N^{14} Level Structure from the $C^{13}(p, n)N^{13}$ Reaction

J. K. BAIR, J. D. KINGTON, AND H. B. WILLARD
Oak Ridge National Laboratory, Oak Ridge, Tennessee

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The neutron yield resulting from proton bombardment of C^{13} has been extended to a proton energy of 5 Mev. Maxima were found at bombarding energies of 3.78, 4.01, 4.10, 4.18, 4.52, and 4.8 Mev. The corresponding energies in the N^{14} compound nucleus are 11.05, 11.26, 11.35, 11.44, 11.74, and 12.0 Mev.

INTRODUCTION

THE threshold for the p, n reaction on C^{13} has been accurately measured by Richards, Smith, and Browne[1] to be 3.236 ± 0.003 Mev. Adamson, Buechner, Preston, Goodman, and Van Patter[2] have measured the neutron yield up to a bombarding energy of approximately 4 Mev. They found one maximum at 3.76 Mev followed by a rather rapid rise indicating that another level might exist at slightly higher energies than they were able to obtain. Blaser, Boehm, Marmier, and Scherrer[3] have investigated the excitation function to 6.8 Mev using a cyclotron and the stacked foil technique. The compound nucleus N^{14} has also been investigated in this energy region by means of the deuteron bombardment of C^{12}. The work of Bonner and the group at Rice Institute[4] and of Bailey, Freier, and Williams[5] yielded a number of levels in N^{14} at energies just above those reached by Adamson *et al.* As part of an effort to obtain further data on the relationship of levels in the same compound nucleus formed by different bombardments, the 5-Mev electrostatic generator at this laboratory has been used to extend the $C^{13}(p, n)N^{13}$ yield to higher energies.

EXPERIMENTAL PROCEDURE

An energy calibration of the magnetically analyzed proton beam was obtained as previously described,[6] and the reaction threshold was used as an additional calibration point. The beam energy determination is believed to be accurate to 0.2 percent relative to the $Li^7(p, n)Be^7$ threshold at 1.882 Mev. Resolution was also 0.2 percent or less. Targets consisted of thin (approximately 5 kev at threshold) carbon layers on platinum and were prepared by cracking methyl iodide vapor. The methyl iodide was obtained from Eastman Kodak Company with an enrichment of 61 percent. The targets were kindly prepared by Dr. H. E. Banta of this laboratory.

The neutron yield was measured by means of a "long counter" located at zero degrees with respect to the proton beam and placed 60 cm from the target. Neutron counts at each energy were measured for a fixed number of microcoulombs of beam as determined by a current integrator. Background, as determined by a run on a platinum target blank, was negligible. Since the $C^{12}(p, n)$ threshold is well above the beam energies used, no neutrons from that source should be produced.

RESULTS

Several runs were made over the energy region between threshold and 5 Mev. Figure 1 shows the unnormalized results not corrected for target thickness. The sharp rise at threshold is the geometrical peak. The rise at 3.78 Mev corresponds to the level found by Adamson *et al.*[2] Further well-defined maxima occur at 4.01, 4.18, 4.52, and 4.8 Mev corresponding to N^{14} excitation energies of 11.26, 11.44, 11.74, and 12.0, respectively. Blaser *et al.*[3] found maxima in our energy region at 4.0 and 4.9 Mev which, considering the 250 kev resolution of the foil technique used, agree well with our results. An unresolved peak was found at approximately 4.08 Mev. The resonances at 4.01 and 4.18 Mev were analyzed by fitting a Breit-Wigner curve to the data. When the effects of these two resonances were subtracted, the energy of the unresolved maximum was 4.10 Mev, corresponding to a N^{14} excitation energy of 11.35 Mev. For the levels at 4.01 and 4.18 Mev, a best fit was obtained using 20 and 30 kev, respectively, as the full widths at half maximum.

Table I lists in columns 1 and 2 our proton bombard-

TABLE I. Level structure of N^{14}: Columns 1, 2, and 3 list respectively the proton energy, width, and N^{14} excitation energy, as obtained from the $C^{13}(p, n)N^{13}$ reaction. Columns 4, 5, and 6 list the corresponding data from the reaction of $C^{12}+D^2$. Column 7 lists the products for which the deuteron-induced level has been observed.

	E_p Mev	$W_{\frac{1}{2}}$ kev	E_x Mev	E_d Mev	$W_{\frac{1}{2}}$ kev	E_x Mev	Type
1	3.78	100	11.05	0.91	100	11.04	$p\gamma n$
2	4.01	20	11.26	1.13	15	11.23	p––
3				1.16	100	11.26	$p\gamma$–
4	4.10	150	11.35				
5	4.18	30	11.44	1.30	50	11.38	$p\gamma n$
6				1.435	5.5	11.49	$p\gamma n$
7				1.62	100	11.65	––n
8	4.52	125	11.74	1.73	150	11.75	–γn
9	4.8	100	12.0				

[1] Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).
[2] Adamson, Buechner, Preston, Goodman, and Van Patter, Phys. Rev. **80**, 985 (1950).
[3] Blaser, Boehm, Marmier, and Scherrer, Helv. Phys. Acta **24**, 465 (1951).
[4] Bennett, Bonner, Richards, and Watt, Phys. Rev. **59**, 781 (1941); Bonner, Evans, Harris, and Phillips, Phys. Rev. **75**, 1401 (1949); Phillips, Bonner, and Richardson, Phys. Rev. **76**, 169 (1949); G. C. Phillips, Phys. Rev. **80**, 164 (1950); Farmularo, Thompson, and Bonner, Phys. Rev. **85**, 742 (1952).
[5] Bailey, Freier, and Williams, Phys. Rev. **73**, 274 (1948).
[6] Willard, Bair, Kington, Hahn, Snyder, and Green, Phys. Rev. **85**, 849 (1952).

