Energy Levels from (d,p) Reactions on Sn^{117} and Sn^{119}†

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The low-lying energy levels of Sn^{118} and Sn^{120} have been identified using the reactions $Sn^{117}(d,p)Sn^{118}$ and $Sn^{119}(d,p)Sn^{120}$. The incident deuteron beam was produced using the tandem Van de Graaff accelerator at Florida State University and the resulting proton groups were detected using a broad-range Browne-Buechner spectrograph. The ground-state Q values for the two reactions have been measured to be 7.09 and 6.89 MeV, respectively. Agreement with previous work is discussed. Special interest has been placed on the agreement with isobaric analog work of Becker *et al.*

I. INTRODUCTION

THE isotopes of tin have been the subject of many theoretical and experimental nuclear investigations. Tin has a closed shell of fifty protons and a large number of isotopes. Although the neutron numbers are not near a closed shell, experimental data from (d,p) reactions on tin are valuable in that the systematics of nuclei can be studied under conditions where the level characteristics and level spacings are expected to be primarily interpreted as arising solely from various neutron configurations.

This paper is concerned with experimental results from the (d,p) reaction on two odd-A stable isotopes of tin. The need for this experiment was suggested because of poor agreement between previously reported levels[1] and energy levels resulting from studies of isobaric analog states.[2]

At Florida State University isobaric analog states

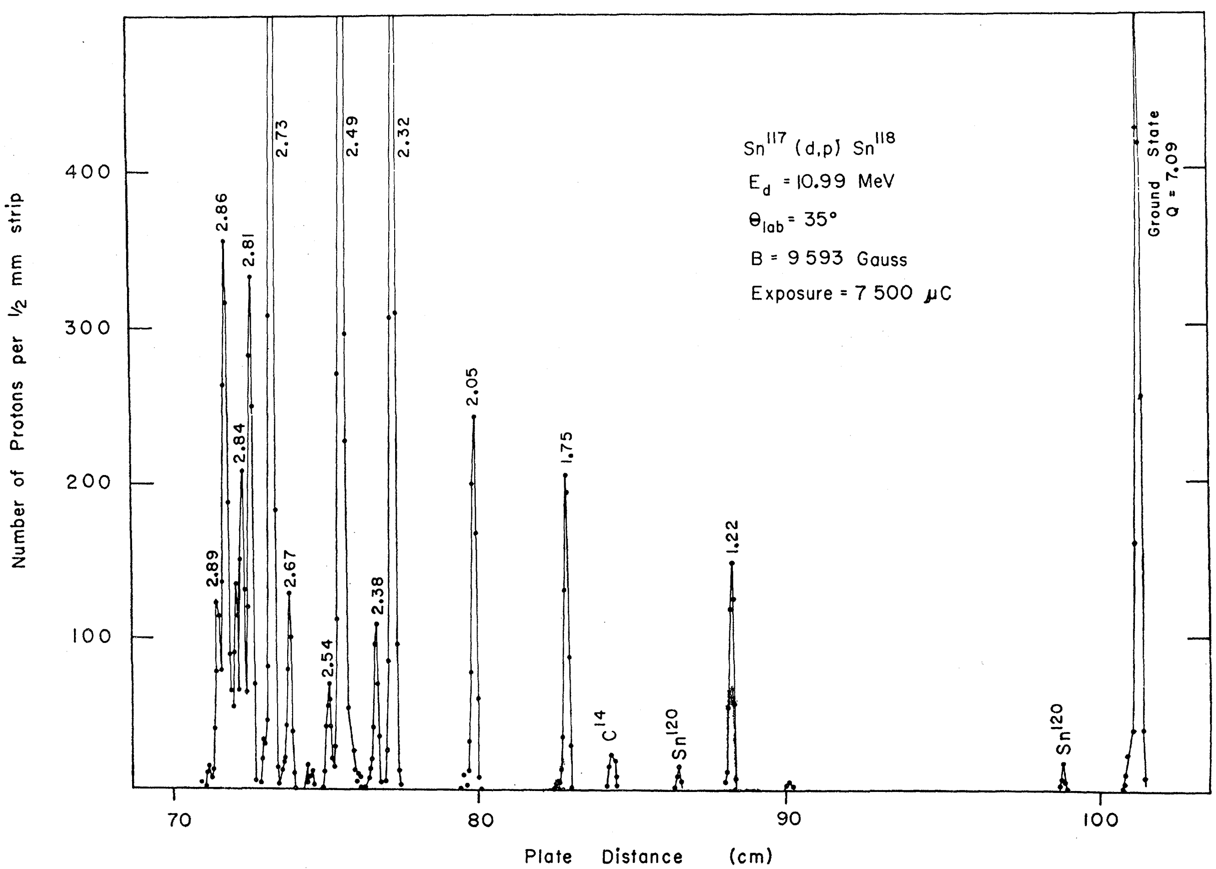

FIG. 1. Spectrum of protons from $Sn^{117}(d,p)Sn^{118}$.

