Cascade Gamma Rays from $_{84}Po^{214}$ (RaC′)†

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Seven gamma cascades of $_{84}Po^{214}$ have been identified by means of coincidence scintillation spectrometry: gamma rays of energy 0.77, 0.93, 1.12, 1.24, 1.38, 1.52, and 1.85 Mev appear in coincidence with the 0.607-Mev photon transition to the ground state. The existence of a weak beta transition to the 0.607-Mev level was also verified.

Four other gamma rays, of energy 0.85, 1.77, 2.20, and 2.40 Mev, appear as direct transitions to the ground state. Both gamma-gamma and beta-gamma coincidences were employed to verify the suggested energy level scheme.

I. INTRODUCTION

ALTHOUGH many reports[1–5] have appeared on the gamma-ray spectrum following the beta decay of $_{83}Bi^{214}$(RaC), the decay scheme has not yet been satisfactorily described. In view of the somewhat discordant reports,[6] an attempt has been made to clarify the problem by means of gamma-gamma and beta-gamma coincidence scintillation spectrometry.

II. APPARATUS AND EXPERIMENTAL PROCEDURES

Approximately 5×10^{-8} curie of RaCl in equilibrium with its daughters was used as the source of RaC′ gamma rays. This source was dried and sealed between two Mylar films (0.88 mg/cm^2) to prevent escape of radon and to insure detection of most of the beta radiation in the beta-gamma coincidence experiments.

Gamma-gamma coincidence spectrometry was performed with two NaI(Tl) crystals, each $2\frac{1}{2}$ in. in diameter and $2\frac{1}{8}$ in. high. Their resolution was approximately 8 percent at 661 kev, and the height of the Compton distribution was 20 percent of the photopeak height in the absence of any collimation.

The pulse-height spectrum in coincidence with any one gamma ray was obtained by accepting from one crystal and its single-channel analyzer a narrow band of pulse heights corresponding to the gamma-ray photopeak and by gating with it the multichannel analyzer. The second crystal fed directly a 24-channel Marconi pulse-height analyzer, which had been modified by the addition of a coincidence gating circuit.

The source was placed directly between the two NaI crystals, and a portion of the RaC′ gamma spectrum was recorded on the multichannel analyzer. Beta-ray detection was eliminated by shielding the source with 1 mm of Pb. The gating crystal was then adjusted to cover each photopeak in turn, and the resulting coincidence spectrum obtained. Its interpretation was carried out by keeping in mind that the counts in the peak, as seen by the gating analyzer, were due to both the desired gamma rays undergoing full energy loss in the crystal and to those gamma rays of greater energy that lost in the crystal energies falling within the band under consideration.

For beta-gamma coincidence spectrometry, one of the $2\frac{1}{2}$ in.$\times 2\frac{1}{8}$ in. NaI crystals was retained to record the gamma spectrum on the multichannel analyzer in coincidence with the beta rays of the source, as detected by a suitable scintillator. For beta energies below 0.8 Mev the latter consisted of a NaI crystal, $\frac{1}{32}$ in. thick and $\frac{1}{2}$ in. in diameter, sealed by a 0.001 in. thick nickel foil, and calibrated with the conversion line from Cs^{137} (0.63 Mev). For beta energies greater than 1 Mev, a $\frac{7}{16}$-in. thick plastic scintillator, $1\frac{5}{8}$ in. in diameter, was employed. In both instances, corrections were made for the gamma response of the beta-ray detector by interposing sufficient thickness of Al to filter out the hardest beta rays. If the residual response to gamma rays was at all appreciable, the resulting gamma-gamma coincidence spectrum was subtracted from the observed beta-gamma coincidence spectrum. The purpose of the beta analysis was to determine which of two gamma rays (not in coincidence) originated from the higher energy level and to thus provide an independent method of verification for the suggested energy level scheme. The beta-ray scintillator, connected to a single-channel analyzer, opened the coincidence gate on the multichannel analyzer when a beta ray was detected in the energy band under consideration. By setting the lower energy limit of this band above the beta-ray end point of a transition to a high-energy level, only those betas were detected which represent transitions to lower energy levels. In coincidence with these betas were detected only those gamma rays originating from energy levels below the limit chosen.

