Reactions ^{54}Fe(p,γ)^{55}Co and ^{54}Fe($p,p'\gamma$)^{54}Fe from 2.35 to 3.90 MeV

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Levels of ^{55}Co between 7.3 and 8.9 MeV have been studied by resonant proton inelastic scattering and capture on ^{54}Fe at beam energies from 2.1 to 3.9 MeV. In all, 163 resonances, some of which are doublets, were identified in this region. Spins of 100 of the resonances were found from their capture spectra and from angular distributions of the ($p,p'\gamma$) and (p,γ) reactions. On the basis of energy and spin, a number of new proposals are made for the ^{55}Co analogs of ^{55}Fe states up to 4 MeV.

I. INTRODUCTION

The nucleus ^{55}Co has received considerable attention from spectroscopists. With $(Z,N)=(27,28)$, its structure is well described in the fp shell model. Such calculations are still at the limit of shell-model technology since the model space is quite large even for simple excitations across the shell closure at 28. States of ^{55}Co are reached in a wide variety of nuclear reactions.[1] Proton stripping on ^{54}Fe is the only single-particle access. The spectroscopic factors indicate that, as would be expected, most of the $f_{7/2}$ strength is concentrated in the ground state, but the $p_{3/2}$, $f_{5/2}$, and $p_{1/2}$ strengths are spread over a large number of levels up to almost 6 MeV in excitation Above this, the first positive-parity valence states appear, notably the $g_{9/2}$ and $d_{5/2}$, at about 8 MeV. Lower-lying positive-parity states are attributed to holes in the sd shell.

Fairly comprehensive information exists for ^{55}Co states up to the proton separation energy of 5.6 MeV. Above this, the level density is high and many of the levels revealed in proton stripping must be assumed to be multiplets. Nevertheless, a number of strong transitions have been reported with the final states being interpreted as analogs of low-lying ^{55}Fe levels.[2-5] Proton capture surveys have been made with beam energies up to 3 MeV,[6-10] although, with the exception of a few narrow regions near the $g_{9/2}$ and $d_{5/2}$ analogs,[11,12] angular distribution spin assignments have not been made above 2.3 MeV. Above 1.8 MeV, elastic and inelastic proton scattering at high resolution have been carried out.[13-16] These display good consistency but have low sensitivity at the lower energies to resonances with $l>1$.

The present experiment, using proton beams from 2.1 to 3.9 MeV and observing the gamma rays from inelastic scattering and capture, was undertaken to complete the picture of ^{55}Co up to $E_x=9$ MeV. Excitation functions, spectra, and angular distributions have allowed assignment of spins and parities to many of the states, both bound and unbound, of ^{55}Co. Together with the earlier results, from stripping and scattering, a set of analogs is proposed for all ^{55}Fe levels up to 4 MeV, excluding only high-spin states. The parent system has been carefully investigated with both gamma-ray and particle spectroscopy in this region of excitation, though spin ambiguities remain for a few levels.[1]

II. EXPERIMENTAL

The experimental procedures and analysis used have been described in earlier reports.[11,12,17] Proton beams ranging in energy from 2.07 to 3.89 MeV from the King Saud University AK Van de Graaff and the McMaster KN Van de Graaff and FN tandem accelerators were used to bombard targets of 96% ^{54}Fe. These were evaporated to a thickness of about 15 μg/cm^2 on thick degassed tungsten backings. The overall system resolution was about 1.2 keV. Excitation functions were measured by integrating selected regions of the γ spectrum at each beam energy for a preset collected charge. In regions of high resonance density, complete spectra were stored for each beam energy, for later detailed analysis.[12] At the strong capture peaks spectra were obtained. The efficiencies for the detector were found from the ^{27}Al(p,γ) reaction at the 0.992 MeV resonance.

Angular distributions were measured at five angles from 0 to 90° with a monitor detector at −90°. In most cases, exposures of a few hundred microcoulombs were used and only ($p,p'\gamma$) distributions were studied. Higher-spin resonances ($J>\frac{5}{2}$) are difficult to distinguish in this way, so where spectra or the ($p,p'\gamma$) angular distributions suggested this likelihood longer exposures were made and (p,γ) distributions were measured. Fitting followed standard least squares procedures.

III. RESULTS

A. Excitation functions

The yield curve for the (p,γ) reaction was quantitatively similar to those shown by earlier workers in the re-

TABLE I. Resonances in $^{54}Fe+p$. "D" represents the doublet, high, and low spin. The asterisk in the table denotes an undetermined value.

Resonance	E_p MeV	E_x MeV	J^π Spect.	J^π Ang. Dis.	J^π Adopted	(p,p)[a]	$(^3He,d)$[b]
1	2.3045	7.327				$(\frac{1}{2}^-)$	
2	2.3129	7.335					
3	2.3230	7.345					
4	2.3387	7.360					
5	2.3499	7.371					
6A	2.3593	7.380				$\frac{1}{2}^-$	
6B	2.3621	7.383					
7	2.3712	7.392					
8	2.3803	7.401		$\frac{3}{2}^-$	$\frac{3}{2}^-$		$\frac{3}{2}^-, \frac{5}{2}^-$
9A	2.4367	7.456				$\frac{1}{2}^-$D	$\frac{3}{2}^-$
9B	2.4395	7.459					
10	2.4767	7.496		$\frac{5}{2}^-$	$\frac{5}{2}^-$		
11	2.4993	7.518				$\frac{1}{2}^-$	$\frac{3}{2}^-$
12	2.5056	7.524					
13	2.5454	7.563		$\frac{5}{2}^-$	$\frac{5}{2}^-$	$\frac{1}{2}^-$	
14	2.5595	7.577	$\frac{5}{2}$		$(\frac{5}{2})$	$(\frac{3}{2}^-)$	$(\frac{3}{2})^+$
15	2.5768	7.594	$\frac{3}{2}$		$(\frac{3}{2})$		
16	2.5931	7.610	$\frac{5}{2}$	$\frac{5}{2}^-$	$\frac{5}{2}^-$	$\frac{5}{2}^+$	
17	2.6037	7.620		$\frac{7}{2}^-$	$\frac{7}{2}^-$		
18	2.6097	7.626	$\frac{5}{2}$		$(\frac{5}{2})$		$\frac{3}{2}^+$
19	2.6158	7.632	$\frac{5}{2}^-$	$\frac{7}{2}^-$	$\frac{7}{2}^-$		
20	2.6250	7.641	$\frac{3}{2}$		$(\frac{3}{2})$	$\frac{1}{2}^-$	
21	2.6333	7.649	$\frac{7}{2}$	$\frac{7}{2}^-$	$\frac{7}{2}^-$		$\frac{5}{2}^-$
22	2.6458	7.662	$\frac{3}{2}$		$(\frac{3}{2})$	$(\frac{1}{2}^-)$	
23	2.6633	7.679	$\frac{5}{2}$		$(\frac{5}{2})$		
24	2.6875	7.703	$\frac{3}{2}, \frac{5}{2}$	$\frac{3}{2}^-, \frac{5}{2}^-$	$\frac{3}{2}^-, \frac{5}{2}^-$	$\frac{1}{2}^-$	$(\frac{5}{2})^-$
25	2.7313	7.746	$\frac{5}{2}$	$\frac{5}{2}^+$	$\frac{5}{2}^+$	$(\frac{5}{2}^+)$	$(\frac{5}{2})^-$
26	2.7335	7.748					
27	2.7521	7.766	$\frac{3}{2}$	$\frac{3}{2}^-$	$\frac{3}{2}^-$	$\frac{3}{2}^-, \frac{1}{2}^-$D	$\frac{3}{2}^-$
28	2.7634	7.777				$\frac{1}{2}^+$	
29	2.7667	7.780					
30	2.7769	7.790					
31	2.7913	7.805	$\frac{3}{2}$		$(\frac{3}{2})$		
32	2.8019	7.815	D			$\frac{1}{2}^-$	
33	2.8235	7.836				$\frac{1}{2}^-$	
34	2.8555	7.868	$\frac{5}{2}$		$(\frac{5}{2})$		
35	2.8634	7.875	$\frac{5}{2}^-$		$(\frac{5}{2}^-)$	$\frac{5}{2}^+$	
36	2.8676	7.879	$\frac{3}{2}^-$		$(\frac{3}{2}^-)$	$(\frac{3}{2}^-)$	
37	2.8719	7.884	$\frac{7}{2}$		$(\frac{7}{2})$		
38	2.8762	7.888					$(\frac{5}{2})^+$
39	2.8830	7.895					
40	2.8967	7.908					
41	2.9187	7.930					
42A	2.9266	7.937	$\frac{3}{2}^-$		$(\frac{3}{2}^-)$		
42B	2.9292	7.940					
43	2.9346	7.945					

TABLE I. (*Continued*).

