Branching-Ratio Measurements on the 6.92- and 7.12-MeV States in O^{16}†

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Measurements have been made on the branching ratios for cascade decay of the 2^+ 6.92- and the 1^- 7.12-MeV states of O^{16} through the 0^+ 6.06-MeV state. For the 6.92-MeV state, the result, $(2.9\pm0.4)\times10^{-4}$, is consistent with earlier results. For the 7.12-MeV state, an upper limit of $<6\times10^{-6}$ is set on the cascade branch which corresponds to a strongly inhibited $E1$ transition. The significance of this latter result for the structure of the 6.06-MeV state is discussed.

I. INTRODUCTION

THERE has been considerable interest recently in the low-lying even-parity states of O^{16}. It is now established[1–5] that several of these are strongly deformed and at least one rotational band, involving the states with $J^\pi=0^+$, 2^+, and 4^+ at 6.06, 6.92, and 10.36 MeV (Fig. 1) has been identified. Several calculations[3–5] have confirmed that these low-lying states are expected to have a large deformation, and it has been suggested[4,5] that the deformed 0^+ state at 6.06 MeV is composed mainly of 4-particle–4-hole excitations from the closed $1p$ shell and also[6] that the state may have an axially asymmetric deformation.

If the 0^+ ground state consists mainly of the ideal spherical closed $1p$ shell, its structure is expected to be very different from that of the excited 0^+ state at 6.06 MeV. However, the effects of any such difference between the ideal deformed 0^+ state and the ideal spherical ground state will be moderated in practice by mixing of these states, so that the real 0^+ states at 0 and 6.06 MeV contain components of both the ideal spherical and ideal deformed unperturbed states. Several theoretical estimates of the extent of this mixing have been made.[7] In the most recent calculation, Brown and Green[5] found it to be about 35% by amplitude. Using the experimental branching ratio for the 6.92-MeV state, Lowe *et al.*[1] also estimated the mixing to be 35%, assuming the 6.92-MeV state to be purely rotational based on the ideal deformed 0^+ state.

In contrast to this rather large mixing predicted theoretically and apparently confirmed experimentally, three experimental results suggest that the ground and 6.06-MeV states are indeed very different in structure:

(a) The γ decay of the 1^-, $T=1$ state at 13.1 MeV to the 6.06-MeV state has been the subject of several experimental investigations.[8] Some discrepancy exists between various workers, but the most recent result (Gorodetzky *et al.*[8]) gives

$$\frac{B(E1;13.1\rightarrow6.06\text{ MeV})}{B(E1;13.1\rightarrow0\text{ MeV})}=0.05.$$

(b) The β decay of N^{16} shows[9] a similar inhibition in the transition to the 6.06-MeV state relative to that to the ground state. Here the experimental result is

$$\frac{ft(N^{16}\rightarrow O^{16}{}_{6.06\text{ MeV}})}{ft(N^{16}\rightarrow O^{16}{}_{0\text{ MeV}})}\geqslant30.$$

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[2] J. D. Larson and R. H. Spear, Nucl. Phys. **56**, 497 (1964).
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[6] G. J. Stephenson and M. K. Banerjee, Phys. Letters **24B**, 209 (1967).
[7] G. E. Brown, in *Comptes Rendus du Congrès International de Physique Nucléaire, Paris, 1964* (Editions du Centre National de la Recherche Scientifique, Paris, 1965), Vol. 1, p. 129.
[8] G. Goldring, Proc. Phys. Soc. (London) **A67**, 930 (1954); S. Gorodetzky, W. Benenson, P. Chevallier, D. Disdier, and F. Scheibling, Phys. Letters **6**, 269 (1963).
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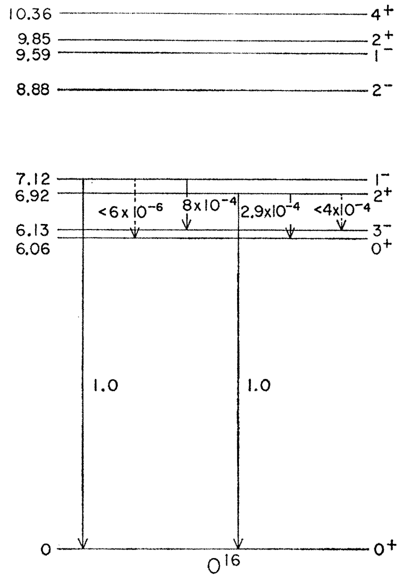

