HALF-LIFE OF A SPONTANEOUSLY FISSIONING ISOMER

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The half-life of a spontaneously fissioning isomer obtained by bombarding U^{238} with O^{16}, Ne^{20}, and Ne^{22} ions is measured and found to be 13.5 ± 1.2 msec. The spontaneous fission of the nuclei was recorded with nuclear emulsions. By comparing the various lifetimes measured it is concluded that the same isomer is observed in these reactions.

In earlier papers [1,2] we described experiments on the observation and identification of spontaneous fission of an isomer with anomalously short half life, obtained by bombarding U^{238} nuclei with O^{16} and Ne^{22} ions. The half life of this isomer was found to be 17 ± 8 milliseconds [2]. Subsequent experiments [3] have shown that spontaneous fission with very short half life is observed also in the interaction between accelerated Ne^{20} and B^{11} ions with U^{238}. However, the half lives obtained from the ratio of the pulses registered in two ionization chambers do not lead to any conclusion as to whether the same isomer was observed in these reactions [3].

The experiments described here were undertaken in order to obtain more reliable information on the half life of this spontaneously-fissioning isomer. Such information is essential for the identification of this isomer, which is obtained in different reactions. The U^{238} was bombarded with O^{16}, Ne^{20}, and Ne^{22} in the internal beam of the U-300 cyclotron of the Laboratory for Nuclear Reactions of the Joint Institute for Nuclear Research. The setup described in [1,2] was used and was additionally outfitted with a semiconductor detector for the measurement of the accelerated-ion energies [3]. The detectors used for the fission fragments were type P-8 nuclear emulsions. When the internal beam of a cyclotron is used, registration of nuclear fission with emulsions has many advantages over ionization chambers.

First, the registration of the coordinates and the emission angles of the fission fragments in emulsion make it possible to determine the time between the production and the decay of the nuclei of this isomer, and then to determine the half-life by the maximum-likelihood method [4]. On the other hand, a large number of ionization chambers cannot be used with the internal beam.

Second, nuclear emulsions, other conditions being equal, have a higher efficiency of registration of fragments from nuclear fission than ionization chambers (or semiconductor detectors), the pulses from which must be blocked during the time that the ions are accelerated in the cyclotron.

Emulsions have a small background when nuclear fission is registered. According to our measurements, the background is less than one event per 10 μA/hr of bombardment with ions of oxygen or neon. A shortcoming of emulsions is the impossibility of obtaining information on the registration of spontaneous nuclear fission during the course of the experiment. This makes their use inconvenient when searching for new spontaneously fissioning nuclei. In the measurements of the spontaneous-fission periods we used ten type P-8 photographic plates simultaneously. The arrangement of the plates has been reported earlier [2].

To prevent peeling of the plates, they were treated in equal parts of water, glycerine, and alcohol. The plates were then marked with fragments from the fission of U^{235} by thermal neutrons, in order to monitor the bombardment process and the subsequent photographic development.

Experiments on the measurement of the periods of spontaneous fission were carried out both in a vacuum and in an atmosphere of argon and methane at 150 mm Hg. The system was filled with gas in order to cool the target, the ion collector, the inlet foil, and the recoil-nuclei collector. The use of gas cooling has made it possible to increase the oxygen and neon ion beam intensities to 5—7 μA, and thus reduce the time of bombardment in the cyclotron.

Following the exposure, the P-8 plates were oxidized in water vapor at 35°C for 2—4 hours, and then developed in an iron-oxalate developer for 1.5—2 hours at 15°C [5]. Prior to drying, the

plates were impregnated in a solution of glycerine, thus reducing the shrinkage of the emulsion to 1.2 —1.6. The developed photographs were scanned under a magnification of 300x—400x by two observers in succession so as to reduce the number of missed fission-fragment tracks.

The half-life was determined for each bombardment, starting from the known geometry of the photoplate arrangement, the period of rotation of the recoil-nuclei collector, and the number of tracks found on each plate. The geometrical efficiencies for the registration of the fission events which occurred on the collector were the same for all the plates. The efficiency of registration of spontaneous fission on the photographic plates was (50 ± 7)%. It was determined by the finite dimensions of the emulsions, by the layer of gas, by the aluminum-foil shield between the collector of the recoil nuclei and the emulsions, by the "knock-in" of the recoil nuclei at depths up to 2 μ in the aluminum collector, and by the omission of tracks with steep dip angles during the scanning. The emulsions covered approximately $^2/_5$ of the periphery of the recoil-nuclei collector. Thus, the geometrical efficiency of the emulsions was close to 20% of the total solid angle of the recoil-nuclei collector. It must be noted that, in spite of the shielding aluminum foil, the first emulsion was usually fogged in the case of bombardments with gas, owing to heating or to the action of the ionized gas. This made it impossible to scan the first emulsions in some of the experiments.

In the present series of the experiments we investigated in greater detail the dependence of the spontaneous fission cross sections and periods, for the interaction between the O^{16} ions and U^{238} at different energies. It was found that, within the limits of error, the half lives are the same at O^{16} ion energies from 92 to 119 MeV (see the table), regardless of the presence or absence of a mixture of cooling gases.

Thus, in experiments with O^{16} ions no indications were observed of the presence of isomers with half-lives different from those measured.

