### 782 kev–345 kev Correlation in $Gd^{152}$

With one discriminator window set on the 782-kev photopeak and the other discriminator window set on the 345-kev photopeak, the correlation function obtained after correction for finite geometry was

$$W(\theta)=1-(0.081\pm0.013)P_2(\cos\theta)+(0.014\pm0.019)P_4(\cos\theta).$$

The uncertainty of the $A_4$ term is larger than the term itself. If one assumes that $A_4=0$, the correlation function becomes

$$W(\theta)=1-(0.076\pm0.011)P_2(\cos\theta).$$

This is in agreement with the theoretical correlation function for a $3(D)2(Q)0$ cascade, namely $W(\theta)=1-0.0714P_2(\cos\theta)$. Hence, a spin of 3 may be assigned to the 1127-kev level in $Gd^{152}$. This result is in agreement with Ofer.[9] Grodzins and Kendall,[2] Nathan and Waggoner,[3] and Bhattacherjee *et al.*[5] obtain $K$-conversion coefficients for the 782-kev gamma ray that are consistent with $E1$ radiation. Hence the 1127-kev level in $Gd^{152}$ is probably a 3− state.

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# Neutron-Capture Gamma Rays in $Cl^{36}$†

R. E. Segel*
*Aeronautical Research Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio*

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$\gamma$-$\gamma$ coincidences on the gamma rays following thermal neutron capture in $Cl^{35}$ have been measured. Combining these results with the energy levels in $Cl^{36}$ known from the $Cl^{35}(d,p)Cl^{36}$ reaction and the $Cl^{35}(n,\gamma)Cl^{36}$ gamma-ray spectrum measured by other workers, a decay scheme is constructed which unambiguously places most of the known gamma rays in $Cl^{36}$. An examination is made of the reduced widths of gamma rays emanating from the capturing state, and it is shown that the reduced widths for gamma rays of the same multipolarity can fluctuate widely, and that these fluctuations do not appear to be correlated with the final-state shell model configuration. It is also shown that the reduced widths for $E1$ and $M1$ transitions emanating from the capturing state are significantly smaller than those calculated from the single-particle estimate, and that $E1$ transitions are more intense than $M1$ transitions by about a factor of four. Evidence is presented for there being collective motion present in some of the higher excited states in $Cl^{36}$.

THE experiment reported herein represents a continuation of the program of investigations of gamma-ray cascades following thermal neutron capture undertaken by the Aeronautical Research Laboratory group at Brookhaven National Laboratory. The experimental technique and philosophy are virtually identical to that employed in the previously reported[1] measurements of gamma-ray cascades in $Hg^{200}$. Briefly summarized, this technique consists of placing a target in a thermal neutron beam, and measuring coincidences between two gamma-ray detectors placed close to the target. One detector is a 3-in.×3-in. NaI(Tl) crystal, while the other is a three-crystal pair spectrometer, also composed of NaI(Tl) crystals.

The gamma-ray spectrum resulting from thermal neutron capture in $Cl^{35}$ has been measured by Groshev, Adyasevich, and Demidov.[2] Their results are shown in Table I. The energy levels in $Cl^{36}$ have been investigated by Paris, Buechner, and Endt,[3] who magnetically analyzed the protons produced by the $Cl^{35}(d,p)Cl^{36}$ reaction. These results are shown in Table II. From the Paris *et al.* measurement of the $Q$ value of the ground-state group, the neutron binding energy can be deduced to be 8.58 Mev, in agreement with the value of 8.57 Mev derived from the mass measurements.[4] Comparing Table I with Table II, one can see that all of the higher energy gamma rays measured by Groshev *et al.*[2] correspond to transitions from the capturing state to states found in the $Cl^{35}(d,p)Cl^{36}$ reaction, with the highest energy gamma ray corresponding to the ground-state transition. However, at excitation energies in $Cl^{36}$ greater than ~2.5 Mev, the level spacing is comparable to the resolution under which the gamma-ray measurements were made.

The angular distributions of several of the proton groups from the $Cl^{35}(d,p)Cl^{36}$ reaction have been studied by Teplov.[5] The angular distributions could be analyzed in terms of a stripping mechanism, and the

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† Work performed under the auspices of the U. S. Atomic Energy Commission.

* Guest scientist at Brookhaven National Laboratory, Upton, New York.

[1] R. E. Segel, Phys. Rev. **111**, 1620 (1958).

[2] Groshev, Adyasevich, and Demidov, *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, 1955* (United Nations, New York, 1956).

[3] Paris, Buechner, and Endt, Phys. Rev. **100**, 1317 (1955).

[4] C. F. Biese and J. L. Benson, Phys. Rev. **110**, 712 (1958).

[5] I. B. Teplov, J. Exptl. Theoret. Phys. U.S.S.R. **31**, 25 (1956) [Translation: Soviet Phys. JETP **4**, 31 (1957)].

resulting values of $l_n$ are given in Table II. This angular distribution work was performed under relatively low energy resolution and, therefore, the meaning of the $l_n$ assignments for groups corresponding states in $Cl^{36}$ at energies $>2.5$ Mev is ambiguous.

A more complete discussion of the work mentioned above, as correlated with the present work, is given in the "Discussion" section.

A rather complete review of work pertaining to $Cl^{36}$ published prior to February 1, 1957, is given by Endt and Braams.[6]

## EXPERIMENTAL RESULTS

The spectrum observed by the three-crystal pair spectrometer viewing an $AlCl_3$ target is shown in Fig. 1.

