Charlesworth, K. P. Jackson, N. Anyas-Weiss, and B. Lalović, Can. J. Phys. 44, 3075 (1966).
[6]A. Gilbert and A. G. W. Cameron, Can. J. Phys. 43, 1446 (1965).
[7]W. M. Mason, G. Kernel, J. L. Black, and N. W. Tanner, Nucl. Phys. A135, 193 (1969).
[8]D. M. Van Patter, Bull. Am. Phys. Soc. 15, 573 (1970).
[9]J. B. Ball, Bull. Am. Phys. Soc. 15, 574 (1970).
[10]L. M. Bollinger and G. E. Thomas, Phys. Rev. Letters 21, 233 (1968).
[11]C. F. Williamson, J.-P. Boujat, and J. Picard, Commissariat à l' Energie Atomique Report No. CEA 3042, 1966 (unpublished).
[12]T. Ericson and T. Mayer-Kuckuk, Ann. Rev. Nucl. Sci. 16, 183 (1966).
[13]S. M. Shafroth, P. N. Trehan, and D. M. Van Patter, Phys. Rev. 129, 704 (1963).
[14]J. Picard and G. Bassani, Nucl. Phys. A131, 636 (1969).
[15]A. Scott, M. L. Whiten, and W. G. Love, Nucl. Phys. A137, 445 (1969).
[16]C. E. Porter and R. G. Thomas, Phys. Rev. 104, 483 (1956).
[17]For example, see D. J. Hughes and R. L. Zimmerman, in *Nuclear Reactions*, edited by P. M. Endt and M. Demeur (North-Holland Publishing Company, Amsterdam, The Netherlands, 1959), Vol. I.
[18]P. Axel, Phys. Rev. 126, 671 (1962).
[19]W. Hauser and H. Feshbach, Phys. Rev. 87, 366 (1952).
[20]L. M. Bollinger and G. E. Thomas, Phys. Rev. C 2, 1951 (1970).
[21]F. G. Perey, Phys. Rev. 131, 745 (1963).
[22]L. M. Bollinger, in *Proceedings of the International Symposium on Nuclear Structure, Dubna, 1968* (International Atomic Energy Agency, Vienna, Austria, 1968).
[23]A. M. Lane and J. E. Lynn, Proc. Phys. Soc. (London) A70, 557 (1957).

PHYSICAL REVIEW C VOLUME 3, NUMBER 1 JANUARY 1971

^{40}K$(n, \gamma)^{41}$K Reaction and the Level Structure of ^{41}K†

D. F. Beckstrand* and E. B. Shera
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87544
(Received 18 September 1970)

The low-lying level structure of ^{41}K has been studied using the thermal-neutron capture reaction ^{40}K$(n,\gamma)^{41}$K on an isotopically separated target of ^{40}K. The γ-ray spectrum from this reaction has been studied in the energy range from 0.1 to 10.1 MeV using a Li-drifted Ge spectrometer system. γ-γ coincidence measurements using Ge(Li) detectors have also been made. Spin and parity assignments for the excited states below 2450 keV are proposed, primarily on the basis of γ-ray branching to levels with established spin and parity values. The proposed level energy [keV(I^π)] values are $0(\frac{3}{2}^+)$, $980.4(\frac{1}{2}^+)$, $1293.4(\frac{7}{2}^-)$, $1559.9(\frac{1}{2}^+)$, $1582.0(\frac{5}{2}^+)$, $1677.5(\frac{5}{2}^+, \frac{7}{2}^+)$, $1698.1(\frac{5}{2}^\pm, \frac{7}{2}^+)$, $2144.1(\frac{5}{2}^+)$, $2166.0(\frac{1}{2}^+, \frac{3}{2}^\pm)$, $2316.5(\frac{5}{2}^+, \frac{7}{2}^+)$, $2447.9(\frac{1}{2}^\pm, \frac{3}{2}^\pm)$. Additional levels have been observed at 2494.7, 2507.9, 2527.9, 2599.8, 2681.5, 2712.2, 2756.5, 2760.7, 3042.1, 3142.1, 3164.5, 3213.4, 3235.6, and 3281.1 keV. These low-lying excited states of ^{41}K are discussed in terms of two-particle, one-hole configurations of the form $p(d_{3/2})^{-1}n(f_{7/2})^2$.

I. INTRODUCTION

This work describes an investigation of the ^{41}K energy levels below ≈3.3 MeV that are populated in the ^{40}K$(n,\gamma)^{41}$K reaction. The low-lying excited levels of ^{41}K have been studied previously by observation of the radioactive decay of ^{41}Ar and ^{41}Ca and by a variety of charged-particle reactions.[1–4] The principal sources of information have been studies of the ^{41}K$(p,p')^{41}$K reaction[2] and the ^{40}Ar$(p,\gamma)^{41}$K reaction,[3] which have identified a rather large number of levels. In addition, spin and parity values have been proposed for the ground state and the five lowest excited levels.[4–7]

No direct study of the ^{40}K$(n,\gamma)^{41}$K reaction has been reported previously, and the only data available on this reaction are from an early pair-spectrometer study in which a natural potassium target was used.[8] Three weak transitions observed in that study were assigned to ^{41}K because they had energies in excess of the binding energy of the other naturally occurring potassium isotopes.

II. EXPERIMENTAL PROCEDURE

A. Capture γ-Ray Spectrum

The thermal-column through-port capture γ-ray facility at the Los Alamos Omega West Reactor was used to record the ^{40}K(n,γ) spectrum. This facility has been described in detail elsewhere.[9] The spectrum was studied throughout the energy range of 0.1–10.1 MeV. The thermal-neutron flux at the target was $\approx 3\times10^{11}$ n/cm^2 sec.

The ^{40}K target was obtained from Oak Ridge National Laboratory and consisted of 55.7 mg of K_2CO_3 powder enriched to 30.3% in ^{40}K. To identify those lines in the spectrum arising from contaminating isotopes, a natural potassium target was also studied.

The target material, enclosed in a high-purity graphite sample container, was inserted into an evacuated Bi channel in the thermal column of the Omega West Reactor. A Ge(Li) detector, located ≈6 m from the target, viewed the sample through a series of collimators.

The spectrometer system used consisted of an ≈6-cm^3 Ge(Li) detector, surrounded by a large bifurcated NaI(Tl) annulus (20 cm diam by 30 cm long, with a 6.5-cm bore along its axis). The Ge(Li) detector has an energy resolution width of ≈4 keV at 1.0 MeV and a resolution of ≈6 keV at 8 MeV. In the energy range below 2 MeV the system was operated as a total-energy spectrometer (anticoincidence mode). For energies >2 MeV the system was operated as a two-quantum escape-pair spectrometer (pair-production mode). The spectra obtained with both modes are substantially free of underlying Compton distributions.

TABLE I. High-energy γ rays from the $^{40}K(n,\gamma)^{41}K$ reaction.

