Measurement of $\alpha_K$, $\alpha_L$ and $\alpha_M$ of the hindered E3 transition in $^{103}$Rh

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The K, L and M internal conversion coefficients of the 39.76 keV $7/2^+ \rightarrow 1/2^+$ hindered transition in $^{103}$Rh are measured using the normalized peak to gamma method. A Mini-orange electron spectrometer and a HPGe detector system have been employed for the study. $\alpha_M$ is being reported for the first time. The present study confirms the systematics of large deviations of experimental ICC of highly hindered high multipole transitions from the theoretical values.

1 Introduction

A recent study has been made on the reliability of internal conversion coefficients (ICC) data from the calculations of three most commonly used tables. It has been pointed out that as a rule, the divergence in ICC values between the three calculations was mainly caused due to the distinctions in the physical assumptions made in these calculations. However, there still remain diversities reaching almost 30% among these tabulations, that could not be explained away by the physical assumptions made. The role of ICC and mixing ratios in assigning spin and parity to nuclear levels is well established. But the accuracy of the theoretical ICC itself depends upon the accuracy of the theoretical ICC.

Many studies have been performed to check the accuracy of internal conversion coefficients (ICC). These, for some transitions, (K, L, M and so on) agree with theory to within 1%. However, the ICC for the E3 and M4 transitions are observed to be consistently less than the theoretical values by 2 to 3%. Theoretical calculations have been performed for the conversion coefficients of some M4 transitions, by using relativistic Hartree-Fock-Slater wave functions, with Rosen-Lindgren exchange term, instead of the Kohn term, as used earlier. It has been found that such an attempt has narrowed down the gap between experiment and theory to about 0.8% for the transitions considered. But, experimental measurements on other high multipole transitions do not provide unambiguous conclusions on the discrepancies, primarily because of the large uncertainties associated with the measurements. One major cause for the large uncertainties associated with the experimental data, in most of the cases, is the determination of the ICC using the X-ray peak to Gamma (XPG) method or the intensity balance method. In the XPG method, the inherent uncertainty associated with the fluorescence yield is quite large. Also, when several transitions are involved, the X-ray intensities have to be corrected for contributions from other transitions. All these set a limit on the minimum uncertainty that can be achieved with this method. Data available on these high multipole transitions is also quite meager. In such a situation, it is not possible to ascertain whether the discrepancy between theory and experiment is real or due to inadequacies in the assumptions made in the theoretical calculations.

Therefore, in order to establish the general trend, more accurate experimental ICC data on high multipole transitions is needed. Nuclear in the mass region around $A \approx 100$ have shown remarkable transition characteristics, intermediate between spherical and deformed ($\gamma$-soft) shapes. As such, they have formed an important subject of study, notably with respect to IBM calculations for negative parity states and other one-proton pickup reactions. The present study involves the determination of the ICC for one such important case - the 39.76 keV E3 transition in $^{103}$Rh. It is well known that the anomalous $7/2^+$ state of $^{103}$Rh, which has been a subject of intense study, decays by an E3 transition of energy 39.76 keV to the $1/2^+$ ground state. However, available measurements of $\alpha_K$ for this transition, as seen in Table 1 are widely divergent with respect to each other, as well as the theoretical value, taken from Ref 2. No consistency is apparent in the values being lower or higher than the theoretical values. From such data, it can be difficult to form a conclusive idea about the general
accuracy of the theoretical values, or to look for any penetration effect that might be responsible for this deviation. It may also be noticed that no M-conversion coefficient measurement has been made, to date, for this transition.

