SOVIET PHYSICS JETP VOLUME 17, NUMBER 3 SEPTEMBER, 1963

PRODUCTION OF NUCLEI WITH AN ANOMALOUS SPONTANEOUS FISSION PERIOD IN REACTIONS INVOLVING HEAVY IONS

S. M. POLIKANOV, WANG T'UNG-SENG, Chr. KECK, V. L. MIKHEEV, Yu. Ts. OGANESYAN, A. A. PLEVE, and B. V. FEFILOV

Joint Institute of Nuclear Research

Submitted to JETP editor August 18, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) **44**, 804—807 (March, 1963)

The interactions of heavy ions (Ne, O, B) with uranium nuclei which lead to the formation of a spontaneously fissioning isotope with an anomalously small lifetime were investigated. The yield curves for the spontaneously fissioning isotope in various reactions were obtained and the half-life was measured. It is suggested that transfer reactions occur with the Ne and O ions and that the atomic number of the unknown isotope is $Z \leq 97$.

INTRODUCTION

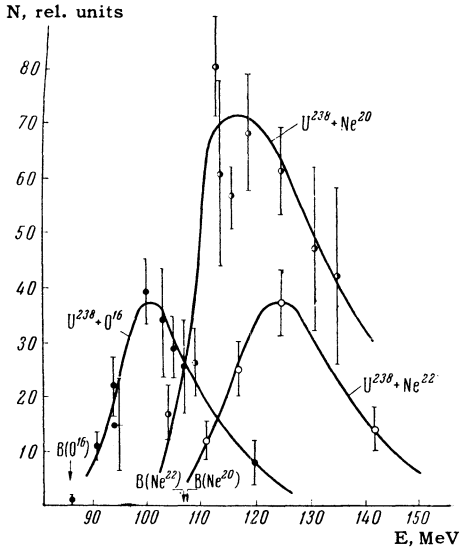
THE detection of spontaneous fission with an anomalously short period has been reported earlier.[1] Spontaneous fission fragments were observed in the bombardment of U^{238} by Ne^{22} and O^{16} ions. The probability of spontaneous fission of the obtained nuclei proved to increase at least 10^9 times in comparison with the probability for spontaneous fission from the unexcited state of the isotopes which can be produced in the interaction of O^{16} and Ne^{22} ions with U^{238}. To explain such a large increase in the probability of spontaneous fission, the isotopes produced in these reactions should be identified, the characteristics of the excited state of these nuclei determined, and the mechanism of the reaction leading to their production explained. It is also of interest to consider whether the observed phenomenon is unique or widely occurring, i.e., whether there exists a large number of isomers of different isotopes with different periods for spontaneous fission.

In the present experiment we measured the half-lives and yield curves for the spontaneous fission of nuclei produced in the bombardment of U^{238} by O^{16}, Ne^{20}, and Ne^{22} ions, of U^{238} by B^{11} ions, of U^{235} by O^{16} ions, and of Th^{232} by Ne^{22} ions.

EXPERIMENTAL METHOD AND RESULTS OF THE MEASUREMENTS

The experiments were carried out in the internal beam of the 300-centimeter cyclotron of the Joint Institute of Nuclear Research which accelerates heavy ions. To record the fragments of spontaneous fission we employed an apparatus described earlier.[1]

The products of the interactions of heavy ions with the target nuclei were knocked out of the thin target as a result of the high momentum obtained by them from the incident ions and were stopped on a collector rotating at 840 rpm. The collector consisted of an aluminum-foil ring mounted on a stainless-steel disc. The nuclear reaction products falling on the collector were carried first to one ionization chamber and then to a second, where the spontaneous fission fragments were recorded. Instead of the ionization chambers we were able to use photographic emulsions[2] to record the spontaneous fission fragments, which made it possible to obtain 10 points on the decay curve of the spontaneously fissioning isotope. An additional arrangement was introduced which allowed us to continu-



Reaction	$U^{238}+B^{11}$	$U^{238}+O^{16}$	$U^{238}+Ne^{20}$	$U^{238}+Ne^{22}$
Number of pulses on first chamber	82	130	289	89
Number of pulses on second chamber	20	28	30	16
Calculated value $T_{1/2}$, msec	15.6±2.8	14.3±1.9	9.7±0.8	12.9±2.1

Note: The values shown for the half-lives determined from the ratio of the effects on both chambers may actually represent some mean values for several isomers with different half-lives.

ously monitor the ion energy by means of a silicon detector [3] without disturbing the measurements of the effect. Shown in the figure are the yield curves for spontaneously fissioning nuclei obtained in the bombardment of U^{238} by O^{16}, Ne^{20}, and Ne^{22} ions. In these experiments the measurement accuracy for the ion energy E was 2% and the energy spread of the beam was a few percent. The yield curves for the bombardment by O^{16} and Ne^{22} ions were somewhat different from the analogous curves reported earlier. [1] The difference was connected with the fact that in the previous work the measurements were not made with high accuracy and the energy was not monitored continuously.

