Alpha-Particle Bombardment of Magnesium Isotopes*

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Energy levels in three aluminum isotopes have been observed with alpha-particle bombardment of magnesium isotope targets. Protons from the reaction were observed with a proportional counter. By using an aluminum foil changer before the counter and recording only those protons near the end of their range, an energy resolution from 4 to 8% was obtained in the various runs. The ground-state Q values were calculated by comparison to the $Mg^{24}(\alpha,p)Al^{27}$ ground-state group using the known Q value for the inverse reaction. The ground-state Q values were found to be -1.29 ± 0.04 Mev for $Mg^{25}(\alpha,p)Al^{28}$, and -2.90 ± 0.04 Mev for $Mg^{26}(\alpha,p)Al^{29}$. Proton groups were found corresponding to excited states in Al^{27} at 0.85, 1.06, 2.17, and 2.64 Mev; in Al^{28} at 1.00, 1.57, 2.18, 2.54, and 2.96 Mev; in Al^{29} at 1.69 Mev. The mass value of Al^{29} was calculated to be 28.98972 ± 0.00006 amu.

INTRODUCTION

By the (α,p) reactions on magnesium isotopes, it is possible to study the energy level structures in three aluminum nuclei, Al^{27}, Al^{28}, and Al^{29}. Earlier work on $Mg(\alpha,p)Al$ was done by Duncanson[1] and by Haxel,[2] however only with natural alpha sources and natural magnesium targets. They obtained three Q values, but the assignment of levels there was uncertain because of the mixture of isotopes in their targets. Energy levels in Al^{27} and Al^{28} have been studied by alternative reactions. Browne *et al.*[3] observed inelastic proton scattering, with magnetic analysis, from an aluminum target, to obtain Al^{27} levels. A very precise measurement of the first excited state in Al^{27} has been made with the same reaction, using an electrostatic analyzer for the protons.[4] The reaction $Si^{29}(d,\alpha)Al^{27}$ also leads to Al^{27} levels, and two excited states obtained by this experiment[5] are in agreement with the later work of Browne. Energy levels in Al^{28} have been obtained from the $Al^{27}(d,p)Al^{28}$ reaction done with magnetic analysis.[6] No previous data are available on the spectrum of Al^{29}. Although two of the reactions reported below lead to final nuclei with considerable previous data available, the third reaction gives new information about the otherwise unexplored energy levels of Al^{29}.

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TARGETS AND DETECTION

For the present work, the three magnesium isotopes were obtained from the Oak Ridge National Laboratory, each with an enrichment of better than 90% (see Table I). The designation of samples and the analyses in Table I are those given by the Oak Ridge National Laboratory. Targets of magnesium were prepared by evaporation onto gold foil from 5-mil tantalum boats. The isotopes were supplied in the chemical form of MgO powder, which has a high melting point, but MgO decomposes on heating in vacuum and actually deposits as the pure metal. The evaporation time for each target was about 5 minutes, near 3000°C. The tantalum boats were 1 in.×2 in. strips cut down to $\frac{1}{4}$ in. wide at the center, and with the sides turned up to localize the hot spot. The shaped boats gave dependable results, whereas flat tantalum strips used previously would often burn through before sufficient magnesium had been evaporated.

Since the Q values for all three reactions are negative, the protons produced in the reactions had relatively short range. At 0° observation angle, very little of the spectra can be seen beyond the elastically scattered protons coming from hydrogen contamination in the targets. At 90° there are no elastic protons, but the first few centimeters of range here are masked by alpha particles scattered from the gold backing. The reaction protons have a slightly longer range at 0°, but considerably more of the spectra can be seen at 90° and therefore all the data was taken at that angle. The proton detector was a single proportional counter, with a mylar window to minimize the basic absorber. An aluminum foil changer was placed in front of the counter and the protons passed through the weighed foils of

TABLE I. Composition of magnesium targets.

	Mg^{24} (%)	Mg^{25} (%)	Mg^{26} (%)	Impurity (%)
Natural Mg	77.4	11.5	11.1	...
Sample 47 (a)	99.5	0.3	0.2	0.08 Na
Sample 520 (a)	5.9	92.3	1.8	0.15 Na
Sample 290 (a)	2.5	1.6	95.9	0.08 Si

TABLE II. Ground-state Q values, and energy levels in aluminum isotopes. The two measured ground-state Q values are listed, and ten excited states are shown compared to previous data from other reactions. The ground state of Al^{28} is a doublet with 31-kev separation, according to reference 6. This was not resolved in the (α,p) reaction, and therefore the -1.29 Mev Q value is probably a mixture of the two states.

