Gamma transitions in O^18

Gamma Transitions in O^{18}

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Abstract. The gamma de-excitation of the 3,92 MeV and 4,45 MeV states in O^{18} has been studied using particle-gamma coincidence methods. The states were produced by inelastic scattering of 5,8 MeV protons. The 3,92 MeV state decays to the 1,98 MeV state and ground state with intensities of 85 and 15 respectively. The 4,45 MeV state de-excites via cascades through the 3,63 and 1,98 MeV states with intensities of 63 and 37 respectively. No 4,45 MeV ground-state transition was found. The significance of these results is discussed.

1. Introduction

The simplicity of 2 neutrons outside the O^{16} closed shell has prompted several theoretical treatments of the O^{18} level structure[1][2][3]. Recent experimental work has identified many levels in O^{18}; however, the properties of only the first few of these levels have been determined[4]. The present measurements were undertaken in order to investigate the gamma de-excitation of O^{18} levels produced by inelastic scattering of 5,8 MeV protons. Inelastic proton groups were seen corresponding to the first, third, fourth and fifth excited states in O^{18}. The gamma decay for the first and third excited states is well known. New information was obtained for the gamma de-excitation of the fourth and fifth excited states.

2. Method

The 5,8 MeV external proton beam of the ETH cyclotron bombarded a thin target containing O^{18}. A silicon $p-n$ junction and a NaI(Tl) crystal were used to detect charged particles and gamma radiation. The $2'' \times 2''$ NaI(Tl) crystal was located 2 cm from the target. Particle spectra were measured at 90° and 135° scattering angle. The 0,5 cm diameter particle-detector was approximately 1,8 cm from the target for coincidence measurements and approximately 9 cm for the singles measurement at 90° scattering angle.

The target was prepared by evaporating NiO enriched to 92% O^{18} onto a thin gold backing. The thickness of the target was determined from the particle spectra. The gold backing was found to be approximately 500 $\mu g/cm^2$ by observing the relative position of proton and alpha groups with the gold toward the beam and with NiO toward the beam. The thickness of gold plus NiO was measured from the energy separation of the 2 proton groups corresponding to the first excited state of C^{12}. The carbon was a target contaminant found on both the front and back surfaces of the

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target (see Figure 3). The thickness of the NiO deduced from these measurements was approximately 250 $\mu g/cm^2$.

Standard, fast-slow coincidence circuits[5]) operating on the passage through zero of double-delay-line-clipped pulses were used with a resolving time, 2τ, equal to 100 ns. Reducing the coincidence resolving time below 120 ns did not decrease the random rate since the cyclotron beam pulse was extremely short and occurred every 60 ns. A single channel in slow coincidence was available in either the gamma or particle coincidence units. The spectrum to be measured was stored in a 128 channel analyzer gated by the fast-slow coincidence circuit. The normal coincidence measurement envolved a channel on a particular proton group with the coincidence gamma spectrum displayed in the multichannel analyzer.

3. Results

For purposes of particle group identification it was convenient to use the particle spectrum obtained at 90° scattering angle. Figure 1 shows the 90° data with the various peaks labelled by their excitation energy and nucleus. There is a sizeable background throughout most of the spectrum due to the low energy tail of the intense elastic groups. This background was less in the 135° measurement. It presented no great trouble in the coincidence measurements since it produced only random coincidences. In Figure 1, the peaks corresponding to the 3,92 MeV state of O^{18} and the triton group leading to the ground state of O^{16} are not resolved. The two groups could be separated by the insertion of a 1 mg/cm² aluminum foil between the target and detector since the triton group lost more energy than the proton group. This is shown in Figures 2a and 2b.

