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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[1] M. Mazari, A. Sperduto, and W. W. Buechner, Phys. Rev. **107**, 365 (1957).

[2] G. M. Foglesong and D. G. Foxwell, Phys. Rev. **96**, 1001 (1954).

[3] G. A. Bartholomew and B. B. Kinsey, Phys. Rev. **89**, 386 (1953).

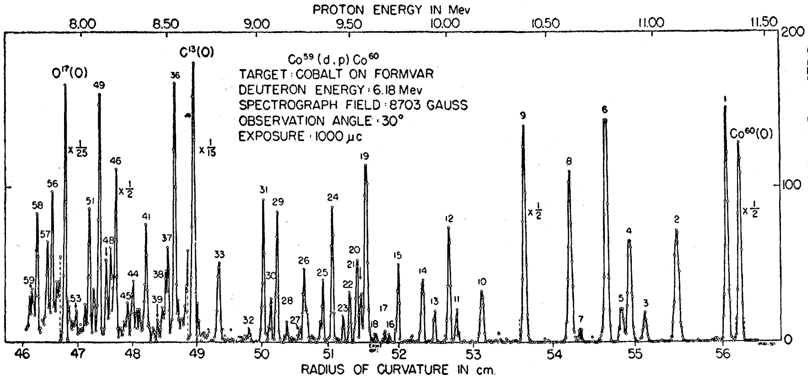

FIG. 1. Spectrum of protons emitted from a cobalt-on-Formvar target bombarded with 6.18-Mev deuterons. Observation angle $\theta_{\text{lab}}=30°$.

Mev, differing by 23 kev from the value determined by the (n,γ) measurements. The present work attempts to resolve this discrepancy.

On the basis of the shell model, ${}_{27}Co^{59}$ is assumed to have a single hole in the proton $1f_{7/2}$ shell, but the positions of the four neutrons above the $1f_{7/2}$ shell are somewhat in doubt. The states $2p_{3/2}$ and $1f_{5/2}$ lie very close together.[4] The experimental magnetic moments[5–7] of Co^{58} and Co^{60}, compared with the calculated magnetic moments,[4] seem to indicate assignments of the thirty-first neutron in the Co^{58} ground state to the $f_{5/2}$ level and the thirty-third neutron in the Co^{60} ground state to the $p_{3/2}$ level.

The spin of the Co^{60} ground state has been determined by Dobrowolski et al.[6] as $I=5$ by paramagnetic resonance hfs measurements. Beta decay and gamma-ray data[8–10] establish the spins and parity of the ground state and first excited state (metastable state at 59 kev) as $I=5^+$ and 2^+, respectively.

II. EQUIPMENT AND PROCEDURE

The experimental arrangements at the MIT-ONR electrostatic generator have been described by Buechner et al.[11] The broad-range spectrograph has been described by Browne and Buechner.[12] Certain details of the techniques adopted when these facilities are being used for an angular-distribution measurement have been discussed in a paper by Bockelman et al.[13] Briefly, protons emerging from the deuteron bombarded target were deflected in the magnetic field of the spectrograph and focused on Eastman Kodak NTA 25-micron nuclear-track plates. The positions of the proton tracks on the plates determined the radii of curvature of the particle orbits in the magnetic field.[12] The proton momentum spectrum was determined by counting the number of tracks within each half-millimeter strip across the plate. To facilitate plate reading, the emulsions were covered with aluminum foil during exposure to prevent charged particles heavier than protons from reaching the plates.

Deuterons with energies of 6.01 Mev were employed. By mistake the exposures at some angles were made with 6.18-Mev deuterons. It is assumed that this change in input energy has a negligible effect on the angular distributions. The targets used were prepared by vacuum evaporation onto a thin Formvar film of naturally monoisotopic Co^{59} in the form of cobalt sponge obtained from Johnson, Matthey and Company, London. A mass analysis obtained by observation in the spectrograph of protons elastically scattered from a target indicated the presence of large amounts of tungsten from the evaporator crucible and carbon and oxygen from the Formvar backing. Small amounts of sodium and chlorine were also present, but no proton groups could be found that could be ascribed to these latter elements in the (d,p) spectra. Since the targets were quite fragile, a total of five targets from two different evaporations were used during the total of 90 hours' exposure time.

