regarded as that corresponding to a pile neutron distribution. This value is seen to be in considerable disagreement with the value of 40^{+40}_{-20} barns reported by Elson and co-workers.[10] No explanation for this large discrepancy is immediately apparent. However, the 760-barn value is consistent with that expected from cross-section systematics in this mass region.[11] Since Pa^{232} consists of an odd number of protons and an odd number of neutrons, the binding energy for an additional neutron is high; hence, an absorption cross section considerably higher than those of Pa^{231} and Pa^{233} is to be expected.

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[10] Elson, Sellers, and John, Phys. Rev. **90**, 102 (1953).

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$N^{14}(\alpha,n)F^{17}$ and $Na^{23}(\alpha,n)Al^{26}$ Reactions*†

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The $N^{14}(\alpha,n)F^{17}$ and $Na^{23}(\alpha,n)Al^{26}$ reactions have been studied by two methods, a proton recoil telescope and a slow neutron threshold detector. An energy level in F^{17} at 0.54±0.04 Mev has been observed and a ground state Q value of -4.76 ± 0.07 Mev was determined. Energy levels in Al^{26} were found at 0.3, 1.0, 1.4, 1.8, 2.5, and 2.9±0.2 Mev and a ground-state Q value of -2.9 ± 0.2 Mev was determined. In the latter reaction an excitation curve of the seven-second beta activity in Al^{26} has been observed with a threshold Q of -3.2 ± 0.2 Mev, indicating the presence of an isomeric state in Al^{26} at about 300 kev.

I. INTRODUCTION

RECENT interest in the hypothesis of charge independence of nuclear forces and conservation of isotopic spin has made desirable the studying of nuclear level structure by several reaction routes. As mentioned in a previous paper,[1] (α,n) reactions have been neglected in the past. In the present work the reactions $N^{14}(\alpha,n)F^{17}$ and $Na^{23}(\alpha,n)Al^{26}$ are investigated.

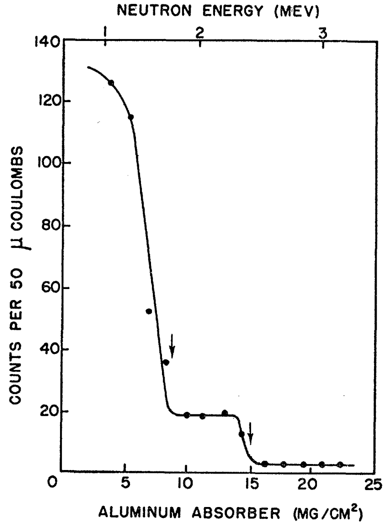

Fig. 1. Integral range curve of recoil protons from $N^{14}(\alpha,n)F^{17}$ reaction. Observation at 0°.

II. METHODS

The energies of the neutron groups were determined using a proton recoil telescope. The recoil protons from a hydrogenous radiator were absorbed in aluminum giving integral range curves, the geometry being determined by coincidences from two unpeaked proportional counters.

Threshold reaction energies for different levels were determined using an enriched BF_3 counter as a slow-neutron detector and varying the energy of the alpha-particle beam from the cyclotron in a helium range cell. A detailed description of these methods has been given in an earlier paper.[1]

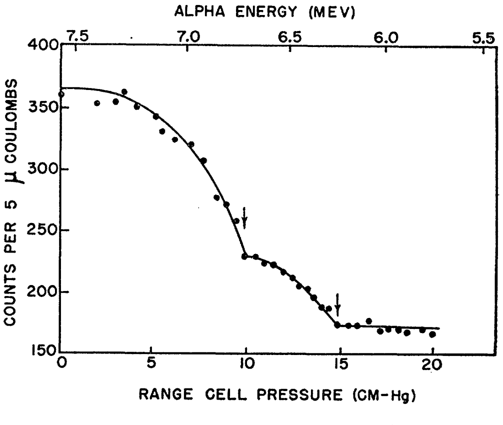

Fig. 2. Slow-neutron threshold curve for $N^{14}(\alpha,n)F^{17}$ reaction.

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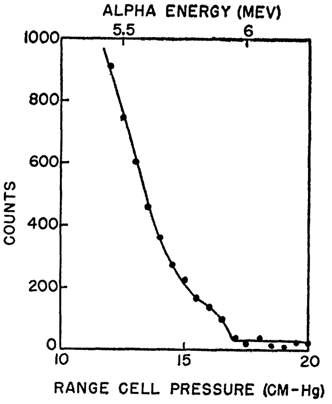

FIG. 3. Beta excitation curve for $N^{14}(\alpha,n)F^{17}$ reaction.

