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THE $Al^{27} \rightarrow Na^{24}$, $Co^{59} \rightarrow Mn^{56}$, *AND* $P^{31} \rightarrow Na^{24}$ *REACTIONS IN THE 260-Mev GAMMA-RAY ENERGY RANGE*

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The dependence of the yield of a number of photonuclear reactions on the peak bremsstrahlung energy from the synchrotron was measured by the induced-radioactivity method. The differential cross sections were computed from the yield curves by the "photon-differences" method. The form of the energy dependence of the effective cross sections indicates that photonuclear reactions at photon energies above 60 — 80 Mev proceed mainly without the formation of an intermediate nucleus.

THE purpose of the present experiments was to obtain information about the character of the interaction of photons and nuclei in the 30- to 260-Mev energy range. Three photonuclear reactions, giving rise to radioactive isotopes, were investigated:

$$Al^{27} \rightarrow Na^{24}, \quad Co^{59} \rightarrow Mn^{56}, \quad P^{31} \rightarrow Na^{24}.$$

The experiments were performed with the 260-megavolt synchrotron of the Physical Institute of the Academy of Sciences. The peak energy of the synchrotron is known within ± 2%. Intermediate values of the energy were established with the same precision. The targets were prepared from sufficiently pure substances, so that the reactions with the impurities could be neglected. The activity of the samples was measured with three identical 4π arrays of beta counters. The efficiency of the arrays was monitored in the course of the experiment against a radium standard within a precision of ± 1%. The radioactive isotopes were identified by their half-lives.

The Al, P, and Co samples were simultaneously irradiated within an identical geometry. To introduce corrections for the nonuniformity of the intensity, its time distribution during irradiation was measured by an ionization chamber with a flux integrator. The intensity integrated over the time of irradiation (~ 40 minutes) was measured by means of the $C^{12}(\gamma, n)C^{11}$ reaction, whose absolute yield was measured as a function of the peak bremsstrahlung energy up to 260 Mev by Barber et al.[1] In all, we carried out 48 irradiations for 15 values of the synchrotron energy. The spread of the irradiation results, carried out at the same nominal energy value but at different times, did not exceed the experimental error, which was determined mainly by the statistical accuracy of each reading and by the energy instability of the synchrotron.

The yield of the reaction investigated

$$B_x(E_0) = \int_0^{E_0} \sigma_x(E_0)\,\eta(E, E_0)\,dE$$

is expressed in terms of the yield of the $C^{12}(\gamma, n)C^{11}$ reaction

$$B_C(E_0) = \int_0^{E_0} \sigma_C(E_0)\,\eta(E\ \ E_0)\,dE$$

and in terms of the quantities measured during the experiment as follows:

$$B_x(E_0) = B_x'(E_0)\,B_C(E_0),$$

where E_0 is the peak value of the bremsstrahlung energy spectrum, E is the energy of the photon, $\sigma_X(E)$ is the effective cross section of the investigated reaction, $\sigma_C(E)$ is the effective cross section of the $C^{12}(\gamma, n)C^{11}$ reaction, $\eta(E, E_0)$ is the spectrum of the bremsstrahlung and $B_X'(E_0)$ is the ratio of the number of active nuclei, produced as a result of the investigated reaction and the $C^{12}(\gamma, n)C^{11}$ reaction with carbon, reduced to equal numbers of irradiated nuclei. We obtained this ratio from measurements of the activities of the investigated samples by introducing corrections for the decay, the registration efficiency, and for the differing number of irradiated nuclei.

The values of $B_X(E_0)$ and $B_X'(E_0)$ are given in Fig. 1. We have plotted the errors connected with the energy instability of the synchrotron along the abscissa, and the statistical errors along the ordinate axis. The precision with which the absolute values of the yields were determined is

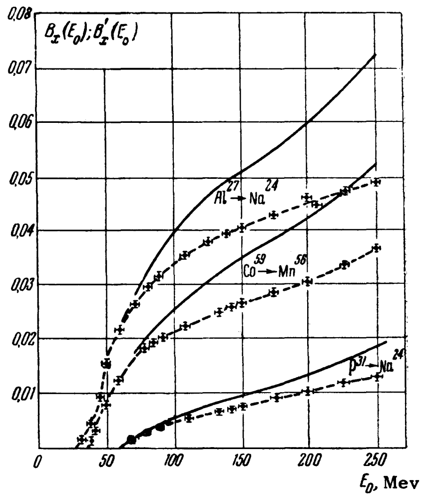

FIG. 1. Active yields of the $Al^{27} \to Na^{24}$, $Co^{59} \to Mn^{56}$, and $P^{31} \to Na^{24}$ reactions as a function of the peak bremsstrahlung energy. The values of $B'_X(E_0)$ are given by the continuous curves, of $B_X(E_0)$ – by the dashed curves [the values of $B_X(E_0)$ are given in arbitrary units].

about 20%. The main part of the errors is connected with the inaccuracy in determining the absolute β activities of the samples.