III. RESULTS

Data were taken at 5-degree intervals for reaction angles between 10 and 60 degrees and at 10-degree intervals between 70 and 110 degrees. Most exposures were 500 microcoulombs in duration, but because of low yield, some were made longer. All results were normalized to 500 microcoulombs and the same target thickness. The result of a typical exposure is shown in Fig. 1. Because of the presence of the intense proton peaks from (d,p) reactions on carbon and oxygen in the target, some levels in Co^{60} could not be observed at all angles. For instance, levels (34) and (35) of Co^{60} are

[4] M. G. Mayer and H. Hans D. Jensen, *Elementary Theory of Nuclear Shell Structure* (John Wiley & Sons, New York, 1955).
[5] H. E. Walchli, Oak Ridge National Laboratory Report ORNL-1469, 1953 (unpublished) quoted in Mayer and Jensen, reference 4.
[6] W. Dobrowolski, R. V. Jones, and C. D. Jeffries, Phys. Rev. **101**, 1001 (1956).
[7] J. C. Wheatley, W. J. Huiskamp, A. N. Diddens, M. J. Steenland, and H. A. Tolhoek, Physica **21**, 841 (1955).
[8] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[9] M. Deutsch and G. Scharff-Goldhaber, Phys. Rev. **83**, 1059 (L) (1951).
[10] J. L. Wolfson, Can. J. Phys. **34**, 256 (1956).
[11] W. W. Buechner, A. Sperduto, C. P. Browne, and C. K. Bockelman, Phys. Rev. **91**, 1502 (1953).
[12] C. P. Browne and W. W. Buechner, Rev. Sci. Instr. **27**, 899 (1956).
[13] C. K. Bockelman, C. M. Braams, C. P. Browne, R. D. Sharp, and A. Sperduto, Phys. Rev. **107**, 176 (1057).

obscured in Fig. 1. However, because of the difference in mass, the contaminant peaks cover at other angles different parts of the spectrum, and the shift is sufficiently large so that no cobalt level was obscured at more than two angles.

The Q values were computed from four exposures at different angles. This insured at least three separate Q value determinations for each level, with but one exception, level (54). The average Q value and excitation energy for the ground level and fifty-nine excited levels are given in Table I. A separate series of computations for the ground level at twelve different angles gave as an average the result shown in the table with a standard random deviation of less than 2 kev. A total standard uncertainty of 11 kev is assigned to all Q values. This error figure is due largely to various systematic uncertainties in the proton and deuteron energies. The uncertainty in the employed $B\rho$ value (331.59 kilogauss-cm) for polonium alpha particles has been discussed in an earlier paper.[14]

When plotted to a larger scale, several peaks in Fig. 1 have half-widths greater than normal, or they display structure. When this is seen at all angles of observation, contaminant elements may be ruled out as the cause, and it is possible that the peaks represent closely spaced doublets. The Q values given apply then to the member of the doublet with the highest proton energy (lowest excitation energy) with errors possibly slightly higher than 9 kev. The following peak numbers represent suspected doublets: (2), (10), (19), and (25), with (19) being the largest and having the most consistent structure.

The agreement of the Q value for the ground-state level, 5.262 Mev, with that which is obtained from the work of Bartholomew and Kinsey, 5.260 Mev, is excellent. The Q value reported by Foglesong and Foxwell is about 20 kev higher. This difference may have been caused by an effect noted by Strait et al.,[15] who observed that, at high field strengths, the iron of the 180-degree annular magnet then used showed saturation effects and caused errors in the energy measurements. In the work of Foglesong and Foxwell, this error would indeed be about 20 kev (high) according to our estimate for the ground-state level.

A comparison with previous work for the various excited levels is also shown in Table I. Except for level numbers less than nine and level (48), the Q values given by Foglesong and Foxwell are in excellent agreement with the present work. No level was found that corresponded to a level with Q value 2.659 Mev reported by Foglesong and Foxwell. The gamma-ray energies quoted from the work of Groshev et al.[16] in Table I are assumed to represent transitions directly to the ground level. Two low-energy gamma rays at 0.454 and 0.562 Mev are not included in the table. Possibly they

[14] H. A. Enge, E. J. Irwin, Jr., and D. H. Weaner, Phys. Rev. **115**, 949 (1959).

[15] E. N. Strait, D. M. Van Patter, W. W. Buechner, and A. Sperduto, Phys. Rev. **81**, 747 (1951).

