced $E2$ transition probabilities, $B(E2)$, which can be obtained directly from the Coulomb excitation cross sections with the $B(E2)$ values which were calculated from the mean lives by using the theoretical internal conversion coefficients. It has been pointed out several times that on the average (except for a few cases which have rather large discrepancies) the $B(E2)$ values obtained from the two methods differ by only a few percent.[7-9] However, the $B(E2)$ values calculated from the mean lives depend on the quantity $(1+\alpha)$, where α is the total conversion coefficient. Thus, for incorrect conversion coefficients, the calculated value of $B(E2)$ will not deviate as much as α itself since the deviation in $(1+\alpha)$ depends on the absolute value of α. For example, in Gd^{154} where α is not much greater than unity, the $B(E2)$ value calculated from the lifetime using the theoretical conversion coefficient differs by only about 10% from the $B(E2)$ value obtained from the Coulomb excitation cross section; however, the conversion coefficient calculated from the lifetime and the cross section differs by 26% from the theoretical value.

It is also possible in the calculations to use Coulomb excitation cross sections obtained from gamma-ray measurements. However, in most cases the gamma-ray results are rather uncertain and the various determinations of the cross sections differ considerably.[8,10] Therefore, the only gamma-ray results included in the evaluation of the conversion coefficients are the recent rather accurate measurements of Goldring and Vager.[8]

For the heavier elements most of the Coulomb excitation cross sections have been obtained by observing the conversion electron decays.[11] Although the errors are somewhat larger for this type of measurement when compared with the accuracy of the measurements of the inelastically scattered particles, the results have been included for the sake of completeness and also for the rea-