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Abstract

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RADIOCHEMICAL STUDY OF THE FISSION PRODUCTS OF LANTHANUM BY PROTONS WITH AN ENERGY OF 660 MeV

(Presented by Academician A. P. Vinogradov, 27 VIII 1957)

Introduction. The fission of nuclei of heavy elements has been studied in sufficient detail. A large number of works, carried out by radiochemical and various physical methods, have been devoted to this question. The fission of nuclei of elements of medium atomic weight has been discovered; it had been predicted as early as 1950 by B. G. Geilikman, and also by Yamaguchi and Fujimoto ([1]). The fission products of tungsten ([2], [3]), tantalum ([4], [5]), and, very recently, rhenium ([5]) and holmium ([5]) nuclei by high-energy protons have been studied in sufficient detail. On the basis of radiochemical-analysis data for the fission products, the yields of stable isotopes were determined by interpolation and the values of the total fission cross sections of these nuclei were estimated. It was found that the fission cross section decreases to a considerable extent with decreasing atomic number of the fissioning nuclei. For example, the fission cross sections of rhenium nuclei ($Z = 73$), tantalum ($Z = 73$), and holmium ($Z = 67$) by protons with an energy of 450 MeV are, respectively, $19 \cdot 10^{-27}$, $5 \cdot 10^{-27}$, and $2 \cdot 10^{-27}$ cm^2.

The study of the fission products of elements lighter than holmium has not been carried out. Only individual fission fragments of various nuclei have been detected. Thus, in the bombardment of copper nuclei ($Z = 29$) by protons with energies up to 660 MeV, the isotopes Na^{22} and Na^{24} ([6], [7]) were found; in products of irradiation of bromine ($Z = 35$) by protons with an energy of 335 MeV the isotope Se^{74} was found; for tin ($Z = 50$), the isotopes Na^{24}, Ca^{45}, Ga^{66} were found; and for barium ($Z = 56$), the isotope Ga^{66} ([6]). From energetic considerations it is evident that these radioisotopes are fission products of the bombarded nuclei. In work ([8]) it is assumed that the formation of Na^{24}, P^{32}, and K^{41} nuclei upon irradiation of silver ($Z = 47$) by α-particles with an energy of 550 MeV, deuterons with an energy of 280 MeV, and protons with an energy of 480 MeV occurs predominantly by the mechanism of asymmetric fission from an excited level.

In the present work some results are presented of a radiochemical study of the fission products of lanthanum by protons with an energy of 660 MeV, which had been detected earlier ([9]). The chief difficulty of this investigation was obtaining

Fig. 1

Figure 1: Fig. 1

the fission products of lanthanum in radiochemically pure form because of their relatively low yield in comparison with such spallation products of lanthanum as barium, cerium, tellurium, antimony, and others.

Method. The investigation was carried out on the synchrocyclotron of the Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research. The bombarded target was a powder of lanthanum oxide weighing up to 1 g, wrapped in aluminum foil. Spectral analysis of the lanthanum oxide showed the presence of $Pr_2O_3 \leq 0.02\%$ and $Ce_2O_3 < 0.02\%$. The targets were irradiated with protons of energy 660 MeV for 1-2 hours. Then the powder was dissolved in hydrochloric acid, and, on isotopic carriers that had been added before dissolution of La_2O_3, the radioisotopes were separated. For separation of the lanthanum fission products a rapid method of chromatographic separation of Mn, Fe, Co,

Ni, Cu, and Zn on the anion exchanger Dowex-1-X-7. The essence of this method consists in the absorption of the indicated elements on the anion exchanger from a 12 M HCl solution or a weakly acidic 12 M LiCl solution, followed by washing with HCl solutions of various concentrations in the first case and with water in the second. The chromatograms obtained are shown in Fig. 1; they indicate a quite satisfactory separation of the elements under investigation.