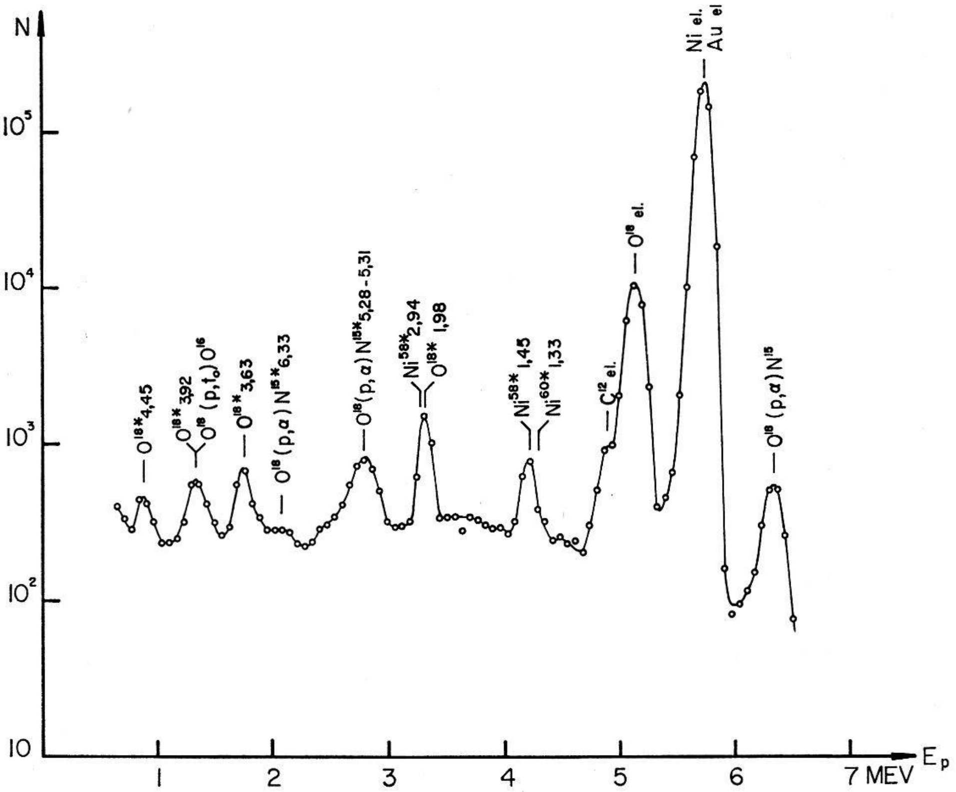

Figure 1

Particle spectrum measured at 90°.

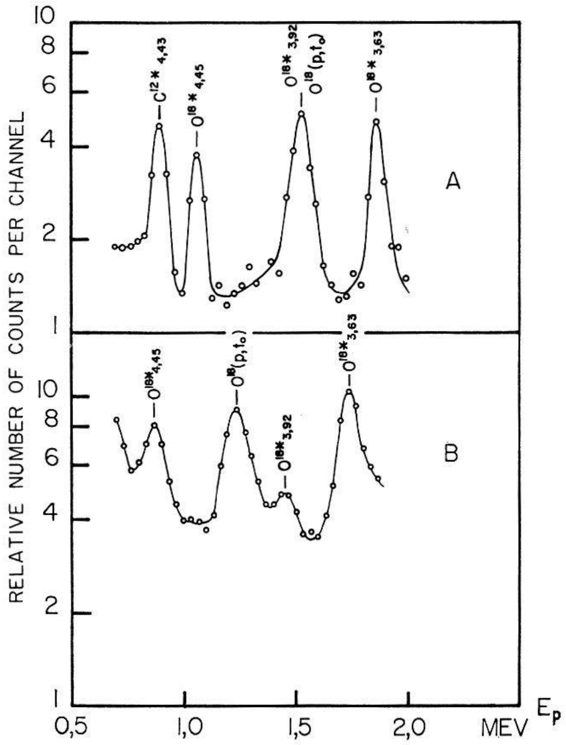

Figure 2

Particle spectrum measured at 90°. An absorber of 1 mg/cm² was used for curve B to separate the triton and proton peaks which were not resolved in curve A.

