Neutrons from the Proton Bombardment of N^{14}†

FAY AJZENBERG, *Department of Physics, Boston University, Boston, Massachusetts and Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts*

AND

WOLFGANG FRANZEN,* *Department of Physics, Princeton University, Princeton, New Jersey*

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The $N^{14}(p,n)O^{14}$ reaction has been investigated at 30, 60, and 150 degrees in the laboratory system by the method of proton recoils in thick nuclear emulsions. The energy of the incident protons was 17.3±0.1 Mev, and the thickness of the melamine target was 0.2 Mev. The results indicate a ground-state Q value of -6.03 ± 0.2 Mev, yielding a mass defect for O^{14} of 12.2 Mev, in good agreement with beta-decay results. The data also indicate levels in O^{14} at excitation energies greater than 5.5 Mev.

I. INTRODUCTION

In the past few years, extensive studies have been made of the level structures of the isobars[1] with $|T_z|=\frac{1}{2}$, where $T_z\equiv(N-Z)/2$. Wherever sufficient evidence is available, a one-to-one correspondence of the levels in $T_z=+\frac{1}{2}$ and $T_z=-\frac{1}{2}$ mirror nuclei is observed, when nonnuclear effects, such as the n-p mass difference and the difference in electrostatic energies, are taken into account.[2] This correspondence is believed to be a good indication of the charge symmetric character of nuclear forces.

Presumably, corresponding states should also occur in pairs of isobars which differ in the substitution of two protons for two neutrons, that is, $T_z=+1$ and $T_z=-1$ nuclei. No levels have been observed in nuclei with $T_z=-1$ until the present data were obtained, and thus this isobaric comparison has not heretofore been possible. Usually the most direct way of studying such proton-abundant nuclides in the region of the light nuclei is by means of (p,n) reactions which frequently have rather negative Q values. At this time, thick photographic emulsions (in particular, Ilford C-2 plates) are the only means of measuring fairly accurately neutron energies in the Mev range. Unfortunately, while it is possible by the method of proton recoils in thick plates to measure neutron energies to 0.5 percent (using a thin target and a well-defined incident beam), the group resolution is poor. The minimum interlevel distance for group resolution depends on the neutron energy as well as on the target thickness and beam energy spread and, in the best cases, is approximately 7 percent of the neutron energy. It was clear that the Princeton cyclotron external beam width (0.15 Mev) and the thick target (0.2 Mev), necessary for intensity reasons, would result in poor group resolution, but we felt that any insight gained in the behavior of $T_z=-1$ nuclei might nevertheless be of interest.

O^{14} was studied in order to check the value of the mass of O^{14} derived from beta-decay studies,[3–5] and because some estimate of the magnitude and direction of the energy shift for corresponding levels in the $T_z=+1$ (C^{14}) and $T_z=-1$ (O^{14}) nuclei might be possible. There has been some indication[6] for a level at approximately 4 Mev in C^{14}. Assuming charge symmetry, a level in O^{14} should then appear near 4 Mev. Similarly, the more reliable levels in C^{14} (6.10,[6,7] 6.78,[8] and 6.98 Mev[8]) should have analogs in O^{14}.

II. EXPERIMENTAL PROCEDURE AND RESULTS

The experimental setup is indicated in Fig. 1. The external proton beam from the Princeton cyclotron bombarded a Melmac target placed at the center of a 12-in. diameter evacuated scattering chamber. The energy of the incident protons was determined, prior to the actual exposure, by measuring their range in aluminum. This range was found to be $(442.3\pm2)\times10^{-3}$ g/cm^2 of aluminum, which is equivalent[9–11] to a proton energy of 17.3±0.1 Mev.

Dr. K. G. Standing prepared the Melmac foil. The particular type of Melmac used (No. 1079 made by the American Cyanamid Corporation) is believed to be 50 percent melamine ($N_6C_3H_6$) and 50 percent filler (probably cellulose). For future experiments, Melmac 404, which is pure melamine, would be preferable.[12] The thickness of the foil was measured to be 2×10^{-3} in.,

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* Now at the University of Rochester, Rochester, New York.

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[11] H. Bichsel and R. F. Mozley, Phys. Rev. 90, 354 (1953) and a very helpful private communication from Dr. R. F. Mozley.

[12] We are very much indebted to Professor Standing for preparing the target and for his comments, which are partially reproduced in the above paragraph.

