Proton Groups from the $S^{33}(d,p)S^{34}$ Reaction*

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Natural and 25% enriched sulfur targets sandwiched between two silver layers were bombarded with deuterons accelerated in the MIT-ONR electrostatic accelerator to an energy of 6.0 MeV. Proton groups from the (d,p) reactions were observed at angles 90, 50, and 20 degrees to the deuteron beam with a broad-range magnetic spectrograph. Twenty-three proton groups corresponding to levels in S^{34} were observed. The ground-state Q value of the $S^{33}(d,p)S^{34}$ reaction was measured as 9.193 ± 0.010 MeV.

I. INTRODUCTION

THE investigation of the protons produced by deuterons impinging on S^{33} nuclei can provide information regarding the energy levels of the nucleus S^{34}. Only the lowest lying levels of this nucleus have previously been measured, mainly through studies of other reactions and from the beta decay of P^{34} and Cl^{34}.[1] The best energy values have been obtained from the $Cl^{37}(p,\alpha)S^{34}$ reaction as investigated at MIT.[2]

The natural abundance of the S^{33} isotope is less than 1%. It is therefore necessary to use targets enriched in S^{33}. Because of the high Q value of the reaction, as compared to that of the $S^{32}(d,p)S^{33}$ reaction which is known to yield a dense proton spectrum,[3] a considerable number of new proton groups from S^{33} reactions are expected to appear in a broad-range spectrograph on the high-energy side of the $S^{32}(d,p)S^{33}$ ground-state group and between the groups corresponding to the lower levels in S^{33}. It should therefore be possible to identify several levels in S^{34} even when there is a considerable amount of S^{32} present in the target.

II. EXPERIMENTAL PROCEDURE

Two targets were prepared from a total amount of 8 mg of sulfur, enriched to 25% in S^{33}. This material was obtained from the Stable Isotopes Division of the Oak Ridge National Laboratory. The sulfur was sublimated and collected on a thin silver backing. During the sublimation, the target was kept in vacuum at a distance of 3 mm from a tantalum boat, which was slightly warmed by a small current. On top of the sulfur a thin layer of silver was evaporated so as to form an Ag-S-Ag sandwich. Silver was used instead of the more usual backing materials with the expectation that a silver sulfide target would be more stable than one of elemental sulfur. In spite of the large solid angle covered by the silver backing during evaporation, only a small fraction of the sulfur was collected on the target. Several targets of natural sulfur were prepared in the same way.

Another method for preparing sulfur targets was tried as well. A silver foil was kept in a small test tube containing H_2S gas prepared from a few mg of natural sulfur. A black layer of Ag_2S was formed on the backing. A test run with the accelerator, however, showed that the targets prepared in this way were too thin for the present experiment.

The targets were bombarded by deuterons accelerated to 6 MeV in the MIT-ONR electrostatic accelerator.[4] Protons resulting from the (d,p) reactions were analyzed in a broad-range magnetic spectrograph[5] at angles of 90, 50, and 20 deg to the incident deuteron beam. Nuclear emulsions were used to detect the protons. The magnetic field of the spectrograph was set so that the ground-state group from the reaction appeared on the nuclear plate near its high-energy edge. Natural sulfur targets were bombarded as well, with the magnet kept at 90 and 50 deg to the deuteron beam. The proton groups obtained with these targets were used for comparison to aid in the identification of the S^{34} peaks.

The energy of the deuterons was determined by measuring the energy of deuterons elastically scattered from the target. At 120 deg, the two deuteron groups corresponding to elastic scattering from S^{32} and S^{33}, respectively, were well separated. When recording proton groups, aluminum foils were used immediately in front of the emulsions to stop the deuterons and heavier particles.

III. EXPERIMENTAL RESULTS

Proton groups obtained by bombarding an enriched and a natural target are seen in Figs. 1(a) and 1(b). The exposures were 3000 and 2000 μC, respectively. Twenty-three proton groups originating from the $S^{33}(d,p)S^{34}$ reaction have been labeled with the letters A–X (without indexes). Of these, all except the groups F and T are seen in Fig. 1(a). The ground-state group

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[1] *Nuclear Data Sheets*, compiled by K. Way *et al.*, National Academy of Sciences, National Research Council (U. S. Government Printing Office, Washington, D. C.).

