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Mean Lives and Angular Correlations in ^{57}Co with the ^{54}Fe(α, $p\gamma$)^{57}Co Reaction*

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The reaction ^{54}Fe($\alpha,p\gamma$)^{57}Co with incident α-particle energies of 9 and 10 MeV has been used to investigate the properties of ^{57}Co levels below 3 MeV in excitation. Using the Doppler-shift-attenuation method, mean lives were obtained for 11 excited levels. These results are as follows: τ(1.22 MeV) = 0.084 ± 0.018, τ(1.68 MeV) = $0.26^{+0.12}_{-0.09}$, τ(1.76 MeV) = 0.36 ± 0.07, τ(1.89 MeV) = 0.12 ± 0.03, τ(1.92 MeV) = 0.03 ± 0.02, τ(2.31 MeV) = 0.32 ± 0.09, τ(2.48 MeV) = $0.036^{+0.014}_{-0.011}$, τ(2.60 MeV) = 0.11 ± 0.03, τ(2.73 MeV) = 0.11 ± 0.03, τ(2.80 MeV) = 0.04 ± 0.02, and τ(2.87 MeV) = 0.05 ± 0.02, all in psec. In addition multipole mixing ratios were obtained for several transitions. Arguments are given for a spin assignment of $J = \frac{7}{2}$ to the 2.31-MeV level.

I. INTRODUCTION

A considerable amount of experimental and theoretical work has been done on the low-lying excited levels of ^{57}Co. Properties of the levels have been investigated by means of the nuclear reactions ^{54}Fe(α,p), ^{56}Fe(^{3}He,d), ^{56}Fe($p,\gamma\gamma$), ^{58}Ni-(^{3}H,α), ^{56}Fe(d,n), ^{58}Ni(n,d), ^{59}Co($p,^3$H), and ^{60}Ni(p,α), and by β- and γ-ray decay studies. From these investigations, spins and parities have been established for several of the levels below 3 MeV, and tentative spin assignments made for others. Also, the mean lives of two levels have previously been measured. A summary of the experimental information available on ^{57}Co has been published recently.[1] An energy-level diagram of ^{57}Co with known spins and γ transitions is shown in Fig. 1.

In contrast to other nuclei in this mass region, the energy-level structure of ^{57}Co has been difficult to explain theoretically. Both shell-model calculations[2-4] and intermediate-coupling calculations[5] have been performed to describe the energy levels of ^{57}Co. These calculations have been only partially successful in predicting the energy levels. Since only two mean lives have been measured in ^{57}Co, comparisons with transition probabilities predicted by the model calculations have not been possible.

In order to make these comparisons possible, we have measured the mean lives of 11 levels in ^{57}Co below 3 MeV, using the Doppler-shift-attenuation method. Multipole mixing ratios were also measured for selected transitions from angular-correlation measurements. The particle-γ-ray angular correlations were obtained using the collinear geometry of Litherland and Ferguson (method II).[6]

II. EXPERIMENTAL PROCEDURE

A. Doppler-Shift-Attenuation Measurements

The ^{54}Fe(α,p)^{57}Co reaction was used to produce ^{57}Co nuclei in excited states. The ^{54}Fe targets were made by evaporating 96% enriched ^{54}Fe onto a thick tantalum backing, using an electron gun and standard vacuum-evaporation techniques. The

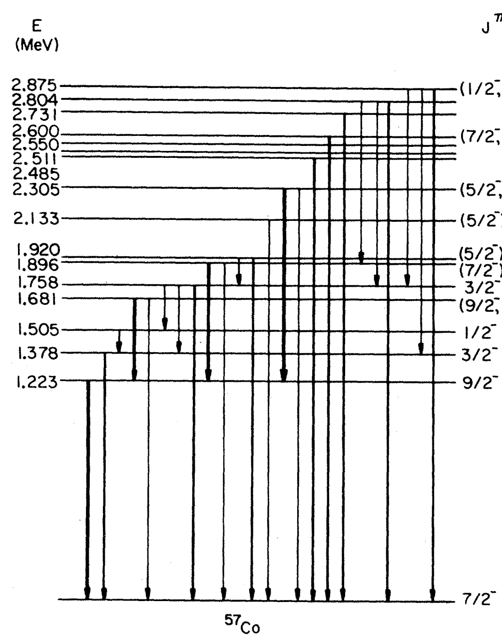

FIG. 1. Energy-level diagram for ^{57}Co. Known γ-ray decay schemes, spins, and parities for levels below 3 MeV are indicated. Studies done on each transition are shown by: heavy lines for angular correlations and Doppler shifts; medium-heavy lines for Doppler shifts; and light lines for transitions not studied. Energies are from Ref. 1.

areal density of the iron was $375 \pm 25\ \mu g/cm^2$. These targets were bombarded with 9.0- and 10.0-MeV $^4He^{++}$ ions accelerated by the University of Arizona 5.5-MV Van de Graaff accelerator.