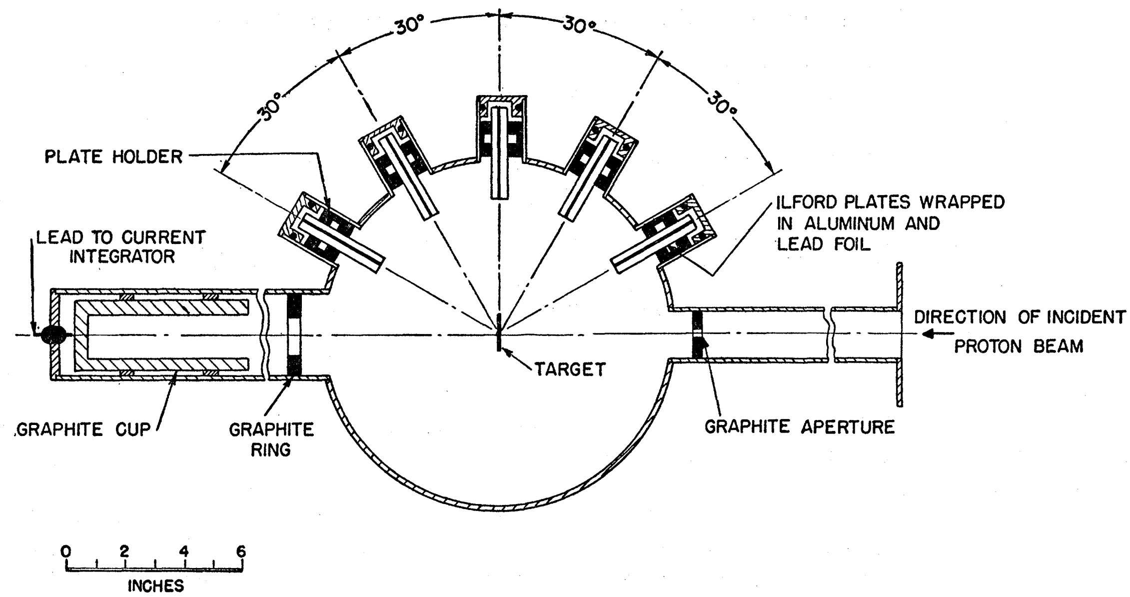

Fig. 1. The experimental setup.

which corresponds to an energy loss of approximately 0.2 Mev for 17-Mev protons.[13]

Ilford C-2 plates, 200 and 400 microns thick, were mounted at five different angles to the incident beam in the evacuated chamber. The plates were wrapped in 2-mil thick aluminum foil for protection from light, and lead sheets 35 mils thick shielded the plates from scattered protons and other charged particles.

The proton beam was collimated by graphite apertures and was stopped in the graphite cup indicated in Fig. 1. As a result, background radiation reached the emulsions from the following sources: Gamma rays from $C^{12}+p$ and from $C^{13}+p$ (presumably mostly from the former since C^{13} has an isotopic abundance of 1.1 percent) and neutrons from $C^{13}+p$. Graphite was chosen because the $C^{12}(p,n)N^{12}$ reaction has a threshold above the bombarding energy used in this experiment (20.0±0.1 Mev).[14]

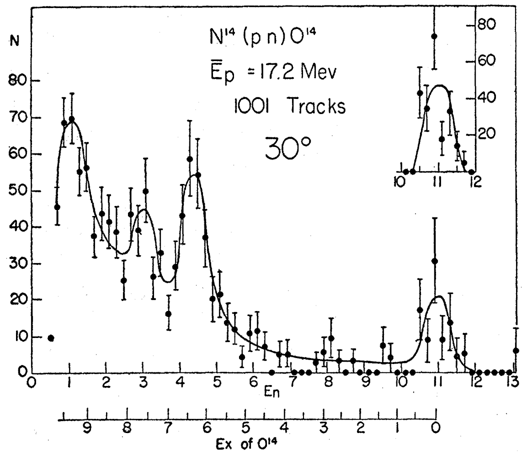

Fig. 2. 30° data. N is the relative number of neutrons per 200-kev interval. $\bar{E}_p$ is the average proton energy.

The gamma rays fogged the plates to such an extent that the maximum exposure possible was 600 microcoulombs, which turned out to be somewhat less than optimum for efficient scanning. While the C^{13}/C^{12} ratio was small, the total amount of graphite seen by the beam was appreciable, and it was feared that the $C^{13}(p,n)N^{13}$ reaction ($Q=-3.003$ mev)[15] would contribute a continuous background of neutrons. This background turned out to be very small (see Figs. 2 and 3). This is reasonable in view of the small solid angle subtended by the photographic emulsions at the graphite cup and apertures, and on account of the angular acceptance criteria for the proton recoil tracks which favored the acceptance of recoils caused by neutrons from the target.

The Melmac target also contained a small amount of C^{13}; the ratio of C^{13} to N^{14} nuclei was approximately 1/100. This might contribute several approximately monoenergetic neutron groups corresponding to the ground state and the first few excited states of N^{13}, if the $C^{13}(p,n)N^{13}$ cross section were fairly high. The upper limit to the number of proton recoil tracks at 30, 60, and 150 degrees which could be ascribed to the ground-state transition is 7, while a total of 2892 tracks were measured. The term "upper limit" is used because the ground-state neutron group from the reaction $N^{15}(p,n)O^{15}$ ($Q=-3.487$ Mev[1]) may be confused with the ground-state neutron group from $C^{13}(p,n)N^{13}$ ($N^{15}/N^{14}=1/250$).

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[13] Aron, Hoffman, and Williams, U. S. Atomic Energy Commission Report AECU-663, 1949 (unpublished).