FIG. 1. Level scheme for O^{16} with branching ratios for the 6.92- and 7.12-MeV states as determined in this and other experiments.

(c) The 1^-, $T=0$ state at 7.12 MeV has not been observed to decay to the 6.06-MeV state, although the ground-state decay is well known. The experimental branching-ratio limit of Gorodetzky *et al.*[10] gives

$$\frac{B(E1;\,7.12\rightarrow 6.06\text{ MeV})}{B(E1;\,7.12\rightarrow 0\text{ MeV})}\leqslant 0.01\,.$$

Qualitatively, these results suggest a substantial difference between the structures of the two 0^+ states; in Sec. V the relation between the branching ratio of the 7.12-MeV state and the mixing of the 0^+ state is examined. In the present paper, a further search is described for the $7.12\rightarrow 6.06$-MeV transition, which search results in a new upper limit. The method used is similar to that used by Lowe *et al.*[1] in a measurement of the branching ratio of the $6.92\rightarrow 6.06$-MeV transition, but incorporates several improvements. It was therefore thought worthwhile to remeasure the branching ratio for the latter transition; this measurement is also described in the present paper.

II. APPARATUS AND METHOD

Excited states of O^{16} were formed in the reaction $F^{19}(p,\alpha)O^{16}$, using protons from the 3.5-MeV Van de Graaff accelerator at Brookhaven National Laboratory. The target consisted of 50 μg/cm^2 of CaF_2 evaporated onto a backing of reactor-grade graphite. For study of the decay of the 6.92-MeV state an incident energy of 2.41 MeV was used, at which the excitation of this state is favored[1,11] relative to other γ-ray emitting states. Excitation of the 7.12-MeV state is favored[11] at an incident energy of about 2.0–2.2 MeV. For the experiment on this state an energy of 2.12 MeV, where the excitation cross section[12] for the 6.06-MeV state is a minimum, was chosen since an appreciable contribution to the background arose from electron-positron pairs from this state.

In each experiment, cascade decay of the 7.12- or 6.92-MeV states through the 6.06-MeV state was identified by a triple coincidence of three NaI(Tl) γ-ray detectors: one 5×5-in. crystal at 0° to the beam line to detect the 1.06- or 0.86-MeV cascade γ rays, and two 3×3-in. crystals, on opposite sides of the target and at 90° to the beam line to detect 511-keV radiation from annihilation of the positron coming from the pair de-excitation of the 6.06-MeV state. Each 3×3-in. crystal was placed with its front face 5 cm from the target and the 5×5-in. crystal was 12.5 cm from the target. A $\frac{1}{8}$-in. thick brass sheet was placed in front of the 5×5-in. detector to minimize background that might arise from electrons entering the crystal directly. Since many sources of background originate from bremsstrahlung and other electromagnetic effects in the region of the target, items in the immediate vicinity of the target were constructed from materials of low Z, and as far as possible from beryllium. These included the $\frac{3}{8}$-in. o.d. by $\frac{3}{16}$-in. i.d. target tube, the vacuum sealing window on the end of the tube, and a beryllium cylinder which was placed over the end of the beam pipe to bring to rest positrons from the decay of the 6.06-MeV state. The dimensions of the Be cylinder, $1\frac{1}{4}$-in. diam by $1\frac{1}{4}$-in. long, with a $\frac{3}{8}$-in. diam by $\frac{5}{8}$-in. deep axial hole, were sufficient so that the most energetic positrons (5 MeV) resulting from the decay of the 6.06-MeV state would be absorbed. Polyethylene foil was wrapped inside the target tube to prevent protons scattered from collimators, etc., from striking beryllium.