	E_p	E_x			J^π		
Resonance	MeV		Spect.	Ang. Dis.	Adopted	$(p,p)^a$	$(^3He,d)^b$
44	2.9400	7.951					
45	2.9445	7.955				$(\frac{1}{2}^+)$	
46A	2.9533	7.964	D			$\frac{1}{2}^-$	
46B	2.9550	7.965	$\frac{5}{2}$		$(\frac{5}{2})$	$\frac{5}{2}^+$	$\frac{5}{2}^+$
47	2.9649	7.975	$\frac{5}{2}^+$		$(\frac{5}{2}^+)$		
48	2.9735	7.983					
49	2.9966	8.006					
50	3.0064	8.016					
51	3.0098	8.019	$\frac{7}{2},\frac{9}{2}$	$\frac{7}{2}^-,\frac{9}{2}^+$	$\frac{7}{2}^-,\frac{9}{2}^+$		
52	3.0202	8.029				$\frac{1}{2}^-$D	$(\frac{5}{2})^-$
53	3.0233	8.032					
54	3.0409	8.050					
55	3.0466	8.055	$\frac{3}{2}$		$(\frac{3}{2})$	$\frac{1}{2}^-$	
56	3.0570	8.065	$\frac{3}{2}$	$\frac{3}{2}^-$	$\frac{3}{2}^-$	$\frac{3}{2}^-$D	
57	3.0616	8.070	$\frac{7}{2}$		$(\frac{7}{2})$		$(\frac{5}{2})^-$
58	3.0755	8.084					
59	3.0828	8.091		$\frac{3}{2}$	$\frac{3}{2}$	$(\frac{3}{2}^+)$	
60	3.0877	8.096					
61	3.0967	8.104	$\frac{3}{2}$		$(\frac{3}{2})$	$(\frac{5}{2}^-)$	$(\frac{5}{2})^-$
62	3.1160	8.123				$(\frac{1}{2}^-)$	
63	3.1218	8.129	$\frac{5}{2}$	$\frac{5}{2}^+$	$\frac{5}{2}^+$	$\frac{5}{2}^+$	$\frac{5}{2}^+$
64	3.1253	8.132	$\frac{3}{2}^-,\frac{5}{2}$	$\frac{5}{2}^+$&$\frac{1}{2}$	$\frac{5}{2}^+$&$\frac{1}{2}$	$\frac{1}{2}^-$	
65	3.1288	8.136		$\frac{5}{2}^-$	$\frac{5}{2}^-$		
66	3.1323	8.139		$\frac{3}{2}^-$	$\frac{3}{2}^-$		
67	3.1364	8.143	$\frac{3}{2}$	$\frac{3}{2}^+$	$\frac{3}{2}^+$	$\frac{1}{2}^-$	
68	3.1476	8.154		$\frac{7}{2}^-$	$\frac{7}{2}^-$		
69	3.1605	8.167		$\frac{5}{2}^+$	$\frac{5}{2}^+$		
70	3.1643	8.171		$\frac{5}{2}^+$	$\frac{5}{2}^+$		
71	3.1664	8.173		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}^-$	$\frac{1}{2}^-$
72	3.1728	8.179					
73	3.1834	8.190	$\frac{1}{2},\frac{3}{2}$	$\frac{5}{2}^-$	$(\frac{1}{2},\frac{3}{2})$&$\frac{5}{2}^-$	$\frac{1}{2}^-$	
74	3.1926	8.199		$\frac{5}{2}^-$	$\frac{5}{2}^-$		
75	3.1973	8.203					
76	3.2017	8.207					
77	3.2059	8.212				$\frac{1}{2}^+$	
78	3.2088	8.214		$\frac{3}{2}^-$	$\frac{3}{2}^-$	$(\frac{3}{2}^+)$	
79	3.2147	8.220					
80	3.2335	8.233	$\frac{5}{2}$		$(\frac{5}{2})$	$\frac{5}{2}^+$	$\frac{5}{2}^+$
81	3.2305	8.236		$\frac{5}{2}$	$\frac{5}{2}$		
82	3.2537	8.259		$\frac{3}{2}^-$	$\frac{3}{2}^-$		
83	3.2671	8.272	$\frac{5}{2}$		$(\frac{5}{2})$		
84	3.2779	8.282	$\frac{5}{2}$	$\frac{3}{2}^-$	$\frac{3}{2}^-$&$(\frac{5}{2})$	$\frac{3}{2}^-$	
85	3.2815	8.286		$\frac{1}{2}$	$(\frac{1}{2})$	$\frac{3}{2}^-$	
86	3.2851	8.289	D			$\frac{1}{2}^-,\frac{3}{2}^-$	$(\frac{5}{2})^-$
87	3.2890	8.293	$\frac{1}{2},\frac{3}{2}$		$(\frac{1}{2},\frac{3}{2})$	$\frac{3}{2}^-$	

TABLE I. (*Continued*).

