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On the Disintegration of Nitrogen by Fast Neutrons

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The cross sections of the $N(n, p)C$ and $N(n, \alpha)B$ reactions were measured for neutrons of energies between 0.2 and 1.7 Mev. Resonances were observed for neutron energies of 0.55, 0.70, and 1.45 Mev.

INTRODUCTION

SINCE Wilhelmy[1] first reported observations indicating the existence of resonances in the disintegration of nitrogen by fast neutrons, many investigations of these resonances have been carried out. The following reactions are known to occur in nitrogen under bombardment by fast neutrons:

$$ {}_7N^{14}+n\rightarrow {}_6C^{14}+p+Q_I \qquad \text{(I)}$$

$$ {}_7N^{14}+n\rightarrow {}_5B^{11}+\alpha+Q_{II}. \qquad \text{(II)}$$

Baldinger and Huber[2] measured the disintegration cross sections of these reactions for 2.8-Mev neutrons and found for reaction I a cross section of 0.04×10^{-24} cm^2 and for reaction II 0.16×10^{-24} cm^2. These authors give for the reaction energies $Q_I=+0.55\pm0.03$ Mev and $Q_{II}=-0.43\pm0.1$ Mev. In previous work the resonances were observed by measuring the distribution in pulse height of the disintegrations occurring in an ionization chamber exposed to a continuous neutron spectrum. The most recent experiments using this method were carried out by Zagor and Valente[3] who studied the resonances in some detail. They find that all the observed resonances are caused by reaction II. The same authors[4] also obtained an estimate of the disintegration cross section of nitrogen by interposing a nitrogen absorber between the source and the nitrogen detector. The fast neutron absorption cross section determined in this manner has the surprisingly high value of 60×10^{-24} cm^2.

In spite of the very large number of pulses recorded by Zagor and Valente not all the peaks observed are too well defined, nor is the agreement with other authors very satisfactory. It appeared, therefore, worth while to carry out a similar experiment using a source of monoenergetic neutrons of variable energy to measure the disintegration cross section as a function of neutron energy.

APPARATUS

The nitrogen disintegrations were observed in a cylindrical ionization chamber with well-defined active volume. The chamber was designed by Koontz and Hall.[5] It was filled with spectroscopically pure nitrogen to a pressure of 4.5 atmos. The active volume of the chamber was 2.54 cm in diameter and 10 cm long. 860 volts obtained from batteries were applied between the central wire and the cylinder. The pulses were amplified by an amplifier of 0.5 μsec. rise time and fed into a pulse analyzer. The pulse analyzer allows one to count all the pulses above a certain bias (integral count) and simultaneously the pulses the height of which lies between two biases (differential count). The differential channel could be moved to any position without changing its width. The over-all response could be measured by artificial pulses fed into the high voltage supply of the chamber. By this procedure the linearity of the amplifier, the width of the differential channel, and its position with respect to the integral channel could be determined.

The neutron flux was monitored by counting the number of fission pulses occurring in an ionization chamber. The amount of fissionable material in the chamber was known.

The monoenergetic neutrons obtained when

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[1] E. Wilhelmy, Zeits. f. Physik 107, 769 (1937).

[2] E. Baldinger and P. Huber, Helv. Phys. Acta 12, 330 (1939).

[3] H. I. Zagor and F. A. Valente, Phys. Rev. 67, 133 (1945). This paper contains references to previous work on the same subject.

[4] F. A. Valente and H. I. Zagor, Phys. Rev. 69, 55 (1946).

[5] P. G. Koontz and T. A. Hall, Rev. Sci. Inst. to be published soon.

Li is bombarded by protons were used as a source. The protons were accelerated by means of the University of Wisconsin's electrostatic generator. The Li target used in the present experiments had a thickness corresponding to an energy loss of the protons of about 30 kev. The chamber filled with nitrogen and the monitor chamber were placed on opposite sides at an angle of 30° with respect to the proton beam. The distance from the Li target to the center of the active volume of the nitrogen chamber was $8\frac{1}{2}''$; the monitor foil was at a distance of $4\frac{1}{2}''$ from the target.

The operation of the chamber was tested by placing it in a flux of thermal neutrons obtained by slowing down the neutrons from a 500-mg Ra-Be source in paraffin. For slow neutrons only the $N(n, p)$ reaction takes place. The pulse height distribution obtained for the disintegration of nitrogen by slow neutrons is shown in Fig. 1. It shows a reasonably sharp peak. In order to determine the effect of γ-rays the Ra-Be source was replaced by a 500-mg Ra source. The pulse size distribution due to γ-rays is shown by the dashed curve in Fig. 1. It indicates that few pulses as large as those due to the nitrogen disintegrations are produced by γ-rays.