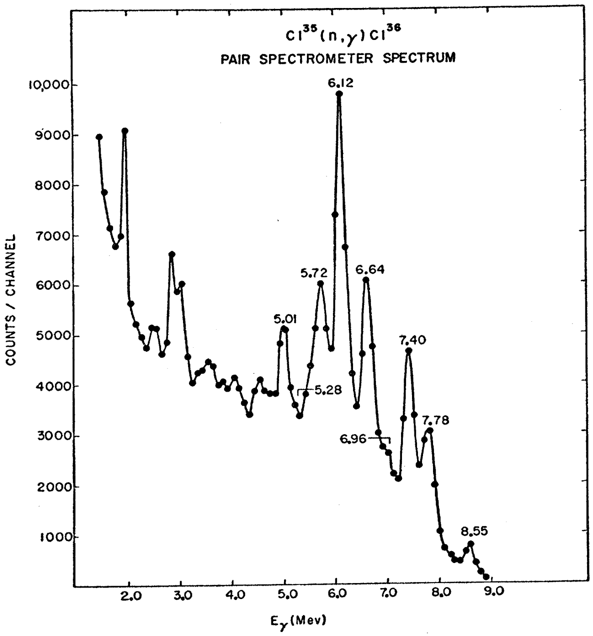

FIG. 1. Three-crystal pair spectrometer spectrum of gamma rays following thermal neutron capture in $Cl^{35}$. The energies are those of reference 2.

The thermal neutron capture cross section in $Cl^{37}$ (34 barns) is far greater than in $Cl^{36}$ (0.6 barn) or $Al^{25}$ (0.2 barn) and, therefore, all of the lines seen in Fig. 1 can be presumed to be due to capture in $Cl^{35}$. The energies of the lines quoted are those of reference 2, as the magnetic spectrometer measurements are more precise than those that can be achieved with a NaI(Tl) crystal. Upon comparing this spectrum with Table I, it can be seen that the relative intensities of the various lines are also in general agreement.

Coincidences were measured between the pair spectrometer and a 3-in.×3-in. NaI(Tl) crystal also placed close to the target. Coincident spectra were measured in the 3-in. crystal with the pair spectrometer channeled to cover the 7.78, 7.41, 6.96, 6.64, 6.12, 5.72, 5.28, and 5.01-Mev lines, respectively. The spectrum in coincidence with the 7.78-Mev line is shown in Fig. 2. The spectrum shows a strong line at ~0.79 Mev, which corresponds to the transition from the 0.79-Mev state

TABLE I. Gamma rays from[a] $Cl^{35}(n,\gamma)Cl^{36}$.

| Energy (Mev) | Photons/100 captures | Level fed (Mev) |
|---|---|---|
| 8.55±0.04 | 2.8 | |
| 7.78±0.03 | 7.8 | 0.79 |
| 7.41±0.03 | 14 | 1.16 |
| 6.96±0.04 | 1.9 | 1.60 |
| 6.64±0.04 | 14.4 | 1.95 |
| 6.12±0.03 | 21.4 | 2.50 |
| 5.72±0.03 | 5.6 | 2.87 |
| 5.49±0.04 | 2 | 3.11 |
| (5.28±0.05) | 1.6 | 3.34 |
| 5.01±0.04 | 6 | 3.60 |
| (4.79±0.05) | 1.9 | |
| (4.64±0.05) | | |
| (4.50±0.05) | 2.2 | |
| (4.15±0.05) | 2.3 | |
| (4.05±0.05) | 2.1 | |
| (3.90±0.05) | 1.8 | |
| (3.63±0.05) | 2.9 | |
| 3.40±0.05 | 3.6 | |
| 3.09±0.02 | 8.0 | |
| 3.02±0.03 | | |
| 2.87±0.02 | 9.5 | |
| 2.68±0.02 | 2.0 | |
| 2.51±0.03 | 1.0 | |
| 1.97±0.01 | 29 | |
| 1.72±0.02 | 1 | |
| 1.67±0.02 | 1 | |
| 1.60±0.01 | 2.4 | |
| 1.165±0.01 | 36 | |
| 0.77±0.01 | 23 | |
| 0.485±0.01 | 26 | |

[a] See reference 2.

TABLE II. Energy levels in $Cl^{36}$ from $Cl^{35}(d,p)Cl^{36}$.

| Excitation energy[a] (Mev) | $l_n$[b] |
|---|---|
| 0 | 2 |
| 0.790±0.005 | 2? |
| 1.163±0.006 | 0 |
| 1.600±0.007 | 0 |
| 1.952±0.007 | 0+3? |
| 2.473±0.007 | 2 |
| 2.498±0.007 | |
| 2.523±0.007 | |
| 2.684±0.007 | 3+1 |
| 2.820±0.007 | |
| 2.872±0.007 | |
| 2.905±0.007 | |
| 3.004±0.007 | |
| 3.110±0.008 | |
| 3.214±0.008 | |
| 3.341±0.008 | |
| 3.474±0.008 | |
| 3.606±0.008 | |
| 3.644±0.008 | |
| (3.673±0.008) | |
| 3.732±0.008 | |
| 3.970±0.008 | |
| 4.003±0.008 | |
| 4.043±0.008 | |

[a] See reference 3.
[b] See reference 5.

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[6] P. M. Endt and C. M. Braams, Revs. Modern Phys. 29, 683 (1957).