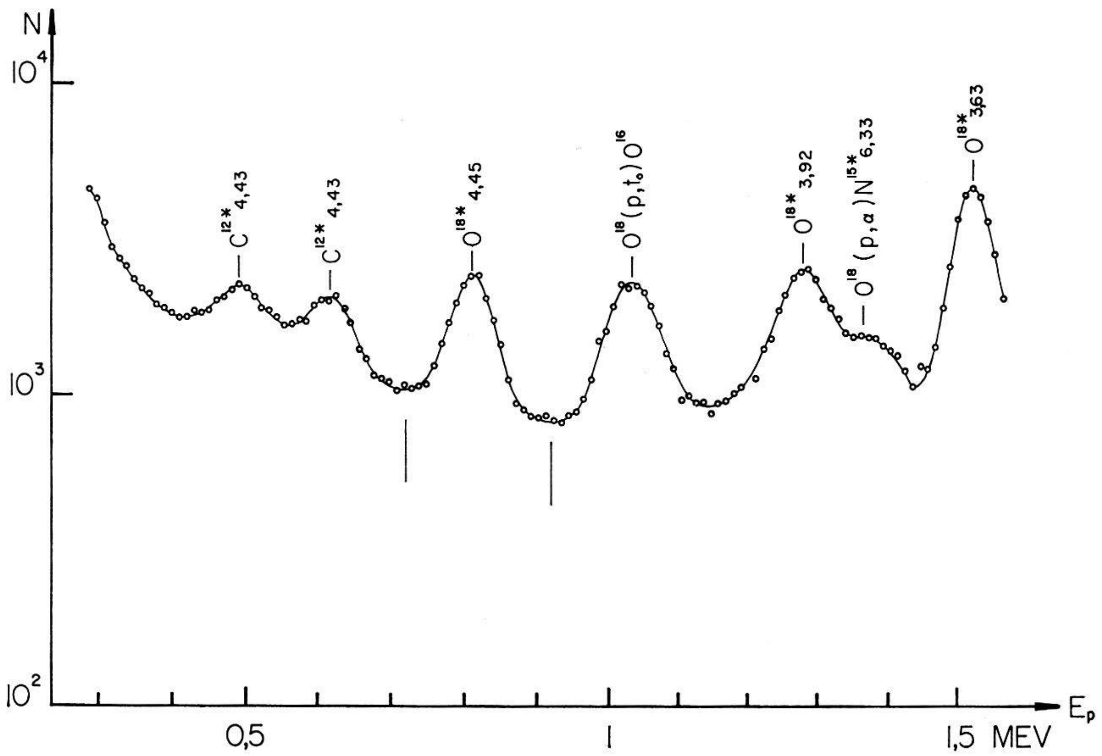

Figure 3

Particle spectrum measured at 135°.

The coincidence gamma spectra were measured with the particle detector at 135° scattering angle. The low energy portion of the 135° particle spectrum is shown in Figure 3. Various alpha groups occur in this spectrum; however, by placing suitable absorbers between target and counter, the alpha groups could be displaced relative to the proton groups so that the channel included only the desired proton group.

No evidence was found for the production of the 3,55 MeV state in O^{18}; however, the sensitivity for observing this state in the particle spectrum was rather low due to the strong group leading to the 3,63 MeV state. The data indicate that the intensity of the 3,55 MeV state is less than or equal to 20% that of the 3,63 MeV state.