One state in each of the reactions was determined from the threshold for beta activity observed with a thick NaI crystal and scintillation detector. The energy of the alpha-particle beam was varied in the helium range cell and the beta activity was determined with the cyclotron off after a controlled bombardment.

III. $N^{14}(\alpha,n)F^{17}$ REACTION

Thick targets of NH_4NO_3, deposited on a lead backing, were used in this experiment. Determination of the neutron energies at 0° was made with the proton recoil telescope using several layers of polyethylene as radiating material. The integral range curve is shown in Fig. 1, with the two sharp breaks indicating the ground state and the first excited state in F^{17}. The energies of the neutrons were obtained using recent range-energy curves for protons in aluminum.[2] The alpha-particle energy has been measured by several independent methods and the value used for the extrapolated beam energy is 8.16 Mev.

The ground-state and first excited state Q values were determined independently for this negative Q reaction by observing the slow-neutron thresholds using the BF_3 counter. The results of a typical run are plotted in Fig. 2. Sharp changes of slope are again observed, corresponding to the ground state and first excited state. The Q values for the two levels were obtained from the average of 10 runs.

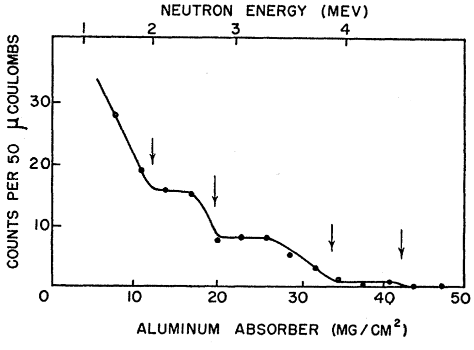

FIG. 4. Integral range curve of recoil protons from $Na^{23}(\alpha,n)Al^{26}$ reaction. Observation at 0°.

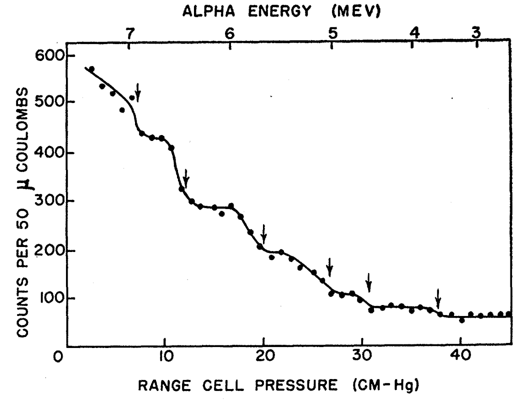

FIG. 5. Slow-neutron threshold curve for $Na^{23}(\alpha,n)Al^{26}$ reaction.

The ground-state Q value was determined in still a third way by observing the 66-second beta activity from F^{17} as a function of bombarding energy. The curve is shown in Fig. 3 and gives the best determination of the Q value for the ground state for this reaction.

The results of the three experiments have been listed in Table I. The ground-state Q agrees within our experimental error with the Q value of -4.75 ± 0.02 Mev calculated for this reaction from mass defects as determined from other reactions.[3] The excitation energy of the first excited state is in agreement with the value of 0.54 ± 0.01 Mev obtained by Ajzenberg[4] from the $O^{16}(d,n)F^{17}$ reaction.

IV. $Na^{23}(\alpha,n)Al^{26}$ REACTION

Recently great interest has been shown in this isotope as the result of the discovery of isomerism in Cl^{34}

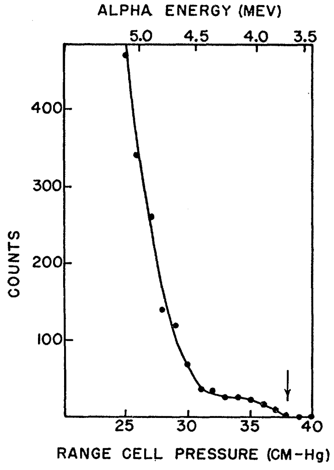

FIG. 6. Beta excitation curve for $Na^{23}(\alpha,n)Al^{26}$ reaction.

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[3] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).

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TABLE I. $N^{14}(\alpha,n)F^{17}$ reaction.