	$Mg^{24}(\alpha,p)Al^{27}$ (Mev)	Previous data $Al^{27}(p,p')Al^{27}$ (Mev)	$Mg^{25}(\alpha,p)Al^{28}$ (Mev)	Previous data $Al^{27}(d,p)Al^{28}$ (Mev)	$Mg^{26}(\alpha,p)Al^{29}$ (Mev)
Ground-state Q-values	Standard	···	-1.29 ± 0.04	(See caption)	-2.90 ± 0.04
Levels	0.85 ± 0.04	0.842 ± 0.006	1.00 ± 0.04	0.97 ± 0.007 1.01 ± 0.007	1.69 ± 0.10
	1.06 ± 0.04	1.013 ± 0.006			
			1.57 ± 0.04	1.37 ± 0.01 1.62 ± 0.01	
	2.17 ± 0.04	2.213 ± 0.006			
	2.64 ± 0.10	2.732 ± 0.006	2.18 ± 0.04	2.14 ± 0.01 2.20 ± 0.01 2.27 ± 0.01	
			2.54 ± 0.06	2.48 ± 0.01 2.58 ± 0.01 2.65 ± 0.01	
			2.96 ± 0.06	2.98 ± 0.01 3.01 ± 0.01	

aluminum absorber. Proton pulses were amplified by a 4-tube preamplifier (+27 db) and a video amplifier (+80 db). A pulse-height discriminator was used to select only the largest pulses, coming from protons near the end of their range. The peaked discriminator in combination with the foil changer gave a differential yield curve with an over-all energy resolution of 4 to 8% in the several runs.

BEAM ENERGY

The energy of the alpha-particle beam from the cyclotron was measured by three methods: range of alpha particles in air, range in aluminum of elastically scattered alpha particles at 90°, and range in aluminum of protons from the ground-state group of the $Mg^{24}(\alpha,p)Al^{27}$ reaction. The greatest accuracy was obtained with the third method, taking the ground-state Q value to be -1.594 ± 0.002 Mev. This figure is available from a precision measurement[4] of the inverse reaction $Al^{27}(p,\alpha)Mg^{24}$. The proton energy was determined to an accuracy of ±30 kev by finding the range of the protons in aluminum. The beam energy was calculated then from the Q-value equation, to an accuracy of ±30 kev. In a typical calibration run, the alpha-particle beam energy corresponding to extrapolated range was found to be 8.37 ± 0.03 Mev. However, due to slight shifts in the beam energy from day to day, runs with Mg^{25} and Mg^{26} were always followed immediately by runs with a Mg^{24} target for direct comparison.

DATA AND CALCULATIONS

The proton groups from the reaction $Mg^{24}(\alpha,p)Al^{27}$ are shown in Fig. 1. The data points were taken in steps of one centimeter air-equivalent. The ranges have been converted to an energy scale in the usual way, first making the aluminum correction[7] and then using the 1949 range-energy curve for air.[8] On a linear energy scale, the shape of proton groups will be nearly the same except for an amplitude factor. Therefore the technique of curve fitting can be used to separate the first excited state doublet in Fig. 1, normalizing each

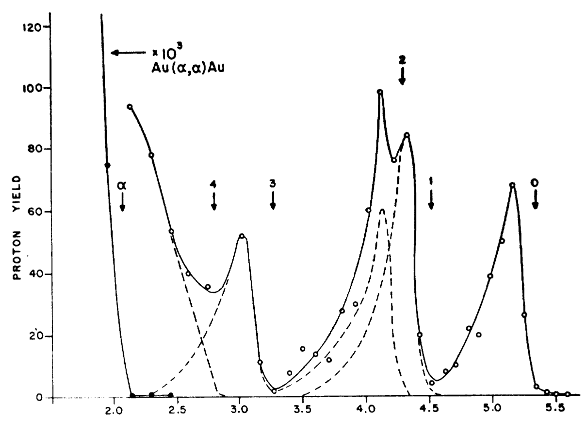

FIG. 1. $Mg^{24}(\alpha,p)Al^{27}$, at 90°. Proton groups corresponding to the ground state and four excited states in Al^{27} are shown. The data points were taken in steps of one centimeter air-equivalent of range, which have been converted to a linear energy scale. The alpha particles scattered from the gold target backing are also shown, having an extrapolated range corresponding to a proton energy of about 2.1 Mev. The broken lines are used to derive an excitation energy value for those levels which are only partially resolved, and the arrows indicate the energies corresponding to extrapolated range used in the calculations. This curve is one of nine runs over the spectrum and shows the best resolution obtained.