Line No.	γ-ray energy (keV)	Partial cross section (mb)	Excitation energy (keV)
1	8802.5 ± 0.4	351 ± 73	1293.5
2	8579.2 ± 0.5	22 ± 5	1516.8
3	8513.7 ± 0.4	55 ± 12	1582.3
4	8417.7 ± 0.4	34 ± 8	1678.2
5	8397.6 ± 0.4	55 ± 13	1698.3
6	7951.2 ± 0.4	816 ± 180	2144.8
7	7791.5 ± 1.1	56 ± 19	2304.5
8	7779.1 ± 0.4	2613 ± 570	2316.9
9	7601.5 ± 0.5	93 ± 21	2494.5
10	7588.3 ± 0.4	189 ± 42	2507.6
11	7416.6 ± 0.7	84 ± 23	2679.3
12	7384.5 ± 0.4	679 ± 150	2711.5
13	7340.2 ± 0.4	626 ± 140	2755.8
14	6979.7 ± 0.7	38 ± 11	3116.2
15	6953.6 ± 0.4	596 ± 140	3142.4
16	6882.2 ± 0.4	489 ± 110	3213.8
17	6860.7 ± 1.0	75 ± 26	3235.3
18	6663.9 ± 0.4	254 ± 57	3432.1
19	6646.0 ± 0.5	93 ± 23	3450.0
20	6629.3 ± 0.7	38 ± 10	3466.7
21	6620.6 ± 0.5	65 ± 15	3475.4
22	6607.2 ± 0.6	27 ± 7	3488.8
23	6574.7 ± 0.5	56 ± 15	3521.3
24	6561.2 ± 1.0	192 ± 43	3534.8
25	6535.5 ± 1.0	27 ± 6	3560.5
26	6500.8 ± 1.5	11 ± 4	3595.2
27	6483.5 ± 1.0	38 ± 9	3612.5
28	6452.8 ± 1.2	13 ± 4	3643.2
29	6445.1 ± 1.0	124 ± 28	3650.9
30	6395.5 ± 1.1	23 ± 6	3700.5
31	6333.6 ± 0.2	498 ± 100	3762.4
32	6320.4 ± 0.3	251 ± 55	3775.5
33	6289.4 ± 0.5	69 ± 16	3806.6
34	6268.0 ± 0.2	267 ± 56	3827.9
35	6225.5 ± 0.3	48 ± 11	3870.5
36	6111.5 ± 0.5	177 ± 51	3984.5
37	6098.7 ± 0.2	1715 ± 350	3997.3
38	6068.6 ± 0.2	46 ± 10	4027.3

The capture γ-ray spectra were recorded with a 1600-channel pulse-height analyzer in four separate runs covering the energy ranges 0.1–2.1, 1.6–4.6, 4.0–6.8, and 6.1–10.1 MeV.

Correction for the nonlinearity of the electronic system was made using a precision pulser to provide reference points at ≈70 channel intervals. Digital gain stabilization was applied to the analyzer analog-to-digital converter to obviate electronic drifts. The stabilizer was locked on artificially generated peaks which were produced by a highly stable pulser.[10] This pulser produces two independent pulse amplitudes so that both the gain and the zero intercept of the analyzer can be simultaneously stabilized. During runs lasting as long as 23 h, no line broadening was observed.

For energies <2 MeV both the relative detection efficiency of the spectrometer and the energy calibration were determined from measurements on a series of calibrated radioactive sources. Above 2 MeV the spectrometer calibration was performed using as standards the energies[11] and cross sections[12] of the $^{14}N(n,\gamma)^{15}N$ lines emitted from a melamine target.

The spectral data were analyzed with the aid of a variable-metric minimization computer program which least-squares fitted a Gaussian function to the observed peaks. This technique permits the energies of the more intense γ-ray transitions to be determined with an accuracy of ≈0.5 keV.

B. γ-γ Coincidence Studies

Coincidences of low-energy γ transitions with other low-energy γ transitions (low-low coincidences) were studied with the coincidence capture γ-ray facility at the Los Alamos Omega West Reactor. The general features of this facility have been described in a previous paper.[13] A neutron beam, $\frac{3}{8}$ in. in diameter, with an intensity of about 3×10^6 n/sec impinges on the target, which is placed outside the biological shield of the reactor. The two Ge(Li) detectors used in the present measurements had active volumes of 35 and 45 cm^3. The detectors were placed close to the neutron beam, 180° apart, and in a line perpendicular to the beam. A thin ceramic disk containing ^{6}LiF was placed between each detector and the target to

TABLE II. Low-energy γ rays from the $^{40}K(n,\gamma)^{41}K$ reaction.

Line No.	γ-ray energy (keV)	Partial cross section (mb)	Level assignment	Confidence
1	198.8±0.5	146±50		
2	246.8±0.4	274±85		a
3	380.8±1.4	48±41		
4	384.2±1.2	69±48	1678→1293	b
5	396.2±0.4	235±74	2712→2317	c
6	445.8±0.4	114±38	2144→1698	c
7	510.9±0.4		Annihilation radiation	
8	516.6±0.7	281±100	2682→2166	b
9	579.3±0.4	443±140	1560→980	c
10	584.1±0.4	599±200	2144→1560	c,d
11	584.2±0.4	147±82	2166→1582	c,d
12	601.2±0.4	460±140	1582→980	c
13	613.1±0.4	328±100	2757→2144	c
14	622.4±1.2	60±26		
15	634.1±0.5	345±110	3142→2508	c
16	640.2±1.3	68±37	2317→1678	b
17	655.9±0.5	282±91	3165→2508	e
18	670.5±0.4	219±70	3165→2495	e
19	694.0±0.5	98±36	3142→2448	b
20	719.2±0.7	98±49	3213→2495	b
21	733.8±0.5	331±120	2317→1582	c
22	788.4±0.8	222±130	3236→2448	b
23	796.9±0.4	407±130	2495→1698	c
24	817.5±0.4	1305±420	2495→1678	c
25	830.5±0.4	1342±430	2508→1678	c
26	850.4±0.4	1536±480	2528→1678	a
27	896.0±0.5	158±59	3213→2317	b
28	918.9±0.4	335±110	3236→2317	c
29	947.6±0.5	178±63	2508→1560	e
30	980.4±0.4	1504±470	980→0	c
31	1006.7±1.3	343±160		
32	1012.7±1.8	321±200	2712→1698	c
33	1017.0±1.4	474±220		
34	1022.9±0.4	4970±1530	2317→1293	c
35	1039.8±0.4	347±110	2600→1560	b
36	1110.1±0.6	243±90		
37	1122.2±0.5	154±61	2682→1560	b
38	1130.6±0.5	492±160	2712→1582	c
39	1164.1±0.5	505±160	2144→980	c
40	1185.8±0.4	225±76	2166→980	c
41	1201.4±0.4	1723±530	2495→1293	c
42	1214.1±0.6	190±87	2508→1293	c
43	1261.7±0.4		$^{12}C(n,\gamma)$	
44	1293.6±0.4	18719±5850	1293→0	c
45	1418.9±0.4	1525±470	2712→1293	c
46	1467.3±0.4	1717±530	2761→1293	c
47	1560.0±0.4	1743±530	1560→0	c
48	1582.0±0.4	1428±440	1582→0	c
49	1677.3±0.4	8031±2460	1678→0	c
50	1697.9±0.4	2957±900	1698→0	c
51	1734.8±0.6	224±97		
52	1737.9±0.9	174±83		
53	1778.5±0.8		$^{27}Al(n,\gamma)$	
54	1849.0±0.8	1307±300	3142→1293	c
55	1895.3±0.9	354±120		
56	1920.0±0.8	643±170	3213→1293	c
57	1942.1±0.9	539±200	3236→1293	c
58	1946.4±1.2	322±170		
59	1950.3±1.2	224±140		
60	1973.9±0.9	270±79		
61	2047.7±1.1	138±54		
62	2062.0±1.3	106±45	3042→980	b
63	2114.4±0.9	325±83		
64	2138.7±0.9	506±140		
65	2144.1±0.8	1655±370	2144→0	b
66	2156.6±0.9	469±130		
67	2167.0±1.3	152±85	2166→0	b
68	2171.4±1.3	156±82		
69	2194.5±1.2	128±62		
70	2202.2±1.3	122±62		
71	2214.6±1.1	266±79		
72	2223.3±0.8		$H(n,\gamma)$	
73	2240.9±1.0	257±77		
74	2248.4±1.3	116±61		
75	2298.3±0.9	135±44		
76	2316.1±0.9	261±77	2317→0	b
77	2319.6±0.9	362±95		
78	2415.1±1.1	184±70		
79	2431.6±1.3	115±52		
80	2437.3±1.0	335±98		
81	2441.6±1.1	202±76		
82	2448.0±1.1	120±53	2448→0	a
83	2460.3±1.0	43±18		
84	2467.7±0.8	162±37		
85	2481.5±0.8	230±50		
86	2487.7±0.8	460±95		
87	2502.6±0.8	352±75		
88	2508.4±0.8	959±200	2508→0	b
89	2532.7±0.8	141±35		
90	2541.8±1.1	77±26		
91	2562.4±0.8	198±46		
92	2600.1±1.3	74±35	2600→0	b
93	2605.2±0.9	126±49		
94	2669.1±0.9	366±89		
95	2677.0±1.1	116±46		
96	2681.9±1.3	61±36	2682→0	b
97	2688.9±1.0	141±47		
98	2702.8±1.0	126±48		
99	2734.7±0.8	185±40		
100	2757.0±0.8	931±200	2757→0	b
101	2764.0±0.9	145±40		
102	2852.2±0.8	253±59		
103	2865.0±0.8	183±49		
104	2899.9±0.8	165±38		
105	2928.0±1.0	185±57		
106	2935.6±0.9	292±75		
107	2950.5±0.8	486±110		
108	2967.6±2.1	73±36		
109	2981.3±0.8	697±160		
110	3024.3±1.0	140±38		
111	3041.5±1.0	219±58	3042→0	b