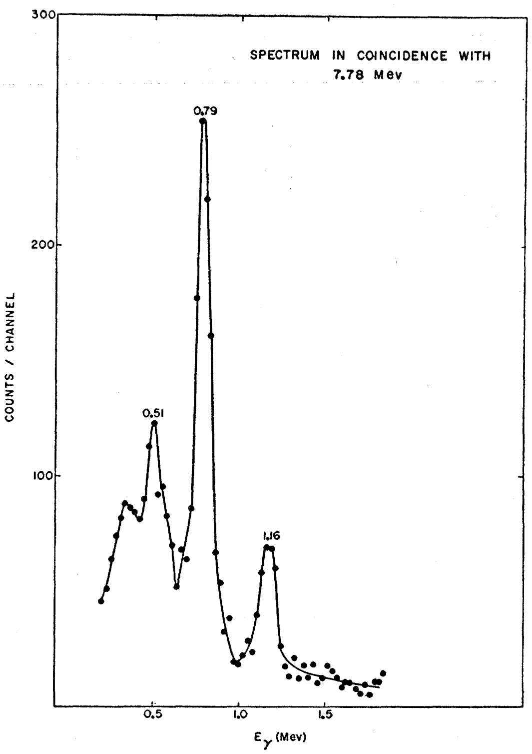

FIG. 2. Spectrum in 3-in.×3-in. NaI(Tl) crystal in coincidence with 7.78-Mev line.

to the ground state. Of course, only a ground state transition is expected from the 0.79-Mev state, as it appears to be the first excited state. A possible state at 0.40 Mev is postulated by Teplov,[5] but the existence of such a state is confirmed neither by the work of Paris *et al.*,[3] nor by the present work.

The weaker line at ~1.16 Mev is due to the 7.41–1.16 Mev cascade (see below). Because of the small separation (~5% in energy) between the 7.78- and the 7.41-Mev lines, some pulses from the 7.41-Mev line fell within the window covering the 7.78-Mev peak. The weak peak at ~0.5 Mev was due to accidental coincidences. The singles spectrum in the 3-in. crystal showed a strong peak at 0.5 Mev which was by far the strongest in the spectrum. This peak was due to the line in the spectrum at ~0.5 Mev (see Table I) and also to annihilation radiation produced in the environs by the high-energy gamma rays emanating from the target. This weak contribution at 0.5 Mev was the only significant effect of accidental coincidences and, therefore, accidentals were not, in general, subtracted from the spectra. The low-energy cutoff was due to the electronics and deserves no further attention.

The spectrum in coincidence with the 7.41-Mev line showed chiefly a line at 1.16 Mev, indicating that the 1.16-Mev second excited state decays primarily directly to the ground state. A weaker 0.79-Mev line was present, due to the nearby 7.78–0.79 Mev cascade. No 0.37-Mev line was found, which indicates that there are few transitions from the second to first excited state.

The 1.60-Mev state, which is fed by the weak 6.96-Mev line, again appears to decay primarily to the ground state. The spectrum in coincidence with the 6.96-Mev region indicated lines at 0.79 and 1.16 Mev, as well as the 1.60-Mev line. These 0.79- and 1.16-Mev lines were due to low-energy tails from the strong 7.78- and 7.41-Mev transitions.

The spectrum in coincidence with the 6.64-Mev lines which feeds a state at 1.95 Mev is shown in Fig. 3. Lines are seen at 1.95, 1.60 (?), 1.16, 0.79, and 0.51 Mev. The 1.95-Mev line corresponds to the ground-state transition. The 1.16- and 0.79-Mev lines are both too strong (by about a factor of 2) to be due to coincidences with the low-energy tails of the 7.78- and 7.41-Mev lines. Cascades through the first and/or second excited states are, therefore, indicated. As the energy of the 1.95-Mev state is equal to the sum of the energies of the first (0.79-Mev) and second (1.16-Mev) excited states (to within ~15 kev, which is the limit of accuracy from the Paris *et al.*[3] measurements), it is impossible to tell whether the cascade proceeds through the first or second excited states; both cascades might be present. The 1.95-Mev state appears to decay ~80% directly to the ground state, and ~20% through the first and/or second excited states.

The rather weak 1.60-Mev peak is probably partially due to a spill-over from the 6.96–1.60 Mev cascade, and partially due to the Compton peak from the 1.95-Mev line. A search for a line at 0.35 Mev, which would correspond to a transition between the 1.95- and the 1.60-Mev states, yielded negative results.

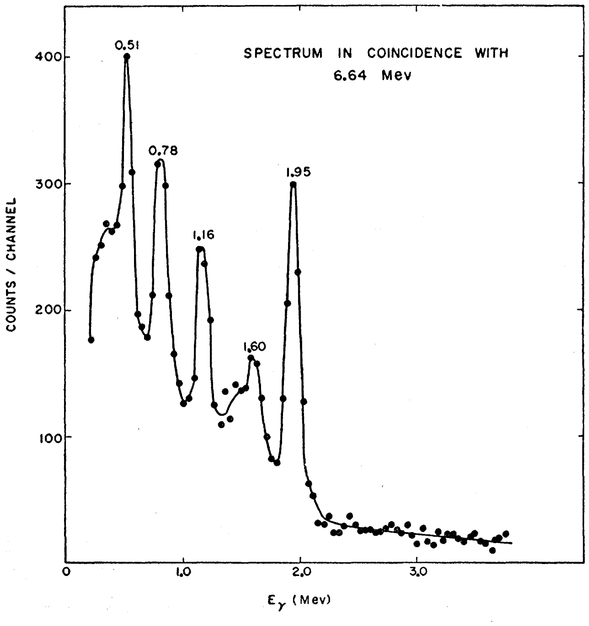

FIG. 3. Spectrum in 3-in.×3-in. NaI(Tl) crystal in coincidence with 6.64-Mev line.

The line at 0.51 Mev is due to a spill-over from the very strong 6.12–0.5 Mev cascade (see below).

As was previously mentioned, the levels become quite closely spaced at excitation energies above 2.5 Mev (see Table II). Therefore, gamma rays emanating from the capturing state which are of energy $<\sim 6.2$ Mev, might very well be multiplets and feed more than one state. It is necessary to keep this in mind in discussing the cascades through the higher excited states. However, for convenience, we will continue to refer to the gamma rays measured in reference 2 (Table I) as "lines."