In the electronics arrangement, all amplifiers provided double-delay-line clipped pulses and the fast-slow coincidence circuitry used zero-crossover timing with a resolving time of about 50 nsec. The spectrum in the 5×5-in. detector in triple coincidence was displayed in one 200-channel section of a 400-channel pulse-height analyzer. Random coincidences between the 5×5-in. detector and the real doubles in the 3×3-in. detectors were displayed simultaneously in the other half of the analyzer. The combined intensity of γ rays from the target de-exciting the 6.13-, 6.92-, and 7.12-MeV states was monitored continuously using the 5×5-in. detector. Automatic servostabilization of gain was used in all three detectors. The strong 0.511-MeV line from the target was used as the stabilizing reference. In order to insure that the stabilizers were locked into

[10] S. Gorodetzky, P. Mennrath, W. Benenson, P. Chevallier, and F. Scheibling, J. Phys. (Paris) **24**, 887 (1963).

[11] L. Ask, Arkiv Fysik **19**, 219 (1961).

[12] W. A. Ranken, T. W. Bonner, and J. H. McCrary, Phys. Rev. **109**, 1646 (1958).

regulation even during periods when the beam was not on the target, a Na^{22} source was suspended several feet above the apparatus such that its γ rays were incident on all three detectors. The contribution to the 0.511-MeV line in each detector due to this source was about 10% of the total rate when the beam was on target.

7.12 → 6.06-MeV Experiment

The triple coincidence pulse-height spectra in the 5×5-in. detector were recorded for a total of about 200 h at a beam current of 0.1 μA. This run was divided into ten counting periods with the following measurements interspersed:

(a) The efficiency of the apparatus for detecting positron-γ coincidences was measured by the technique described below.

(b) The dead-time loss arose from many sources in individual elements. Rather than estimating individual contributions, the total loss was measured directly by placing a weak Na^{22} source in the region of the target. When these tests were made, the Na^{22} stabilization source mentioned above was removed. Na^{22} decays by the emission of a 1.28-MeV γ ray in coincidence with a positron, and therefore gives real triple coincidences, resulting in a 1.28-MeV peak in the multichannel analyzer spectrum. The source was weak enough so that, with the beam still on, counting rates in individual detectors were changed negligibly, and with the beam off the counting rates due to the source alone produced a negligible dead-time loss. Hence the dead-time correction in the experiment was measured directly as the ratio of the 1.28-MeV counting rates in these two situations.

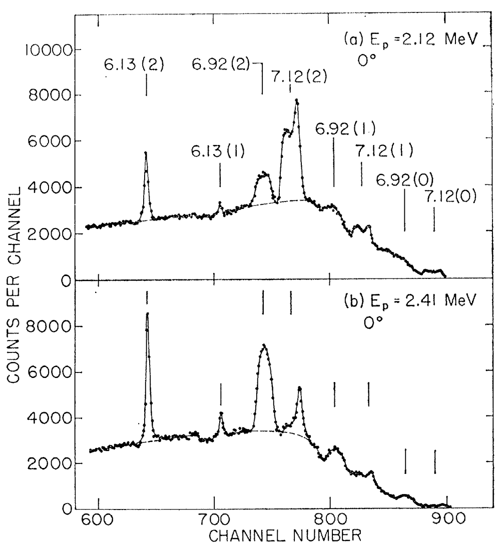

FIG. 2. Pulse-height spectra in the Ge(Li) detector at 0° from the $F^{19}(p,\alpha)O^{16}$ reaction at bombarding energies of (a) 2.12 MeV and (b) 2.41 MeV. Peaks attributed to the ground-state decays of the 6.13-, 6.92-, and 7.12-MeV states are shown. Numbers in parentheses indicate whether a peak is a full-energy loss peak (0), a one-quantum escape peak (1), or a two-quantum escape peak (2).

