# SUM-PEAK COINCIDENCE STUDIES OF Yb-175 AND Lu-177

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**ABSTRACT.** The attenuation factors are determined from the adder and zero bias sum-peak coincidence scintillation spectra, recorded in the $4\pi$ geometry arrangement. With knowledge of the experimentally determined photopeak efficiencies, the fractional intensities for crossover and cascade are obtained for 396 and 251 keV levels in the decay of Yb-175. In the case of Lu-177 the same are evaluated for the 208, 250 and 321 keV peaks obtained in the spectra. The obtained crossover and cascade relative intensity is corrected for internal conversion and admixture of other multipoles and compared with the values obtained from the Unified model. Reasonable agreement is observed in both the isotopes.

## INTRODUCTION

The 4.2d negatron emitting *Yb*-175 feeds levels in Lu-175 at energies 114, 251 and 396 keV (Mize *et al*, 1956, Klema, 1958) with three beta groups 468 (80%), 355 (5%) and 72 (15%) keV going to ground state and the excited levels 114 and 396 keV respectively (Hatch *et al*, 1956). Energy levels existing, in Hf-177 fed by beta decay of Lu-177, are at 113, 250 and 321 keV (El-Nesr and Bashandy, 1962) and the four beta groups of maximum energies 497, 384, 249 and 174 keV, feeding the ground and the three excited states, are with relative intensities 90%, 2.9%, 0.31% and 6.72% respectively. Both Lu-175 and Hf-177 nuclei being deformed odd $A$ nuclei, resemble each other in many respects and exhibit intrinsic states characteristic of the nuclear structure and rotational states above the intrinsic states. The intrinsic states are characterized by three asymptotic quantum numbers $[Nn_z\Lambda]$ from the strong coupling model (Mottelson and Nilsson, 1958), and in addition, for each rotational band another quantum number $K$, the projection of total angular momentum on the nuclear symmetry axis, and parity $\pi$ are constant. In the case of Lu-175 the ground state has been assigned the orbitals $I = 7/2$ (7/2+[404]) and the levels at energies 114 and 251 keV are the members of ground state rotational band with $K = 7/2$ and spins $(9/2)^+$ and $(11/2)^+$ respectively. The level at 396 keV is interpreted as a single particle excitation with orbital (9/2−[514]) which is considered as the second excited intrinsic state, the first excited intrinsic state being at 343 keV, observed in the decay of Hf-175. The large admixture of M2 with E1 transition (20%) in the case of 396 keV and 2-4% in that of the 282 keV gamma ray corresponds to the fact that the E1 radiation

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would be forbidden by the asymptotic quantum number selection rules while the M2 radiation is allowed according to those selection rules. The 396 keV level decays by three strongly hindered E1 transitions to the members of ground state rotational band. The decay scheme is shown in figure 1. Similarly, the ground state of Hf-177 is (7/2−[514]) with $I = 7/2$ and the rotational levels with this configura-

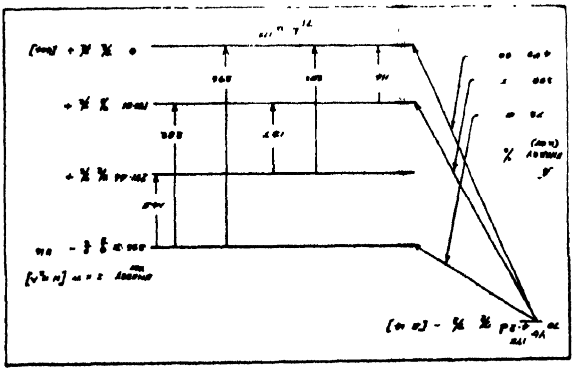

Figure 1. Decay scheme of Yb-175.