The particle-γ coincidence version of the Doppler-shift-attenuation method was used to measure the mean lives of the levels at 1.22, 1.68, 1.76, 1.89, 1.92, 2.31, 2.48, 2.60, 2.73, 2.80, and 2.87 MeV. The experimental procedures and methods of analysis have been discussed previously.[7,8] A few points should be mentioned. In the measurements of the Doppler-shifted γ-ray energies, two ^{54}Fe targets of the same thickness were bombarded simultaneously. The experimental arrangement is shown in Fig. 2. Annular particle detectors were located in front of each target and detected reaction protons in the angular cone between 142 and 167°. The p-γ coincidence condition therefore defined a cone of forward recoiling nuclei whose γ decay was recorded. The targets were positioned so that γ rays originating in the first target and satisfying the coincidence condition were emitted at 26.5° with respect to the direction of the recoil velocity. The γ rays detected from the second target were emitted at 153.5° relative to the recoil direction. The difference in the energies of γ rays from the two targets then gave the attenuated Doppler shift $\Delta E_\gamma(\langle v\rangle)$, which depended on the average velocity $\langle v\rangle$ of the recoiling nuclei at the time of decay. To obtain the experimental attenuation factor F, given by

$$F = \Delta E_\gamma(\langle v\rangle)/\Delta E_\gamma(v_i) ,$$

the full Doppler shift $\Delta E_\gamma(v_i)$, which is the shift in energy for recoiling nuclei traveling with the full initial velocity v_i, was calculated. The calculation took into account the range of velocities of the recoiling ^{57}Co nuclei as determined by the finite size of the proton detectors and the appropriate averages over the finite size of the γ-ray detector. After the experimental attenuation factor had been obtained, theoretical attenuation factors were calculated for various values of the mean life τ. In these calculations, the stopping-power theory of Lindhard, Scharff, and Schiøtt[9] was used. Large-angle nuclear scattering was also considered by using the theory of Blaugrund[10] to calculate the velocity of the recoil ions as a function of time.

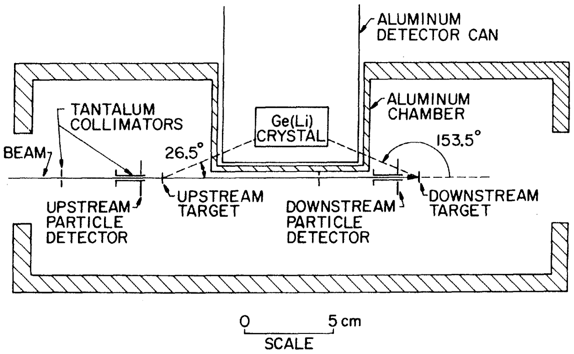

FIG. 2. Target chamber and detector arrangement for Doppler-shift-attenuation measurements.

B. Angular-Correlation Measurements

The experimental procedures used for the angular-correlation measurements have been described previously.[7] The targets used in these experiments were the same as those used in the Doppler-shift experiments, and were bombarded with 10-MeV α particles. In the p-γ coincidence measurements, protons were detected by an annular silicon surface-barrier detector which subtended angles between 175 and 164° with respect to the incident beam direction. γ rays were detected in a 7.62-cm$\times$7.62-cm NaI(Tl) detector which was 82 $\pm$ 1 mm from the target. The detector was mounted so that it could be rotated to angles between 0 and 90° relative to the incident beam, and data were taken at six angles in this range.

The theory of the angular correlations used in the analysis of the data has been given by Poletti and Warburton.[11] For the reaction $^{54}Fe(\alpha,p)^{57}Co$, the analysis is particularly simple, since by utilizing collinear geometry, the only magnetic substates populated in ^{57}Co are $m = \pm\frac{1}{2}$. With this restriction, there are no unknown population parameters in the expression for the angular correlation.

III. RESULTS

A sample proton spectrum for the reaction $^{54}Fe(\alpha,p)^{57}Co$ with 10-MeV incident α particles is shown in Fig. 3. Proton gates which were used for the coincidence measurements are indicated in this figure. Doppler-shift measurements were made on all the levels indicated on this spectrum with the exception of the level at 1.50 MeV. The experimental γ-ray spectra for the Doppler-shift measurements are shown in Figs. 4–7. The spectra at the top of each figure are γ rays detected in coincidence with protons from the upstream target at $\theta_\gamma = 26.5°$, and the spectra at the bottom are γ rays in coincidence with protons from the downstream target at $\theta_\gamma = 153.5°$. From Fig. 6 there appear to be two γ rays with energies of 2.12 and 2.13 MeV which are not well resolved. There have been previous suggestions that there is a doublet at 2.13 MeV, and our results indicate that this is possible.[12] Because of the unresolved nature of these γ rays, no mean life was determined for the known level at 2.13 MeV. Mean lives of the remainder of the levels in Fig. 3 have been deter-

