Analysis of the $T_<$ States in ^{55}Co†

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Previous data from the ^{54}Fe(^{3}He, d)^{55}Co reaction are reanalyzed. Deuteron groups corresponding to low-lying states in ^{55}Co and having $l_p=1$ are identified as $T_<$ states and their existence is explained. States at 3.327- and 4.185-MeV excitation in ^{55}Co are analyzed and found to contain a large percentage of the missing $l_p=3$ strength of the $T_<$ states. Spectroscopic factors are extracted and the strength of the isobaric spin-dependent potential is calculated.

INTRODUCTION

In a recent paper, we examined the formation of $T=T_z$ states via the (^{3}He, d) reaction on ^{89}Y.[1] This work has led us to reconsider previously published (^{3}He, d) data[2] in the light of the success of the simple model used to describe the antianalog states in ^{90}Zr, and their mixing with "core-polarization" states. The previous application[2] of a shell-model interpretation to the low-lying states of ^{55}Co populated through the ^{54}Fe(^{3}He, d) reaction was not extended to the higher states. Specifically, there are a number of $\frac{1}{2}^-$ and $\frac{3}{2}^-$ low-lying states in ^{55}Co which were not understood. The predictions based on Ref. 1 are also noticeably in disagreement with the previous results[2] in the complete absence of observed $l_p=3$ transitions below the $\frac{5}{2}^-$ isobaric analog state identified at 5.76-MeV excitation. The same (^{3}He, d) reaction was also previously investigated by Armstrong and Blair[3] with a resolution of 100–120 keV full width at half-maximum (FWHM). In their analysis, two of the angular distributions of the deuteron groups were analyzed as an admixture of $l_p=1$ and $l_p=3$. This paper considers the states resulting from a reanalysis of the data of Ref. 2 as antianalog states. From this point of view, the existence of the $l_p=3$ low-lying states, as found in Ref. 3, is justified, as well as the appearance of a number of $p_{3/2}$ and $p_{1/2}$ states. The discussion given here will follow very closely the formalism and notation of Ref. 1.

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[1] George Vourvopoulos and J. D. Fox, Phys. Rev., this issue, **177**, 1558 (1969).

[2] Baruch Rosner and C. H. Holbrow, Phys. Rev. **154**, 1080 (1967).

[3] D. D. Armstrong and A. G. Blair, Phys. Rev. **140**, B1226 (1965).

DATA

The data previously reported[2] were reanalyzed. The results of the reanalysis of the angular distributions of the deuteron groups leading to the 3.32- and 4.18-MeV levels in ^{55}Co are shown in Fig. 1. These previously reported $l_p=1$ transitions are seen to have an appreciable $l_p=3$ admixture, and a very large fraction of the total expected $l_p=3$ strength is contained in these transitions. Table I, a revised version of Table I of Ref. 2, summarizes our present results.

DISCUSSION

The states in ^{55}Co at 4.76, 5.19, and 5.77 MeV have been identified[2] as the isobaric analogs of the ground state, the 0.417-, and 0.93-MeV states in ^{55}Fe, respectively. In pictorial form, and in the n-p formalism, the ground state of ^{55}Fe can be depicted as in Fig. 2. Its isobaric analog state in ^{55}Co is similarly depicted in Fig. 3, corresponding to the expansion[4]

$$\chi_>=(2T_0+1)^{-1/2}[\chi_{pC}+(2T_0)^{1/2}\chi_{nA}].$$

In a similar fashion, Fig. 4 represents the configuration for the antianalog state. As it can be seen, the $\chi_>$ and $\chi_<$ states have the same shell-model configuration except for a difference in sign of the χ_{nA} part and coef-

[4] D. Robson, Phys. Rev. **137**, B535 (1965).

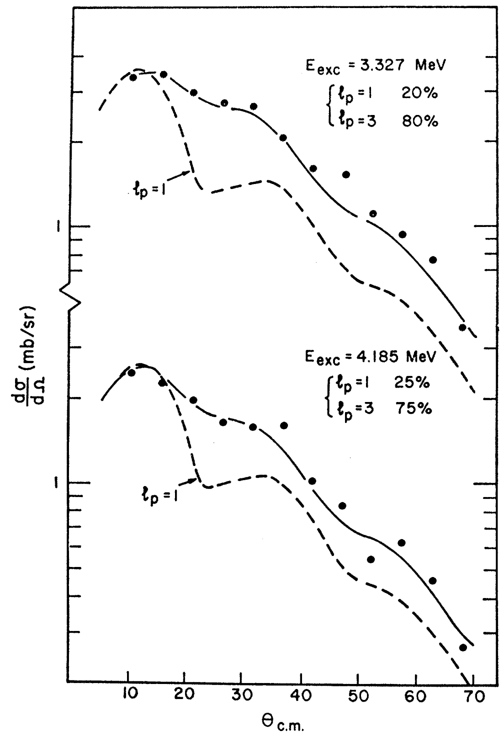

FIG. 1. Deuteron angular distributions for the 3.327- and 4.185-MeV states in ^{55}Co. Solid lines represent DWBA predictions as an admixture of $l_p=1$ and $l_p=3$.

