Transition Rates in ^{44}Ca†

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The mean lives of states in ^{44}Ca up to an excitation energy of 3360 keV have been measured by the Doppler-shift attenuation method, using both solid and gas backings to slow the recoiling nuclei. Most of the states have lifetimes in the range of a few picoseconds, a "time region" at the limit of sensitivity of either method alone. The combination of the two methods gives accurate upper and lower limits, and a value for the mean life. The resulting experimental transition probabilities are compared to a calculation which assumes the existence of a core-excited rotational band in ^{44}Ca identical to that found to be necessary in ^{42}Ca. A general agreement is obtained. A value has also been measured for the mean life of the 2750-keV 4^+ state in ^{42}Ca.

I. INTRODUCTION

The nuclei with a few nucleons in excess of the doubly magic ^{40}Ca core have attracted considerable interest over the years. Although initially the interest existed because these nuclei appeared to have spectra explainable in terms of the shell model, more recently it has become apparent that there are more low-lying states than a simple calculation can account for. Evidence has accumulated in both even and odd nuclei that the addition of a few nucleons increases the ease with which the core can be excited. The excitations appear to take the form of deformations, resulting in large quadrupole transition matrix elements between the states.

In the even nuclei, the lowest-lying core-excited states seem to come from excitation of two particles from the core to the next shell-model orbital, in this case the $1f_{7/2}$ shell. This leads to states with the same parity as those formed from the original extra-core particles, and the two types of states mix through the particle-hole interaction. The 1836-keV 0^+ and 2422-keV 2^+ levels of ^{42}Ca have been accounted for in this fashion by Gerace and Green,[1] and in an analogous but more detailed calculation by Flowers and Skouras.[2] Both calculations provide excellent energy fits to the low-lying ^{42}Ca levels, and both account for the observed transition probabilities in a satisfactory fashion.

The success of the calculations leads one to seek examples of similar excited configurations in neighboring nuclei. The nucleus ^{44}Ca, with two more neutrons added to the $1f_{7/2}$ shell, is the most natural next choice. The spectra of ^{42}Ca and ^{44}Ca up to about 3300 keV are very similar, as shown in Fig. 1, and one is immediately led to the supposition that the 1885-keV 0^+ level and the 2657-keV 2^+ level in ^{44}Ca are cousins to the 1836- and 2422-keV levels in ^{42}Ca. To make this more than a supposition requires a determination of transition probabilities between the states.

The available information on the low-lying ^{44}Ca levels is in most cases quite detailed, so that all that is lacking to a knowledge of the transition probability is the state lifetime. The γ-ray spectrum has been exhaustively studied. With the states in ^{44}Ca populated by β decay,[3] neutron capture,[4] and inelastic scattering,[5] γ-ray energies are accurately determined, and branching ratios and multipole mixing ratios have been measured. Additional information, not pertinent to γ-ray lifetimes but providing parallel information on the wave functions of the ^{44}Ca levels, comes from the ^{43}Ca(d,p) reaction[6] and the spectroscopic factors deduced therefrom. The lifetime of the first excited state, at 1157 keV, has recently been accurately measured by Coulomb excitation.[7] Plunger measurements have also yielded a value for the lifetime of the 3285-keV 6^+ state.[8] The former gives a value $\tau = 4.1 \pm 0.1$ psec; the latter, $\tau = 19.7 \pm 2.2$ psec. In the work described in this paper we have used the Doppler-shift attenuation method to determine the mean lives of the states in ^{44}Ca up to an energy of 3.360 MeV. Transition probabilities obtained from these mean lives are compared to those obtained from calculations similar to the type performed by Towsley, Cline, and Horoshko[7] to attempt to relate the values obtained here to the extensive ^{42}Ca calculations cited above.

II. EXPERIMENTAL METHODS

Most of the states in ^{44}Ca with energies below 3.5 MeV have mean lives between 3 and 30 psec, and several of them have mean lives of about 5 psec. Such mean lives are long enough so that they are hard to measure by the Doppler-shift attenuation method with solid backings and short enough so that plunger or gas-backing Doppler-shift measurements are difficult. In these experiments we have made Doppler-shift measurements with both solid and gas backings, and have thus managed to obtain results which would have been difficult to deduce from either measurement alone.

