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THE MASSES AND EXCITED STATES OF ^{24}Al AND ^{28}P

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The $^{24}Mg(^3He,t)^{24}Al$ and $^{28}Si(^3He,t)^{28}P$ reactions have been studied at ^3He energies in the range 37.8 to 40.1 MeV. The mass excesses of ^{24}Al and ^{28}P are, respectively, -0.07 ± 0.06 and -7.12 ± 0.06 MeV; 18 excited states of ^{24}Al and 12 excited states of ^{28}P have been observed.

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††J. Simon Guggenheim Fellow 1965-1966; now at Haverford College, Haverford, Pennsylvania.

There is very little known[1)],[†] about the proton-rich nuclei, $^{24}_{13}Al$ and $^{28}_{15}P$. The positron decay has been observed[1-3)] to various of the states in the corresponding $T_z = 0$ nuclei, $^{24}_{12}Mg$ and $^{28}_{14}Si$. The atomic mass excesses of ^{24}Al ^{28}P are [4)],[††] 0.09±0.3 MeV and -7.69±0.3 MeV. If the ^{24}Al $E_{\beta+}$ (max) reported by Scott and Polichar[3)] are assumed to be due to transitions to the ^{24}Mg states at 4.12 MeV[1)] and 8.44 MeV[4,5)], the atomic mass excess of ^{24}Al is -0.01±0.13 MeV. No energy levels of ^{24}Al and ^{28}P have been reported. By analogy with the mirror nucleus ^{24}Na, the ground state of ^{24}Al should have $J^{\pi} = 4+$. The corresponding T = 1 state in ^{24}Mg has been located[3)] at E_x = 9.512±0.008 MeV. The ground state of ^{28}P is possibly a $J^{\pi} = 3+$ state, by analogy with the 3+, first T = 1 state[1)] in ^{28}Si at E_x = 9.324±0.011 MeV[3)], although the close spacing of the next T = 1 state (ΔE_x = 31 keV in ^{28}Al, between the $J^{\pi} = 3+$ and 2+; $E_x \approx$ 60 keV in ^{28}Si, between the $J^{\pi} = 3+$ and 2+) would permit $J^{\pi} = 2+$ as an alternative.

The two types of reaction which can be used to study ^{24}Al and ^{28}P are the (p,n) and the (^3He,t) reactions on ^{24}Mg and ^{28}Si with Q values of -14 to -15 MeV. We will report on a study of the $^{24}Mg(^3He,t)^{24}Al$ and $^{28}Si(^3He,t)^{28}P$ reactions[†††] at E(^3He) ≈ 40 MeV.

[†]C. Van der Leun, private communication. We are indebted to Dr. Van der Leun for information concerning more recent evidence on ^{24}Al and ^{28}P.

[††]These mass excesses have been calculated on the basis of the ^{24}Mg and ^{28}Si masses given by ref. 4, and the Q of the ^{24}Al and ^{28}P β+ decay given by ref. 1.

[†††]These reactions have been observed, but no results have been published: See M. Rickey and R. G. Matlock, Bull. Am. Phys. Soc. 10 (1965) 463.

A beam of 40 MeV ^{3}He particles, accelerated by the Berkeley 88-inch spiral ridge cyclotron, was used for the experiments. The experimental procedures were identical to those described in another paper[6]. The ^{24}Mg and Si targets† were self-supporting foils. The magnesium target was enriched to 99.96% ^{24}Mg and its thickness was 270±30 μg/cm^2. The silicon was not enriched and therefore contained 92.2% ^{28}Si: the target thickness was 160±15 μg/cm^2. ^{12}C foils used for calibration purposes ranged from 150 to 300 μg/cm^2.