The differential effective cross sections σ were calculated from the yield curves by the "photon differences" method.[2] The results obtained are shown in Figs. 2 – 4.

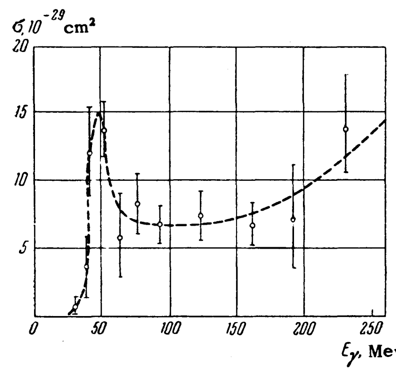

FIG. 2. Effective cross section for the $Al^{27} \to Na^{24}$ reaction.

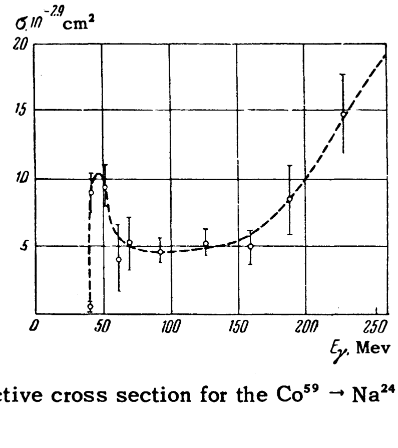

FIG. 3. Effective cross section for the $Co^{59} \to Na^{24}$ reaction.

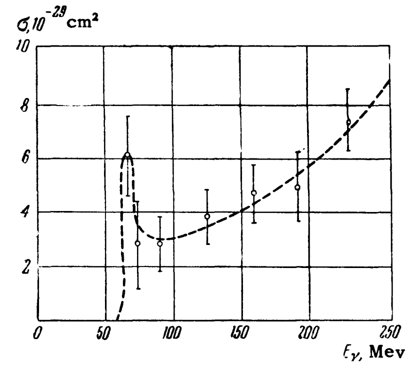

FIG. 4. Effective cross section for the $P^{31} \to Na^{24}$ reaction.

The reactions $Al^{27} \to Na^{24}$ and $Co^{59} \to Mn^{56}$ can result from three different processes [(γ, He^3), (γ, Dp), and $(\gamma, 2pn)$] whose thresholds, calculated with account of the Coulomb barrier, are 23, 29, and 31 Mev for Al^{27}, and 34, 41, and 43 Mev for Co^{59}, respectively. Since the registration of the corresponding activities of Al and Co begins at energies around the threshold of the (γ, Dp) and $(\gamma, 2pn)$ reactions, it is obvious that, of the three, the two latter processes play the most substantial part in both elements.

The reaction $P^{31} \to Na^{24}$ is the result of a large number of processes of which the energetically most convenient (γ, Be^7) has a threshold of about 40 Mev; the energetically least convenient process $(\gamma, 4p3n)$ has a threshold of about 90 Mev. The experimental threshold of the Na^{24} yield from P^{31} is in the neighborhood of 60 Mev. This indicates that in this reaction processes involving emission of bound nucleons, i.e., of the type $(\gamma, He^4, 2pn)$, play a substantial part.

However, regardless of the relation between the discussed processes, the effective cross sections for the production of Na^{24} and Mn^{56} should have a resonance character if the reactions proceed with the formation of an intermediate nucleus.[4] The presence of various processes should only lead to an increase in the resonance width. The experimentally-obtained effective cross sections do indeed have a maximum in the energy range of ~ 10 Mev above threshold. However, they do not fall off to zero after the maximum, as expected according to the intermediate-nucleus model, but after reaching approximately half their maximum value, they remain constant in the Al and Co reactions, and even increase in the P reaction. This fact can be explained in two ways. One can assume that at large energies interactions involving the formation of an intermediate nucleus play the main part, but that the effective cross sections of the investigated reactions remain constant, owing to the increase in the effective cross section for photon absorption. However, available experimental data indicate that the effective cross sections for photon absorption by nuclei in the 60- to 130-Mev energy range increase very slowly,[5] and consequently such an explanation is unsatisfactory. The following explanation is more probable. At photon energies exceeding 60 Mev the interaction between photons and nuclei does not lead to the formation of an intermediate nucleus. The energy and momentum of the photon are absorbed not by the nucleus as a whole, but by a group of nucleons which leaves the nucleus, transferring to it only a part of the energy. One such mechanism is probably the much-discussed "quasi-neutron mechanism."[6] In such an interaction it may turn out that the probability of transferring to the nucleus a given portion of energy varies little with the energy of the incident particle, and consequently the effective cross section for the production of a given isotope will also vary little.

Thus, the variation of the effective cross sections which we have obtained permits us to assume that at energies above 60 — 80 Mev the interaction of photons with nuclei proceeds mainly without the formation of an intermediate nucleus, via photon absorption by a group of intranuclear nucleons. This conclusion and also the experimental results are in agreement with those obtained in analogous experiments with heavy particles.[7]

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