TABLE II *(Continued)*

Line No.	γ-ray energy (keV)	Partial cross section (mb)	Level assignment	Confidence
112	3047.9 ± 1.6	137 ± 65		
113	3052.4 ± 1.8	153 ± 53		
114	3067.0 ± 1.1	136 ± 41		
115	3073.9 ± 0.8	373 ± 84		
116	3089.6 ± 0.9	62 ± 19		
117	3099.4 ± 0.8	147 ± 37		
118	3145.9 ± 0.9	121 ± 31		
119	3152.6 ± 0.9	91 ± 24		
120	3163.4 ± 0.8	203 ± 48		
121	3179.9 ± 0.8	215 ± 49		
122	3229.1 ± 0.9	181 ± 45		
123	3244.1 ± 0.9	123 ± 30		
124	3251.9 ± 0.9	174 ± 40		
125	3259.6 ± 0.8	375 ± 82		
126	3281.1 ± 1.1	58 ± 18	3281 → 0	b

[a]See discussion in Sec. IV B.
[b]Energetically possible.
[c]Definite – coincidence evidence.
[d]This doublet is unresolved in the singles spectrum. Intensities are apportioned from the coincidence data.
[e]Probable – not certain.

prevent scattered neutrons from reaching the detectors. In the 180° geometry coincidences can result from the backscatter of a single γ ray from one detector into the other. Several such backscatter peaks appear in the coincidence data and have been appropriately identified.

A 1600 × 1600-channel two-parameter magnetic-tape storage analysis system was used to record the coincidence spectra. The average true-to-chance coincidence ratio was ≈11. The coincidence studies required approximately three weeks, during which time electronic drifts were obviated by digital stabilization. In total, about 1.6×10^7 coincidence events were recorded. The primary mode

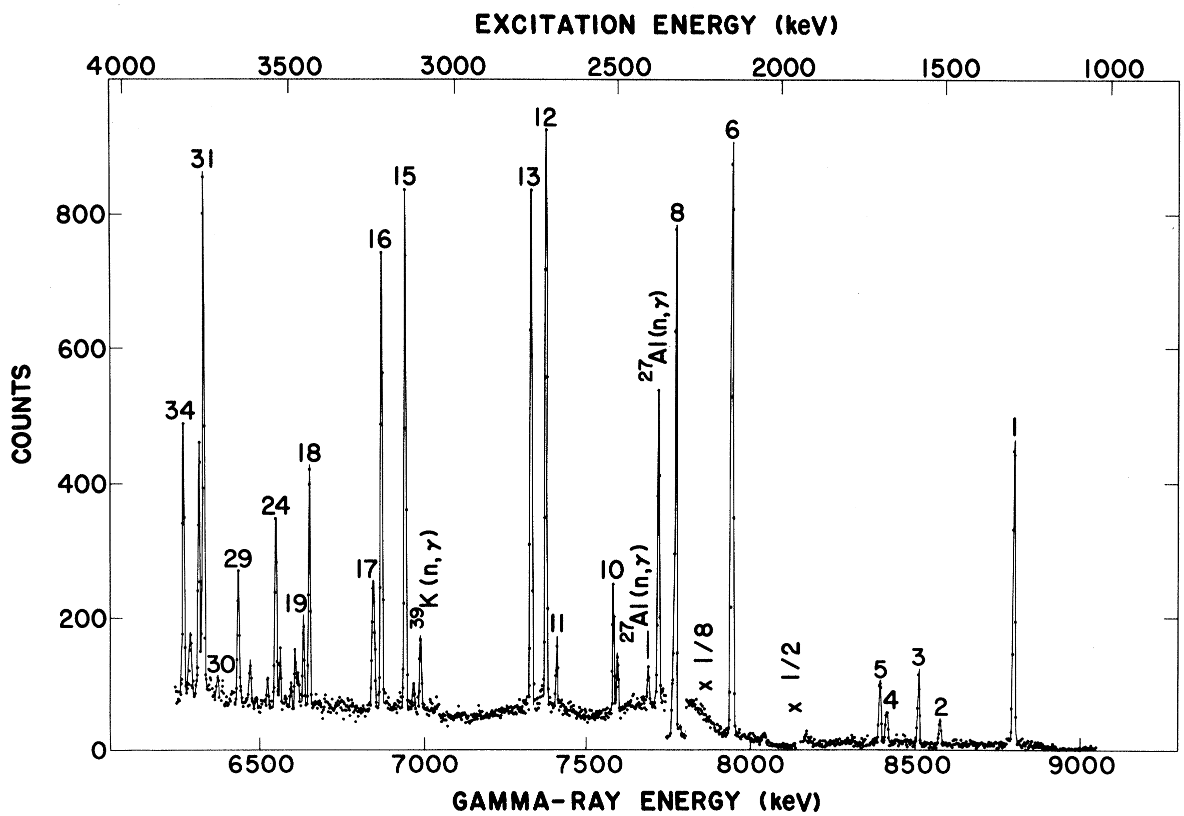

FIG. 1. High-energy portion of the γ-ray spectrum from the $^{40}K(n,\gamma)^{41}K$ reaction, obtained with a Ge(Li) detector. Only double-escape peaks are present in this spectrum (Sec. II A) and the abscissa is the γ-ray energy to be associated with the double-escape peaks. The numbered peaks correspond to entries in Table I.