Figure 1 shows parts of the triton spectra for the ^{24}Mg(^{3}He,t)^{24}Al reaction at E(^{3}He) = 39.3 MeV, θ = 20° and 25°. Additional spectra were also obtained at E(^{3}He) = 39.3 MeV (θ = 30°, 50°, 55°, and 60°) and at E(^{3}He) = 40.1 MeV (θ = 30°). The FWHM of peaks corresponding to single states is ≈ 85 keV. The Q value for the ground-state reaction was determined to be -13.88±0.06 MeV. From this and the masses given by Mattauch et al.[4] for ^{24}Mg, ^{3}He, and t, the mass excess of ^{24}Al is determined to be -0.07±0.06 MeV. The excitation energies of the observed states of ^{24}Al are displayed in table 1. The first excited state we observe in ^{24}Al at E_x = 0.47±0.03 MeV is in good agreement with the energy of the known[1] first state in the mirror nucleus ^{24}Na, E_x = 0.473±0.003 MeV. The higher states cannot be meaningfully compared. It is clear that some of our triton groups correspond to unresolved levels. The differential cross section for formation of the ground state of ^{24}Al decreases from 67±15 μb/sr at 23.4°c.m. to 6±2 μb/sr at 68.4°c.m.

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†The targets were prepared by C. E. Ellsworth and A. Johns. We acknowledge with thanks their invaluable help. The separated ^{24}Mg was furnished by the Stable Isotopes Division of ORNL.

Figure 2 shows parts of the triton spectra for the $^{28}Si(^{3}He,t)^{28}P$ reaction at $E(^{3}He)$ = 37.8 MeV, θ = 20° and 35°. Additional spectra were obtained at $E(^{3}He)$ = 40.1 MeV, θ = 30° and 35°. The Q value for the ground state reaction was determined to be -14.38±0.06 MeV. From this the mass excess of ^{28}P was determined to be -7.12±0.06 MeV. The excitation energies of the observed ^{28}P states are shown in table 1. The ground state and first excited states of ^{28}P were resolved by fitting the triton peaks with two Gaussian peaks. It is clear here also, by comparison with ^{28}Al, that many of the triton groups are due to unresolved states. The differential cross section for the ground state of ^{28}P falls from 70±15 μb/sr at 22.8° c.m. to 25±6 μb/sr at 39.7° c.m.

By use of the method of Wilkinson[7] and the 1964 mass tables[4], the excitation energy of the first T = 1, T_z = 0 level was predicted for the A = 24 and A = 28 isobaric triplets. The first T = 1 level of ^{24}Mg is 9.512±0.008 MeV[3], compared with predicted values of 9.502±0.008 and 9.54±0.07 MeV based on the masses of ^{24}Na and ^{24}Al respectively. The first T = 1 level of ^{28}Si is 9.324±0.011 MeV[3] compared with predicted values of 9.378±0.008 and 9.35±0.07 MeV based on the masses of ^{28}Al and ^{28}P respectively.

We are grateful to the entire staff of the 88-inch cyclotron, and in particular to Joel Moss, Creve Maples, Jr., Donald A. Landis, and Fred S. Goulding. We are greatly indebted to Dr. Bernard G. Harvey and Dr. J. Cerny for their interest and many useful comments.

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Table 1

Energy levels of ^{24}Al and ^{28}P

Levels of ^{24}Al				Levels of ^{28}P			
Group no.	E_x[a]	Group no.	E_x[a]	Group no.	E_x[a]	Group no.	E_x[a]
1	0	11	3.92±30	1	0	11	4.17±70
2	0.47±30	12	4.34±40	2	0.125±30	12	4.53±50
3	1.12±30	13	4.53±40	3	1.14±40	13	4.94±30
4	1.28±50	14	4.77±50	4	1.31±30		
5	1.62±40	15	4.48±60	5	1.54±40		
6	2.38±40	16	5.93±40	6	2.12±30		
7	2.88±30	17	6.81±40	7	2.65±100		
8	3.06±40	18	7.07±50	8	3.24±30		
9	3.35±50	19	(8.25±50)[b]	9	3.59±30		
10	3.71±50			10	3.84±30		

[a]Energies given in MeV ± keV.

[b]Assignment to ^{24}Al not certain.

Figure Captions

Fig. 1. Spectra from the $^{24}Mg(^3He,t)^{24}Al$ reaction at $E(^3He) = 39.3$ MeV, $\theta = 20^\circ$ and 25°. N represents the number of counts per channel. The E_x scale gives the excitation energy in ^{24}Al. The binding energy ($E_b = 1.88$ MeV) for breakup into $^{23}Mg + p$ is indicated. The locations of possible contaminant groups from $^{12}C(^3He,t)^{12}N$ and $^{16}O(^3He,t)^{16}F$ are also shown.