tion are at 113 keV ($I = 9/2$) and 250 keV ($I = 11/2$). An intrinsic excitation has been observed at 321 keV with configuration (9/2+[624]) with a spin value 9/2. The 321 keV level decays by three strongly hindered E1 transitions to the ground state rotational band, with a 0.1% admixture of M2 radiation, consistent with the the selection rules of asymptotic quantum numbers. The 113 keV transition is mostly E2 with 3% admixture of M1, 208 keV is mostly E1 with no more than 2% admixture of M2 and the crossover 250 keV transition is E2 with a small admixture of M1. The fractional intensities of crossover and cascade from an excited level in simple decay schemes can be obtained by Kantele's (1962) $4\pi$ sum-peak coincidence method and a comparison of the transition probabilities thus obtained and from the Unified model for Lu-175 and Hf-177 is a sensitive test for for the validity of the strong coupling model for these nuclei. Hence investigations are undertaken on these isotopes with the above said technique.

## EXPERIMENTAL-DETAILS

The experimental set up consists of two well matched scintillation spectrometers each with 4.45 cm in diameter and 5.08 cm in height NaI(Tl) crystal coupled to DuMont 6292 photomultiplier. The outputs of the two scintillation heads are electronically added in a linear adding circuit (Dumuynck and Segaert, 1962). The differential out-put of the adder circuit and the integral outputs of the individual channels are connected in triple coincidence. The experimental arrangement and other details of the sum coincidence spectrometer (Hoogenboom, 1958) are given elsewhere (Radhakrishna Murty and Swami Janananda, 1967). The fast coincidence cricuit is completely removed in the present mode of operation and the removal of lead shields and placing face to face the two photomultipler combinations with the readioactive isotope sandwiched in between the two scintillating crystals enables to form the $4\pi$ geometry sum-peak coincidence arrangement. However, the de Waard (1955) stablizer in each channel followed by sine modulated single channel analyzer in the feed back circuit to the photomultiplier dynode resistor chain is retained. The difference between the sum coincidence spectrometer and this arrangement lies in that the former arrangement records the single channel spectrum satisfying the coincidence condition enforced by the adder channel, while the latter records the adder spectrum satisfying the coincidence condition enforced by the individual channels. The 10-channel analyzer is not used for the present work and the sum and $4\pi$ zero bias sum-peak coincidence spectra are simultaneously recorded by positioning the single channel analyzer in the adder channel.

The experimental method for the method of branching ratios is based on the qualitative comparison of spectra taken with sum and $4\pi$ geometry sum-peak mode. The measured attenuation factors $f_m$'s for zero bias ($B = 0$) are qualitatively compared with $f_\gamma$'s for corresponding energies and with general ranges of $f_{\gamma\gamma}$ and $f_{\gamma\gamma\gamma}$. This comparison reveals immediately all peaks due to singles (not summed) gammas and gives at least a qualitative information on types of sum peaks and on magnitudes of mixtures of cascades and crossovers involved. For the decay mode of an excited state by a ground state transition $\gamma_3$ and a two gamma cascade $\gamma_1$ and $\gamma_2$, the observed attenuation factor $f_m$ for this sum line varies between $f_{\gamma 3}$, that of a single transition and that of $f_{\gamma_1\gamma_2} = \frac{1}{2}(1+f_{\gamma 1}+f_{\gamma 2})$ for pure cascade. The fractional intensity for crossover transition is given by $(X)$

$$X = \left(1+\frac{\epsilon_{p3}}{\epsilon_{p1}\epsilon_{p2}}\,\frac{f_m-f_{\gamma 3}}{f_{\gamma_1\gamma_2}-f_m}\right)^{-1}$$

where $\epsilon_{p1}$, $\epsilon_{p2}$, $\epsilon_{p3}$ are the respective photopeak efficiencies. The cascade intensity is $1-X$ and the branching ratio can be obtained in simple cases of one cascade and crossover and for complex decay schemes the procedure is somewhat different and has not been attempted here.

The attenuation factors for simple gamma transitions are determined for the present set-up in an energy range of 80-1330 keV employing Tl-170, Ce-141, Au-198, Cs-137, Co-60, Sc-46 and Cs-134 sources. Further, the photopeak efficiencies are calculated from the given calculated intrinsic efficiency curves for zero distance (Wollicki *et al*, 1956) and the experimentally determined peak-to-total ratios in the energy range 80-1330 keV using Tm-170, Ce-141, Au-198, Cs-137, Rb-86 and Co-60 sources.