In the singles measurements of the high-energy γ rays in the 5×5-in. detector, it was not possible to resolve the γ rays from the three states excited. It was therefore necessary to determine the fraction of the total counting rate arising from 7.12-MeV γ rays. For this purpose, in a separate experiment, a thin CaF_2 target was bombarded with 2.12-MeV protons and the singles γ-ray spectrum at 0° examined with an 8 cm^3 Ge(Li) detector. Two escape peaks from the ground-state decays of the 6.13-, 6.92-, and 7.12-MeV levels were clearly resolved [Figure 2(a)]. Similar measurements made at 90° to the beam direction demonstrated that the γ-ray angular distributions were relatively weak, so that negligible errors were introduced by the small differences in geometry between the Ge(Li) detector at 0° and the 5×5-in. detector at 0° used in the triples measurements. (We may note that since, in the triples measurements, the cascade and ground-state γ rays were detected in the same crystal, and since both final states are $J^{\pi}=0^+$, any possible angular-distribution effects cancel out in the determination of the branching ratio, both transitions being $E1$.)

6.92 → 6.06-MeV Experiment

The experimental apparatus was identical to that used in the 7.12 → 6.06-MeV experiment, except that, as discussed above, a beam energy of 2.41 MeV was used.

The triples spectrum was recorded for 30 h at a beam current of 0.15 μA, with triples efficiency and total dead-time loss measurements interspersed as described above. The relative intensities of 6.13-, 6.92-, and 7.12-MeV γ rays were again determined at 0° with a Ge(Li) detector separately from the main experiment [Fig. 2(b)].

III. EFFICIENCY CALIBRATION

The efficiency of the apparatus for detecting positron–γ-ray coincidences was determined from the triple-coincidence rate using a Na^{22} source having a measured strength of 2.48×10^4 dis/sec. The source, which is encapsulated in a $\frac{5}{16}$-in. diam×$\frac{1}{8}$-in. high Al cylinder, was held in place at the end of the target tube by the Be absorber. To compute the efficiency for detection of the cascade decay of the O^{16} 6.92- or 7.12-MeV states from the measured efficiency for the Na^{22} source, the following corrections were necessary:

(a) The efficiency of the 5×5-in. detector is higher for 1.06- or 0.86-MeV γ rays from O^{16} than for 1.28-MeV γ rays from Na^{22} because of changes both in the total efficiency and in the fraction of the spectrum in the full-energy peak. The corrections for these effects were taken, respectively, from tables of Vegors *et al.*[13] and data of Young *et al.* and of Olness.[14] The correc-

[13] S. H. Vegors, L. L. Marsden, and R. L. Heath, Phillips Petroleum Company Report (unpublished).

[14] F. C. Young, H. T. Heaton, G. W. Phillips, P. D. Forsyth, and J. B. Marion, Nucl. Instr. Methods **44**, 109 (1966); J. W. Olness (private communication).

tion was (12±2)% for 1.06-MeV γ rays and (27±2)% for 0.86-MeV γ rays.

(b) The absorption of γ rays by the beam pipe, the beryllium absorber, and the 5×5-in. crystal can is different for 1.06- or 0.86-MeV and for 1.28-MeV γ rays. This correction was computed, using standard absorption coefficients, to be 2% for 1.06-MeV and 5% for 0.86-MeV γ rays.