Fig. 2. Spectra from the $^{28}Si(^3He,t)^{28}P$ reaction at $E(^3He) = 37.8$ MeV ($\theta = 20^\circ$ and 35°). The binding energy (2.03 MeV) for breakup into $^{27}Si+p$ is shown. See also caption for fig. 1.

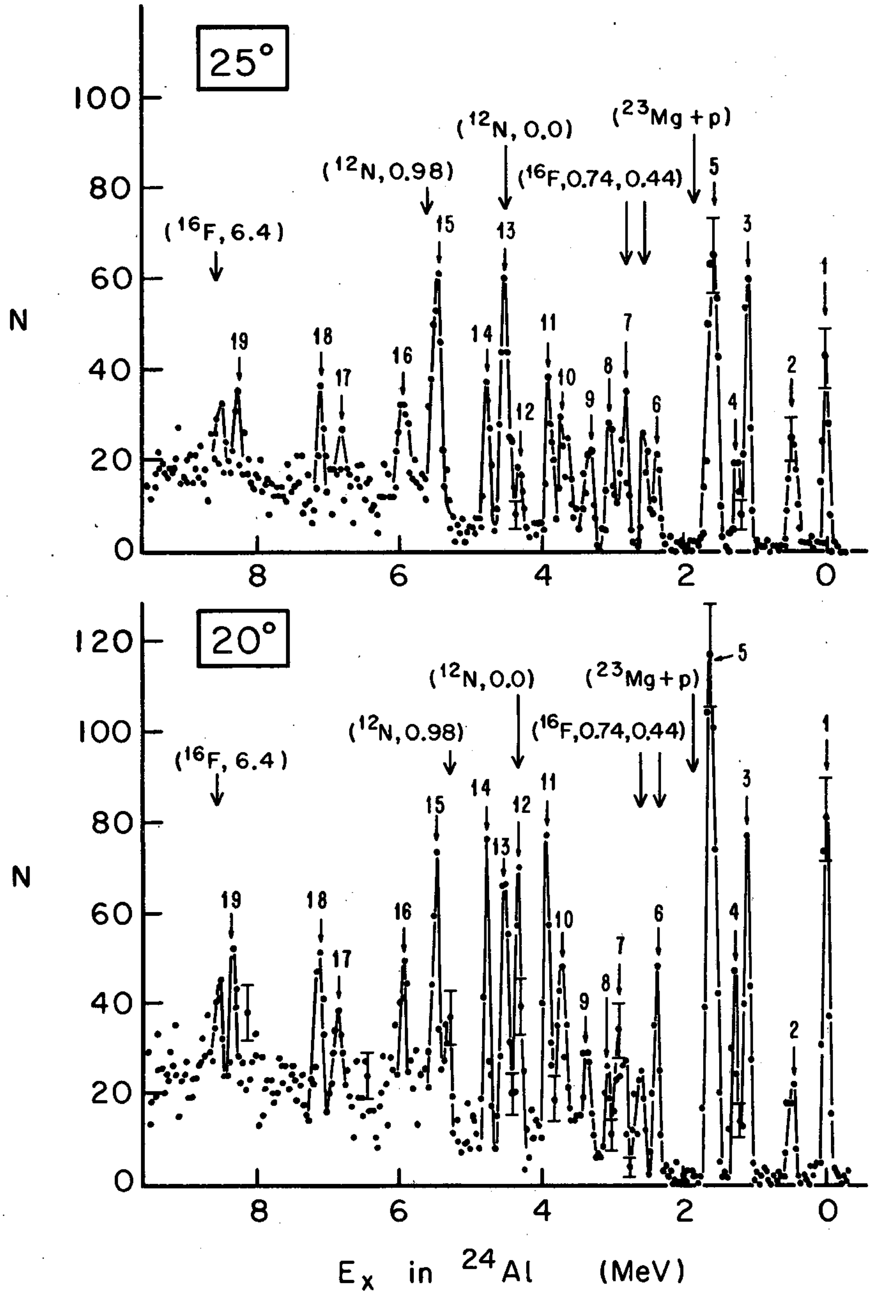