For all methods of detection, the false coincidence contributions were evaluated in an identical manner. The radium source was left between the two detectors, so that the gamma spectrum presented to the multichannel analyzer would be unchanged in either rate or shape. The gating analyzer was turned off, after the

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[1] C. D. Ellis and G. H. Aston, Proc. Roy. Soc. (London) **A129**, 180 (1930).
[2] C. D. Ellis, Proc. Roy. Soc. (London) **A143**, 350 (1935).
[3] R. M. Pearce and K. C. Mann, Can. J. Phys. **31**, 592 (1953).
[4] M. Mladjanovic and A. Hedgran, Arkiv Fysik **8**, 49 (1954).
[5] G. D. Latyshev, Revs. Modern Phys. **19**, 132 (1947).
[6] F. Demichelis and R. Malvano, Nuovo cimento **9**, 1106 (1952); **10**, 405 and 1359 (1953); **12**, 358 (1954).

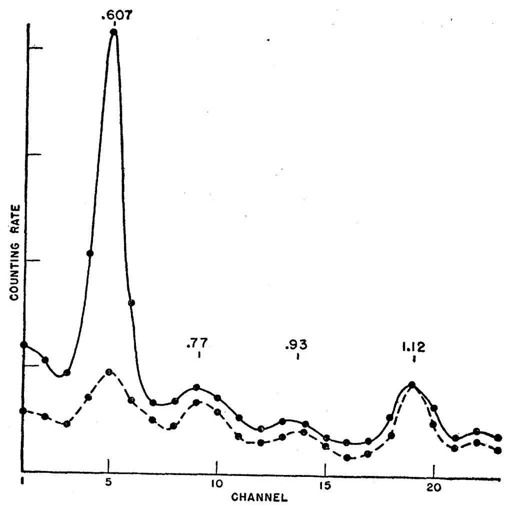

FIG. 1. The solid curve shows the pulse-height spectrum of the RaC′ gammas between the 0.607- and the 1.12-Mev photopeaks as seen by the large NaI crystal. The dashed curve is obtained by gating the multichannel analyzer with the 0.607-Mev photopeak. Both curves are normalized at the 1.12-Mev photopeak.

gating rate had been determined. An independent source of pulses was then applied to the gating circuit of the multichannel analyzer at the same rate obtained in the coincidence experiment. These random pulses originated from a weak radioactive source placed in a remote location.

III. EXPERIMENTAL RESULTS

A. Gamma-Gamma Coincidences

The pulse-height spectra were investigated in three consecutive portions of the 0.5–2.5-Mev energy band, and typical results are shown in Figs. 1 to 3. The solid and broken lines denote respectively the ungated spectrum and the spectrum gated by the 0.607-Mev line; in Figs. 1 and 2 the two curves have been normalized on the 1.12-Mev photopeak in order to estimate roughly the intensities involved. It is evident from these data that of the ten gamma rays resolved by the crystal in the ungated spectra, six are in coincidence with the 0.607-Mev line. Their energies are 0.77, 0.93, 1.12, 1.24, 1.38, and 1.52 Mev. In addition, the previously reported weak photon of 1.85 Mev,[3,4] overshadowed by the 1.77-Mev peak in the ungated spectrum, is clearly detected in coincidence analogous to the others. The small peak at 0.607 Mev, in Fig. 1, that occurs when the analyzer is gated by the 0.607 photopeak, is due to the fact that the coincidence gate may be opened by Compton scattered components of gammas harder than 0.607 Mev, and that the 0.607-Mev gamma is in coincidence with some of these.

By repeating this technique with each of the other photopeaks in turn, no other coincidence peak was revealed outside the 0.607-Mev line.

