Gamma-Ray Spectrum of Ac^{228}

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The gamma radiation from a radioactively pure source of Ac^{228} has been studied using a NaI scintillation spectrometer. Gamma rays of 0.098, 0.127, 0.336, 0.410, 0.458, 0.907, 0.965, 1.587, 0.155, 0.220, 0.278, and 0.790 Mev are indicated, of which the last four are previously unreported. A double scintillation spectrometer is described which was used to investigate gamma-gamma coincidences. A decay scheme for Ac^{228} is suggested.

I. INTRODUCTION

THE analysis by Black[1] of the beta spectrum of Ac^{228} (MsTh II) indicated gamma-ray energies of 0.058, 0.080, 0.129, 0.184, 0.250, 0.319, 0.462, 0.915, and 0.970 Mev. Thibaud[2] examined the excited photoelectron spectrum of Ac^{228} mixed with the active deposit of thorium and found conversion lines corresponding to gamma-ray energies of 0.333, 0.461, 0.913, and 0.967 Mev. A recent investigation by Kyles *et al.*[3] showed that this spectrum is more complex than indicated by the earlier work. Their data suggest six beta end points of energies 0.450, 0.640, 1.100, 1.700, 1.850, and 2.180 Mev and seventeen gamma-rays of energies 0.057, 0.078, 0.098, 0.113, 0.127, 0.179, 0.184, 0.336, 0.410, 0.458, 0.907, 0.965, 1.035, 1.095, 1.587, and 1.640 Mev. These investigators have proposed a decay scheme based in part on coincidence measurements between the halves of a double beta spectrometer and between the beta spectrometer and a scintillation detector. The latter coincidence measurements were hampered by the poor energy resolution of the scintillation detector which was not of the NaI type. Jenkins and O'Kelley[4] have also analyzed the beta spectrum of Ac^{228} and found end-point energies of 2.030, 1.740, and 1.100 Mev. Because of the complexity of its disintegration neither the decay scheme nor even the gamma-ray spectrum of Ac^{228} is certain and for this reason further investigation seemed to be warranted.

In a recent investigation by the authors using a NaI scintillation spectrometer, not all of the reported gamma-ray energies were evident while some energies not previously reported were observed. In addition, coincidence measurements were made using two NaI scintillation spectrometers. A decay scheme based on these results is suggested which is not in agreement with that of Kyles *et al.*

II. APPARATUS AND TECHNIQUES

The scintillation detector consisted of a NaI crystal, $1\frac{1}{2}$ inches in diameter by 1-inch thick, optically coupled to the photocathode of a 6292 DuMont photomultiplier tube using Dow Corning silicone stopcock grease. Magnesium oxide powder was packed around the crystal to insure good light collection.[5] Pulses from the detector were linearly amplified and analyzed by means of a single-channel analyzer. Alternatively, the pulses could be displayed on an oscilloscope and the pulse distribution obtained photographically. Unknown gamma-ray energies were determined by measuring the amplitude of their associated photoelectron peaks. A calibration of pulse height *versus* energy for the spectrometer was obtained by using a number of standard gamma-ray emitters. Among others, the 2.090-, 1.274-, and 1.085-Mev lines of In^{116}, the 0.794-Mev line of Cs^{134}, the 0.662-Mev line of Ba^{137}, the 0.411-Mev line of Au^{198}, the 0.137-Mev line of In^{116}, the 0.077-Mev line of Po^{210}, and the 0.059-Mev line associated with electron capture in W^{181} were used as energy references. The over-all energy resolution of the spectrometer was tested using the 0.794-Mev gamma ray of Cs^{134} and found to be about 8 percent.

A block diagram of the apparatus used for coincidence measurements is shown in Fig. 1. The apparatus is patterned in large part after the design of Johansson and Almquist.[6] The window of the single-channel analyzer in the lower channel is adjusted to straddle

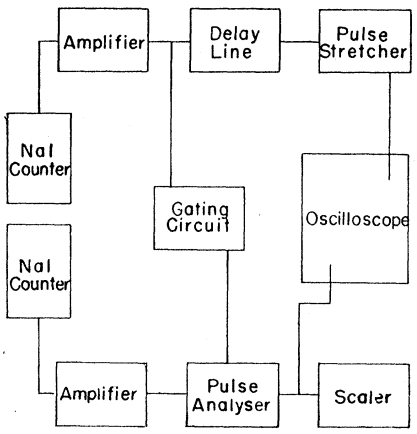

FIG. 1. Schematic diagram of the coincidence spectrometer.