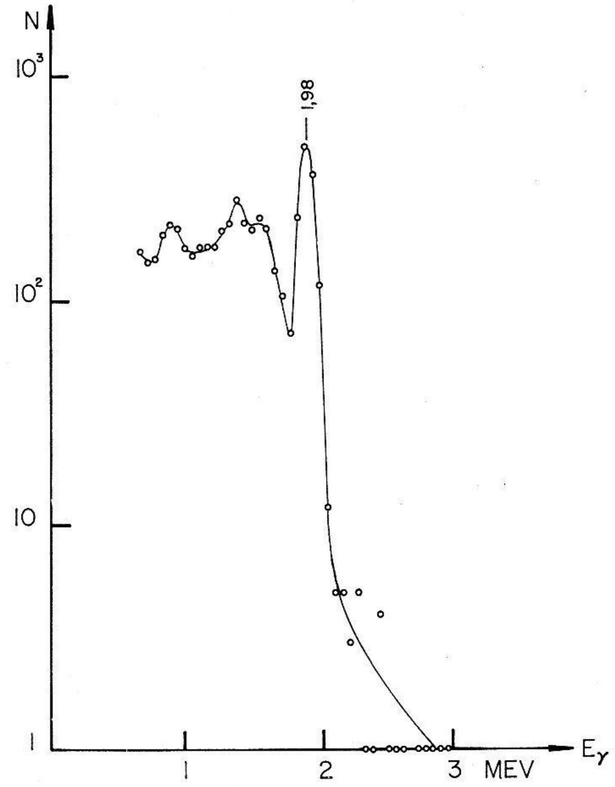

Figure 4

Gamma-ray spectrum in coincidence with the first excited state proton group.

The gamma spectra in coincidence with protons leading to the first, third, fourth and fifth excited states are shown in Figures 4, 5, 6 and 7 respectively. The solid curves in these figures are the actual coincidence spectra with no backgrounds subtracted. The dashed curves in Figures 5, 6 and 7 represent the random coincidences for these measurements. The random spectra were constructed from the shape of the gamma singles spectrum normalized to the coincidence spectra above 4 MeV in Figures 5 and 6 and to the coincidence spectrum above 5 MeV in Figure 7.

The gamma spectra in coincidence with the first and third excited state proton groups are exactly what one would expect for the de-excitation of these two states. Figure 4 shows the 1,98 MeV gamma spectrum of the first excited state to ground-state transition. In Figure 5 one sees the 1,65 MeV and 1,98 MeV gamma rays from the cascade of the 3,63 MeV level through the first excited state. No evidence is found for the 3,63 MeV transition to the ground state within the statistical accuracy of the

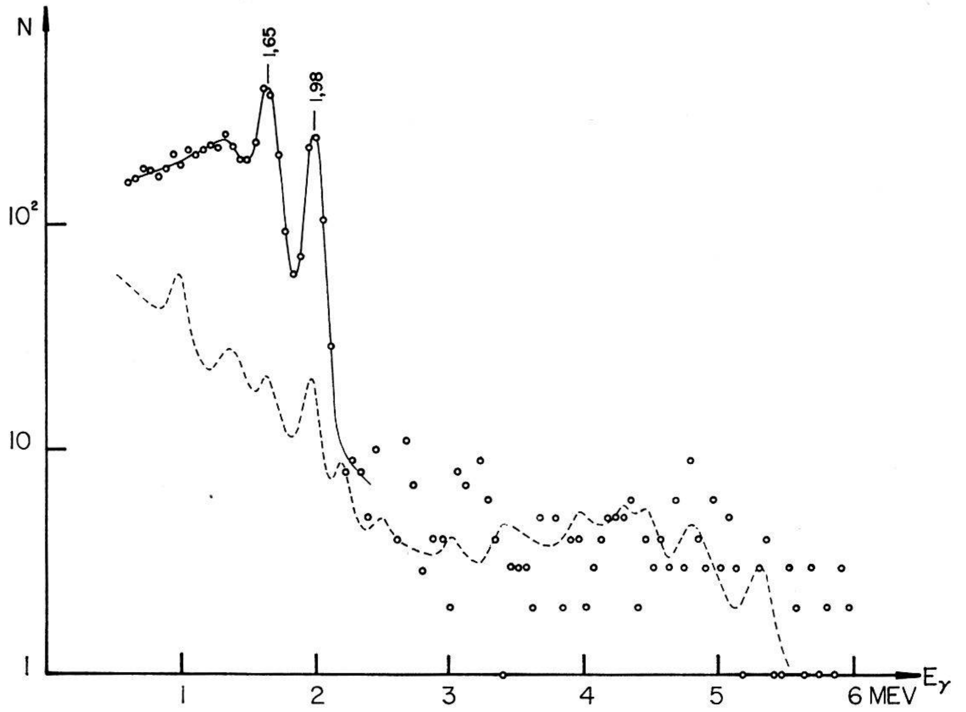

Figure 5
Gamma-ray spectrum in coincidence with the 3,63 MeV state proton group.

