Search for Low-Energy Gamma Rays in O^{16}*

WILLIAM W. PRATT, *Department of Physics, The Pennsylvania State University, University Park, Pennsylvania*

AND

ROBERT G. COCHRAN,† *College of Engineering and Architecture, The Pennsylvania State University, University Park, Pennsylvania*

(Received July 29, 1959)

In the expectation that at least one low-energy transition from the fourth excited state of O^{16} may compete to an observable extent with the 7.11-Mev ground-state transition, a search was made for the 0.97 Mev ($1^- \rightarrow 3^-$) and the 1.05 Mev ($1^- \rightarrow 0^+$) gamma rays. Limiting values, $I(7.11)/I(0.97) \gtrsim 200$ and $I(7.11)/I(1.05) \gtrsim 370$, were found for the branching ratios.

INTRODUCTION

IN the de-excitation of the four lowest excited states of O^{16}, only the ground-state transitions have been observed to date. There are, however, reasons to believe that at least one of the lower energy interlevel transitions may be expected to be observable with currently available techniques. We report here an attempt to observe a transition from the fourth excited $(1-)$ state to either the first excited $(0+)$ state or the second excited $(3-)$ state, following the β decay of N^{16}. The transition energies are 1.05 Mev and 0.97 Mev, respectively, whereas the ground-state transition energy is 7.11 Mev.

If the transition probabilities are determined accurately by the single-particle matrix elements as estimated by Weisskopf,[1] neglecting the influence of isotopic spin, the intensity ratios $I(7.11)/I(1.05) \approx 310$ and $I(7.11)/I(0.97) \approx 6.2 \times 10^7$ are obtained. In the special case of self-conjugate nuclei, however, there is a selection rule for $E1$ radiation,[2] $\Delta T = \pm 1$. If it is assumed that all of the states involved here are states with $T=0$,[3] a selection rule results by which the ground-state transition and the 1.05-Mev transition are completely forbidden. It has, however, been pointed out by Gell-Mann and Telegdi[3] that there are two mechanisms by which this selection rule is expected to be violated. Expanding the interaction Hamiltonian in terms of Kr_i, they find the second-order term to be nonvanishing from which they deduce an "inhibition factor" of the order of $(KR)^4$ by which the uninhibited transition probability is to be multiplied. Secondly, as has been investigated by Jones and Wilkinson,[4] there is expected to be some mixture of $T=1$ states which will give rise to an additional inhibition factor of the order of f^2, where f is the relative amplitude of the $T=1$ contribution to the wave function. If the Weisskopf estimate[1] of the uninhibited transition probability is taken as quantitatively correct, and if the amplitude mixture f is assumed approximately constant from one state to another, the branching ratios may be estimated:

$$\frac{I(7.11)}{I(1.05)} \approx \frac{T_{E1}(7.11)}{T_{E1}(1.05)} \frac{(K_{7.11}R)^4+f^2}{(K_{1.05}R)^4+f^2},$$

$$\frac{I(7.11)}{I(0.97)} \approx \frac{T_{E1}(7.11)}{T_{E2}(0.97)} [(K_{7.11}R)^4+f^2],$$

where T_{E1} and T_{E2} are the Weisskopf estimates for the transition probabilities, $K_{7.11}$ and $K_{1.05}$ are photon wave numbers, and R is the nuclear radius. In Fig. 1 these branching ratios are plotted as functions of f. It is seen that for any value of f at least one of the branching ratios is expected to be no greater than several hundred. Boehm, Peaslee, and Perez-Mendez[5] have found $I(\sim 6)/I(\sim 1) \geq 20$ which, from the known decay scheme of

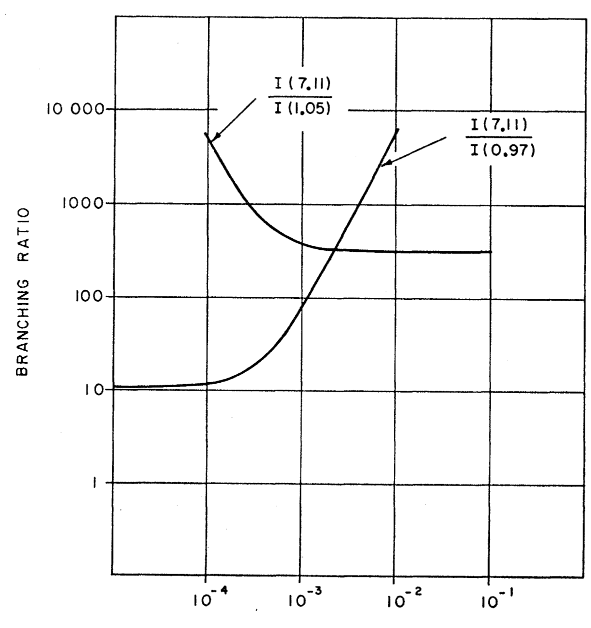

FIG. 1. Estimated branching ratios.

* This research was supported in part through a grant from The National Science Foundation.

† Present address: The Texas Agricultural and Mechanical College, College Station, Texas.

