The Neutrons from the Disintegration of the Separated Isotopes of Magnesium by Deuterons*

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(Received May 8, 1950)

When Mg^{25} is irradiated by deuterons, four groups of neutrons appear from which nuclear energy levels are deduced in Al^{26} at 2.00±0.18 Mev, 3.63±0.18 Mev, and 5.13±0.18 Mev. The Q-value for the formation of Al^{26} in the ground state is 5.58±0.10 Mev. From the disintegration data, the mass of Al^{26} is calculated to be $25.9935\pm9\times10^{-4}$ mu.

Bombardment of Mg^{26} by deuterons gives rise to eight groups of neutrons corresponding to energy levels in Al^{27} at 0.88±0.07, 1.92±0.07, 2.75±0.07, 3.65±0.07, 4.33±0.07, 5.32±0.07, and 5.81±0.07 Mev. The Q-value for the formation of Al^{27} in the ground state is 5.68±0.05 Mev.

No quantitative analysis was made of the reaction $Mg^{24}(D, n)Al^{25}$. However, since Mg^{24} was the principal isotopic impurity, it was necessary to show that its presence made no contribution to the spectra of the two preceding reactions.

I. INTRODUCTION

THE separation of stable isotopes under the program of the United States AEC has made several elements available for study which have not been previously investigated. Among these are the three isotopes of magnesium, Mg^{24}, Mg^{25}, and Mg^{26}. Seventy-five percent of naturally occurring magnesium is Mg^{24}, the remaining percentage being about evenly divided between the two isotopes of higher mass numbers. The isotopic percentages in the various samples of separated materials are summarized in Table I.

The separated isotopes, in the form of MgO, were supplied together with the isotopic analyses, by the Y-12 plant, Carbide and Carbon Chemicals Division, Union Carbide and Carbon Corporation, Oak Ridge, Tennessee.

The experimental data to be described were obtained by irradiating thick targets of MgO by deuterons of energy 1.47 Mev, supplied by the Bartol Van de Graaff statitron. Ilford C_2 emulsions, making angles of 0° and 90° with the bombarding beam in the laboratory system of coordinate axes, were employed as detectors of the emergent neutrons. The track lengths of recoil protons making angles as great as 12° with the forward direction were accepted. From the track lengths, the neutron energies were deduced.

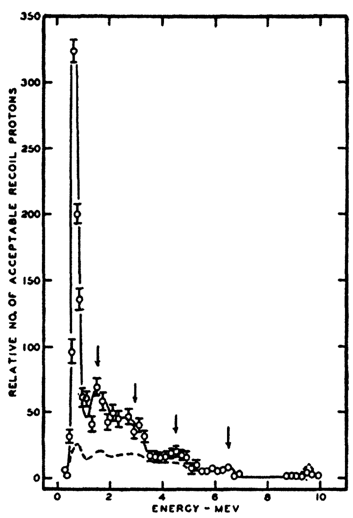

FIG. 1. Recoil protons of the neutrons from the disintegration of Mg^{25} by deuterons. Angle of observation 90°.

TABLE I. Isotopic composition of samples.

Mg^{24} Isotope	Mg^{24} Percent	Mg^{25} Isotope	Mg^{25} Percent	Mg^{26} Isotope	Mg^{26} Percent
24	99.5	24	10.7	24	2.53
25	0.3	25	86.8	25	1.56
26	0.2	26	2.5	26	95.91

II. MAGNESIUM (25)

Among the several nuclear reactions occurring when Mg^{25} is bombarded by deuterons is the one concerned with neutron emission,

$$Mg^{25}+D\rightarrow Al^{26}+n^1+Q_1. \quad (1)$$

The energy spectrum of the neutrons emitted at 90° in this reaction is shown in Fig. 1. The intense group of particles in the vicinity of 1 Mev is the group of

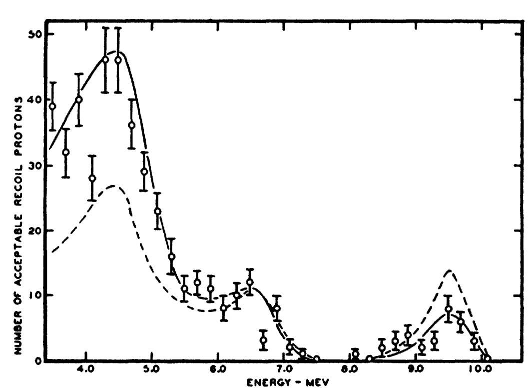

FIG. 2. High energy recoil protons of the neutrons from the disintegration of Mg^{25} by deuterons. Angle of observation 90°. The group of neutrons at 9.5 Mev is ascribed to the first excited state of the reaction $B^{11}(D,'n)^*C^{12}$.

