LETTERS TO THE EDITOR

THE EFFECTIVE CROSS SECTION OF THE $Be^9(n, 2n)$ REACTION

S. S. VASIL'EV, V. V. KOMAROV and A. M. POPOVA

Moscow State University

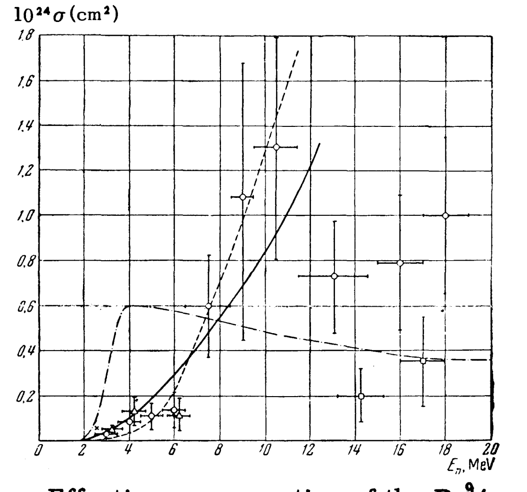
Submitted to JETP editor March 15, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) 33, 527-528 (1957)

We have investigated the course of the cross section for the $Be^9(n, 2n)$ reaction and obtained certain values of the cross sections of the principally competing reactions emitting charged particles -- $Be^9(n, \alpha) He^6$ and $Be^9(n, t) Li^7$ — under the action of neutrons from the reaction Li(d, n) with energies from 1.5 to 19 Mev.

To reduce the number of scattered neutrons, the irradiation of the lithium target was carried out, after extraction from the cyclotron, with a focused beam of 4-Mev deuterons. The beam of fast neutrons was carefully collimated with a system of slits.

In the case of the $Be^9(n, 2n)$ reaction two α-particles are emitted, the tracks of which can be observed, in the form of two-prong stars, in photoemulsions loaded with Be^9. To facilitate the observation of the stars formed in reactions with Be^9, a specially prepared disk was prepared which contained Be^9 powder with grain size of ~ 1—2μ between two emulsion layers. More than 200 stars from Be^9 grains were found which were related to the reaction $Be^9(n, 2n)$ and the reactions $Be^9(n, \alpha) He^6$ and $Be^9(n, t) Li^7$.



Effective cross section of the $Be^9(n, 2n)$ reaction: ○ — obtained in this work; dashed curve — from the formula of Sachs[4] for R = 4.44, a = —1.16; dash-dot curve — from the formula of Sachs for R = 1.39, a = 0.463; solid curve — from Mamasakhlisov.[1] The effective cross section of the $Be^9(n, \alpha) He^6$ reaction; Δ — our work; × — from Allen.[6] The effective cross section of the $Be^9(n, t) Li^7$ reaction; □ — our work.

Assuming a known direction for the incident neutron, and with the help of the laws of conservation of energy and momentum, the energy of the primary neutron E_p was calculated for each star. In the case of the $Be^9(n, 2n)$ reaction the total energy of the two emitted neutrons and the polar angle were calculated from the sum of the momenta relative to the direction of the primary neutron. The competing reactions with emission of charged particles were identified by calculation. The neutron spectrum for each series of irradiations was determined from the proton recoil spectrum observed in the emulsion pellicles used for the study of the reactions. The values of the effective cross sections of the $Be^9(n, 2n)$ reaction and of the principally competing reactions $Be^9(n, \alpha) He^6$ and $Be^9(n, t) Li^7$, as a function of the energy of the neutrons, is shown on the figure. The principal errors for each cross section point are composed of the errors in the measurement of the neutron beam (≈ 12%), errors in the determination of the amount of material in the emulsion pellicle (≈ 15%), and statistical errors.