[1] V. F. Weisskopf, Phys. Rev. **83**, 1073 (1951).
[2] L. A. Radicati, Phys. Rev. **87**, 521 (1952).
[3] M. Gell-Mann and V. L. Telegdi, Phys. Rev. **91**, 169 (1953).
[4] G. A. Jones and D. H. Wilkinson, Phys. Rev. **90**, 722 (1953).
[5] Boehm, Peaslee, and Perez-Mendez, Phys. Rev. **90**, 1119 (1953).

N^{16},[6] implies $I(7)/I(\sim 1)\approx 1.4$. Jones and Wilkinson[4] found $I(7.11)/I(\sim 1)\approx 120$, from which they conclude that $f>0.002$ for the fourth excited $(1-)$ state. In the work reported here, in which we have investigated the two branching ratios separately, we find $I(7.11)/I(1.05)\gtrsim 370$ and $I(7.11)/I(0.97)\gtrsim 200$.

EXPERIMENTAL PROCEDURE

The search for low-energy γ rays was carried out by looking for coincidences between the γ ray in question and the radiation following it. A strong source of N^{16} was produced by the $O^{16}(n,p)N^{16}$ reaction in a sample

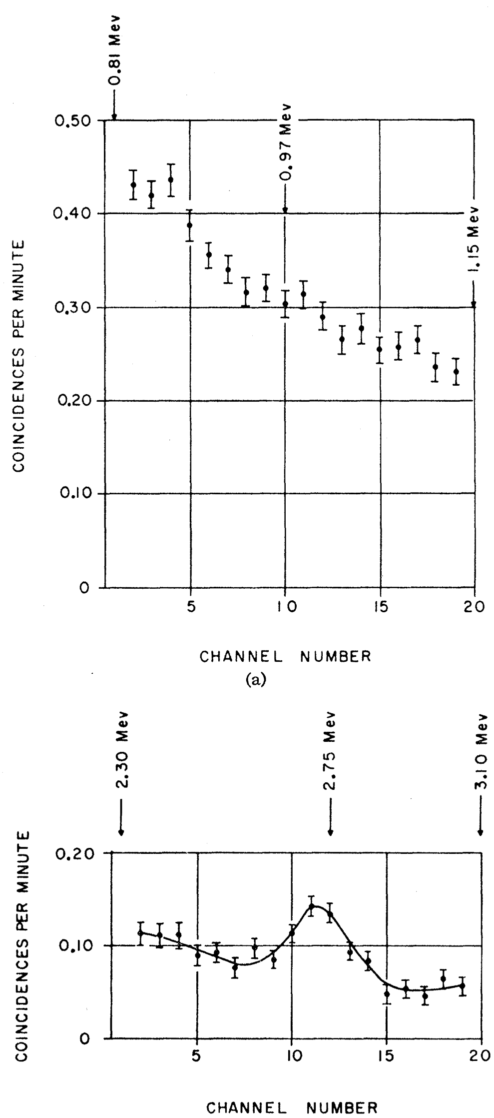

FIG. 2. (a) Coincidence spectrum of 0.97-Mev γ ray gated by 6.14-Mev γ ray. (b) Coincidence spectrum of 2.75-Mev γ ray gated by 6.14-Mev γ ray. Errors indicated in all figures are standard deviations due to counting statistics.

