YIELD OF FAST PHOTONEUTRONS FROM C^{12} *AND* Al^{27}

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A threshold detector was employed to measure the yield of fast photoneutrons ($E_n \geq 11$ Mev) produced by γ quanta with energies up to 85 Mev on C^{12} and Al^{27} nuclei. The experimental results indicate the predominance of a single-particle mechanism of fast photoneutron production (in which only one fast neutron is emitted from the nucleus).

MEASUREMENTS of the yield of fast photoneutrons (> 11 Mev) from C^{12} and Al^{27} were carried out to obtain additional information on the production mechanism for these particles. The fast neutrons were recorded by the method of threshold detectors. A natural mixture of the isotopes of copper served as the detector. In the interaction of neutrons of energies > 11 Mev with Cu^{63} nuclei, an active isotope appears with a half-life of 10 min and a maximum positron energy of 2.9 Mev. [1]

The positrons were recorded by a self-quenching Geiger counter of the type STS-6. To decrease the noise, this counter was surrounded by a guard ring of nine other counters of the same type, connected in parallel and in anticoincidence with the working counter. The system of counters was surrounded by a protective layer of iron of 150 mm thickness, and by a lead layer of 100 mm thickness. It was possible to decrease the background of the working counter by such means to ~ 3 counts/min. The background remained constant during the entire period of measurement. A hollow iron cylinder was placed between the ring and the working counter for the purpose of preventing the simultaneous incidence of positrons in the working counter and in one of the counters of the protective ring.

To lessen the effect of oscillations in the radiation intensity, the relative radiation dose was measured by the method of activation of a thin copper foil placed directly in the beam of the γ rays. The resultant β^+ activity was measured by an end-window counter. The equivalent dose of γ radiation (in absolute units) was determined from calibration measurements at constant radiation intensity with the help of a so-called quantometer. [2]

The target had the shape of a cylinder 100 mm long and 58 mm in diameter. Copper activated by photoneutrons was prepared in the shape of hollow cylinders with walls 0.6 mm thick.

Other possible reactions cannot give an appreciable contribution to the measured activity of the reactions $Cu^{63}(n, 2n)Cu^{62*}$ and $Cu^{63}(\gamma, n)Cu^{62*}$, as verified by the results of control measurements of the decay period. Measurement of the effect was alternated with measurement of the background (in the absence of a target). The background did not exceed 30 percent on average. A systematic control was maintained on the stability of the apparatus.

The method used makes it possible to determine the relative number of fast neutrons by the number of radioactive decays in the copper specimen per unit of monitor reading. For this purpose, it is necessary to know the neutron energy dependence of the cross section σ of the reaction $Cu^{63}(n, 2n)$ Cu^{62*}, and the form of the energy spectrum of the photoneutrons from a target irradiated by bremsstrahlung with different maximum γ-quantum energies, $E_{\gamma max}$.

The dependence of σ on the neutron energy is sufficiently well known. [3] Information on the energy spectra of photoneutrons is limited. Only the energy spectrum of photoneutrons emitted from the C^{12} nucleus in the photodecay of bremsstrahlung with $E_{\gamma max} = 88$ Mev has been studied. [4] However, the dependence of the cross section of the reaction $C^{12}(\gamma, n)C^{11}$ on the energy of the γ rays is known. [5] On the basis of available data, [3,5] we can compute the energy spectra of the photoneutrons, assuming that the product nucleus in the reaction $C^{12}(\gamma, n)C^{11}$ remains in the ground state or in a weakly excited state. The results of the study of the reaction $C^{12}(\gamma, p)B^{11}$ can serve as the basis of such an assumption. [6] Calculations have shown that the shapes of the energy spectra of fast neutrons emitted by a C^{12} nucleus

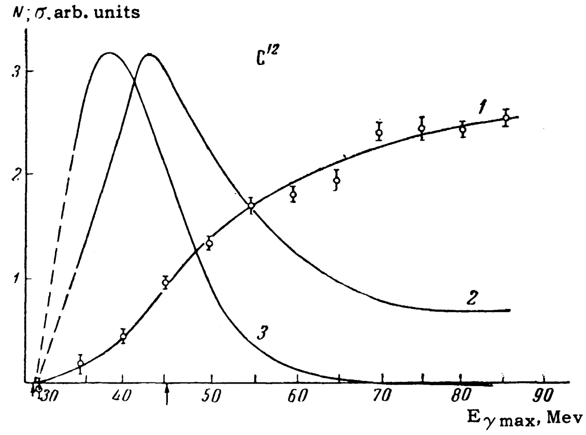

FIG. 1

are virtually identical for different $E_{\gamma max}$ over a rather wide range of values of the latter. Therefore, it was taken into account in the treatment of the experimental data for C^{12} that the neutron spectrum in the case $E_{\gamma max} = 85$ Mev decays as E^{-n} with n = 1.5, as was found by us earlier. [4] The same form of the neutron spectrum was assumed for all values of $E_{\gamma max} < 85$ Mev. Measurements of the energy spectrum of fast photoneutrons from Al^{27} were not carried out in the energy range studied. Experimental points of the yield for Al^{27} were computed by us, initially under the assumption that the neutron spectrum decays in the same way as in the case of C^{12} ($\sim E^{-1.5}$), and then under the assumption of a spectrum of the form $E^{-2.5}$, which corresponds approximately to the decay of the spectrum of protons from the Al^{27} nucleus. [7]

The cross sections were determined by the method of Penfold and Leiss. [8] They were computed from the yield curves, which were drawn through the experimental points and smoothed according to their first differences.

