Gamma Radiation from Ce^{144} and Pr^{144}

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The gamma radiation following the decay of Ce^{144} and Pr^{144} has been studied with a 4-in. diameter, 4-in. high cylindrical NaI(Tl) crystal, and single-channel and twenty-channel pulse-height analyzers. With the aid of photopeak to total ratios, previously determined for this crystal, the relative gamma-ray intensities have been determined in terms of the 0.134 Mev gamma ray of Ce^{144}. If an intensity of unity is assumed for the 0.134-Mev gamma radiation, the photon radiation intensities for the 0.081, 0.696, 1.49, and 2.185-Mev transitions are respectively 0.287, 0.116, 0.023, and 0.059.

INTRODUCTION

MEASUREMENTS of the relative intensities of gamma-ray transitions[1] and the determination of the consequent disintegration schemes[2,3] for the $Ce^{144}\rightarrow Pr^{144}\rightarrow Nd^{144}$ chain has been difficult because of the low energies of the radiations following the decay of Ce^{144}, and because of the low intensity of the radiations following the decay of Pr^{144}. The relative transition probabilities have been determined primarily from observations of the electron spectra (beta ray plus internal conversion). The study described in this paper is concerned primarily with the spectral distribution of the gamma quanta and attempts to fit these measurements with the information obtained in the previous investigations.

APPARATUS

The availability of large NaI(Tl) crystals has produced great improvements in gamma-ray scintillation spectrometry techniques. An appreciable fraction of the gamma quanta incident upon the crystal can be totally absorbed within it, thereby enhancing the intensity of the total absorption peaks (sometimes called photopeaks) recorded for these quanta. As a result there is a suppression of the lower-energy continuous Compton distribution.

The particular experiment arrangement used here utilizes a packaged 4-in. diameter by a 4-in. high cylindrical NaI(Tl) crystal surrounded by lead to reduce background. Inserts which fit into a stair-step well in that portion of the lead separating the crystal and the cerium-praseodymium source provide cylindrical apertures, either 1.4 cm or 2.6 cm in diameter, or no aperture when a background record is desired. A DuMont type 6292 photomultiplier tube is used as detector for the scintillations produced in the crystal.

The sources were dried by evaporation from solution in the end of a 0.5-cm inside diameter closed glass tube. When the source was being studied, careful alignment

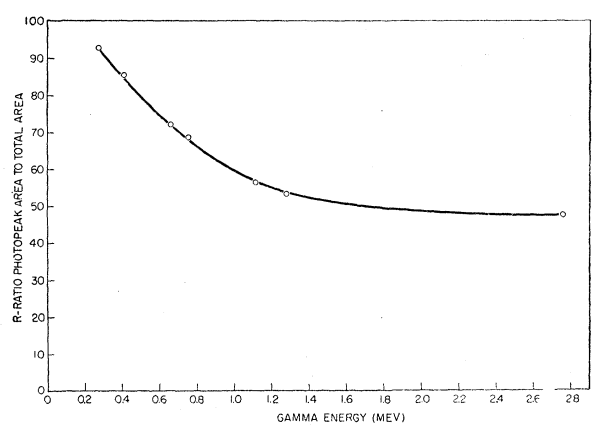

FIG. 1. Plot of the ratio of total absorption peak area to total pulse-height spectrum area as a function of gamma-ray energy, for a 4-in. diameter, 4-in. high cylindrical NaI(Tl) crystal, with a source on the axis of the crystal whose radiations are collimated by a cylindrical aperture in the lead shield which surrounds the crystal.

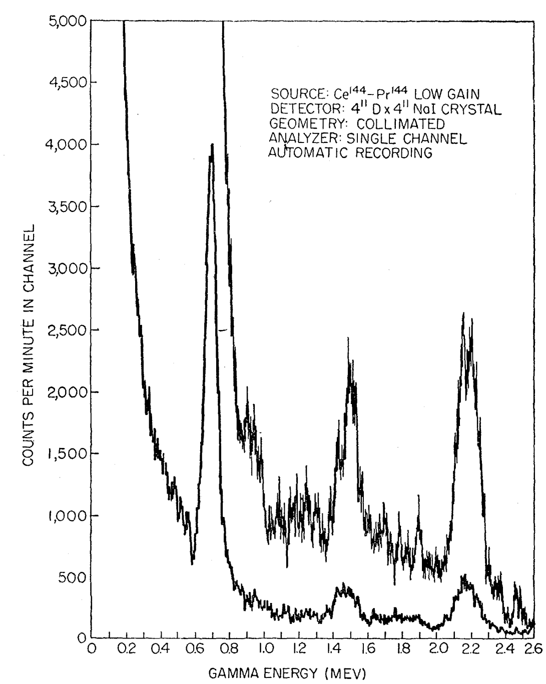

FIG. 2. Pulse-height spectrum for the higher-energy Pr^{144} gamma radiations as recorded in the single-channel analyzer. The upper curve is ×5.