The theoretical values for the ratio of transition probabilities for gamma transitions of the same multipolarity $L$ between an initial state $J_iK_i$ and two final states $J_f$, $K_f$ and $J_f'$, $K_f$ with energy $E_\gamma$ and $E_\gamma'$ of the same rotational band are obtained from the strong coupling model formula

$$\frac{T(L, J_i \rightarrow J_f)}{T(L, J_i \rightarrow J_f')} = \frac{J_i L K_i K_f - K_i | J_i L J_f}{J_i L K_i K_f - K_i | J_i L J_f' K_f} \left( \frac{E_\gamma}{E_\gamma'} \right)^{2L+1}$$

It is convenient to multiply the Clebsch-Gordan coefficients by the energy terms as it affords a direct comparison of intensities. As the crossover cascade intensity is measured by a coincidence method and the large conversion of one of the gamma rays of the cascade decreases the sum-peak area, the intensities thus determined are to be corrected for internal conversion. The experimentally obtained realtive intensity of cascade and crossover is to be divided by the factor $(1+\alpha)$ of these transitions.

## RESULTS

Radioactive Yb-175 source is obtained as Ytterbium chloride in dilute hydrochloric acid solution. A small quantity of the liquid is taken in a perspex cylindrical tube and the singles spectrum obtained at source to crystal distance of 10 cm from one of the spectrometers with lead shield is shown in figure 2, which shows prominent peaks at 55, (K-X-rays), 114, 185, 282, and 396 keV. The peak at-

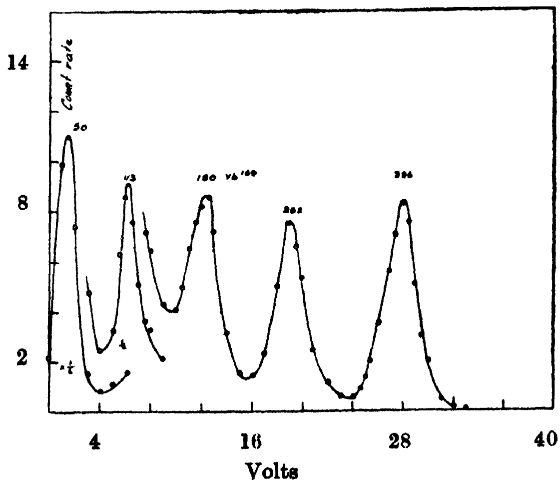


Figure 2. Singles spectrum of Yb-175.

185 keV is due to the presence of Yb-169 impurity in the source. The sum coincidence spectrum recorded at an adder gate of 396 keV showed a prominent sum peak at energy 396 keV and the peaks for cascades at energies 282-114 keV and 251-145 keV in agreement with the well established decay scheme. As a next step the weaker source is sandwiched in between the detectors and the resultant adder and $4\pi$ zero bias sum-peak coincidence spectra are shown in figures 3 and 4 respec-

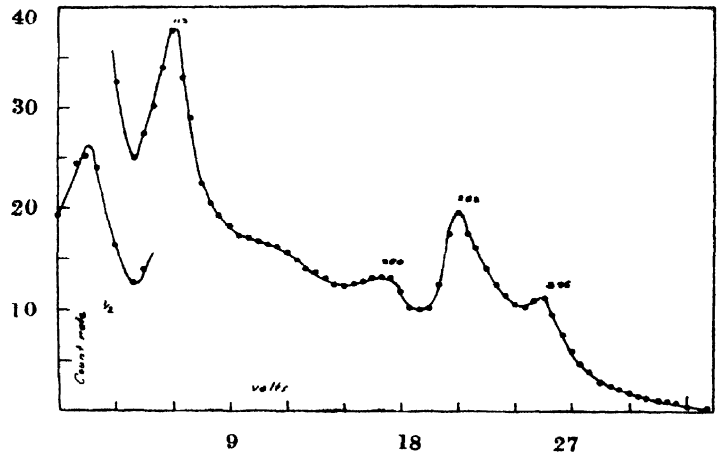


Figure 3. Adder spectrum of Yb-175.