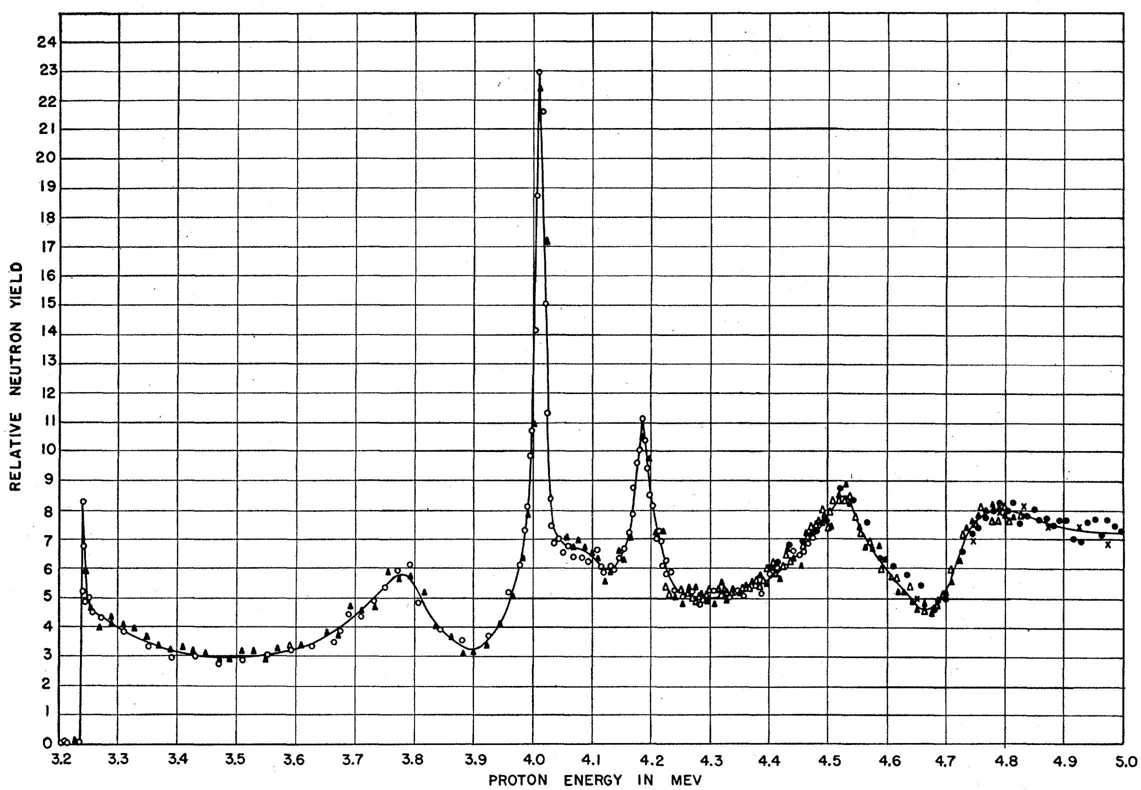

FIG. 1. $C^{13}(p, n)N^{13}$ yield curves in the forward direction.

ing energies and an estimate of the full width at half-maximum. Column 3 gives the excitation energies in N^{14}. Columns 4, 5, and 6 give corresponding data from the deuteron disintegration of C^{12}. Column 7 gives observed modes of disintegration of the deuteron induced reaction. The mass values of Li, Whaling, Fowler, and Lauritsen[7] were used to determine the excitation energies, $C^{13}+p-N^{14}=7.542$ Mev and $C^{12}+d-N^{14}=10.264$ Mev.

For maximum 1 of Table I, both the width and the excitation energies obtained by $C^{12}+d$ and $C^{13}+p$ are, as has been pointed out,[2] in good agreement. Although the excitation energy of our level at 4.01 Mev agrees best with that of the 1.16-Mev $d-p$ and $d-\gamma$ level, the width agrees much better with the 1.13 Mev $d-p$ level. Since the energy discrepancy is small (30 kev) and since the angular distribution can cause apparent energy shifts of this amount, we feel that it is more reasonable that our level at 4.01 Mev corresponds to that produced by 1.13-Mev deuterons. It would also appear that our maxima at 4.18 Mev and 4.52 Mev correspond to those produced by 1.30 and 1.73-Mev deuterons, respectively. It is possible that the wide unresolved maximum, number 4, at 4.10 Mev may correspond to the level excited by 1.16-Mev deuterons. A careful search over the region of proton bombarding energies from 4.2 to 4.5 Mev gave no indication of any maxima corresponding to those produced by 1.435- or 1.62-Mev deuterons. These measurements were made with the long counter at 0° with the proton beam, 60 cm from the target and also at 80° and 30 cm. The target thickness used was 4 kev (at threshold). No maximum in the deuteron data corresponds to that induced by 4.8-Mev protons; the next highest deuteron peak is at approximately 2.2 Mev, corresponding to a proton bombarding energy of about 5.0 Mev.

It is evident that the possibly expected correlation in N^{14} level structure as determined separately by proton and deuteron bombardment was not observed. It seems particularly interesting that at least two levels ($E_d=1.435$ and 1.62 Mev) appearing in the deuteron bombardments were not found in the present experiment. Apparently the explanation of the phenomena must await a more detailed description of the quantum states involved.

[7] Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).