THE
PHYSICAL REVIEW
A journal of experimental and theoretical physics established by E. L. Nichols in 1893

SECOND SERIES, VOL. 69, NOS. 3 AND 4 FEBRUARY 1 AND 15, 1946

Fast Neutron Resonance with Nitrogen†

FRANK A. VALENTE,* *Hanford Engineer Works, Richland, Washington*

AND

HERBERT IVAN ZAGOR, *Reeves Sound Laboratories, Apparatus Division, New York, New York*

(Received September 16, 1945)

Studies of the $_7N^{14}(n, a)\ _5B^{11}$ reaction indicate the emission of heavy particle groups possibly as a result of resonance transmutation by fast neutrons from a Ra—Be source. When a nitrogen absorber is placed before the nitrogen detector, the heavy particle groups apparently do not appear. Upon interposition of carbon as a retarding material between nitrogen absorber and detector, the reappearance of some of the groups in question occurs. This behavior would appear to indicate that nitrogen has a larger than normal probability to undergo transmutation by certain fast neutron groups. Two interpretations suggest themselves: (1) the experimental points, while based on more than 100,000 pulses, possess statistical fluctuations sufficient to produce the observed apparent resonance phenomena for fast neutrons or (2) nitrogen has a fast neutron absorption cross section of the order of 60×10^{-24} cm², much larger than the theoretical upper limit of about 0.7×10^{-24} cm². The resonance interpretation is supported by supplementary evidence. Further development of these techniques should make it possible to (1) estimate widths of nuclear levels, (2) measure nuclear energy levels, (3) check the reality of observed groups, and (4) determine which isotope is responsible for a group. Additional investigation of the subject is indicated.

I. INTRODUCTION

IN a previous study by the authors[1] of the transformation $_7N^{14}(n, a)_5B^{11}$ by fast neutrons of continuous energy, discrete groups were found for the emitted heavy particles. The method employed was that of Wilhelmy,[2] in which neutrons from a continuous source irradiate the target gas in an ionization chamber which is coupled to a linear amplifier and recording oscillograph. If discrete groups are emitted, the energy distribution of the resulting particles, when measured, shows peaks. There is evidence that such emission resonance correlates with an absorption resonance of the neutrons.[3] Accordingly, an absorber of resonance neutrons, intermediate between source and chamber, should be responsible for the absence of heavy particle groups. To test if resonance absorption of fast neutrons could be detected, the following series of experiments were performed. The apparatus and source used were the same as that previously described,[1] and the nitrogen pressure in the ionization chamber was 336 cm Hg.

† Work done in 1939–1942, while the authors were at New York University.

* Major, Corps of Engineers; Chief, Operation Units.

[1] H. I. Zagor and F. A. Valente, Phys. Rev. **67**, 133 (1945).

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

[3] W. Maurer, Zeits. f. Physik **107**, 721 (1937).

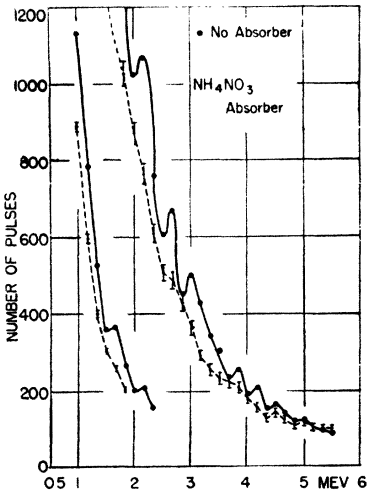

FIG. 1. Upper curve is a plot of number of pulses against $E_{\alpha+B}$ for $_7N^{14}(n, \alpha)_5B^{11}$ reaction. Dotted lower curve is plot of number of pulses against pulse size, with NH_4NO_3 as absorber. Curves at left, $\frac{1}{5}$ scale.

II. RESULTS

The upper curve in Fig. 1 shows the result of a plot of the sum of the energies of disintegration products of nitrogen against the number of associated oscillographic pulses. The curve shows several principal maxima at the energies 1.68, 2.15, 2.64, 2.98, 3.82, 4.14, and 4.48 Mev.[1,4] Previous experiments indicate these groups to be heavy particle groups arising from the fast neutron reaction $_7N^{14}(n, \alpha)\ _5B^{11}$.

The experiment was repeated with NH_4NO_3 and a nitrogen thickness of 0.38 g/cm² as an absorber. The lower curve in Fig. 1 shows the result that the distribution is smooth; all the groups have faded out.

