Triton-Induced Activities in Magnesium and Aluminum*†

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Triton bombardment of Al^{27} and Mg^{26} gave a 6.5-min aluminum activity as a result of $Al^{27}(t, p)Al^{29}$ reaction and 21.8-hr activity of magnesium produced by the $Mg^{26}(t, p)Mg^{28}$ reaction.

Studies of the gamma-ray spectrum of Mg^{28} showed that a 391±5-kev gamma ray and possibly two more gamma rays with energies 0.95 and 1.35 Mev were associated with the decay of this isotope.

A search was made for a $P^{31}(t, p)P^{33}$ reaction but negative results were obtained.

INTRODUCTION

A RELATIVELY large number of (d, p) reactions have been investigated, and certain aspects of such reactions have been explained in terms of the polarization of the deuteron by the Coulomb field of the nucleus.[1] On the other hand, it is expected that the same type of process may occur with tritons; however, relatively few such reactions have been demonstrated experimentally.[2] We have recently had occasion to examine triton-induced activities in magnesium and aluminum realized by the (t, p) reaction. This type of reaction is of interest not only from the theoretical but also from the experimental point of view, since it enables one to produce radioisotopes which are two neutrons removed from the nearest stable isotope and thereby confirm in some instances uncertain mass assignment of such isotopes and in other instances to produce new isotopes.

EXPERIMENTAL

The bombardment of magnesium and aluminum was accomplished by the use of tritons from the $d-d$ and $Li^6(n, t)He^4$ reactions. In general, it was found most convenient to incorporate the deuterium or lithium in a chemical compound with the atoms to be bombarded. In the case of aluminum, $LiAlD_4$ was bombarded with deuterons from our electrostatic generator and in the case of magnesium, some experiments were made with $MgSO_4 \cdot 6D_2O$. In general, deuteron bombardment of these compounds gave low yields of the (t, p) reaction products and is being utilized only in case of short-lived isotopes. In the case of isotopes of moderately long life such as Mg^{28}, it was found to be more convenient to bombard, with pile neutrons, a Li-Mg alloy formed by heating a 2–1 mole ratio of Li to Mg at 700°C. In both the accelerator and pile irradiations, more than one activity is produced in general, necessitating chemical processing of the target material. In the case of aluminum, the $LiAlD_4$ was dissolved in HCl and carriers of NO_3^- and Mg^{++} were added to remove N^{13} formed by $C^{12}(d, n)N^{13}$ and Mg^{27} formed by $Al^{27}(n, p)Mg^{27}$. The C^{12} which is the source of N^{13} arises from diffusion pump oil vapor. The Mg separation was realized by making the solution sufficiently basic with NaOH so that the Al would dissolve but the Mg would precipitate as the hydroxide. This procedure repeated twice was sufficient to remove interfering activities. The aluminum was removed from solution by precipitating as $Al(OH)_3$. After washing, the precipitate was dissolved in HCl and counted in a dip counter.

The Li-Mg alloy after irradiation was dissolved in HCl to which carriers of Cu, Ni, Fe, Co, Mn, and Na which were suspected impurities were added. The Cu, Ni, etc., were separated from the Mg by hydrogen sulfide precipitation. This process was repeated several times and then the Mg was precipitated as the hydroxide which was liberally washed with water containing NaOH. A portion of this precipitate was used for half-life measurements with an end-window Geiger-Mueller counter and the remainder for gamma-ray measurements. As a confirmation of the mass assignment of the magnesium activity, Al^{28} activity was milked out by precipitating the magnesium as the hydroxide in a strongly basic NaOH solution. The $Mg(OH)_2$ was then centrifuged and the supernatant liquid was examined for Al^{28} activity using a dip counter.

The gamma-ray spectrum of a Mg^{28} source was analyzed by means of an NaI(Tl) crystal scintillation spectrometer. The source was enclosed in an Al container 6 mm thick to absorb all the beta rays, including those of the daughter nucleus Al^{28}, and placed immediately above a crystal of dimensions 2.1 cm×2.1 cm×1.1 cm. The pulse-size spectrum was determined by means of an Atomic Instrument Company linear amplifier and single-channel analyzer. The source intensity was sufficient to yield good readings in one or a few minutes. Curves were taken at various photomultiplier voltages in order to explore the spectral region from 0.05 to 2 Mev. The resolution of the

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[1] J. R. Oppenheimer and M. Phillips, Phys. Rev. **48**, 500 (1935).