Resonance	E_p MeV	E_x MeV	Spect.	Ang. Dis.	J^π Adopted	(p,p)[a]	$(^3He,d)$[b]
88	3.2935	8.298		$\frac{3}{2}^-$	$\frac{3}{2}^-$	$\frac{1}{2}^-$	
89	3.3033	8.306					
90	3.3320	8.335		$\frac{5}{2}^+$	$\frac{5}{2}^+$		
91	3.3516	8.355					
92	3.3552	8.358	$\frac{7}{2},\frac{9}{2}$	$\frac{7}{2}^-,\frac{9}{2}^+$	$\frac{7}{2}^-,\frac{9}{2}^+$		
93	3.3652	8.368		$\frac{3}{2}^-$	$\frac{3}{2}^-$	$\frac{1}{2}^-,\frac{3}{2}^-$	
94	3.3695	8.372	$\frac{5}{2}$		$(\frac{5}{2})$	$\frac{1}{2}^-,\frac{3}{2}^-$	
95	3.3798	8.382	$\frac{5}{2}$	$\frac{5}{2},\frac{7}{2}^-$	$\frac{5}{2}$	$\frac{5}{2}^+$	$(\frac{5}{2})^-$
96	3.3865	8.389	D	$\frac{3}{2}^-$	$\frac{3}{2}^-$ & *	$\frac{3}{2}^-$	$(\frac{3}{2})^-$
97	3.4084	8.410	$\frac{3}{2}$		$(\frac{3}{2})$	$\frac{1}{2}^-,\frac{3}{2}^-$	
98	3.4142	8.416	$\frac{5}{2}$	$\frac{5}{2}^+$	$\frac{5}{2}^+$	$\frac{5}{2}^+$	$\frac{5}{2}^+$
99	3.4280	8.430	$\frac{3}{2}$	$\frac{3}{2}^-$	$\frac{3}{2}^-$	$\frac{3}{2}^+,(\frac{5}{2}^+)$	
100	3.4323	8.434	$\frac{5}{2}$		$(\frac{5}{2})$		
101	3.4369	8.438	D				$\frac{1}{2}^-,\frac{3}{2}^-$
102	3.4539	8.455	$\frac{1}{2},\frac{3}{2}$		$(\frac{1}{2},\frac{3}{2})$[c]	$\frac{3}{2}^+,(\frac{5}{2}^+)$	
103A	3.4610	8.462	$\frac{7}{2},\frac{9}{2}$	$\frac{9}{2}^+$	$\frac{9}{2}^+$[c]		
103B	3.4625	8.464	$\frac{5}{2},\frac{7}{2}$	$\frac{5}{2}^-,\frac{7}{2}^-$	$\frac{5}{2}^-,\frac{7}{2}^-$[c]		
104A	3.4650	8.466	$\frac{7}{2},\frac{9}{2}$	$\frac{9}{2}^+$	$\frac{9}{2}^+$[c]	$\frac{9}{2}^+$	$\frac{9}{2}^+$
104B	3.4662	8.467	$\frac{7}{2}$		$(\frac{7}{2})$[c]	$\frac{9}{2}^+$	
105	3.4709	8.472	$\frac{1}{2},\frac{3}{2}$	$\frac{1}{2}$	$\frac{1}{2}$[c]	$\frac{1}{2}^-$	$\frac{1}{2}^-$
106A	3.4743	8.475	$\frac{7}{2},\frac{9}{2}$	$\frac{9}{2}^+$	$\frac{9}{2}^+$[c]	$\frac{9}{2}^+$	
106B	3.4761	8.477	$\frac{5}{2}$		$(\frac{5}{2})$[c]		
107	3.4957	8.496				$\frac{1}{2}^-$	
108	3.5034	8.504	D	$\frac{3}{2}^+$	$\frac{3}{2}^+$ & *	$\frac{3}{2}^-$	
109	3.5068	8.507		$\frac{5}{2}^+$	$\frac{5}{2}^+$	$\frac{5}{2}^+$	
110	3.5133	8.513		$\frac{5}{2}^-$	$\frac{5}{2}^-$		
111	3.5313	8.531		$\frac{5}{2}^-$	$\frac{5}{2}^-$		
112	3.5559	8.555	$\frac{7}{2}$	$\frac{5}{2}^-,\frac{7}{2}^-$	$\frac{7}{2}^-$		$(\frac{1}{2},\frac{3}{2})^-$
113	3.5581	8.557	$\frac{7}{2},\frac{9}{2}$	$\frac{7}{2}^-,\frac{9}{2}^+$	$\frac{7}{2}^-,\frac{9}{2}^+$		
114	3.5609	8.560					
115A	3.5665	8.566		$\frac{3}{2}^-$	$\frac{3}{2}^-$	$\frac{1}{2}^-$ & $\frac{3}{2}^-$	
115B	3.5690	8.568		$\frac{1}{2}$	$(\frac{1}{2})$	$\frac{1}{2}^+$	
116	3.5759	8.575		$\frac{3}{2}^+$	$\frac{3}{2}^+$		
117	3.5828	8.582	D	$\frac{5}{2},\frac{7}{2}$	$\frac{5}{2},\frac{7}{2}$	$\frac{5}{2}^+$	
118	3.5965	8.595		$\frac{1}{2}$	$(\frac{1}{2})$		
119	3.6056	8.604					
120	3.6292	8.627		$\frac{3}{2}^-$	$\frac{3}{2}^-$	$\frac{3}{2}^-$	
121	3.6359	8.634		$\frac{1}{2}$	$(\frac{1}{2})$		
122	3.6447	8.642	$\frac{5}{2}$	$\frac{5}{2}^+$	$\frac{5}{2}^+$	$\frac{5}{2}^+$	$(\frac{5}{2})^+$
123	3.6507	8.648		$\frac{5}{2}^-,\frac{7}{2}^-$	$\frac{5}{2}^-,\frac{7}{2}^-$	$\frac{3}{2}^+$	
124	3.6532	8.651	D				
125	3.6646	8.662		$\frac{3}{2}^+$	$\frac{3}{2}^+$	$\frac{1}{2}^-$ & $\frac{3}{2}^-$	$(\frac{9}{2})^+$
126	3.6684	8.666		$\frac{3}{2}^-$	$\frac{3}{2}^-$	$\frac{3}{2}^-$	
127	3.6811	8.678	D			$\frac{1}{2}^+$	

TABLE I. (*Continued*).

Resonance	E_p MeV	E_x MeV	Spect.	J^π Ang. Dis.	J^π Adopted	$(p,p)^{a}$	$(^3\mathrm{He},d)^{b}$
128	3.6843	8.681	D				
129	3.6912	8.688		$\frac{5}{2}^{+}\&\frac{1}{2}$	$\frac{5}{2}^{+}\&\frac{1}{2}$	$\frac{5}{2}^{+}$	
130	3.6938	8.691	D				
131	3.7052	8.702	$\frac{7}{2}$	$\frac{5}{2}^{-},\frac{9}{2}^{+}$	$\frac{9}{2}^{+}$		$(\frac{9}{2})^{+}$
132	3.7084	8.705	D	$\frac{5}{2}^{+}\&\frac{3}{2}^{-}$	$\frac{5}{2}^{+}\&\frac{3}{2}^{-}$		
133	3.7129	8.709					
134	3.7199	8.716					
135	3.7231	8.719				$\frac{1}{2}^{+}$	
136	3.7282	8.724				$\frac{5}{2}^{+}$	
137	3.7320	8.728		$\frac{3}{2}^{+}$	$\frac{3}{2}^{+}$		
138	3.7478	8.743	D				
139	3.7483	8.744		$\frac{5}{2}^{-}$	$\frac{5}{2}^{-}$	$\frac{3}{2}^{-}\&\frac{5}{2}^{+}$	$(\frac{5}{2})^{+}$
140	3.7522	8.748	$\frac{5}{2},\frac{7}{2}$	$\frac{5}{2}^{-},\frac{7}{2}^{-}$	$\frac{5}{2}^{-},\frac{7}{2}^{-}$	$\frac{5}{2}^{-}$	$\frac{5}{2}^{-}$
141	3.7563	8.752	D	$\frac{5}{2}^{-}$	$\frac{5}{2}^{-}\&*$	$\frac{5}{2}^{-}\&\frac{3}{2}^{+}$	
142	3.7602	8.756					
143	3.7692	8.765					
144	3.7717	8.767					
145	3.7769	8.772		$\frac{3}{2}^{-}$	$\frac{3}{2}^{-}$	$\frac{1}{2}^{+}$	
146	3.7942	8.789		$\frac{5}{2}^{-},\frac{7}{2}^{-}$	$\frac{5}{2}^{-},\frac{7}{2}^{-}$		
147	3.8017	8.797	$\frac{1}{2},\frac{3}{2}$	$\frac{3}{2}^{-}$	$\frac{3}{2}^{-}$	$\frac{3}{2}^{-}$	
148	3.8068	8.802	D	$\frac{7}{2}^{-},\frac{9}{2}^{+}$	$\frac{7}{2}^{-},\frac{9}{2}^{+}\&*$	$\frac{5}{2}^{+},\frac{3}{2}^{-}$	
149	3.8181	8.813		$\frac{5}{2}^{+}$	$\frac{5}{2}^{+}$	$\frac{5}{2}^{+}$	$\frac{5}{2}^{-}$
150	3.8298	8.824		$\frac{7}{2}^{-}$	$\frac{7}{2}^{-}$	$\frac{5}{2}^{-},\frac{7}{2}^{-}$	
151	3.8391	8.833		$\frac{5}{2}^{-}$	$\frac{5}{2}^{-}$	$\frac{5}{2}^{-},\frac{7}{2}^{-}$	
152	3.8492	8.843				$\frac{1}{2}^{-}$	
153	3.8599	8.854	$\frac{5}{2}$		$(\frac{5}{2})$	$\frac{5}{2}^{-}$	$\frac{5}{2}^{+}$
154	3.8853	8.879		$\frac{3}{2}^{+}$	$\frac{3}{2}^{-d}$		
155	3.8895	8.883		$\frac{3}{2}^{+}$	$\frac{5}{2}^{+d}$		

[a]References 13–16.
[b]Reference 4.
[c]Reference 12.
[d]Reference 11.

gions of overlap from 2.07 to 2.87 MeV. Figure 1 shows the (p,γ) and $(p,p'\gamma)$ yield curves for the region of proton energies from 2.3 to 3.9 MeV. The resonances found over the entire range studied are listed in Table I. Resonances 1 to 35 correspond to resonances 38 to 67 in the study by Erlandsson and Lyttkens.[7] Visually, the region from 2.1 to 3.0 MeV closely resembles the yield curve of Ahmed *et al.*,[6] but those authors do not list all their resonance energies so a quantitative comparison could not be made. The work of Hänninen and Din[8] extends only as far as resonance 6. The King Saud University Van de Graaff was used to repeat their work from 2.07 and to overlap the McMaster KN data up to 2.52 MeV (resonance 12). The slightly better resolution allowed the doublet nature of the resonances at 2.36 and 2.44 MeV (resonances 6 and 9) to be seen more clearly. Resonance 32 was observed using both the KN and FN accelerators, providing continuity. Resonance 154 corresponds to resonance 1 of Ref. 11 while resonances 102 to 106B are resonances 1 to 6B of Ref. 12.