The photopeaks of 1.77, 2.20, and 2.4 Mev do not appear to be in coincidence with either the 0.607-Mev gamma or any other gamma. From these data we have constructed the decay scheme as shown in Fig. 4.

B. Beta-Gamma Coincidence

Beta-gamma coincidences offered the possibility of confirming the existence of at least some of the energy levels assumed in Fig. 4.

Thus, for the 0.77-Mev gamma to be in coincidence with the 0.607-Mev gamma, it must originate from an energy level at least 1.38 Mev above the ground state. Since the beta energy to the ground state is 3.17 Mev,[7]

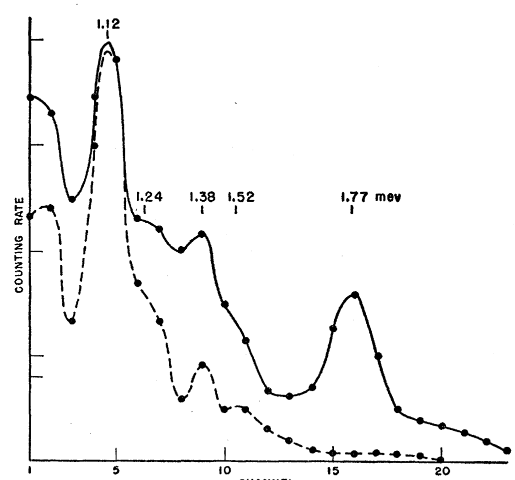

FIG. 2. The solid curve shows the pulse-height spectrum of the RaC′ gammas between the 1.12- and the 1.77-Mev photopeaks. The dashed curve is obtained by gating the multichannel analyzer with the 0.607-Mev photopeak. Both curves are normalized at the 1.12-Mev photopeak.

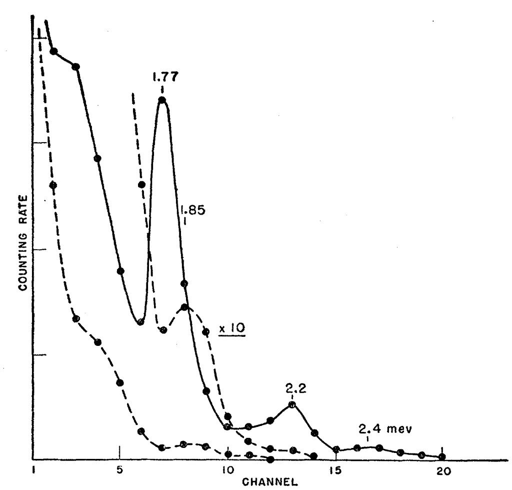

FIG. 3. The solid curve shows the pulse-height spectrum of the RaC′ gammas between the 1.77- and the 2.4-Mev photopeaks. The dashed curve is obtained by gating the multichannel analyzer with the 0.607-Mev photopeak.

[7] A. H. Wapstra, Physica 18, 1247 (1952).

the beta ray decaying to the level in question must have an end point of 1.79 Mev. When the plastic scintillator is biased to look at beta energies greater than 1.8 Mev, no coincidences with the 0.77-Mev gamma ray should appear if our decay scheme is correct. When this test was made, the beta-gamma coincidence spectrum showed two peaks, corresponding to the expected 0.607-Mev gamma and to one at 0.85 Mev, as shown in Fig. 5. Hence, the assumption that the 0.77-Mev gamma originated from a level at least as high as the 1.38-Mev level is correct. The appearance of the gamma ray at 0.85 Mev confirms the findings of Pearce and Mann,[3] and the other at 0.607 Mev verifies the existence of a weak beta transition to this level as suggested by Wapstra[7] and others,[8] since residual gamma-gamma coincidences were duly taken into account.