The 6.12-Mev line, which is the strongest line emanating from the capturing state, feeds one or more of the three states at $\sim 2.50$ Mev. The spectrum in coincidence with this line is shown in Fig. 4. Lines are seen at 0.51, 0.79, 1.16, and 1.95 Mev. It is important to note that no line is seen at 2.50 Mev, which would correspond to a ground-state transition(s). The strong 0.51-Mev line, which corresponds to the 0.485-Mev line measured by Groshev *et al.*,[2] together with the rest of the spectrum suggests that the 6.12-Mev line feeds the 2.47-Mev state, which decays to the 1.95-Mev state. However, comparing Fig. 3 with Fig. 4, one can see that the relative intensities of the 0.79-, 1.16-, and 1.95-Mev lines are different in the two spectra. (The intensity scales are chosen such that the 1.95-Mev peak will be of the same height in both spectra.) Specifically, both the 0.79- and the 1.16-Mev peaks in Fig. 4 are about twice as high as they are in Fig. 3. Furthermore, no other transitions of comparable intensity appear to be present, thereby ruling out the possibility that there are strong transitions present from one of the states at about 2.5 Mev to the first and second excited state. The only explanation, therefore, seems to be that there are two states at $\sim 1.95$ Mev, one of which is primarily fed by the 6.64-Mev gamma ray from the capturing state, the other being fed by the 6.12–0.51 Mev cascade. The 1.95-Mev state fed by the 6.12–0.51 Mev cascade decays $\sim 60\%$ directly to the ground state, and $\sim 40\%$ by stop-over transitions to the first and/or second excited states. Evidence for a doublet at about 1.95 Mev is also reported by Teplov,[5] who found that the proton angular distribution could only be fitted by assuming two values of $l_n$, namely $l_n = 0$ and 3. As these two values of $l_n$ lead to states of opposite parity, a doublet at $\sim 1.95$ Mev is implied.

In the Paris *et al.*[3] work, there are no indications of structure in the proton group leading to the 1.95-Mev state. These data can be reconciled with the present work if either the two levels are $<\sim 15$ kev apart, or one of the groups was missed in the study by Paris *et al.*[3] These workers took data at only one angle (90°), and in view of the presence of low minima in an angular distribution of a reaction where direct interaction is the prominent mode, it is possible that a group was missed.

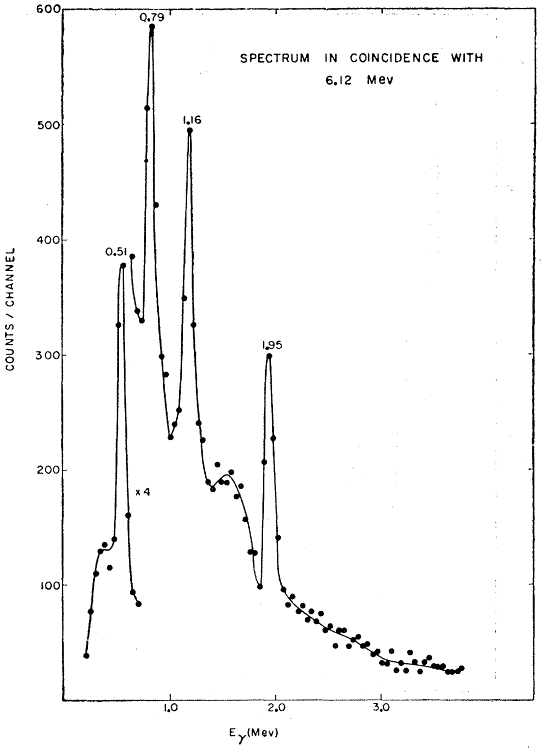

FIG. 4. Spectrum in 3-in.×3-in. NaI(Tl) crystal in coincidence with 6.12-Mev line.

It is not possible to choose between the above two possibilities from the information presently available.

An intense peak at 2.87 Mev was the chief feature of the spectrum in coincidence with the 5.72-Mev line, indicating that the 2.87-Mev state decays mainly directly to the ground state. Peaks were also present at 0.51, 0.79, 1.16, and 1.95 Mev which were due to low-energy tails from higher energy lines. A weak peak, whose presence must be considered doubtful, was seen at 2.08 Mev. This line would, of course, correspond to a transition from the 2.87-Mev to the 0.79-Mev state. While Groshev *et al.*[2] (Table I) do not list a line at 2.08 Mev, their published data seem to allow a weak line at this energy.

A coincidence spectrum was taken with the pair spectrometer centered on 5.28 Mev. As can be seen from Fig. 1, the 5.28-Mev line is not really resolved from the stronger 5.01-Mev line. The spectrum in coincidence with 5.28 Mev appeared to show a peak at about 3.30 Mev, indicating a two-step cascade through the 3.34-Mev state (Table II). This 3.34-Mev line probably corresponds to the 3.40-Mev line of Groshev *et al.*[2]

The spectrum in coincidence with the 5.01-Mev line is shown in Fig. 5. This spectrum shows peaks at 0.51, 0.79, 1.16, 1.65, and 1.95 Mev, and no peaks of comparable intensity at any energy greater than 1.95 Mev. All of these peaks are too intense to be due to low-energy