† Work supported in part by the U. S. Air Force Office of Scientific Research and by the U. S. Atomic Energy Commission.
[1] B. L. Cohen and R. E. Price, Phys. Rev. 121, 1441 (1961); also, B. L. Cohen and R. E. Price, Phys. Rev. 123, 283 (1961).
[2] J. D. Fox, C. F. Moore, and D. Robson, Phys. Rev. Letters 12, 198 (1964).

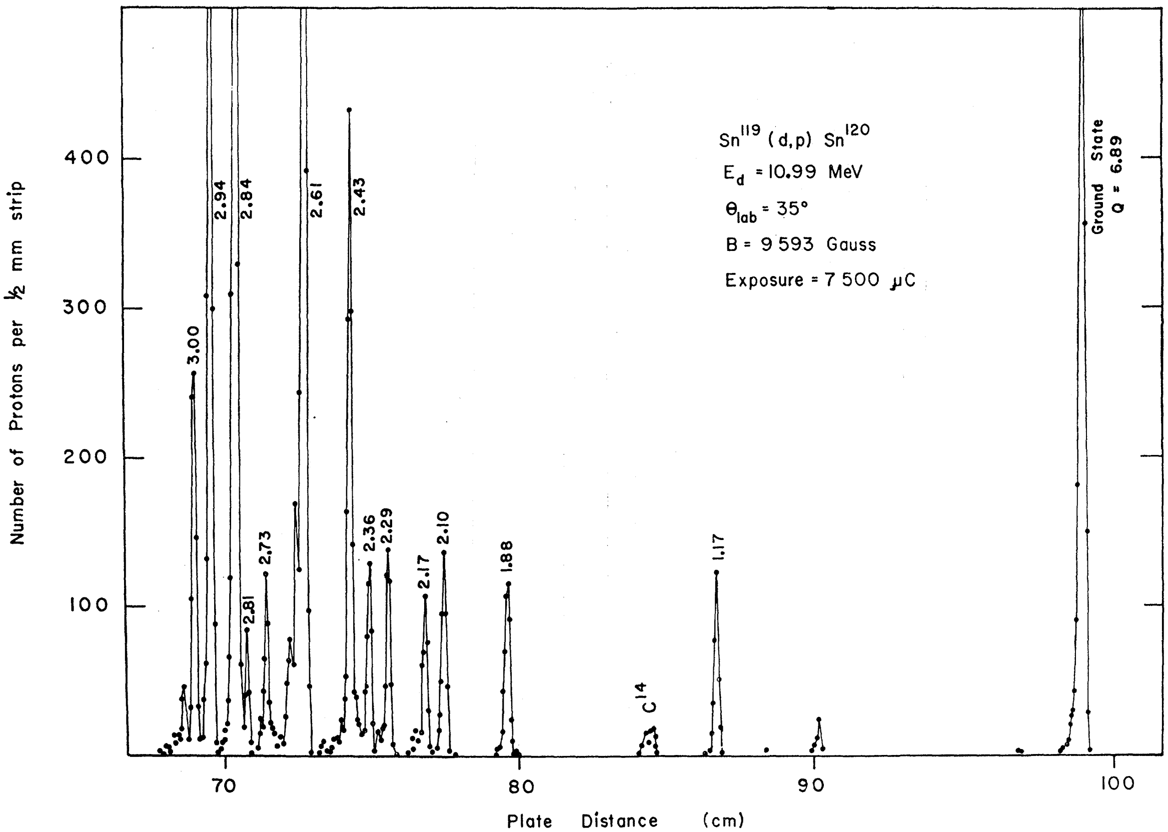

FIG. 2. Spectrum of protons from $Sn^{119}(d,p)Sn^{120}$.

were excited as compound nucleus resonances by means of elastic scattering of protons on the tin isotopes.[3] These states are isobaric analogs of the low-lying states in the neighboring isobar formed by a (*d,p*) reaction. Good agreement had been established between the isobaric analog states in the antimony isotopes corresponding to the low-lying states of Sn^{113}, Sn^{117}, Sn^{119}, Sn^{121}, Sn^{123}, and Sn^{125}. Good comparison could not be made, however, for the case of (Sn^{118}:Sb^{118*}) and (Sn^{120}:Sb^{120*}). In particular, several more isobaric analog states were found above 2-MeV excitation than were known from the previous (*d,p*) reaction studies.