[2] D. N. Kundu and M. L. Pool, Phys. Rev. **73**, 22 (1948).

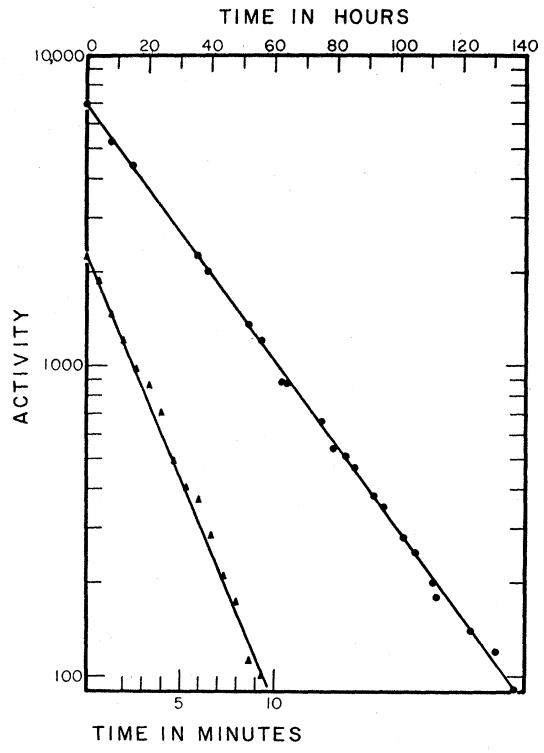

FIG. 1. The decay of Mg^{28} is given by the upper curve. The lower curve gives the decay of Al^{28} milked from an equilibrium mixture of Mg^{28} and Al^{28}.

spectrometer corresponded to 27 percent full width at half-maximum for the Cd^{109} line at 88 kev. Energy calibration was supplied by the photoelectric peaks of several known lines, expecially the annihilation radiation, the Na^{22} line at 1.28 Mev and the ThC″ line at 2.62 Mev. In some experiments, a qualitative picture of the spectrum was obtained by photographing the pulses from the linear amplifier on a synchroscope screen.

RESULTS AND DISCUSSION

Triton-Induced Activity in Magnesium

The decay of the Mg^{28} as a function of time is given in Fig. 1. A half-life of $21.8_5 \pm 0.32$ hr, where the 0.32 hr is the standard deviation, was obtained for Mg^{28}; this is in good agreement with the half-life reported by Sheline and Johnson.[3]

The correctness of the mass assignment of this activity is further confirmed by the Al^{28} milking experiments, the result of which is given by the lower plot in Fig. 1. The half-life obtained here is 2.1 ± 0.2 min which, to within our experimental error, is the generally accepted value. These results, therefore, indicate that Mg^{28} was produced by the $Mg^{26}(t, p)Mg^{28}$ reaction.

Mg^{28} will probably find wide use as a tracer in certain chemical, geological, and biological problems. For many of these applications pile production of Mg^{28} offers some advantages over the accelerator-produced material because of the wider availability of the pile irradiation and because considerably greater yields of the radioisotope are possible. Mg^{28} as produced by the (t, p) reaction is isotopic with the target material, and consequently this method would not be used for producing the isotope carrier-free.

[3] R. K. Sheline and N. R. Johnson, Phys. Rev. **89**, 520 (1953).

Gamma-Ray Spectrum of $Mg^{28}-Al^{28}$

Preliminary exploration indicated a strong gamma-ray photoelectric peak near 0.4 Mev. To perform an energy determination, this peak was compared with the 238.6-kev line of ThB and the annihilation radiation, other experiments having shown that the scale was accurately linear in this region at the voltage employed. The result was 391 kev, with an error estimated at ± 5 kev.

A complete differential pulse-size spectrum in the region 0.25–1.8 Mev is shown in Fig. 2. The photoelectric peak at 1.8 Mev due to the Al^{28} line is not well resolved from the Compton continuum. At lower energies the curve shows several maxima which cannot be entirely assigned to the 1.8-Mev line. The most pronounced of these maxima occur at 0.9–1.0 Mev and 1.3–1.4 Mev. They may be due to photoelectric peaks of lines of the corresponding energies. To compare these results with the effects of a monochromatic gamma-ray of 1.8 Mev, a source of Al^{28} was examined under identical conditions. As the short life of this isotope prevented use of the pulse analyzer, the less quantitative method of photographing pulses displayed on the oscilloscope screen was employed. A block of pure aluminum was irradiated with slow neutrons and then placed near the crystal; the exposure time was two half-lives of the Al^{28}. Sufficient intensity was present to yield good photographs of the spectrum. These, both on visual inspection and from densitometer curves, showed a weak but well-resolved photoelectric peak, the Compton distribution, and a pair peak (with escape of the annihilation radiation) at the expected positions.