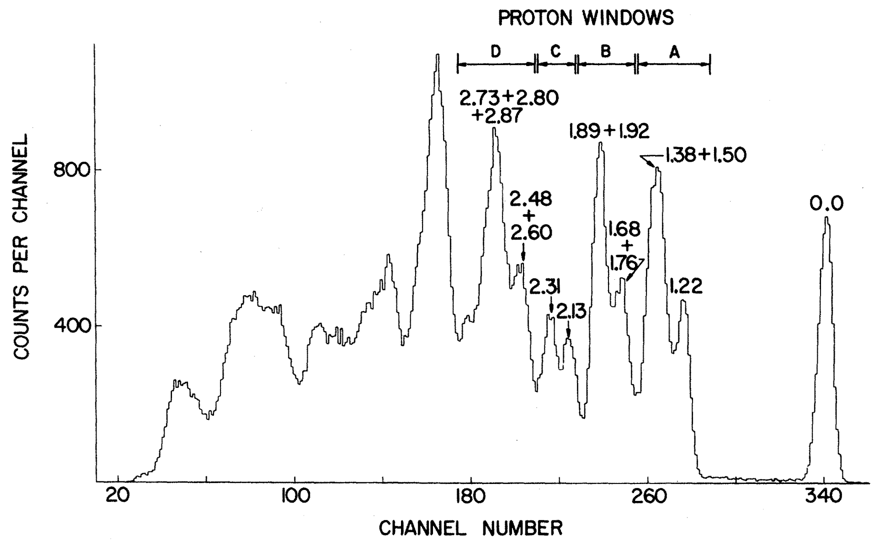

FIG. 3. Proton spectrum from the reaction $^{54}Fe(\alpha, p)^{57}Co$. The incident α-particle beam energy was 10 MeV. Proton gates used in the angular correlation and Doppler-shift experiments are labeled. The detector was covered with 0.05-mm Al foil to stop elastically scattered α particles.

mined, and the results are indicated in Table I. The mean life of the 1.38-MeV level has been previously measured as 28 ± 5 psec.[13] This is outside the range of the Doppler-shift-attenuation method as used here, and thus this γ ray appeared zero-shifted in our spectra.

Angular-correlation measurements were made for the transitions 1.22 MeV $(\frac{9}{2}^-) \to 0\ (\frac{7}{2}^-)$, 1.68 MeV $(\frac{11}{2}^-) \to 1.22$ MeV $(\frac{9}{2}^-)$, 1.89 MeV $(\frac{7}{2}^-) \to 1.22$ MeV $(\frac{9}{2}^-)$, and 2.31 MeV $(\frac{5}{2}^-, \frac{7}{2}^-) \to 1.22$ MeV $(\frac{9}{2}^-)$ to obtain multipole mixing ratios for these transitions. A sample NaI(Tl) γ-ray spectrum is shown in Fig. 8 and the results of the experiments are indicated in Table II.

Previous angular-correlation studies have been done by Dayras and Cujec[14] and by Coop, Graham, and Titterton.[15] The results of these investigations are compared with the present results in Table III. The only serious disagreement is for the transition $1.68 \to 1.22$ MeV, where the present re-

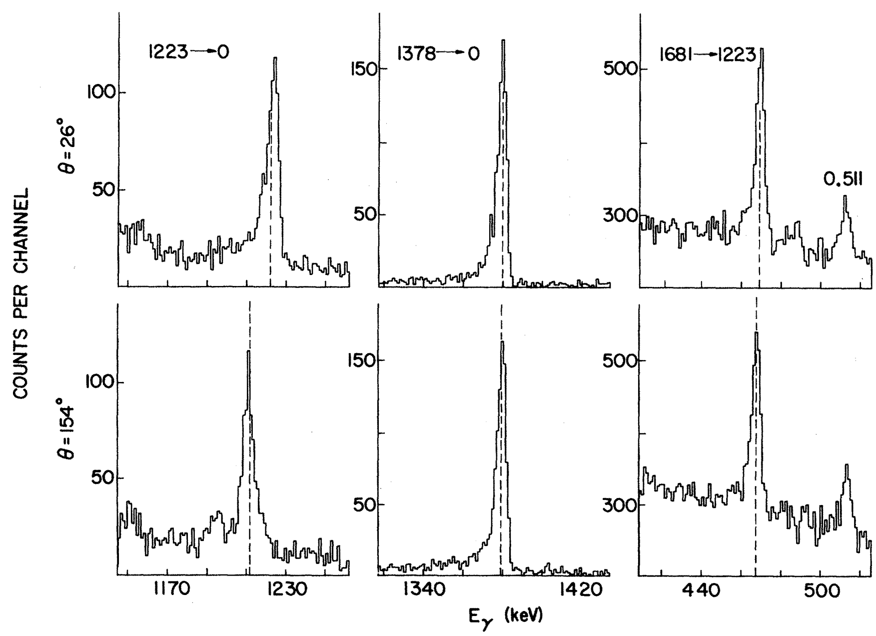

FIG. 4. Coincident γ-ray spectra for ^{57}Co showing experimentally obtained Doppler shifts. Spectra to the left and in the center were obtained using gate A; those on the right were obtained with gate B (see Fig. 3).