Experiments on the bombardment of U^{235} by O^{16} ions at a different energy showed that the cross section for the reaction leading to the production of a spontaneously fissioning isotope in this case is at least one order of magnitude smaller than in the bombardment of a U^{238} target by O^{16} ions.

Experiments on the bombardment of Th^{232} by Ne^{22} ions, in which the same compound nucleus as in the case of the $U^{238} + O^{16}$ reaction is produced, showed that the cross section of the reaction considered by us is approximately two orders of magnitude less than in the bombardment of U^{238} by O^{16} ions.

The bombardment of U^{238} by B^{11} ions showed that in this case, too, the spontaneously fissioning isotope is produced; the yield of the corresponding reaction was several times greater than, for example, in the bombardment of U^{238} by O^{16} ions. For the case of $U^{238} + O^{16}$ the decay curve for the spontaneously fissioning nuclei has been studied at an ion energy of 102 MeV. It was obtained in experiments with photographic emulsions by V. P. Perelygin. Within the limits of statistical error, only one half-life period is evident. Calculations by the method of least squares yielded the value 14 ± 1 msec.

Assuming that we are dealing with only one half-life, we can estimate the period from the ratio of the counts in the two chambers. The data obtained in this way for different bombarding ions are collected in the table; the errors in the values of the half-lives take into account only the statistical rms errors in the number of recorded pulses.

DISCUSSION OF RESULTS

The yield curves for the spontaneously fissioning nuclei in the reactions $U^{238} + O^{16}$, $U^{238} + Ne^{20}$, $U^{238} + Ne^{22}$ are shown in the figure. The curves are of similar shape and have a maximum.[1] Estimates of the cross sections for the production of the spontaneously fissioning nuclei for the maxima of the yield curves give $\sim 2 \times 10^{-32}$ cm^2 for the $U^{238} + Ne^{22}$ and $U^{238} + O^{16}$ reactions and $\sim 4 \times 10^{-32}$ cm^2 for the $U^{238} + Ne^{20}$ reaction. The fact that the spontaneously fissioning isotope is produced in the $U^{238} + B^{11}$ reaction leads to the conclusion that its charge is $Z \leq 97$. Further experiments on the bombardment of U and Pu isotopes by B, Be, and He ions should give a final answer to the question of the charge and mass number of the spontaneously fissioning isotope.

As regards the mechanism of the reaction leading to the production of nuclei with the unusual properties, we can say that in the case of the U + O and U + Ne reactions the isotope of interest to us is apparently not a product of a compound-nucleus decay. This conclusion follows from a comparison of the results of the $U^{238} + O^{16}$ and $Th^{232} + Ne^{22}$ experiments. In the case of the complete fusion of the interacting nuclei, the compound nucleus Fm^{254} is produced in both cases. Then the yields of any given product of the compound-nucleus decay cannot differ basically. Thus, it was shown in [4] that for the evaporation of four nucleons from this same compound nucleus Fm^{254} the yield of Fm^{250} in the $U^{238} + O^{16}$ reaction is only four times as great as in the $Th^{232} + Ne^{22}$ reaction. Meanwhile, in our case the yield of the $U^{238} + O^{16}$ reaction is approximately two orders of magnitude greater than the yield of the $Th^{232} + Ne^{22}$ reaction. Complete fusion apparently does

---

[1] The Coulomb barriers of the reactions are indicated by the arrows in the figure.

not occur, but some of the nucleons of the bombarding nucleus are transferred to the target nucleus. In favor of this suggestion is the fact that the yield weakly depends on the identity of the bombarding particle (O^{16}, Ne^{20}, Ne^{22}), while the effect sharply changes with a change in the target nucleus (Th^{232}, U^{235}, U^{238}). This conclusion is also confirmed by the fact that the production of a nucleus with $Z \leq 97$ by means of the evaporation of nucleons from a compound nucleus requires the emission of such a large number of nucleons that this process is energetically impossible.