$Al(NO_3)_3 \cdot 9H_2O$, having a nitrogen thickness of 0.26 g/cm², was used next as the intermediate absorber and the experiment repeated. The resulting distribution is shown in Fig. 2, and it is seen that the distribution is smooth with only evidence for the 2.64-Mev group remaining. However the intensity of this group is markedly diminished.

To eliminate the possibility that the fading out of the groups was caused by the H_2O or Al in the $Al(NO_3)_3 \cdot 9H_2O$ and not to the nitrogen, the distribution was remeasured first with an H_2O absorber, and then with an Al absorber. The thickness of the H_2O absorber in the latter measurement was 1.4 g/cm² as compared with the 1.1 g/cm² thickness of H_2O in the original $Al(NO_3)_3 \cdot 9H_2O$ absorber.

The result with the H_2O absorber is shown in Fig. 3. The distribution is not smooth and the 1.68-, 2.15-, 2.98-Mev groups show up clearly, though they are not sharp. The reason for their lack of sharpness is that the incident neutrons suffer appreciable slowing in passing through the H_2O. This condition is similar to the case in which a paraffin plug is placed between source and chamber[5] and one would expect a diminution sharpness of the peaks.

The thickness of aluminum used in remeasuring the distribution was 0.91 g/cm² as compared with 0.17 g/cm² aluminum in the original $Al(NO_3)_3 \cdot 9H_2O$ absorber. The resulting distribution in Fig. 4 shows the 1.68-, 2.15-, 2.64-, and 2.98-Mev alpha-groups appearing sharply.

Finally, commercial cyanamid ($CaCNNH_2$) with a nitrogen thickness of 0.5 g/cm² was used as absorber. The distribution, shown in Fig. 5,

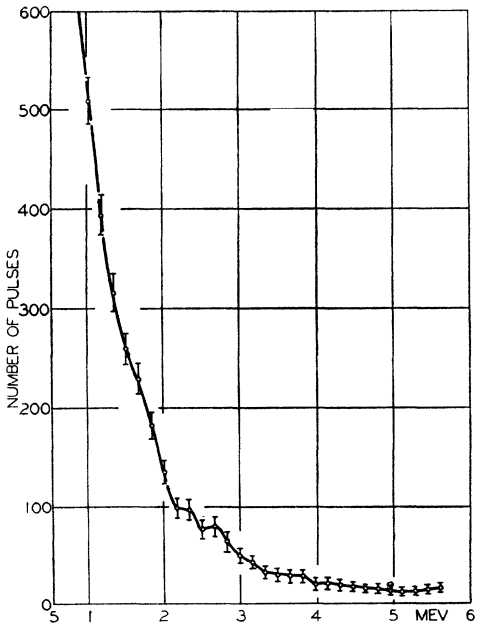

FIG. 2. $Al(NO_3)_3 \cdot 9H_2O$ absorber between source and chamber.

[4] The background averaged about one count per minute and showed a random distribution. It was thus disregarded in the calculation.

[5] See Figs. 4 and 5, reference 1.

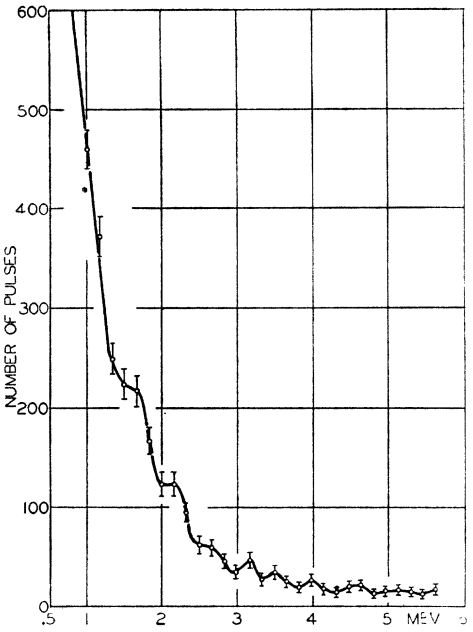

FIG. 3. H_2O absorber between source and chamber.

