Proton Groups from the Bombardment of Argon by Deuterons

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The deuteron bombardment of argon in both ordinary form and with a 26 percent concentration of A^{36} shows the presence of thirteen groups of protons. Correct assignment to isotope can be made for ten of these and probable assignment for the others. The Q-values for the reactions are: $A^{36}(dp)A^{37}$ 6.59; 5.06; 4.92; 4.32; 4.03; 3.13 and 1.58 and $A^{40}(dp)A^{41}$ 3.84; 3.18; 2.63; 2.50; 1.90; 1.57; 1.04; 0.55; 0.15; −0.17. The mass difference $A^{37}-A^{36}$ is 0.99951 and $A^{41}-A^{40}$ is 1.00247. Considering that the nuclei differ by four neutrons there is surprisingly little difference in general level structure. The first excited state of A^{37} is at an unusually high value.

INTRODUCTION

THE observation of proton groups produced in the bombardment of argon by deuterons can be made to give information on the energy levels of A^{41} and A^{37}. There is some interest in energy levels of two isotopes differing by four neutrons, especially as it is likely that a new neutron shell is being developed at about this mass number.

This method was employed by W. L. Davidson, Jr.[1] Davidson reported excited states at 1.36 and 2.14 Mev in A^{41}. The maximum nuclear energy change (Q-values) was given as 4.37 Mev. A repetition of this work using postwar counting methods was reported by two of the authors[2] in which Q-values were reported at 3.82, 3.19, 2.65, 1.97, 0.95 Mev. These confirm the two excited states found by Davidson but give a new value for the maximum Q.

Ordinary argon contains A^{40}, 99.63 percent; A^{38}, 0.061 percent; and A^{36}, 0.307 percent. It was thought likely that by a reasonable separation of A^{36}, new proton groups of sufficient intensity would be found and therefore energy levels in A^{37} could be discovered.

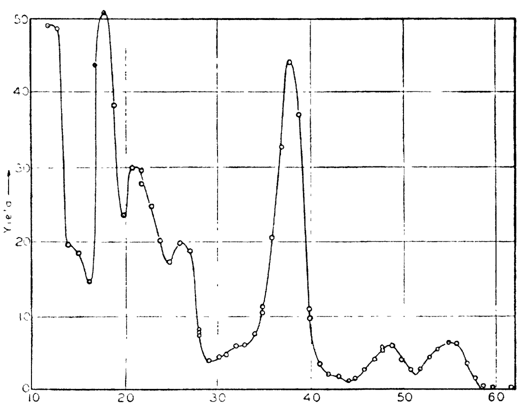

FIG. 1. Proton groups from the bombardment of ordinary argon by deuterons. All the groups are assigned to A^{41}.

The separation of argon isotopes was achieved by one of us (J. O. Buchanan) by means of thermal diffusion columns: the technique will be described in a separate paper. Mass spectrographic analysis showed that the separated gas sample contained 26.2 percent A^{36}, 1.6 percent A^{38}, 72.2 percent A^{40} and <0.2 percent N_2^{28}. This was considered adequate for work and the results are herein described.

EXPERIMENTAL RESULTS

The gas was bombarded in a special bombardment chamber in which the beam was brought through an aluminum foil into a space with an exit port for observation of protons at 90° to the beam. The details of this bombardment chamber are described in a paper by one of us (P. W. Davison).[3] The thickness of the target can be varied by varying the gas pressure and it has been our experience that such targets can be made to give very precise evidence regarding group structure. Protons were observed with a proportional counter containing argon at 20 cm pressure. Bias was employed to ensure counting protons which are nearly stopped. Experimental results are given in Figs. 1, 2, and 3. Figure 1 shows the result of bombarding ordinary argon. The

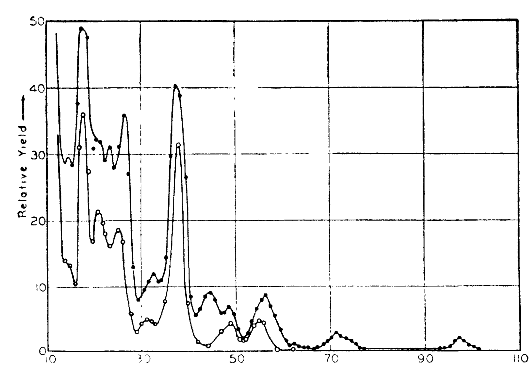

FIG. 2. Proton groups from argon enriched in A^{36} (black dots) together with normal argon (white rings) for comparison. The presence of longer range groups is clearly seen, also some change in the relative intensities indicating groups due to A^{36} at shorter range.

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[1] W. L. Davidson, Jr., Phys. Rev. **57**, 244 (1940).
[2] E. Pollard and P. W. Davison, Phys. Rev. **73**, 1241A (1948).
[3] P. W. Davison, Phys. Rev. **75**, 757 (1949).

group structure can be seen and has been analyzed into the Q-values listed in Table I.