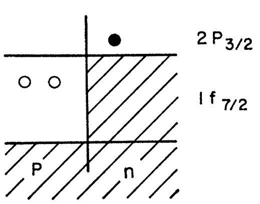

FIG. 2. Pictorial representation in the n-p formalism of the ground state of ^{55}Fe. Shaded areas indicate filled shells.

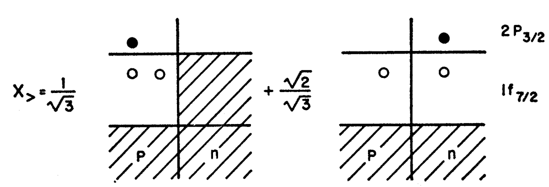

FIG. 3. Pictorial representation in the n-p formalism, of the $\frac{3}{2}^-$ $T_>$ state in ^{55}Co.

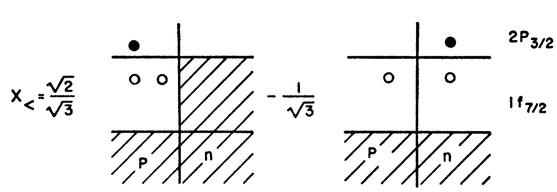

FIG. 4. Pictorial representation in the n-p formalism of the corresponding $\frac{3}{2}^-$ antianalog state in ^{55}Co.

ficients. Both states are produced in the (^{3}He, d) reaction through the $|pC\rangle$ channel, i.e., the (proton+target) channel.

Examining specifically the $|nA\rangle$ part of the antianalog state, we observe that it involves an n-p interchange, with the neutron hole and proton hole in the

TABLE I. Revised summary of experimental results obtained in the ^{54}Fe(^{3}He, d)^{55}Co reaction.

Level no.	E_x (MeV)	l_p	$(2J+1)C^2S$	$J\pi$
0	g.s	3	1.68	$\frac{7}{2}^-$
1	2.162	1	1.68	$\frac{3}{2}^-$
2	2.559	1	1.04	($\frac{1}{2}^-$)
3	2.938	1	0.46	($\frac{3}{2}^-$)
4	3.327	(20%1, 80%3)	0.66, 2.53	($\frac{3}{2}^-$), $\frac{5}{2}^-$
5	3.657	1	0.26	($\frac{3}{2}^-$)
6	3.870			
7	3.970			
8	4.185	(25%1, 75%3)	0.46, 1.33	($\frac{1}{2}^-$), $\frac{5}{2}^-$
9	4.650			
10	4.755	1	0.92	$\frac{3}{2}^-$ [a]
11	5.188	1	0.48	$\frac{1}{2}^-$ [a]
12	5.382			
13	5.566	(1)	0.30	$\frac{1}{2}^-$
14	5.670			
15	5.765	3	1.56	$\frac{5}{2}^-$ [a]
16	5.955			
17	6.037			
18	6.080	4	5.0	$\frac{9}{2}^+$
19	6.215			
20	6.277			
21	6.342			
22	6.850			($\frac{1}{2}$)[a]
23	6.928			($\frac{5}{2}$)[a]
24	7.108			

[a] Analog states.

$f_{7/2}$ shell coupling to $J_0=0$.[5] However, there is another set of states, core-polarization states, in which the hole-hole pair couples to $J_0\neq 0$. If we are considering the $\frac{3}{2}^-$ states, we calculate that there are three core-polarization states that can admix with the $T_<(J^\pi=\frac{3}{2}^-)$ state. We further calculate that all three core-polarization states can admix with the $T_<$ state considering the residual interaction to be a two-body interaction. Thus we expect a total of four $\frac{3}{2}^-$ $T=T_z$ states to be populated in the ^{54}Fe(^{3}He, d) reaction.

[5] J. B. French, Argonne National Laboratory Report No. ANL-6878, 1964, p. 181 (unpublished).

TABLE II. Spectroscopic results.

Group	$\Sigma(2J+1)C^2S$ expt.	$\Sigma(2J+1)C^2S$ theor.	$E_<$ (MeV)	$E_>-E_<$ (MeV)	V_1 (MeV)
$p_{3/2}$	3.06	2.7	2.65	2.10	120
$p_{1/2}$	1.50	1.3	3.05	2.14	107
$f_{5/2}$	3.86	4	3.62	2.14	112

Similar calculations can be performed for the $\frac{1}{2}^-$ $T_<$ state in ^{55}Co. In this case, the number of core-polarization states that can admix is one, and therefore two $J^\pi=\frac{1}{2}^-$ states are expected to appear in addition to the analog state at 5.19 MeV. For the $f_{5/2}$ case, calculations show that six $J^\pi=\frac{5}{2}^-$ states should appear.

