SOVIET PHYSICS JETP VOLUME 36(9), NUMBER 3 SEPTEMBER, 1959

FISSION INDUCED IN HEAVY ELEMENTS BY CARBON, NITROGEN, AND OXYGEN NUCLEI

S. M. POLIKANOV and V. A. DRUIN

Submitted to JETP editor September 13, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 744-747 (March, 1959)

The energy dependences of the cross sections for bismuth and uranium fission induced by accelerated C^{12}, N^{14}, and O^{16} nuclei are presented along with the dependences of the gold, rhenium, and ytterbium fission cross sections on the N^{14} ion energy. The measurements were performed with an ionization chamber and a monochromatic beam from a 150-cm cyclotron. Experimental results of the measurement of the ranges and angular anisotropies of the U^{238} and Au fission fragments produced by accelerated C^{12} ions are also presented.

MULTIPLY-CHARGED ions interact with nuclei of heavy elements to form compound nuclei excited to an energy equal to several tens of Mev. The decay of these nuclei proceeds either via fission or via neutron evaporation. The relation between these two processes depends on the charge and mass of the compound nucleus and on the excitation energy. We have carried out several experiments on the determination of the fission cross section of several elements irradiated by multiply-charged ions. In addition, we began experiments on the more detailed investigation of the fission process, in particular on the study of the angular distribution and the ranges of the fragments.

We report below the result of these experiments.

1. EXPERIMENTS ON THE DETERMINATION OF THE FISSION CROSS SECTION OF NUCLEI INTERACTING WITH MULTIPLY-CHARGED IONS

Experiments on the determination of the fission cross section were performed both inside the cyclotron chamber as well as with the external ion beam at a distance of 12 meters from the cyclotron. We investigated the energy dependences of the fission cross sections σ_f of various elements acted upon by C^{12}, N^{14}, and O^{16} nuclei.

In the experiment with the external beam, the fission fragments were registered with an ionization chamber. In this case we determined both the relative course of the curve $\sigma_f = f(E)$ and the absolute magnitude of the fission cross section. In experiments with the internal beam we determined only the relative variation of σ_f with energy of bombarding particle. The fragments were identified by their beta activity.

The energy of carbon, nitrogen, and oxygen ions, as determined from their absorption in aluminum and from the energy dependence of the ion range in aluminum as determined experimentally in our laboratory.[1] The particle energy was varied by placing aluminum absorbers in front of the target.

In the first experiments on the fission of uranium, bismuth, gold, and rhenium by nitrogen nuclei,[2] the energy of the N^{14} was measured and varied with the aid of a focusing magnet, placed between the ionization chamber and the cyclotron. The magnet was calibrated here with deuterons of known energy. However, owing to a certain difference between the trajectories of the multiply-charged ion and the deuteron, and also owing to the presence of ions entering the gap of the focusing magnet at different angles, the energy of the multiply-charged ion corresponding to a specified value of the magnetic field was not determined sufficiently accurately. Experiments with aluminum absorbers permitted to dispense with the calibration of the focusing magnet and made it possible to obtain a more exact energy dependence of the cross section. The results of the experiments are shown in Figs. 1, 2, and 3.

It is seen from Figs. 1 and 2 that the cross section of fission of Bi and U^{238} by C^{12}, N^{14}, and O^{16} nuclei are adequately described by the following formula

$$\sigma = \pi r_0^2 (A_{\text{targ. nuc.}}^{1/3} + A_{\text{part.}}^{1/3})^2 (1 - B/E)$$

with $r_0 = (1.4 - 1.5) \times 10^{-13}$ cm for bombarding-particle E energies exceeding the coulomb barrier B. Figure 3 shows the great dependence of the fission cross section on the Z^2/A of the compound nucleus for a specified excitation energy.

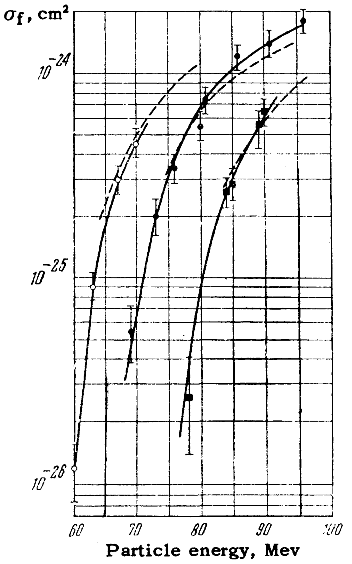

FIG. 1. Dependence of the fission cross section of bismuth on the ion energy: ○ – C, ● – N, ■ – O (solid lines – experimental curves, dotted lines – calculated from the formula $\sigma = \sigma_0(1 - B/E)$ for values of r_0 = 1.5 f (light circles) and 1.55 f (solid circles).

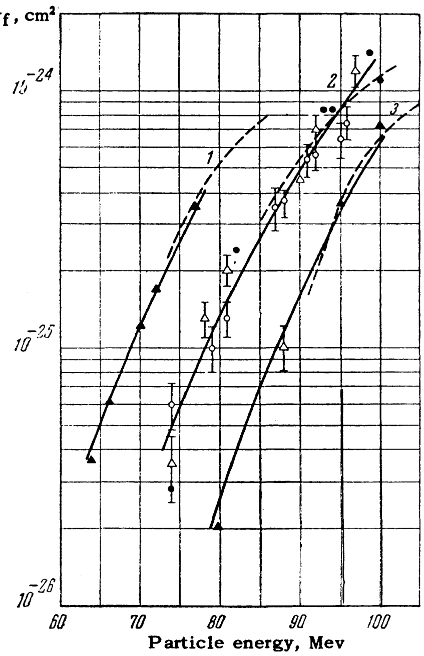

FIG. 2. Dependence of the uranium fission cross section on the ion energy: 1) C, 2) N, 3) O. Solid curves – experimental, dotted – theoretical for r_0 values of 1.4 f (1), 1.45 f (2), and 1.52 f (3). Δ – chamber data for U^{238}, ○ – chamber data for U^{235}, ●▲ – activation data for U^{238}.

