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

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Proton groups from cobalt targets bombarded with 5-Mev deuterons from the MIT-ONR electrostatic generator have been analyzed with a 180-degree focusing magnetic spectrograph. The ground-state Q value for the $Co^{59}(d,p)Co^{60}$ reaction was found to be 5.283±0.008 Mev. The 60-kev metastable state and thirty-four additional excited states were observed and their Q values measured.

I. INTRODUCTION

To date, the best information on the binding energy of the last neutron in Co^{60} and the excited states of Co^{60} is found in the (n,γ) work of Bartholomew and Kinsey.[1] However, they could not determine whether the most energetic gamma ray seen (7.486 Mev) was attributable to a transition to the ground state or to the known metastable state[2] at 58.9±0.5 kev, inasmuch as both transitions were not observed. Earlier cobalt (d,p) analyses, by Bateson and Pollard,[3] Hoesterey,[4] and Harvey,[5] had resulted in binding energies which were, in general, consistent with the results of Bartholomew and Kinsey, but were not of sufficient precision to permit a resolution of the above-mentioned indeterminancy or to make possible the construction of a definite energy-level diagram for Co^{60}.

The present work was undertaken in order to clarify the position of the ground state of Co^{60} in relation to Co^{59}, with the secondary purpose of studying the region of excitation covered in the (n,γ) work.

II. EXPERIMENTAL PROCEDURE

Platinum- and Formvar-backed cobalt targets were bombarded with magnetically analyzed deuteron beams from the MIT-ONR electrostatic generator, and the protons emerging at 90 degrees to the incident beam were analyzed by a 180-degree focusing, 35-cm radius, magnetic spectrograph and photographically detected. This installation and the details of the experimental technique have been described in a recent paper.[6]

The targets were made by vacuum evaporating cobalt pellets onto thin Formvar films and clean platinum sheets. The high boiling point of cobalt required the use of a technique of clamping the pellets between sharpened carbon electrodes.[7] A spectrochemical analysis of the cobalt used showed impurities between 0.1 and 10 percent nickel, 0.01 and 1 percent magnesium and copper, and less than 0.1 percent of other metals. Cobalt is naturally monoisotopic.

III. RESULTS

A typical proton spectrum, obtained at a deuteron energy of 5.0 Mev, is shown in Fig. 1. The numbered

TABLE I. Q values for $Co^{59}(d,p)Co^{60}$ and excited states of Co^{60}. Excitation energy in Mev.

Group	Q value in Mev	Present work	Bartholomew and Kinsey[a]
0	5.283±0.008	0	
1	5.223±0.009	0.060±0.003	
2	4.997±0.009	0.286±0.003	0.285
3	4.838±0.009	0.445±0.003	0.445
4	4.770±0.009	0.513±0.003	0.512
5	4.726±0.009	0.557±0.005	
6	4.661±0.009	0.622±0.004	0.619
7	4.491±0.009	0.792±0.003	0.796
8	4.271±0.009	1.012±0.003	1.012
9	4.046±0.009	1.237±0.005	1.236
10	3.889±0.009	1.394±0.004	1.376
11	3.750±0.010	1.533±0.006	1.520
12	3.620±0.010	1.663±0.006	
			1.760
13	3.458±0.010	1.825±0.006	1.840
14	3.278±0.010	2.005±0.006	
15	3.218±0.010	2.065±0.006	
16	3.129±0.010	2.154±0.006	2.135
17	2.988±0.010	2.295±0.006	2.307
18	2.913±0.015	2.370±0.013	
19	2.673±0.010	2.610±0.006	2.583
20	2.659±0.010	2.624±0.006	
21	2.497±0.012	2.786±0.009	
22	2.413±0.015	2.870±0.013	
23	2.359±0.012	2.924±0.009	2.90
24	2.245±0.012	3.038±0.009	
25	2.163±0.012	3.120±0.009	3.12
26	2.145±0.012	3.138±0.009	
27	2.075±0.012	3.208±0.009	
28	1.995±0.012	3.288±0.009	
29	1.979±0.012	3.304±0.009	3.30
			3.46
			3.80
			4.13
30	1.062±0.012	4.221±0.009	
31	0.981±0.013	4.302±0.010	
32	0.862±0.013	4.421±0.010	
33	0.789±0.015	4.494±0.013	
34	0.750±0.015	4.533±0.013	
35	0.712±0.015	4.571±0.013	

[a] See reference 1.

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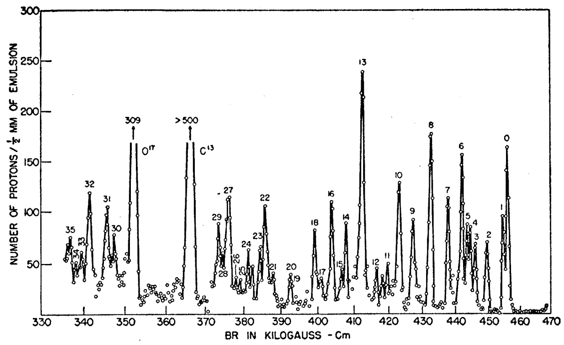

FIG. 1. Typical proton spectrum from a solid-backed cobalt target bombarded with 5-Mev deuterons. The ground-state groups from the $O^{16}(d,p)O^{17}$ and $C^{12}(d,p)C^{13}$ reactions are labeled with the residual nucleus. The numbered groups are presumed to arise from the $Co^{59}(d,p)Co^{60}$ reaction.

peaks were assigned to cobalt primarily on the basis of the reproducibility of the Q values calculated on this assumption as the bombarding energy was changed from 5.0 to 5.8 Mev. For each of the numbered peaks, the Q values thus obtained agreed to within 10 kev. Actually, this is equivalent to stating that the mass of the target nucleus responsible for any peak lies between 50 and 80. However, since the spectrochemical analysis showed that in this range of masses the only impurities present were small amounts of nickel and copper and since there was no evidence for any groups which correspond to known levels in these nuclei, it is probable that the assignment of these groups is correct. It is also probable that some of the weaker groups from cobalt have not been detected in these experiments.

The Q values for these groups are listed in Table I, together with the corresponding energies of excitation in Co^{60}. The ground-state Q value is based on three separate observations, at different bombarding energies, which agreed to within 3 kev. The energy of the first excited state in Co^{60} was determined from these observations to be 60 ± 3 kev, in excellent agreement with the value 58.9 ± 0.5 kev found by Caldwell[2] for the metastable level.

Also included in Table I are the energies obtained for certain of the excited states in Co^{60} calculated on the assumption that each of the gamma rays observed by Bartholomew and Kinsey originated in a transition direct from the capturing state to the state in question, and that this highest-energy gamma ray is associated with a transition direct to the ground state. It is seen that there is generally good agreement between the two sets of values, the only serious discrepancy being in the region between groups 29 and 30, where it is possible that the assumption regarding the gamma-ray assignments is incorrect or that weak groups might have been missed in the present work because of background from the carbon and oxygen groups. In view of this agreement, it is surprising that the Q value for the $Co^{59}(d,p)Co^{60}$ reaction, derived by subtracting the deuteron-binding energy from the value for the most energetic gamma ray, is 5.260 ± 0.007 Mev, which differs by 23 kev from the present measurement.

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