The measurements consist of determining the Doppler-shift attenuation factor

$$F=\frac{\langle E_\gamma(v)\rangle_{\theta_1}-\langle E_\gamma(v)\rangle_{\theta_2}}{\langle E_\gamma(v_i)\rangle_{\theta_1}-\langle E_\gamma(v_i)\rangle_{\theta_2}}\,, \qquad (1)$$

where $\langle E_\gamma(v)\rangle_{\theta_i}$ is the space- and time-averaged energy of γ rays seen by a detector located at an angle θ_i with respect to the direction of the recoiling nuclei. The numerator and denominator of this expression are, respectively, the attenuated and unattenuated differences in energy of Doppler-shifted γ rays emitted from the states of interest in ^{44}Ca. In this work the numerator was measured and the denominator was calculated from the known kinematic and geometric conditions of the experiment. The calculations have been checked experimentally many times. In the case of the solid-backing experiments the check is made by measuring the Doppler shifts of γ rays from states with very short mean lives for which the attenuation factor should be $F=1$. In the case of the gas-backing experiments, it is made by measuring Doppler shifts of γ rays from nuclei recoiling in a vacuum, making an appropriate correction for slowing down in the target before the vacuum recoil is achieved. In both cases the calculated kinematic and geometric shifts were found to be valid to better than 2%.

Mean lives are deduced by comparing the measured Doppler-shift attenuation factor F with values calculated by the method of Blaugrund[9] using stopping powers of Lindhard, Scharff, and Schiott.[10] For calcium ions recoiling in tantalum we used errors of 20% for the calculated stopping powers. We have checked the calculated slowing-down properties for calcium ions recoiling in krypton by measuring the attenuation of the Doppler shift of γ rays from the 0^+ 1.838-MeV state in ^{42}Ca. The mean life of this state is well known,[11] and these measurements on ^{42}Ca showed that, within the 12% errors of the measurement, the theory of Lindhard *et al.* correctly gives the electronic stopping power of krypton for calcium. The ^{42}Ca experiments also provided a measurement of the 2750-keV 4_1^+ state lifetime, which is in the 3–10-psec range, and for which conflicting measurements exist.[12,13]

In all three experiments the excited Ca nuclei were produced in the reaction K(α,p)Ca, using 9-MeV He^{++} ions from a model CN Van de Graaff, incident upon KI targets. γ rays were detected with a Ge(Li) detector with a resolution of 3 keV full width at half maximum at 1.33 MeV. The γ rays were observed in coincidence with the proton groups corresponding to the excitation of the initial state. In both solid-backing and gas-backing experiments the proton resolution was sufficient

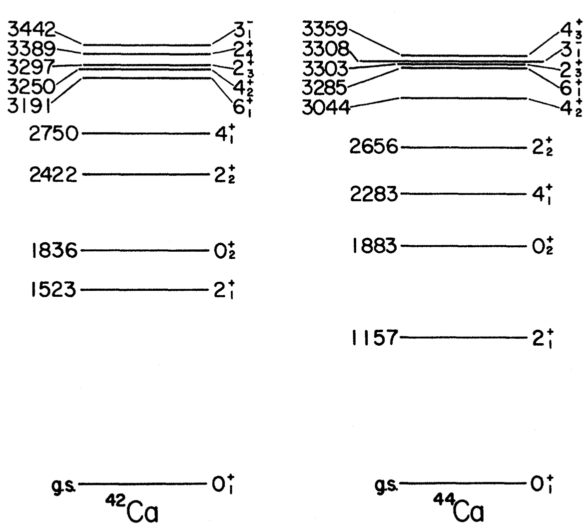

FIG. 1. Energy-level diagrams for ^{42}Ca and ^{44}Ca. Energies are given in keV.