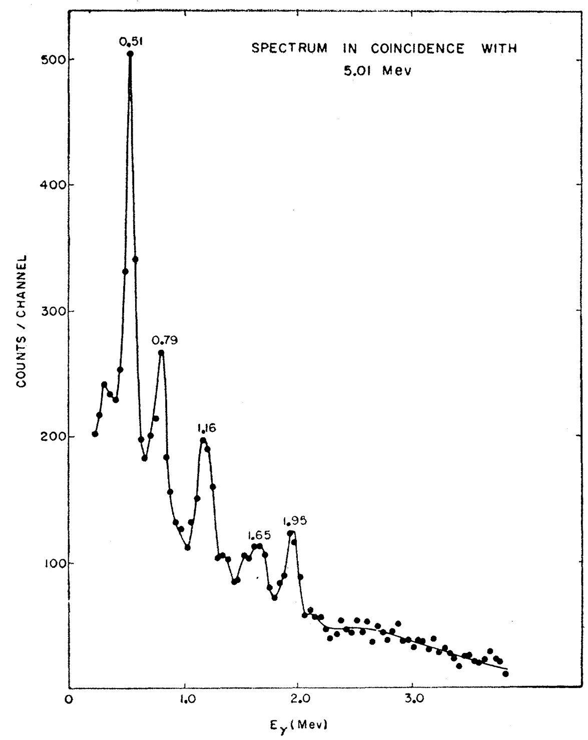

FIG. 5. Spectrum in 3-in.×3-in. NaI(Tl) crystal in coincidence with 5.01-Mev line.

tails from higher energy transitions. The most natural conclusion to be drawn from these data is that the 3.60-Mev state, which is the state fed by the 5.01-Mev line, decays chiefly via two modes:

1. By a 1.13-Mev transition to the 2.47-Mev state. The 1.13-Mev line was not resolved from the 1.16-Mev line either in the present work or by Groshev *et al.*[2]

2. By a 1.65-Mev transition to one of the 1.95-Mev states. The data are inconclusive as to which of the two 1.95-Mev states is fed.

In addition to the data taken with the 100-channel analyzer, several pictures were taken on an "*X-Y-Z*" analyzer.[7] One of these pictures is shown in Fig. 6. Two-step cascades, in which the intermediate state decays directly to the ground state, lie on a straight line. This line is referred to as the "full-energy line" since the sum of the energies of the two gamma rays is equal to the binding energy. It can be seen from Fig. 6 that points on the full-energy line corresponding to the 5.01- and 6.12-Mev lines are missing. (A weak "dot" is seen on the full-energy line in coincidence with 6.12 Mev. This is probably due to summing in the 3-in. crystal. A weak peak at ~2.47 Mev was seen in some of the spectra taken in coincidence with 6.12 Mev, and the intensity of this peak was consistent with it being entirely due to summing in the crystal.)

The case for there being two states at 1.95 Mev is also strengthened by the data shown in Fig. 6. The dots corresponding to the 6.64–1.95 and the 6.12–1.95 Mev coincidences are about equally intense, while the 6.12–1.16 and 6.12–0.79 Mev dots are considerably more intense than the 6.64–1.16 and 6.64–0.79 Mev dots, respectively.

The decay scheme measured in the present work is shown in Fig. 7. Those transitions which are uncertain are enclosed by parentheses.

Finally, it is noted that the decay scheme found here is, in general, consistent with the singles spectrum of Groshev *et al.*[2] The only transition identified in the present work which does not correspond to a line listed by Groshev *et al.*[2] is the weak 2.08-Mev transition from the 2.87- to the 0.79-Mev states, and this transition is uncertain. All of the lines listed by Groshev *et al.*[2] whose intensity is greater than 3 photons per 100 captures is accounted for in the present work, with the exception of the 3.02- and 3.09-Mev lines (see Table I).

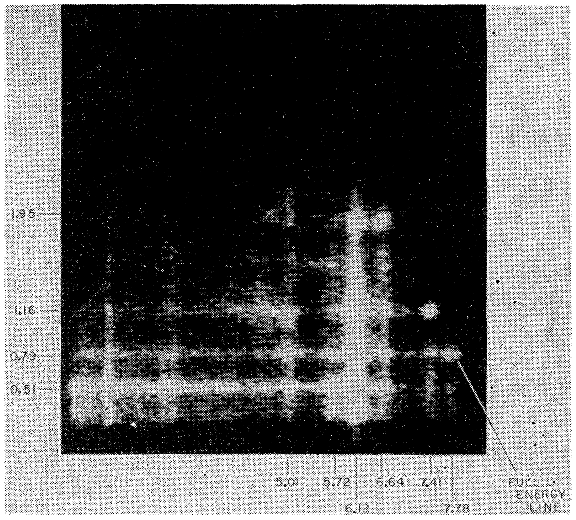

FIG. 6. Coincidence picture taken on "*X-Y-Z*" analyzer.[7] The pair spectrometer pulses were on the *Y* deflection plates.

## DISCUSSION

The nucleus $Cl^{36}$ lies in the region of the periodic table where nuclear states appear to be susceptible to a shell model description. This description appears to be applicable to many of the excited states, as well as to the ground state. However, there has also been evidence found recently that collective motion may play a major role in determining the properties of some of the states of rather light nuclei.[8] We note, for completeness, the recent theoretical studies have shown that the difference between an individual particle

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[7] L. Grodzins, Rev. Sci. Instr. **26**, 1028 (1955).

[8] D. A. Bromley in *Proceedings of the Rehovoth Conference on Nuclear Structure* (North-Holland Publishing Company, Amsterdam, 1958), p. 108.

and a collective model of the nucleus may be more apparent than real, but we shall not discuss this basic question in this paper.

The status of the neutron-capturing states deserves special mention. In a great number of nuclei, of which $Cl^{36}$ is an example, a good bit of detailed information is available about the low-lying excited states and about the states between the neutron binding energy and ~10 kev above the neutron binding energy. This last remark must be qualified by noting that only those states which can be populated via $s$-wave neutron absorption are really open to direct investigation.

This gap in knowledge between the states reached through $\beta$-decay, $(d,p)$ reactions, etc., and those in the neutron resonance region exists for all but the very light nuclei. It has not been possible, therefore, to describe these neutron resonance states in terms of the models that are postulated to apply to the low-lying states. The present work is partially designed to throw light on this question, and we shall refer to it again in the ensuing discussion.