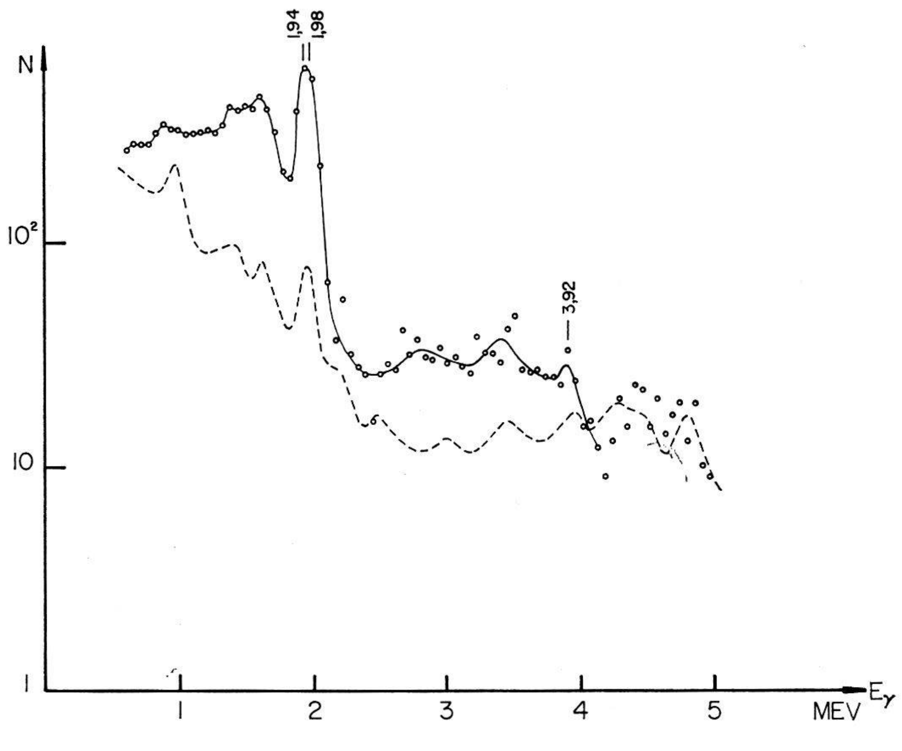

Figure 6
Gamma-ray spectrum in coincidence with the 3,92 MeV state proton group.

measurement. The intensity of the ground-state transition is less than or equal to 3% that of the cascade. The absence of this transition is to be expected since a single gamma ray transition between two O^+ states is completely forbidden.

In Figure 6, the rather wide peak at 1,96 MeV is due to the unresolved 1,94 MeV and 1,98 MeV photo peaks resulting from the cascade of the 3,92 MeV state through the first excited state. One also sees the 3,92 MeV ground-state transition. The intensities of the cascade and the direct ground-state transition are 85 ± 5 and 15 ± 5 respectively.

In Figure 7 one sees photo peaks of 0,83, 1,65, 1,98 and 2,48 MeV. The 0,83 MeV peak is due to the 4,45 to 3,63 MeV transition. There is a slight discrepancy between measured gamma energy and expected energy of the transition (see following paragraph). The 2,48 MeV peak results from the 4,45 to 1,98 MeV transition. The 1,98 MeV and 1,65 MeV peaks are lower members of the cascades originating with the 0,83 and 2,48 MeV transitions. The intensities of the 0,83 and 2,48 MeV transitions are 63 ± 5 and 37 ± 5 respectively. No direct ground-state transition is seen within the statistical accuracy of the measurement. The intensity of the ground-state transition is less than or equal to 2% of the 0,83 MeV transition.

