Excited States of P^{32}†*

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The proton groups from the $P^{31}(d,p)P^{32}$ reaction have been studied at angles of 30, 50, 70, and 90 degrees. The incident deuteron energy was 6 Mev, and the protons were analyzed with a broad-range magnetic spectrograph. Fifth-two excited states were found in the region between the ground state and 6.2 Mev in P^{32}.

According to the shell model, the P^{32} nucleus in its ground state should consist of a single $s_{\frac{1}{2}}$ proton and a single $d_{\frac{3}{2}}$ neutron outside of closed shells, and the energies, spins, and parities of the excited states provide an important check on calculations based on this model. To determine these parameters, a number of investigations have been carried out using the $P^{31}(d,p)P^{32}$ reaction with analysis of the angular-distribution data on the basis of stripping reaction theory.[1–3] For the energies of the lower excited states, the analysis of the data in these experiments has involved the use of the results of an earlier investigation in this laboratory[4] of the $P^{31}(d,p)P^{32}$ reaction. This earlier work covered the region of excitation in P^{32} from the ground state to 4.3 Mev and was performed with magnetic analysis of the reaction products. This study utilized bombarding energies of 1.8 and 2.0 Mev and was limited to an angle of observation of 90 degrees. In this, the excitation region between 3.3 and 4.3 Mev was difficult to study because of the presence of various contaminant groups of protons, and more recent work[1] has shown the existence of at least one excited state in this region, as well as a number in the region of excitation above 4.3 Mev. The present investigation was undertaken to clarify the level scheme of P^{32} using higher bombarding energies and a wider range of observation angles than was possible in our earlier study.

The equipment and techniques employed were essentially those described in a previous publication.[5] Considerable difficulty was experienced in obtaining suitable thin phosphorus targets. The copper phosphate previously used was unsatisfactory because of the large number of proton groups from copper which are produced at the 6-Mev bombarding energy. After some experimentation with various phosphorus compounds,

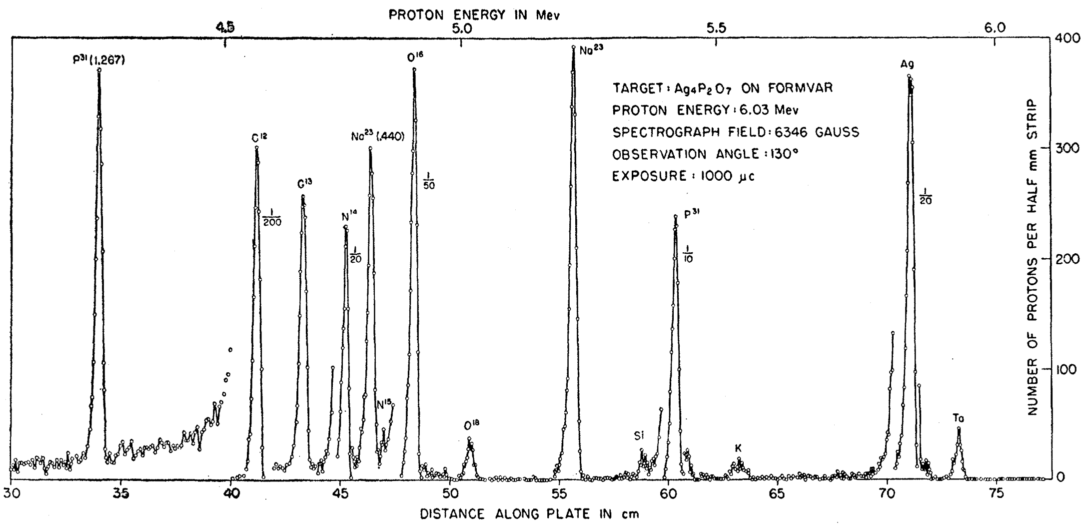

FIG. 1. Spectrum of elastically scattered protons from silver pyrophosphate target.