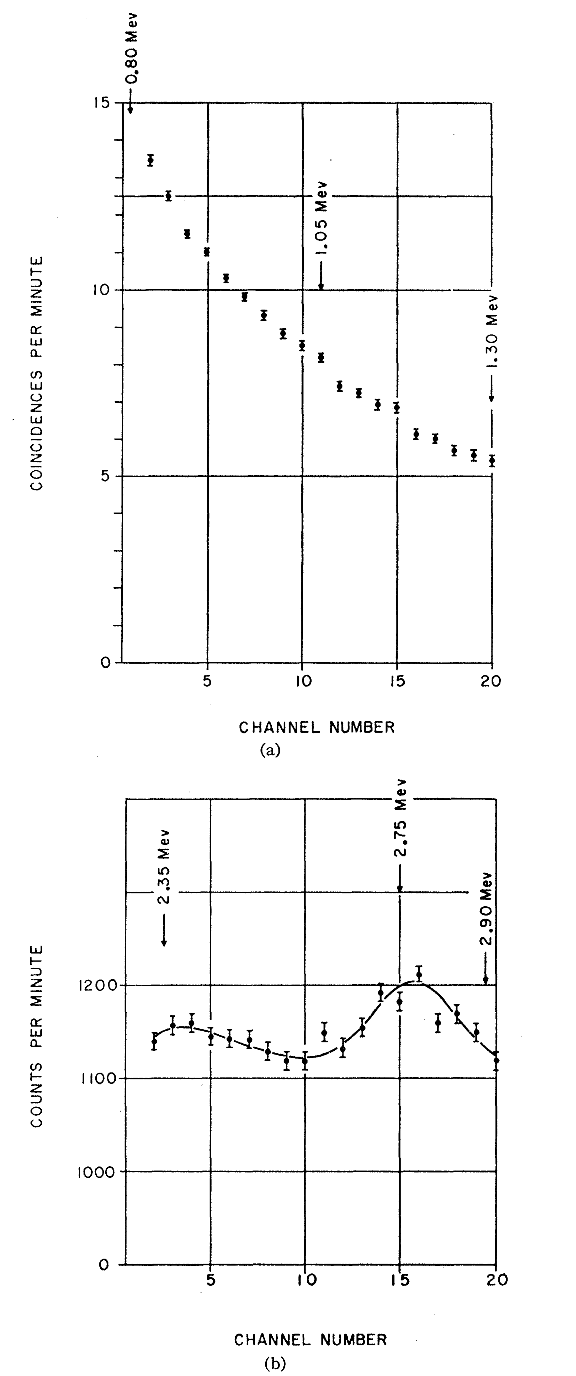

FIG. 3. (a) Coincidence spectrum of 1.05-Mev γ ray gated by annihilation radiation. (b) Singles spectrum of 2.75-Mev γ ray.

of water which was pumped continuously past the core of The Pennsylvania State University reactor and then through a counting cell between two NaI scintillation spectrometers. The counting cell consisted of a coil of aluminum tubing imbedded in a block of lead shielding in such a way as to minimize backscattering of γ rays from one crystal to the other. The pulses from one

[6] David E. Alburger, Phys. Rev. **111**, 1586 (1958).

crystal were analyzed in a 20-channel analyzer. The pulses from the other crystal were passed through a single-channel analyzer forming part of a fast-slow coincidence circuit of about 200 mμsec resolving time, which was used to gate the 20-channel analyzer. In the search for the 0.97-Mev γ ray the single-channel analyzer was adjusted to accept pulses from the peak due to the 6.14-Mev γ ray which follows it. In the search for the 1.05-Mev γ ray, which is followed by pair emission from the 6.06-Mev state, the single-channel analyzer was adjusted to accept pulses from the peak due to 0.511-Mev annihilation radiation. From the known counting efficiency of the crystals and the $N^{16}-O^{16}$ decay scheme,[6] the coincidence counting rates may be used to deduce the γ-ray intensities.

THE 0.97-Mev TRANSITION

The coincidence spectrum of pulses in the vicinity of 0.97 Mev gated by pulses of 6.14 Mev is shown in Fig. 2(a). The bulk of the counting rate may be attributed to accidental coincidences and backscattering from one crystal to the other. Instead of attempting to subtract these spurious effects, which it is not feasible to do with sufficient precision for our purposes, we search for the presence of a peak at 0.97 Mev superimposed on the continuous background. In Fig. 2(b) is shown the coincidence spectrum of pulses in the vicinity of 2.75 Mev gated by pulses of 6.14 Mev. The peak representing the transition from the 8.87-Mev state to the 6.14-Mev state is apparent here. We believe the data of Fig. 2 to be inconsistent with the presence of a peak at 0.97 Mev with an amplitude appreciably greater than $\frac{1}{8}$ that of the 2.75-Mev γ ray. From the known counting efficiency of the crystals and the known decay scheme of $N^{16}-O^{16}$, we deduce that the intensity of the 7.11-Mev γ ray relative to that of the 0.97-Mev γ ray is $I(7.11/I(0.97)\gtrsim 200$.

THE 1.05-Mev TRANSITION

The coincidence spectrum of pulses in the vicinity of 1.05 Mev gated by annihilation photons is shown in Fig. 3(a). A smooth curve of quadratic form (not shown) may be fitted to the experimental points, using the five points on each side of the peak position. Such a curve exhibits a standard deviation (0.071 counts/min) substantially the same as that indicated by counting statistics (0.069 counts/min); so the data are consistent with the complete absence of a peak. However, there is an indication of a "break" in the experimental curve at channel 11 as well as one at channel 15. One of these, channel 11, is precisely at the position corresponding to the 1.05-Mev transition. If this break, although explicable on the basis of counting statistics alone, is regarded as genuine, it implies a peak counting rate of 0.25 counts/min. This value, when compared with the single counting rate for the 2.75-Mev transition (Fig. 3(b)], utilizing the known efficiency of the crystals and the $N^{16}-O^{16}$ decay scheme, corresponds to a 1.05-Mev γ ray 1/370 as intense as the 7.11-Mev γ ray. Thus we find $I(7.11)/I(1.05)\gtrsim 370$.

CONCLUSIONS

The results for the branching ratios $I(7.11)/I(0.97)\gtrsim 200$ and $I(7.11)/I(1.05)\gtrsim 370$, compared with the theoretical curves in Fig. 1, imply both a lower limit and an upper limit on f of about 0.1%. Unfortunately both of these limits, particularly the latter, are very sensitive functions of both the measurements and the theoretical curves (an error of 20% would be adequate to raise the upper limit from 0.1% to 100%). Thus, although our results are certainly consistent with a $T=1$ mixture of about 0.1%, the assignment of a significant value to this mixture would require a considerably better knowledge of the theoretical curves than is presently available.