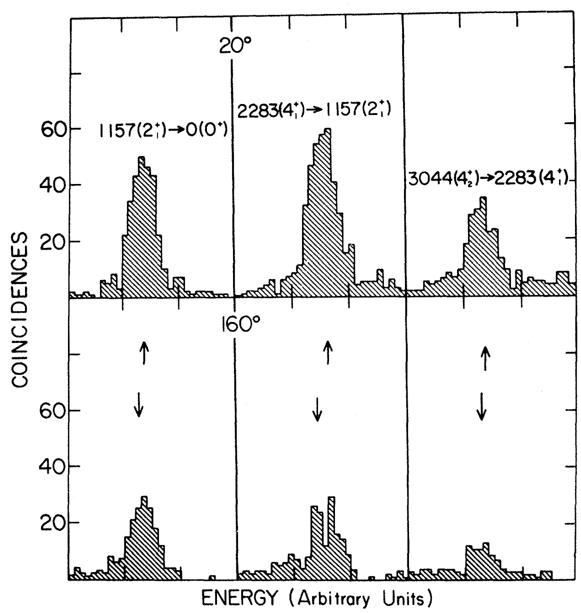

FIG. 2. Pulse-height spectra of γ rays from ^{44}Ca in coincidence with protons, obtained in the solid-backing Doppler-shift experiments. The upper spectra are for γ rays emitted at 20° with respect to the recoiling nuclei, and the bottom, at 160°. The dispersion for these spectra is about 0.5 keV/channel. All energies are given in keV. The arrows indicate the centroids calculated for each of the peaks.

to eliminate cascades from other states populating the initial state of any γ ray. The targets for ^{42}Ca determinations used natural KI; in the ^{44}Ca studies, the targets were enriched to 99% ^{41}K. Further details of the two types of experiments are given below.

A. Solid Backing

The details of these measurements are identical to those described by Hershberger, Wozniak, and Donahue.[14] Two targets were used, and γ rays from nuclei in one target emitted at 20° with respect to the recoiling nuclei were detected simultaneously with γ rays from nuclei in the other target emitted at 160° with respect to the recoiling nuclei. The difference in the centroids of the peaks of the γ rays from the two targets was then calculated and used as the numerator of Eq. (1). The targets used for these solid-backing measurements were made by evaporating the enriched KI onto thick tantalum backings. The resulting KI targets were 255 ± 10 $\mu g/cm^2$ thick.

B. Gas Backing

These measurements were made using the method described by Donahue and Hershberger.[15] The numerator of Eq. (1) was determined by taking the difference between energies of γ rays emitted at zero degrees to ions recoiling in krypton gas and the energies of γ rays emitted from nuclei which were at rest. Nuclei at rest were obtained by causing nuclei produced in the $^{41}K(\alpha, p)^{44}Ca$ reaction to recoil into tantalum. Nuclei with mean lives greater than a few picoseconds will stop in tantalum before they decay. The nuclei recoiling in the krypton gas were produced by reactions in a target of KI evaporated onto the back of a 5-μm pressure-retaining foil. This target consisted of a KI film, 108 ± 5 $\mu g/cm^2$ thick for the ^{44}Ca experiments, and 80 ± 10 $\mu g/cm^2$ for the ^{42}Ca experiments. The beam energy degradation occurring because of passage through the pressure-retaining foil was calculated, and taken into account in the results.

III. RESULTS

Figure 2 illustrates the spectra of γ rays in coincidence with protons to the 1157-, 2283-, and 3044-keV states in ^{44}Ca, measured at 20° and at 160° with respect to the recoiling ^{44}Ca nuclei. These spectra were obtained from the solid-backing measurements, with the ^{44}Ca nuclei recoiling in tantalum. Similar spectra for γ rays from the same states in ^{44}Ca recoiling into tantalum and into 16.7-atm krypton gas are shown in Fig. 3. Figure 4 shows spectra obtained in the gas-backing experiment for γ rays from the 1884- and 3285-keV states in ^{44}Ca. Doppler-shift attenuation factors obtained from spectra such as these are shown, plotted on a calculated curve of F vs τ, for solid and gas backings, respectively, in Figs. 5 and 6. As can be seen from these figures, the attenuation factors for γ rays from the 1157-, 2283-, and 3044-keV states are nearly zero for the solid-backing measurements, and quite large for the gas-backing measurements. The solid-backing data are therefore least certain in their upper limit on

