Fig. 4. No anomaly is observed at 4.52 Mev, but at 4.60 Mev a maximum with a width $\Gamma \approx 100$ kev is resolved.

An angular distribution of these inelastic protons to the first excited state is shown in Fig. 5, where the bombarding proton energy was 4.60 Mev. The data are the intensities corrected to center of mass plotted as a function of the cosine of the center-of-mass angle. The distribution shows strong interference effects with a level of opposite parity. No analysis of level parameters has been attempted.

ACKNOWLEDGMENT

The author would like to express his appreciation for the efforts of Donald E. Faulkner who aided in obtaining much of the experimental data presented here.

PHYSICAL REVIEW VOLUME 122, NUMBER 3 MAY 1, 1961

Delayed Neutrons from N^{17}†

G. J. Perlow, W. J. Ramler, A. F. Stehney, and J. L. Yntema
Argonne National Laboratory, Argonne, Illinois
(Received December 19, 1960)

The energies of the delayed neutrons which follow the decay of N^{17} have been measured by means of a triple proportional-counter recoil spectrometer. The N^{17} was obtained from the $C^{14}(\alpha,p)N^{17}$ reaction at a mean α-particle energy of 25-Mev. Two neutron groups were observed, with energies of 1.22 ± 0.06 Mev and 0.426 ± 0.018 Mev. These correspond to neutron emission from the $\frac{3}{2}^-$ states of O^{17} at 5.38 and 4.55 Mev, respectively. This result is consistent with the expected J^π of $\frac{1}{2}^-$ for the ground state of N^{17} and with the small stripping widths for these levels in $O^{16}(d,p)O^{17}$. The ratio of the intensity of the high-energy group to the low-energy one is 1.6, which corresponds to a ratio of 4 for the squares of the β-decay matrix elements.

INTRODUCTION

The nucleus N^{17} decays by β decay to excited states of O^{17} with a half-life of 4.1 sec.[1] At least some of these lie above the neutron separation energy and therefore decay predominantly and promptly by neutron emission.

Alvarez[2] measured the neutron energy by examining the energy of the O^{16} ions which recoiled from the neutron emission in a proportional counter. He deduced a neutron spectrum centered at 0.9 Mev and having a width at half-maximum of less than 0.5 Mev. He also measured the β rays in coincidence with the neutrons and obtained an end point of 3.7 ± 0.2 Mev. Hayward[3] made use of proton recoils in a hydrogen-filled cloud chamber. She found the neutron energy to be peaked at about 1 Mev with a width at half-maximum of approximately 0.2 Mev. There was, in addition, some evidence for a weak emission of higher energy neutrons. The mass excess $(M\text{-}A)$ of N^{17} has been determined from the $B^{11}(Li^7,p)N^{17}$ reaction[4] as 12.93 ± 0.06 Mev.[5] From this value of the mass excess and the observed neutron and β spectra, one would conclude that the β decay proceeds primarily to the $\frac{3}{2}^+$ level of O^{17} at 5.08 Mev. It seemed of interest to attempt a more accurate identification of the levels of O^{17} to which the β decay from N^{17} proceeds, especially since decay to the $\frac{3}{2}^+$ state requires an unlikely ground-state configuration of N^{17}: This has been done by measuring the spectrum of neutron energies.

EXPERIMENTAL PROCEDURE

The N^{17} was produced by the reaction $C^{14}(\alpha,p)N^{17}$ at the Argonne 60-in. cyclotron. The 43-Mev beam was degraded by absorbers to about 28 Mev where the cross section is known[6] to be maximal. The target contained 41% elemental C^{14}. It was prepared by generating CO_2 from active $BaCO_3$ obtained from Oak Ridge, and reducing it in a quartz tube with hot magnesium. The fused mass resulting from the reaction was treated with HCl and then with HF and HNO_3. Only carbon remained after filtering and washing. This was compressed into a pellet of 1-cm diameter containing 14 mg of the isotopic mixture and was sealed between Al foils 0.001 in. thick. The external α beam of the cyclotron was focused by means of 3 sets of quadrupole magnets to produce a beam of approximately 2 μa over a 0.25-in. diameter region at the target. The target was placed at 45° to the beam inside a tube separated from the cyclotron beam tube and was cooled by an air jet which then passed through a filter and into the air exhaust system. The filter was checked periodically for activity to avoid contamination in the event the target container ruptured. The cyclotron shutter was controlled by a

† This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] N. Knable, E. O. Lawrence, C. E. Leith, B. J. Mayer, and R. L. Thornton, Phys. Rev. **74**, 1217 (1948).

[2] L. W. Alvarez, Phys. Rev. **75**, 1127 (1949).

[3] E. Hayward, Phys. Rev. **75**, 917 (1949).

[4] Carol Littlejohn, Phys. Rev. **114**, 250 (1959).

[5] F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. **11**, 221 (1959).

[6] K.-H. Sun, B. Jennings, W. E. Shoupp, and A. J. Allen, Phys. Rev. **82**, 267 (1951).