[16] L. V. Groshev, A. M. Demidov, V. N. Lutsenko, and V. I. Pelekhov, Atomnaya Energ. **3**, 187 (1957).

TABLE I. $Co^{59}(d,p)Co^{60}$ Q values and excitation energies.

Peak number	Present work: Q value (Mev) ±0.011	Present work: E_x (Mev) ±0.006	Q value[a] (Mev) ±0.012	E_x (Mev)[a] ±0.009	E_x (Mev)[b]	E_x (Mev)[c]
Ground	5.262	0	5.283	0		
(1)	5.204	0.058	5.223	0.060		
(2)	4.980	0.282	4.997	0.285	0.290	0.285
(3)	4.830	0.432	4.838	0.445		0.445
(4)	4.761	0.501	4.770	0.513	0.511	0.512
(5)	4.721	0.541	4.726	0.557		
(6)	4.650	0.612	4.661	0.622	0.562	0.619
(7)	4.524	0.738			0.735	
(8)	4.479	0.783	4.491	0.792	0.80	0.796
(9)	4.256	1.006	4.271	1.012		1.012
(10)	4.055	1.207	4.046	1.237	1.25	1.236
(11)	3.925	1.337				
(12)	3.885	1.377	3.889	1.394		1.376
(13)	3.815	1.447				
(14)	3.750	1.512	3.750	1.533	1.520	1.520
(15)	3.624	1.638	3.620	1.663	(1.60)	
(16)	3.578	1.684			1.69	
(17)	3.555	1.707				
(18)	3.514	1.748				1.760
(19)	3.463	1.799	3.458	1.825	1.78	
(20)	3.433	1.829			1.84	1.840
(21)	3.412	1.850				
(22)	3.375	1.887				
(23)	3.339	1.923				
(24)	3.283	1.979	3.278	2.005		
(25)	3.231	2.031	3.218	2.065	2.03	
(26)	3.131	2.131	3.129	2.154		2.135
(27)	3.112	2.150				
(28)	3.045	2.217			2.20	
(29)	2.988	2.274	2.988	2.295		
(30)	2.952	2.310			2.30	2.307
(31)	2.914	2.348	2.913	2.370		
(32)	2.835	2.427				
(33)	2.671	2.591	2.673	2.610	2.59	2.583
			2.659	2.624		
(34)	2.528	2.734				
(35)	2.500	2.762	2.497	2.786		
(36)	2.417	2.845	2.413	2.870		
(37)	2.378	2.884			2.88	
(38)	2.363	2.899	2.359	2.924		2.90
(39)	2.320	2.942				
(40)	2.295	2.967				
(41)	2.252	3.010	2.245	3.038		
(42)	2.214	3.048				
(43)	2.197	3.065				
(44)	2.176	3.086	2.163	3.120		
(45)	2.147	3.115	2.145	3.138		3.12
(46)	2.077	3.185	2.075	3.208		
(47)	2.047	3.215			3.21	
(48)	2.024	3.238	1.995	3.288		
(49)	1.978	3.284	1.979	3.304		
(50)	1.948	3.314				3.30
(51)	1.923	3.339			3.35	
(52)	1.895	3.367				3.36
(53)	1.843	3.419				
(54)	(1.798)	(3.464)				3.46
(55)	1.764	3.498				
(56)	1.698	3.564				
(57)	1.671	3.591			3.60	
(58)	1.609	3.653				
(59)	1.580	3.682				3.69

[a] See reference 2.
[b] L. V. Groshev, A. M. Demidov, V. N. Lutsenko, and V. I. Pelekhov, Atomnaya Energ. **3**, 187 (1957).
[c] See reference 3.

represent transitions from levels (4) and (6) to level (1). Two gamma rays at 3.36 and 3.69 Mev, observed by Bartholomew and Kinsey,[3] possibly also arise from transitions from excited states to the ground state. The other excitation energies quoted in the last column are