[1] D. Alburger and J. Kraushaar, Phys. Rev. **87**, 448 (1952).
[2] F. T. Porter and C. S. Cook, Phys. Rev. **87**, 464 (1952).
[3] Emmerich, Auth, and Kurbatov, Phys. Rev. **94**, 110 (1954).

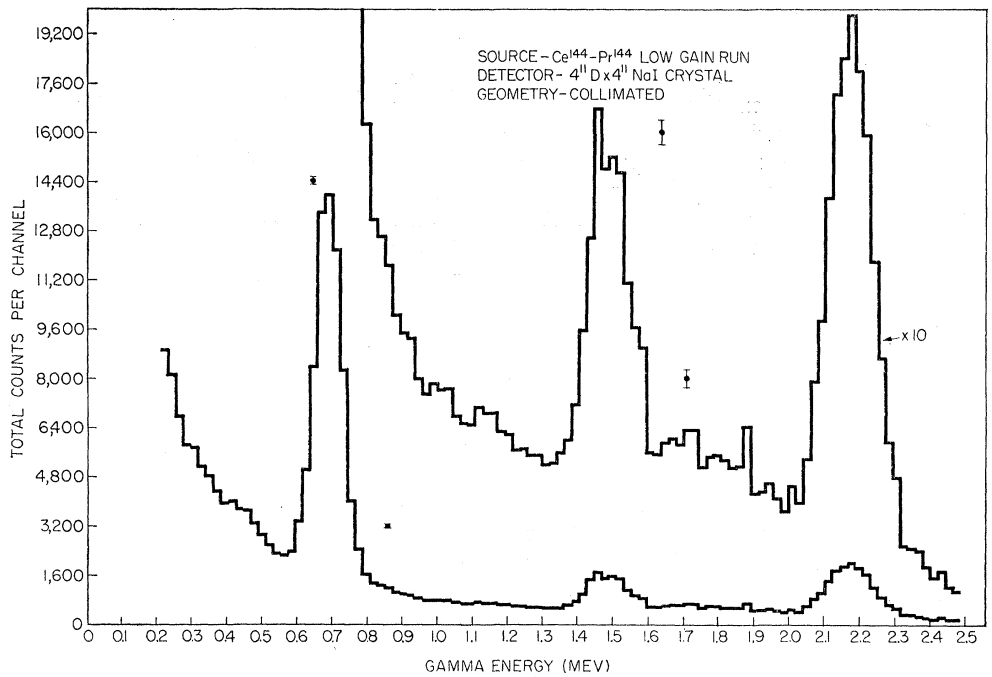

FIG. 3. Same as Fig. 2 but recorded by means of a twenty-channel analyzer.

was made to ascertain that the NaI(Tl) saw the entire source through the aperture. A piece of aluminum 5 mm thick was placed over the aperture to absorb the energetic 2.97-Mev beta radiation from Pr^{144}.

The ratio of the area under the total absorption (photo) peak to the total area of pulse height distribution as a function of energy for a series of monoenergetic gamma rays has been determined,[4] and is plotted in Fig. 1, for the conditions used in this experiment. Thus, a measurement of the area of any total absorption peak from any single gamma-ray energy, corrected for the ratio of total area to peak area, for the relative number of quanta absorbed in the NaI(Tl) crystal and for the relative number of quanta absorbed in the aluminum beta-absorber, gives a figure proportional to the number of gamma quanta of that energy. The technique is similar to that used by Mijatovic and Wintersteiger[5] in their studies of the radiations from Xe^{131}.

The data were collected by means of either a single-channel analyzer or a Bell-Kelly-type twenty-channel analyzer, operated so as to record the spectrum under consideration in a total of 120 channels. In the case of the single-channel analysis, a channel of appropriate width was swept through the spectrum synchronously with the movement of recording paper through a Brown Recorder, on which the count rate (intensity) was plotted as a function of pulse height (energy). Recording of the data from the twenty-channel analyzer was made by means of scaling strips and mechanical registers.

[4] W. E. Kreger and L. McIsaac, Phys. Rev. **93**, 943 (1954).
[5] A. M. Mijatovic and V. Z. Wintersteiger, Bulletin of the Institute of Nuclear Sciences "Boris Kidrich" **3**, 57 (1953).

RESULTS

A typical pulse-height distribution from the single-channel analyzer, as recorded on the Brown strip chart, is shown in Fig. 2 for the 0.695, 1.48, and 2.185 Mev gamma rays. The same region as a histogram from the results of the twenty-channel analyzer is shown in Fig. 3. The low-energy pulse-height distribution is shown in Fig. 4. In this plot can be seen a peak associated with the 81- and 134-kev gamma rays and a peak produced by the x-rays resulting from the internal conversion, with possible additional effects from a