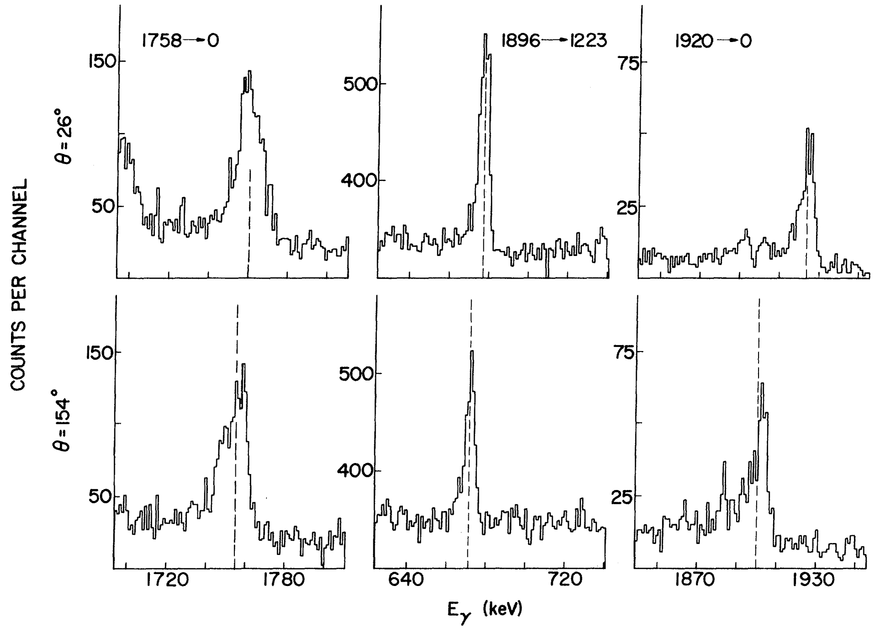

FIG. 5. Coincident γ-ray spectra for ^{57}Co showing experimental Doppler shifts obtained with proton gate B (see Fig. 3).

sult does not agree with that of Dayras and Cujec.[14]

For the decay of the 2.31-MeV level, spins of $\frac{5}{2}^-$ and $\frac{7}{2}^-$ were considered, since previous experiments have indicated that either assignment is allowed.[16,17] The angular correlations were also consistent with either spin, and the mixing ratios corresponding to each spin possibility are given in Table II. Using the measured mean lifetime $\tau = 0.32 \pm 0.09$ psec, the branching ratio for the $2.31 \rightarrow 1.22$-MeV transition of 68% obtained by Coop, Graham, and Titterton,[15] and the measured multipole mixing ratios for each spin possibility, the

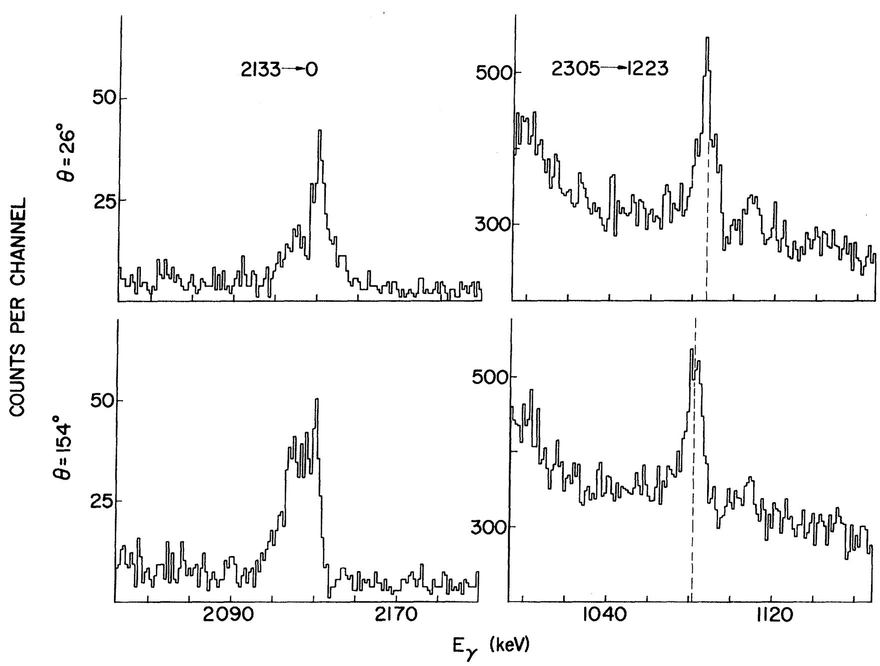

FIG. 6. Coincident γ-ray spectra for ^{57}Co showing experimental Doppler shifts obtained with proton gate C (see Fig. 3).

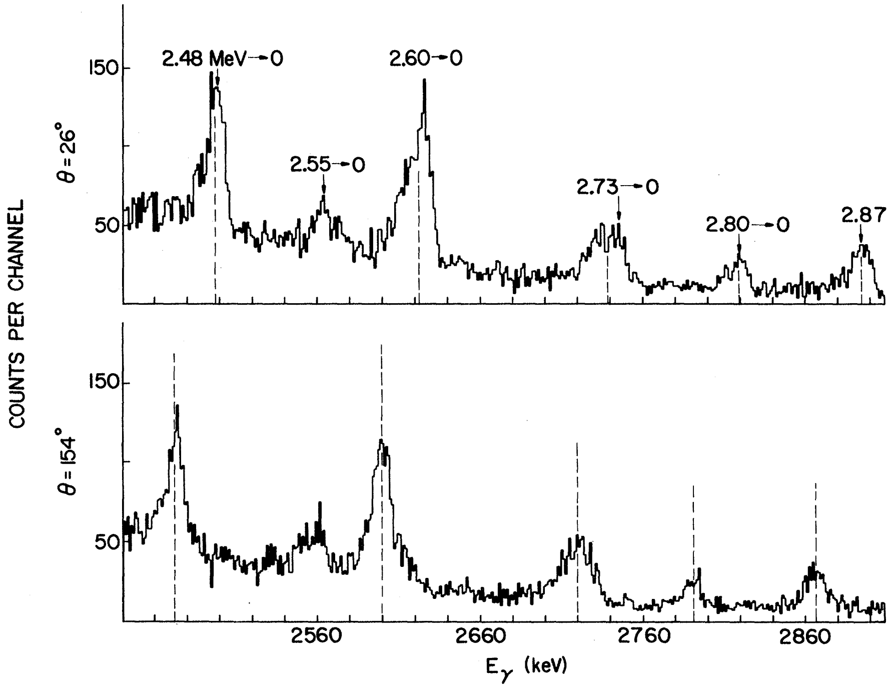

FIG. 7. Coincident γ-ray spectra for ^{57}Co showing experimental Doppler shifts obtained with proton gate D (see Fig. 3).