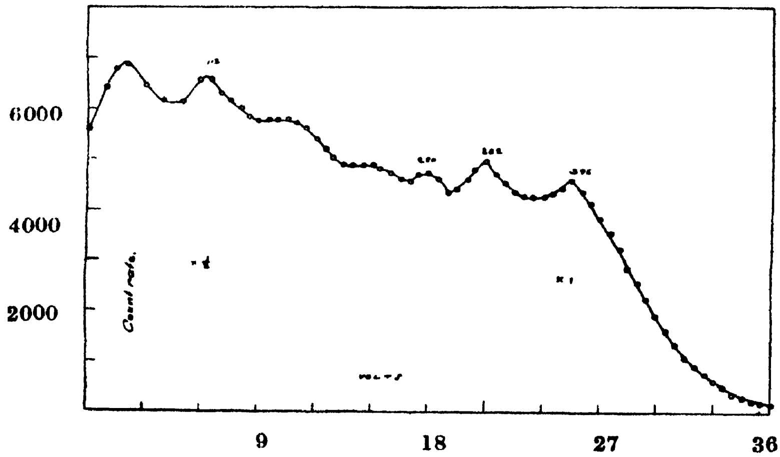


Figure 4. 4π geometry zero bias sum-peak coincidence spectrum of Yb-175.

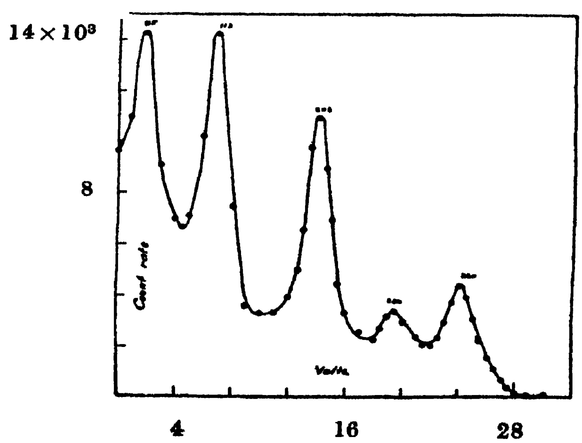


Figure 5. Adder spectrum of Lu-177.

tively. The former shows a slight indication for the peak at 251 keV. Lu-177 is in the form of Lutecium chloride in dilute hydrochloric acid. The singles spec-

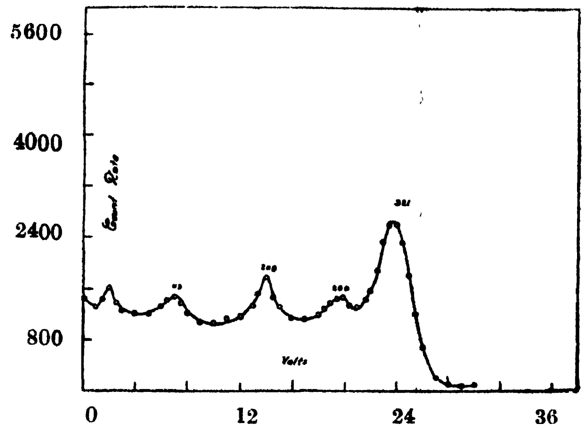


Figure 6. $4\pi$ Geometry zero bias sum-peak coincidence spectrum of Lu-177.

trum has prominent peaks at 55, 113, 208 and 321 keV. The recorded adder and zero bias $4\pi$ sum-peak coincidence spectra with the weak source in between the crystals are shown in figures. 5 and 6 respectvely.