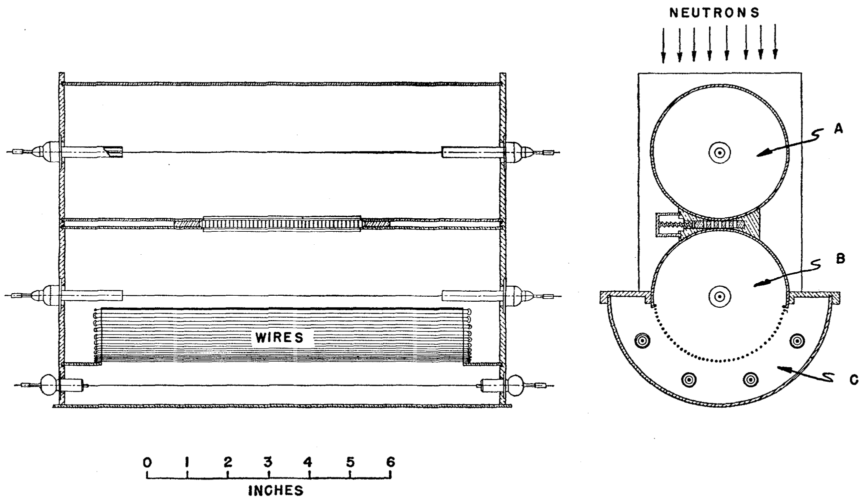

FIG. 1. The neutron spectrometer. Omitted from the drawing is a collimated Cm alpha-particle source on a bellows arrangement fastened to the cylindrical surface of *C*. It can be used to send particles through *C*, *B*, and *A*, respectively.

timer which likewise controlled the counting apparatus. The cycle used had a duration of 24 sec, of which 7.5 sec was occupied with the bombardment, 2 sec with waiting, and the remainder with counting.

The neutron energies were measured by means of a neutron spectrometer which has been described[7] elsewhere in detail. A schematic drawing of the spectrometer is given in Fig. 1. It consists of proportional counters A, B, and C containing a methane filling common to all three. Neutrons incident on A may produce proton recoils in the gas which, if directed within 26° of the neutron direction, can pass through a collimator plate into counter B. An anticoincidence $AB\bar{C}$ indicates that the recoil track is entirely contained in A and B, the point of origin in A being immaterial, and causes a gating pulse to be supplied to a 20-channel analyzer which measures the sum of the pulse heights, P_A+P_B. This is proportional to the ionization of the proton, and hence to the energy of the neutron. A certain range of energies may be accommodated at one counter pressure, then the pressure must be changed. The efficiency is nearly independent of pressure, however, and may be expressed, aside from a geometrical factor, as the product σR_0, where R_0 is the STP range of the maximum energy recoil in the CH_4, and σ is the (n,p) scattering cross section. This product varies nearly linearly with energy in the region of interest.

The counter used in this investigation differed from that of reference 7 in having an α-particle calibrator consisting of a thin Cm source on a nickel rod which could be moved by means of a bellows to direct a weak beam of alphas through counters C, B, and A. The calibrator was used for comparison of runs taken at different times, and was not considered absolute.

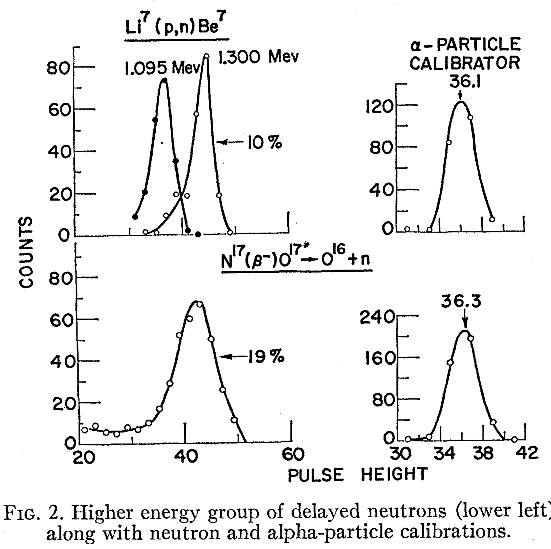

FIG. 2. Higher energy group of delayed neutrons (lower left) along with neutron and alpha-particle calibrations.

RESULTS

In Fig. 2 we show results obtained at a counter pressure of 25.2 cm Hg. The lower left curve in the figure is a pulse-height spectrum of the delayed neutrons of interest. Directly above are two of a group of calibration curves taken some months previously with neutrons from the reaction $Li^7(p,n)Be^7$ produced in a thin target at the Van de Graaff generator. The upper and lower plots on the right side of the figure represent α-particle calibrations taken at the two times. Using the calibration data, and averaging four runs, we obtain a neutron energy of 1.22 ± 0.06 Mev, which would correspond to a transition from a level at 5.45 Mev in O^{17}. The energy-level diagram for O^{17} is shown in Fig. 3. The level at 5.38 Mev is known from $O^{16}(d,p)O^{17}$ to be a $\frac{3}{2}^-$ level, and the next higher level known is at 5.70 Mev. Thus, despite the 70-kev discrepancy, which is just outside the estimated experimental error, we are undoubtedly observing transitions involving the $\frac{3}{2}^-$ state.