[2] P. M. Endt, C. H. Paris, A. Sperduto, and W. W. Buechner, Phys. Rev. **103**, 961 (1956).

[3] P. M. Endt and C. H. Paris, Phys. Rev. **110**, 89 (1958).

[4] W. W. Buechner, M. Mazari, and A. Sperduto, Phys. Rev. **101**, 188 (1956).

[5] C. P. Browne and W. W. Buechner, Rev. Sci. Instr. **27**, 899 (1956).

was observed at 50 and 20 deg. The Q value calculated from this group is 9.193±0.010 MeV. The Q values and excitation energies of the S^{34} levels corresponding to the groups A–X are listed in Table I. The error in the excitation energy is in most cases 10 keV. It includes the statistical error of the Q value obtained from the small number of tracks in the ground-state group. However, the Q value of higher levels in S^{34} was gener-

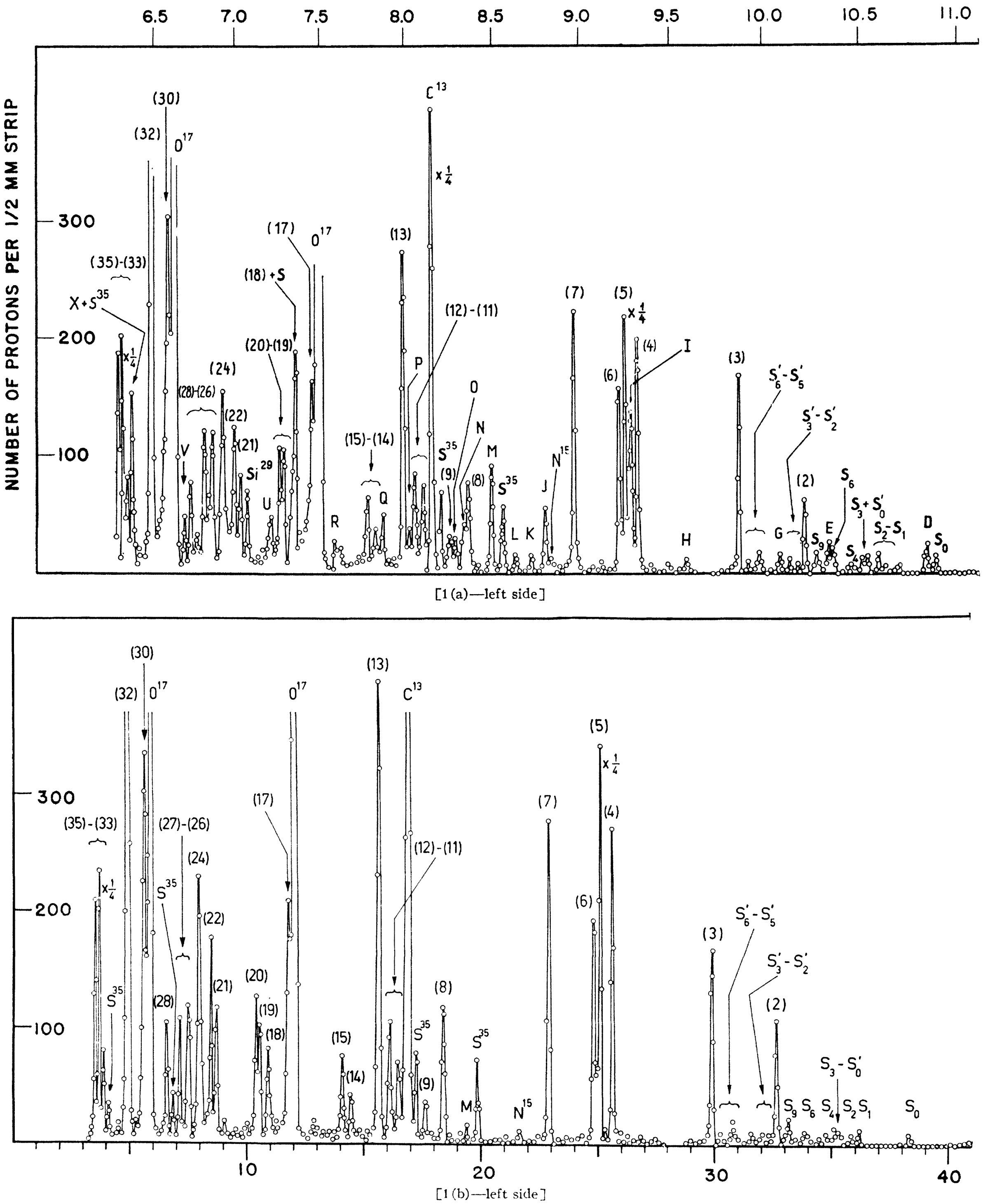
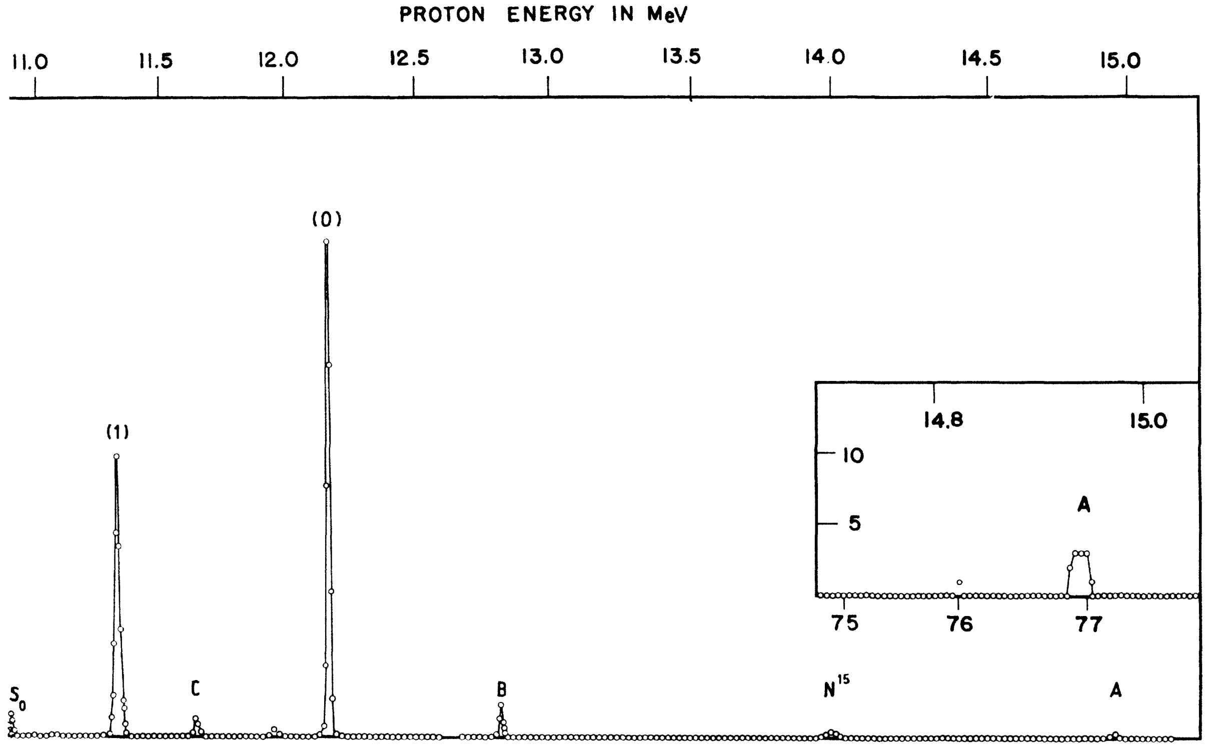
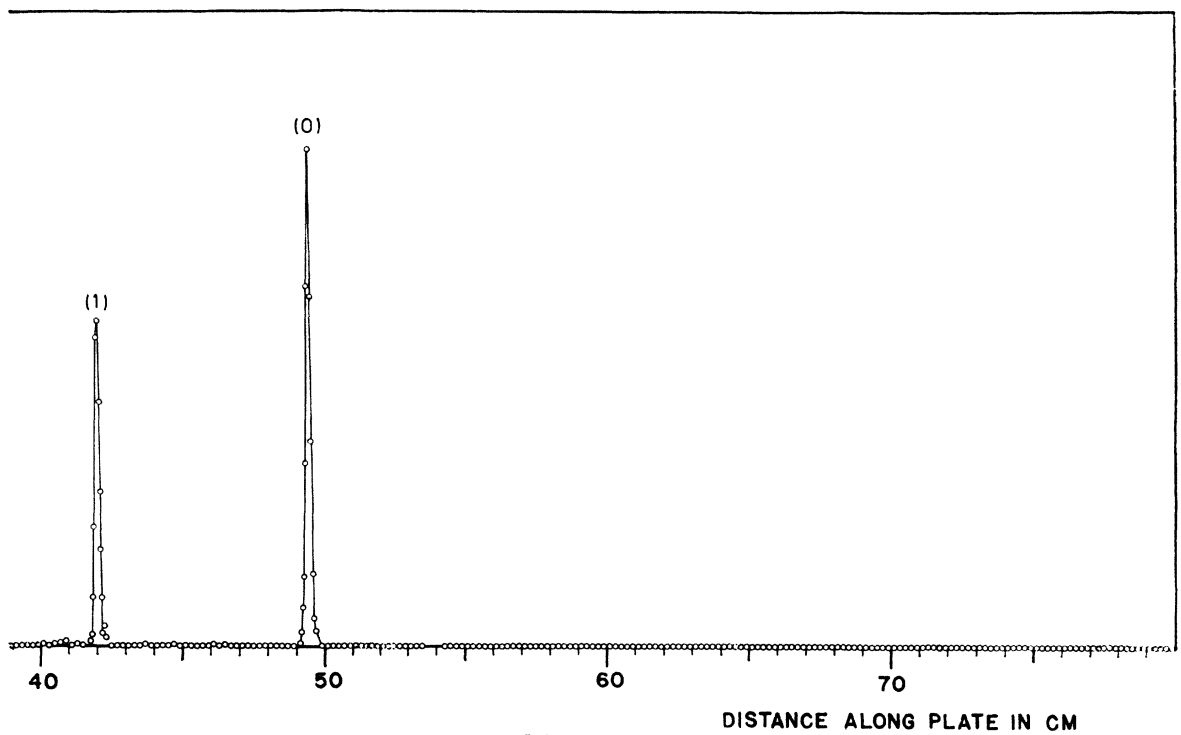