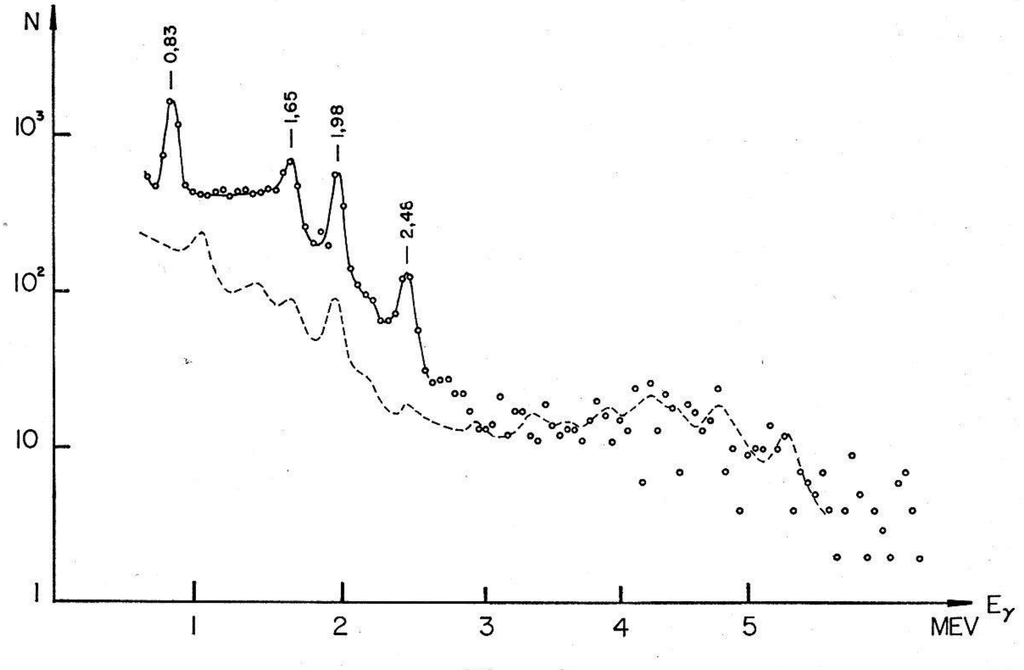

Figure 7

Gamma-ray spectrum in coincidence with the 4,45 MeV state proton group.

The accuracy of the energy calibration in Figure 7 was not sufficient for one to be entirely certain that the low energy gamma ray seen in this figure was due to the transition from the 4,45 MeV state to the 3,63 MeV state and not that to the 3,55 MeV state. In order to determine more accurately the energy of this gamma ray, a second coincidence measurement was made displaying only the lower portion of the gamma spectrum in the entire analyzer. Energy calibrations were made before and after the measurement using annihilation radiation, Cs^{137} and Co^{60}. No shift greater than the

8 keV accuracy of the measurements was observed. One sees in the coincidence spectrum of Figure 8 a photo peak with a measured energy of 0,835 ± 0,012 MeV. This value is in reasonable agreement with the expected energy of 0,822 ± 0,007 for the 4,45 MeV to 3,63 MeV transition as determined from the recent Q-value measurements of the $O^{16}(t, p)O^{18}$ reaction [6]). The measured gamma energy is sufficiently removed from the 0,900 ± 0,007 MeV expected energy for the transition to the 3,55 MeV state so that one can be certain that the observed gamma ray is not due to this transition.