With the combination of the tandem accelerator and a high resolution spectrograph, careful (*d,p*) measurements of tin have been accomplished. The (*d,p*) results are found to be in close agreement with results of isobaric analog studies.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

Targets of separated Sn^{117} and Sn^{119} oxides were bombarded in a deuteron beam from the HVEC tandem Van de Graaff accelerator at Florida State University. The protons resulting from the (*d,p*) reaction were analyzed with a Browne-Buechner broad-range spectrograph[4] and recorded on nuclear emulsion plates (Eastman NTA 50 μ). Tracks on the developed plates were counted under a microscope in $\frac{1}{2}$- by 8-mm strips. The number of tracks per unit length at a given position served to determined intensity as a function of energy for the proton spectrum.

The isotopically enriched targets (89.2% for Sn^{117} and 89.8% for Sn^{119}) were made by high-vacuum evaporation of SnO_2 onto carbon backings. The carbon backings had a 3-keV energy loss for 12-MeV deuterons and the tin-oxide layers had approximately 10- and 7-keV energy losses for Sn^{119} and Sn^{117}, respectively. A detailed description of the target preparation is given by R. Kenefick.[5]

The deuteron beam energies were 10.99, 11.00, and 12.02 MeV at laboratory angles of 35°, 45°, and 55°, respectively. The beam was collimated to a $\frac{1}{4}$- by 3-mm spot on the target. The beam current averaged to be about $\frac{1}{2}$ μA. The acceptance solid angle of the spectrograph was 2×10^{-4} sr.

[3] J. A. Becker, C. Nealy, C. F. Moore, D. Robson, and J. D. Fox, Bull. Am. Phys. Soc. **9**, 107 (1964); also, D. Robson *et al.*, Tandem Accelerator Laboratory Technical Report No. 6, 1964 (unpublished).

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

[5] R. A. Kenefick, dissertation, Florida State University, August 1963 (unpublished).