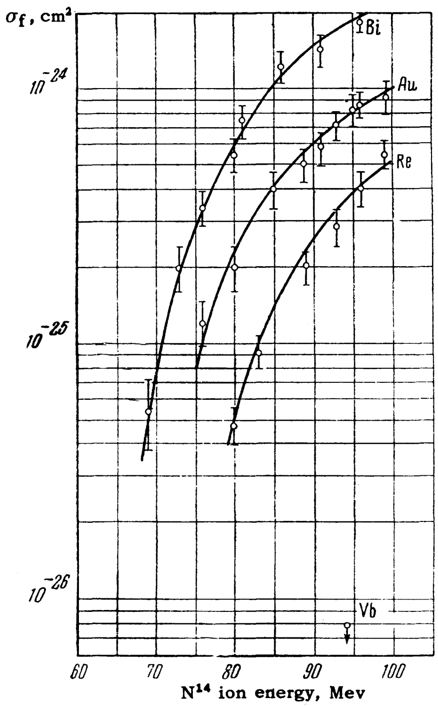

FIG. 3. Dependence of the fission cross section of bismuth, gold, uranium, and ytterbium on the energy of the N^{14} ions.

2. ANGULAR DISTRIBUTION AND RANGES OF FRAGMENTS OF THE FISSION OF URANIUM AND GOLD BY CARBON

One of the features of the reactions that occur in the interactions with multiply-charged ions is that the resultant compound nuclei have large angular momenta. Theoretical estimates made by Strutinskiĭ and Pik-Pichak (private communication) show that the large angular momentum of the compound nucleus leads to an anisotropic distribution of the fission fragments. One can expect the fission fragments to be emitted essentially in the forward direction.

We undertook an experimental investigation of the angular anisotropy in the fission of nuclei of uranium and gold by carbon nuclei. In the performance of these experiments we also succeeded in obtaining experimental estimates of the ranges of the fragments.

The experiments were made in the internal cyclotron beam. The fission fragments emitted at angles of 90 and 135° to the beam of incident particles were registered. The targets employed were thick foil (several microns) of uranium and gold, located at 45° to the carbon-ion beam. The fission fragments, emitted at angles of 90° and 135°, were stopped in 35-micron aluminum foils placed at these angles. After irradiation for an hour, the number of beta particles emitted from these foils was measured. No chemical separation of the fragments was made. This involves the danger of appearance of a background due to the activation of the aluminum and of its various impurities by neutrons and scattered carbon nuclei. However, control experiments carried out by irradiating a copper foil instead of an uranium or gold foil have shown that the background can be neglected in practice. The experiments have shown that the ratio of the activity of a foil at 135° to that of a foil at 90° is 1.18 ± 0.06 for uranium and 1.48 ± 0.06 for gold. Here the fragments registered are those leaving a layer of thickness equal to the range of the fragment. The fragment-registration efficiency for 135° is therefore higher than that for 90°. Knowledge of the dependence of the fission cross section on the energy makes it possible to determine this difference. After taking this difference into account, we obtain for $J(135°)/J(90°)$ values of 1.05 ± 0.10 for uranium and 1.21 ± 0.10 for gold. A recalculation to the center-of-mass system yields $J(141°)/J(99°) = 1.15 \pm 0.10$ for uranium and $J(142°)/J(101°) = 1.36 \pm 0.13$ for gold. The effect obtained is averaged in the carbon energy range of 73 — 78 Mev.

The measurements began immediately after termination of the irradiation and continued until the number of counts became comparable with the counter background. The ratio of the activities of the foils remained almost constant in this case.

In addition to experiments on the angular anisotropy, we made an experimental estimate of the fragment ranges. For this purpose we placed other aluminum foils, 5, 7, or 10μ thick in front of the 35-μ aluminum foil. After irradiation we measured the ratio of the activity of the first foil to that of the 35-μ foil. This ratio is related to the fragment range R as follows

$$R = \Delta [1 + (N_{35} / N_x) \alpha],$$

where Δ is the thickness of the first foil, N_{35}/N_x is the ratio of the activity of the 35-μ foil to the activity of the first foil, and α is a coefficient that accounts for the change in the fission cross section with the depth of the layer of the fissioning substance.

It is seen from the experiments that in changing from a 5-μ foil to a 10-μ foil the ratio N_{35}/N_x diminishes, in the case of uranium, by a factor 7.5 for 90° and 8.2 for 135°, while in gold the decrease is 10 and 27 fold for 90° and 135° respectively.

After processing the experimental data we obtain the following values for the range of aluminum fragments (in microns):

Angle	Element	
	Uranium	Gold
90°	11.2±0.8	10.8±1.0
135°	11.1±0.8	10.1±1.0

The authors are indebted to Prof. G. N. Flerov for continuous attention to the work. We thank Yu. V. Lobanov for help in the measurements and in the processing of the results.

[1] Yu. Ts. Oganesyan, J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 936 (1959), Soviet Phys. JETP this issue, p. 660.

[2] Druin, Polikanov, and Flerov, J. Exptl. Theoret. Phys. (U.S.S.R.) **32**, 1298 (1957), Soviet Phys. JETP **5**, 1059 (1957).

Translated by J. G. Adashko
137