(c) The positrons from the decay of the pair state of O^{16} have kinetic energies up to 5.04 MeV, and therefore come to rest with a distribution through the beryllium absorber different from that for the low-energy positrons from Na^{22}. Because the annihilation quanta are emitted at 180° to one another, the efficiency for detecting these O^{16} positrons will be less than for those from the Na^{22} source, which annihilate close to the common axis of the 3×3-in. detectors. This correction was measured by comparing the double coincidence rate in the 3×3-in. detectors, due to the Na^{22} source, with that from high-energy positrons from the 6.06-MeV state in O^{16}. For this purpose a resonance, at a proton bombarding energy of 1.875 MeV, for preferential excitation[12] of the 6.06-MeV state relative to the γ-ray emitting states was used. The correction measured in this way was (7±4)%. Attempts to determine this by computation and by measuring the variation of efficiency with Na^{22} source position gave results consistent with this value, but with larger uncertainties. Finally, the efficiency of the 5×5-in. crystal used for singles counting of the 6.92- or 7.12-MeV γ rays was taken from Refs. 13 and 14.

IV. RESULTS

7.12 → 6.06-MeV Experiment

Using the data of Hechtl[15] for the efficiency of the Ge(Li) detector, the relative intensities of the 6.13-, 6.92-, and 7.12-MeV γ rays at 0°, based on the spectrum in Fig. 2(a), were found to be 0.12 : 0.20 : 0.68, respectively. Measurements of the same quantities at 90° yielded the values 0.18 : 0.22 : 0.60, which are in good agreement with the results of Ask,[11] who obtained 0.21 : 0.21 : 0.58 for a beam energy of 2.10 MeV and an angle of 90° to the beam. In the analysis of the data of Fig. 2, and the corresponding runs at 90°, a small correction was made in each case to the area under the 7.12 (2) peak because of the presence of the weak unresolved 6.13 (0) peak.

The triple-coincidence pulse-height spectrum, after subtraction of the smoothed randoms spectrum, is shown by the upper curve in Fig. 3. The continuous background, which decreases with increasing energy, arises mainly from bremsstrahlung emitted by electrons and positrons following direct excitation of the 6.06-MeV state. Smaller contributions arise from internal bremsstrahlung in the decay of this state, and from positrons from the conversion of high-energy γ rays in the vicinity of the target. Although a 0.86-MeV γ ray from cascade decay of the 6.92-MeV state is clearly visible, there is no indication of a 1.06-MeV γ ray from the 7.12 → 6.06-MeV decay. It is estimated that a peak of height equal to the statistical error on each point would have been visible, if present, and the count corresponding to such a peak is taken as an upper limit on the branching ratio. The result is

$$R_1 = \frac{7.12 \rightarrow 0.06 \text{ MeV}}{7.12 \rightarrow 0 \text{ MeV}} < 6 \times 10^{-6}.$$

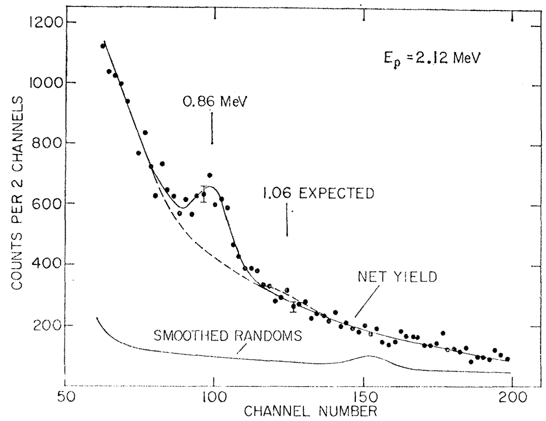

FIG. 3. The triple-coincidence pulse-height spectrum in the 5×5-in. detector after subtraction of the smoothed random curve shown in the lower part of the figure. The data were for $E_p = 2.12$ MeV. The dashed peak indicated at 1.06 MeV, such as would correspond to the decay of the 7.12-MeV state to that at 6.06-MeV, has a height equal to the statistical error per point at that energy, and corresponds to the upper limit on R_1 quoted in the text. The peak seen at 0.86 MeV arises from the decay of the 6.92-MeV state to that at 6.06 MeV. In the random spectrum, both here and in Fig. 4, the peak at about channel 150 results from the 1.28-MeV γ rays from the Na^{22} stabilization source. This peak also occurs in the total spectrum but, as may be seen in the net data, it disappears upon subtraction of the background.