$E2$ and $M3$ transition probabilities were calculated for $J^\pi(2.31)=\frac{5}{2}^-$ and the $M1$ and $E2$ transition probabilities were calculated for $J^\pi(2.31)=\frac{7}{2}^-$. The spin and parity of the 1.22-MeV level were taken as $\frac{9}{2}^-$ in both cases. From these transition probabilities, the following transition strengths, in Weisskopf units,[18] were obtained:

$$B_{\text{expt}}(E2)/B_W(E2)=73\pm2\ ,$$

$$B_{\text{expt}}(M3)/B_W(M3)=(1.0\pm0.3)\times10^8\ ,$$

for $J^\pi(2.31)=\frac{5}{2}^-$, and

$$B_{\text{expt}}(M1)/B_W(M1)=0.05\pm0.02\ ,$$

$$B_{\text{expt}}(E2)/B_W(E2)=1.4\pm0.6\ ,$$

TABLE I. Doppler shifts and mean lives of levels in ^{57}Co.

Transition (MeV)	Measured[a] Doppler shift (keV)	Calculated full Doppler shift (keV)	$F(\tau)$	τ (psec)
1.22→0.0	9.84±0.26	14.32	0.687±0.018	0.084±0.018
1.38→0.0	−0.14±0.10	16.05	−0.009±0.006	>4
1.68→1.22	2.06±0.36	5.57	0.370±0.065	$0.26^{+0.12}_{-0.09}$
1.76→0.0	5.79±0.22	20.30	0.285±0.011	0.36 ±0.07
1.89→1.22	4.63±0.21	7.75	0.597±0.027	0.12 ±0.03
1.92→0.0	19.80±0.80	22.10	0.896±0.036	0.03 ±0.02
2.31→1.22	4.11±0.41	12.74	0.323±0.032	0.32 ±0.09
2.48→0.0	24.10±0.54	28.20	0.854±0.019	$0.036^{+0.014}_{-0.011}$
2.60→0.0	18.29±0.22	29.50	0.620±0.012	0.11 ±0.03
2.73→0.0	18.66±0.55	30.80	0.606±0.018	0.11 ±0.03
2.80→0.0	26.78±0.72	31.50	0.850±0.023	0.04 ±0.02
2.87→0.0	25.97±0.61	32.30	0.804±0.019	0.05 ±0.02

[a]These measured shifts were obtained with 10-MeV incident $^4He^{++}$ ions.

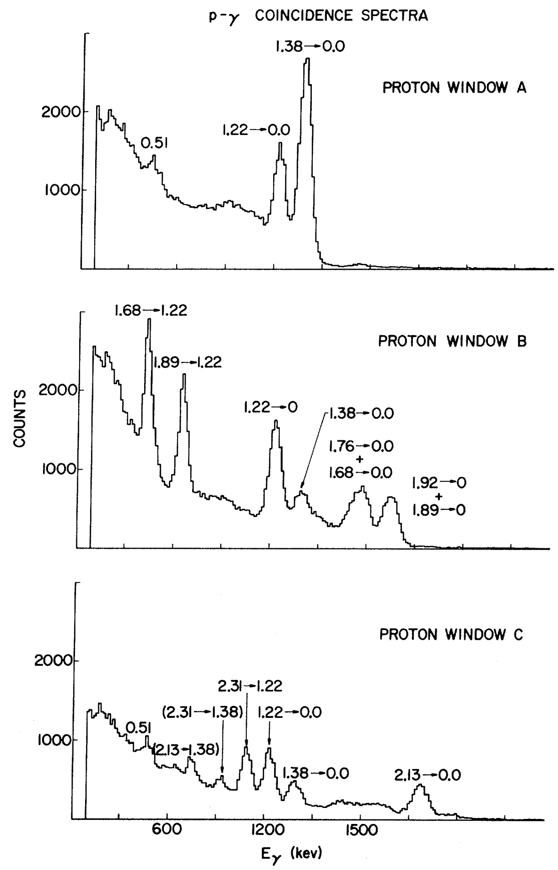

FIG. 8. ^{57}Co coincident γ-ray spectra obtained with a NaI(Tl) detector. These spectra were obtained with the detector at 50°, with an incident α-particle beam energy of 10 MeV. Proton windows are shown in Fig. 3.

for $J^\pi(2.31)=\frac{7}{2}^-$. The $M3$ transition strength for the spin-$\frac{5}{2}$ case is 7 orders of magnitude larger than observed $M3$ strengths for other nuclei in this mass region.[18] Thus we conclude that the spin of the 2.31-MeV level is $\frac{7}{2}^-$. This result is consistent with the measurements of Coop, Graham, and Titterton.[15]