Accurate determinations of the areas for all the peaks above the continuous pulse height distribution, occurring in the zero bias sum-peak coincidence spectra are determined with the help of a planimeter. The attenuation factors ($f_m$'s), determined in comparison with those of the adder spectra by drawing each of the peaks on a larger scale, are furnished in table 1, along with the interpolated

Table 1

Values of Attenuation factors in the decay of Yb-175 and Lu-177

| S.No. | Energy in keV | Measured attenuation factor ($f_m$) | Interpolated attenuation facttor ($f_\gamma$) |
|---|---|---|---|
| *Yb*—175. | | | |
| 1. | 114 | 0.022 | 0.02 |
| 2. | 250 | 0.0929 | 0.035 |
| 3. | 282 | 0.045 | 0.046 |
| 4. | 396 | 0.1144 | 0.06 |
| *Lu*—177. | | | |
| 1. | 113 | 0.021 | 0.02 |
| 2. | 208 | 0.03 | 0.025 |
| 3. | 250 | 0.0668 | 0.036 |
| 4. | 321 | 0.515 | 0.045 |

values of the attenuation factors ($f_\gamma$'s) for single gamma transitions of Yb-175 and Lu-177.

From table 1 it can be seen that the values of attenuation factors $f_m$ and $f_\gamma$ agree well for energies 114, 282 in Yb-175 and for 113 keV transition in Lu-177, indicating that alternative modes of decay do not exist in these cases, in confirmity with the decay schemes. The values of attenuation factors for 251 and 396 keV in Yb-175 and 208, 250 and 321 keV in Lu-177 however, are slightly different from $f_\gamma$ values for single gamma transitions. The crossover and cascade fractional intensities are calculated in each case assuming a crossover and one cascade. The estimates are expected to be accurate within 10% in general, an error of about 5% being in $f_m$ and another 5% error arising from the errors and uncertainities of the photopeak efficiencies. However, additional error may be associated with the value of 396 keV level in Yb-175 and 321 keV level in Lu-177 because of neglecting the other cascades of decay 145-251 keV and 71-250 keV respectively.

## DISCUSSION

*Decay of Yb-175*

*396 keV level* : The crossover cascade relative intensity obtained for this transition is 5.5. Since the 145-251 keV cascade is very weak, only 282-114 keV is taken into account. The relative intensity value becomes 1.7 when divided by $(1+\alpha_{tot})$ of the 114 keV transition where $\alpha_{tot} = 2.22$, taken from work of Hatch *et al (1956). From the same reference the* 396 keV transition is 0.8 E1 and 282 keV transition is 0.98 E1, the ratio of the transition probabilities becomes

$$\frac{T(E1)_{396}}{T(E1)_{282}} \quad \frac{1.7\left(1+\frac{0.02}{0.98}\right)}{\left(1+\frac{0.2}{0.8}\right)} = 1.388$$

The theoretical value is obtained as 12.24 based on Unified model which differs with the experimental value only by a factor of 8. As the intensity and multipolarity are sufficiently accurate this can only be due to $E1$ hindrance effects. The same value obtained from single particle estimates is 2.756. The present value of the ratio of fractional intensities is lower which may be due to the admixture of M1 present whereas the fractional intensities estimated on the single particle model are based on pure electric dipole transitions. The ratio of transition probabilities from the experimental fractional intensity for M2 admixture is

$$\frac{T(M2)_{396}}{T(M2)_{282}} = 1.7 \times \frac{0.2}{0.02} = 17$$

The theoretical value from Unified model is 7.75 which differs by a factor of 2.2 only. In this case also M2 is allowed and E1 is forbidden by the asymptotic selection rules. The single particle estimates yield a value of 5.409.

251 *keV level* : The cascade contributing to this sum peak is 114-137 keV and the ratio of fractional intensities of the crossover and cascade is calculated as 4. Dividing this by $(1+\alpha_{tot})$ of the 137 keV transition yields a value of 1.8. From Coulomb excitation work of Martin *et al* (1959) the 250 keV transition is $E_2$ and the 137 keV transition is 0.3 E2. The ratio of the E2 transition probabilities becomes

$$\frac{T(E2)_{250}}{T(E2)_{137}} = 1.8\left(1+\frac{1}{\delta_{137}{}^2}\right) = \frac{1.8}{0.3} = 6.$$

where $\delta^2 = E2/M1$. The value based on Unified nuclear model being 4.378, agrees excellently well with the experimental value. The value calculated on single particle model is 10.19 and is greater than the experimental value.