Before proceeding to a detailed analysis, it is necessary to note that $Cl^{36}$ is an odd-odd nucleus and, therefore, must contain at least two unpaired nucleons. For this reason, odd-odd nuclei have notoriously complex energy level spectra, and, therefore, tend to be more difficult to analyze.

The ground-state spin of $Cl^{36}$ has been directly measured to be 2, and a positive parity is deduced from the $Cl^{36}$ beta decay.[6] This spin assignment is consistent with the shell model, which predicts $(d_{3/2}, d_{3/2}^{-1})$ configuration for the $Cl^{36}$ ground state.[9] This prediction is confirmed by the stripping data,[5,10] which show a virtually pure $l_n=2$ angular distribution for the ground-state protons from the $Cl^{35}(d,p)$ reaction. As the $Cl^{35}$ ground state is $3/2^+$ (which is the shell model prediction—we are in the $d_{3/2}$ shell for both neutrons and protons) the spin and partiy requirements would also be met if $l_n=0$; and the fact that only $l_n=2$ is observed for the ground-state group demonstrates that the next neutron is, indeed, added to the $d_{3/2}$ shell.

The capturing is effected by combining an $s$-wave neutron with the $Cl^{35}$ ground state, and can, therefore, have a spin of either 1 or 2, and must have even parity. Brugger *et al.*[11] have measured the chlorine total neutron cross section as a function of energy, and conclude that the thermal capture is dominated by a negative-energy resonance. These workers get a better fit to their data if they assign a spin of 2 to this negative-energy state. However, this assignment cannot be taken as unquestionable.

From the $(d_{3/2},d_{3/2}^{-1})$ configurations one would expect four states, all of even parity and of spins 0, 1, 2, and 3. These states should, furthermore, all be characterized by an $l_n=2$ stripping pattern in the $Cl^{35}(d,p)Cl^{36}$ reaction. As mentioned above, one of these states is obviously the ground state. The 0.79-Mev first excited state also appears to belong to this group of states, though Teplov[5] was not certain of the $l_n=2$ assignment. The other groups for which Teplov finds $l_n=2$ are in the region corresponding to an excitation energy in $Cl^{36} > 2.5$ Mev, and it is obvious from the work of Paris *et al.*[3] (Table II) that these groups really represent reactions leading to more than one final state. The values of $l_n$ assigned to these lower proton energy groups, therefore, cannot be given much credence.

The 1.16-, 1.60-, and one of the 1.95-Mev states are found to have an $l_n=0$ by Teplov[5] and, therefore, these states must all have even parity and spins of either 1 or 2. Because these states are populated by an $s$-wave neutron they could not belong to the $(d_{3/2},d_{3/2}^{-1})$ configuration. A possible configuration for these states is $(d_{3/2},s_{1/2}^{-1})$ i.e., a nucleon (neutron or proton) is promoted from the $s_{1/2}$ shell to the $d_{3/2}$ shell, leaving an unpaired nucleon in the $d_{3/2}$ shell and a corresponding

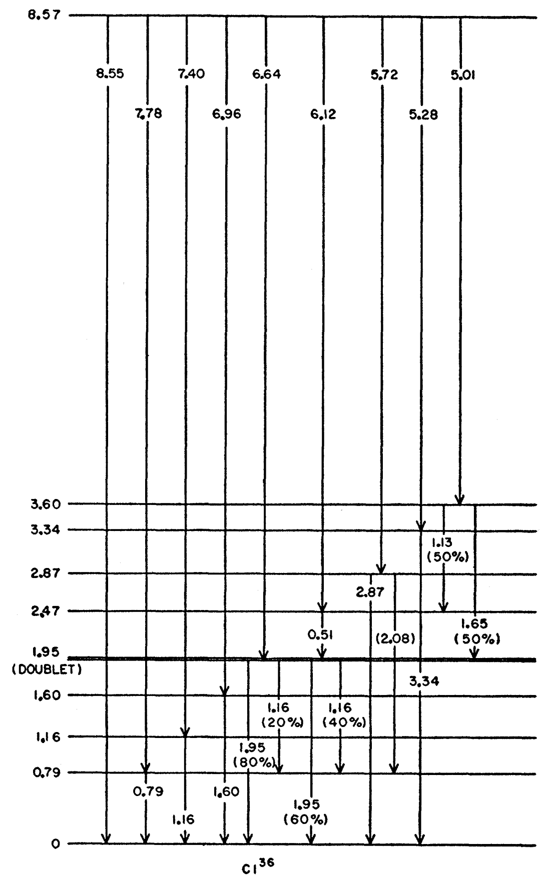

FIG. 7. Gamma-ray cascades measured following thermal neutron capture in $Cl^{35}$. For an explanation of the 1.95-Mev doublet, see text.

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[9] J. H. D. Jensen, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1955), Chap. XV.

[10] J. S. King and W. C. Parkinson, Phys. Rev. **88**, 141 (1952).

[11] Brugger, Evans, Joki, and Shankland, Phys. Rev. **104**, 1054 (1956).