Based on these calculations, in the analysis of the data in Ref. 2, the most conspicuous disagreement is the complete absence of $l_p=3$ transitions below the isobaric analog state at 5.76 MeV. However, an observation of the $l_p=1$ angular distributions as given in Fig. 4 of Ref. 2 shows two states at 3.327 and 4.185 MeV whose angular distributions are far different from the distorted-wave Born-approximation (DWBA) prediction. As previously mentioned, reanalysis of the angular distribution for these two states showed that they contain a large percentage of $l_p=3$ admixture. Based on this analysis and because of lack of any experimental evidence, tentative spin assignments are given in Table I. The 2.16-MeV state is again assumed to have $J^\pi=\frac{3}{2}^-$ because of its large spectroscopic factor. Since we expect four states with $J^\pi=\frac{3}{2}^-$ and two states with $J^\pi=\frac{1}{2}^-$, we assign the 2.94, 3.32, and 3.36 MeV as $\frac{3}{2}^-$ states and the 2.56 and 4.18 MeV as $\frac{1}{2}^-$ states. With these assignments there is no larger disagreement with the theoretical sum rules than the previous grouping of states,[2,3,6] with the added advantage, as seen in Table II, of having the energy difference $E_>-E_<$ the same for all three groups. Previous spin assignments[3] located the $p_{1/2}$ $T_<$ centroid approximately 1 MeV higher, which would result in a rather large discrepancy for the $p_{1/2}$ $E_>-E_<$ as compared to that of the other groups. It should be noted that in the present evaluation of the $E_<$ for the $p_{1/2}$ group we chose not to include the $p_{1/2}$ state at 5.56 MeV, since we believe that this state does not belong to the $T_<$ group studied, but to a $T_<$ group of some other higher state.

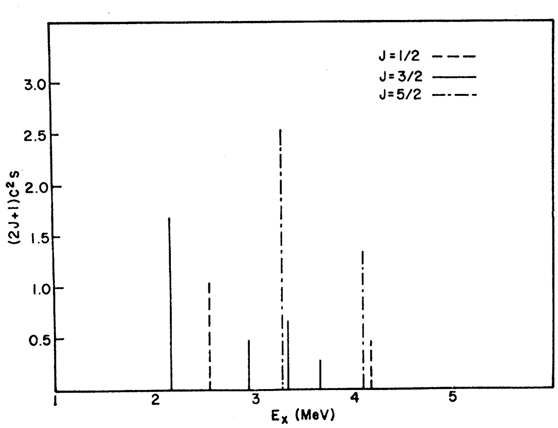

FIG. 5. Experimental $(2J+1)C^2S$ versus excitation energy. For demonstration purposes the excitation energy of the $J=\frac{5}{2}$ states has been shifted slightly lower from the actual position.

Furthermore, as can be seen in Table I, the 2.16-MeV $\frac{3}{2}^-$, 2.56-MeV $\frac{1}{2}^-$, and 3.33-MeV $\frac{5}{2}^-$ states contain a large fraction of their respective strength. It is our belief that these states are the antianalog states of the 4.75 MeV $\frac{3}{2}^-$, 5.19-MeV $\frac{1}{2}^-$, and 5.76 $\frac{5}{2}^-$ states since the energy spacing of the antianalog states is very close to the energy spacing of the analog states. In this case, one could argue that the actual position of the core-polarization states is higher than 3.33 MeV, with the result that the spreading of the $T_<$ states as a function of energy is forward peaking, as shown in Fig. 5. The present spin assignments do not contradict any criteria previously used for the spin assignments for the low-lying states in ^{55}Co. However, the best criterion would be the experimental verification of these assignments.

Concerning the number of states observed for each of the $T_<$ groups, we see that we have a good agreement between calculations and experimental results. The prediction of six $J^\pi=\frac{5}{2}^-$ states and the observance of only two of them is not a very serious disagreement, since a good percentage of the total strength is contained in these two peaks and there exist other nonidentifiable peaks between 3.6- and 5.6-MeV excitation in ^{55}Co.

Calculations were also carried out concerning the magnitude of the potential V_1 responsible for the splitting between $T_>$ and $T_<$ states. As it has been shown,[1]

$$V_>-V_<=(T_0+\tfrac{1}{2})V_1/A,$$

and the knowledge of the position of the analog states and the centroid of the $T_<$ states allows the determination of $V_>$ and $V_<$. The values of V_1 as determined from these calculations together with other pertinent spectroscopic results are contained in Table II. The values of V_1 obtained are consistent among them, but considerably lower than the values determined in Ref. 1.

ACKNOWLEDGMENT

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[6] B. J. O'Brien, W. E. Dorenbusch, T. A. Belote, and J. Rapaport, Nucl. Phys. A104, 609 (1967).