FIG. 1. Proton groups from deuteron bombardment of sulfur targets sandwiched between silver on Formvar backing at E_d=6.017 MeV, θ=50°, B=9970 G: (a) sulfur 25% enriched in S^{33}; (b) natural sulfur.

ally determined with a better accuracy. To be sure that a group originated from the $S^{33}(d,p)S^{34}$ reaction, it was required that (1) the relative position of the groups as observed at different angles agree within the limits of error with the position expected from theoretical considerations based on the conservation of energy and



[1(a)—right side]



[1(b)—right side]

FIG 1.—*Continued.*

TABLE I. Q values and excitation energies (in MeV) of S^{34} levels observed from the $S^{33}(d,p)S^{34}$ reaction.

Level	Q values	Excitation energies from (d,p) reaction	Excitation energies from (p,α) reaction[a]
A	9.193±0.010	0	0
B	7.071±0.006	2.122±0.010	2.127±0.008
C	5.891±0.006	3.302±0.010	3.302±0.008
			3.915±0.008
			4.073±0.008
D	5.073±0.006	4.120±0.010	4.114±0.008
E	4.564±0.006	4.629±0.010	4.621±0.008
F	(4.491±0.010)	(4.702±0.014)	4.685±0.008
G	4.305±0.006	4.888±0.010	4.876±0.008
H	3.809±0.006	5.384±0.010	
I	3.503±0.006	5.690±0.010	
J	3.020±0.006	6.173±0.010	
K	2.942±0.006	6.251±0.010	
L	2.849±0.006	6.344±0.010	
M	2.713±0.010	6.480±0.014	
N	2.559±0.006	6.634±0.010	
O	2.503±0.006	6.690±0.010	
P	2.234±0.006	6.959±0.010	
Q	2.081±0.006	7.112±0.010	
R	(1.795±0.010)	(7.398±0.014)	
S	1.562±0.006	7.631±0.010	
T	1.443±0.010	7.750±0.014	
U	1.410±0.010	7.783±0.014	
V	0.894±0.010	8.299±0.014	
X	(0.571±0.010)	(8.622±0.014)	