B. Spectra

A typical spectrum, taken at $E_p = 3.465$ MeV, is shown in Fig. 2. The labeled peaks all arise from transitions in ^{55}Co (resonances 104 and 105), except for the room background, target backing and contaminations, and ^{55}Co decay lines noted. From the spectra, branching fractions to bound levels of ^{55}Co were derived and are shown in Table II. From the final-state spins (Table V), assuming the predominance of dipole transitions, tentative assignments of spin, and occasionally parity, have been made for the resonances. In some cases, further spin restrictions were made on the basis of similarities of spectra to those of resonances of measured spin, using the analysis developed in Ref. 18. These appear in the fourth column of Table I.

The spectra were also used to find the Q value for the ^{54}Fe$(p,\gamma)^{55}$Co reaction. The presence of the ^{19}F$(p,\alpha\gamma)^{16}$O background in all the spectra provides a calibration for capture lines near 6 MeV. The energy of the ^{16}O γ ray was taken to be 6.1291 MeV.[19,20] The Q value found from the 20 most carefully measured resonances is 5.065±0.001 MeV, where most of the uncertainty arises from possible systematic errors in the proton beam energy and from the Doppler shift corrections.

C. Angular distributions

Angular distributions of the γ rays from inelastic scattering may be used to determine, or at least limit, the spin and parity of proton resonances on spin-0 targets, providing it is assumed that the inelastic decay proceeds with only one or two angular momenta. A complication which arises in this reaction is the coincidence in energy at 1.408 MeV between the $2^+ \rightarrow 0^+$ ^{54}Fe transition and the $\frac{7}{2}^- \rightarrow \frac{3}{2}^-$ decay in ^{55}Fe which occurs in about 22% of

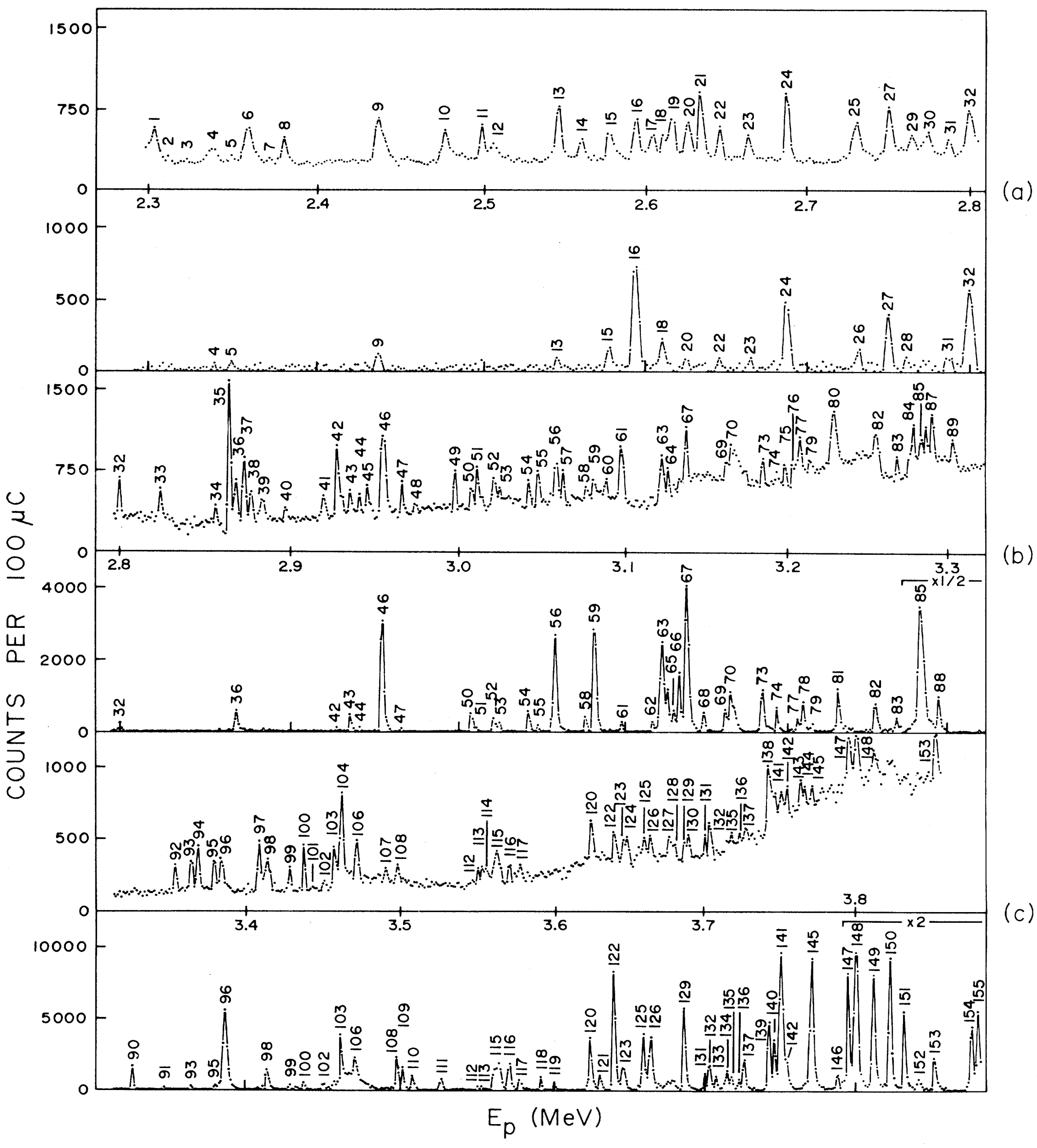

FIG. 1. Gamma-ray yield from ^{54}Fe$+p$ for $2<E_\gamma<5$ MeV (upper) and $E_\gamma=1.408$ MeV (lower). Part (a): KN Van de Graaff; (b) and (c) FN tandem.

^{55}Co β decays. That this is not a serious problem can be seen from the low intensity of the 0.931-MeV line which occurs in all the β decays.[1]

The results of all the angular distribution measurements are compiled in Tables III and IV and the resulting spin-parity assignments are included in Table I. Also included in Table I are the previous spin-parity assignments in the $d_{5/2}$ and $g_{9/2}$ regions.[11,12]