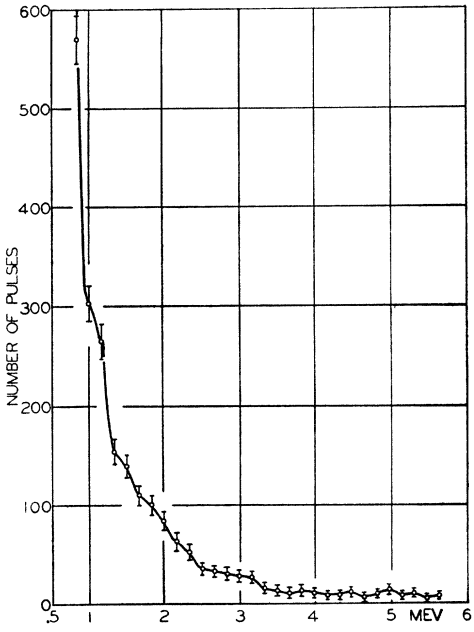

FIG. 5. $CaCNNH_2$ absorber between source and detector.

is completely smooth, with all the groups being washed out.

It thus appears that the interposition of a nitrogen absorber between the source and nitrogen chamber causes the groups to disappear,

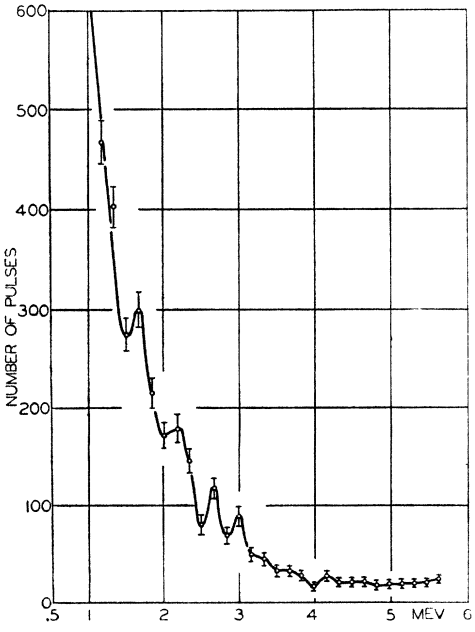

FIG. 4. Al absorber between source and chamber.

whereas non-nitrogeneous absorbers do not cause the groups to fade out. Since the groups detected are heavy particles arising from a fast neutron reaction, the evidence would appear to indicate that resonance absorption of fast neutrons has been detected.

The work of Hornbostel and Valente[6] suggested that the placing of a slowing or moderating material between the nitrogen absorber and the nitrogen chamber should change the neutron spectrum emerging from the nitrogen absorber by shifting the spectrum so as to replace, at least partially, the absorbed neutrons. The neutrons striking the slowing material will have a distribution corresponding to a spectrum with absorption bands in it. The effect of the retarding material is to shift (by retardation of the neutrons) the spectrum, thereby modifying the distribution so that the absorption bands are at least partially reduced and the distribution assumes more nearly its original condition. If the proper thickness of retarder is used, some of the groups would be expected to reappear.

A carbon slab of thickness 1.27 g/cm^2 was

[6] J. Hornbostel and F. A. Valente, Phys. Rev. **55**, 108 (1939).

interposed between the NH_4NO_3 absorber and nitrogen chamber. The resulting distribution was measured, and is shown in the lower curve in Fig. 6. The 1.68-, 2.15-, and 2.64-Mev groups reappeared sharply, whereas the remaining groups do not. Since all the groups did not reappear, the thickness of carbon slab used must have been such as to cause only a partial replacement of the absorbed neutrons. The upper curve is the nitrogen distribution curve without carbon retarder and has been shown previously as the upper curve in Fig. 1.

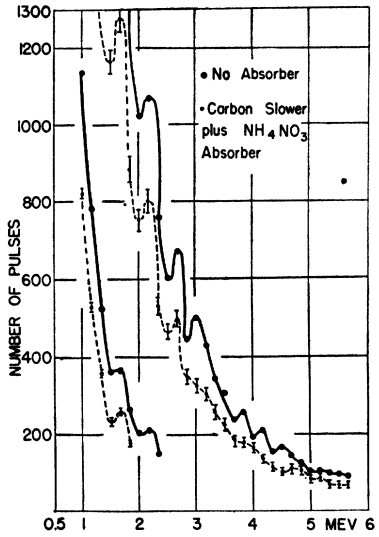

FIG. 6. Upper curve is distribution with no absorber. (Same as upper curve, Fig. 1.) Dotted lower curve is distribution with carbon slower placed between NH_4NO_3 absorber and nitrogen ionization chamber. Curves at left, $\frac{1}{3}$ scale.