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Fig. 1

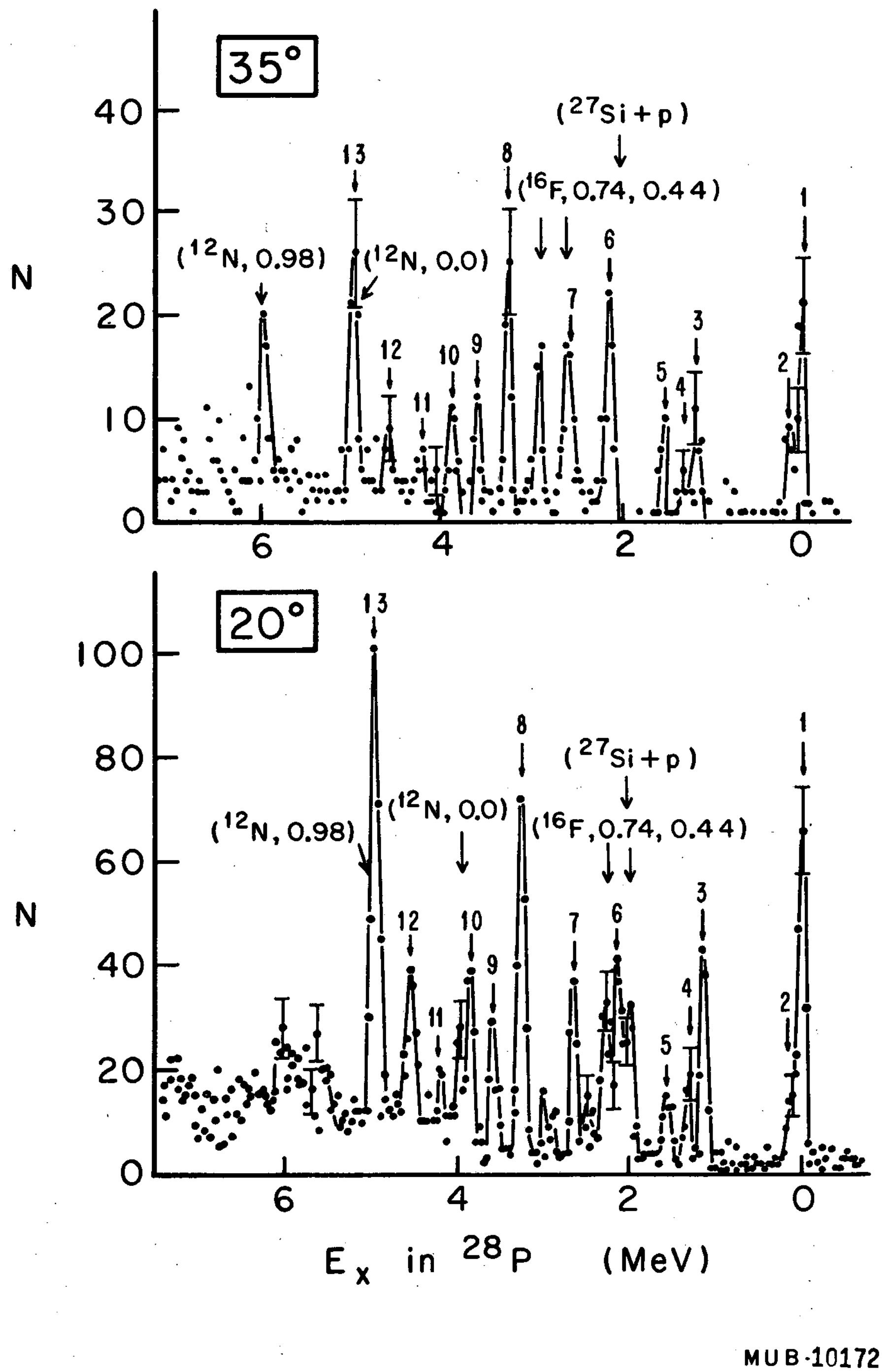
35°
(²⁷Si + p)
(¹⁶F, 0.74, 0.44)
(¹²N, 0.98)
(¹²N, 0.0)
N
20°
(²⁷Si + p)
(¹²N, 0.98)
(¹²N, 0.0)
(¹⁶F, 0.74, 0.44)
N
E_x in ²⁸P (MeV)
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Fig. 2