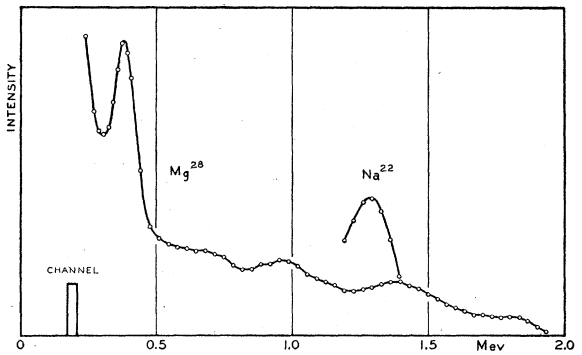

FIG. 2. Pulse size spectrum from a Mg^{28} source. The width of the channel is indicated by a rectangle. The photoelectric peak of the Na^{22} line at 1.28 Mev was used for energy calibration.

Hence it seems certain that the maxima observed near 1.35 and 0.95 Mev are not due to the Al^{28} line, but represent additional lines of Mg^{28}. From our experiments, the energies of these lines cannot be accurately determined, owing to the low intensity of the photoelectric peaks obtained with the relatively thin crystal employed.

The decay of the 391-kev line was followed for 4 half-lives by setting the spectrometer to cover its photoelectric peak. The decay curve thus obtained was exponential within the limit of experimental error and yielded a half-life of 22 hours, in agreement with other determinations.

After our experiments had been completed, Sheline and Johnson[4] reported gamma-ray lines of Mg^{28} at 0.40, 0.95, and 1.35 Mev. The low-energy line agrees well with our determination; the others also agree with the low maxima observed on our curve.

Triton Induced Activities in Aluminum

The aluminum activities obtained by deuteron bombardment of $LiAlD_4$ are indicated in Fig. 3. Aluminum activities of 2.5-min and 6.5-min half-lives are observed, corresponding to the accepted values of Al^{28} and Al^{29}, respectively. Although the yield of Al^{29} is lower than might be desired, there does not seem to be much question as to its presence, which indicates the realization of the $Al^{27}(t, p)Al^{29}$ reaction here.

Search for (t,p) Reaction in Phosphorus

The phosphorus activity produced by pile irradiation of lithium phosphate was examined for evidence of the $P^{31}(t, p)P^{33}$ reaction. The activity was followed for six half-lives and no deviation was obtained from the accepted half-life of P^{32}, indicating that very little or no P^{33} was formed. A possible explanation for this behavior may be the fact that the compound nucleus formed by incorporation of two neutrons from the triton is in an excitation state whose energy is appreciably greater than the binding energy of the neutron, thereby resulting in a "boiling off" of the neutron and production of P^{32}.

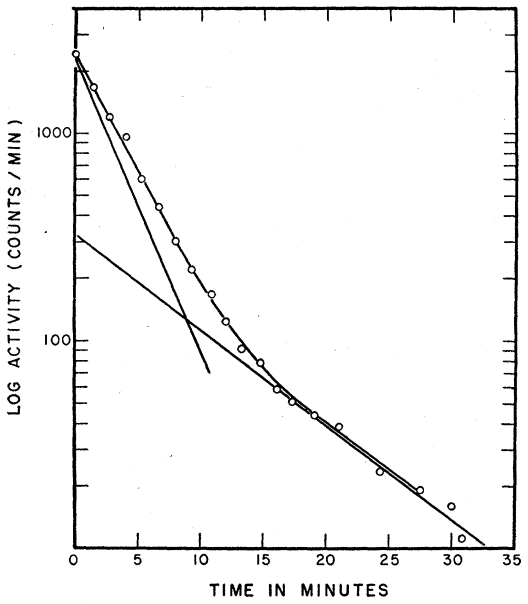

FIG. 3. Aluminum activities produced by bombardment of $LiAlD_4$ with deuterons.

We are indebted to Dr. V. W. Cohen and members of the Isotope Branch of the Brookhaven National Laboratory for the various pile neutron irradiations that were made during the course of work reported here.

[4] R. K. Sheline and N. R. Johnson, Phys. Rev. **90**, 325 (1953).