Internal Conversion in Pr^{144}, In^{114}, Ba^{137}, and Cd^{110}*

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(Received August 20, 1951)

Beta-ray spectrometer measurements have been made of the internal conversion ratio α_K/α_L for four nuclear transitions. Values obtained are: 5.3±0.1 for the 132-kev transition in Pr^{144}; 1.30±0.05, 192 kev, In^{114}; 4.57±0.05, 662 kev, Ba^{137}; and 14±2, 656 kev, Cd^{110}. Tentative assignments of multipolarity are given.

I. INTRODUCTION

FROM measurements of the conversion coefficient for the K shell or the ratio of the K conversion coefficient to the L conversion coefficient, one can, in principle, obtain the multipole order of nuclear transitions and hence the spin and parity changes needed to establish decay schemes. However, the only reliable values of conversion coefficients existent are the values of α_K calculated by Rose *et al.*[1] using exact relativistic wave functions for a wide range of energies, Z values, and multipole orders. Experimental determinations of α_K alone are difficult except when the decay scheme is known to be simple. A few methods have been proposed to obtain α_K for a gamma-ray emitted in a complex decay scheme by utilizing Compton scattering[2] or external conversion.[3] In addition to the experimental difficulty, one faces the possibility that the interpretation of values of α_K may be ambiguous if mixtures of electric 2^l-pole and magnetic 2^{l-1}-pole processes occur in nuclides of low Z.[4] Therefore, one would prefer to measure α_K/α_L and from the ratio to obtain an unambiguous assignment of multipolarity. For the interpretation, the experimentalist will have to await the exact calculation of the L conversion coefficient, which is reported[1] to be under way. Meanwhile, approximate calculations are available for tentative assignments.[5–7]

In this experimental study, beta-ray spectrometer measurements were made of the ratio of α_K/α_L for gamma-rays emitted by the nuclides praseodymium 144, indium 114, barium 137, and cadmium 110.

II. EXPERIMENTAL

Quade and Halliday[8] have described the construction and electron optical properties of the magnetic lens beta-ray spectrometer used in these studies. Additional precautions were taken in the present work to reduce scattering within the chamber and alignment errors. Antiscattering baffles were installed near the source and near the counter. The interior of the spectrometer was covered with a rough coating of ceresin wax. A simple experiment showed that this wax reduces electron scattering by a factor of at least two. It was found necessary to locate the central baffle quite accurately so that the annular aperture at the center of the spectrometer would be uniformly wide. Failure to do this led to a broadening of internal conversion lines.

For this work, a thin-window Geiger counter was developed in which the beta-particles entered at right angles to the axis of the counter. Such a counter has the advantages that both ends of the central wire are accessible for flashing the wire and that the sensitive volume of the counter extends to the window. The counter showed a long term stability, a flat plateau (1.6 percent per 100 volts), and a low background (30 counts/minute). The window had an areal density of 30 μg/cm^2 and transmitted electrons to energies as low as 5 kev.

Three of the four radioactive materials were available at reasonably high specific activities. Cesium 137, the parent of barium 137, was obtained from Oak Ridge as cesium chloride at an activity of 1.05 mC/ml and with total solids not exceeding 2.4 mg/ml. Cerium 144 was obtained there also as cerium nitrate (3.06 mC/ml and 1.8 mg/ml). Indium 114 was produced in the University of Pittsburgh cyclotron by a $Cd^{114}(d,n)$ reaction and cleanly separated at the radiochemistry laboratory of the Atomic Power Division, Westinghouse Electric Corporation, by H. A. Brightsen. Silver 110, produced at Oak Ridge by neutron bombardment, had a low specific activity (3.97 mC/ml and 150 mg/ml). The thick source resulting from the low specific activity caused difficulty in resolving the cadmium 110 conversion lines. The sources were prepared by depositing a minimal amount of the concentrated radioactive solution upon an aluminum backing of thickness 0.00025 inch. Average areal densities of the sources were obtained by weighing. The areal density of the cerium, indium, and cesium sources was about 0.1 mg/cm^2. That of the silver source was 10 mg/cm^2.

Data were taken automatically.[9] Enough counts were recorded that the statistical error associated with each

* Part of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Pittsburgh.

† Assisted by the joint program of the AEC and ONR and by the Research Corporation.