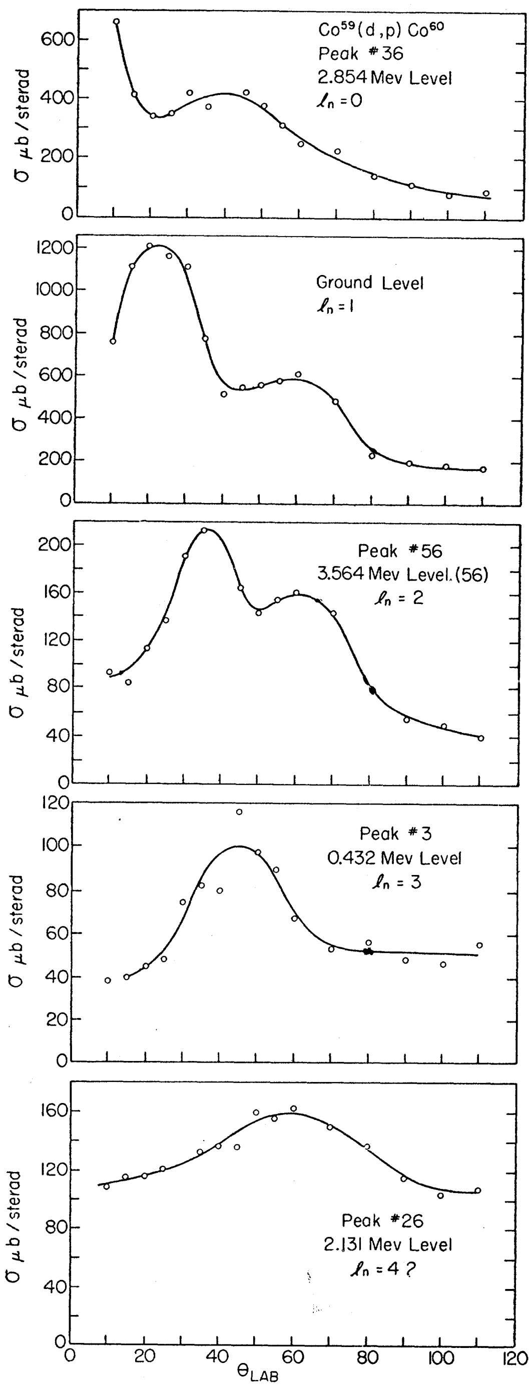

FIG. 2. Examples of experimental angular distributions of protons with the l_n value of the captured neutrons as indicated on each individual graph. The curves are smooth experimental curves, not theoretical ones.

computed on the assumption that the gamma rays observed represent transitions directly from the capture state to the excited state in question.

Figure 2 shows some examples of the experimental angular distributions. The cross section in microbarns per steradian was obtained by using a conversion factor equal to 1.31 μb/steradian per proton track. This is based on the known solid angle used for the spectrograph, 3.55×10^{-4} steradian, and a target thickness of approximately 7.9×10^{17} cobalt atom/cm^2, determined by an alpha-particle thickness gauge[17] and by Rutherford scattering at 3 Mev.

The angular-distribution curves have been compared with theoretical stripping curves calculated with the aid of the tables prepared by Enge and Graue,[18] based on the stripping theory as presented by Friedman and Tobocman.[19] Peaks in the angular distribution centered around 0, 23, 35, and 45 degrees have been recognized as arising from $l_n=0$, 1, 2, and 3 stripping, respectively. Level (26) in Fig. 2 has a maximum cross section at 60 degrees, suggesting $l_n=4$ stripping. A compromise value for the nuclear radius $R=6\times10^{-13}$ cm produces maxima in the theoretical distribution approximately at said angles. The stripping analysis further yields a value of $(2J+1)\gamma$ where J is the spin of the produced nuclear level and γ is its reduced width. The value for γ hereby obtained actually only resembles the reduced width for single-particle levels, and it is well known that for these levels the values obtained from stripping analyses are too small. The peak cross section, the cross section at 100–110 degrees (back angle), the l_n value, and the value of $(2J+1)\gamma$ are presented in Table II. Many of the levels that have not been assigned an l_n value appear to have forward peaking, indicating a stripping process. However, the experimental uncertainties are too large to determine the true positions of the maxima in these cases, partly because of low yield and partly because of interference by more intense Co^{60} or contaminant peaks in the spectrum.