III. DISCUSSION

The experimental results suggest that we may be observing resonance absorption of fast neutrons. Interposition of a nitrogen absorber between source and nitrogen detector results in the disappearance of the groups, and this effect is independent of the kind of nitrate used. When subsequently a graphite retarder is placed between the nitrogen absorber and nitrogen detector, some of the groups reappear. The interposition of absorbers, other than paraffin,[5] between the nitrogen absorber and nitrogen detector do not cause the disappearance of the detected groups. The interposition of a paraffin plug between source and detector results in the non-appearance of the groups,[5] indicating the observed phenomena to be produced by fast neutrons. That instrumentation may not be the cause of the groups is shown by the relatively smooth curve obtained with hydrogen.[7]

Nevertheless, and despite that more than 100,000 pulses were counted in the nitrogen-filled chamber, the possibility of describing the data by a smooth curve, drawn through the experimental points, cannot be excluded entirely. Hansen,[8] in studying the range velocity relation for boron, also investigated the reaction $_7N^{14}(n, a)_5B^{11}$ with D+Be neutrons. From his data Hansen questions whether the maxima he observed have physical meaning or are caused by statistical fluctuations. As a check, he applied the χ^2 test and found "that if the points were represented by the smooth curve, then the chance that the deviations were as large as those observed was about 3 to 10." He concludes that this does not prove that the smooth curves are not the best representations of the points. Hansen points out that although it is unlikely that an event which has three chances in ten of happening should happen in six consecutive runs, a possible interpretation might be that all six runs are equally bad.

In this connection, it should be pointed out that the value of the nitrogen cross section, as deducted from experiment, is roughly 100-fold greater than the maximum theoretical cross section, though the character of the resonance is otherwise qualitatively in accord with the Bohr theory.

The maximum theoretical value of the cross section for a reaction of a neutron with a nucleus is given by the larger of the two expressions, namely:

$$\pi \text{ (geometrical radius of nucleus)}^2,$$

or

$$\pi \text{ (neutron wave-length divided by } \pi)^2.$$

For 1-Mev neutrons on nitrogen, both these expressions are of the order of magnitude of 0.7×10^{-24} cm^2. From this value, the thickness of nitrogen absorber required to make the resonance

[7] See Fig. 8, reference 1.
[8] W. Hansen, Ph.D. thesis (Yale University, 1941), p. 42.

groups disappear is calculated as follows:

$$\text{thickness in g/cm}^2 = \frac{\text{atomic weight of nitrogen}}{\text{cross section} \times \text{Avogadro's number}}$$

$$= 14/0.7 \times 10^{-24} \times 0.6 \times 10^{24} \sim 33 \text{ g/cm}^2.$$

In contrast to this theoretical value, the experimental figure for the thickness required to observe the apparent disappearance of the resonance groups in question was about 0.38 g/cm^2.

In view of the importance to theory of this question of interpretation, additional investigation of the subject is indicated.

IV. APPLICATIONS

Resonance absorption can be applied to check the reality of observed groups. If the observed groups can be caused to fade out by interposition of the appropriate resonance absorber, it is reasonably certain that the observed groups are real and are not the result of instrumentation.

In the case of isotopes, the use of an enriched isotope resonance absorber might permit determining precisely which isotopes are responsible for particular groups.

The method of interposition of slower between resonance absorber and ionization chamber can be applied to estimate experimentally the widths of nuclear levels. To do this, the experiment would be repeated with varying thicknesses of scattering material between resonance absorber and detector. As the thickness of the scattering material is increased, the groups should begin to reappear, but not uniformly. The assumption made is that narrower levels will yield groups more easily detected than broad levels under these conditions. In particular, the minimum thickness of scatterer at which a particular group reappears is noted. From a knowledge of the neutron-scatterer cross section, the width of the level can be estimated. However considerable difficulties due to the large number of corrections necessary are involved in this method.

In addition, energy levels in nuclei could be measured by an extension of the method of resonance absorption by the following procedure. The element to serve as detector is placed into the ionization chamber. The experimental procedure discussed in the text is followed, and the nuclear levels measured, each heavy particle group being associated with a nuclear level. The element whose nuclear levels are to be measured is then placed as absorber between detector and source and the energy distribution of the detector is redetermined. If any of the levels in the absorber overlap a level in the detector, then the group corresponding to that level should vanish. This is an extention of the method employed by Salant, Horvath, and Zagor[9] for slow neutrons. A limitation in this application is that the absorber must have overlapping levels in the same energy region as the detector or else resonance absorption will not be detected. However, this might be overcome by the interposition of various thicknesses of scatterers between absorber and detector in order to shift the neutron energy spectrum entering the detector into the proper energy region.

[9] E. Salant, W. Horvath, and H. I. Zagor, Phys. Rev. 55, 111 (1939).