The result of bombarding the sample enriched in A^{36} is shown in Fig. 2. The unenriched curve is shown for comparison. It can be seen that several groups are present at longer ranges than any previously observed and moreover, two groups at shorter ranges can be seen to be clearly enhanced in yield.

The detail of the long range groups is shown in Fig. 3. The width of the second group at range 76 cm is greater than that of a single group and we are confident that this group is double. A group of low yield appears just beyond the Q_0 group from $A^{40}(dp)^{41}$ and in addition there is clearly an increased width to the group ending near 60 cm which is due to the superposition of the q_4 group from $A^{36}(dp)A^{37}$ on the Q_0 group from $A^{40}(dp)A^{41}$. It is thus possible to assign the ground state and four excited states to the A^{37} nucleus. Assignment within the group structure of A^{41} is difficult, but it can be seen from Fig. 3 where the curves for separated and unseparated targets are plotted for comparison, that groups at 47 cm and 28 cm and possibly 24 cm are due to A^{37} excited states. There is also a likelihood that the large yield group at 40 cm is wider for the separated sample. It is very likely that two or three groups from A^{36} are masked by abundant A^{40} groups.

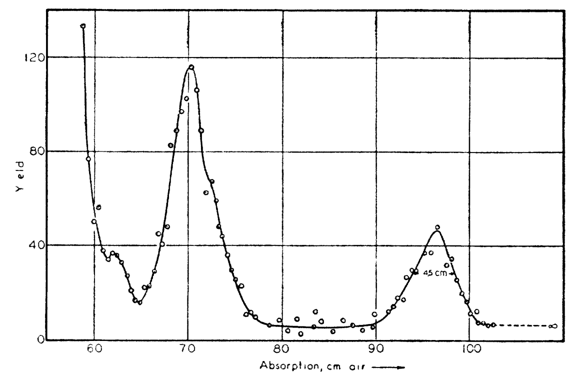

FIG. 3. Detail of the groups from A^{36} which have range beyond any due to A^{40}. The group with peak at 70 cm, is double. A total of five groups due to the light isotope can be recognized.

The result of this analysis is given in Table I which lists the Q-values for the two reactions. Doubtful assignments are starred.

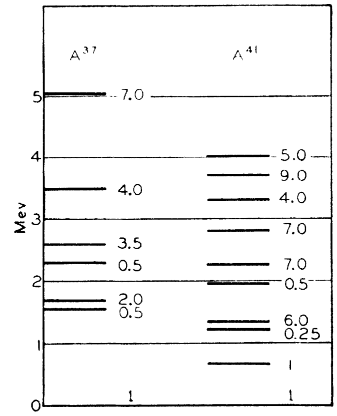

FIG. 4. Energy levels and relative abundances for A^{37} and A^{41}. The first excited state of A^{37} is unusually wide and the second unusually narrow. Gaps undoubtedly exist in the levels indicated for A^{37} above 2.6 Mev excitation owing to the masking of group structure by A^{41} groups. Below that, the structure should be complete.

TABLE I. Q-values for the two $A(dp)$ reactions.

	$A^{36}(dp)A^{37}$	Relative yield		$A^{40}(dp)A^{41}$	Relative yield
q_0	6.59 ± 0.03	1	Q_0	3.84 ± 0.03	1
q_1	5.06 ± 0.03	0.5	Q_1	3.18 ± 0.05	1
q_2	4.92 ± 0.05	2.0	Q_2	2.63 ± 0.04	0.25
q_3	4.32 ± 0.05	0.5	Q_3	2.50 ± 0.04	6.0
q_4	4.03 ± 0.03	3.5	Q_4	1.90 ± 0.04	0.5
q_5*	Probably masked		Q_5	1.57 ± 0.05	7.0
q_6*	3.13	4.0	Q_6	1.04 ± 0.05	7.0
q_7*	Probably masked		Q_7	0.55 ± 0.03	4.0
q_8	1.58	7.0	Q_8	0.15 ± 0.05	9.0
			Q_9	-0.17 ± 0.05	5.0

DISCUSSION

The energy levels for A^{37} and A^{41} are shown in Fig. 4. The first excited state of A^{37} is wider than usual and appears to be double. The average spacing of the first four levels is only slightly greater than that of A^{41}. The difference of four neutrons appears therefore to produce no very dramatic effect.

We feel reasonably confident that the first four Q-values we list in each case are single and do not contain overlapping groups. The expected line width, in view of the known beam inhomogeneity and target thickness is about the experimentally found line width. At higher excitations this is not true and there may be an overlapping. It will be noticed that in any event there seem to be more protons in highly excited states than in the states of low excitation. This is generally observed in dp reactions.

Taking the values 1.00812 and 2.01471 for the mass of the proton and deuteron respectively the values of the mass differences $A^{37}-A^{36}$ and $A^{41}-A^{40}$ are 0.99951 and 1.00247 ± 0.0001 in each case.