*Decay of Lu*-177

321 *keV Transition* : As in the case of Lu-175 the large conversion of 113 keV transition must be taken into account. Taking $\alpha = 2.18$ from the work of West *et al* (1961), and dividing the crossover cascade fractional intensity ratio (0.064) becomes 0.01988. This gives the gamma intensity of 321 keV transition relative to that of 208 keV transition. From the same reference 321 keV transition is $0.85E1$ and the 208 keV transition is 0.996 E1. Now the ratio of the two E1 transition probabilities becomes

$$\frac{T(E1)_{321}}{T(E1)_{208}} \quad \frac{0.01988\left(1+\frac{1}{\delta_{208}{}^2}\right)}{\left(1+\frac{1}{\delta_{321}{}^2}\right)} \quad 0.01697$$

The value obtained from the Unified model for these transitions, employing the formula given earlier is 16.3, This differs with the experimental value by a factor of 1000. It is not surprising because of the strongly hindered 321 E1 transition. The intensity ratio for the M2 transition is

$$\frac{T(M2)_{321}}{T(M2)_{208}} = \frac{0.01988(1+\delta_{208}{}^2)}{(1+\delta_{321}{}^2)} = 0.7461$$

The theoretical value for this case is 12.5. This value differs by a factor of 16.75. This when compared to the above E1 factor shows that M2 is allowed and E1 is forbidden by the asymptotic selection rules. In general, the M2 ratios agree excellently. In this case the M2 admixture in the 208 keV transition is too small to be measured accurately. It may here be mentioned that the ratio of transition probabilities in a single particle model is given by $(E_\gamma/E_\gamma')^{2L+1}$ and hence do not allow a reasonable comparison.

*208 keV transition* : The cascade contributing to this peak is 72-136 keV. The ratio of the fractional intensities of crossover and cascade, which is the relative intensity is obtained as 103. Dividing this by $(1+\alpha_{tot})$ the correction for conversion of the 136 keV transition, the ratio is 75. The conversion coefficient of 136 keV transition is taken as 1.38 (West *et al*, 1961). Assuming both 208 and 72 keV transitions to be purely E1, the ratio is

$$\frac{T(E1)_{208}}{T(E1)_{72}} = 75.$$

the theoretical value is obtained as 250 which differs only by a factor of 3.3. Good agreement than this can be expected in this case. However, the too small intensity will not allow to determine the intensities and multipolarities accuratily.

*250 keV transition* : The branching ratios from this level where throughly worked out in many coulomb excitation studies. The transitions from this evel occur in the same band with $K = 7/2$. The cascade contributing to the 250 keV sum-peak is 137-113 keV only. The The branching ratio is obtained as 14 from the determined fractional intensities. This when corrected for the interna conversion coefficient of 113 keV transition becomes 3.4. The 136 keV transition is 0.03 M1 and the 250 keV transition 0.985 E2. The ratio of the E2 transition probabilities experimentally is

$$\frac{T(E2)_{250}}{T(E2)_{136}} \quad \frac{4.4\left(1+\frac{1}{\delta_{136}^{2}}\right)}{\left(1+\frac{1}{\delta_{250}^{2}}\right)} = 4.468$$

and that from Unified model is obtained as 4.35. This good agreement is due to the pure rotational behaviour of the levels. The ratio of the M1 transition probability for the present intensity ratio is

$$\frac{T(M1)_{250}}{T(M1)_{137}} = 4.4\times\frac{0.015}{0.03} = 2.2$$

whereas the Unified model formula gives a value of 0.

Thus from the comparison of branching ratios with theoretical values, it can be stated that the agreement for both Lu-175 and Hf-177 nuclear levels is reasonably good and hence lends support to Unified model interpretation of these levels.

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