In the case of O and Ne ions, a reaction in which two α particles are transferred to the U^{238} nucleus with a possible subsequent emission of neutrons leading to the production of a Cm isotope is probable. In this connection it should be noted that a definite correlation between the binding energy of the two α particles in the bombarding ion and the cross section of the corresponding reaction is observed. The binding energy of the two α particles is 14.4 and 15.9 MeV for O^{16} and Ne^{22} and 10.8 MeV for Ne^{20}. In conformity with this, the reaction yield changes: in the first two cases the yields are close to one another and in the case of Ne^{20} the yield is almost twice as great.

In the case of the $U^{238} + B^{11}$ reaction, the complete fusion reaction with the subsequent evaporation of a proton and several neutrons can lead to the production of Cm isotopes. Here the isotopes Cm^{243}—Cm^{246} can be obtained.

The products of the transfer reaction can have their own characteristic angular distribution. The study of the angular distributions gives additional information on the reaction mechanism and the influence of the transferred angular momentum, which can play an important role in the production of an isotope with an anomalous period for spontaneous fission.

It should be mentioned that the angular distribution of the transfer reaction products can somewhat change with the ion energy. The yield curves shown in the figure were obtained with a target mounted in a water-cooled cassette, in which the products of the nuclear reactions were emitted through an opening of 2-mm diameter and 1.5 mm in depth. Therefore the drop in the yield curve with increasing ion energy can be partly related to the presence of collimation of the recoil nuclei as a result of the cassette design.

The half-lives for the spontaneously fissioning nuclei obtained in experiments on the bombardment of U^{238} by B^{11}, O^{16} and Ne^{22} ions are in agreement within the limits of error (see table). A somewhat smaller value of the half-life in the case of the $U^{238} + Ne^{20}$ reaction possibly indicates a certain mixture of a shorter-lived emitter, but the data are insufficient to make more definite conclusions on this score. Further experiments in which the decay curves will be carefully studied will give a final answer to the question of whether one or more isomers are produced in our experiments.

It has been suggested earlier [1] that the observed effect is connected with the spontaneous fission from an isomeric state. The present experiments give additional arguments in favor of this suggestion. In fact, in the bombardment of U^{238} by B^{11} ions the known elements with $Z \leq 97$ are produced. They all have lifetimes in the ground state much greater than 0.015 sec, while the half-lives for spontaneous fission of these isotopes are $\geq 10^7$ y. It follows from this that the spontaneous fission of the nuclei obtained in our experiment is enhanced by a factor of 10^{16}. The conclusion regarding the anomalous increase in the spontaneous-fission probability does not change even if the lifetime of the nuclei obtained in our experiment is determined by α decay or by some other form of decay. Although the data on the transfer of nucleons from the incident ion to the target nucleus are quite insufficient, it can be assumed [5] that the cross section of these reactions does not exceed 10^{-26} cm^2. Hence, even with allowance for other possible branches of the decay, the spontaneous fission of the nuclei found in our experiment is enhanced by at least a factor of $\sim 10^{10}$. The investigation of other branches of the decay will give an accurate value for the increase in the probability of spontaneous fission.

In conclusion, the authors consider it their duty to thank Professor G. E. Flerov who guided this work for his numerous suggestions, advice, and comments both during the preparatory phases and during the actual experiments and for a discussion of the results. We also thank A. S. Pasyuk for his great assistance in carrying out the experiments.

---

[1] Polikanov, Druin, Karnaukhov, Mikheev, Pleve, Skobelev, Subbotin, Ter-Akop'yan, and Fomichev, JETP **42**, 1464 (1962), Soviet Phys. JETP **15**, 1016 (1962).

[2] Perelygin, Almazova, Gvozdev, and Chuburkov, JETP **42**, 1472 (1962), Soviet. Phys. JETP **15**, 1022 (1962).

[3] Bredel', Mikheev, and Polikanov, PTÉ No. 6, 44 (1961).

[4] Donets, Karnaukhov, Kumpf, Gvozdev, and Chuburkov, Joint Institute of Nuclear Research, Preprint R-896, Dubna, 1962.

[5] A. Ghiorso and T. Sikkeland, Second United Nations Conf. on the Peaceful Uses of Atomic Energy, Geneva, 1958, Report P/2440.

Translated by E. Marquit
135