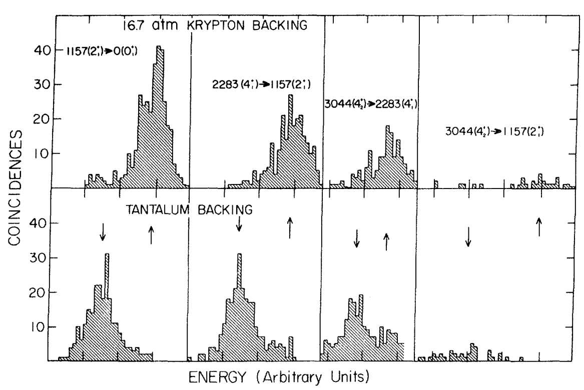

FIG. 3. Pulse-height spectra of γ rays from ^{44}Ca in coincidence with protons, obtained from the gas-backing Doppler-shift measurements. The upper spectra are for γ rays emitted at 0° with respect to nuclei recoiling in 16.7-atm krypton gas and the lower spectra are for γ rays emitted from nuclei at rest. The dispersion for these spectra is about 0.5 keV per channel. All energies are in keV. Calculated centroids are indicated by the arrows.

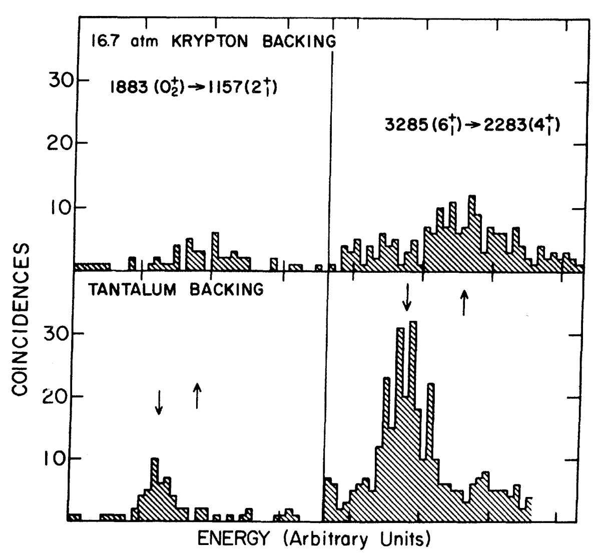

FIG. 4. Spectra similar to those in Fig. 3 for the $0_2^+ \to 2_1^+$ and $6_1^+ \to 4_1^+$ transitions in ^{44}Ca.

the lifetime, and the gas backing in the lower limit. By using both backings, we can place accurate upper and lower limits and obtain a value for the lifetime.

The results of both sets of measurements for ^{44}Ca are shown in Table I. The fourth column of that table gives the lifetime adopted for the state. This was obtained by a weighted averaging of the results of the separate experiments, taking into account the uncertainties in upper and lower limits described above. Only the 3044-keV 4_2^+ state has branching such that two measurements of the lifetime could be made, and then only in the gas-backing experiment. The 3303-keV 2_3^+ state has a strong branch to the 2_1^+ state, but because of Doppler broadening this could not be disentangled from the 3308-keV 3_1^- state's decay to the same final state. This also made it impossible to say more than that the $3_1^- \rightarrow 2_1^+ \gamma$ ray was very nearly full shifted. Meaningful limits could not be placed on the shift, and no lifetime limit is recorded in Table I.

The branching ratios listed in column 6, with one exception, are taken from the paper of Lawley *et al.*[5] The branches of transitions from the 3359-keV state were measured in this work. A recent study of the decay of ^{44}Sc quotes a 10% branch for the 3303-→2656-keV transition. However, we found no 647-keV γ rays corresponding to this transition, and our measurements on the branches from the 3303-keV state are not in disagreement with those of Lawley *et al*. Finally, the reduced transition rates given in Table I were calculated from our mean lives, the branching ratios of Lawley *et al*., and various multipole mixing ratios as indicated in the table.

For the ^{39}K$(\alpha, p)^{42}$Ca experiment only gas-backing data were taken. The pressure of the Kr was reduced to 1.0 atm to make the experiment more sensitive in the 500-psec range of lifetimes. The results for the lifetime of the 1836-keV level indicated that the Lindhard, Scharff, and Schiott[10] calculations give good values for the electronic stopping power; using the measured value $\tau = 480 \pm 30$ psec, the factor f_e commonly used to renormalize the Lindhard values was determined to be $f_e = 0.96 \pm 0.12$.