6.92 → 6.06-MeV Experiment

Relative intensities at 0° of the 6.13-, 6.92-, and 7.12-MeV γ rays were measured as 0.25 : 0.58 : 0.17, respectively, based on the spectrum in Fig. 2(b) corrected for detector efficiency. Measurements taken at 90° yielded values of 0.21 : 0.57 : 0.22. The 6.92-MeV γ-ray yield at 90° seems to be significantly higher than that given by Ask,[11] who obtained 0.23 : 0.48 : 0.29 at a beam energy of 2.40 MeV. However, it is possible that the difference in beam energy could account for the discrepancy.

The triple-coincidence pluse-height spectrum at $E_p = 2.41$ MeV is shown by the upper curve in Fig. 4. The smoothed randoms spectrum has been subtracted. The count in the 0.86-MeV peak from the 6.92 → 6.06-MeV cascade was determined by interpolating the smoothed background from either side into the peak

[15] S. Hechtl (private communication).

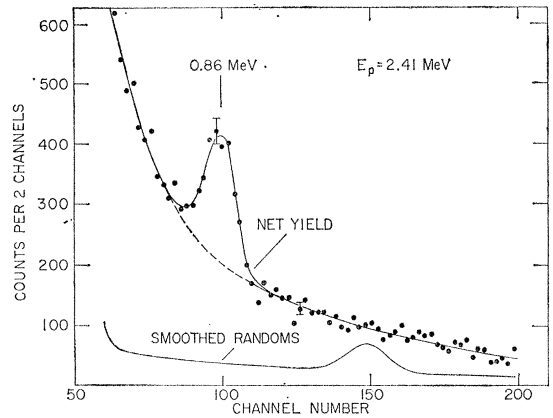

FIG. 4. The triple-coincidence pulse-height spectrum in the 5×5-in. detector, after subtraction of the smoothed random curve shown in the lower part of the figure. These data were for $E_p=2.41$ MeV.

region. The peak corresponds to a branching ratio of

$$R_2=\frac{6.92\to 6.06\ \text{MeV}}{6.92\to 0\ \text{MeV}}=(2.9\pm0.4)\times10^{-4}.$$

The main contributions to the error are statistics, uncertainty in the background subtraction, and errors in the population ratios from the Ge(Li) spectra. As a check, the 0.86-MeV peak in the spectrum from the 2.12-MeV run (Fig. 3) was analyzed in the same way, yielding a branching ratio of $R_2=(2.5\pm0.5)\times10^{-4}$, which is consistent but with a larger error.

V. DISCUSSION

The previous results for the branching ratio R_2 of the 6.92-MeV state have been summarized by Lowe *et al.*[1]; the value obtained by Lowe *et al.* is $(2.3\pm0.5)\times10^{-4}$, and the weighted mean of their, and earlier, results is $(2.5\pm0.4)\times10^{-4}$. The present result is reasonably consistent with these, and the weighted mean of all results to date is $(2.7\pm0.3)\times10^{-4}$. Since this is essentially unchanged from the value of Ref. 1, the comparison with theory given in that reference remains valid.

The most recent measurement of the branching ratio R_1 of 7.12-MeV state is that of Gorodetzky *et al.*,[10] who obtained $R_1\leq4\times10^{-5}$. The present result reduces this upper limit by a factor of 7.

Together with the known[16] ground-state width of the 7.12-MeV state, this branching ratio yields a strength for the 7.12→6.06-MeV transition of $<0.8\times10^{-6}$ Weisskopf units.[17,18] This corresponds to a strongly inhibited transition as is demonstrated in Fig. 5, where the strength is compared with those of other $E1$ transitions in light nuclei. The inhibition can not arise from any unusually high isotopic spin purity of the 7.12-MeV state, since this state is known[16] to have an $E1$ decay probablity to the $T=0$ ground state of 4.2×10^{-4} Weisskopf units. Such a value is typical[17] for isotopic-spin-forbidden $E1$ transitions in this mass region (see Fig. 5), and has been accounted for satisfactorily[19] by the Coulomb admixture of components of the giant dipole state in the wave function. The inhibition must therefore arise from some property of the 6.06-MeV state.