In a similar manner, each of the gamma rays appearing in coincidence with the 0.607-Mev line was verified to come from an energy level as indicated by the decay scheme. The beta-gamma coincidence technique was admittedly not as decisive as the gamma-gamma coincidence technique, but it appeared adequate to determine that the photons of 1.12, 1.24, and 1.77 Mev all came from nearly the same level; that those of 0.77 and 0.93 Mev originated from below this level; and that those of 1.38, 1.52, 2.2, and 2.4 Mev came from above this level.

Some of the 1.38-Mev gammas have been shown to be in cascade with the 0.607-Mev gamma by both gamma-gamma and beta-gamma techniques. The latter, however, were not rigorous enough to exclude the possibility that some of the 1.38-Mev photons originate as an alternative to the 0.77–0.607-Mev cascade.

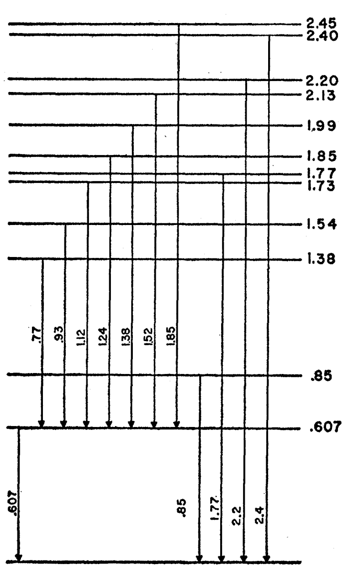

FIG. 4. The energy level system of $_{84}Po^{214}$, as determined by NaI coincidence scintillation spectrometry. Only those gamma rays actually detected in this work are included in this level scheme.

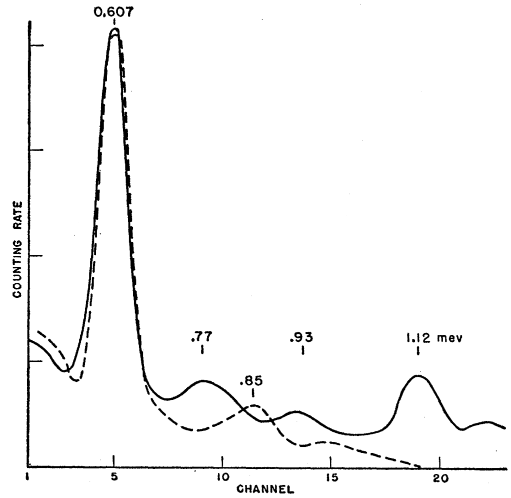

FIG. 5. The solid curve shows the pulse-height spectrum of the RaC′ gammas between the 0.607- and the 1.12-Mev photopeaks. The dashed curve is obtained by gating the multichannel analyzer with betas of energy greater than 1.8 Mev.

IV. CONCLUSION

The decay scheme as determined by gamma-gamma coincidences, and in a sense verified by the beta-gamma coincidences, describes satisfactorily the cascades and energy level origins of the more intense gammas from $_{84}Po^{214}$. Pearce and Mann,[3] and others,[9] have reported some gammas below 600 kev. These were not seen in coincidence with the 0.607-Mev line but were not looked for in coincidence with the other gammas. It is assumed that they must be very weak.

We were unable to confirm the coincidences between 0.76-Mev and 1.29-Mev gammas, as reported by Demichelis and Malvano.[6] We have, however, verified the other three pairs reported by them, namely those of 1.12, 1.38, and 1.52 Mev with the 0.607-Mev gamma.

ACKNOWLEDGMENTS

I would like to thank Mr. L. D. Marinelli for valuable suggestions and discussions concerning this work. The modification of the Marconi multichannel analyzer to coincidence-anticoincidence spectrometry was designed and engineered by Dr. C. E. Miller of this Laboratory.

[8] R. A. Ricci and G. Trivero, Atti accad. nazl. Lincei **17**, 44–46 (1954).

[9] K. C. Mann and M. J. Ozeroff, Can. J. Research **A27**, 164 (1949).