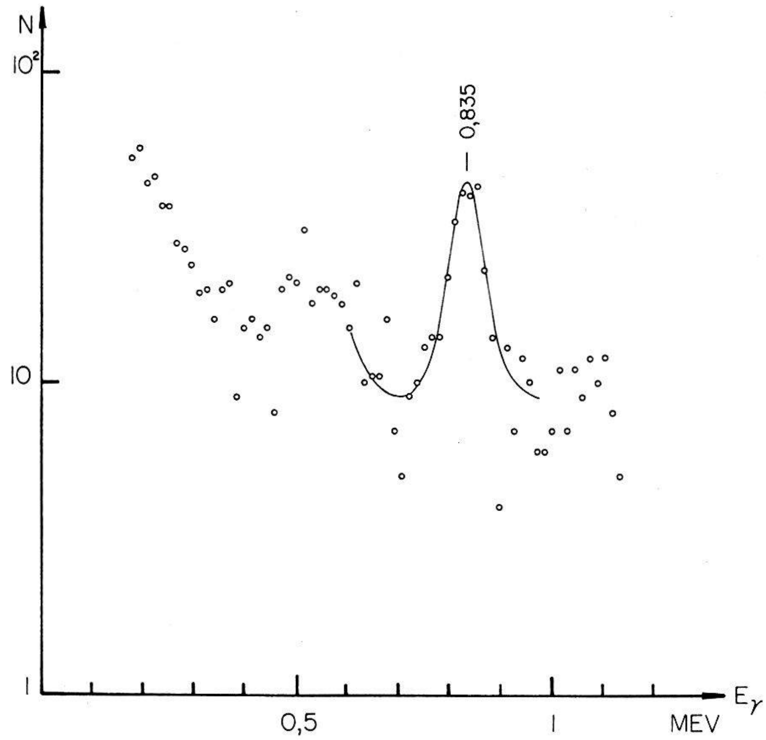

Figure 8
Low energy gamma-ray spectrum in coincidence with the 4,45 MeV state proton group.

4. Discussion

The low lying levels of O^{18} are shown in the energy level diagram of Figure 9. The information regarding spin, parity and energy of the levels has been obtained from the review article by LAURITSEN and AJZENBERG-SELOVE [4]). The values listed for the lifetimes are from the recent Doppler-shift measurements of LITHERLAND et al. [7]). The gamma intensities are from the present measurement.

The spin and parity of each of the levels up to and including the fourth excited state in O^{18} have been determined in several ways [7])[8])[9])[10])[11]) and these assignments seem quite certain. The situation regarding the spin of the 4,45 MeV level is not quite as clear. The recent $O^{17}(d, p)O^{18}$ stripping measurements by YAGI et al. [11]) indicate that l_n is equal to 1 for the 4,45 MeV state. This implies odd parity and spin less than or equal to 4. The $O^{16}(t, p)O^{18}$ double stripping measurements of JAFFE et al. [10]) suggest 3^- for the spin and parity of the 4,45 MeV level; however, this assignment was listed as uncertain since the measurement was made for only a limited range of angles.

Previous gamma de-excitation measurements[9]) have shown that the intensity of the 3,92 MeV ground-state transition is less than or equal to 15% that of the cascade through the first excited state. The intensities found in the present measurement are 85 ± 5 and 15 ± 5 for the ground-state transition and cascade respectively. For the 4,45 MeV state, only the cascade through the first excited state has been reported[7]). The intensities found in the present work for the cascade through the third excited state, the cascade through the first excited state and the ground-state transition are 63 ± 5, 37 ± 5 and ≤ 3 respectively.

From the gamma intensities and known lifetime of the 3,92 MeV state, one finds the partial width of the $E\,2$ ground-state transition to be 0,2 Weisskopf units (nuclear radius equal to 3,1 f.) This width is considerably smaller than the average value of 5 Weisskopf units found for $E\,2$ transitions in light nuclei[12]). The small width indicates no collective enhancement of the 3,92 MeV $E\,2$ transition. The present gamma intensity measurement for the 3,92 MeV state does not substantially change the partial width for the cascade transition quoted by LITHERLAND et al.[11]).

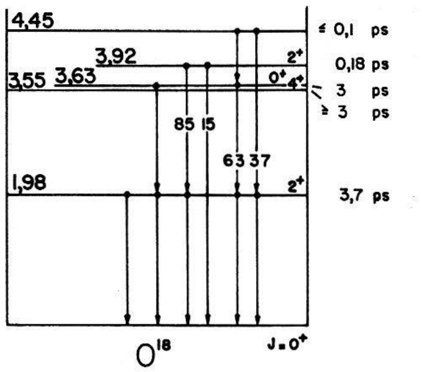

Figure 9
O^{18} energy level diagram.