IV. DISCUSSION

Early shell-model calculations performed by Vervier[2] and McGrory[3] were quite unsuccessful in predicting the observed energy levels in ^{57}Co. However, the recent calculations of Gatrousis *et al.*[4] in which the nucleons outside a closed ^{40}Ca core were allowed to occupy the $f_{7/2}$, $p_{3/2}$, $f_{5/2}$, and $p_{1/2}$ orbits had considerably more success in accounting for the observed energy levels. The predicted levels of the three calculations mentioned above are compared with the experimentally observed levels in Fig. 9. In the following discussion, we will consider only the calculation of Gatrousis *et al.*[4]

From comparison of experimental and theoretical energy levels, one finds that below 2 MeV in excitation only the 1.76-MeV level is not accounted for, and only two additional levels, with spins $\frac{9}{2}^-$ and $\frac{13}{2}^-$, are predicted. For levels above 2 MeV, the correspondence is quite difficult because the spins of only a few levels are known. The wave functions calculated by Gatrousis *et al.*[4] contain considerable configuration mixing, with no single configuration contributing more than 50% to the wave function. They point out that this collective nature of the wave functions could lead to large enhancements and retardations in the transition rates. This is qualitatively in agreement with our experimental reduced transition probabilities which are given in Table IV. We find the ground-state decays of the 1.22-, 1.68-, and the 1.76-MeV level, and the transitions to the 1.22-MeV level of the 1.68- and 2.31-MeV levels all have $E2$ strengths which are enhanced over the single-par-

TABLE II. Parameters from the angular-correlations analysis for ^{57}Co.

Transition energies (MeV)	Initial and final spins	Experimental A_2/A_0	Experimental A_4/A_0	Theoretical[a] A_2/A_0	Theoretical[a] A_4/A_0	Multipole mixing ratio δ
1.22→0	$\frac{9}{2}^- \to \frac{7}{2}^-$	0.19 ± 0.01	0.05 ± 0.01	0.19	0.03	−0.27 ± 0.01
1.68→1.22	$\frac{9}{2}^- \to \frac{9}{2}^-$	−0.11 ± 0.02	−0.01 ± 0.02	−0.05	−0.12	0.65 ± 0.04
	$\frac{11}{2}^- \to \frac{9}{2}^-$	−0.11 ± 0.02	−0.01 ± 0.02	−0.12	0.00	−0.09 ± 0.01
1.89→1.22	$\frac{7}{2}^- \to \frac{9}{2}^-$	−0.18 ± 0.02	0.02 ± 0.01	−0.19	0.00	−0.02 ± 0.01
2.31→1.22	$\frac{5}{2}^- \to \frac{9}{2}^-$	−0.32 ± 0.02	−0.07 ± 0.02	−0.32	−0.07	−0.47 ± 0.02
	$\frac{7}{2}^- \to \frac{9}{2}^-$	−0.32 ± 0.02	−0.07 ± 0.02	−0.35	0.00	−0.13 ± 0.02

[a]These coefficients were determined, for the spins indicated, using the value of δ which gave the best fit to the data.

TABLE III. Comparison of multipole mixing ratios with previous work.

Transition energies (MeV)	Initial and final spins	Multipole mixing ratio, δ Dayras and Cujec (Ref. 14)	Coop, Graham, and Titterton (Ref. 15)	This work
$1.22 \to 0$	$\frac{9}{2}^- \to \frac{7}{2}^-$	-0.22 ± 0.03	-0.23 ± 0.03	-0.27 ± 0.01
$1.68 \to 1.22$	$\frac{11}{2}^- \to \frac{7}{2}^-$	0.00 ± 0.03	-0.07 ± 0.06	-0.09 ± 0.01
$1.89 \to 1.22$	$\frac{7}{2}^- \to \frac{9}{2}^-$		$0.04^{+0.22}_{-0.17}$	-0.02 ± 0.01
$2.31 \to 1.22$	$\frac{7}{2}^- \to \frac{9}{2}^-$		-0.06 ± 0.10	-0.13 ± 0.02

ticle estimates. Since calculated transition probabilities are not available, a detailed comparison is not possible at this time. The energies of the levels are in qualitative agreement, although the ordering of the predicted levels is quite different from the observed situation.

Attempts have also been made to describe ^{57}Co using the weak-coupling and intermediate-coupling versions of the unified model. The weak-coupling approach to the unified model, in which an $f_{7/2}$ proton hole was coupled to the first vibrational level of a ^{60}Ni core, has been used with some success to describe the energy-level spectrum of ^{59}Co.[19] Thus it has seemed reasonable to try to describe ^{57}Co using this model. The earliest attempt to do this was by Chilosi, Monario, and Ricci,[20] but their results were inconclusive. This was probably due to the lack of information on the level structure of ^{57}Co at that time. More recently, Gatrousis *et al.*[4] and Nordhagen, Elbek, and Herskind[19] have considered ^{57}Co in the framework of this model.