The secondary maxima in the experimental angular distributions are much larger than in the theoretical distributions. At first it was thought that these secondary maxima indicated admixtures of higher l_n value stripping. In most cases this is probably not so. For instance, the secondary maximum in the angular distribution for the $l_n=1$ ground state (Fig. 2) is not in the same position as the $l_n=3$ peak [level (3)]. Another argument is that recent work in this Laboratory shows that also in cases where higher l_n value mixing is forbidden, the secondary maxima are large. A third argument is that the ratio of amplitudes of the two maxima stays reasonably constant for the majority of

[17] H. A. Enge, M. Wahlig, and I. Aanderaa, Rev. Sci. Instr. **28**, 145 (1956).
[18] H. A. Enge and A. Graue, Univ. i Bergen, Årbok Naturvitenskap Rekke No. 13 (1955); and Rev. Sci. Instr. **27**, 1078 (1956).
[19] F. L. Friedman and W. L. Tobocman, Phys. Rev. **92**, 93 (1953).

TABLE II. Excitation energies, maximum and back-angle cross sections, l_n and γ values for the states of Co^{60} formed through the $Co^{59}(d,p)Co^{60}$ reaction.

Peak number	E_x (Mev)	Max cross section μb/sr (lab)	Back-angle cross section μb/sr (lab)	θ_{opt} degrees (lab)	l_n	$2(J+1)\gamma$ (kev) for $R=6\times10^{13}$ cm	Remarks
Ground	0	1200	177	23	1	55	
(1)	0.058	720	94	23	1	33	
(2)	0.282	477	87	23	1, (3)	21	(Double)
(3)	0.432	108	50	46	3	27	$(I=1^+)$
(4)	0.501	375	57	23	1	17	
(5)	0.541	107	39	45	3	32	$(I=2^+)$
(6)	0.612	710	114	24	1	31	
(7)	0.738	35	21				Poor statistics
(8)	0.738	525	84	23	1	22	
(9)	1.006	1130	180	25	1, (3)	47	
(10)	1.207	136	55		(1, 3)	6	Poor statistics (double)
(11)	1.337	40	11				Poor statistics
(12)	1.377	235	108	29	(1, 3)	9	
(13)	1.447	54	11				Poor statistics
(14)	1.512	145	26	25	1	6	
(15)	1.638	100	26				
(16)	1.684	13					Very weak
(17)	1.707	13					Very weak
(18)	1.748	20					Weak
(19)	1.799	460	196	46	3	125	Double
(20)	1.829	88					
(21)	1.850	156	26	27	1	5	
(22)	1.887	91		(25)	(1)	3	
(23)	1.923	52					
(24)	1.979	220	71	45	3	57	
(25)	2.031	90	26	25	1	3	Double
(26)	2.131	160	110	58	(4)	86	
(27)	2.150	13					Very weak
(28)	2.217	19					
(29)	2.274	203	32	26	1 (3)	7	
(30)	2.310	57					
(31)	2.348	188	50	45	3	49	
(32)	2.427	15					Very weak
(33)	2.591	150	50				
(34)	2.734	87					
(35)	2.762	214	30	27	1	6	
(36)	2.854	663	73	0^+	0	7	Interference from C^{13}
(37)	2.884	109					ground state
(38)	2.899	85					
(39)	2.942	24					
(40)	2.967	24					
(41)	3.010	281	54	0^+	0	3	
(42)	3.048	60					
(43)	3.065	48					Not well resolved.
(44)	3.086	83					Possibly more levels
(45)	3.115	60					
(46)	3.185	885	118	0^+	0	9	
(47)	3.215	130					Poor statistics
(48)	3.238	206	47	0^+	0	2	
(49)	3.284	410	88	0^+	(0, 2)	4	
(50)	3.314	53					Poor statistics
(51)	3.339	253	58	0^+	(0, 2)	3	
(52)	3.367	53					
(53)	3.419	23					
(54)	3.464	47					
(55)	3.498	82					Interference from O^{17}
(56)	3.564	212	40	35	2	20	ground state
(57)	3.591	237	51	0^+	0	3	
(58)	3.653	171	46				
(59)	3.682	80	23				

the levels. Only in cases where the relative secondary maximum in an $l_n=1$ curve is higher than usual and also displaced so as to line up better with the pure $l_n=3$ peak, is an $l_n=3$ contribution assumed (Table II). In this connection, it should be noted that the maximum cross section for one and the same value of γ drops off very rapidly with increasing l_n value. The ratio between the calculated $l_n=1$ and $l_n=3$ cross sections in the present work is about 7. For an $l_n=3$ contribution to be detectable under the present circumstances, the final state would have to be at least a one-to-one mixture of f state into the p state,