In addition, the ^{39}K$(\alpha, p)^{42}$Ca experiment was done at a pressure of 16.7 atm to provide a new measurement of the mean life of the 2750-keV 4^+ state in ^{42}Ca. This lifetime has been measured by the Doppler-shift technique with solid backings[12] to be 3 ± 1 psec, and by plunger techniques[13] to be 11.5 ± 2.5 psec. The disagreement is unsatisfactorily large, but the Doppler-shift measurements are of a lifetime corresponding to the limit of accuracy of the technique and are hence suspect. The value obtained in our measurements is $\tau = 2.3 \pm 1$ psec, in agreement with the smaller values previously measured.

IV. DISCUSSION

The energy levels of ^{44}Ca are expected to arise in the simplest shell model from states generated by recoupling the four $1f_{7/2}$-shell neutrons. Although there are more levels observed than this model can account for, still some properties of the observed levels seem consistent with this view. The transition probabilities in the $(1f_{7/2})^4$ model,

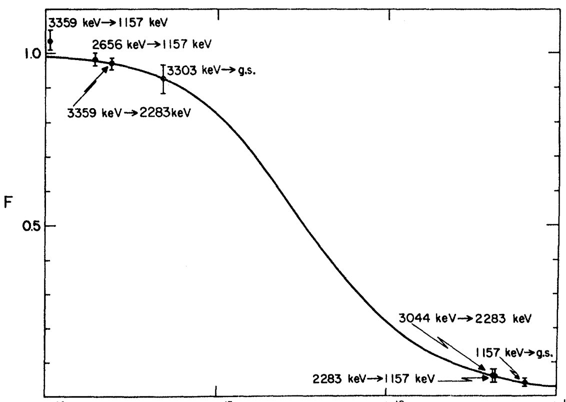

FIG. 5. A calculated curve of the Doppler-shift attenuation factor, F, vs mean life τ for ^{44}Ca ions recoiling in a 255-μg/cm^2 KI target and tantalum backing, together with measured values of F for various transitions in ^{44}Ca. Stopping powers used in the calculations are those of Lindhard, Scharff, and Schiott (Ref. 10).

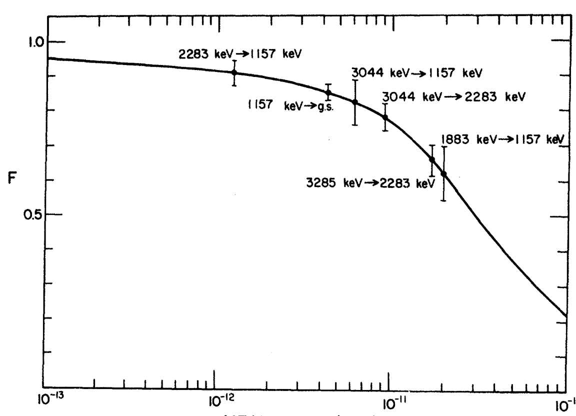

FIG. 6. A calculated curve of the Doppler-shift attenuation factor, F, vs mean life τ for ^{44}Ca ions recoiling in a 108-μg/cm^2 KI target and 16.7-atm krypton, together with measured values of F for various transitions in ^{44}Ca. Stopping powers in the calculation are those of Linfhard, Scharff, and Schiott (Ref. 10).

TABLE I. Experimental lifetimes and transition probabilities.