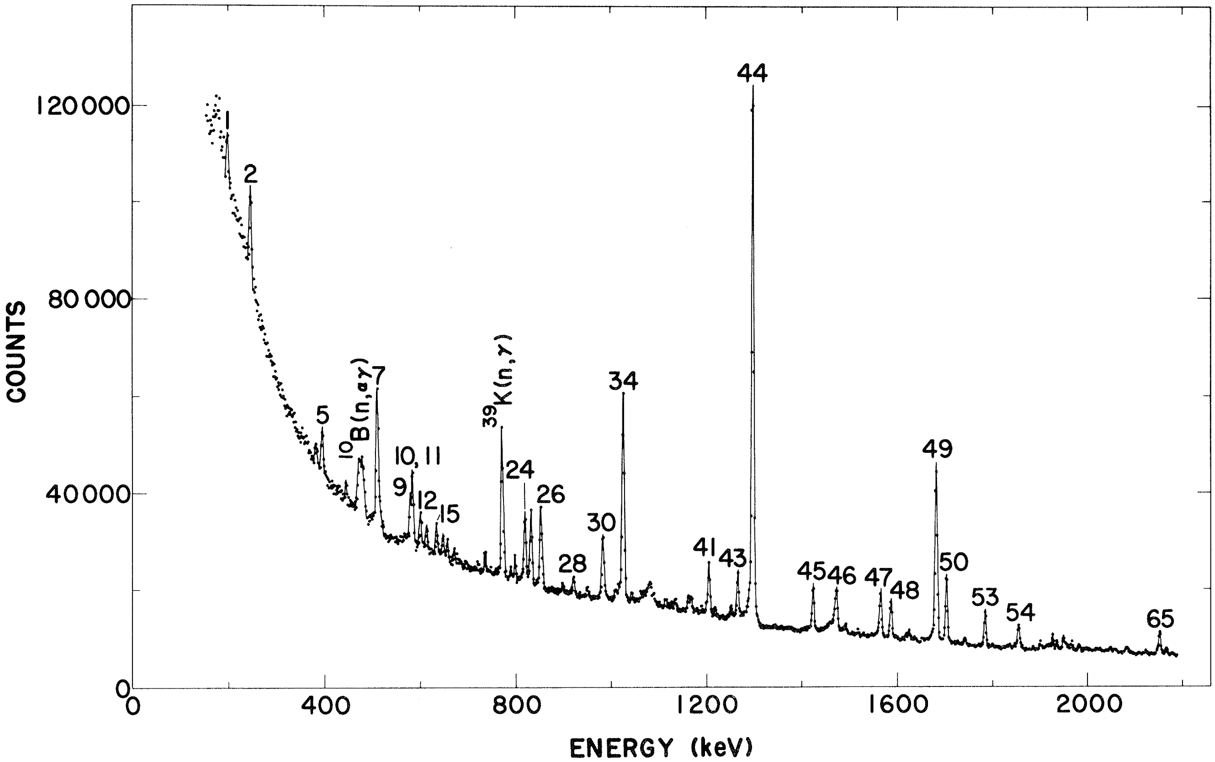

FIG. 2. Low-energy portion of the γ-ray spectrum from the $^{40}K(n,\gamma)^{41}K$ reaction, obtained with a Ge(Li) detector. The detector was operated inside a large anticoincidence NaI annulus (Sec. II A). The numbered peaks correspond to the γ rays listed in Table II.

of data processing was to scan the data tape to obtain the spectrum in coincidence with particular transitions.

III. EXPERIMENTAL RESULTS

Analysis of the $^{40}K(n,\gamma)^{41}K$ γ-ray spectra yields the results summarized in Tables I and II. Excluded from each table are some γ rays which were observed but which have been identified as arising from contaminants. The major source of such contamination is the $^{39}K(n,\gamma)^{40}K$ reaction. No γ rays were observed which could be attributed to either the $^{40}K(n,p\gamma)^{40}Ar$ or the $^{40}K(n,\alpha\gamma)^{37}Cl$ reactions.

Figures 1 and 2 show portions of the ^{40}K capture γ-ray spectra. In these figures the lines are numbered to correspond to the tables, and the more intense peaks due to contaminants are identified.

The radiative capture cross section σ_c for ^{40}K can be determined from the relationship

$$\sigma_c = \frac{1}{B_n} \sum_{\gamma} E_\gamma \sigma_\gamma ,$$

where B_n is the neutron binding energy of ^{41}K, σ_γ is the partial cross section of the γ ray with energy E_γ, and the sum is taken over all transitions. From this equation the cross section was calculated to be $\sigma_c = 30 \pm 8$ b, which is considerably below the value of 70 ± 20 b reported in the work of Hughes and Schwartz.[14]

The results of the low-low γ-γ coincidence mea-

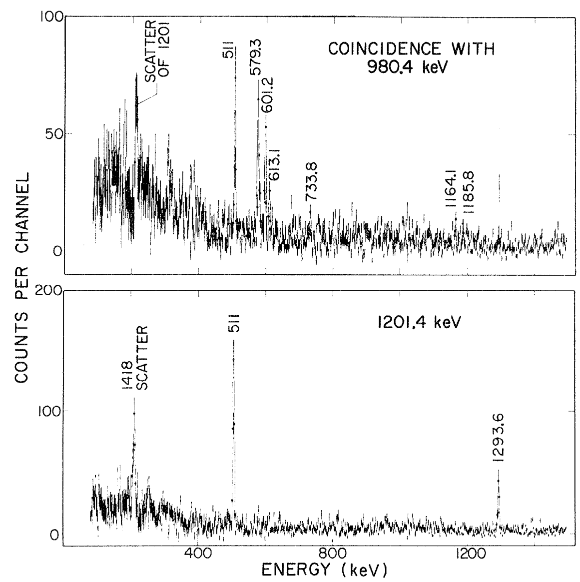

FIG. 3. $^{40}K(n,\gamma\gamma')$. Spectra of low-energy γ rays in coincidence with the 980.4- and 1201.4-keV transitions.

TABLE III. Relative intensities of low-energy transitions from the reaction $^{40}K(n, \gamma)^{41}K$ as observed in coincidence with other low-energy transitions. Intensities are normalized to unity for the strongest line in each coincidence spectrum. Blanks indicate that no coincidence was observed. Errors in the listed intensities vary from about ±10% for the more intense lines to about ±30% for the weaker lines.