The measurements of the half lives were carried out also for the interaction between Ne^{20} and Ne^{22} ions with U^{238}. These periods coincide, within the limits of errors, with the period obtained from experiments with O^{16} ions. Bombardment with Ne^{20} was carried out with the recoil-nuclei collector rotated both clockwise and counterclockwise. The half lives of the isomer were found in these experiments to equal 14.1 ± 3 and 14.3 ± 3.5 milliseconds, respectively, thus confirming the identical geometrical efficiency for the registration of fission fragments by all the photographic plates.

Thus, in the experiments with Ne^{20} and Ne^{22} no deviations were noted in the half lives apart from measurement errors. These experiments serve as proof of the fusion of one and the same spontaneously fissioning nucleus in the reactions between O^{16}, Ne^{20}, and Ne^{22} with U^{238}.

Therefore, in determining the more exact value of the half-life of this isomer, the number of tracks obtained for all the series of measurements was summed for the second to tenth emulsions inclusive. The results of this summation are shown in Fig. 1. The time scale on this figure is in terms of the period of revolution of the recoil-nuclei collector, and is reckoned from the instant of passage of the collector over the center of the target.

The half-life of the spontaneously fissioning isomer was determined by the maximum-likelihood method [4]. It was found to be 13.5 ± 1.2 milliseconds. In addition to measuring the half-life, we also determined the cross sections for the production of this isomer for the interactions of the O^{16}

No. of experiment	Reaction	E, MeV	Number of events	$T_{1/2}$, msec	Rotation of collector	Gas pressure, mm Hg
1	$U^{238}+O^{16}$	92	47	14.1±4	cw	150
2	$U^{238}+O^{16}$	96	87	10.7±2	»	150
3	$U^{238}+O^{16}$	101.0	120	10.5±1.7	»	Vacuum
4	$U^{238}+O^{16}$	103	203	15.2±2.2	»	150
5	$U^{238}+O^{16}$	111.5	35	15±4.2	»	Vacuum
6	$U^{238}+O^{16}$	119	20	13.3±4.5	»	Vacuum
$\Sigma_1^6 n$	$U^{238}+O^{16}$	—	466	13.4±1.4	»	—
7	$U^{238}+Ne^{20}$	118	89	14.1±3	»	150
8	$U^{238}+Ne^{20}$	116	67	14.3±3.5	ccw	150
$\Sigma_{7,8}$	$U^{238}+Ne^{20}$	—	156	14.2±2.2	»	150
9	$U^{238}+Ne^{22}$	150	66	12.3±3	»	Vacuum
Σ_1^9	$U^{238}+O^{16},Ne^{20,22}$	—	699	13.5±1.2	»	—

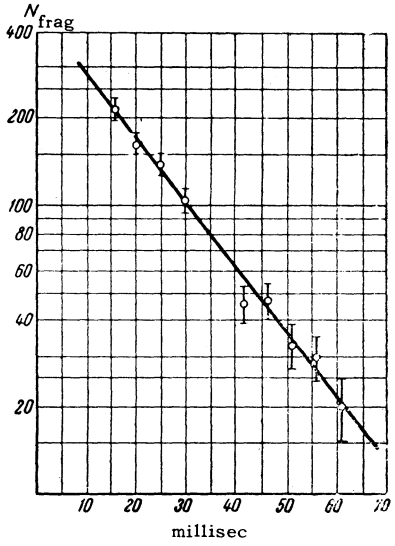

FIG. 1. Decay of spontaneously fissioning isomer (ordinates—number of observed fission fragments).

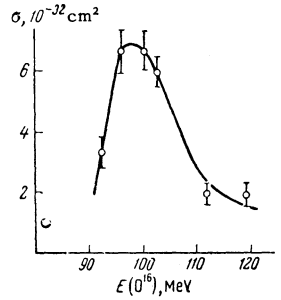

FIG. 2. Dependence of cross section for the production of a spontaneously fissioning isomer on the energy of the O^{16} ions.

ions with U^{238} at ion energies from 92 to 119 MeV. The results of these measurements are shown in Fig. 2.

It must be noted that the cross section for the production of the spontaneously fissioning isomer, obtained in experiments without the cooling gas, turns out to be approximately twice as large as in experiments with the gas. This result can be attributed to the smallness of the momentum transferred to the compound nucleus in grazing interaction, and to the large thickness of the U^{238} target. Therefore, a considerable part of the recoil nuclei has low energy, is slowed down in the gas layer, and does not strike the aluminum collector. The excitation function for the formation of a spontaneously fissioning isomer in the reaction between O^{16} and U^{238} agrees well with the data of Polikanov et al[3]. The cross section for the production of the isomer at the maximum of the curve was found to be $(7 \pm 2) \times 10^{-32}$ cm^2. It must be noted that the fall off in the excitation curve, which we obtained for this reaction at high energies, was obtained in bombardments without a cooling gas, that is, the deceleration in the gas did not influence noticeably the course of the excitation curve obtained in the cited work[3].

The main result of the present experiments was the establishment of the fact that within the limits of measurement errors all the decay curves of a given isomer have one half life, 13.5 milliseconds. Measurements of the half life for U^{238} bombarded with Ne^{29}, Ne^{22}, and O^{16} ions have made it possible to conclude that the same spontaneously fissioning isomer is produced in these reactions.

Knowledge of the half life of a given isomer is necessary, first, in the search for new spontaneously fissioning nuclei and their identification by half life; second, the half life is essential in order to establish the presence or absence of α decay of a given isomer, which competes with the spontaneous fission.

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