It is instructive to compute the partial width in Weisskopf units of the 0,83 MeV transition between the 4,45 MeV and 3,63 MeV states assuming various multipolarities for the transition. From the gamma intensities and the limit measured for lifetime of the 4,45 MeV level, one finds the partial width for the 0,83 MeV transition to be greater than or equal to 0,016, 3,6, 4900 and 10^5 Weisskopf units assuming $E\,1$, $M\,1$, $E\,2$ and $M\,2$ multipolarity respectively. It is clear that only the dipole assumption results in sensible Weisskopf widths. The $O^{17}(d, p)O^{18}$ stripping measurements indicate negative parity for the 4,45 MeV state. Thus one concludes that the 0,83 MeV transition to the O^+, 3,63 MeV state is an $E\,1$ transition and the 4,45 MeV state has spin and parity 1^-.

It is now interesting to compare the partial widths expressed in Weisskopf units of other $E\,1$ transitions from the 4,45 MeV level with the width of the 0,83 MeV transition. Since the 2,48 MeV transition between the 1^-, fifth excited state and the 2^+, first excited state is an $E\,1$–$M\,2$ transition, one can obtain a limit for the $E\,1$ partial width of this transition by considering the $M\,2$ partial width to be zero. Thus from the gamma intensities, one finds the $E\,1$ partial width of the 2,48 MeV transition to be at least a factor of 47 smaller than the width of the 0,83 MeV transition (both widths expressed in Weisskopf units). Similarly, from the limit on the intensity of the direct ground-state transition, one finds the partial width of this $E\,1$ transition to be at least a factor of 3000 smaller than the width of the 0,83 MeV transition (again both widths expressed in Weisskopf units).

The weakness of the $E\,1$ transition to the first excited state and to the ground-state is difficult to explain. It has been pointed out by M. HARVEY[13]) that all $E\,1$ transitions from the 1^- level have zero width in the SU-3 model[14])[15])[16]). Thus any observed $E\,1$ transition might be due to the departure of either initial or final state wave function from those of the SU-3 model. It is therefore tempting to explain the weak 2,48 MeV and 4,45 MeV $E\,1$ gamma rays as transitions between almost pure SU-3 states. The relatively strong 0,83 MeV, $E\,1$ transition could then be explained by a somewhat impure SU-3 wave function for the 3,63 MeV, O^+ level.

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References

1) J. P. ELLIOTT and B. H. FLOWERS, Proc. Roy. Soc. *A 229*, 536 (1955).
2) M. G. REDLICH, Phys. Rev. *110*, 468 (1958).
3) J. F. DAWSON, I. TALME, J. D. WALECKA, Annals of Phys. *18*, 339 (1962).
4) T. LAURITSEN and F. AJZENBERG-SELOVE, Landolt-Börnstein Tables, Vol. 1 (Springer-Verlag, Berlin, 1961).
5) R. L. CHASE, Rev. Sci. Instr. *31*, 945 (1960).
6) S. HINDS, H. MARCHANT and R. MIDDLETON, Nucl. Phys. *38*, 81 (1962).
7) A. E. LITHERLAND, M. J. L. YATES, B. M. HINDS and D. ECCLESHALL, Nucl. Phys. *44*, 220 (1963).
8) H. E. GOVE and A. E. LITHERLAND, Phys. Rev. *113*, 1078 (1959).
9) A. E. LITHERLAND, R. BATCHELOR, A. J. FERGUSON and H. E. GOVE, Can. J. Phys. *39*, 276 (1961).
10) A. A. JAFFE, F. DE S. BARROS, P. D. FORSYTH, J. MUTO, I. J. TAYLOR and S. RAMAVATARAM, Proc. Phys. Soc. *76*, 914 (1960).
11) K. YAGI, Y. MAKAJIMA, K. KATORI, Y. AWAYA and M. FUJIOKA, Nucl. Phys. *41*, 584 (1963).
12) D. H. WILKINSON, Nuclear Spectroscopy, Part B (Academic Press, New York and London, 1960) pp. 852–889.
13) M. HARVEY (private communication).
14) J. P. ELLIOTT, Proc. Roy. Soc. *A 245*, 128 (1958).
15) J. P. ELLIOTT, Proc. Roy. Soc. *A 245*, 562 (1958).
16) M. HARVEY, Phys. Letters *3*, 209 (1963).