Initial state	τ (psec) solid	τ (psec) gas	$\langle\tau\rangle$ (psec)	Transition	Branch [a]	δ	$B(M1)$ (e^2 fm^2)	$B(E2)$ (e^2 fm^4)
2_1^+ (1157 keV)	6.7 ± 1.7	4.5 ± 1.5	5.1 ± 1.0	$2_1^+\to0_1^+$	1.0	...	...	75 ± 15
0_2^+ (1883 keV)	...	20 ± 6	20 ± 6	$0_2^+\to2_1^+$	1.0	...	...	200 ± 60
4_1^+ (2283 keV)	$4.3_{-1.3}^{+2.0}$	1.3 ± 1.3 (<4)	2.8 ± 1.0	$4_1^+\to2_1^+$	1.0	...	...	160 ± 60
2_2^+ (2657 keV)	<0.03	...	<0.03	$2_2^+\to2_1^+$	0.88	0.14 ± 0.01 [b]	$>55\times10^{-4}$	≥60
				$2_2^+\to0_1^+$	0.12			≥24
4_2^+ (3044 keV)	$4.3_{-1.4}^{+2.2}$	9.3 ± 2.8	$6.7_{-1.4}^{+1.8}$	$4_2^+\to2_1^+$	0.49	...		2.5 ± 0.6
		6.3 ± 3.8		$4_2^+\to4_1^+$	0.51	$0.25_{-0.09}^{+0.31}$ [c]	$(1.0_{-0.2}^{+0.5})\times10^{-4}$	15_{-10}^{+60}
6_1^+ (3285 keV)	...	17 ± 4	17 ± 4	$6_1^+\to4_1^+$	1.0	...	...	50 ± 12
2_3^+ (3303 keV)	0.05 ± 0.025	...	0.05 ± 0.025	$2_3^+\to0_1^+$	0.33			15_{-5}^{+15}
				$2_3^+\to2_1^+$	0.67	0 (assumed)	$8.5_{-3}^{+8.5}\times10^{-4}$	
3_1^- (3308 keV)								
4_3^+ (3359 keV)	<0.04	...	<0.04	$4_3^+\to4_1^+$	0.88 [d]			
				$4_3^+\to2_1^+$	0.12			

[a] Reference 5, except for 4_3^+ branching, which is from this experiment.
[b] References 3 and 5.
[c] Reference 5.
[d] Based on a measurement at 20° only.

for instance, are subject to stringent selection rules: All $M1$ transitions are forbidden, and $E2$ transitions are only permitted if there is a seniority change $\Delta v=2$. Thus the transition $4_2^+(v=2)\to4_1^+(v=4)$ should be a pure $E2$, and the $4_2^+(v=2)\to2_1^+(v=2)$ transition should be forbidden for both $M1$ and $E2$. The level at 3044-keV seems to have these properties and may reasonably be associated with the $v=2$ shell-model state.

At the same time, it is clear there are significant departures from this view. First, the existence of the 1885-keV 0_2^+ level and the 2657-keV 2_2^+ level, which cannot be explained by the $(1f_{7/2})^4$ model, suggests the presence of competing configurations which may mix with the shell-model levels. Second, the $B(E2)$ values are too large for the shell model to account for, and the strongest single transition is from the second 0^+ state to the first 2^+ state. Finally, the spectroscopic factors deduced in ^{43}Ca$(d,p)^{44}$Ca leave no doubt that the first two 2^+ states are essentially equal mixtures of the shell-model state and some other configuration, although in these experiments the 4_2^+ state at 3044 keV again seems to contain almost all the shell-model $v=2$ component.

The extra states do not seem to arise from effects of including the p shell in the calculation. McGrory, Wildenthal, and Halbert[16] have carried out extensive calculations to see if an extra 0^+ state from the full (fp^4) configuration can be forced this low in energy, with negative results. Neither can they obtain a second 2^+ state below about 3 MeV. And the lowest 2^+ state in their calculation contains 85% of the (d,p) stripping strength to 2^+ states, as opposed to the experimental value of 43%.

However, the parallel with the ^{42}Ca spectrum is even more complete than a simple comparison of energies would suggest. The pattern of $B(E2)$ values in Table I is very similar to that in ^{42}Ca,[1,2] and the complete mixing of the stripping strength between the lowest two 2^+ states also occurs[17] in ^{41}Ca$(d,p)^{42}$Ca. To see how far the parallel can be pursued we have adopted a procedure in the spirit of that used by Towsley, Cline, and Horoshko.[7] We assume that the states below 3300 keV are due to two configurations: the $(1f_{7/2})^4$ particle configuration, and a complex core excitation which can be parametrized by an intrinsic quadrupole moment, Q_0. The core-excited configuration is assumed to act like a rigid rotator, so that its spectrum follows the $I(I+1)$ rule, and $B(E2)$ values can be obtained from Q_0. This is in essence the view which Gerace and Green[1] adopted for ^{42}Ca, except there the particle configuration included the entire (fp) shell. We have restricted ours to the $(1f_{7/2})^4$ configuration for ease of calculation.