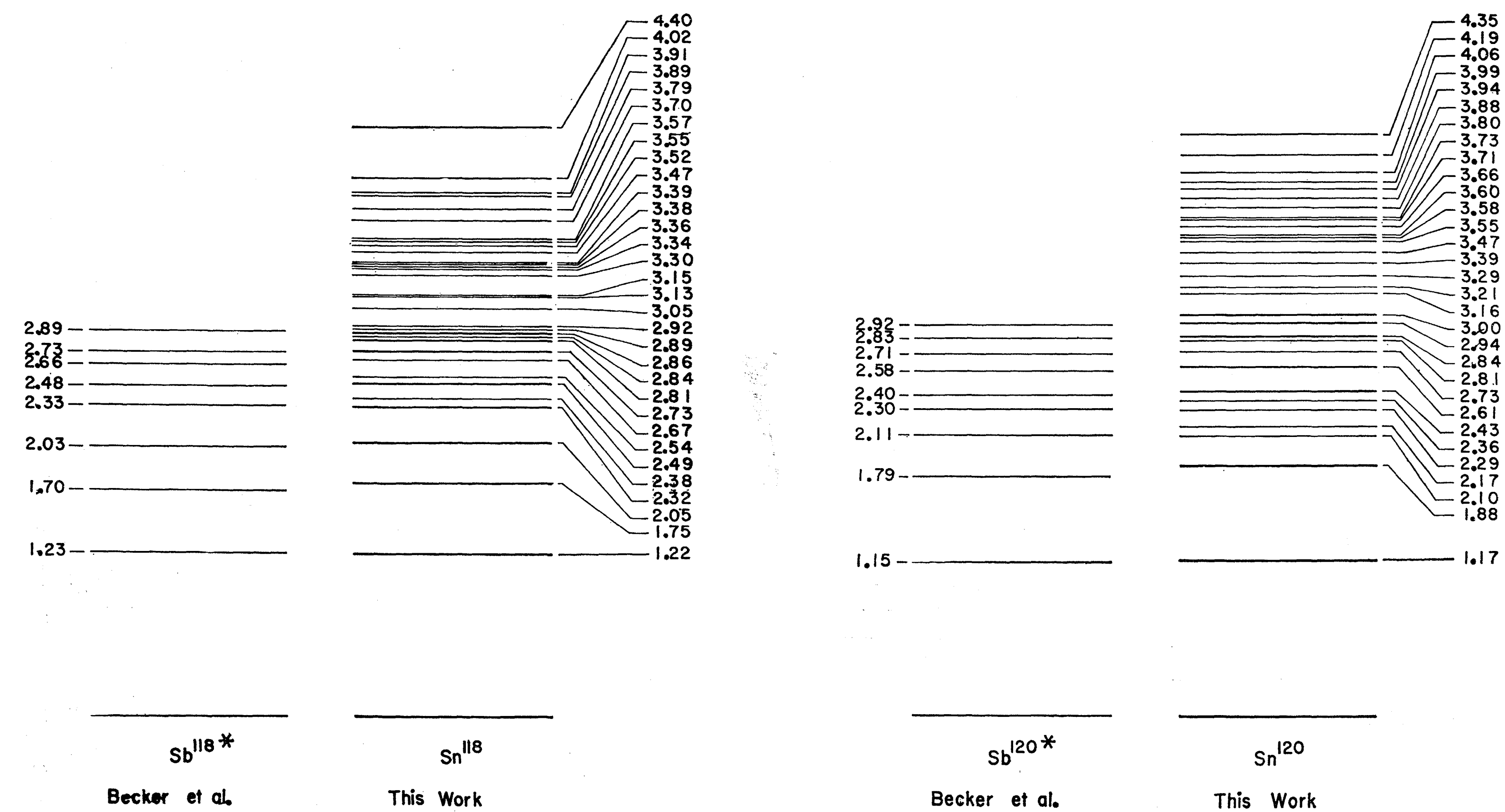

FIG. 3. The results of the $Sn^{117}(d,p)Sn^{118}$ and $Sn^{119}(d,p)Sn^{120}$ work reported here is compared with the corresponding analog levels in Sb^{118} and Sb^{120}. The energies of excitation of the levels in Sb^{118*} and Sb^{120*} that are isobaric analogues of levels in Sn^{118} and Sn^{120} are obtained by subtracting the resonance energies from the resonance energy of the ground-state analog, which is 4.45 and 4.63 MeV for the incident proton beam on Sn^{117} and Sn^{119}, respectively.

III. DATA REDUCTION AND EXPERIMENTAL RESULTS

The track number density data were plotted (# counts per $\frac{1}{2}$- by 8-mm strip versus plate position) for each isotope at each angle. The resulting spectrum from $Sn^{117}(d,p)Sn^{118}$ is shown in Fig. 1 and $Sn^{119}(d,p)Sn^{120}$ is shown in Fig. 2. The graphical display of the spectra was useful to compare proton group shapes at the different angles.

The raw data were analyzed using the IBM 709 code HILDE.[6] This program selects peaks from the data using a least-square fitting criterion to fit a curve to the peak shape and then assigns a position to the peak. When the positions of the peaks have been determined the corresponding radius of curvature was obtained from a calibration curve in which the Po^{210} alpha source was used as a standard. The Q values for the proton groups are then evaluated using the relativistic energy-$B\rho$ relationship and the relativistic kinematic equations. Also, an extensive impurity search was made using information contained in the literature and all the possible contaminants are listed which have Q values within 15 keV of the experimentally obtained results.

Energy levels for Sn^{118} and Sn^{120} were assigned only in cases where the results were consistent at all three angles. These results are shown in Fig. 3.

The ground-state Q value for the reactions $Sn^{117}(d,p)Sn^{118}$ is 7090 ± 12 keV and $Sn^{119}(d,p)Sn^{120}$ is 6890 ± 12 keV. These Q values agree closely with the values extracted from recent mass data[7]; $Sn^{117}(d,p)Sn^{118}$, $Q=7.09$ MeV and $Sn^{119}(d,p)Sn^{120}$, $Q=6.87$ MeV. The 2^+ first excited state in Sn^{118} is found at 1.22 MeV and it is slightly lower for Sn^{120} at 1.17 MeV.

The energy levels determined by this experiment have been compared with the previously reported levels measured by Cohen and Price[1] and with the excited states resulting from analog state studies.[8] The major result of the present (d,p) work is the energy determination of many more levels above 2-MeV excitation than was previously reported. In particular we find strongly excited levels at 2.05, 2.32, 2.49, 2.73, and 2.86 MeV in Sn^{118} which agree closely with their analog levels in Sb^{118*}. Similarly in Sn^{120} we find intense levels at 2.43, 2.61, 2.84, and 2.94 MeV which are in good agreement with analog states in Sb^{120*}. In the case of previously reported levels in Sn^{118} and Sn^{120} one could not determine which levels were associated with the analog states, possibly because of poorer experimental resolution. Figure 3 shows a detailed comparison between the levels observed here and the corresponding isobaric analog states.

IV. SUMMARY

The energies of the low-lying states in Sn^{118} and Sn^{120} have been measured and many more levels than previously reported have been found. Excellent agreement with the known isobaric analog levels excited as compound nucleus resonances by proton bombardment on Sn^{117} and Sn^{119} is obtained.

ACKNOWLEDGMENTS

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[6] C. F. Moore and C. E. Watson, Tandem Accelerator Laboratory Technical Report No. 7, 1964 (unpublished).

[7] R. A. Damerow, R. R. Ries, and W. H. Johnson, Jr., Phys. Rev. **132**, 1673 (1963).

[8] J. A. Becker (private communication).