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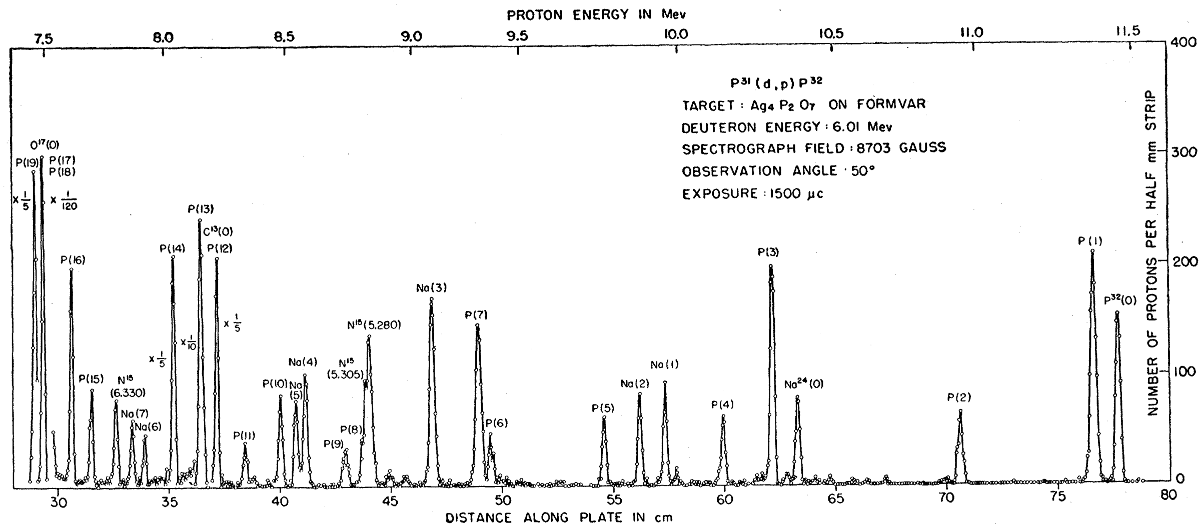

FIG. 2. High-energy portion of the spectrum of proton groups observed at 50 degrees from silver pyrophosphate target bombarded with 6-Mev deuterons.

it was found that silver pyrophosphate evaporated from a tantalum boat onto thin Formvar films provided targets which were sufficiently stable under bombardment for the purposes of the experiment. The targets actually employed were approximately 8- to 10-kev thick for the 6-Mev incident deuteron beam used in these experiments.

These targets were analyzed for isotopic constitution by measuring the spectrum of protons elastically scattered through 130 degrees. A typical analysis is shown in Fig. 1, where the observed proton groups are labeled according to the target nucleus responsible for their formation. While small quantities of sodium and nitrogen are usually present as impurities on targets using Formvar as a support, their relatively high concentrations in the present targets presumably arose from the use of silver nitrate and sodium pyrophosphate in the production of the commercially supplied silver pyrophosphate used. In the analysis of the data from the (d,p) reaction, the characteristic shift in energy of the observed proton groups with angle of observation was used to distinguish the groups arising from the various nuclei present in the targets.

With a 6-Mev incident deuteron energy and the broad-range magnetic spectrograph for analysis of the proton groups, exposures were made at laboratory angles of 30, 50, 70, and 90 degrees. These exposures were 500, 1500, 1000, and 1000 microcoulombs, respectively. In these, aluminum foils of sufficient thickness to stop charged particles heavier than protons were

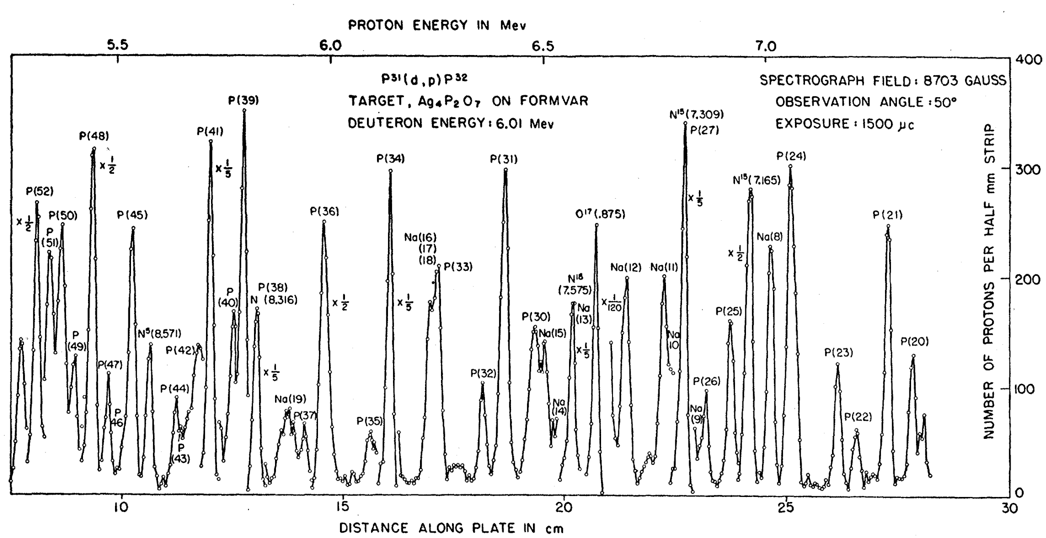

FIG. 3. Low-energy portion of the spectrum of proton groups observed at 50 degrees from silver pyrophosphate target bombarded with 6-Mev deuterons.