IV. DISCUSSION

A. Resonances

The final two columns of Table I identify the resonances found in the present study with those reported in the high-resolution elastic scattering experiments and with the proton stripping work. The proton energies of the resonances agree within 2 keV with those reported by Erlandsson and Lyttkens[7] up to 2.87 MeV. There is a small systematic difference of about 1 keV with the scattering results,[13–16] about the same as that found among them. Relative energies agree, over limited ranges, to within 1 keV. The excitation energies found from the spectra agree well with those from proton stripping[3] and with the earlier capture studies.[1,7,8,12] In the majority of cases, the spin assignments from the present study agree with those of others. Table I documents the cases of disagreement. There appears to be a large number of $\frac{1}{2}^-$ assignments from low-energy elastic scattering for which we find either anisotropic $(p,p'\gamma)$ angular distributions or strong capture to $\frac{5}{2}^-$ states, suggesting spin $\frac{3}{2}$. Such disagreements of j consistent with the same l are not uncommon, and come about from channel mixing in elastic scattering which can favour a lower-j misinterpretation. Cases where there is evidently a disagreement in l as well may be interpreted in two ways. Occasionally, $(p,p'\gamma)$ angular distributions reveal anomalous admixtures of j', the total angular momentum of the unobserved scattered proton. This was seen for a few of the $d_{5/2}$ resonances of Ref. 11. In the present work, examples are resonances 80, 95, and 123, all $l \geq 2$ resonances. Others of the discrepancies between the γ-ray and elastic scattering assignments may be accounted for by the presence at nearly the same energy of doublets, only one member of which is observed in each experiment. At the level density present, this likelihood is small but not negligible. The most notable disagreement with the proton stripping is in our failure to confirm the $\frac{9}{2}^+$ levels (other than the analog and one other state). In a few cases, internal disagreements occur, for instance between spin assignments from $(p,p'\gamma)$ angular distributions and

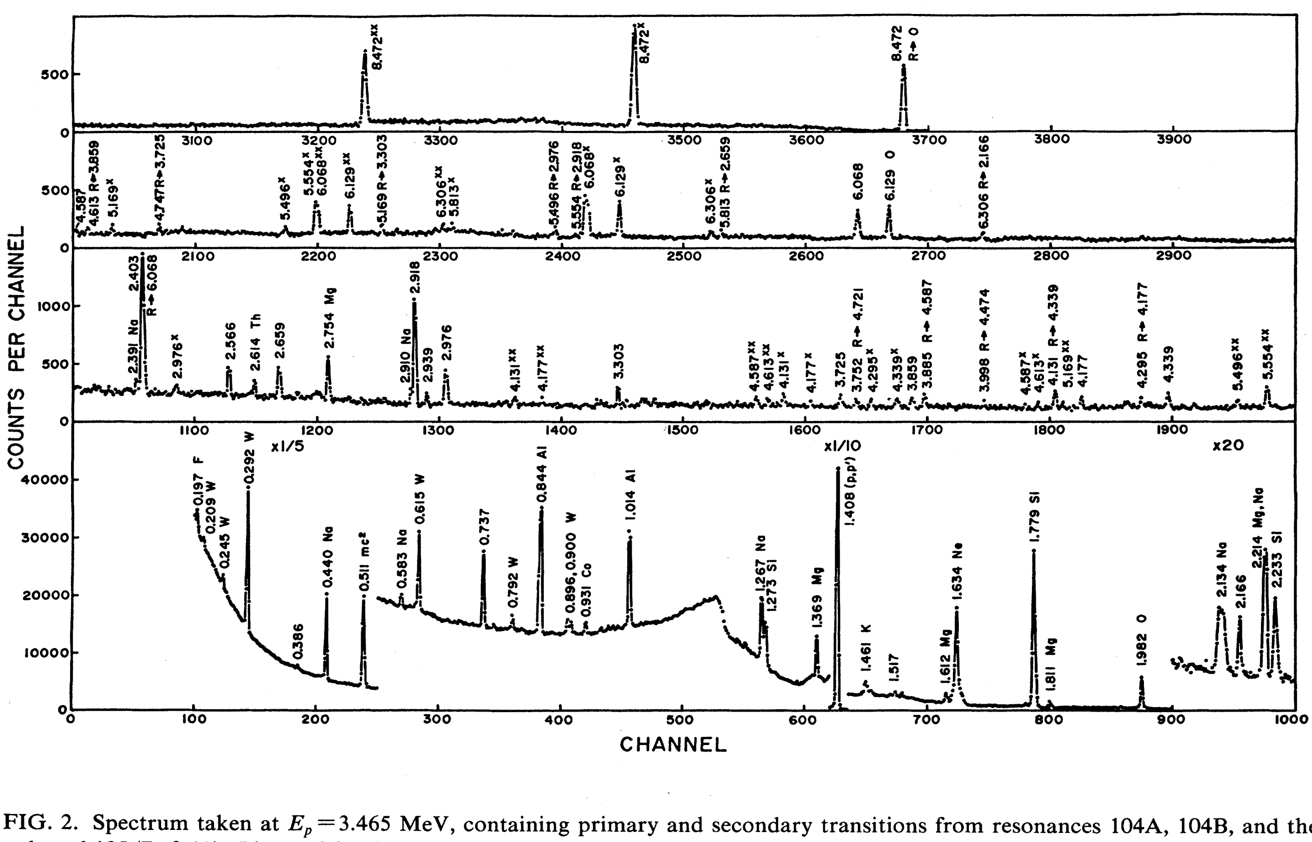

FIG. 2. Spectrum taken at $E_p = 3.465$ MeV, containing primary and secondary transitions from resonances 104A, 104B, and the very broad 105 (Ref. 12). Lines arising from target backing and contaminants and from room background are labelled.

TABLE II. Gamma-decay branching from ^{5}Fe+p resonances.

Resonance E_f (MeV)	13	14	15	16	18	19	20	21	22	23	24	25	27	31	32	34	35	36
0.	11	14		20	52	79		41		10	2	64	3		48	19	33	9
2.166	4	18	24	9	12	3	22		21		10		4	78	5	17		8
2.566	1	15	7		36	3		4	41	43	14	23				13	27	11
2.659	16		12	8			7		5		7	5	31		16		3	13
2.918				10		2		25							2		8	
2.922	3		3				37						6					
2.939	7						10		6		25		6		20			8
2.976						2		3									4	
2.992																		
3.303	2		7			2		5			6							
3.323	14						8		6		9		16		2			
3.563	7	25		4			3		7								4	7
3.643	6	15	12	13		1				29	2	6	9		2	27	3	35
3.725	3	4	9			1		2		6	1		4	22	2			
3.859				4		4		4		9					1			
3.942																		9
4.164	2								5		3		5		2			
4.177	3		14	2			4		5							13		
4.264		2															5	
4.339																		
4.474		3															2	
4.548	1										9							
4.587	4			4				4								11	3	
4.628			2	5			2		2				3					
4.721	1	1							2		2		2				4	
4.748	5	3					2	2			2	2	4				4	
4.851	4																	
4.961	1						5						4					
4.988	3					3		5										
5.099				12									3					
5.121			3								8							
5.259	2			9				1										
5.351								4										
5.560										3								
5.642			7															
6.068																		

Resonance E_f (MeV)	37	42A	46A	46B	47	51	55	56	57	61	63	64	67	73	80	83	84	86
0.	9	3	2	45	82	87			27		13	10			40	45	34	25
2.166		4	7	6			29	30		16	17	21	10		13			
2.566		39		14				23		17	31	9		19	5	3	21	33
2.659	10	8	9	16				16					13		7		13	
2.918	15					2			20			17						
2.922		7	16		6													16
2.939		9	14				13			6			15	46				
2.976	24		4			4			5									
2.992																		
3.303	13	3	6		4				11	8			7			11		
3.323		18	10				19	6				12	28					
3.563			6							6	5				25	8		11
3.643		6	16	7			15	21		14		31	12	10	11		4	
3.725	11	3	6						11				9			6		
3.859					3				14	7								
3.942						3								24				
4.164													6	11				
4.177	13						14		12								5	
4.264										5						7	27	
4.339																		

TABLE II. (*Continued*).

Resonance E_f (MeV)	37	42A	46A	46B	47	51	55	56	57	61	63	64	67	73	80	83	84	86
4.474						2	10									9		
4.548	6			2														
4.587					5	4		4		6								
4.628				7						7	6							3
4.721										8	17							8
4.748			4	3							11							
4.851																		
4.961																		
4.988																		
5.099																		
5.121																		
5.259																		
5.460																		
5.560																		
5.642																		
6.068																		

Resonance E_f (MeV)	87	92	94	95	96	97	98	99	100	101	102	103A	103B	104A	104B	105	106A	106B
0.		79	25	8	6		20		75	32		84	100	65	43		62	30
2.166	27			22	46		31									75		
2.566	25			36	21		28	8		16						16		
2.659			43		7	19			14	7					9			20
2.918												4		12	10		11	
2.922					10	6		66										
2.939	14					2				14	44							
2.976		21										4			9			
2.992																9		
3.303			32			6		16	11						7			
3.323	2				10	28		10										
3.563				8							56							
3.643	32					21												
3.725															8			
3.859														2				50
3.942										7								
4.164						18				18								
4.177																		
4.264																		
4.339														3	7		4	
4.474																	4	
4.548																		
4.587														1	7			
4.628				6														
4.721				10			10			3								
4.748				10			11			3								
4.851																		
4.961																		
4.988																		
5.099																		
5.121																		
5.259																		
5.460																		
5.560																		
5.642																		
6.068												8		17			19	

TABLE II. (*Continued*).