Fig. 1. Separation of Ni, Mn, Co, Cu, Fe, and Zn on a column 15 cm long and 0.4 cm in diameter. Dowex-1-X-7 resin. Elution was carried out: *a*—with hydrochloric acid of various concentrations at a rate of 0.05 ml/min; *b*—with water after sorption from a 12 M LiCl solution at a rate of 0.04 ml/min at $t = 90^\circ$.

The application of the first variant of the method described made it possible to separate the principal studied products of lanthanum fission—Ni, Cr, Co, Zn, Ga, and Zn—into individual fractions, which were then subjected to additional purification. Thus, nickel was precipitated with dimethylglyoxime, cobalt with α-nitroso-γ-naphthol, zirconium with phenylarsonic acid, chromium as barium chromate. Gallium was extracted with diethyl ether from 6 N hydrochloric acid, and zinc as dithizonate with chloroform.

For the isolation of the remaining elements—Se, P, and Ca—methods developed earlier were used (^{7,9}).

Methods for identifying radioisotopes by half-life and radiation energy, and the calculation of the values of their formation cross sections, are also described in works (^{7,9}).

Table 1

Products of lanthanum fission and cross sections for their formation

Isotope	Type of decay	Half-life, observed	Half-life, from tables	Formation cross section, mb
$_{15}P^{32}$	β^-	14 days	14.5 days	0.004
$_{20}Ca^{47}$	β^-	4.2 days	4.5 days	0.02
$_{24}Cr^{48}$	EC	~ 27 h	23 h	0.01
Cr^{51}	EC	27.8 days	27.8 days	~ 0.1
$_{27}Co^{55}$	$\beta^+ \sim 60\%$; EC $\sim 40\%$	20 h	18 h	0.03
Co^{56}	EC	75 days	80 days	
Co^{58}	EC $\sim 85\%$; $\beta^+ \sim 15\%$	75 days	72 days	
Co^{61}	β^-	120 min	110 min	0.06
$_{28}Ni^{65}$	β^-	3 h	2.6 h	0.1
Ni^{66}	β^-	55 h	56 h	0.01
$_{30}Zn^{69m}$	IT	12 h	13.8 h	0.02
Zn^{72}	β^-	49 h	49 h	0.04
$_{31}Ga^{73}$	β^-	5 h	5 h	0.015
$_{34}Se^{72}$	EC	9.7 days	9.7 days	0.05
Se^{73}	β^+, EC	8.3 h	7.1 h	
$_{40}Zr^{95}$	β^-	65 days	65 days	0.03

Results. The experimental data obtained and the calculated cross sections are given in Table 1, from the data of which it follows that in the fission of lanthanum, isotopes with an excess of neutrons are formed predominantly. These isotopes lie in a wide range of atomic numbers from $Z = 15$ to $Z = 40$.

Figure 2 presents the distribution of yields of lanthanum fission products by protons with energy 660 MeV as a function of atomic number. The character of this distribution has the form of a flat curve, which indicates a high probability of both symmetric and asymmetric fission. This conclusion agrees with theory, according to which, for nuclei of medium atomic weight,

$(A < 160)$, for which

$$\frac{Z^2/A}{(Z^2/A)_{\text{lim}}} < 0.6,$$

the barrier for asymmetric fission is lower than the barrier for symmetric fission (^{10}).

Fig. 2. Distribution of yields of lanthanum fission products by protons with an energy of 660 MeV according to atomic number

Figure 2: Fig. 2. Distribution of yields of lanthanum fission products by protons with an energy of 660 MeV according to atomic number

The formation cross sections of individual fragments range from 10^{-30} to 10^{-28} cm^2. From the area bounded by the envelope curve, one can estimate the total fission cross section of lanthanum by protons with an energy of 660 MeV, equal to $0.6 \cdot 10^{-27}$ cm^2. This value is in reasonable agreement with the fission cross section of rhenium, tantalum, and holmium by protons with an energy of 450 MeV.

Fig. 2. Distribution of yields of lanthanum fission products by protons with an energy of 660 MeV according to atomic number

For a more complete characterization of the fission process of lanthanum and determination of its threshold, further investigations must be carried out.

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Note: Figure translations are in progress. See original paper for figures.