γ-ray energy (keV)	817	830	850	980	1022	1201	1293	1467	1560	1582	1677	1697	1849
246			0.11								0.18		
396					0.05		0.07						
445												0.36	
579				1.00									
584				0.39					1.00	0.44			
601				0.75									
613				0.28									
634		0.14									0.14		
655		0.08											
670							0.04						
733										0.17			
796												1.00	
817											0.89		
830											1.00		
850											1.00		
918					0.08		0.09						
947									0.10				
1012												0.32	
1022							1.00						
1130										1.00			
1164				0.32									
1185				0.21									
1201							0.27						
1214							0.10						
1293					1.00	1.00		1.00					1.00
1418							0.52						
1467							0.49						
1677	1.00	1.00	1.00										
1697													
1849							0.28						
1920							0.14						
1942							0.26						

surements for the $^{40}K(n, \gamma)^{41}K$ reaction are presented in Table III, and some sample spectra are shown in Figs. 3 and 4.

IV. INTERPRETATION

A. General Considerations

A level scheme which summarizes the experimental results is shown in Fig. 5. The primary γ-ray transition energies together with the $^{41}K(p, p')$ data[2] were used to locate low-lying levels. The coincidence data were then used to define the positions of the low-energy transitions in the level scheme. Some transitions whose locations were not definitely established by the coincidence data were assigned on the basis of energy and intensity considerations. There remain a few low-energy transitions for which no unique assignment could be determined from the existing data. Presumably, most of these unassigned transitions involve states of high excitation energy.

A computer routine was used to search for alternate placements of the transitions among the known levels as well as to attempt to define new levels on the basis of energy loops involving the known transitions. Table II indicates the level of origin for each assigned transition and the degree of confidence ascribed to that assignment. These confidence specifications are based, in part, on the results of the computer analysis described above.

B. Level Energies

A weighted least-squares analysis was used to obtain the level energies shown in Fig. 5. In this analysis "best values" for the level energies were deduced from the energies of the known γ-ray transitions. In Table IV these level energies are listed and compared with level excitation energies derived from the $^{41}K(p, p')$ data.[2]

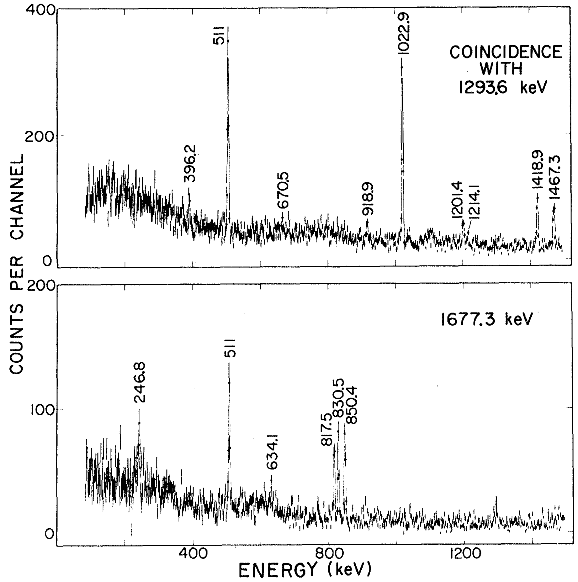

FIG. 4. ^{40}K$(n,\gamma\gamma')$. Spectra of low-energy γ rays in coincidence with the 1293.6- and 1677.3-keV transitions.

A value of $B_n = 10\,096.0 \pm 0.8$ keV was deduced for the neutron binding energy of ^{41}K on the basis of the least-squares level-energy analysis. This value is slightly higher than the value of 10 090.5 ± 3.7 keV listed in current Q-value tables.[15, 16]

Not shown in Fig. 5 are possible levels at 1516.8, 2304.5, and 3116.2 keV. Evidence for the existence of each of these levels consists of the observation of a low-intensity high-energy γ transition, which is assumed to directly populate the level. No transitions depopulating these levels were observed, which is perhaps not unexpected in view of the low intensity of the primary transitions.

On the basis of the coincidence studies two additional levels are suggested. In particular, a moderately intense transition with an energy of 1467.3 keV is seen in coincidence with only a single line, namely, the strong transition which depopulates the 1293.4-keV level. This result is most reasonably interpreted as evidence of a 1467.3–1293.4-keV cascade which depopulates a previously unobserved level at 2760.7 keV. Similarly, a level at 2527.9 keV is suggested by the coincidence of the 850.4-keV transition with the previously assigned 1677.3-keV transition. This latter proposal is

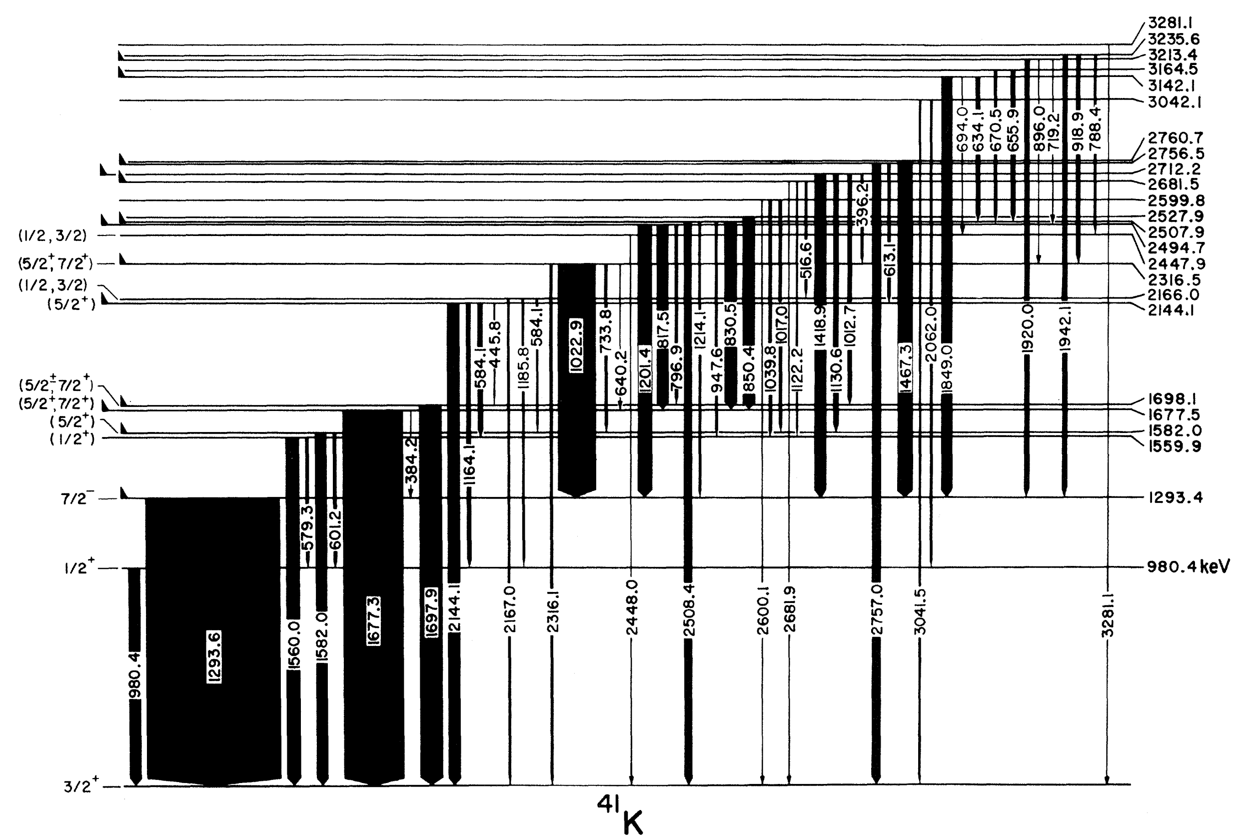

FIG. 5. Level structure of ^{41}K. All energies are in keV. γ-ray intensities are proportional to the widths of the lines representing them. Flags on the left indicate direct population by primary transitions.