Therefore, in the present study, we have taken up the measurement of the K- and L- conversion coefficients for the 39.76 keV transition. ICC for the M-conversion has also been measured and is being reported for the first time. We have employed the NPG method for the first time in our calculations of these ICC and have used a spectroscopy system that involves a Mini-orange spectrometer for the conversion electron spectrum. In the normalised peak to gamma (NPG) method the gamma and conversion electron intensities are normalised to that of the most intense line in the decay and the ICC determined relative to that of this transition. As such, the only major contributions to the error in the final measurement would be statistical in nature and also that associated with the normalising ICC. While the former can be minimised to a great extent by acquiring spectra for long time durations, the ICC for most of the intense lines has already been determined with very little error. Hence, the error associated with the final measurement is expected to be much lower than that associated with the measurements made earlier.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Method</th>
<th>( \alpha_k ) (expt.)</th>
<th>( \alpha_L ) (expt.)</th>
<th>( \alpha_M ) (expt.)</th>
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<tr>
<td>12</td>
<td>XPG</td>
<td>180(20)</td>
<td></td>
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<tr>
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<td>XPG</td>
<td>159(25)</td>
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<tr>
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<td>XPG</td>
<td>138(5)</td>
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<td>XPG</td>
<td>123(14)</td>
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<tr>
<td>16</td>
<td>XPG</td>
<td>137(19)</td>
<td>1010(67)</td>
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<td>127(6)</td>
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<tr>
<td>18</td>
<td>XPG</td>
<td>-</td>
<td>1159(90)</td>
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<td>Present work</td>
<td>NPG</td>
<td>153(5)</td>
<td>1185(59)</td>
<td>234(15)</td>
</tr>
</tbody>
</table>

### 2 Experimental Details

#### 2.1 Gamma intensity measurements

The radioactive liquid source of \(^{103}\)Rh was produced by \((\alpha,\gamma)\) reactions at the Bhabha Atomic Research Center, Mumbai. From this, the uncovered sources were prepared by drying the source solution on mylar foils. The count rate for these sources was kept at about 250 counts/sec.

The gamma detector employed is of EG & G ORTEC make (model GMX-10180-P), with a resolution of 665 eV (at 5.9 keV of \(^{55}\)Fe) and 190 keV (at 1.33 MeV of \(^{60}\)Co). The relative efficiency at 1.33 MeV of \(^{60}\)Co is about 12%. The efficiency calibration for the HPGe detector in the energy range 20-600 keV and for the Sn(Li) in the energy region of 4-90 keV was done using standard radioactive sources, viz. \(^{241}\)Am, \(^{133}\)Eu and \(^{133}\)Ba. The intensities of the standard rays used for calibration from the above mentioned sources has been taken from Ref. 19. On an average, we observe that the error in the efficiency of the HPGe was between 0.8% and 1%. For intense peaks, an error of less than 0.8% was achieved. Using the energy and efficiency of the standard lines as input, we then employ a cubic spline interpolation to arrive at the detector efficiency for the required energies. Since the number of standard lines was quite large in the considered energy region, we achieve a low 0.6% error in this interpolation. Spectra were acquired for time duration of 25000-150000 seconds, depending on the counting statistics, using a PC based 4K multichannel analyzer. This long period of acquisition ensured that the background contribution, especially for the low energy 39.76 keV gamma, remained at a bare minimum. The gamma peaks were analyzed using the computer code FIT.

Background contribution to the areas of low energy gamma rays is a common feature in most of gamma spectra acquired by Ge or HPGe detectors. Unless suitable care is taken to minimise and estimate their contribution, a magnified error can always result. Enhanced periods of acquisition could be one answer to the problem. Moreover, modern instrumentation methods in spectroscopy amplifiers give some scope to tackle this problem. By the selection of a suitable gain factor, we ensure that the low energy gamma did not fall in the region of maximum background. Analytically, for the background estimation and corrections to the area, the program FIT employs an algorithm developed by Sonneveld and Visser\(^{21}\). The points belonging to the background can be either determined through an automatic
selection procedure or be selected by the user. It was found that the automatic selection gave a better result in our experience. After this selection, a least-squares polynomial degree (≤8 and user selected to achieve the best fit factor) estimates the background and subtracts it from the peak. The gamma intensity of the 39.76 keV gamma, relative to the most intense 497 keV gamma of $^{103}$Rh was then determined. The partial gamma spectrum, showing the 39.76 keV and the 497 keV gamma peaks is shown in Fig 1(a).