TABLE II. Calculated wave functions in ^{44}Ca.

Energy (keV)	State	Amplitude of basis state $(1f_{7/2})^4 v = 0$ or 2	$(1f_{7/2})^4 v = 4$	Rotational
0	0_1^+	+0.858		+0.513
1890	0_2^+	+0.513		−0.858
1160	2_1^+	+0.670	+0.147	−0.727
2660	2_2^+	+0.733	−0.268	+0.625
4170	2_3^+	+0.101	+0.958	+0.284
2280	4_1^+	+0.560	+0.509	−0.656
3100	4_2^+	−0.585	+0.801	+0.128
4280	4_3^+	+0.587	+0.319	+0.745
3280	6_1^+	+0.892		+0.452
6020	6_2^+	+0.452		−0.892

If we assume the particle spectrum used by Gerace and Green is a pure $(1f_{7/2})^2$ spectrum, the $(1f_{7/2})^4$ spectrum can be generated by standard techniques.[18] This spectrum has one 0^+ and one 6^+ state, but two 2^+ and two 4^+ states; for the latter spins, the states are distinguished by their seniority. The parameters of the rotational band we assume to be identical to those in ^{42}Ca. The plausibility of this assumption is discussed by Towsley, Cline, and Horoshko.[7] To obtain the complete fractionation of the stripping strength for the 2^+ states, we choose the particle 2^+ $v=2$ state and the rotational 2^+ state to be degenerate before diagonalization. In this fashion we construct the diagonal matrix elements for the energy matrix for each spin, the dimensions of which are 3×3 for $I=2$ and $I=4$ and 2×2 for $I=0$ and $I=6$.

Rather than calculating the off-diagonal terms from a known particle-hole interaction, as did Gerace and Green, we leave them as free parameters to be determined by forcing the characteristic energies of the matrix to agree with the low-lying ^{44}Ca states. Determining the off-diagonal

TABLE III. Comparison of calculated transition probabilities with experiment.

Transition	Experiment $B(M1)$ (e^2 fm^2)	$B(E2)$ (e^2 fm^4)	Calculated $B(M1)$ (e^2 fm^2)	$B(E2)$ (e^2 fm^4)
$2_1^+ \to 0_1^+$	···	95 ± 5 [a]	···	85
		75 ± 15		
$0_2^+ \to 2_1^+$	···	200 ± 60	···	265
$4_1^+ \to 2_1^+$	···	160 ± 60	···	120
$2_2^+ \to 2_1^+$	$>55\times 10^{-4}$	≥ 60	22×10^{-4}	60
$2_2^+ \to 0_1^+$	···	≥ 24	···	1
$4_2^+ \to 4_1^+$	$(1.0^{+0.5}_{-0.2})\times 10^{-4}$	15^{+60}_{-10}	2.4×10^{-4}	2
$4_2^+ \to 2_1^+$	···	2.5 ± 0.6	···	2
$6_1^+ \to 4_1^+$	···	50 ± 12	···	70
		40 ± 5 [b]		
Quadrupole moment		Q, e fm^2		Q, e fm^2
2_1^+		-14 ± 7 [a]		−14

[a] See Ref. 7. [b] See Ref. 8.

TABLE IV. Spectroscopic factors from ^{43}Ca$(d,p)^{44}$Ca.

State	Energy (keV)	Experiment [a] $[(2J_B+1)/8]S$	Calculated $[(2J_B+1)/8]S$
0_1^+	g.s.	$0.36(l=3)$	0.37
2_1^+	1157	$0.36(l=3)+0.05(l=1)$	0.37
0_2^+	1883	$0.07(l=3)$	0.13
4_1^+	2283	$0.22(l=3)+0.008(l=1)$	0.47
2_2^+	2657	$0.45(l=3)+\leq 0.01(l=1)$	0.45
4_2^+	3044	$1.46(l=3)$	0.51
6_1^+	3285	$2.45(l=3)$	1.72
2_3^+	3303		

[a] See Ref. 6.

matrix elements determines the mixing between the particle and rotational states, and single-particle transition matrix elements can be calculated. The resulting wave functions are listed in Table II. In Table III the γ-ray transition probabilities calculated with these wave functions are compared with experiment. Table IV shows similar results for the ^{43}Ca$(d,p)^{44}$Ca stripping experiments.

