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Resonance Capture of Protons by Mg^{25} *

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ABSTRACT

Protons from a Van de Graaff generator have been used to bombard targets of Mg^{25} . The reaction $Mg^{25}(p, \gamma)Al^{26}(\beta^+)Mg^{26}$ has been studied by observing the positron yield as a function of proton energy in the region between 300 and 1200 kev. Resonance peaks occur for protons with energies of 388, 494, 510, 563, 588, 650, 683, 722, 777, 812, 880, 928, 986, 1043, 1081, 1098, 1132, and 1197 kev. The cross section is of the order of 10^{-27} cm² for the stronger resonances.

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INTRODUCTION

The bombardment of light nuclei with protons of low energy is commonly characterized by resonant capture processes. Among the many nuclei which exhibit such capture resonances are the three stable isotopes Mg^{24} , Mg^{25} , and Mg^{26} . In natural magnesium these isotopes have relative abundances of 77.4, 11.5, and 11.1 percent respectively. When this element is bombarded with protons, the following capture reactions may occur:

Gamma rays are emitted by the excited aluminum nuclei. Both Al^{25} and Al^{26} are unstable and decay by positron emission to Mg^{25} and Mg^{26} respectively.

The first experimental work on these reactions was reported in 1939 by Curran and Strothers¹ who bombarded natural magnesium targets of appreciable thickness with protons at energies between 180 and 1000 kev. Eight gamma-ray resonances were observed, five of which had an associated positron activity. These latter resonances were assigned to the reaction $\text{Mg}^{25} (p, \gamma) \text{Al}^{26}$ since Al^{25} was unknown at that time. The other three resonances were attributed to the reaction $\text{Mg}^{26} (p, \gamma) \text{Al}^{27}$.

1. S. C. Curran and J. E. Strothers, Proc. Roy. Soc. A, 172 72 (1939)

Next Hole, Holtsmark, and Tangen² found eight gamma-ray resonances when thin targets of natural magnesium were bombarded with protons at energies between 200 and 500 kev. Six years later Tangen³ investigated the proton capture resonances in this same energy region with greatly improved equipment and techniques. Not only was the gamma-ray yield as a function of energy measured, but also the positron activity. Seven gamma-ray resonances not accompanied by the positron activity and another seven which had associated positron yields were found. By estimating the energy of the gamma-rays from absorption measurements, Tangen was able to assign tentatively five of these positron resonances to the reaction $\text{Mg}^{25}(\text{p}, \gamma)\text{Al}^{26}$ and two to the reaction $\text{Mg}^{24}(\text{p}, \gamma)\text{Al}^{25}$. These assignments were confirmed by the work of Grottdahl, Lönsjö, Tangen and Bergström⁴ who bombarded minute quantities of isotopic Mg^{24} obtained from a mass spectrograph.

In 1950 a preliminary survey⁵ of capture reactions in natural magnesium for protons with energies up to 1600 kev revealed the existence of a number of levels, many of which were very close together. The availability of separated isotopes of magnesium

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2. N. Hole, J. Holtsmark, and R. Tangen, *Naturwiss.* 28, 399 (1940)
 3. R. Tangen, *Kgl. Nord. Vid. Selsk. Skr. NR1* (1946)
 4. T. Grottdahl, O. M. Lönsjö, R. Tangen, and I. Bergström, *Phys. Rev.* 77, 296 (1950)
 5. J. N. Cooper, W. E. Taylor, J. C. Harris, and G. R. Grove, *Phys. Rev.* 80, 131 (1950)

suggested a simple way of resolving this complex spectrum. Upon allocation by the Isotopes Division of the Atomic Energy Commission, small amounts of the oxides of the separated magnesium isotopes were obtained from Carbide and Carbon Chemicals Division, Union Carbide and Carbon Corporation, Y-12 Plant, Oak Ridge, Tennessee. The present paper reports on the yield from proton-capture reactions in one of these isotopes, Mg^{25} .

APPARATUS AND PROCEDURE

Protons at energies between 300 and 1200 kev were separated from the ion beam of a Van de Graaff generator by means of an analyzing magnet and were focussed on a 1/32 in. defining slit. Those protons passing through the slit fell upon a target composed of a very thin layer of Mg^{25} , which had been condensed⁶ upon a 0.5 mil tantalum backing. This target was placed at the terminal end of a Faraday cage which collected the incident protons. The energy of the protons was determined by measurement of the current in the analyzing magnet. This magnet current was calibrated in terms of proton energy by use of the well known fluorine resonances⁷ at 340.4, 486, 598, 669, 843, 873.5, and 935.3 kev.

Proton capture by Mg^{25} resulted in an excited state of Al^{26} which was detected in two different ways. The first involved the

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6. L. N. Russell, W. E. Taylor, and J. N. Cooper, Rev. Sci. Inst. 23, 764 (1952).
 7. C. Y. Chao, A. V. Tollestrup, W. A. Fowler, and C. C. Lauritsen, Phys. Rev. 79, 108 (1950)

observation of the gamma-rays which are emitted by the excited Al^{26} nuclei as they drop to lower energy levels. The second consisted of detecting the positrons emitted as the unstable Al^{26} nuclei decayed to Mg^{26} . The half-life of Al^{26} is approximately 6.5 seconds.⁸ Experiments showed that, with the equipment available, the method of detecting positrons was far more sensitive than the gamma-ray method and also permitted greater discrimination against contaminants.