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[2] J. Thibaud, Ann. phys. **5**, 73 (1926).
[3] Kyles, Campbell, and Henderson, Proc. Phys. Soc. (London) **A66**, 519 (1953).
[4] W. A. Jenkins and G. D. O'Kelley (unpublished). See Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).
[5] C. J. Borkowski and R. L. Clark, Rev. Sci. Instr. **24**, 1046 (1953).
[6] S. A. E. Johansson and S. Almquist, Arkiv. Fysik **5**, 427 (1952).

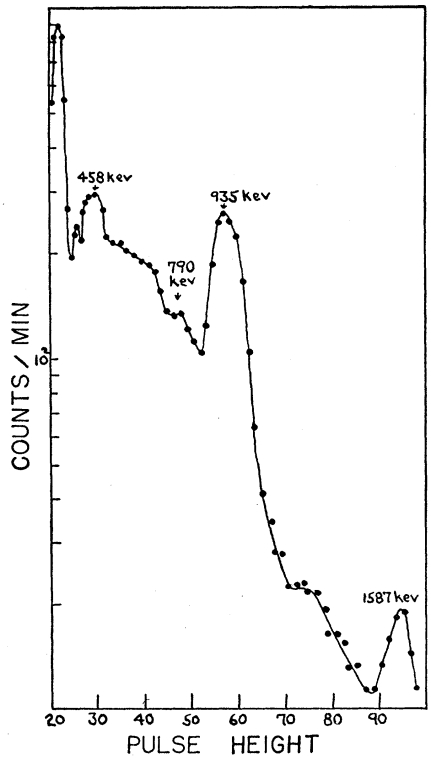

FIG. 2. High-energy portion of the gamma-ray spectrum of Ac^{228}.

the photopeak of a particular gamma ray in the spectrum and the output from the analyzer triggers the oscilloscope sweep. Pulses in the upper channel are delayed for 3 microseconds, in order to compensate for the delay in the lower channel caused by the single-channel analyzer, passed through a pulse stretcher, and applied to the vertical deflection plates of an oscilloscope. Pulses which are coincident with triggering pulses in the lower channel are displayed on the ocsilloscope screen from which a photographic record of the coincident spectrum is obtained. A reference picture of the normal spectrum may be obtained by changing the mode of triggering the oscilloscope trace from external to internal.

The principal difference between the apparatus used in this work and that used by Johannson is in the method of preventing noncoincident pulses in the lower channel from causing a bright base-line trace. Johansson incorporates a separate coincidence circuit which increases trace intensity only when a pulse in the upper channel is coincident with a triggering pulse in the lower channel. However, this circuit also affects oscilloscope deflection sensitivity. In the apparatus used for this work the gating circuit between channels, as shown in Fig. 1, prevents the single-channel analyzer from generating a triggering pulse except when coincident pulses occur and does not effect the gain of the system. Consequently, coincident and reference pictures of pulse distributions may be compared directly. The resolving time of the coincidence spectrometer is 1.5 microseconds.

The sources used in this investigation were prepared from a primary source of Ra^{228} (MsTh I) which has a half-life of 6.7 years. The Ra^{228} source was free from radium (Ra^{226}) contamination, having been prepared from a 13-year old sample of thorium nitrate. Radioactively pure sources of Ac^{228} were extracted from the primary source by using the method of Haissinsky[7] as improved by McLane and Peterson[8] whereby the isotopes of radium, thorium, lead, and bismuth are successively precipitated from a solution containing Ac^{228} and its decay products.