For the measurement with fast neutrons, the nitrogen filled chamber and the monitor chamber were covered with Cd sheet, $\frac{1}{32}''$ thick. In view of the fact that the monitor chamber did not have a good plateau, its counting rate was checked before each run in a paraffin geometry using a Ra-Be source. The amount of active fissionable material in the chamber had previously been calibrated in terms of the counting rate in the same paraffin geometry.

RESULTS

The results of the measurements are not as complete as would be desirable, since the accelerator was available for only two days for this experiment. At fourteen values of neutron energy differential bias curves were taken. Three typical differential bias curves are shown in Fig. 2. The counts at different neutron energies are normalized to the same number of monitor counts. At all other energies only integral counts were taken. At neutron energies below 1 Mev a well-defined peak due to the disintegration protons appears (see curve for 750 kev). At 1 Mev the range of the disintegration protons is approximately equal to the radius of the chamber. Because of this fact, the peak due to the protons becomes broader above 1 Mev. At 1.3 Mev a second peak due to the disintegration

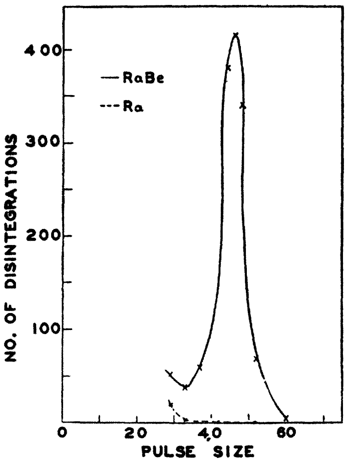

FIG. 1. The solid curve is a differential bias curve for $N(n, p)$ disintegrations caused by thermal neutrons. The counter filled with nitrogen to a gauge pressure of 55 lb./in.^{2} is operated as an ionization chamber. 500 mg of Ra-Be in a paraffin geometry serve as a neutron source. The dashed curve indicates the effect of γ-rays. It was obtained under the same conditions as the solid curve except that the Ra-Be source was replaced by a Ra source.

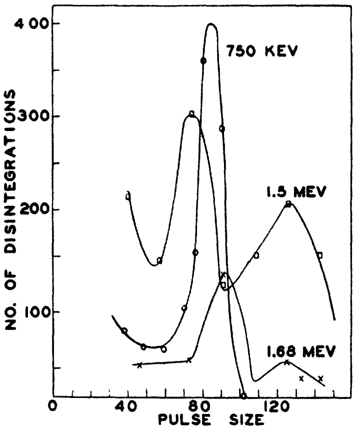

FIG. 2. Differential bias curves taken for neutrons of energies 0.75 Mev, 1.50 Mev, and 1.68 Mev. The number of pulses per channel, seven pulse size units wide, is plotted against pulse size. The peak occurring for 750-kev neutrons is attributed to protons. The peak of smaller pulse sizes at 1.50 and 1.68 Mev is believed to be owing to α-particles, the peak at larger pulse size to protons. At different neutron energies the ordinates are reduced to the same monitor count.

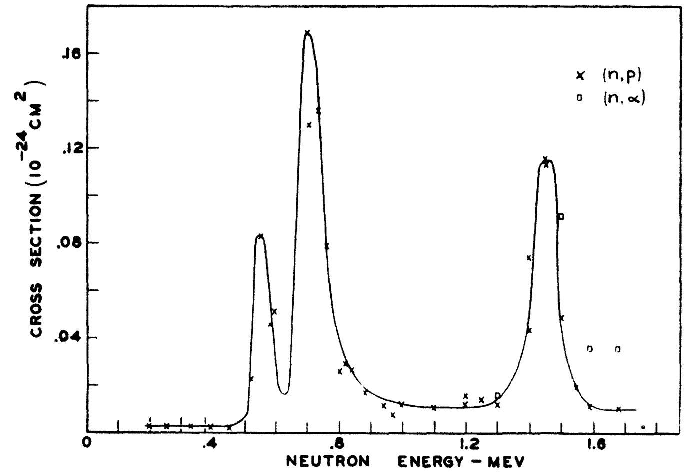

FIG. 3. The cross sections of the $N(n, p)$ and $N(n, \alpha)$ reactions are plotted against neutron energy.

α-particles appears clearly above the γ-rays and nitrogen recoils.

The peak due to α-particles appears in Fig. 2 for the differential bias curves taken at 1.5 and 1.68 Mev. At the highest energy the wall effect for the protons becomes so important that the peak is not well resolved.