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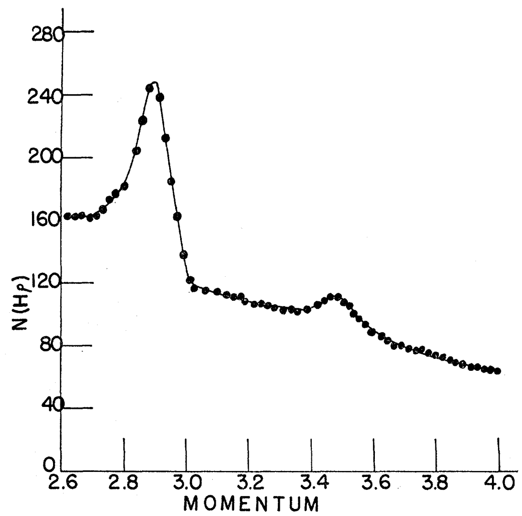

FIG. 1. The electron spectrum of $Ce^{144}-Pr^{144}$ in the region of the conversion peaks of the 132-kev gamma-ray of Pr^{144}. $N(H\rho)$, the number of electrons per unit time per unit momentum interval, is plotted against the electron momentum in arbitrary units.

experimental point did not exceed two percent except where the curves approached the background level.

III. RESULTS

A. Praseodymium 144

A portion of the electron spectrum of cerium 144-praseodymium 144 is shown in Fig. 1. To obtain the conversion peaks of the gamma-ray at 132 kev, it was necessary to subtract the continuous spectrum from the total curve. This was done by making a Fermi plot for cerium and with its help reconstructing the continuous spectrum at the conversion peaks. By subtraction of the continuous spectrum, the conversion peaks of Fig. 2 were obtained. The spread of the K peak is 4 percent. The low energy portion of each line is approximately exponential, a measure of the degradation of the energy of the electrons as they leave the source. In addition to the experimental evidence of Fig. 2, there seems to be theoretical justification[10] for regarding this portion of the curve as exponential. An exponential curve has been fitted to the K peak to extend it to the momentum axis through a region of the total curve where other conversion lines are present. An exponential curve fitted to the L peak extended it to the momentum axis. The correction to the high energy side of the K peak was negligible. The ratio of the areas under the peaks gave $\alpha_K/\alpha_L=5.3\pm0.1$.

The converted gamma-ray must be ascribed to praseodymium 144. Best agreement for the energy of of the gamma-ray is obtained by adding to the energies of the K and L conversion electrons the binding energies for praseodymium. Critical absorption experiments were carried out using aqueous solutions of barium and cesium as absorbers. The absorption data showed conclusively the presence of x-rays which could be either praseodymium $K\alpha$ or neodymium $K\alpha$. Energy considerations make it likely that it is the former. This assignment agrees with that by Emmerich *et al.*[11]

The experiment value of 5.3 ± 0.1 for α_K/α_L indicates an electric quadripole radiation if one uses the non-relativistic calculations of Hebb and Nelson.[5] Their results give the following conversion ratios: E 2^1-pole, 8.4; E 2^2-pole, 4.5; E 2^3-pole, 1.2. Emmerich *et al.*[11] report an approximate value of 7 for α_K/α_L.

B. Indium 114

Conversion peaks for the 192-kev gamma-ray of metastable indium 114 are shown in Fig. 3. The spread is 3.3 percent. The contribution of the 2.05-Mev beta-group to the electron intensity at this energy is negligible.

Separation of the two peaks for purposes of planimetry was effected by a method involving successive approximations to the separate curves. First, a gaussian curve[12] was fitted to the high energy side of the K peak. By subtracting this curve from the total curve between the two peaks, one could decide how to continue the L peak in an exponential. The exponential portion of the L peak was then subtracted from the total curve to give a second approximation to the high energy portion of the K peak.

α_K/α_L was found to be 1.30 ± 0.05 and indicates either an electric 2^4-pole or an electric 2^5-pole transition.

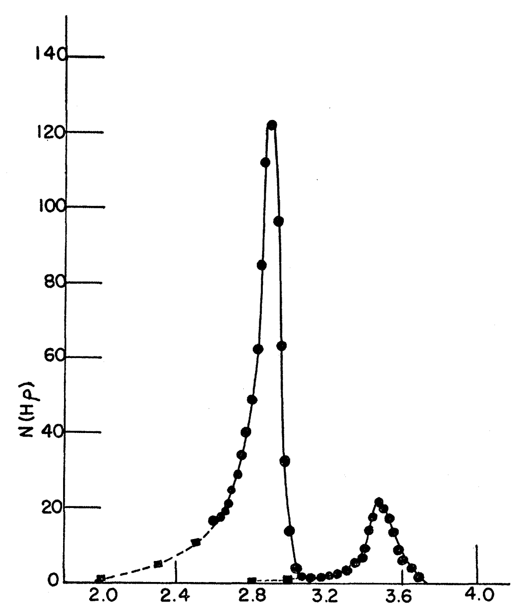

FIG. 2. The conversion electrons of the 132-kev gamma-ray of Pr^{144}. Circles show the experimental points, squares show points on the calculated exponential curves.

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Hebb and Nelson give the following values: E 2^4-pole, 1.7; E 2^5-pole, 0.9. Lawson and Cork[13] report a value of 1.0±0.1 for α_K/α_L. Boehm and Preiswerk[14] give 1.1±0.1, and Steffen[15] reports 1.10±0.05.