* Assisted by the joint program of the ONR and AEC.

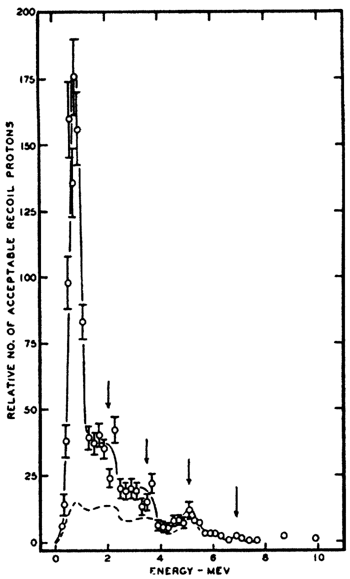

FIG. 3. Recoil protons of the neutrons from the disintegration of Mg^{25} by deuterons. Angle of observation 0°.

neutrons from the reaction

$$C^{12}+D\rightarrow N^{13}+n^1+Q_2. \quad (2)$$

The remaining four groups of higher energy are attributed to reaction (1). In order to obtain greater statistical accuracy in the region of higher energy, measurements accepting only neutrons of energy greater than 3.5 Mev were carried out. The tracks of Fig. 1 beyond 3.5 Mev were combined with these newly obtained tracks to give Fig. 2. The Q-value for formation of Al^{26} in its ground state is 6.22 Mev, as calculated from known mass values.[1] The appearance of the neutron group at 9.5 Mev could not therefore be explained by reaction (1). A spectrographic analysis had shown boron to be present to the extent of 0.01 percent as a chemical impurity. From the length of bombardment, the area of the photographic plate surveyed, and the intensity of the group, it was concluded that the group could be assigned to the first excited state of C^{12} in the reaction

$$B^{11}+D\rightarrow {}^*C^{12}+n^1+Q_3. \quad (3)$$

By a consideration of relative intensities, it can be shown that the remaining groups of the spectrum cannot be attributed to the presence of any contaminating boron.[2]

The neutrons of reaction (1) were also recorded in the forward direction as shown in Fig. 3, where the four groups from Mg^{25} are again present along with the neutrons from $C^{12}(D, n)N^{13}$. There was difficulty in locating precisely the peaks of the various groups owing to their breadths. It is probable that the two lower Q-values of reaction (1) may be mean values for several closely spaced overlapping groups in each case. The average Q-values for reaction (1), calculated from the data of Figs. 1 and 3, are 0.45±0.15, 1.95±0.15, 3.58±0.15 and 5.58±0.10 Mev, corresponding to energy levels in the residual nucleus, Al^{26}, at 2.00±0.18 Mev, 3.63±0.18 Mev, and 5.13±0.18 Mev. The mass of Al^{26} is calculated to be $[25.9935\pm 9\times 10^{-4}]$ mu, using the Q-value for the ground state of Al^{26} found in the present experiment and the mass values of reference 1.

The broken lines of Figs. 1, 2, and 3 represent the energy distribution of the neutrons from reaction (1), corrected for the variation with energy of the neutron-proton scattering cross section and the acceptance probability. The areas under the dotted lines are a measure of the intensities of the various groups.

III. MAGNESIUM (26)

When Mg^{26} is irradiated by deuterons, the mono-isotopic Al^{27} is formed in the reaction

$$Mg^{26}+D\rightarrow Al^{27}+n^1+Q_4. \quad (4)$$

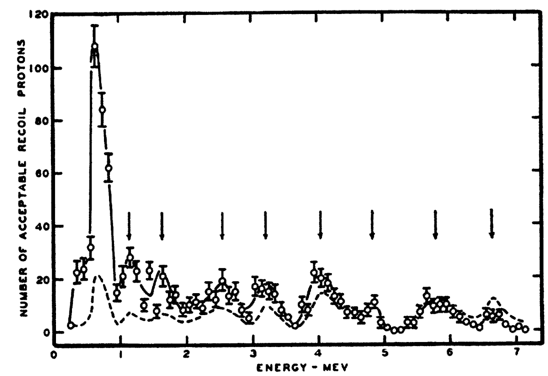

FIG. 4. Recoil protons of the neutrons from the disintegration of Mg^{26} by deuterons. Angle of observation 90°.