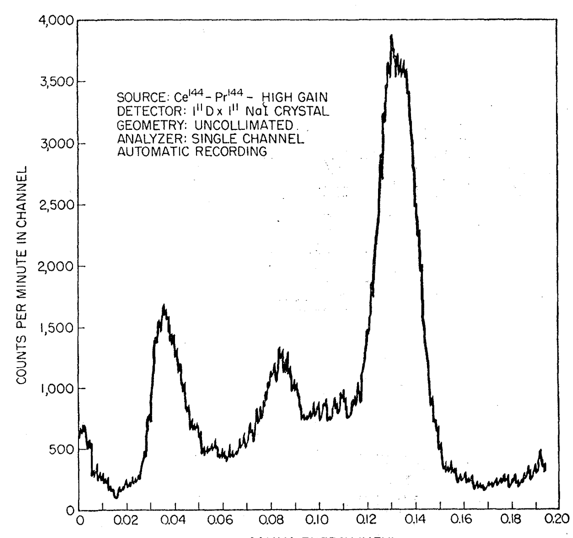

FIG. 4. Single-channel analyzer recording of the pulse-height spectrum of the lower-energy photons from $Ce^{144}-Pr^{144}$.

34-kev gamma ray. There is no clear evidence for other gamma rays in this region except for the fact that the valleys between peaks do not drop as low as would be expected from the assumption that the peaks should show a Gaussian-type shape.

Analysis of the measured peak areas to obtain relative gamma-ray intensities indicates that, if an intensity of unity is assumed for the 134-kev gamma ray, the 81-kev line will be 0.287; the 0.695-Mev gamma, 0.116; the 1.48-Mev gamma, 0.0226; and the 2.185-Mev gamma, 0.0589.

Errors in these values can arise because of an inability to determine the exact base and shape for the total absorption peak and because of counting rate statistics. These errors are present both in the spectrum under observation and in the experimental determination of the peak to total ratios. Experience gained in the analysis of a considerable number of gamma-ray spectra has led to the conclusion that the uncertainty in the value quoted for the 0.695, 1.48, and 2.185 Mev quanta is about ± 8 percent and for the 81 kev quantum about ± 15 percent.

If it is assumed that 22 percent of the Ce^{144} disintegrations produce the 134-kev transition[2,3] and that 6.6 percent of the Ce^{144} disintegrations are internally converted in the 134-kev transition[2] (leaving 15.4 percent of the transitions as photon radiation), then the 0.695-Mev gamma ray occurs following 1.79 percent of the Pr^{144} disintegrations, the 1.48-Mev gamma ray follows 0.35 percent of the transitions and the 2.185-Mev gamma ray, in 0.91 percent of the transitions. This would be indicative that Pr^{144} decays through the 2.28-Mev beta group 1.44 percent of the time, and the 0.80-Mev group 1.26 percent, differing somewhat from the figures proposed by Emmerich *et al.*[3]

From the fact that only the 81- and 134-kev transitions are distinctly evident in the low-energy photon spectrum as well as being most prominent in the internal conversion spectrum,[2,3] we find no evidence contradictory with the decay scheme proposed for Ce^{144} by Emmerich *et al.*,[3] except that the 223-kev beta transition may have an intensity of as much as six percent.

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Nuclear Quadrupole Spectra in Solids*

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Numerical values for the energy levels, Zeeman splitting parameters, and intensity parameters of the pure quadrupole spectrum are given for ten values of the asymmetry parameter for spins 5/2, 7/2, and 9/2. The intensity parameters for the $m \to -m$ transition in a magnetic field for large asymmetric quadrupole interaction are given. They show that the corresponding lines should be observable. A method of increasing the accuracy of perturbation calculations is presented for the Zeeman splitting case and the strong magnetic field case.

INTRODUCTION

SINCE the first observations of nuclear quadrupole spectra in solids by Pound[1] and by Dehmelt and Kruger,[2] it has become abundantly clear that such observations provide a powerful means of investigation of the structure of solids. The theory of nuclear quadrupole interactions in solids has two aspects: first, the purely formal task of describing spectra in terms of interaction parameters; and second, the calculation of the interaction parameters or, conversely, the drawing of inferences about structure from experimental observations. It is toward the first aspect that this paper is addressed, in the hope of providing a broader theoretical basis for experiments which stress the second aspect.

The present state of the spectrum theory may be summarized as follows: (1) Pound has discussed the Hamiltonian; (2) Bersohn treated the broadening of a magnetic resonance line by a small quadrupole interaction;[3] (3) Pound gave third order perturbation formulae for the splitting of the magnetic resonance line by nuclear quadrupole interaction with a symmetric field gradient;[4] Bersohn treated the general case to third order; Volkoff *et al.*, have discussed the explicit orientational dependence of the first and second order formulas;[5] (4) Explicit numerical formulas giving the effect of small asymmetry on the pure quadrupole

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[1] R. V. Pound, Phys. Rev. **79**, 685 (1950).

[2] H. G. Dehmelt, Naturwiss. **37**, 111 (1950).

[3] R. Bersohn, J. Chem. Phys. **20**, 1505 (1952).

[4] See also E. F. Carr and C. Kikuchi, Phys. Rev. **78**, 470 (1950).

[5] Volkoff, Petch, and Smellie, Can. J. Phys. **30**, 270 (1952); G. M. Volkoff, Can. J. Phys. **31**, 820 (1953).