TABLE I. Energies of the excited states of P^{32}.

Level	Present work	Van Patter et al.[a]	Dalton et al.[b]
1	0.077±0.003	0.077±0.002	
2	0.516±0.003	0.515±0.005	
3	1.149±0.003	1.154±0.007	
4	1.322±0.003	1.316±0.008	
5	1.755±0.004	1.750±0.009	
6	2.177±0.004	2.177±0.009	
7	2.223±0.004	2.227±0.009	
8	2.657±0.005	2.650±0.008	
9	2.743±0.005	2.742±0.008	
10	3.007±0.005	2.999±0.010	
11	3.148±0.005	(3.141±0.012)	
12	3.265±0.005	3.259±0.009	
13	3.324±0.005	3.318±0.009	
14	3.447±0.005		3.45±0.10
15	3.798±0.006		
16	3.890±0.006		
17	3.994±0.006		
18	4.010±0.006		
19	4.040±0.006	4.032±0.009	
20	4.158±0.006		
21	4.209±0.006	4.207±0.010	
22	4.280±0.006		
23	4.316±0.006		
24	4.412±0.006		4.43±0.1
25	4.560±0.007		
26	4.615±0.007		
27	4.664±0.007		
28	4.878±0.007		
29	4.944±0.007		4.90±0.07
30	5.010±0.007		
31	5.077±0.007		5.11±0.1
32	5.129±0.007		
33	5.232±0.007		
34	5.346±0.007		5.37±0.07
35	5.394±0.007		
36	5.510±0.006		
37	5.550±0.008		
38	5.657±0.008		
39	5.700±0.008		
40	5.724±0.008		
41	5.775±0.008		5.75±0.1
42	5.813±0.008		
43	5.835±0.008		
44	5.858±0.008		5.82±0.07
45	5.964±0.008		
46	5.989±0.008		
47	6.024±0.008		
48	6.062±0.008		
49	6.096±0.008		6.09±0.07
50	6.131±0.008		
51	6.160±0.008		
52	6.196±0.008		6.20±0.1

[a] See reference 4.
[b] See reference 1.

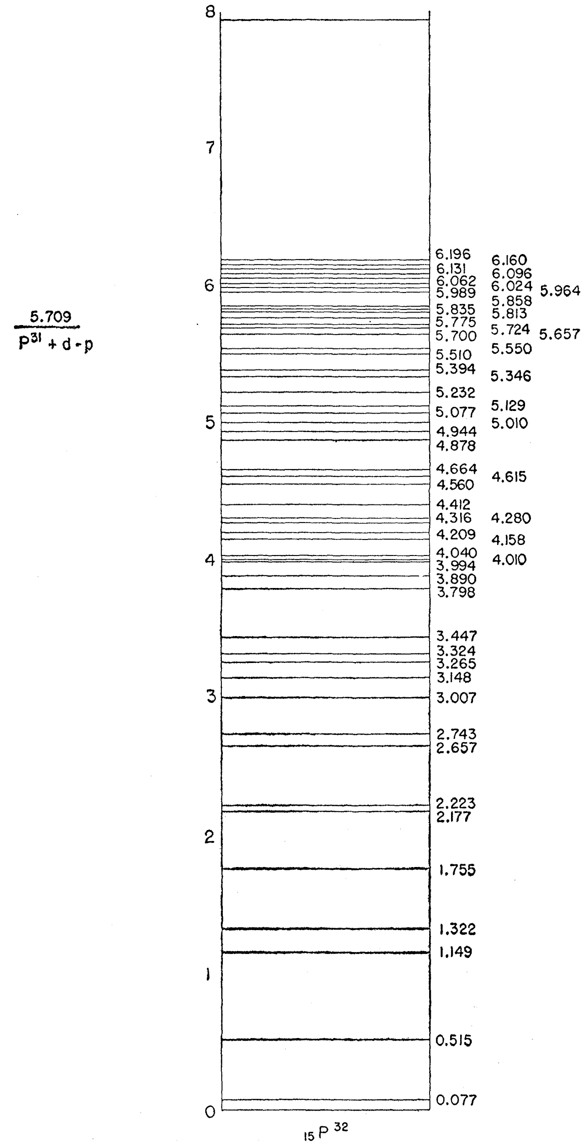

FIG. 4. Energy-level diagram for P^{32}.

placed immediately in front of the nuclear-track plates. Separate shorter exposures were made, using uncovered portions of the plates, to record elastically scattered deuterons from the targets for the purpose of determining the incident beam energy.