The calculation of transition probabilities introduces further parametrization. For the $E2$ particle transitions we must choose the product $e\langle\frac{7}{2}\|Q\|\frac{7}{2}\rangle$, which is effectively $e\langle r^2\rangle$. The choice of $\langle r^2\rangle$, the rms radius parameter, affects the quoted value of e, the effective charge. We have chosen $e\langle\frac{7}{2}\|Q\|\frac{7}{2}\rangle$ to be 5.91 e fm^2. This is somewhat larger than the Gerace-Green value, and is consistent with (1) the value of $\langle r^2\rangle$ calculated with oscillator wave functions and used in Ref. 13, and (2) an effective neutron charge of 1.0. The $E2$ rotational transition probability is calculated using $Q_0 = 106$ e fm^2, which is the Gerace-Green value.

For $M1$ transitions, only the diagonal matrix elements of the magnetic-moment operator for particle and rotational basis vectors contribute. We choose values $g_n = -0.376\mu_N$, the value deduced from ^{43}Ca, and $g_R = Z/A = 0.45\mu_N$ to calculate these.

As can be seen, the calculation reproduces the observed $2_1^+\to 0_1^+$, the $0_2^+\to 2_1^+$, and the $2_2^+\to 2_1^+$ $B(E2)$ values quite well, as well as the 2_1^+ quadrupole moment measured by Towsley, Cline, and Horoshko.[7] It fails to account for the observed enhancement of the $2_2^+\to 0_1^+$ transition. The restricted basis set used in the calculations and the nature of the orthogonality requirements make it virtually impossible to obtain simultaneous enhancement of all four $B(E2)$ values, no matter what parameters are used for the wave functions. It may be that including the full fp configuration will help to rectify this difficulty, although the lowest 0^+ and 2^+ states in a pure $(fp)^4$ calculation are still relatively pure $(1f_{7/2})^4$ states.[7] This same difficulty obtains in the Gerace-Green calculation for ^{42}Ca, although it is not so pronounced there.

The enhancement of the $4_1^+ \to 2_1^+$ and the lack of enhancement for the $4_2^+ \to 2_1^+$ predicted by the calculation are in agreement with the experimental results. This comes about in the calculation because of the smallness of the core-excited component in the second 4^+ state. The relative $B(E2)$ values thus mimic the behavior one might expect from pure $(f_{7/2})^4$ seniority states, even though the wave function of each 4^+ state is a thorough mixture of seniorities. The $M1$ transition between the 4^+ states is small because of cancellation of matrix elements.

The $6_1^+ \to 4_1^+$ transition is dominated by the effects of the core-excited configuration, and agrees reasonably well with experiment. The $B(E2)$ value is quite a bit larger than for the corresponding ^{42}Ca transition, not because of the difference in calculated mixing in the 6^+ state, but because of the difference in the 4^+ state. From these results it seems likely that the 6^+ state in ^{42}Ca has applicable rotational components, and that the small $B(E2)$ value observed in ^{42}Ca is due to cancellation effects.

The calculated spectroscopic factors for ^{43}Ca$(d,p)^{44}$Ca assume a pure $(1f_{7/2})^3$ configuration for ^{43}Ca, and are in good agreement for the $l=3$ strength in the 0^+ and 2^+ states. However, the calculations have the $l=3$ strength spread equally among the three 4^+ states, while experimentally most of it is concentrated in the 4_2^+ state. Because of the restriction to the $1f_{7/2}$ shell, the calculation cannot reproduce the observed $l=1$ strength to the 2_1^+ and 4_1^+ states.

The calculations presented here do not constitute a model calculation, since the parameters are adjusted to force a fit to experimental energies. They are more of a check to see if a true model calculation constrained to the assumed shell-model space would have any hope of success. The results seem to indicate that for much of the data the $(f_{7/2})^4$ + rotational-band space could be adequate, but to obtain agreement for all data will require a more extensive calculation.

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