TABLE III. Calculated and experimental radiation widths for capturing state radiation.

| $E_\gamma$ | $\Gamma_\gamma$(exp) (ev) | $\Gamma_\gamma$(calc) |  | $\lvert M\rvert^2=\Gamma_\gamma(\text{exp})/\Gamma_\gamma(\text{calc})$ |  |
|---|---|---|---|---|---|
|  |  | $M1$ | $E1$ | $M1$ | $E1$ |
| 8.55 | 0.009 | 1.05 |  | 0.009 |  |
| 7.78 | 0.037 | 0.79 |  | 0.047 |  |
| 7.41 | 0.050 | 0.69 |  | 0.073 |  |
| 6.96 | 0.007 | 0.57 |  | 0.012 |  |
| 6.64 | 0.062 | 0.49 | 22.8 | 0.13 | 0.0027 |
| 6.12 | 0.11 | 0.39 | 18.3 | 0.28 | 0.0060 |
| 5.72 | 0.048 | 0.32 | 14.6 | 0.15 | 0.0033 |
| 5.28 | 0.007 | 0.25 | 12.3 | 0.028 | 0.0006 |
| 5.01 | 0.036 | 0.21 | 9.9 | 0.17 | 0.0036 |

hole in the $s_{1/2}$ shell. The $s_{1/2}$ shell appears to lie close under the $d_{3/2}$ shell[9] and, therefore, one might expect the states arising from this configuration to lie fairly close to the states arising from the $(d_{3/2},d_{3/2}^{-1})$ configuration. The "stripping" process would, therefore, consist of a nucleon going from the $s_{1/2}$ to the $d_{3/2}$ shell as the incoming neutron enters the $d_{3/2}$ shell, giving no net change of orbital angular momentum and, therefore, an $l_n=0$ proton angular distribution.

The other 1.95-Mev state appears to be populated by an $f$-wave neutron.[5] One would then suspect that this neutron enters the $f_{7/2}$ shell, which is the next higher shell above the $d_{3/2}$ shell. This other 1.95-Mev state must, therefore, have negative parity and spin 2, 3, 4, or 5.

As we have mentioned above, the proton groups leading to the states of excitation energy $>1.95$ Mev were not resolved and, therefore, we cannot say anything about the character of the individual states.

The gamma rays in the spectrum of Groshev *et al.*[2] of energy $>5$ Mev can be presumed to originate at the capturing state. All of the gamma rays in this energy region that were resolved by Groshev *et al.* are sufficiently intense that they must be dipole radiation. The ground state and the first three excited states all have positive parity, as does the capturing state, and therefore, the transition to these states must be $M1$. In Table III is shown the partial radiations widths for those transitions studied in this work together with their calculated values. For the total $\Gamma_\gamma$ we use the value of 0.48 ev,[11] while the calculated widths are from the estimate of Weisskopf,[12] corrected by a factor of $D/D_0$ as suggested in Blatt and Weisskopf.[13]

For the experimental values of $\Gamma_\gamma$ we have used the relative gamma-ray intensities as measured in the present work. These values are in rather good agreement with the values measured by Groshev *et al.*[2] We have taken $D=2\times10^4$ ev and $D_0=5\times10^5$ ev [13] in calculating the theoretical widths.

It is clear from Table III that the experimental $\Gamma_\gamma$ for the four definitely established $M1$ transitions of 8.55, 7.78, 7.40, and 6.96 Mev are all considerably below the single-particle estimate.[12,13] An average of these four values of $|M|^2$, where $|M|^2$ is defined as the estimate of the ratio of the experimental to the calculated corrected single-particle estimate, yields a value of $|M|^2\sim0.05$. This value can be contrasted to the situation in $Hg^{200}$,[1] where three $M1$ transitions all gave $|M|^2\sim1$. This comparison is qualitatively in accord with the observations of Bartholomew,[14] who notes that the partial widths of transitions from the capturing state to low-lying excited states reaches a maximum in the region of doubly magic $Pb^{208}$.

Another interesting fact is the wide variation of the partial $M1$ widths, again in contrast to the case in $Hg^{200}$.[1] In the present case of $Cl^{36}$, the partial widths for different $M1$ transitions vary by about a factor of 10. This result forms an interesting corollary to the results of Kennett, Bollinger, and Carpenter[15] who find significant differences in the partial widths of transitions from two resonances of the same spin in $Mn^{55}$ to the same low-lying states in $Mn^{56}$.

No obvious systematics seem to be present in the partial width fluctuations. The intensities of the transitions to the ground state and first excited state, both of which appear to be of a $(d_{3/2},d_{3/2}^{-1})$ configuration differ by about a factor of 5, as do the transitions to the second and third excited states, both of which are formed through $s$-wave neutron absorption. However, the average of the reduced widths for the transitions to the ground and first excited states is about equal to the average value for the transitions to the second and third excited states. In other words, the capturing state, which is formed through $S$-wave neutron absorption appears as inclined to decay to states formed by $l_n=2$ as it is to states formed by $l_n=0$. This point will be further discussed below after the transitions to and from the more highly excited states have been discussed.

One of the 1.95-Mev states shows an $l_n=0$ pattern in the $Cl^{35}(d,p)Cl^{36}$ reaction[5] and, therefore, this state must be accessible via an $M1$ transition from the capturing state (regardless of whether the capturing state is $1^+$ or $2^+$). From the analysis of the gamma rays in coincidence with the 6.12- and 6.64-Mev lines, we see that the relative populations of the two states at 1.95 Mev differ by at least a factor of two in the two cascades (see Figs. 3 and 4 and accompanying text). Since at least part of the 6.64-Mev line must be to the even-parity 1.95-Mev state, and since the remainder of the 6.64-Mev line would have an unusually small reduced width to be an $E1$ transition to the odd-partiy 1.95-Mev state (an $M2$ transition would be negligibly weak), we conclude that the 6.64-Mev line must be primarily an $M1$ transition to the even parity 1.95-Mev state. This assignment must be considered as tentative,

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[12] V. F. Weisskopf, Phys. Rev. **83**, 1073 (1951).

[13] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952).

[14] G. A. Bartholomew in *Proceedings of the International Conference on the Neutron Interactions with the Nucleus* (unpublished).

[15] Kennett, Bollinger, and Carpenter, Phys. Rev. Letters **1**, 76 (1958).

though additional arguments will be given below to support its plausibility. We note that the reduced width for this 6.64-Mev transition appears to be about a factor of 2 higher than it is for the highest of the other $M1$ transitions.