Resonance E_f (MeV)	108	112	113	117	122	124	127	128	130	131	132	138	140	141	147	148	153
0.	35	44	41	86	79	20	32	16	24	83	84	12	100	25		40	54
2.166	29							16	11		4	10		14	69	6	13
2.566				6			15	10	9		5					5	3
2.659	14			8	9		5		16			25				6	
2.918		17	22						9		1						2
2.922	8						45	31			2						
2.939						48											
2.976			37						11	10				25			
2.992																	
3.303																	9
3.323	5					32						53				3	
3.563								8			1						6
3.643															23	20	2
3.725									11					8			5
3.859		29												12			
3.942									9	4							
4.164	6														8		
4.177																10	
4.264								6								4	3
4.339																	
4.474								5									
4.548	3	10						4						16			3
4.587										3							
4.628								4									
4.721					6						3					3	
4.748					6		3									3	
4.851																	
4.961																	
4.988																	
5.099																	
5.121																	
5.259																	
5.460																	
5.560																	
5.642																	
6.068																	

from decay branching. These discrepancies are most likely due to the existence of unresolved doublets. In cases of special interest, efforts have been made to resolve such doublets.[12] Otherwise, a notation "D" has been entered in Table I.

B. Isobaric analog states

Reference 1 contains the proposals of earlier workers for several isobaric analogs of the ^{55}Fe states in the range 0–4.5 MeV. Table V lists these, with the notation "a" along with proposals for analogs in the range covered by this experiment. A number of $l=3$ assignments are made, some of which must remain tentative until the spin ambiguities in the ^{55}Fe parent states are resolved.

The trend of the Coulomb displacement energy,

$$E_c = E_x(\mathrm{Co}) - E_x(\mathrm{Fe}) + Q(\mathrm{Co}\rightarrow\mathrm{Fe}) + Q(n\rightarrow\mathrm{H}) ,$$

with excitation energy and spin, as illustrated in Fig. 3, is similar to that found for $A=51$.[21] An initial increase is followed by a small decrease at excitation energies above 3 MeV in ^{55}Fe. The $f_{7/2}$ hole state (at 1.408 MeV in ^{55}Fe) appears anomalous. In $A=51$, the $\frac{1}{2}^-$ and $\frac{3}{2}^-$ intruder states at 0.75 MeV have anomalously low displacement energies.

C. $\frac{9}{2}^+$ states

In addition to the $g_{9/2}$ IAS whose three fragments near $E_p=3.47$ MeV were explored in Ref. 12, a number of other $\frac{9}{2}^+$ states were reported in the (^{3}He,d) study of Fortier.[4] Only one of these, resonance 131, is confirmed by this work. Two others, resonances 82 and 125, appear to have lower spin. Further states which may be $\frac{9}{2}^+$ appear at resonances 51, 92, 113, and 148, although in none of these cases is $\frac{7}{2}^-$ excluded. If these states are indeed $\frac{9}{2}^+$

TABLE III. $^{55}Fe(p,\gamma)$ angular distributions.

Resonances	E_i (MeV)	E_f	J_j^π	A_2	A_4	J_i^π
8	7.401	0.	$\frac{7}{2}^-$	0.00(4)	−0.07(4)	$\frac{3}{2}^-,\frac{5}{2},\frac{7}{2}^-$
		2.166	$\frac{3}{2}^-$	−0.61(6)	0.00(6)	$\frac{3}{2}^-,\frac{5}{2}$
10	7.496	0.	$\frac{7}{2}^-$	0.10(6)	−0.05(7)	$\frac{3}{2},\frac{5}{2}^-,\frac{7}{2}^-,\frac{9}{2}^-$
		2.659	$\frac{5}{2}^-$	0.85(5)	−0.23(6)	$\frac{5}{2},\frac{9}{2}^-$
		3.725	$\frac{5}{2}^-$	0.84(15)	−0.28(15)	$\frac{5}{2}^-,\frac{9}{2}^-$
13	7.563	0.	$\frac{7}{2}^-$	−0.35(7)	−0.07(9)	$\frac{5}{2},\frac{7}{2}^-,\frac{9}{2}$
		2.659	$\frac{5}{2}^-$	0.38(7)	−0.06(7)	$\frac{3}{2}^-,\frac{5}{2},\frac{7}{2}^-$
		3.323	$\frac{1}{2}^-$	−0.30(8)	0.10(10)	$\frac{3}{2},\frac{5}{2}^-$
		3.643	$\frac{3}{2}^-$	0.90(13)	0.04(14)	$\frac{3}{2}^-,\frac{5}{2}^-,\frac{7}{2}^-$
		3.563	$\frac{3}{2}^+$	0.59(14)	−0.17(15)	$\frac{3}{2}^+,\frac{5}{2},\frac{7}{2}^+$
16	7.610	0.	$\frac{7}{2}^-$	−0.82(6)	−0.04(7)	$\frac{5}{2}^-,\frac{9}{2}^-$
19	7.632	0.	$\frac{7}{2}^-$	−0.02(2)	−0.14(3)	$\frac{7}{2}^-$
21	7.649	0.	$\frac{7}{2}^-$	0.21(4)	−0.05(4)	$\frac{3}{2},\frac{5}{2}^-,\frac{7}{2}^-,\frac{9}{2}^-$
		2.918	$\frac{7}{2}^-$	0.62(4)	−0.07(5)	$\frac{7}{2}$
24	7.703	2.566	$\frac{3}{2}^-$	0.53(10)	−0.25(13)	$\frac{3}{2},\frac{5}{2},\frac{7}{2}^-$
		2.939	$\frac{1}{2}^-$	−0.15(5)	−0.22(6)	$\frac{3}{2}^-,\frac{5}{2}^-$
		4.548	$\frac{5}{2}^-$	0.02(9)	−0.02(10)	$\frac{1}{2}^-\frac{3}{2}^-,\frac{5}{2}^-$
25A	7.746	0.	$\frac{7}{2}^-$	0.04(7)	−0.16(8)	$\frac{3}{2}^-,\frac{5}{2},\frac{7}{2}^-$
		2.565	$\frac{3}{2}^-$	−0.05(9)	−0.35(15)	$\frac{3}{2}^-,\frac{5}{2}$
51	8.019	0.	$\frac{7}{2}^-$	−0.21(3)	−0.07(7)	$\frac{5}{2},\frac{7}{2}^-,\frac{9}{2}$
92	8.358	0.	$\frac{7}{2}^-$	−0.06(8)	−0.06(8)	$\frac{5}{2},\frac{7}{2}^-,\frac{9}{2}$
112	8.555	0.	$\frac{7}{2}^-$	0.04(11)	−0.24(12)	$\frac{5}{2},\frac{7}{2}^-,\frac{9}{2}^-$
113	8.557	0.	$\frac{7}{2}^-$	−0.29(7)	−0.07(8)	$\frac{5}{2},\frac{7}{2}^-,\frac{9}{2}$
131	8.702	0.	$\frac{7}{2}^-$	−0.30(6)	−0.07(7)	$\frac{5}{2},\frac{7}{2}^-,\frac{9}{2}$

"orphans", like those previously found in ^{59}Cu,[22] ^{51}Mn and ^{53}Mn,[21,23] they do not emulate the IAS by decaying to the 6.068 MeV antianalog state. Another common signature of $\frac{9}{2}^+$ resonances is the population in inelastic scattering of the 4^+ target state.[24] This channel was not found in any of the high-spin resonances studied in this work.