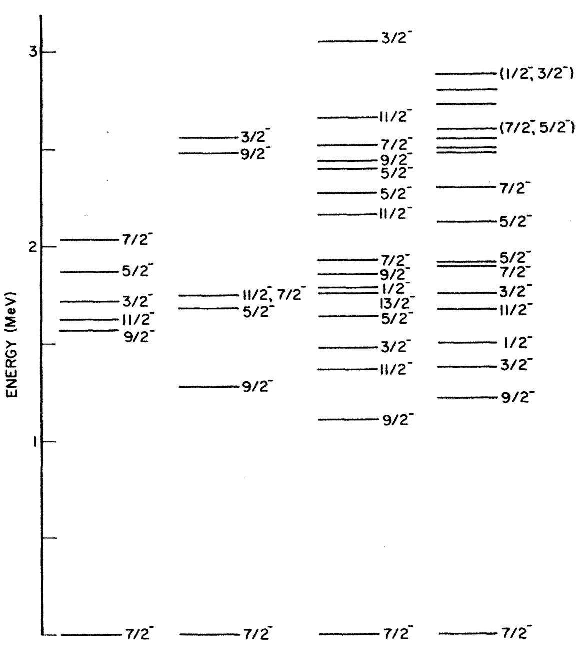

FIG. 9. Comparison of theoretically predicted and experimental levels for ^{57}Co. The predictions are from (a) Ref. 2, (b) Ref. 3, and (c) Ref. 4.

If we assume that ^{57}Co can be described as an $f_{7/2}$ proton hole which is weakly coupled to a ^{58}Ni core, then we can generate "core multiplets" by coupling the $f_{7/2}$ hole to the 0^+ ground state and the 2^+ vibrational state. This will give a $\frac{7}{2}^-$ ground state and a multiplet of states with a center of mass at 1.45 MeV and with spins $\frac{3}{2}^-$, $\frac{5}{2}^-$, $\frac{7}{2}^-$, $\frac{9}{2}^-$, and $\frac{11}{2}^-$ corresponding to the coupling of the $\frac{7}{2}^-$ hole to the 2^+ vibrational core state.

Following their study of ^{59}Co, and using previous reaction spectroscopy data,[17,21] Nordhagen *et al.*[19] indicated that the ^{57}Co levels at 1.76, 1.22, and 1.68 MeV are probably correlated with the ^{59}Co levels at 1.097, 1.189, and 1.458 MeV, which they believe to be members of a core multiplet in ^{59}Co. This implies that the 1.22-, 1.68-, and 1.76-MeV levels are probably the $\frac{9}{2}^-$, $\frac{11}{2}^-$, and $\frac{3}{2}^-$ members of a core multiplet based on the first 2^+ excited states in ^{58}Ni. Nordhagen, Elbeck, and Herskind[19] have determined the $B(E2)\downarrow$ values for the ground-state decays of the ^{59}Co levels mentioned above. They are $B(E2{:}\ 1.097 \to 0) = 10 \times 10^{-51}\ e^2\,\text{cm}^4$, $B(E2{:}\ 1.189 \to 0) = 18 \times 10^{-51}\ e^2\,\text{cm}^4$, and $B(E2{:}\ 1.458 \to 0) = 8 \times 10^{-51}\ e^2\,\text{cm}^4$. These are quite similar to the values measured for the ^{57}Co 1.76-, 1.22-, and 1.68-MeV levels which are given in Table IV.

A general feature of the weak-coupling scheme is that all the electromagnetic transitions from members of the 2^+ core multiplet to the ground state should have the same collective enhancement that the $2^+ \to 0^+$ transition in the ^{58}Ni core has. The $B(E2)\downarrow$ for this transition has been measured[22] to be $14.6 \pm 1.4 \times 10^{-51}\ e^2\,\text{cm}^4$. Further, transitions between members of the same multiplet should have no $E2$ enhancement. From Table IV, we see that the transitions to the ground state of the 1.22-, 1.68-, and 1.76-MeV levels do have an $E2$ enhancement which is roughly the same in all cases and similar to that of the $2^+ \to 0^+$ transition in ^{59}Ni. However, the transition from the 1.68-

TABLE IV. A comparison of the $B_{expt}(\sigma L)$ deduced from experimental results with the Weisskopf single-particle estimates for ^{57}Co. Only the results for the most probable spin assignments are included.

Transition energies (MeV)	Initial and final spins	Multipole mixing ratio δ	Multipole type σL	$B_{expt}(\sigma L)\downarrow$ (e^2 cm^{2L})	$B_{expt}(\sigma L)/B_W(\sigma L)$
1.22 → 0	$\frac{9}{2}^- \to \frac{7}{2}^-$	−0.27 ± 0.01	$M1$	$4.1 \pm 0.9 \times 10^{-29}$	0.19 ± 0.04
			$E2$	$2.4 \pm 0.5 \times 10^{-50}$	18 ± 4
1.38 → 0 [a]	$\frac{3}{2}^- \to \frac{7}{2}^-$	0 [b]	$E2$	$6 \pm 1 \times 10^{-52}$	0.44 ± 0.08
1.68 → 1.22	$\frac{11}{2}^- \to \frac{9}{2}^-$	−0.09 ± 0.01	$M1$	$1.1 \pm 0.4 \times 10^{-28}$	0.5 ± 0.2
			$E2$	$5.9 \pm 0.3 \times 10^{-50}$	39 ± 2
1.68 → 0	$\frac{11}{2}^- \to \frac{9}{2}^-$	0 [b]	$E2$	$1.3 \pm 0.5 \times 10^{-50}$	10 ± 4
1.76 → 0	$\frac{3}{2}^- \to \frac{7}{2}^-$	0 [b]	$E2$	$1.3 \pm 0.2 \times 10^{-50}$	10 ± 2
1.89 → 1.22	$\frac{7}{2}^- \to \frac{9}{2}^-$	−0.02 ± 0.01	$M1$	$1.1 \pm 0.4 \times 10^{-28}$	0.6 ± 0.2
			$E2$	$1.3 \pm 1.3 \times 10^{-51}$	1 ± 1
2.31 → 1.22	$\frac{7}{2}^- \to \frac{9}{2}^-$	−0.13 ± 0.02	$M1$	$1.0 \pm 0.4 \times 10^{-29}$	0.05 ± 0.02
			$E2$	$1.9 \pm 1.0 \times 10^{-51}$	1.4 ± 0.6