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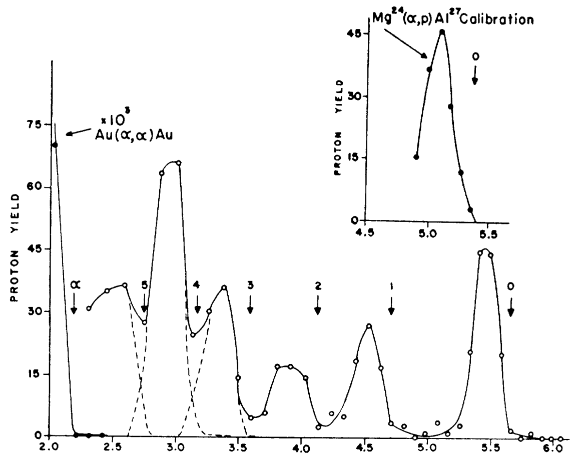

FIG. 2. $Mg^{25}(\alpha,p)Al^{28}$, at 90°. Six proton groups are shown from this reaction, as well as the calibration proton group from $Mg^{24}(\alpha,p)Al^{27}$ and the elastically scattered alpha particles. See the caption of Fig. 1 for further explanation. A small background due to 6% of Mg^{24} in the target has been subtracted out. Six runs were taken with the Mg^{25} target to confirm this spectrum, and the calibration group in addition was repeated five times in order to obtain the ground-state Q value.

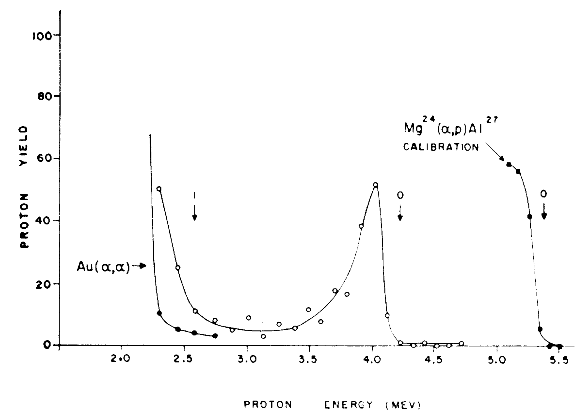

FIG. 3. $Mg^{26}(\alpha,p)Al^{29}$, at 90°. The ground state and first excited state are shown from this reaction, as well as the calibration proton group from $Mg^{24}(\alpha,p)Al^{27}$ and the elastically scattered alpha particles. The first excited state here could not be fully resolved from the background of alpha particles appearing at that short range. However, the sharply rising proton yield above background was observed in five separate runs, and with high probability this represents the first excited state.

peak to the shape of the well-resolved ground-state group. Similarly the fourth excited state was obtained by subtracting the normalized yield from the third.

The excitation energies were calculated relative to the ground-state group making use of the differentiated Q-value formula. We did not calculate a separate Q value for each level, since the error assignment for Q values must include any uncertainty in beam energy and in basic absorber. These uncertainties cancel if only the energy difference of two proton groups is taken, and therefore excitation energies are known more accurately than Q values. The calculated energy levels are given in Table II. The fourth excited state has a larger error assignment since it is not completely resolved.

The spectra of Al^{28} and Al^{29} are shown in Fig. 2 and Fig. 3, respectively. A linear proton energy scale was plotted, as for the previous isotope. In the Mg^{25} and Mg^{26} targets there was also some Mg^{24} contamination (see Table I), and a small background normalized to Fig. 1 was subtracted out. The calculated energy levels are given in Table II. The levels in Al^{27} and Al^{28} already observed with other reactions[9] are given for comparison.

The agreement with previous data on Al^{27} is within the limits of error. The spectrum of Al^{28}, however, is one of the most complex in the entire low-Z region of the periodic table. Owing to limited resolution with the alpha-particle beam, the reported levels correspond to doublets or triplets which had been seen in the (d,p) reaction previously.

As observed here, Al^{29} has no excited states below 1.69 Mev, with an upper limit on intensity of such a state of about one-fifth of the ground-state group. This is a very simple spectrum, especially when compared with the preceding isotope Al^{28}. Al^{28} has three doublets in this region near the ground state. However, Al^{28} is an odd-odd nucleus whereas Al^{29} is odd-even, and it might be expected from the single-particle model that a single unpaired nucleon as in Al^{29} would give fewer excited states. The nucleus Al^{27} is also odd-even, and again has relatively wide spacing between excited states, compared to its neighbor.

The six-minute beta decay of Al^{29} had been studied previously,[10] and from the beta energy a mass value of Al^{29} was derived: 28.99006±0.00020 amu. There was one earlier experiment[11] also on beta decay of Al^{29} which gave a lower mass value with only slightly lower experimental accuracy: 28.98974±0.00027 amu. From the ground-state Q value in the present work, the Al^{29} mass was obtained with higher accuracy: 28.98972 ±0.00006 amu. There is evidently good agreement with the earlier of the two beta-decay measurements.

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