DOUBLE GAMMA EMISSION IN THE 6.06-Mev MONOPOLE TRANSITION OF O^{16}†

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In a continuation of our work on double gamma-ray emission in electric monopole transitions we have undertaken a study of the 6.06-Mev transition in O^{16}. This case was considered theoretically by Oppenheimer and Schwinger[1] in 1939, and then by Dalitz[2] and by Cameron.[3] Very recently, Yoccoz[4] has proposed a more complete theory of this problem and gives as preliminary result for the ratio of the probabilities of double gamma-ray emission and pair creation: $3\times10^{-3} \leq \Gamma_{\gamma\gamma}/\Gamma_\pi \leq 8\times10^{-3}$. At present, more detailed calculations are being undertaken.

The 6.06-Mev level was excited by the reaction $F^{19}(p,\alpha)O^{16}$, at the 1880-kev resonance. An excitation curve[5] for nuclear pair emission had shown that this resonance was the most advantageous one for a study of the monopole transition.

The method of summing the energies of the two gamma radiations, previously used in an attempt to detect double gamma-ray emission from the 1.75-Mev transition in Zr^{90},[6] was not suitable for the 6.06-Mev transition in O^{16}. Indeed for the gamma-ray energies occuring in O^{16} the total absorption rate in the crystals used is much lower than in Zr^{90}. We have thus been led to the use of $(\alpha-\gamma-\gamma)$ triple coincidence ($2\tau = 5\times10^{-8}$sec), gating a multichannel analyzer which records the energy spectrum of the alpha particles (Fig. 1). The gamma-rays were detected by two 4-in. × 4-in. NaI crystals at 180°, and the alpha particles by a

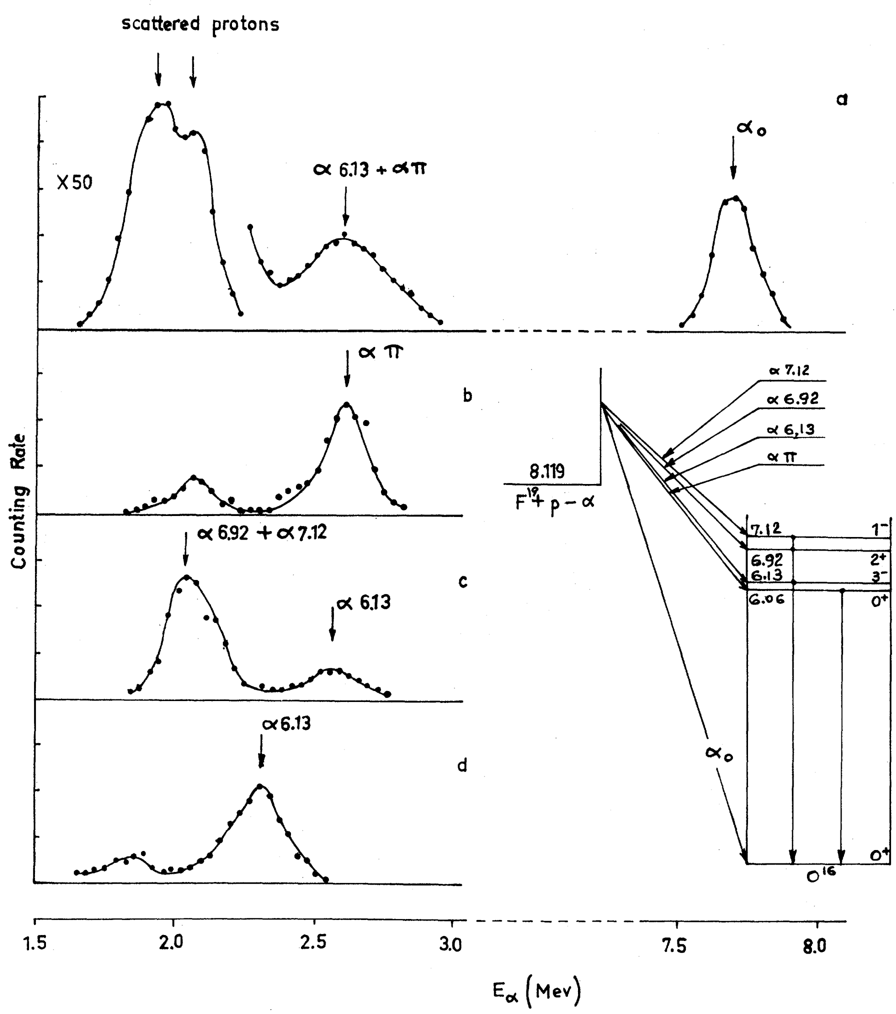

FIG. 1. (a) $E_p = 1880$ kev, direct alpha-particle spectrum. (b) $E_p = 1880$ kev, alpha-particle spectrum gated by alpha-gamma-gamma triple coincidences. Gamma-ray window at 0.511 Mev (annihilation radiation). Accidentals subtracted. (c) $E_p = 1880$ kev, alpha-particle spectrum gated by alpha-gamma double coincidences ($E_\gamma > 2$ Mev). Accidentals subtracted. (d) $E_p = 1375$ kev, alpha-particle spectrum gated by alpha-gamma double coincidences ($E_\gamma > 2$ Mev). Accidentals subtracted.