The results from the 50-degree exposure are shown in Figs. 2 and 3. It will be noted that the data in Fig. 3 are plotted to a more expanded scale than is the case for Fig. 2. The results from the other exposures were similar except for the relative positions of the groups from phosphorus and those from the various nuclei present as contaminants on the target. A number of low-intensity groups can be seen in Fig. 2. Other investigations in this laboratory have shown that these can be attributed to the (d,p) reaction of the isotopes of silver.

The most troublesome contaminant groups were those from the $Na^{23}(d,p)Na^{24}$ reaction. Twenty of the observed proton groups were assigned to this reaction on the basis of their shift in energy with angle of observation and the correspondence of their Q values calculated on this assumption with those measured for sodium in a previous investigation in this laboratory.[6] The Q value for the ground-state group from the $Na^{23}(d,p)$ reaction was measured as 4.731±0.010 Mev, in exact agreement with the previous figure. The Q values for the other

[6] A. Sperduto and W. W. Buechner, Phys. Rev. 88, 574 (1952).

groups identified as arising from sodium were also in excellent agreement, and in no case did the difference between the results of the present investigation and those from the previous work differ by more than 6 kev. It is interesting to note that, although this previous study was carried out using an incident deuteron energy of 2 Mev, the present work, using much higher deuteron energies, did not disclose any additional excited states in Na^{24} between its ground state and 4.5-Mev excitation energy. In the present investigation, levels in Na^{24} up to an excitation energy of approximately 5 Mev might have been detected. No evidence was found for states in this region above 4.5 Mev, although it is quite possible that low-intensity groups associated with sodium might have been obscured by the high density of intense groups from phosphorus.

The Q value measured for the $P^{31}(d,p)P^{32}$ reaction was 5.709±0.010 Mev. This is in good agreement with the value of 5.704±0.008 Mev reported previously.[4] As in the previous work, the $B\rho$ value for the polonium alpha particles used for calibration purposes was assumed to be 331.59 kilogauss-centimeters. The energies of the excited states in P^{32} as determined in the present investigation are listed in Table I where they are compared with our earlier results and those of Dalton et al.[1] The level tentatively measured at 3.141 Mev in the other work is confirmed, and several new levels have been found in the region of excitation which was previously obscured by contaminant groups. It appears that several of the proton groups whose angular distributions were measured by previous investigators probably consisted of several unresolved components. The results of the present study are summarized in Fig. 4 which shows an energy-level diagram for P^{32}.

It is probable that the first excited state and the ground state of P^{32} have spins of 2 and 1, respectively. The relative intensities of these related states, as excited in this reaction, would then be expected to be in the ratio of $2J+1$, or 1.67. The experimentally determined ratios were found to be 1.61 at 30 degrees; 1.52 at 50 degrees; 1.44 at 70 degrees; and 1.41 at 90 degrees. In the previous work, carried out at 90 degrees, the ratios were 1.7 and 1.2 for deuteron bombarding energies of 1.8 and 2.0 Mev, respectively.

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Results of Stripping Analysis of the $Co^{59}(d,p)Co^{60}$ Reaction*†

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The MIT-ONR electrostatic generator and broad-range magnetic spectrograph have been used to investigate proton groups produced by bombarding thin cobalt targets with 6.0-Mev deuterons. The angular distributions of the twenty-eight most intense proton groups corresponding to as many levels in Co^{60} were analyzed in terms of stripping theory to determine the orbital angular momentum of the captured neutron. The Q values of the (d,p) reaction were measured for sixty levels of Co^{60}. The ground-state Q value was found to be 5.262±0.011 Mev.

I. INTRODUCTION

CHARGED-PARTICLE studies of Co^{59} by proton bombardment[1] and of Co^{60} through the $Co^{59}(d,p)Co^{60}$ reaction[2] have been done earlier at this Laboratory. The objectives of the present work have been to try to resolve an uncertainty in the ground-state Q value for the $Co^{59}(d,p)Co^{60}$ reaction, to determine more fully the excited levels of Co^{60}, and to furnish information on the angular momentum and parity of these levels through stripping analysis.

A Q value for the ground-state transition of 5.260 ±0.007 Mev can be determined by subtracting the binding energy of the deuteron from the highest energy gamma ray observed by Bartholomew and Kinsey in the $Co^{59}(n,\gamma)Co^{60}$ reaction.[3] The $Co^{59}(d,p)Co^{60}$ work of Foglesong and Foxwell[2] gave a Q value of 5.283±0.008

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