Telescope Q (Mev)	Threshold Q (Mev)	β^+ excitation Q (Mev)	Average Q (Mev)	Average E^* (Mev)
−4.70	−4.79	−4.75	−4.76±0.07	0.00
−5.25	−5.32	···	−5.30±0.07	0.53±0.04

TABLE II. $Na^{23}(\alpha,n)Al^{26}$ reaction.

Telescope Q (Mev)	Threshold Q (Mev)	β^+ excitation Q (Mev)	Average Q (Mev)	Average E^* (Mev)
−2.9	···	···	−2.9±0.2	0.0
−3.4	−3.2	−3.2	−3.2±0.2	0.3±0.2
···	−3.9	···	−3.9±0.2	1.0±0.2
···	−4.2	···	−4.3±0.2	1.4±0.2
−4.6	−4.8	···	−4.7±0.2	1.8±0.2
−5.4	−5.4	···	−5.4±0.2	2.5±0.2
···	−5.9	···	−5.9±0.2	2.9±0.2

by Arber and Staehelin.[5] Staehelin,[6] and independently Moszkowski and Peaslee,[7] have suggested that Al^{26} may also have isomeric states. They reach this conclusion on the basis of observed regularities in the spins and positions of the lowest $T=0$ levels in the odd-odd $N=Z$ nuclei. They find, in fact, that the spin of the lowest $T=0$ levels of these nuclei exhibits a periodicity from which they deduce a spin of $J=5^+$ for Al^{26}. Moreover for these nuclei the height of the lowest $T=1$, $J=0^+$ states above the lowest $T=0$ state decreases regularly with increasing A, the order of the levels changing in the region near $A=26$. According to Arber and Staehelin, in Cl^{34} the ground state is $T=1$. The observed regularities would suggest that Al^{26} may also have a $T=1$ ground state. Since the $T=0$ level has $J=0^+$, the two levels were expected to undergo independent β^+ decay with the well-known 6.7-second activity assigned to the $T=1$ state. Estimates of the half-life of the $T=0$ state range from 10^4 to 10^6 years. The predicted level has received striking direct confirmation with the discovery of a long-lived positron activity in Al^{26} by Simanton, Rightmire, Long, and Kohman.[8] The question of whether the $T=1$ level lies below the $T=0$ level as in Cl^{34} has been raised in several recent investigations[9] and it is considered here as well.

The $Na^{23}(\alpha,n)Al^{26}$ reaction is studied here by several methods. Figure 4 shows the average of seven integral curves of the recoil protons taken with the proton recoil telescope. Observation was at 0°. Thin targets of NaBr and $NaHCO_3$ were used. Several groups, indicated by vertical arrows, are present. The gentle slope between the second and third group may well indicate the presence of an unresolved level at an excitation energy of 1 Mev. The strong rise at the fourth group suggests the presence of several levels, the lowest of which has the energy indicated.

Slow-neutron thresholds for this reaction, using thick Na metal targets have also been observed. Figure 5 shows a typical run. The ground-state threshold is lost in the background. Because of the Coulomb barrier it would be expected to be weak. As can be seen in Fig. 5 the thresholds become progressively weaker at lower bombarding energies. The level at $E^*=1.4$ Mev appears clearly in the threshold curve but it is absent or weak in the telescope curve.

An excitation curve of the β^+ activity in Al^{26} was also observed by bombarding thick Na metal targets at known beam energies in a range cell. After the target was saturated, the cyclotron was switched off and the activity was monitored for 15 seconds with a NaI scintillation counter. The excitation curve so obtained is shown in Fig. 6. The shape of the curve shows the influence of the Coulomb barrier as well as the threshold. The activity threshold coincides with the lowest neutron threshold observed and indicates that the 6.7-second activity originates in an excited state of Al^{26} at about 300-kev excitation. Kavanagh, Sherr, and Mills[9] have recently reported a level in this region at 219 kev which they have shown to have the spin and parity appropriate to the $T=1$ level expected in Al^{26}.

The Q values obtained using the three methods, together with mean Q values and excitation energies E^*, are listed in Table II.

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[5] W. Arber and P. Staehelin, Helv. Phys. Acta **26**, 433, 584 (1953).

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[8] Simanton, Rightmire, Long, and Kohman, Phys. Rev. **96**, 1711 (1954).

[9] Kluyver, van der Leun, and Endt, Phys. Rev. **94**, 1795 (1954); Haslam, Roberts, and Robb, Can. J. Phys. **32**, 361 (1954); C. P. Browne, Phys. Rev. **95**, 860 (1954); and Kavanagh, Mills, and Sherr, Phys. Rev. **97**, 248 (1955).