TABLE IV. Comparison of the ^{41}K level excitation energies deduced from the $^{40}K(n,\gamma)^{41}K$ reaction and the $^{41}K(p,p')^{41}K$ reaction.

Level No.	Level energy from $^{40}K(n,\gamma)^{41}K$ (keV)	Level energy from $^{41}K(p,p')^{41}K$ [a] (keV)
1	980.4 ± 0.4	978 ± 6
2	1293.4 ± 0.4	1291 ± 6
3	1516.8 ± 0.6	···
4	1559.9 ± 0.4	1559 ± 6
5	1582.0 ± 0.4	1580 ± 6
6	1677.5 ± 0.6	1675 ± 6
7	1698.1 ± 0.7	1696 ± 6
8	2144.1 ± 0.5	2143 ± 6
9	2166.0 ± 0.9	2165 ± 6
10	2304.5 ± 1.1	···
11	2316.5 ± 0.7	2315 ± 6
12	2447.9 ± 0.7	2438 ± 6
13	2494.7 ± 0.5	2493 ± 6
14	2507.9 ± 0.5	2507 ± 6
15	2527.9 ± 0.7	···
16	2599.8 ± 0.7	2588 ± 6
17	2681.5 ± 1.5	2673 ± 6
18	2712.2 ± 0.9	2709 ± 6
19	2756.5 ± 0.8	2755 ± 6
20	2760.7 ± 0.7	···
21	3042.1 ± 0.8	3045 ± 6
22	3116.2 ± 0.7	···
23	3142.1 ± 0.5	3139 ± 6
24	3164.5 ± 1.0	3173 ± 6
25	3213.4 ± 0.6	3212 ± 6
26	3235.6 ± 0.6	3230 ± 6
27	3281.1 ± 1.1	3279 ± 6

[a] Excitation energies are from Kelley, Moore, and Enge (Ref. 2).

more tentative, since both the 850.4- and 1677.3-keV transitions are seen in coincidence with an unassigned 246.8-keV γ ray.

In an earlier paper[8] it was proposed that a high-energy (9390 ± 60-keV) transition may populate directly a level at ≈710 keV. In the present work no evidence was found for either a γ ray with $E_\gamma \approx 9390$ keV or a level at 710 keV.

C. Spin and Parity Assignments

Since ^{40}K has a ground-state spin and parity of 4^-,[17] the compound state formed through capture of a thermal neutron must have a spin and parity of $\frac{7}{2}^-$ or $\frac{9}{2}^-$. It is assumed that dipole transitions from the capturing state predominate in the high-energy capture spectrum, so that ^{41}K levels with $I^\pi = (\frac{5}{2}, \frac{7}{2}, \frac{9}{2}, \frac{11}{2})^\pm$ should be populated strongly by direct transitions. Levels with spins outside this range can be excited, of course, by secondary γ-ray transitions.

Ground State

The ^{41}K ground-state spin has been measured to be $\frac{3}{2}$ by means of molecular-beam techniques.[18] ^{41}K falls near the Schmidt limit for which $I=j=l-\frac{1}{2}$, implying $l=2$ and hence positive parity. As would be expected, no transition was observed to proceed directly from the capture state to the $\frac{3}{2}^+$ ground state in the $^{40}K(n,\gamma)^{41}K$ reaction.

980.4-keV Level

The assignment of $I^\pi = \frac{1}{2}^+$ for the 980.4-keV level is discussed by Sharp *et al.*[7] and is supported by the inelastic neutron scattering study of Nichols and McEllistrem,[5] and the $^{42}Ca(d,{}^3He)^{41}K$ study of Yntema.[4] The present work also supports this assignment, since no direct transition to this level from the capture state is observed.

1293.4-keV Level

The isomeric level at 1293.4 keV has been assigned[19,20] $I^\pi = \frac{7}{2}^-$ on the basis of the multipolarity ($M2$) of the transition to the ground state. This multipolarity was deduced from a half-life measurement of $\approx 6.7\times10^{-9}$ sec for the 1293.4-keV level. The inelastic neutron scattering study[5] and the $^{42}Ca(d,{}^3He)$ study[4] support this assignment. This level is the lowest-lying level found to be populated directly in the $^{40}K(n,\gamma)^{41}K$ reaction. The direct (n,γ) population is consistent with the $\frac{7}{2}^-$ assignment.

1559.9-keV Level

The level at 1559.9 keV is not observed to be populated directly in the $^{40}K(n,\gamma)^{41}K$ reaction, so it probably has a spin outside the range $\frac{5}{2} \le I \le \frac{11}{2}$. Inelastic neutron scattering studies[5] are in agreement with this limitation and suggest a spin range of $I \le \frac{5}{2}$ for this level. Since the 1559.5-keV level decays to the $\frac{3}{2}^+$ ground state and to the $\frac{1}{2}^+$ level at 980.4 keV, but not to the $\frac{7}{2}^-$ level at 1293.4 keV, the most probable spin assignment for this level is $I=\frac{1}{2}$ or $\frac{3}{2}$. The 1559.9-keV level may be identical with one excited at 1590 ± 40 keV in the $^{42}Ca(d,{}^3He)^{41}K$ reaction. On the basis of the $^{42}Ca(d,{}^3He)^{41}K$ study, Yntema[21] has suggested $I^\pi = \frac{1}{2}^+$ for the ≈1590-keV level.

1582.0-keV Level

The 1582.0-keV level is populated directly from the capture state and therefore presumably has $\frac{5}{2} \le I \le \frac{11}{2}$. The 1582.0-keV level decays to the $\frac{3}{2}^+$ ground state by a 1582.0-keV transition and to the $\frac{1}{2}^+$ level at 980.4 keV by a 601.2-keV transition, as listed in Table II. Thus, the most probable spin assignment for this level is $\frac{5}{2}$. If one assumes $I=\frac{5}{2}$, a negative-parity assignment for the 1582.0-keV level would require that the 1582.0-keV ground-state transition have $E1$ character and that the 601.2-keV transition have $M2$ character. If the parity is assumed to be positive, however, the 1582.0-keV transition would be $M1$ and the 601.2-keV transition would be $E2$. The relative intensities of the two transitions involved favors the latter choice. It should be noted that the $\frac{5}{2}^+$ assignment suggested in this paper is outside the range $I^\pi=(\frac{9}{2}, \frac{11}{2})^\pm$ which was previously suggested for this level on the basis of $(n, n'\gamma)$ angular-distribution studies.[5] However, the angular-distribution work employed a NaI(Tl) detector, and the spectrum was not well resolved in the region including this level.