[a] Reduced transition probability calculated using previous mean-life measurement $\tau = 28 \pm 5$ psec. (See Ref. 13.)
[b] Assumed value for the multipole mixing ratio.

to the 1.22-MeV level also has an enhanced $E2$ transition probability, and this would be forbidden by the weak-coupling model. This fact, coupled with the presence of the low-lying levels at 1.38 and 1.50 MeV, indicates that the weak-coupling model does not adequately describe the ^{57}Co nucleus.

The intermediate-coupling approach, which has been applied to ^{57}Co by Satpathy and Gujrathi,[5] is essentially the same coupling, but now there is assumed to be an interaction between core multiplets. In the calculations, core states up to three-phonon states were considered. In addition, proton-hole states $(1d_{3/2})^{-1}$ and $(2s_{1/2})^{-1}$ were also considered. Coupling with these states enters only for positive-parity levels, and thus does not affect the low-lying negative-parity levels. The energy levels predicted in this calculation are shown together with the experimental energy-level spectrum in Fig. 10. If the $\frac{3}{2}^-$ level predicted at 1.39 MeV is identified with the observed $\frac{3}{2}^-$ level at 1.76 MeV, then the predicted $B(E2)\downarrow$ value of 18.8 $\times 10^{-51}$ e^2 cm^4 is in reasonably good agreement with the measured $B(E2)\downarrow$ for the 1.76-MeV level of 13 $\pm 2 \times 10^{-51}$ e^2 cm^4. No other calculated $B(E2)$'s are available for comparison. With the identification of the calculated 1.39-MeV level as the observed 1.76-MeV level, the model does not account for the observed $\frac{3}{2}^-$ level at 1.38 MeV or the $\frac{1}{2}^-$ level at 1.50 MeV. Thus, the intermediate-coupling

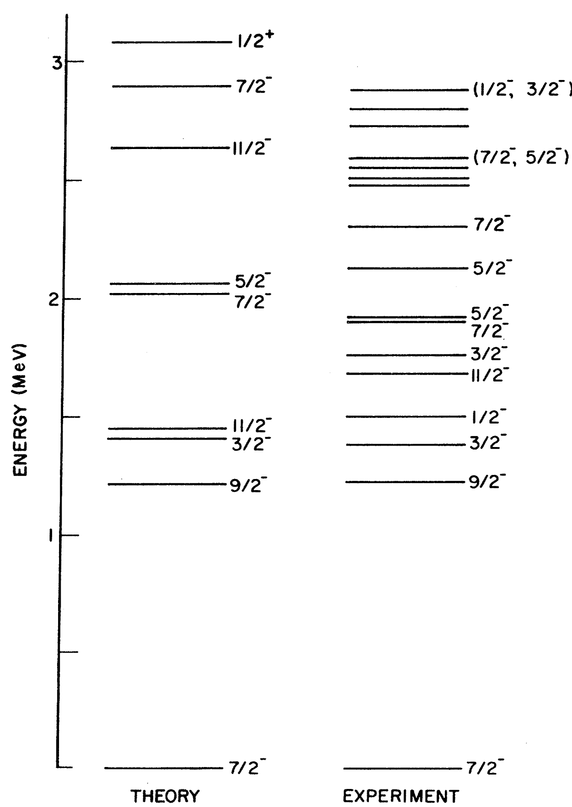

FIG. 10. Comparison of energy levels for ^{57}Co predicted by intermediate coupling with experimental levels. Predictions are from Ref. 5.

model, as applied here, is not sufficient to completely describe the ^{57}Co nucleus.

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Neutron Activation Cross Sections for As, Br, Rb, and Sr Isotopes at 14.4 MeV*

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Activation cross sections at an incident neutron energy of 14.4 ± 0.3 MeV are measured for the $(n,2n)$, (n,p), and (n,α) reactions on isotopes of As, Br, Rb, and Sr, by using the mixed-powder method and γ detection by Ge(Li) spectrometer. The use of a stoichiometric chemical compound as an alternative to the mixed-powder technique, where one of the constituents serves as the neutron flux monitor, is investigated and is recommended, whenever applicable, over all other methods for measurement of relative activation cross sections.

INTRODUCTION

Activation cross sections for $(n, 2n)$, (n, α), and (n,p) reactions for arsenic, bromine, rubidium, and strontium at 14.4 ± 0.3-MeV incident neutron energy are measured as part of a general program to determine accurate cross sections over a large range of mass numbers at a single neutron energy by means of the mixed-powder technique with Ge(Li) γ detection. A complete survey of the existing cross-section measurements on $(n, 2n)$ reactions relevant to the present work in the energy range 13 to 15 MeV is also presented for comparison and discussion of the need for more precise