The results obtained for C^{12} are plotted in Fig. 1. The experimental points represent the number of fast neutrons N with energy > 11 Mev per unit reading of the monitor for a given $E_{\gamma max}$. The curve 1 is a smoothed one, drawn through the experimental points. The curve of the cross section of all the fast neutrons (> 11 Mev), calculated on the basis of curve 1, is given by curve 2, and the cross section for photoneutrons in the energy range 11 — 21 Mev is shown by curve 3.

The results of an experimental investigation of photoneutrons with energies > 11 Mev are given in Fig. 2 for the case of Al^{27}. The computed curves 2 and 3 are constructed under the assumption that the spectrum of photoneutrons decays according to the laws $E^{-1.5}$ and $E^{-2.5}$, respectively.

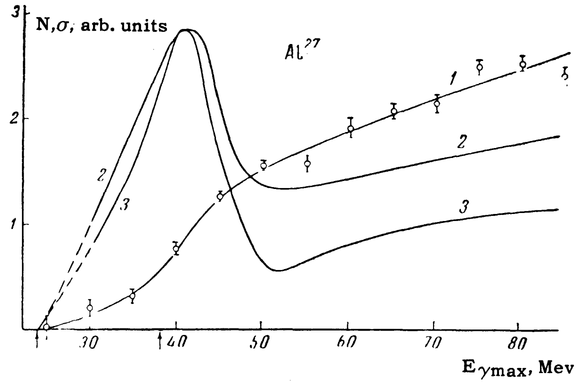

FIG. 2

In both drawings, the arrows at the left on the abscissa indicate the energy threshold of the reaction (γ, n) with emergence of a neutron having the energy 11 Mev (minimum recording energy, E_n^{min}). The arrows to the right show the energy of a γ quantum, E_γ, necessary for the formation of a neutron with energy E_n^{min} under the condition that there exists a quasideuteron mechanism of γ quantum absorption. In this case, E_γ was computed according to a formula obtained from the conservation laws for the photodecay of a deuteron

$$E_\gamma = 2E_n/[1 - E_n/Mc^2 + (P/Mc)\cos\vartheta],$$

where $E_n = E_n^{min} + E_0/2$ [E_0 is the threshold of the reaction (γ, pn)], M is the mass of the neutron, P is the momentum of the neutron, c is the speed of light, and ϑ the angle of flight of the neutron relative to the direction of the γ quanta (in the laboratory system of coordinates).

As follows from Fig. 1, the cross section for all neutrons with energy 11 Mev in the case of the C^{12} nucleus is a curve with a broad maximum, which falls off slowly in the high-energy region. For a narrower range of energies of recorded neutrons, one can expect a contraction of the cross section curve and its displacement in the direction of lower energies, which is also confirmed by curve 3 in the same drawing. The experimentally measured threshold for formation of neutrons with energies > 11 Mev is in excellent agreement with the value computed under the assumption that a neutron with energy 11 Mev is produced in the single-particle reaction $C^{12}(\gamma, n)C^{11}$.

An important part of the curves, especially for curve 3, lies below the region corresponding to the quasideuteron mechanism. It obviously can be shown that an important part of the curves lies in an energy range where emission of only a single neutron is possible from the nucleus without the simultaneous emission of a proton. It is known that the difference in the thresholds of the reactions (γ, n) and (γ, np) is equal to ~ 9 Mev. If we take it into account that in the emission of the neutron the C^{11} nucleus remains in an excited state in half the cases (by analogy with the results of the study of the reaction $C^{12}(\gamma, p)B^{11}$,[6] and also consider the great width of the energy recording range, then we see that in the region close to the right-hand arrow there should be very few neutrons accompanied by an emission of protons.

Similar conclusions can be drawn relative to the results for Al^{27} shown in Fig. 2, although here some difference is observed from the results for C^{12} (the width of the maximum is significantly less and, in the region of high energies, an increase in cross section is observed).

In conclusion, it can be shown that the value of the threshold for production of fast photoneutrons and the existence of a broad maximum in the region of comparatively low energies of the γ quanta indicate the predominance of a mechanism for which only a single fast neutron is emitted from the nucleus in the reaction (γ, n). However, it is impossible to deny that the quasideuteron absorption mechanism plays a substantial role in the region of energies of γ quanta behind the broad maximum.

It should be observed that the cross sections of the reaction (γ, n) are of the same form as those of the (γ, p) reaction for the C^{12} nucleus.[9] In this case the experimental points on the yield curves of the reaction (γ, n) reveal a break for high energies of the γ quanta, corresponding to the inflexion in the yield curve for the (γ, p) reaction. This can serve as proof of the possibility of the existence of a second maximum in the cross section curves. However, this maximum is not shown in Fig. 1, since the cross section curve was computed on the basis of a smoothed yield curve.

The angular distribution and the values of the cross section for fast photoneutron production[4,10] do not agree with the calculations,[11] which are based on the single nucleon mechanism of absorption of γ quanta.

In previous researches,[4,10] qualitative agreement has been observed in the angular distributions of fast photoneutrons with calculations according to the quasideuteron model. However, the results of the present work show that the quasideuteron mechanism does not appear to be dominant for fast photoneutron production in the nuclei investigated. Recently, calculations of the cross sections of fast photonucleon production were carried out by Shklyarevskii on the basis of the shell model, with account of pair correlations of nucleons in the nucleus. Account of pair correlations leads to the correct value of the cross section of fast photonucleon production; as calculations on a simplified model have shown, this makes it possible to explain qualitatively the shift forward in the angular distribution of fast photoneutrons.

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