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Weak Gamma-Transition Intensities in the Electron Capture Decay of $^{144}\text{Pm}$

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(April 9, 1996)

Abstract

We have determined the absolute intensity of weak gamma transitions in the level scheme of $^{144}{\text{Nd}}$, observed following the electron capture decay of $^{144}{\text{Pm}}$. The absolute intensity of the 1397-keV E3 branch from the 2093-keV ($5^-_1$) level was determined to be $(4.9 \pm 0.7) \times 10^{-4}$%. This leads to a revised absolute transition rate of $B(E3; 5^-_1 \rightarrow 2^+_2) = 26^{+15}_{-12}$ W.u., which is still consistent with an interpretation of the $5^-_1$ level based on quadrupole-octupole coupling.

21.10.-k, 23.20.Lv, 23.40.-s, 27.60.+j
One of the crucial pieces of evidence for quadrupole-octupole coupling (QOC) in \(^{144}\)Nd [1] is the similarity of the \(B(E3; 5^-_1 \rightarrow 2^+_2)\) and \(B(E3; 3^-_1 \rightarrow 0^+_2)\) values, each around 34 W.u. However, the large error on the \(B(E3; 5^-_1 \rightarrow 2^+_2)\) value also allows for a neutron quasiparticle component of up to 60\% in the 5\(^-\) state wave function. This large error is due to large uncertainties in both the lifetime of the 5\(^-\) level [1] and the branching ratio for the relevant 1396-keV transition [2]. In order to reduce the latter contribution we have remeasured the intensity of this very weak branch by observing gamma transitions following the electron-capture (EC) decay of a \(^{144}\)Pm source. Figure 1 shows the levels in \(^{144}\)Nd populated in this decay.

The \(^{144}\)Pm source was produced by bombarding 0.25 mm thick Pr foils with a beam of 20-MeV \(\alpha\) particles from the Lawrence Berkeley National Laboratory’s 88-Inch Cyclotron. A beam current of 3 \(\mu\)A was used, with a total irradiation time of 20.5 hours. The resulting Pm activity was separated using the procedure outlined by Hindi et al. [3] and sealed into a small plastic ampoule. Gamma rays from the source were counted using a 20\% Ge detector with a resolution of \(\sim 4\) keV at 1332 keV. Calibrated sources of \(^{60}\)Co, \(^{54}\)Mn, \(^{22}\)Na, and \(^{137}\)Cs were used to determine the absolute efficiency function of the Ge detector, and from this the activity of the Pm source was determined to be \(5.34 \pm 0.09\) \(\mu\)Ci of \(^{144}\)Pm and \(1.86 \pm 0.04\) \(\mu\)Ci of \(^{143}\)Pm. Trace amounts of \(^{22}\)Na and \(^{152}\)Eu were also detected.

With the Pm source in a reproducible geometry some 10 cm from the front face of the detector, a gamma spectrum was recorded with no absorber between the source and detector. A portion of this spectrum, around 1400 keV, is shown in Fig. 2. As can be seen, in this region of interest, the spectrum is dominated by random pile up and true coincidence summing effects. These effects were studied independently using the calibrated sources listed above. Using a \(^{137}\)Cs source, the minimum resolving time of the pile-up rejection circuitry of the Ortec 572 amplifier used was determined to be \(485 \pm 9\) ns. The effect of true coincidence summing, which can be estimated from the measured absolute detector efficiency and the angular-correlation coefficients of coincident gamma rays, was verified using a \(^{60}\)Co source. The contribution of these effects to the sum peaks observed in the \(^{144}\)Pm spectrum was then
calculated and agreed, to within a few percent, with that observed. From the previously published intensity for the 1397-keV transition ($\sim 6 \times 10^{-4}\%$) [2] it can be estimated that random pile-up and (778-keV + 618-keV) coincidence summing contribute about 95% of the events in the peak indicated at that energy in Fig. 2. Therefore, to reduce the influence of these effects in the region around 1400 keV an absorber of $\sim 3.8$ cm of lead was placed between the source and the detector. The effective thickness of the lead was determined (using the calibrated sources) to be $3.79 \pm 0.02$ cm. For this thickness of lead the number of pile up and summing events in the 1397-keV peak is reduced to 0.02% of the previous number, whereas the number of true 1397-keV events is reduced to 10% of the previous value. This means that the true 1397-keV events should now contribute about 95% of the counts in the relevant peak. Spectra were accumulated in this configuration for a total time of 48 days. To minimize the contribution of external background sources the whole setup (source + detector) was surrounded by several centimeters of lead. To determine the influence of any remaining background contributions spectra were taken, with the source removed, for a total of 18 days.

Figure 3 shows the energy region around 1400 keV for the $^{144}$Pm source, with the absorber in place. A peak at 1397 keV is now clearly visible, but surprisingly there is a more intense 1413-keV peak. (This peak was not present in the background spectrum and will be discussed below.) The region around the 1397-keV peak was fitted, taking into account the background lines from $^{214}$Bi, a possible residual (697-keV + 697-keV) pile-up peak, and the 1413-keV peak. After correcting for absorption, detector efficiency, and the small residual summing contribution, the intensity of the 1397-keV transition was determined to be $(4.9 \pm 0.7) \times 10^{-4}\%$, relative to the strong 697-keV transition. Table 1 shows a comparison between the intensities determined in this work and those values reported by Raman and Gove [2].