D. Bound states

A large number of spectra were recorded in the present study, and a few new spectroscopic results were obtained for bound states of ^{55}Co. Table VI lists the bound states observed. Those of established J^π were used in attributing spin-parity values to resonances. From their population in the decay of assigned resonances, inferences may be drawn limiting J^π values for some of the previously unassigned levels, mostly above 4 MeV in excitation.

High-lying bound states strongly fed from analog states may be suspected to be antianalogs. Near $A=55$, such states lie about 2.5 MeV below the corresponding analogs. The clearest examples in ^{55}Co are the $\frac{9}{2}^+$ IAS and

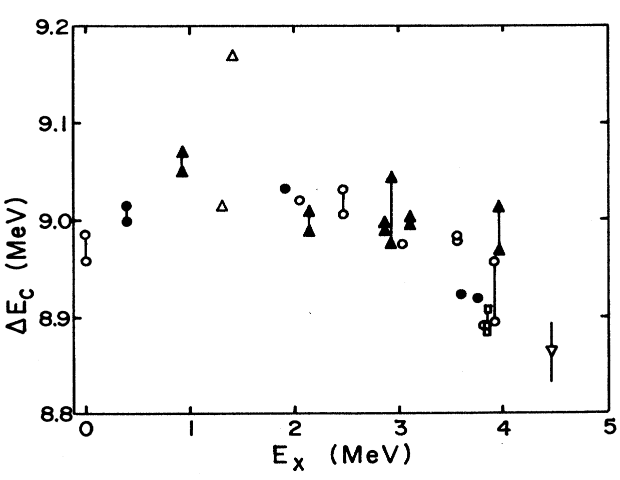

FIG. 3. Variation of the Coulomb displacement energy with excitation energy for $A=55$: ●($\frac{1}{2}^-$), ○($\frac{3}{2}^-$), ▽($\frac{5}{2}^+$), △($\frac{5}{2}^-$), ▲($\frac{7}{2}^-$), and □($\frac{9}{2}^+$).

TABLE IV. ^{54}Fe$(p,p'\gamma)$ angular distributions.

Resonance	A_2	A_4	J^π	Resonance	A_2	A_4	J^π
8	−0.03(8)	0.12(9)	$\frac{1}{2},\frac{3}{2}^-$	98	0.45(2)	−0.50(2)	$\frac{5}{2}^+$
10	0.11(5)	−0.06(6)	$\frac{3}{2}^-$	99	0.25(2)	0.00(2)	$\frac{3}{2}^-$
13	0.25(4)	−0.14(7)	$\frac{3}{2}^-,\frac{5}{2}^-$	108	0.49(2)	0.04(2)	$\frac{3}{2}^+$
16	0.46(2)	0.13(3)	$\frac{3}{2}^+$	109	0.51(3)	−0.42(3)	$\frac{5}{2}^+$
19	0.46(5)	−0.28(5)	$\frac{7}{2}^-,\frac{9}{2}^+$	110	0.34(4)	0.28(4)	$\frac{5}{2}^-$
21	0.44(4)	−0.35(4)	$\frac{5}{2}^-,\frac{7}{2}^-,\frac{9}{2}^+$	111	0.28(1)	0.54(3)	$\frac{5}{2}^-$
24	0.28(2)	−0.16(2)	$\frac{5}{2}^-,\frac{7}{2}^-,\frac{9}{2}^+\&\frac{1}{2}$	112	0.28(2)	0.31(2)	$\frac{5}{2}^-,\frac{7}{2}^-$
25A	0.62(3)	−0.45(3)	$\frac{5}{2}^+$	113	0.47(2)	−0.22(2)	$\frac{5}{2}^-,\frac{7}{2}^-,\frac{9}{2}^+$
26	0.22(2)	−0.10(3)	$\frac{3}{2}^-$	115A	0.13(4)	−0.08(4)	$\frac{3}{2}^-$
51	0.27(2)	−0.14(2)	$\frac{5}{2}^-,\frac{7}{2}^-,\frac{9}{2}^+\&\frac{1}{2}$	115B	0.04(2)	−0.02(3)	$\frac{1}{2}$
56	0.11(2)	0.01(2)	$\frac{3}{2}^-$	116	0.45(3)	−0.02(3)	$\frac{3}{2}^+$
59	0.45(2)	−0.01(2)	$\frac{3}{2}^+$	117	0.01(5)	−0.42(6)	$\frac{5}{2},\frac{7}{2}$
63	0.41(2)	−0.53(2)	$\frac{5}{2}^+$	118	−0.10(5)	−0.01(6)	$\frac{1}{2}$
64	0.17(2)	−0.21(2)	$\frac{5}{2}^+\&\frac{1}{2}$	120	0.11(4)	0.06(5)	$\frac{3}{2}^-$
65	0.51(2)	−0.33(2)	$\frac{5}{2}^-,\frac{7}{2}^-$	121	0.02(9)	−0.01(10)	$\frac{1}{2}$
66	0.22(2)	−0.04(2)	$\frac{3}{2}^-$	122	0.57(4)	−0.49(4)	$\frac{5}{2}^+$
67	0.47(2)	0.01(2)	$\frac{3}{2}^+$	123	−0.20(5)	−0.09(5)	$\frac{5}{2}^-,\frac{7}{2}^-$
68	0.19(2)	0.51(2)	$\frac{7}{2}^-$	125	0.56(4)	0.01(5)	$\frac{3}{2}^+$
69	0.52(2)	−0.42(2)	$\frac{5}{2}^+$	126	0.26(5)	−0.04(5)	$\frac{3}{2}^-$
70	0.32(2)	−0.39(2)	$\frac{5}{2}^+\&\frac{1}{2}$	129	0.44(4)	−0.42(4)	$\frac{5}{2}^+\&\frac{1}{2}$
71	0.08(2)	−0.08(2)	$\frac{1}{2}$	131	0.48(2)	−0.28(2)	$\frac{5}{2}^-,\frac{9}{2}^+$
73	0.36(2)	−0.12(2)	$\frac{5}{2}^-,\frac{7}{2}^-$	132	0.48(4)	−0.40(4)	$\frac{5}{2}^+\&\frac{3}{2}^-$
74	0.49(2)	−0.09(2)	$\frac{5}{2}^-$	137	0.47(4)	−0.01(4)	$\frac{3}{2}^+$
78	0.32(2)	−0.01(2)	$\frac{3}{2}^-$	139	0.57(4)	−0.24(4)	$\frac{5}{2}^-$
80	−0.16(2)	−0.38(2)	$\frac{5}{2}$	140	0.29(4)	0.56(5)	$\frac{5}{2}^-\ \frac{7}{2}^-$
82	0.38(2)	0.04(2)	$\frac{3}{2}^-$	141	0.33(3)	0.14(3)	$\frac{5}{2}^-$
84	0.18(2)	0.01(2)	$\frac{3}{2}^-$	145	0.12(5)	−0.06(6)	$\frac{3}{2}^-$
85	0.03(2)	0.01(2)	$\frac{1}{2}$	146	0.28(9)	0.37(10)	$\frac{5}{2}^-,\frac{7}{2}^-$
88	0.35(2)	0.03(2)	$\frac{3}{2}^-$	147	0.29(3)	0.00(3)	$\frac{3}{2}^-$
90	0.47(2)	−0.56(2)	$\frac{5}{2}^+$	148	0.45(3)	−0.28(4)	$\frac{7}{2}^-,\frac{9}{2}^+$
92	0.38(5)	−0.21(6)	$\frac{5}{2}^-,\frac{7}{2}^-,\frac{9}{2}^+$	149	0.61(4)	−0.52(4)	$\frac{5}{2}^+$
93	0.10(2)	−0.02(2)	$\frac{3}{2}^-$	150	0.65(2)	−0.45(2)	$\frac{7}{2}^-$
95	−0.05(2)	−0.21(2)	$\frac{5}{2},\frac{7}{2}$	151	0.36(4)	0.45(4)	$\frac{5}{2}^-$
96	0.07(2)	−0.01(2)	$\frac{3}{2}^-$				

TABLE V. Analog states in ^{55}Co.