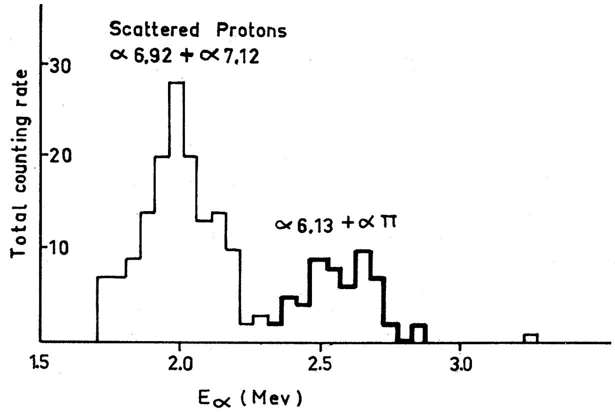

FIG. 2. $E_p = 1880$ kev, alpha-particle spectrum gated by alpha-gamma-gamma triple coincidences. Gamma-ray windows from 1.5 to 4.5 Mev. Accidentals not subtracted (see Table I).

20-mm^2 RCA junction detector at 150° to the direction of the incident beam.

A preliminary experiment[7] had given an upper limit: $\Gamma_{\gamma\gamma}/\Gamma_\pi \leq 6\times10^{-3}$.

Since this first experiment the apparatus has been improved by the use of a lead target chamber forming a conical diaphragm for the NaI crystals. Only gamma rays between 1.5 and 4.5 Mev were accepted by the circuit.

At $E_p = 1880$ kev a series of 166 measurements, each of 30 minutes duration, were made. Figure 2 shows the spectrum obtained. We have verified that the distribution of the coincidences in time follows the Poisson law.

Since the measurement of the accidental coincidence rate would be excessively time consuming because there are several possible kinds of such coincidences, we calculated[8] the rate from the various counting rates and the coincidence resolving time. Measurements made at the 1375-kev resonance [predominantly producing the 6.13-Mev level—see Fig. 1(d)] seem to show that the method is correct. The probability of double gamma-ray emission from this level is theoretically very small. Under the same experimental conditions as at 1880 kev (in particular, the same counting rate) no real events were observed; all the coincidences obtained could be attributed to accidentals. Furthermore, this method has been verified at the 1880-kev resonance by measuring the accidental coincidences of different kinds that occur with a greater beam intensity. We estimate that the maximum error in the calculation of accidentals is 20%.

Results obtained at the two resonances are shown in Table I.

The experimental results are related to the double gamma-ray emission probability by the following formula:

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_\pi} = \frac{1}{2}\frac{N_{\alpha_0}}{N_{\alpha_\pi}}\frac{N_{\alpha_{\gamma\gamma}}}{N_{\alpha_0}}\frac{C}{a^2\epsilon\langle\Omega\eta\rangle_{av}^2}\frac{E_0^7/140}{\int_{1.5\text{ Mev}}^{4.5\text{ Mev}}[Ep(E)]^3[(E_0-E)p(E_0-E)]^3dE}, \quad (1)$$

where $E_0 = 6.06$ Mev, $\langle\Omega\eta\rangle_{av}$ = the mean value of the product of the solid angle and the efficiency of a crystal, ϵ = the efficiency of the coincidence circuit (here $\epsilon = 1$), $C = 0.89$ = a factor due to the $(1+\cos^2\theta)$ correlation between the two $E1$ gamma rays detected, and $a = 0.87$ = the mean transmission of gamma rays by the absorber which stops the electrons from nuclear pair creation.

The product $\langle\Omega\eta\rangle_{av}$ was measured directly at the 1375-kev resonance from the ratio

$$N_{coinc}(\alpha-\gamma)_{6.13}/N_{\alpha 6.13},$$

Table I. Alpha-gamma-gamma measured coincidences and calculated accidentals.

		Scattered protons $+\alpha_{6.92}+\alpha_{7.12}$	$\alpha_{6.13}+\alpha_\pi$
1375 kev	Measured coincidences	40	55
	Calculated accidentals	43	52
1880 kev	Measured coincidences	146	55
	Calculated accidentals	147	15

taking into account the α-γ angular correlation. We obtained $\langle\Omega\eta\rangle_{av}\epsilon = 3.66\times10^{-2}$. This result was verified by a measurement made with a calibration source of Co^{60} corrected to our energy by the use of curves given by Wolicki et al.[9]

Using the energy spectrum of double gamma-ray emission, which has the form $E^3(E_0-E)^3$,[10-12,4], we have calculated the integral in the denominator of Eq. (1) and find

$$\frac{140}{E_0^{\,7}}\int_{1.5\text{ Mev}}^{4.5\text{ Mev}} [Ep(E)]^3\,[(E_0-E)p(E_0-E)]^3dE = 0.24, \qquad (2)$$

where $p(E)$ is the form factor of the energy spectrum of a gamma ray of energy E in a 4 in.×4 in. NaI crystal. The term $140/E_0^{\,7}$ is the normalization factor. The number $N_{\alpha 0}$ is measured directly during the experiment. In a separate experiment the ratio $N_{\alpha 0}/N_{\alpha\pi}$ has been measured as 2.8. The factor 1/2 is due to the indistinguishibility of the two gamma rays.

Since approximate calculations have shown that the internal and external bremsstrahlung coming from the pairs are negligible,[13] we believe that the true coincidences observed can be attributed to double gamma-ray emission. Insofar as no unknown phenomena of the same order of magnitude are taking place, our experimental result leads to the value

$$\Gamma_{\gamma\gamma}/\Gamma_{\pi} = (2.5\pm1.1)\times10^{-3}.$$

In addition, the measurement made at 1375 kev allows us to give an upper limit for the double gamma-ray decay of the 6.13-Mev $E3$ transition of O^{16}:

$$\Gamma_{\gamma\gamma}/\Gamma_{\gamma} \leq 5\times10^{-4}.$$

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