The calculations of Brown and Green[5] indicate that the ideal deformed component of the 0^+ state at 6.06 MeV consists of 2-particle–2-hole and 4-particle–4-hole excitations and it is shown in Ref. 1 that the lifetime for the 6.92→6.06-MeV transition suggests that these components are present in comparable proportions. In the work of Elliott and Flowers,[19] the 7.12-MeV state is regarded as a 1-particle–1-hole state.[20] On this assumption, which we adopt for our initial discussion, decay to the 4-particle–4-hole components of the 6.06-MeV state is forbidden, but a further selection rule is required to explain the absence of a transition to the 2-particle–2-hole components. It has been pointed out by Brink and Nash[3] that such a selection rule exists if the 2-particle–2-hole components are well described by $SU(3)$, and belong to the representation with $(\lambda,\mu)=(4,2)$. The $T=1$ admixtures in the 7.12-MeV

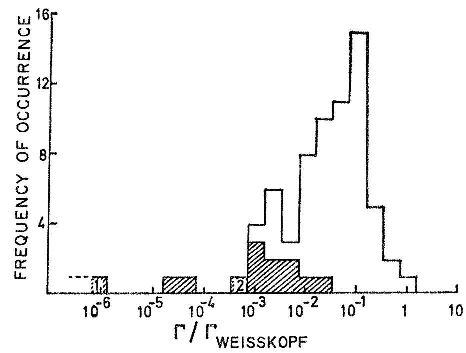

FIG. 5. Histogram showing experimental values of the strengths (Refs. 17, 18) of $E1$ transitions in nuclei with $A<20$. The cross-hatched section consists of isotopic-spin forbidden transitions. The square labeled 1 corresponds to the present result for the upper limit of the 7.12→6.06-MeV decay, and that labeled 2 to the ground-state decay of the 7.12-MeV state.

[16] F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. **11**, 1 (1959).

[17] D. W. Wilkinson, in *Nuclear Spectroscopy*, edited by F. Ajzenberg-Selove (Academic Press Inc., New York, 1960).

[18] The Weisskopf units used here are as defined in Ref. 17, with a radius parameter of $r_0=1.2$ fm.

[19] J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. (London), A242, 57 (1957).

[20] Throughout the following discussion, it is assumed that a $T=0$, 1-particle–1-hole state contains $T=1$ admixtures which are exclusively 1-particle–1-hole. Although other admixtures will be present, they are probably unimportant for the present arguments for several reasons, the most important of which are: (a) The Coulomb matrix elements, which give rise to the T admixtures, are smaller, in general, if the number of particle-hole pairs in the $T=1$ state differs from that in the $T=0$ state. (b) Matrix elements between states with appreciably different deformation are expected to be reduced by lack of overlap of the "core" particles (Ref. 5). In the present case, this effect may reduce either the Coulomb matrix elements connecting 1-particle–1-hole and 3-particle–3-hole states, or the matrix elements of subsequent γ-ray transitions to 4-particle–4-hole states.

state belong to the (1,0) or (2,1) representations of $SU(3)$, which do not decay to states with $(\lambda,\mu)=(4,2)$ by the dipole operator, which has symmetry (1,0) or (0,1). Thus the transition from the 7.12-MeV state to the deformed component of the 6.06-MeV state would be forbidden.

