PRODUCTION OF Mo^{93m} IN THE REACTION $Se^{80}(O^{16}, 3n)$

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The isomer Mo^{93m} has been obtained by irradiating the separated isotope Se^{80} with O^{16} ions accelerated in a 150-cm cyclotron. The isomer results when three neutrons evaporate from the compound nucleus produced by the complete coalescence of Se^{80} and O^{16} nuclei. The excitation function of this reaction and the absolute cross section for Mo^{93m} production have been measured.

It has been established in a number of investigations[1-5] that the excitation energy of the isomer Mo^{93m} is 2460 kev and that its half-life is 6.95 hrs. The isomeric nucleus drops to its ground level by the successive emission of 270-, 690-, and 1490-kev gamma rays. Mo^{93m} cannot be produced very easily; it was not detected after the bombardment of Mo^{92} with 10-Mev deuterons[1] or thermal neutrons,[3,4] or after the irradiation of Mo^{94} by 23- and 32-Mev γ rays.[2,4] The reaction $Mo^{94}(n, 2n)Mo^{93m}$ has a small cross section. The data in references 1 — 3 show that the cross section for $Mo^{92}(d, p)Mo^{93m}$ with $E_\alpha = 10$ Mev and that for $Mo^{92}(n, \gamma)Mo^{93m}$ are smaller than 10^{-30} cm^2, and that the cross section for $Mo^{94}(n, 2n)Mo^{93m}$ is of the order of 10^{-29} cm^2.

The cross section for the reaction $Nb^{93}(p, n)Mo^{93m}$ with 6.7-Mev protons is 2×10^{-27} cm^2, which is considerably smaller than the cross sections for the production of the isomeric and ground states by means of the indicated (p, n) reaction in neighboring nuclei.[2]

According to Goldhaber[6] and to Kraushaar[7] the spin of Mo^{93m} is $^{23}/_2$, although the value $^{21}/_2$ is suggested in reference 8. This large spin evidently accounts for the small cross sections for the production of Mo^{93m} in the reactions that have been mentioned.

Reactions with heavy ions at ~ 100 Mev result in the formation of compound nuclei whose angular momentum may be as high as ~ 50. The evaporation of neutrons cannot essentially reduce the angular momentum of the compound nucleus; we can therefore expect that a relatively large yield of Mo^{93m} will result from reactions with heavy ions.

In the present work Mo^{93m} was produced by the reaction $Se^{80}(O^{16}, 3n)$. For this purpose we used a procedure developed at the Atomic Energy Institute of the U.S.S.R. Academy of Sciences for studying nuclear reactions induced by multiply-charged ions accelerated in a 150-cm cyclotron. Stacks of aluminum foils bearing hot pressed layers of 92% enriched Se^{80} were bombarded in the internal cyclotron beam by monoenergetic quintuply-charged oxygen ions at 102 ± 2 Mev. The oxygen ion current was ~ 0.1 μa and the irradiation time was 1 to 1.5 hrs. γ rays from the isomer Mo^{93m} were analyzed by means of a scintillation spectrometer with a NaI(Tl) crystal, which had been calibrated by means of well-known lines of Hf^{181} (56, 135, 340, and 480 kev), Cs^{137} (662 kev) and Co^{60} (1170 and 1320 kev). The spectral sensitivity was determined by two methods, the first of which employed Cu^{61} γ rays from 70 to 1200 kev, whose relative intensities are given in reference 9. The γ-ray spectrum was measured under exactly the same conditions as the main experiment. The β activity of the specimens was measured at the same time by a calibrated β-ray counter. Through a comparison of the γ-ray and β-particle intensities from Cu^{61} we were able to determine the relative spectral sensitivity of the spectrometer and its absolute efficiency for the registration of γ rays. Cu^{61} was obtained through the reaction $V^{51}(C^{13}, 3n)Cu^{61}$, which we have investigated previously.[10]

In the second method the number of β particles from Cs^{137}, measured by a β-ray counter with 4π solid angle, was compared with the number of 662-kev γ rays registered by the spectrometer. The results obtained by the two methods were in agreement.

One of the γ-ray spectra is shown in Fig. 1; 270-, 690-, and 1490-kev γ rays are seen to result from the bombardment of Se^{80} by O^{16} ions. These lines have a half-life of 7 hrs and the fact that they belong to a molybdenum isomer was verified through the chemical separation of molybdenum from the selenium target. β activity with the same half-life at about 300 kev was also detected;

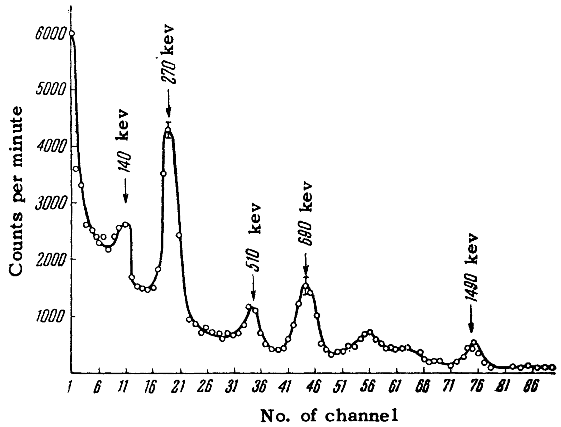

FIG. 1

this is evidently due to internal conversion electrons from the decay of Mo^{93m}. The chemical analysis, investigation of the γ-ray spectrum and measurement of the half-life provide the basis for assigning the observed activity to Mo^{93m}.

The dependence of the cross section for $Se^{80}(O^{16}, 3n)Mo^{93m}$ on the energy of the oxygen ions was studied in two experiments. In the first of these experiments, represented by the solid lines in Fig. 2, a stack of five foils was irradiated. A 3 mg/cm^2 layer of Se^{80} was deposited on each 5-micron aluminum foil. In the second experiment, represented by the dashed lines in Fig. 2, the stack consisted of four 2-micron foils with a 7 mg/cm^2 layer of Se^{80}.

Figure 2 shows that the energy dependence of the cross section for Mo^{93m} production has the form of the typical excitation function of reactions that proceed via a compound nucleus accompanied by competing processes. The maximum cross section for 70-Mev oxygen ions is 240 mbn with a possible error of 50%. When the oxygen ion energy is ~ 100 Mev the cross section does not exceed 5 mbn.

These experiments show that nuclear isomers can be produced efficiently by means of heavy ions, especially those isomers which possess large spin.

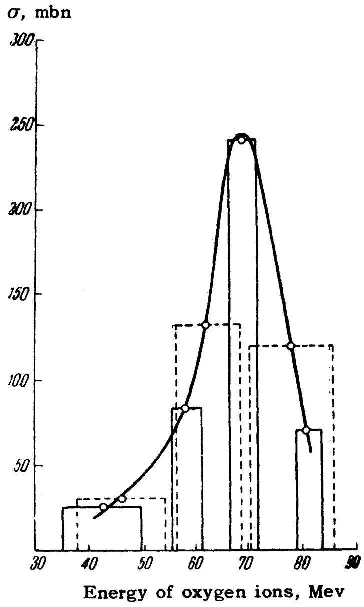

FIG. 2

In performing this work we were constantly assisted by the valuable suggestions of G. N. Flerov and by the experimental procedures for work with multiply-charged ions that have been developed by the group which he directs.

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