The runs taken with a pressure of 25 cm in the counter indicated the presence of a group of lower energy

[7] G. J. Perlow, Rev. Sci. Instr. 27, 460 (1956).

neutrons. In order to investigate this in more detail, the counter pressure was reduced to 4.77 cm Hg. The results are shown in Fig. 4, together with 2 calibration peaks obtained at neutron energies of 410 kev and 450 kev from the $Li^7(p,n)Be^7$ reactions with the Van de Graaff and the α-particle calibrations used in the correction of the energy scale. The peak energy is found to be 426 ± 18 kev. The width of the neutron line again is observed to be considerably greater than the one obtained with the $Li^7(p,n)Be^7$ reaction. We believe that the greater width is primarily due to instrumental fluctuations during the long running times and possibly also to the high background present in the experimental area. Our measurement would correspond to a level in O^{17} at 4.60 ± 0.02 Mev. This must be identified with the $\frac{3}{2}^-$ level at 4.56 Mev. The existence of these two groups had been conjectured by Jones and Mandl.[8]

Calculating counter efficiency as in reference 7, we get for the ratio of the intensities of the two neutron groups, $I(1.22)/I(0.426)=1.6$. From the ratio of ft values calculated from this result we get for the ratio of the β-decay matrix elements for the transition leading to these groups, $|M|^2(1.22)/|M|^2(0.426)=4$.

An attempt was made to observe neutrons from higher excited states in O^{17}. However, the spectrometer

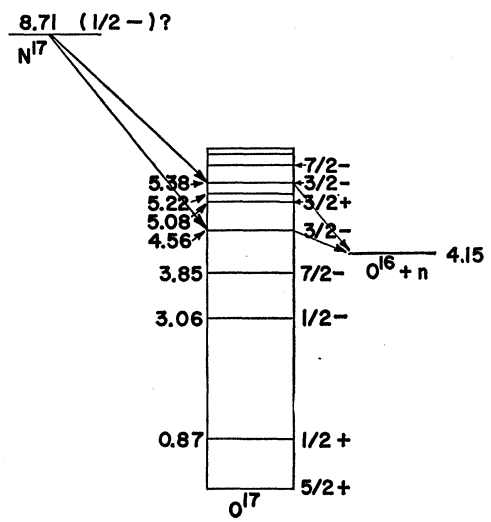

FIG. 3. Energy level diagram for O^{17}.

[8] G. A. Jones and F. Mandl, Nuclear Phys. 4, 690 (1957).

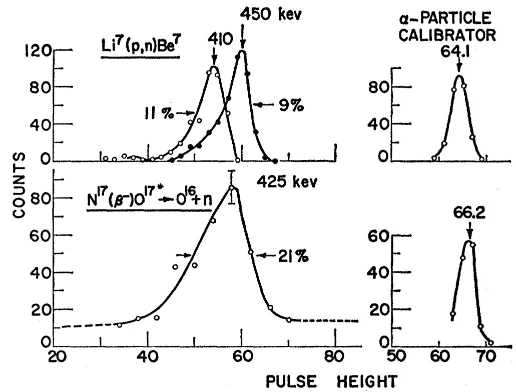

FIG. 4. Lower energy group of delayed neutrons.

is not suitable for neutrons with energies of more than 1.6 Mev and no positive result was obtained.

The principal ground-state configuration of N^{17} is probably $[(\pi p)^5]_{\frac{1}{2}}[(\nu p)^6]_0[(\nu d_{\frac{5}{2}})^2]_0$. In β decay, the neutron cannot decay into a proton with a different value of l. The decay of either a p or a d neutron must then lead to a state of O^{17} which contains at least one vacancy in the $(p)^{12}O^{16}$ core. Such core-excited states are characterized by small stripping widths in $O^{16}(d,p)O^{17}$. Conversely, any state having a large stripping width cannot be associated with a strong branch in the β decay of N^{17}. Analysis[9] of the (d,p) data indicates that the 4.56- and 5.38-Mev $\frac{3}{2}^-$ states of O^{17} have stripping widths considerably smaller than the single-particle value. This is then consistent with our observation of two strong groups of delayed neutrons from these states.

The $\frac{1}{2}^-$ state at 3.06 Mev in O^{17} lies below the neutron separation energy. Its very small stripping width in $O^{16}(d,p)O^{17}$ suggests that it may be populated by an observable branch of the β decay of N^{17}.

ACKNOWLEDGMENTS

We are indebted to D. Kurath, R. D. Lawson, M. H. Macfarlane, and B. J. Raz for discussions on the interpretation of the experimental results, and to E. Sundahl, W. J. O'Neill, and M. C. Oselka for technical assistance.

[9] M. H. Macfarlane and J. B. French, Revs. Modern Phys. 32, 567 (1960).