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The plates were processed in a manner suggested by Dr. A. H. Armstrong[16] and then scanned with a binocular Leitz microscope[17] using a 100× oil-immersion objective and 10× eyepieces. The criteria for the measurement of the recoil-proton tracks have been discussed previously.[18] The range-energy relation used was that derived by Rotblat.[19] The data shown on Figs. 2 and 3 have been corrected for geometry[20] and for variation of the *n-p* scattering cross section with neutron energy.[21]

Plates exposed at 30, 60, and 150 degrees to the incident beam were scanned for proton-recoil tracks. Figures 2 and 3 indicate the data at the two smaller angles. The insets in these figures show the appearance of the ground-state groups when additional ground-state tracks were measured. The insets at each of the angles represent fifty ground-state tracks. The ground-state Q value, derived from the results at the three angles, is -6.03 ± 0.2 Mev. The ground-state neutron group width is greater than that calculated on the basis of target thickness, beam width, straggling, the size of the source, and the scanning area and multiple scattering effects. The group width is also larger than predicted from an extrapolation of thin target, "monoergic" beam results.[22] However, it is not felt that the low points at $E_n = 11.1$ Mev (30°) and 10.3 Mev (60°) are significant. The resultant high-energy groups, if the points were to be believed, would have a width somewhat smaller than that warranted by the resolution of this experiment.

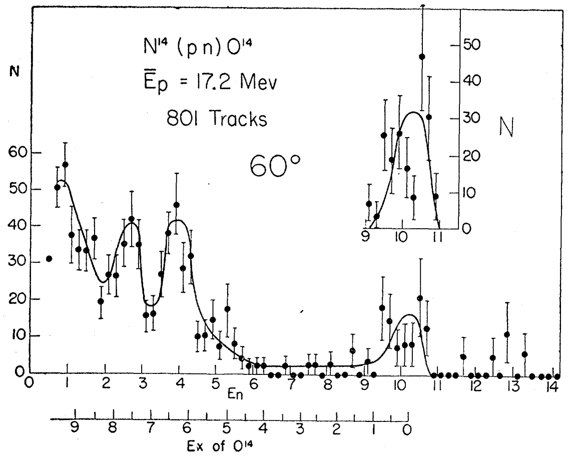

FIG. 3. 60° data. N is the relative number of neutrons per 200-kev interval.

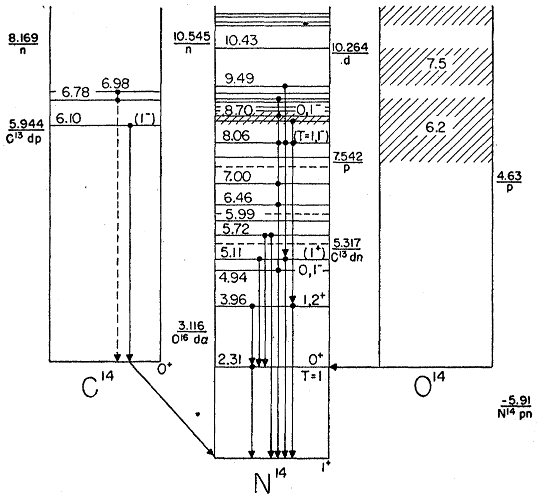

FIG. 4. The mass-14 isobaric triad.

The region between the ground state and an excitation of approximately 5.5 Mev seems to be free of levels unless the corresponding neutron groups are low in intensity at the various angles (less than $\frac{1}{4}$ of the intensity of the ground-state neutron group). The data for $E_n \lesssim 5$ Mev indicate energy levels in O^{14}. It is thought that the peaks corresponding to excitation energies of 6.2, 7.5, and 9.3 Mev are due either to very wide levels, or to a number of unresolved levels in O^{14}. Figure 4 is an attempt to show how the information derived from this work fits into the known picture of the mass-14 triad.[1,2,23] The dashed areas in O^{14} show the upper and lower limits of the regions in which wide or unresolved levels may be located.

In conclusion, we are in agreement with the mass defect for O^{14} predicted from beta-decay results.[1,3–5] Our value for the mass defect is 12.2 ± 0.2 Mev. We do not find a state in O^{14} analogous to the 4-Mev state[6] in C^{14}, unless it has been shifted upwards in O^{14} by about 1.5 Mev. If the group at an excitation energy of 6.2 Mev corresponds to the 6-Mev levels in C^{14} and not to the 4-Mev state, then the energy shift of the corresponding levels in the mirror nuclei O^{14} and C^{14} appears to be small.

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[16] A. H. Armstrong (private communication) and Allred, Armstrong, and Rosen, Phys. Rev. **91**, 90 (1953).

[17] The microscope was kindly loaned by the Department of Physics, Smith College, Northampton, Massachusetts.

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[22] See, for instance, F. Ajzenberg, Phys. Rev. **82**, 43 (1951).

[23] Private communications from D. H. Wilkinson, A. Sperduto, and R. J. Mackin.