We were also able to place a definite value on the intensity of the 1508-keV ($4^- \rightarrow 2^+$) transition. To do this the total counts in the broad peak at $\sim 1510$-keV were corrected for the known 1510-keV background contribution ($^{226}$Ra) and for the intensity of the real 1511-keV ($3^- \rightarrow 0^+$) transition. The latter contribution can be derived by taking the known
$B(E3; 3^- \rightarrow 0^+)$ value [4] and the measured lifetime of the 3^- state [1], and calculating a branching ratio of $(2.4 \pm 0.3) \times 10^{-4}$ for the 1511-keV branch to the ground state. This leads to an absolute intensity of this transition, in the EC decay of $^{144}$Pm, of $(1.3 \pm 0.2) \times 10^{-4}$%. After these corrections were applied the remaining intensity in the ~1510-keV peak was taken to belong to the 1508-keV transition, corresponding to an intensity of $(2.0 \pm 1.5) \times 10^{-4}$%.

No 1413-keV gamma transition had been previously reported in the EC decay of $^{144}$Pm. However, a strong 1412.9-keV transition has been identified in the $^{143}$Nd(n, $\gamma$)$^{144}$Nd reaction [5] and placed as depopulating a level at 2110-keV. The spin and parity of this level had previously been tentatively assigned as $2^+$ [5], but recent evidence has indicated that a $4^+$ assignment is more likely [4]. Therefore, both from energy and spin/parity considerations, it is certainly possible for this level to be populated directly in the EC decay of the 5^- ground state of $^{144}$Pm. To verify this, a short coincidence experiment was performed to see if the weak 1413-keV peak could be seen in coincidence with the strong 697-keV transition. This experiment was performed by detecting the 697-keV gammas in a small NaI detector, placed close to the source, and recording the Ge detector signal in coincidence with this. Data were recorded for approximately 10 days in this configuration and Fig. 4 shows a portion of the resulting coincidence spectrum between 750 keV and 1500 keV. The appearance of a definite 1413-keV peak in this spectrum confirms that the 2110-keV level is indeed populated in the EC decay. The absolute intensity of the 1413-keV transition was determined to be $(4.3 \pm 0.1) \times 10^{-3}$%. That this transition was not noted by Raman and Gove [2] can be explained by the fact that the weak transition intensities they investigated were very weak branches from well established levels, which were searched for specifically. The 1413-keV transition is the strongest branch from the 2110-keV level and no other clues exist as to the population of this level in this decay.

The result for the intensity of the 1413-keV transition allows us to calculate [6] a log$t$ value of $11.2 \pm 0.1$ for the EC decay of the 5^- ground state of $^{144}$Pm to the 2110-keV level. This provides further evidence in favor of the $4^+$ assignment for this level since, according
to the rules proposed by Raman and Gove [2], such a logft value is not consistent with a 2+ assignment.

Finally, using our value for the branching ratio of the 1397-keV transition, and the previously measured lifetime of the 2093-keV \((5^-_1)\) level [1], we can deduce an absolute transition probability of \(B(E3; 5^-_1 \rightarrow 2^+_1) = 26^{+15}_{-12}\) W.u. This value is still consistent with the \(B(E3; 3^-_1 \rightarrow 0^+_1)\) value of \(33.9 \pm 1.7\) W.u. [4] and thus still leaves the QOC interpretation of the \((5^-_1)\) level [1] as a possibility. The lower bound on this value is also still consistent with a quasiparticle component of up to 60% in the wave function of the \((-5^-_1)\) state. Any more detailed interpretation must await a further reduction in the uncertainty of the \(B(E3; 5^-_1 \rightarrow 2^+_1)\) value. However, the dominant contribution to this uncertainty now comes only from the lifetime of the \(5^-\) state itself \((1.2^{+1.1}_{-0.4}\) ps) and any significant reduction in this error will be useful.

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REFERENCES

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FIGURES

FIG. 1. Level scheme of $^{144}$Nd populated in the electron-capture decay of $^{144}$Pm, including weak transition intensities determined in the current work. Transition and level energies are given in keV.

FIG. 2. A portion of the gamma spectrum of the Pm source around 1400 keV, taken with no absorber between the source and Ge detector. The energies of prominent peaks, including those due to random and true coincidence summing, are given in keV.

FIG. 3. The same as Fig. 2 but with $\sim$3.8 cm of lead absorber between the source and detector.

FIG. 4. A portion of the Ge detector spectrum recorded in coincidence with the strong 697-keV ($2^+_1 \rightarrow 0^+_1$) transition. The peak energies are given in keV.
TABLES

TABLE I. Intensities of gamma rays observed in the present study of the electron-capture decay of $^{144}\text{Pm}$, compared with previously determined values.

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Current$^b$</th>
<th>Previous$^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>477</td>
<td>44 (2)</td>
<td>42.2 (2)</td>
</tr>
<tr>
<td>618</td>
<td>99 (3)</td>
<td>99.1 (10)</td>
</tr>
<tr>
<td>697$^d$</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>779</td>
<td>1.51 (3)</td>
<td>1.52 (5)</td>
</tr>
<tr>
<td>814</td>
<td>0.55 (1)</td>
<td>0.55 (3)</td>
</tr>
<tr>
<td>890</td>
<td>0.039 (1)</td>
<td>0.04 (1)</td>
</tr>
<tr>
<td>1397</td>
<td>0.00049 (7)</td>
<td>0.0006 (2)</td>
</tr>
<tr>
<td>1413</td>
<td>0.0043 (1)</td>
<td></td>
</tr>
<tr>
<td>1508</td>
<td>0.00020 (15)</td>
<td>&lt;0.0007</td>
</tr>
<tr>
<td>1511</td>
<td>0.00013 (2)</td>
<td>&lt;0.0005</td>
</tr>
</tbody>
</table>

$^a$Errors in the least significant digits are given in parentheses.

$^b$Quoted errors include statistical and systematic contributions.

$^c$Taken from Ref. [2].

$^d$Used for normalization.
\[ Q_{EC} = 2330 \text{ keV} \]