[a] See reference 2.

momentum, and that (2) the peak appear in a spectrum obtained with an enriched target, but not to any considerable amount in the corresponding natural spectrum. In some cases only the second requirement was met, and the corresponding energies are enclosed in parentheses. The energies of the levels, when observed at different angles, deviated from their mean value by 1 or 2 keV but in no case by more than 5 keV.

Several groups from the $S^{32}(d,p)S^{33}$ reaction were observed and are labeled O–35 in Fig. 1. The ground-state Q value of this reaction and the excitation energies of the 35 levels in S^{33}, as obtained in the present investigation, agree within the limits of error with the values reported by Endt and Paris.[3]

Also in Fig. 1 are shown twelve peaks that are due to the $Ag^{107}(d,p)Ag^{108}$ and $Ag^{109}(d,p)Ag^{110}$ reactions. These are labeled S_0–S_9 and S_0'–S_6' to correspond with the order number of the levels in Ag^{108} and Ag^{110}, as reported by Mazari.[6] Four peaks are due to the $S^{34}(d,p)S^{35}$ reaction. S^{34} was present in the enriched targets in approximately the same concentration (4.2%) as in natural sulfur. The Q values and the excitation energies corresponding to these groups were in agreement with previous work in this laboratory.[7,8] Also, two groups marked O^{17} are due to the $O^{16}(d,p)O^{17}$ reaction and two groups originate from the reaction $N^{14}(d,p)N^{15}$. One peak

[6] M. Mazari, Massachusetts Institute of Technology Laboratory for Nuclear Science Progress Report, 1957 (unpublished), p. 44.
[7] C. H. Paris, W. W. Buechner, and P. M. Endt, Phys. Rev. **100**, 1317 (1955).
[8] P. M. Endt and C. H. Paris, Phys. Rev. **110**, 89 (1958).

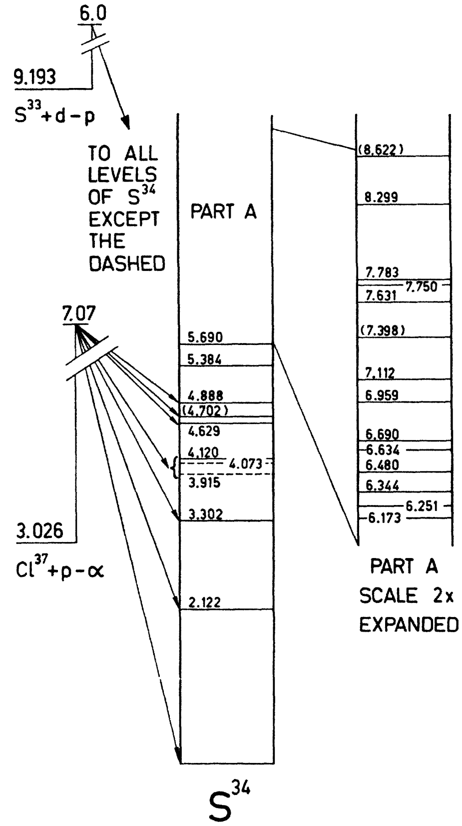


FIG. 2. Energy-level scheme of S^{34}.

marked Si^{29} is due to a 1.310-MeV level in Si^{29} formed from Si^{28} by the (d,p) reaction. The latter impurity is known to be present in the enriched target to an amount of 0.05%, according to the spectrographic analysis given by Oak Ridge National Laboratory.

The energies of the S^{34} levels, as known from the $Cl^{37}(p,\alpha)S^{34}$ reaction, are also tabulated in Table I. The two levels found from the (p,α) studies at 3.915 and 4.073 MeV were not observed in the present investigation. The energies of the other levels, as obtained from the present work and from the (p,α) reaction, agree within the limits of the experimental errors. Figure 2 shows the levels in S^{34} and their formation through the (d,p) and (p,α) reactions.

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