C. Barium 137

Figure 4 shows the K and $L-M$ conversion peaks of the 662-kev gamma-ray of metastable barium 137. The spread of the K line is 1.4 percent. A value of 4.57±0.05 is found for α_K/α_{LM} in good agreement with the result $\alpha_K/\alpha_{LM}=4.54$ obtained by Langer.[16] Mitchell and Peacock[17] report the value 4.8 for α_K/α_L, and Osoba[18] finds $\alpha_K/\alpha_L=5.0$. Tentatively, one may assign a multipolarity of electric 2^5 to the transition. It must be emphasized, however, that the nonrelativistic theory may be considerably in error at this energy.

D. Cadium 110

Cadmium 110 is the daughter nucleus by negatron emission of silver 110. The K and $L-M$ conversion peaks of the 656-kev gamma-ray of cadmium 110 have been measured with a line spread of 3.7 percent. The peaks were separated by the procedure referred to above. However, a correction must be applied to the $L-M$ peak to correct for the presence of K conversion electrons due to a gamma-ray of energy 676 kev whose K peak is superimposed (within 2 kev) upon the $L-M$ peak of the 656-kev gamma-ray. The 676-kev line was discovered by Siegbahn[19] in studying the photoelectron spectrum of these radiations in a lead converter. Three lines in the spectrum (676 kev, 705 kev, 759 kev) have about the same photoelectric intensities. Siegbahn concludes that the gamma-intensities are probably about the same upon the assumption that the lines are of the same multipole order. On this basis, the conversion coefficient should be approximately the same, and the K peak of the 706-kev line should approximate that of the 676-kev line. The K peak of the 706-kev line can be readily measured. After applying this plausible, although certainly not rigorous, correction, α_K/α_{LM} was found to be 14±2.

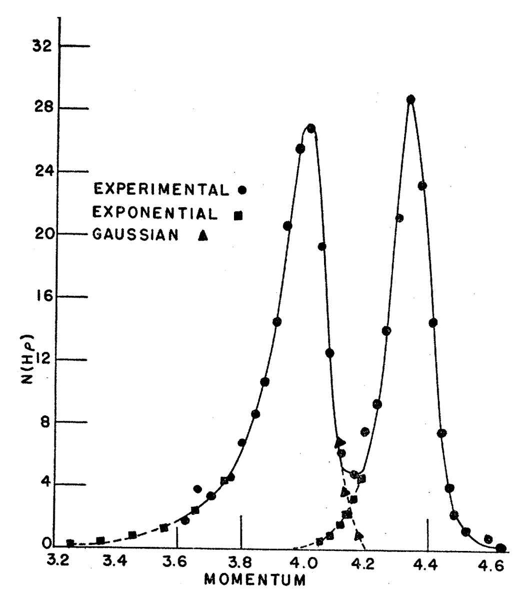

FIG. 3. The conversion electrons of the 192-kev gamma-ray of In^{114}.

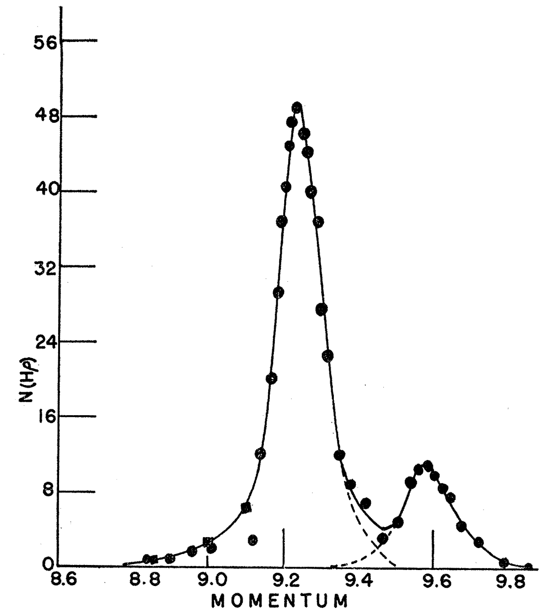

FIG. 4. The conversion electrons of the 662-kev gamma-ray of Ba^{137}. Circles show the experimental points, squares show points on the calculated curves.

This result indicates electric dipole radiation according to the calculations of Hebb and Nelson. However, the difficulties introduced by the source thickness, the approximate nature of the correction for the interfering line, and the nonrelativistic theory used reduce the certainty of the assignment.

By two independent means, Siegbahn[19] has found α_K for this line to be 2.5×10^{-3}. The precise theory shows that this is consistent with either electric or magnetic dipole radiation.

The author would like to acknowledge the support and encouragement given him by Drs. D. Halliday, A. J. Allen, and G. E. Owen. Mr. Kenneth Metzgar assisted with the instrumentation. Mr. Samuel Broder prepared tables of the Fermi function.

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