III. RESULTS AND CONCLUSIONS

With sufficient absorber placed between the source and the detector to remove the beta radiations, the pulse distribution from Ac^{228} was analyzed by means of the single-channel analyzer. The high-energy portion of the distribution is shown in Fig. 2 and the low-energy portion in Fig. 3. These spectra verify the existence of the following previously reported gamma-ray energies: 0.098, 0.127, 0.336, 0.410, 0.458, and 1.587 Mev. In addition, the gamma rays reported of 0.907 and 0.965 Mev are indicated, but not resolved, together yielding a broad maximum at 0.935 Mev. Previously unreported gamma rays of 0.220, 0.278, and 0.790 Mev are also present. A fourth unreported gamma ray of 0.155 Mev is hardly discernable in the normal spectrum but becomes evident when a coincidence spectrum is taken with the single-channel analyzer set on the 0.935-Mev maximum. The absence

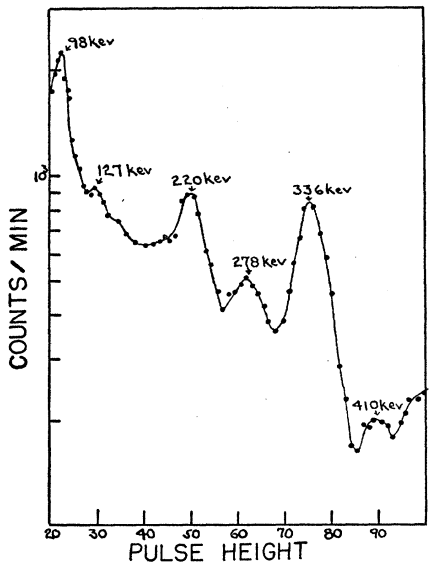

FIG. 3. Low-energy portion of the gamma-ray spectrum of Ac^{228}.

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[8] C. K. McLane and S. Peterson, U. S. Atomic Energy Commission Report No. MDDC-1742, 1948 (unpublished).

from our spectrum of the 0.057- and 0.184-Mev gamma ray which have been established from internal conversion measurements might be accounted for by an extremely high conversion coefficient for these transitions.

Coincidences between gamma rays of the following energies have been observed: 0.336 and 0.790, 0.278 and 0.790, 0.220 and 0.127, 0.098 and 0.458, 0.098 and 0.410 Mev. Additional coincidence measurements between higher-energy radiation and the 0.220-Mev gamma ray have been hampered by radiation backscattered from one crystal to the other. The energy of the backscattered radiation is also in the neighborhood of 0.200 Mev and gives rise to false coincidences. Coincidences between the 0.935-Mev maximum and the 0.458, 0.410, 0.155, and 0.098 Mev radiations have also been observed. Efforts to split the 0.935-Mev maximum by measuring coincidences with the 0.458-Mev gamma ray indicate that the 0.907-Mev transition is coincident with that of 0.458 Mev and the 0.965-Mev transition is coincident with that of 0.410 Mev. Measurement of coincidences with the 0.098-Mev gamma ray does not appear to split the 0.935-Mev maximum.

These results are in agreement with the gamma-gamma coincidence measurements of Kyles *et al.* who found, using scintillation detectors, that gamma radiations of between 0.400 and 0.500 Mev are coincident with radiations of energies between 0.900 and 1.100 Mev and further, that gamma rays of under 0.900 Mev are coincident with gamma rays of less than approximately 0.400 Mev. These investigators also measured coincidences between gamma radiations and certain portions of the beta spectrum containing strong conversion lines. It was found that the 0.127, 0.184, and possibly the 0.098-Mev radiations are coincident with other gamma rays. The situation regarding the 0.098-Mev gamma ray was undecided because of the proximity of its conversion lines to the *K* conversion line of the 0.184-Mev radiation. There is no disagreement between our coincidence measurements and those made by Kyles *et al.* However, on the basis of more precise gamma-gamma coincidence relationships obtained with the NaI scintillation detectors, we are lead to conclude that the decay scheme proposed by these investigators is untenable.

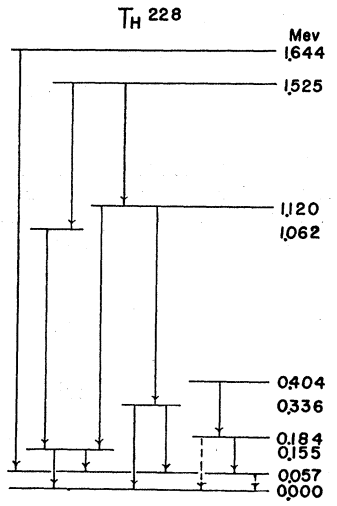

FIG. 4. Proposed decay scheme for Ac^{228}.

A decay scheme consistent with all of the foregoing observations is given in Fig. 4. The 0.057- and 0.184-Mev transitions, not observed by us, have been included and are shown as broken lines.

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