1677.5-keV Level

Direct population of the 1677.5-keV level from the capture state implies $\frac{5}{2} \leq I \leq \frac{11}{2}$. Since the strongest decay transition proceeds to the ground state, it is probable that $I^\pi=(\frac{5}{2}, \frac{7}{2})^\pm$. The decay mode of this level yields no further restrictions on the assignment. However, studies of the β decay of ^{41}Ar suggest positive parity.[6] The $(n, n'\gamma)$ angular distribution studies[5] suggest $I \leq \frac{5}{2}$, but, as mentioned previously, this region of the spectrum was not well resolved in that work.

1698.1-keV Level

The 1698.1-keV level is populated directly from the capture state, implying $\frac{5}{2} \leq I \leq \frac{11}{2}$. Since no level other than the ground state is observably populated by the decay of the 1698.1-keV level, spin and parity values of $\frac{5}{2}^\pm$ or $\frac{7}{2}^+$ are suggested.

2144.1-keV Level

Direct population of the 2144.1-keV level from the capture state implies $\frac{5}{2} \leq I \leq \frac{11}{2}$. This level decays to the $\frac{3}{2}^+$ ground state, the $\frac{1}{2}^+$ level at 980.4 keV, the $\frac{3}{2}^+$ level at 1559.9 keV, and the $\frac{5}{2}^\pm$ level at 1698.1 keV. Decay to the low-spin levels eliminates spin values of $I \geq \frac{7}{2}$, leaving $I=\frac{5}{2}$ as the preferred assignment. A negative-parity assignment would require that the 1164.1-keV transition to the 980.4-keV level have $M2$ character and that the ground-state transition have $E1$ character. A positive-parity assignment would require the 1164.1-keV transition to be $E2$ and the ground-state transition to be $M1$. The relative transition intensities favor the latter case.

2166.0-keV Level

Since no transition has been observed that directly connects the capture state with the 2166.0-keV level, and since this level decays to levels with spin values in the range $\frac{1}{2} \leq I \leq \frac{5}{2}$, the 2166.0-keV state presumably has $I^\pi=\frac{1}{2}^\pm$ or $I^\pi=\frac{3}{2}^\pm$.

2316.5-keV Level

The 2316.5-keV level is populated directly from the capture state by the 7779.1-keV transition, which is assumed to have $E1$ character, since it is the most intense transition in the high-energy (n, γ) spectrum. Direct population by an $E1$ transition implies a spin range of $\frac{5}{2} \leq I \leq \frac{11}{2}$ and positive parity for this level. The 2316.5-keV level deexcites to levels with spin and parity assignments of $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{7}{2}^-$, which suggests a probable assignment of $I^\pi=\frac{5}{2}^+$ or $\frac{7}{2}^+$.

2447.9-keV Level

A level at 2447.9 keV is proposed on the basis of three otherwise unassigned transitions which can connect a state at this energy with other low-lying states. Since no direct population of this level from the capture state was detected and since the proposed level is observed to decay only to the ground state, the spin is assumed to be $I=\frac{1}{2}$ or $\frac{3}{2}$. The 2447.9-keV level may be identical to a level reported at 2438 ± 6 keV in a ^{41}K(p, p') study.[2]

Higher Energy Levels

Many levels have been identified at excitation energies ≥2400 keV. In general, there is insufficient experimental information available to define the spin of these levels beyond the usual restrictions implied by direct population from the capture state.

D. Theoretical Interpretation

Since ^{41}K has two neutrons in excess of the 20-neutron closed shell and one proton missing from the 20-proton closed shell, it is expected that the ^{41}K level structure should include many positive-parity two-particle, one-hole (2p-1h) states arising from various couplings of the $p(d_{3/2})^{-1}n(f_{7/2})^2$ configuration. A calculation of the low-lying ^{41}K 2p-1h states has been published by Pellegrini.[22] In his calculation, it is assumed that these states arise from a pure $p(d_{3/2})^{-1}n(f_{7/2})^2$ configuration, so that the interaction matrix elements are given by

$$\langle p(d_{3/2})^{-1}n(f_{7/2})^2{}_{I'}|V_{nn}+\sum_{\text{pairs}} V_{pn}|p(d_{3/2})^{-1}n(f_{7/2})^2{}_I\rangle_J$$

$$=\langle n(f_{7/2})^2|V_{nn}|n(f_{7/2})^2\rangle_{I'}\delta_{II'}$$

$$+2\sum_{J'} U(\tfrac{7}{2}\,\tfrac{7}{2}J\tfrac{3}{2}|I'J')U(\tfrac{7}{2}\,\tfrac{7}{2}J\tfrac{3}{2}|IJ')$$

$$\times\langle p(d_{3/2})^{-1}n(f_{7/2})^1|V_{pn}|p(d_{3/2})^{-1}n(f_{7/2})^1\rangle_{J'} ,$$

where V_{nn} is the neutron-neutron interaction and V_{pn} is the proton-neutron interaction. In the present paper we have repeated the calculation of Pellegrini using the most recent experimental information to define the nucleon-nucleon interactions.

If the low-lying levels of ^{42}Ca result from pure $n(f_{7/2})^2$ configuration, these level energies then give the interaction energies between two neutrons in the $f_{7/2}$ shell. These energies are $E(0^+)=0.0$ MeV, $E(2^+)=1.524$ MeV, $E(4^+)=2.751$ MeV, and $E(6^+)=3.190$ MeV.[1]

The assumption was made by Pellegrini that ^{41}K 2p-1h states arise from a pure $p(d_{3/2})^{-1}n(f_{7/2})^2$ configuration. It is probable that the low-lying states of ^{41}K also include some admixture of other shell-model configurations. In particular the ground state of ^{41}K is known[23,24] to contain a significant $p(s_{1/2})^{-1}n(f_{7/2})^2$ component. The effect of such mixing should be included. Presumably, the interaction between an $f_{7/2}$ neutron and an $s_{1/2}$ proton hole would result in a multiplet of high-energy states in the level structure of certain nuclei, such as ^{32}P, but the present experimental data are insufficient to locate such a multiplet. The low-lying 1p-1h states of ^{40}K presumably arise primarily