**2.2 Conversion electron spectrum**

The mini-orange spectrometer used for the conversion electron measurements, schematically depicted in Fig 2, comprises of, (i) a windowless Si(Li) detector (surface area of 78 mm$^2$, sensitive depth of 5.3 mm, FWHM of 2.3 keV for the 624.5 keV conversion electrons from the $^{137}$Cs decay), (ii) a mini-orange filter composed of nine thin wedge-shaped permanent magnets fixed in a circular array in a brass frame of diameter 16.2 cm, with a central absorber made of lead that prevents the direct exposure of the detector to the gamma rays from the source. The entire non-magnetic stainless steel (304L) casing to hold the filter and the source is shown in Fig 3. A clean vacuum of about 10$^{-7}$ mbar was maintained throughout.

Separate thin uncovered sources of $^{103}$Ru were prepared by drying the source solution on aluminized mylar backing, supported on an aluminum ring of diameter 1.0 cm. The count rate was kept between 500 and 1000 counts/sec. The transmission curve was optimized for best transmission of conversion electrons for a source to magnets distance of 7.5 cm and magnets to detector distance of 4.5 cm. This transmission curve has been used to obtain the intensities of the conversion lines. The over-all uncertainty due to the efficiency calibration was
estimated to be around 3%, in the entire energy region of 10 to 500 keV. Many spectra were acquired for time periods ranging from 30,000 to 300,000 seconds. A typical conversion electron spectrum is shown in Fig. 1(b).

The conversion coefficients are determined relative to $\alpha_\alpha$ (497) = 0.0048(5), using a M1-E2 mixing ratio (6) value of 0.368(11), which is well supported by the IBFM predictions as well, thus confirming its multipolarity. The 497 keV line is also the most intense in $^{103}$Ru decay and hence, its intensities involve minimal errors. In our experiment, we estimate it to be about 0.3%.

3 Results and Discussion

As can be seen from the Table 1, $\alpha_K$, $\alpha_L$, and $\alpha_M$ values are more than those predicted. Thus, with minimal errors, present values show large deviations from all theoretical E3 conversion coefficients. Any admixture of M4 in the 39.76 keV transition would only worsen the discrepancies between the theoretical predictions and experimental values $\alpha_M$ determined for the first time also follows a similar trend. From Fig. 1(b), the K-conversion line is observed to be broader than the L- and M-conversion lines. The Rh $K_\alpha$ fluorescence probability is small, but a non-negligible quantity. This causes the photo-ionization of the L- subshells, resulting in the emission of photoelectrons of about 16.7 to 17.2 keV energies. A consequent correction in the K-conversion line intensity has been considered.

The 53 keV transition connecting the 9/2$^+$ level at 93 keV and the 7/2$^+$ level at 39.76 keV has been studied earlier. It has been established in this study that the observed E2 enhancement gave an indication of the presence of a strong collective component in the 7/2$^+$ state. The rather large B(E2) value obtained for the 53 keV 9/2$^+$ / 7/2$^+$ transition also confirms the collectivity of the 7/2$^+$ state. As such, a strong hindrance may be expected for the 39.76 keV transitions originating from this level. The transition probability for the 39.76 keV transition, using the present values of ICC, has been calculated to be around $1.308 \times 10^{-7}$ sec$^{-1}$ by applying the formula:

$$T(E3) = \frac{0.693}{T_{1/2} (1 + \alpha_\gamma)}$$

The single particle estimate is computed by using the relation (E given in MeV)

$$T(E3) = 34 \times (A)^2 E$$

It turns out to be $5.67 \times 10^{-5}$ sec$^{-1}$, thus obtaining a hindrance factor of 433. The anomalies in the ICC values can probably be explained by the large hindrance factor, which fits well into the systematics studied, where a correlation has been established with reference to large deviations of experimental ICCs of high multipole transitions observed with highly hindered transitions.

4 Conclusions

From our studies, we therefore conclude that the ICCs for the 39.76 keV transition involving the anomalous 7/2$^+$ level are in keeping with the large deviations of the experimental ICC from the theoretical values. Extensive studies of more such highly hindered transitions may help evolve a model that can help understand these large deviations from theoretical calculations. Such an understanding will go a long way in determining the
structures of nuclei, especially in transitional regions, which may in turn lead to a possible explanation for the peculiar properties of such nuclei.

References

4. Rosel F et al., At Data Nucl Data Tables, 21 (1978) 91.