To determine the relative positron yield at each energy the following procedure was followed: The target was bombarded with a constant beam current for 35 seconds, approximately five half-lives of Al^{26} . This insured excitation of 97% of the activity which an infinite bombardment with a proton beam of this strength would produce. Then the beam was cut off by a magnetically operated shutter. After a very short, but well defined, time interval a Geiger tube and accompanying scalar were activated and the positron activity from the aluminum isotope was counted for a period of four half-lives. Yield curves were plotted showing the relative number of positron counts per unit beam current as a function of the energy of the incident protons. The energy values were adjusted for target thickness.

In working with proton energies between 420 and 460 kev, a complication arose in the form of the positron activity from the

8. L. Katz and A. G. W. Cameron, Phys. Rev. 84, 1115 (1951)

reaction $\text{Cl}^{12}(\text{p}, \gamma) \text{N}^{13}(\beta^+) \text{Cl}^{13}$. Presumably the carbon on the target comes from oil molecules from the diffusion pump. The resulting positron activity has a half-life of approximately 10 minutes. Since this length of time is long compared with the seven second half-life of Al^{26} , it is possible to make a correction for the nitrogen activity by counting positrons during four half-lives of Al^{26} and then taking a background for an equal period. The differences between the two readings should be a fair measure of the Al^{26} activity.

EXPERIMENTAL RESULTS

Relative positron yield from the reaction $\text{Mg}^{25}(\text{p}, \gamma) \text{Al}^{26}(\beta^+) \text{Mg}^{26}$ is shown as a function of proton energy in Figures 1 and 2. In each case the curve represents a composite of data taken with several targets on various days. Eighteen levels in the compound nucleus Al^{26} correspond to the following proton energies: 388, 494, 510, 563, 588, 650, 683, 722, 777, 812, 880, 928, 986, 1043, 1081, 1098, 1132, and 1197 kev. The stronger peaks are probably correct to 10 kev in absolute value and the weaker ones to perhaps 15 kev. In addition to these relatively strong resonances there are a number of weaker ones. Over the region covered by the data the cross section for proton capture in Mg^{25} is never greater than a few millibarns. It is estimated that the cross section at the 588 kev resonance is $3 \times 10^{-27} \text{ cm}^2$. A comparison of these results with those of Tangen³, whose maximum proton energy was 525 kev, shows excellent agreement. In no case do the energies assigned differ by more than four kev.

The other magnesium isotopes were present in appreciable amounts in the Mg^{25} sample, but since the reaction $\text{Mg}^{26}(\text{p}, \gamma)\text{Al}^{27}$ produces a stable nucleus, the only expected activity at these proton energies could come from $\text{Mg}^{24}(\text{p}, \gamma)\text{Al}^{25}(\beta^+)\text{Mg}^{25}$, which has a weak resonance at 420 kev and a stronger one at 824 kev. Mg^{24} was present to the extent of 10.7% in the Mg^{25} sample and the yield from this isotope shows clearly in the data with the expected intensity. The dashed lines under the 420 and 824 kev peaks suggest what the yield from pure Mg^{25} might be at these energies.

In addition to the two peaks due to the Mg^{24} impurity there is a small double peak at 440 kev which has associated with it a half-life considerably longer than that of Al^{26} . This small double peak occurred not only with targets of Mg^{25} but also in targets prepared from Mg^{24} . Since the two peaks appeared in targets of both isotopes and since the activity has a considerably longer half-life than either Al^{26} or Al^{25} , it appears they are not associated with any magnesium isotope. Their origin is not understood.

The position of energy levels of Al^{26} can be determined from the energy available for excitation at each resonance, the masses of the particles involved and the Q of the reaction. If the mass values given by Mattauch and Flammersfeld⁹ are used, the Q for the reaction $\text{Mg}^{25}(\text{p}, \gamma)\text{Al}^{26}$ is 5.2 ± 0.25 Mev. Then the levels of the

9. J. Mattauch and A. Flammersfeld, Isotopic Report (Special issue of Z. Naturforsch. a 1949)

compound nucleus Al^{26} can be calculated and are listed in Table I. Determinations by Tangen³ and by Curran and Strothers¹ have been modified by using the above values for Q . Energies of levels of Al^{26} lying below five Mev have been determined by Swann, Mandeville, and Whitehead¹⁰ through use of the reaction $Mg^{25}(d,n)Al^{26}$. These are also shown in this table.

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10. C. P. Swann, C. E. Mandeville, and W. D. Whitehead, Phys. Rev. 79, 598 (1950)

TABLE I. Energy levels of Al^{26} in Mev.

This Research	Swann, Mandeville, and Whitehead ¹⁰	Tangen ³	Curran and Strothers ¹
	2.00		
	3.63		
	5.13		5.35
		5.48	
5.55		5.56	
5.65		5.65	5.64
5.67		5.67	
		5.68	
5.72			5.73
5.75			
5.81			
5.84			
5.87			
5.93			
5.96			
6.02			
6.07			
6.13			
6.18			
6.22			
6.24			
6.27			
6.33

FIG. 1. The relative positron yield from Al^{26} formed by the bombardment of Mg^{25} with protons of energies from 300 to 750 kev.

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FIG. 2. The relative positron yield from Al^{26} formed by the bombardment of Mg^{25} with protons of energies from 750 to 1200 kev.

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