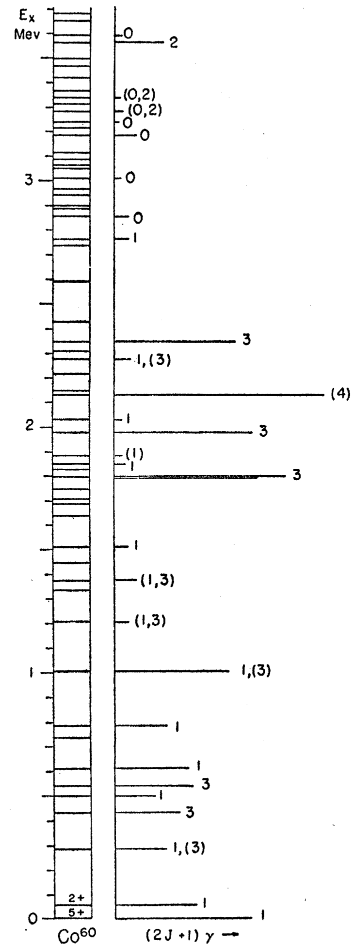

FIG. 3. Energy-level diagram of Co^{60} with relative stripping amplitudes shown to the right. The numbers beside the lines are the assigned l_n values.

IV. DISCUSSION

The target nucleus, Co^{59}, has spin and parity $\frac{7}{2}^-$. The spin assignments for the levels with $l_n=0$, 1, 2, 3, and 4 stripping are therefore, respectively, 3^- and 4^-, 2^+ to 5^+, 1^- to 6^-, 0^+ to 7^+, and finally 0^- to 8^- for $l_n=4$. Not all of these spin values are equally probable. Especially are the "strong" $l_n=3$ levels not likely to have spin 0 or 7, since this would involve capturing the neutron in the $f_{7/2}$ subshell. This is presumably already filled. Proton spin flip is not likely either for the levels with large stripping cross sections.

It is interesting to compare the results of this work with the results of the stripping analysis of the $Ni^{60}(d,p)Ni^{61}$ reaction.[20] The difference between the two residual nuclei is that in Ni^{61} the proton $f_{7/2}$ shell is filled; in Co^{59} one proton is removed from this shell. In Ni^{61} the ground state is formed by $l_n=1$ stripping. The state is presumably a $p_{3/2}$ state. There is also a strong $l_n=1$ state at 0.28 Mev and some weaker ones around 1 and 2 Mev. Corresponding to each of these Ni^{61} levels, one might hope to find multiplets in Co^{60}, for example, four $(f_{7/2})^{-1}p_{3/2}$ states with spin 2^+, 3^+, 4^+, and 5^+. The two strong p states in Ni^{61} should then appear in Co^{60} as two multiplets with a total of eight or six states, depending upon whether the 0.28-Mev state also is $p_{3/2}$ (most likely) or $p_{1/2}$. There are seven p states of comparable intensity listed in Table II. Of these states, level (2) is almost certainly a doublet, but one of the members is rather weak. It is fruitless to do any more speculation about the structure of these levels before exact spin assignments have been made. Because of the large number of states involved, the relative-intensity rule (factor $2J+1$) used with some success earlier[14] is not of much help in this case.

In Ni^{61} only one level (at 65 kev) was found with strong $l_n=3$ stripping contribution. In Co^{60} one should hope to find six corresponding levels, that is, members of the $(f_{7/2})^{-1}(f_{5/2})$ multiplet. Table II shows that there are six levels [since No. (19) is a doublet] with pure or almost pure $l_n=3$ stripping. The excitation energies range from 0.43 to 2.35 Mev. If these levels are indeed the members of the $(f_{7/2})^{-1}(f_{5/2})$ multiplet, they should have spin values $J=1^+$ to 6^+, and the relative values of $(2J+1)\gamma$ would be expected to be determined mostly by the factor[21] $(2J+1)$. The level with the lowest intensity and, hence, presumably the lowest spin value is No. (3), the $l_n=3$ state with the lowest energy. This agrees with Nordheim's "strong rule" predicting the $f_{7/2}$ proton and the $f_{5/2}$ neutron to couple antiparallel in the lowest state.

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[20] R. A. Fisher and H. A. Enge, Bull. Am. Phys. Soc. 4, 287 (1959).

[21] Previous results tend to indicate that the relative intensities of the members of a multiplet increase with spin somewhat slower than the theoretical factor $2J+1$.