However, as discussed in Sec. I, the ideal spherical and ideal deformed 0^+ states are expected to be strongly mixed, so that the real 6.06-MeV state contains an appreciable proportion of the spherical closed $1p$ shell. Since, with the wave functions of Elliott and Flowers,[19] the decay of the 7.12-MeV state to this spherical state is not forbidden by the configurations present, the effectiveness of the $SU(3)$ selection rule in practice will be reduced by this mixing, and on the above assumptions, the observed branching ratio for the $7.12\rightarrow 6.06$-MeV decay can give a direct measure of the mixing. Specifically, if the wave functions are written

$$6.06\ \text{MeV}=a\psi_{\text{deformed}}+b\psi_{\text{spherical}},$$
$$0\quad \text{MeV}=a\psi_{\text{spherical}}-b\psi_{\text{deformed}},$$

then the present result gives $b\leq 0.04$. This value is appreciably less than the theoretical[5] or experimental[1] estimates quoted in Sec. I, and if this mixing is the dominant impurity in the ground state, it implies that this is a strikingly pure doubly closed shell.

Thus the inhibition of the $7.12\rightarrow 6.06$ MeV decay can arise from the simultaneous operation of two conditions:

(a) If the 2-particle–2-hole components of the wave function of the 6.06-MeV state are significant, they are well described by the $(\lambda,\mu)=(4,2)$ representation of $SU(3)$, and

(b) The admixture of the spherical ground state into the 6.06-MeV state does not exceed 4% by amplitude.

Before accepting the surprisingly low value of b suggested above, we may examine some of the assumptions to see if failure of these may provide an alternative explanation of the inhibition of the transition. Of course, the simultaneous failure of both the above conditions, with a partial cancellation of the resulting contributions to the matrix element, can not be ruled out. However, if such an explantion is to be consistent with values of b of 0.3–0.4 expected theoretically (Sec. I), this would imply a rather bad failure of the $SU(3)$ model in a region where it has been found to work reasonably well in other nuclei.[3,21,22]

Probably the most dubious assumption made here is that the 7.12-MeV state is a pure 1-particle–1-hole state. Elliott and Flowers[19] found that it was difficult to account for the energy of the state if a pure 1-particle–1-hole configuration were assumed, and postulated that mixing with a nearby 3-particle–3-hole state may occur. An obvious candidate for the latter is the 1^-, $T=0$ state at 9.59 MeV, which is believed[7,19] to consist mainly of 3-particle–3-hole configurations. A similar conclusion was reached in more recent calculations by Brown,[23] and by Mavromatis *et al.*[24] If this mixing of these 1^- states occurs, then the 3-particle–3-hole components in the 7.12-MeV state may decay to the deformed part of the 6.06-MeV state, providing an approximate cancellation of the term in the matrix element arising from mixing of the 0^+ states.

An accidental cancellation such as this is, perhaps, unlikely since three unrelated cancellations are required to explain the three experimental results listed in Sec. I. Nevertheless, if the cancellation suggested above occurs, it has two interesting consequences. Firstly, if the mixing of the 0^+ state is assumed to be about 35% as suggested by Brown and Green,[5] then the same cancellation that strongly inhibits the $7.12\rightarrow 6.06$-MeV transition also gives rise to some inhibition of the $9.59\rightarrow 0$-MeV decay. In fact, this decay is known[2] to be relatively weak. Secondly, a cancellation in the $7.12\rightarrow 6.06$-MeV matrix element implies a reinforcement in the matrix element for the $9.59\rightarrow 6.06$-MeV $E1$ decay. This reinforcement may be sufficiently effective to enable this transition to be observed experimentally; if so, this would provide a simple experimental test of the assumptions made here.

Finally, it should be pointed out that isotopic-spin impurities in the 0^+ states, the presence of 1-particle–1-hole components in the 6.06-MeV state, and 2-particle–2-hole states with $(\lambda,\mu)\neq(4,2)$ have been ignored in the above arguments. While it is unlikely that any of these alone would be responsible for the observed inhibition of the $7.12\rightarrow 6.06$-MeV decay, it is possible that several effects together could combine to produce the necessary cancellations. Although no unique interpretation of the remarkably low value of R_1 is possible at this time, it remains a quantity of which any detailed model of the states involved is obliged to give a satisfactory account.

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