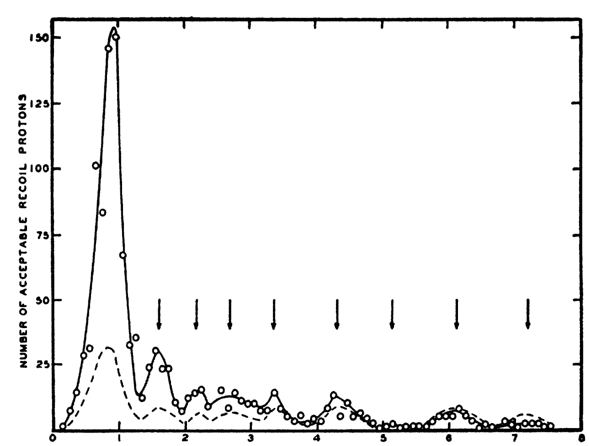

FIG. 5. Recoil protons of the neutrons from the disintegration of Mg^{26} by deuterons. Angle of observation 0°.

[1] H. A. Bethe, *Elementary Nuclear Theory* (John Wiley and Sons, Inc., New York).

[2] The relative intensities of the neutron groups from $B^{11}(D, n)C^{12}$ are known from a bombardment at 1.4 Mev in this laboratory. The data are unpublished.

TABLE II. Nuclear energy levels in Al^{27}.

Proton scattering Rochester (1941)	Proton scattering Princeton (1948)	Proton scattering Cambridge (1949)	Deuteron scattering Cambridge (1949)	Deuteron scattering Liverpool (1949)	$Mg^{27}\rightarrow Al^{27}+\beta^-$ Stockholm (1948)	$Mg^{26}+D\rightarrow Al^{27}+n^1+Q$ Bartol (1950)
0.87	0.9	0.80, 0.97	0.88	0.99	0.84	0.88
2.03		2.15	2.15	2.17	1.85	1.92
2.70	2.9					2.75
3.5						3.65
						4.33
						5.32
						5.81

The Q-value for formation of Al^{27} in the ground state is 5.31 Mev when calculated from known mass values.[1] The neutron groups observed at 90° are shown in Fig. 4. In addition to the intense group of low energy neutrons from $C^{12}(D, n)N^{13}$, there are eight other groups corresponding to the formation of Al^{27} in the ground state and various excited states. The Q-values calculated from the neutron energies are (−0.13), 0.256, 1.35, 2.03, 2.93, 3.76, 4.80, and 5.68 Mev, giving energy levels at 0.88±0.07, 1.92±0.07, 2.75±0.07, 3.65±0.07, 4.33±0.07, 5.32±0.07, and 5.81±0.07 Mev in the nucleus of Al^{27}. As in the case of the previous figures, the broken line represents the corrected energy distribution.

Similar groups of neutrons were found in the forward direction as shown in Fig. 5. However, Q-values were not calculated because of difficulties in locating the exact position of the group corresponding to the ground state. It was possible to find only a few acceptable very long tracks.

The nuclear energy levels of Al^{27} have been investigated by several different methods such as inelastic scattering of protons by aluminum,[3–5] inelastic scattering of deuterons by aluminum[6,7] and by an analysis[8] of beta-decay of Mg^{27}. All of the data relating to levels of Al^{27} are summarized in Table II. Although the energy values of Table II are not in general very accurate, the striking similarity of the level structure revealed by the various different methods makes it seem extremely probable that the several methods of excitation do excite the same energy levels.

IV. MAGNESIUM (24)

A short bombardment at 1.47 Mev with the photographic plates close to the target of $Mg^{24}O$ gave evidence of no tracks having a range in excess of that of the neutrons from $C^{12}(D, n)N^{13}$. This was to be expected since mass values[1] indicate a Q-value of only 0.17 Mev. These data also show that the neutrons from $Mg^{24}(D, n)Al^{25}$ made no appreciable contribution to the observed spectra of $Mg^{25}(D, n)Al^{26}$ or $Mg^{26}(D, n)Al^{27}$. Mg^{24} was the largest isotopic impurity in the samples of $Mg^{25}O$ and $Mg^{26}O$.

The writers wish to acknowledge the continued interest of Dr. W. F. G. Swann, Director of the Bartol Research Foundation.

[3] R. H. Dicke and J. Marshall, Jr., Phys. Rev. **63**, 86 (1943).
[4] H. W. Fulbright and R. R. Bush, Phys. Rev. **74**, 1323 (1948).
[5] E. H. Rhoderick, Nature **163**, 848 (1949).
[6] Greenlees, Kempton, and Rhoderick, Nature **164**, 663 (1949).
[7] J. R. Holt and C. T. Young, Nature **164**, 1000 (1949).
[8] Benes, Hedgran, and Hole, Arkiv. f. Mat. Astr. o. Fys. **35A**, No. 12 (1948).