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Abstract

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Experimental and Calculated Cross Sections of the Reaction $Bi^{209}(p, xn)$Po at a Bombarding-Proton Energy of 135 MeV

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In studying nuclear reactions under the action of particles with energies of 100-400 MeV, the "cascade-evaporation" model ([1]) is adopted, the use of which makes it possible to calculate the nuclear cascade and the evaporation process ([2–4]). In the calculation one can obtain the formation cross sections of products arising in a nuclear reaction. These cross sections depend on the distribution, after the cascade, of the residual nuclei according to their excitation energies and on the individual properties of the nuclei—the binding energy, the density of nuclear levels and, in the case of heavy nuclei, their ability to undergo fission.

In the experimental determination of independent (individual) formation cross sections of nuclear-reaction products, difficulties arise that are associated with the presence of groups of isotopes with complex genetic decay chains. It is most expedient to compare calculated and experimental data for the cross sections of reaction products close in Z to the initial nucleus. We have carried out such a comparison for the reaction $Bi^{209}(p, xn)$Po at a proton energy of 135 MeV. The formation cross sections of the isotopes $Po^{200-209}$, which decay with emission of α-particles and by E-capture, were determined experimentally.

The α-activity was measured in an ionization α-chamber with a 31-channel pulse-height analyzer. For α-particles of the isotope Po^{208} with an energy of 5.108 MeV, the chamber made it possible to obtain a peak half-width of 28–32 keV. Po sources were prepared by electrochemical deposition of Po from HCl onto polished silver disks. The intensities of the α-lines were compared with the intensity of the α-line of Po^{206}. Knowing the ratio of the probabilities of α-decay and E-capture (α/E) for the isotopes studied, it was possible to determine their relative yields. For the isotopes $Po^{200,201,203}$ this ratio was measured by us ([5]).

The determination of the relative yield of Po isotopes undergoing predominantly E-capture was carried out with a 4π-scintillation counter ([6]) from the activity of the daughter products of Po (Bi, Pb, Tl) obtained by chemical separation. To eliminate the error associated with losses during chemical separation of individual elements and because of the large difference in half-lives, an internal reference was chosen in each daughter fraction. The yield of Po^{200} and Po^{201} nuclei was thus determined experimentally relative to the yield of Po^{203} nuclei,

Fig. 1. Cross sections of the reaction products $Bi^{209}(p, xn)Po$

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that of Po^{203} nuclei relative to the yield of Po^{205} nuclei, and the number of Po^{205} nuclei formed relative to the yield of Po^{206}. The absolute cross section of the reaction $Bi^{209}(p, 4n)Po^{206}$ was measured by the generally accepted method ([7]) from the yield of the reaction $Al^{27}(p, 3pn)Na^{24}$.

The experimental cross-section values were compared with values of the cross sections calculated theoretically. In the theoretical calculation, the Serber ([1])–Goldberger ([2])–Weisskopf ([8]) model was used.

The calculation was carried out by the method of random trials (the Monte Carlo method) [(9–13)]. The computations were performed with the aid of an electronic computer of the "Ural" type, for which a special program was developed. A total of 1170 cases of a proton with energy 135 MeV striking the nucleus were calculated. The parameter r_0 in the formula for the nuclear radius $R = r_0 A^{1/3}$ was chosen equal to $1.45 \cdot 10^{-13}$ cm. In the course of the calculation of evaporation, the possibility was taken into account

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of competition from fission under the assumption of an emission mechanism [(14)]. The level density of the nuclei was determined on the basis of the Fermi-gas model and was expressed in the form

$$\rho = C \exp 2[a(E - \delta)]^{1/2};$$

C is a constant depending on the type of evaporating particle and independent of the excitation energy of the nucleus; E is the excitation energy of the nucleus; a is the level-density parameter, taken equal to $A/10$, where A is the atomic number; δ is a parameter taking into account the evenness effect and the shell effect of changes in level densities.

The binding energy of the evaporating particles was determined with the aid of the data from Cameron' s tables [(15)] and the experimental data presented in Ref. [(16)].

The dependence of the cross section of the reaction products on A for Po isotopes is shown in Fig. 1. The circles indicate theoretically calculated cross-section values, and the crosses indicate the experimental data. For the theoretical data, errors associated with the statistical error of the calculation are given. The errors of the experimental results, as a rule, lie within 15–20%.

The fission cross section for Bi obtained as a result of the theoretical calculation under bombardment by protons with energy 135 MeV is 95 ± 13 mb, which is in satisfactory agreement with the fission cross section of about 80 mb determined radiochemically [17], and with the cross section of about 125 mb determined with the aid of an ionization chamber [18]. According to the calculation, at this energy predominantly Po isotopes undergo fission, with about 60% of the fission events occurring in neutron-deficient Po isotopes with mass numbers from 199 to 200. The fairly good agreement between the experimental and theoretical results—considerably better than that obtained in the comparatively rough theoretical calculation in the study of the similar reaction $\mathrm{Au}(p, xn)\mathrm{Hg}$ [19]—indicates the possibility of applying the "cascade-evaporation" model for calculating the cross sections of nuclear-reaction products and confirms the reasonableness of the proposed reaction mechanism.

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