It should be mentioned that no direct evidence was obtained which proves that the peak of lower energy is caued by α-particles and not by protons which might leave the C^{14} nucleus in an excited state. But since Baldinger and Huber[2] found that at 2.8 Mev the (n, α) reaction is four times as probable as the (n, p) reaction one would expect to find evidence of the (n, α) reaction at 1.5 Mev. As will be shown later, the energy of the observed particles agrees well with the assumption that they are α-particles.

The differential bias curves obtained enable one to determine the integral bias setting to count the protons and α-particles. At each neutron energy, all pulses counted above one bias were assumed to be due to protons, all pulses above a lower bias were assumed to be caused by α-particles and protons. The choice of these biases was subject to considerable uncertainty, and the lack of definition of the peaks is the principal cause of error in the results.

The counting rate of the nitrogen chamber was compared with that of the monitor chamber. Using the known values of the cross section of the fissionable material as a function of energy, the cross sections for the disintegration processes were computed. A summary of the results obtained is shown in Fig. 3. The (n, p) reaction shows resonances at 550, 700, and 1450 kev. In the neighborhood of these resonances the counting rates fluctuated presumably because of small fluctuations in the neutron energy. The true width of the resonances may be narrower than measured, since the measured width corresponds to what one would expect due to the thickness of the Li target. On the basis of the same argument, the true height of the resonances may also be larger than measured. The (n, α) cross section was measured at only four neutron energies. The values are indicated by rectangles in Fig. 3. There is a definite indication (see also Fig. 2) that the (n, α) process shows a resonance at the same energy as the (n, p) reaction. This is to be expected, since both processes result from the disintegration of the same compound nucleus unless selection rules favor one mode of disintegration.

Errors in the measurements of the cross sections are caused by the following facts:

(1) Lack of definition of the peaks, principally because of wall effects,
(2) Uncertainty in the calibration of the monitor chamber,
(3) Lack of resolution of the resonances because of the energy spread of the neutrons,
(4) Large size of the detectors compared to the distances from the neutron source.

It is difficult to estimate the error caused by these factors. It is not unreasonable to assume that values of the cross sections may be in error by 25 percent.

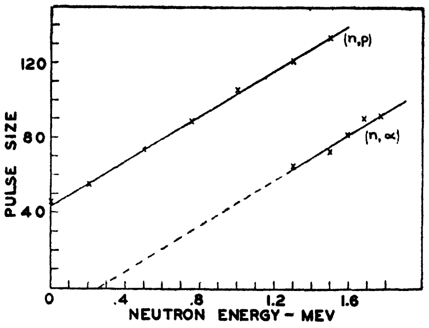

FIG. 4. The pulse sizes corresponding to the $N(n, p)$ and $N(n, \alpha)$ peaks are plotted against neutron energy. The best straight line through the pulse sizes of the (n, p) reaction intersects the axis of abscissae at −710 kev, a line through the (n, α) points intersects at +260 kev.

In Fig. 4 the positions of the peaks in pulse size due to the two reactions are plotted as a function of neutron energy. The line through the pulse sizes of the (n, p) reaction intersects the axis of abscissae at −710 kev. If one draws a line parallel to that for the (n, p) reaction through the (n, α) points, the intersection occurs at 260 kev. In Table I the present results are compared with those computed from the known masses of the nuclei involved and those obtained by other authors. The reaction energies obtained in the present measurements depend on the energy calibration of the electrostatic generator. The reasonable agreement with other measurements is evidence for the proper assignment of the observed peaks to the two reactions.

If one wants to compare the observed resonances with those previously reported, one has to add the reaction energy to the neutron energy since in earlier work a continuous neutron spectrum was used and only the energy of the products was measured. From the Q values given by the present measurements this yields 1.26, 1.41, and 2.16 Mev for the (n, p) reaction and 1.19 Mev for the (n, α) reaction. According to Table V of reference 3, resonances have previously been reported at the following energies: 0.60, 0.75, 0.90, 1.05, 1.25, 1.31, 1.33, 1.40, 1.42, 1.60, 1.64, 1.75, 1.94, 2.00, 2.04, 2.05, 2.15, 2.16, 2.25 Mev, and at higher energies. Since these values form almost a continuum within the accuracy of the measurement, it is difficult to say which resonances found in the present work might correspond to those observed previously. If the lowest energy resonances found by Valente and Zagor[4] are caused by α-particles, their measurements do not cover the same energy range as the present experiments and are not in contradiction with this work.

ACKNOWLEDGMENTS

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TABLE I. Reaction energies of N-reactions.

	$Q(n, p)$ (kev)	$Q(n, \alpha)$ (kev)
Computed from masses	605	−280
Bonner and Brubaker[a]	620	−300
Baldinger and Huber[b]	550	−430
Present measurements	710	−260

[a] Bonner and Brubaker, Phys. Rev. 49, 778 (1936); 50, 781 (1936)
[b] See reference 2.