As can be seen from the figure, the dependence of the cross section obtained by us in the interval 4 to 10 Mev coincides with the cross section dependence calculated by Mamasakhlisov.[1] Besides, the average effective cross section for incident neutrons with energies from 2 to 11 Mev, $\overline{\sigma}$ = 200 ± 120 mb, found by us in these experiments, agrees within the limits of error with the results on the average effective cross section for a Ra + Be source: $\overline{\sigma}$ = 300 ± 100 mb.[2,3]

Recently Sachs[4] has suggested a semi-empirical model, describing a direct decay into light nuclei under the action of low-energy nucleons, and examined as an example the Be^9(n, 2n) Be^8 reaction. Using the value of $\bar{\sigma}$ (see Refs. 2 and 3) for the spectrum of a Ra + Be source, he obtained a curve for the effective cross section of the Be^9(n, 2n) Be^8 reaction which differed sharply from Mamasakhlisov's curve and from our experimental results (see figure). A set of constants, characterizing the size of the interaction, derived from our data would yield R = 4.44 and a = —1.16, and using these the dependence of the cross section would change and become similar to Mamasakhlisov's curve. In this way, the dependence of the cross section of the Be^9(n, 2n) reaction obtained experimentally agrees, within the limits of error, with the dependence of the cross section given by Ref. 1 and by Sachs' formula with corrected coefficients in the energy interval from 4 to 10 Mev. It is not possible, on the basis of the obtained experimental results, to make a choice between the assumptions made in these papers on the reaction mechanism, but it is possible that it will allow in the future the working over of the available experimental material.

As can be seen from the drawing, the theoretically determined dependence of the cross section from the quoted works differs from the experimental dependence for energies greater than 10 Mev. There is no reason to assume the existence of any appreciable errors for high energies. Because of this one may think that for high energies another reaction mechanism begins to operate to an appreciable extent. Indeed the following types of reactions are possible:

(1) $Be^9(n, n') Be^{9*} \rightarrow n'' + Be^8(2\alpha)$; (2) Be^9 (n, 2n) $Be^8(2\alpha)$; (3) Be^9 (n, $2n2\alpha$).

Calculation of the excitation energy for Be^8 at $E_n \leq 10$ Mev has indicated the presence of known levels of this nucleus, which is evidence of the formation of Be^8 in the course of the Be^9(n, 2n) reaction, that is of the prevalence of reactions (1) and (2) for this primary neutron energy.

For energies greater than 10 Mev, the third type of reaction apparently plays a part to an appreciable extent: the simultaneous decay of the compound nucleus into two neutrons and two α-particles, which follows from the comparison of the α-particle energy distribution, obtained from experiment, with the distribution computed on the principle given in the work of Ref. 5. At the same time, in the center-of-mass system, an anisotropy is observed with a preferential forward emission of the neutrons and α-particles. This provides a basis for assuming also the existence of a direct interaction of the incident neutron with one of the subgroups of the Be^9 nucleus.

The effective cross section, obtained by us for the Be^9(n, α) He^6 reaction (see figure) for corresponding values of the neutron energy, agrees within the limits of error with the results obtained in other works.[6]

Besides several disintegration events were found, which can be related to the Be^9(n, t) Li^7 reaction, and for which the obtained cross sections are exhibited on the same drawing.

[1]V. I. Mamasakhlisov, J. Exptl. Theoret. Phys. (U.S.S.R.) 25, 36 (1953).

[2]E. Funfer and W. Bothe, Z. Physik 122, 769 (1944).

[3]F. Ajzenberg and T. Lauritsen, Revs. Mod. Phys. 27, 77 (1955).

[4]M. Sachs, Phys. Rev. 103, 671 (1956).

[5]G. E. Uhlenbeck and S. Goudsmit, Pieter Zeeman Verhandelingen (Martinus Nijhoff, The Hague, 1935), p. 201.

[6]Allen, Burcham, and Wilkinson, Proc. Roy. Soc. (London) A192, 114 (1947).

Translated by Fay Ajzenberg-Selove
96

MODULATION EFFECTS IN NUCLEAR MAGNETIC RESONANCE

K. V. VLADIMIRSKII

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor April 18, 1957

J. Exptl. Theoret. Phys. U.S.S.R. 33, 529-530 (August, 1957)

MODULATION effects in nuclear magnetic resonance were experimentally observed and explained in a previous work by the author[1] in terms of the dynamics of nuclear magnetization. The existence of such effects has been noted also in optical and microwave spectroscopy.[2] In nuclear magnetic resonance, the