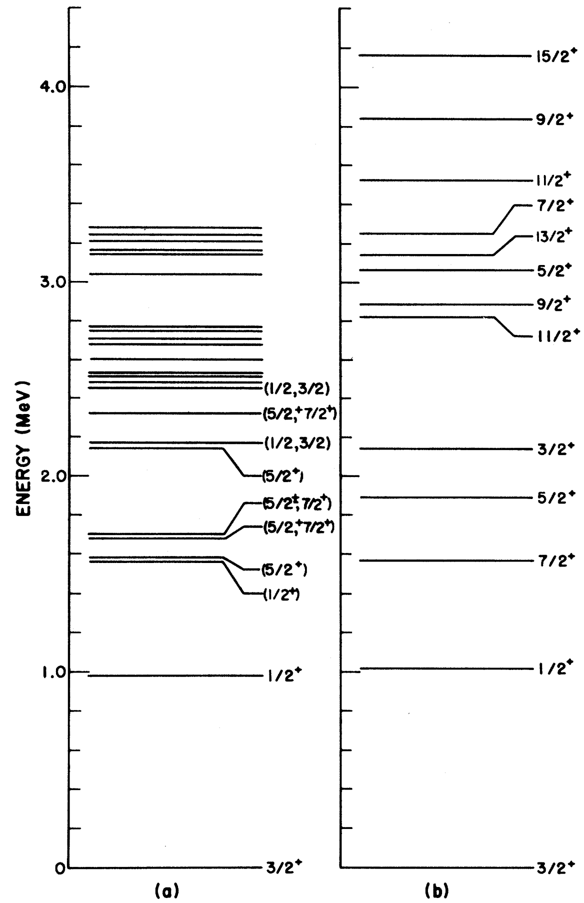

FIG. 6. (a) Experimental levels of ^{41}K with the known negative-parity states omitted. (b) Calculated eigenvalues of the $p(d_{3/2})^{-1}n(f_{7/2})^2$ configuration in ^{41}K.

TABLE V. Calculated eigenvalues and eigenvectors of the $p(d_{3/2})^{-1}n(f_{7/2})^2$ configuration in ^{41}K.

Energy (MeV)	I^π	$(d_{3/2})^{-1}(f_{7/2})^2{}_0$	$(d_{3/2})^{-1}(f_{7/2})^2{}_2$	$(d_{3/2})^{-1}(f_{7/2})^2{}_4$	$(d_{3/2})^{-1}(f_{7/2})^2{}_6$
0	$\frac{3}{2}^+$	0.9184	−0.3957		
1.018	$\frac{1}{2}^+$		1.0000		
1.570	$\frac{7}{2}^+$		0.9297	−0.3683	
1.890	$\frac{5}{2}^+$		0.8362	−0.5484	
2.140	$\frac{3}{2}^+$	0.3957	0.9184		
2.816	$\frac{11}{2}^+$			−0.5713	0.8207
2.885	$\frac{9}{2}^+$			0.8759	−0.4825
3.065	$\frac{5}{2}^+$		0.5484	0.8362	
3.137	$\frac{13}{2}^+$				1.000
3.254	$\frac{7}{2}^+$		0.3683	0.9297	
3.523	$\frac{11}{2}^+$			0.8207	0.5713
3.845	$\frac{9}{2}^+$			0.4825	0.8759
4.163	$\frac{15}{2}^+$				1.000

from the $p(d_{3/2})^{-1}n(f_{7/2})^1$ configuration, with some admixture of the $p(s_{1/2})^{-1}n(f_{7/2})^1$ configuration. If it is assumed that the proton configuration of ^{40}K is not significantly altered by the addition of a neutron, then the ^{41}K and ^{40}K proton configurations should be similar. Therefore, it has been assumed that configuration mixing in ^{41}K can be implicitly included by using the experimentally derived interaction energies obtained from the level structure of ^{40}K. These proton-neutron interaction energies are $E(4^-)=0.0$ MeV, $E(3^-)=0.030$ MeV, $E(2^-)=0.800$ MeV, and $E(5^-)=0.890$ MeV.[1]

Calculation of the appropriate matrix elements and diagonalization of the resulting matrices were performed using the interaction energies listed above. The results of this calculation are summarized in Table V. In Fig. 6 the calculated eigenvalues are compared with the experimental ^{41}K levels (the known negative-parity levels have been deleted for clarity). For the lowest few states there is seen to be a satisfactory correspondence between the calculated and observed energies. It is not surprising that at higher energies many more levels exist than can be accounted for on the basis of a simple 2p-1h description.

In addition to the 2p-1h states, levels should be observed which result from excitation of the unpaired proton into the $f_{7/2}$ shell, giving a proton configuration of $(d_{3/2})^{-2}(f_{7/2})^1$ with perhaps some $(s_{1/2})^{-2}(f_{7/2})^1$ mixing. Such a proton excitation is assumed to be the origin of the negative-parity level at 1293.4 keV.

---

†Work supported by the U. S. Atomic Energy Commission.

*Associated Western Universities Fellow.

[1]P. M. Endt and C. van der Leun, Nucl. Phys. A105, 1 (1967).

[2]J. W. Kelley, W. H. Moore, and H. A. Enge, Massachusetts Institute of Technology Laboratory Nuclear Science Progress Report, May 1958 (unpublished), p. 111.

[3]S. E. Arnell and P. O. Persson, Arkiv Fysik 27, 41 (1964).

[4]J. L. Yntema, Phys. Rev. 186, 1144 (1969).

[5]D. B. Nichols and M. T. McEllistrem, Phys. Rev. 166, 1074 (1968).

[6]W. W. Pratt, Phys. Rev. 139, B509 (1965).

[7]R. D. Sharp, L. F. Chase, Jr., R. M. Friedman, E. K. Warburton, and E. G. Shelley, Phys. Rev. 124, 1557 (1961).

[8]B. B. Kinsey, G. A. Bartholomew, and W. H. Walker, Phys. Rev. 85, 1012 (1952).

[9]E. T. Jurney, H. T. Motz, and S. H. Vegors, Jr., Nucl. Phys. A94, 351 (1967).

[10]M. G. Strauss, L. L. Sifter, F. R. Lenkszus, and R. Brenner, IEEE Trans. Nucl. Sci. NS-15, No. 3, 518 (1968).

[11]R. C. Greenwood, Phys. Letters 27B, 275 (1968).

[12]G. E. Thomas, D. E. Blatchley, and L. M. Bollinger, Nucl. Instr. Methods 56, 325 (1967).

[13]E. B. Shera and D. W. Hafemeister, Phys. Rev. 150, 894 (1966); E. B. Shera and H. H. Bolotin, *ibid.* 169, 940 (1968).

[14]*Neutron Cross Sections*, compiled by D. J. Hughes and R. B. Schwartz, Brookhaven National Laboratory Report No. BNL 325 (Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 1958), 2nd ed.; see also H. Pomerance, Phys. Rev. 88, 412 (1952).

[15]C. Maples, G. W. Goth, and J. Cerny, Nucl. Data A2, 429 (1966).

[16]J. H. E. Mattauch, W. Thiele, and A. H. Wapstra, Nucl. Phys. 67, 1, 32 (1965).

[17]L. Davis, Jr., D. E. Nagle, and J. R. Zacharias, Phys. Rev. 76, 1068 (1949).

[18]J. H. Manley, Phys. Rev. 49, 921 (1936).

[19]T. C. Engelder, Phys. Rev. 90, 259 (1953).

[20]L. G. Elliott, Phys. Rev. 85, 942 (1952).

[21]J. L. Yntema, Phys. Rev. 186, 1144 (1969).

[22]F. Pellegrini, Nuovo Cimento 48B, 1715 (1967).

[23]G. Bertsch and A. Molinari, Nucl. Phys. A148, 87 (1970).

[24]G. Sartoris and L. Zamick, Phys. Rev. Letters 18, 292 (1967).