The decay of the 1.16-, 1.60-, and the even-parity 1.95-Mev states are all consistent with the $J=1^+$ or $2^+$ implied by the $l_n=0$ assignment from the stripping data.[5] As the ground state is $2^+$, these three states should decay primarily to the ground state which is, indeed, the case. The ratio of $\sim 4$ of the crossover to the stopover transition is consistent with the theoretical estimate of $\sim(1.95/1.16)^3=4.7$ if both transitions are dipole radiation. Therefore, $|J_{1.95}-J_{0.79}|\leq 1$ is implied for the even-parity 1.95-Mev state.

The 6.12-, 5.72-, and 5.01-Mev transitions all appear to have reduced widths which are, on the average, about a factor of 4 larger than the average reduced width for the four established $M1$ transitions (though not substantially greater than for the 6.64-Mev line). An $E1$ assignment, therefore, seems most appropriate to these transitions. Odd-parity states formed by the $(d_{3/2},f_{7/2})$ configuration are to be expected in this region of excitation energy. Assuming the 6.12-, 5.72-, and 5.01-Mev transitions to be $E1$, an average value of $|M|^2$ of $\sim 0.004$ is obtained (see Table III). This value is again much lower than that found in $Hg^{200}$,[1] where the one rather definitely established $E1$ transition which originated at the capturing state has a reduced width about 1/10 of the single-particle estimate. However, the ratio of $E1/M1\sim 4$ is about the same for the capture gamma rays in $Cl^{36}$ as it is for the capture gamma rays in $Hg^{200}$. This ratio can be compared to the single-particle estimate of $E1/M1\sim 40$. The fact that the experimental $M1$ widths lie closer to the predicted values than the $E1$ widths has been noted by Bartholomew[14] in his survey of all the available capture gamma-ray data.

We have mentioned above that the lower lying odd-parity states in $Cl^{36}$ are most probably due to a $(d_{3/2},f_{7/2})$ configuration. The configuration can, in a sense, be thought of as being formed by adding an $f_{7/2}$ neutron to a $Cl^{35}$ nucleus. The 8.57-Mev capturing state is formed by adding an $s_{1/2}$ neutron to a $Cl^{35}$ nucleus. However, the relative strength of transitions from the capturing state to these odd-parity states compared to states of other configurations is about what would be expected from the theoretical estimate with no cognizance being taken of the final-state configuration. In making the above statement, we assume that the $E1/M1$ single-particle estimate is too high by about a factor of 10. This correction is based on the aggregate of all slow-neutron capture gamma-ray data, where assumedly effects due to the final-state configuration would average out.

In $Cl^{36}$ we have transitions from the capturing state to states of $(d_{3/2},d_{3/2}^{-1})$, $(d_{3/2},s_{1/2})$ and $(d_{3/2},f_{7/2})$ configuration. The transition probabilities to these states appear, on the average, to be determined solely by the multipolarity of the radiation (and, of course, its energy), and not to depend strongly on the final-state shell-model configuration. A possible explanation of this phenomenon lies in considering the nature of the capturing state. This state lies in a region of closely spaced levels, and the mixing between states should be relatively great. Therefore, one would expect the capturing state not to be described by a unique configuration, but rather to be a mixture of several configurations which have only to fulfill the appropriate spin and parity conditions. The capturing state, therefore, "forgets" that it was formed by an $s$-wave neutron and can decay with roughly equal probability to states of different configurations.

It must be emphasized that the arguments only apply "on the average," and that transitions of the same multipolarity can still have significantly different reduced widths, as witness the 8.55-, 7.78-, 7.40-, and 6.96-Mev lines in the present work.

The $\Gamma_\gamma$ of the 5.28- and the 5.49-Mev lines appear to be most consistent with these transitions being $M1$.

The decay of the 2.47- and 3.60-Mev states merits special attention. Arguments are given above for assigning the 1.95- (odd parity), 2.47-, and 3.60-Mev states to the $(d_{3/2},f_{7/2})$ configuration. The decay scheme for these states (see Fig. 7) is suggestive of a series of vibrational states. This resemblance is caused mainly by the level spacing and the decay of the 3.60-Mev state. The presence of a strong "stopover" transition to the 2.47-Mev state, and a "crossover" to the 1.95-state is similar to the decay of second excited states which have been more definitely identified as belonging to vibrational bands. It would not be surprising to find states formed through a collective motion superimposed on a single-particle configuration in $Cl^{36}$. However, the positive identification of the 2.47- and 3.60-Mev states as being such, must await further information, particularly in regard to spins and transition probabilities.

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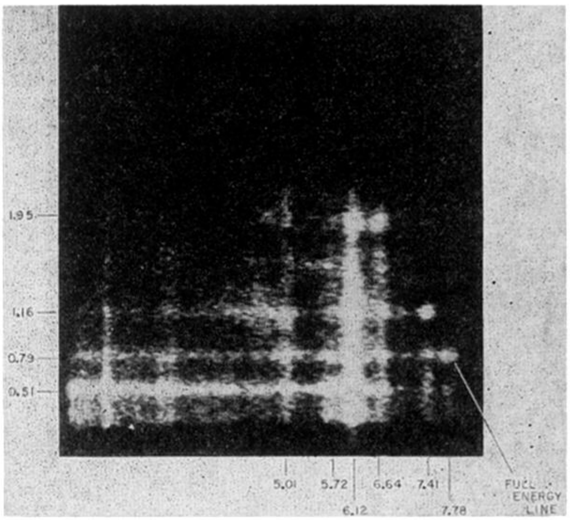

FIG. 6. Coincidence picture taken on "*X-Y-Z*" analyzer.[7] The pair spectrometer pulses were on the *Y* deflection plates.