^{55}Fe		^{55}Co				^{55}Fe		^{55}Co			
E_x (MeV)	J^π	Resonance	J^π	E_x (MeV)	E_c (MeV)	E_x (MeV)	J^π	Resonance	J^π	E_x (MeV)	E_c (MeV)
0.	$\frac{3}{2}^-$	a	$\frac{3}{2}^-$	4.721	8.958	1.316	$\frac{7}{2}^-$	a	$(\frac{7}{2})^-$	6.093	9.014
		a	$\frac{3}{2}^-$	4.748	8.985	1.408	$\frac{7}{2}^-$		$(\frac{5}{2}^-,\frac{7}{2}^-)$	6.341	9.170
0.411	$\frac{1}{2}^-$	a	$\frac{1}{2}^-$	5.172	8.998	1.918	$\frac{1}{2}^-$	a	$\frac{1}{2}^-$	6.713	9.032
			$(\frac{1}{2})^-$	5.189	9.014	2.052	$\frac{3}{2}^-$	a	$\frac{3}{2}^-$	6.834	9.019
0.931	$\frac{5}{2}^-$	a	$\frac{5}{2}^-$	5.743	9.049	2.144	$\frac{5}{2}^-$	a	$(\frac{5}{2})^-$	6.893	8.986
			$(\frac{5}{2}^-)$	5.764	9.069			a	$\frac{5}{2}^-$	6.917	9.010

TABLE V. (*Continued*).

^{55}Fe E_x (MeV)	J^π		Resonance	^{55}Co J^π	E_x (MeV)	E_c (MeV)	^{55}Fe E_x (MeV)	J^π		Resonance	^{55}Co J^π	E_x (MeV)	E_c (MeV)
2.470	$\frac{3}{2}^-$	a		$(\frac{3}{2}^-)$	7.239	9.006	3.599	$\frac{1}{2}^-$		85	$(\frac{1}{2})$	8.286	8.924
		a		$\frac{3}{2}^-$	7.269	9.036	3.790	$\frac{1}{2}^-$	a	105	$\frac{1}{2}$	8.472	8.919
2.578	$\frac{5}{2}^-$						3.801	$\frac{3}{2}^-$		102	$(\frac{1}{2},\frac{3}{2})$	8.455	8.891
			18	$(\frac{5}{2})$	7.626	8.991			b	103A	$\frac{9}{2}^+$	8.462	8.885
2.872	$\frac{5}{2}^-,\frac{7}{2}^-$		19	$(\frac{5}{2}^-)$	7.632	8.997	3.814	$\frac{9}{2}^+$	a,b	104A	$\frac{9}{2}^+$	8.466	8.889
			or 21	$(\frac{7}{2})$	7.649	9.014			a,b	106A	$\frac{9}{2}^+$	8.475	8.898
			21	$(\frac{7}{2})$	7.649	8.947				118	$(\frac{1}{2})$	8.595	8.925
2.939	$\frac{5}{2}^-,\frac{7}{2}^-$		23	$(\frac{5}{2})$	7.679	8.977	3.907	$\frac{1}{2}^-,\frac{3}{2}^-$		121	$(\frac{1}{2})$	8.634	8.964
			or 24	$(\frac{5}{2}^-)$	7.703	9.001				*or* 115A	$\frac{3}{2}^-$	8.566	8.896
			25	$(\frac{5}{2})$	7.746	9.044				120	$\frac{3}{2}^-$	8.627	8.957
3.028	$\frac{3}{2}^-$	a	27	$(\frac{3}{2})$	7.766	8.975				146	$\frac{5}{2}^-,\frac{7}{2}^-$	8.789	8.969
			34	$(\frac{5}{2})$	7.868	8.996	4.057	$\frac{5}{2}^-,\frac{7}{2}^-$		151	$(\frac{5}{2}^-)$	8.833	9.013
3.109	$\frac{5}{2}^-,\frac{7}{2}^-$		35	$(\frac{5}{2})$	7.875	9.003				*or* 148	$(\frac{7}{2}^-)$	8.802	8.982
			or 37	$(\frac{7}{2})$	7.884	9.012				150	$\frac{7}{2}^-$	8.824	9.004
3.552	$\frac{3}{2}^-$	a	87	$(\frac{1}{2},\frac{3}{2})$	8.293	8.978	4.463	$\frac{5}{2}^+$	a	c	$\frac{5}{2}^+$	9.090	8.864
			88	$\frac{3}{2}^-$	8.298	8.983							

[a]Reference 1.
[b]Reference 12.
[c]Reference 11.

TABLE VI. Bound states in ^{55}Co.

E_x (MeV)	J^π a	b	Resonance	E_x (MeV)	J^π a	b	Resonance
0.0	$\frac{7}{2}^-$			4.264		$(\frac{3}{2},\frac{5}{2})$	8,35,61,83
2.166	$\frac{3}{2}^-$			4.339		$(\frac{9}{2})$	104A,104B,106A
2.566	$\frac{3}{2}^-$			4.474		$(\frac{5}{2}^+)$	35,83,106A
2.659	$\frac{5}{2}^-$			4.548	$\frac{5}{2}^-$		
2.918	$\frac{7}{2}^-$			4.587		$(\frac{5}{2})$	21,34,51,61,104B
2.922	$\frac{1}{2}^+$			4.628	$\frac{1}{2}^-,\frac{3}{2}^-$	$(\frac{3}{2})$	46B,61,63,95
2.939	$\frac{1}{2}^-$			4.721	$\frac{3}{2}^-$		
2.976	$\frac{9}{2}^-$			4.748	$\frac{3}{2}^-$		
2.992	$(\frac{3}{2})^-$	$(\frac{1}{2},\frac{3}{2})$	105	4.851		$(\frac{1}{2}-\frac{5}{2})$	13
3.303	$\frac{5}{2}^-$			4.961	$(\frac{1}{2})$	$(\frac{1}{2}-\frac{5}{2})$	20,27
3.323	$\frac{1}{2}^-$			4.988		$(\frac{3}{2}^-,\frac{5}{2})$	13,19,21
3.563	$(\frac{3}{2}^+)$	$(\frac{3}{2})$	14,16,95	5.099		$(\frac{3}{2}-\frac{7}{2})$	16,27
3.643	$\frac{3}{2}^-$			5.121		$(\frac{1}{2}-\frac{5}{2})$	15,24
3.725	$\frac{5}{2}^-$			5.259		$(\frac{5}{2})$	13,16
3.859		$(\frac{5}{2}^+)$	19,21,23,57,61,106B	5.351		$(\frac{5}{2}-\frac{9}{2})$	21
3.942	$\frac{1}{2}^-\frac{3}{2}^-$	$(\frac{1}{2})$	9,36,51,73	5.560	$\frac{1}{2}^-,\frac{3}{2}^-$	$(\frac{3}{2}-\frac{7}{2})$	23
4.164	$\frac{1}{2}^-$			5.642		$(\frac{1}{2}-\frac{7}{2})$	15
4.177	$\frac{5}{2}^-$			6.068	$\frac{9}{2}^+$		

[a]Reference 1.
[b]This work.

AIAS at 8.47 and 6.07 MeV and the $\frac{3}{2}^-$ IAS and AIAS at 4.72 and 4.75 and 2.17 and 2.57 MeV. In addition to their decay to antianalogs, analog states are often characterized by decay to other levels of strong single-particle nature. In ^{55}Co only the $g_{9/2}$ and $f_{7/2}$ strengths are strongly concentrated, so the usual simple decay modes of analogs are not to be expected, nor are they seen. It is interesting that the $\frac{9}{2}^+$ and $\frac{7}{2}^-$ analogs decay strongly not only to the $\frac{7}{2}^-$ ground state but also to the 2.918 MeV level. It is likely that this state also has a large single particle content, missed in the proton stripping experiments because of the presence of nearby low-l states.

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