Precise Measurement of α_K and α_T for the 39.8-keV E3 Transition in ^{103}Rh to Test Internal Conversion Theory

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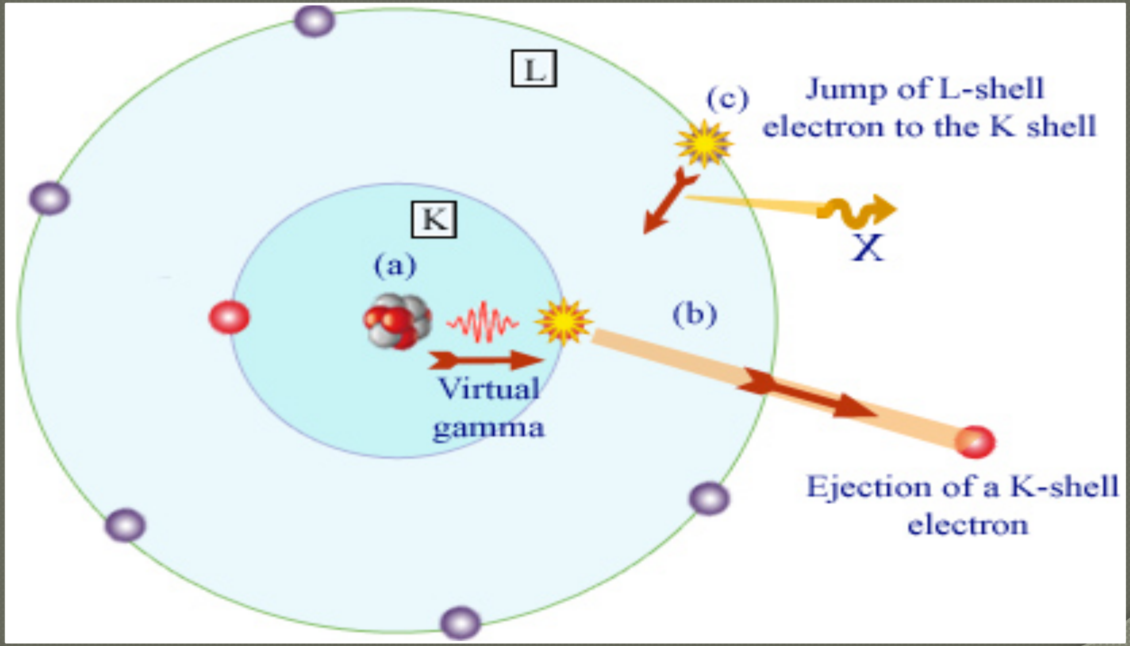
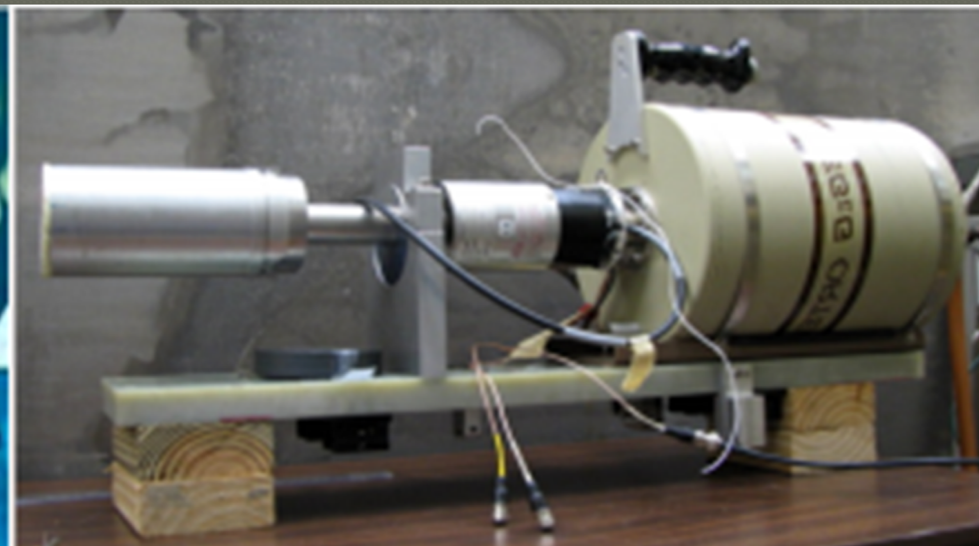
Internal Conversion Theory

- A nuclear decay process due to the electromagnetic interaction wherein an excited nucleus decays by ejecting an electron from the atom.



Experimental Setup



- Sample of Ruthenium metal was deposited onto a Cu backing.
- Sample was activated at the TAMU TRIGA Reactor. (left)
- High Purity Germanium (HPGe) detector has been calibrated for efficiency to a precision of about ± 0.15% relative uncertainty. (right)

Internal Conversion Coefficient (ICC)

- The ratio of the emitted electrons to γ-rays for an electromagnetic transition during the decay of a nucleus.
- $\alpha_T = \alpha_K + \alpha_L + \alpha_M + \ldots$
- Due to the difficulty of measuring electrons, we measured the number of x-rays that are emitted instead.
- $\omega_k =$ K-shell fluorescence yield, or the probability of emitting K x-rays after K-shell ionization.

Basic Formulas

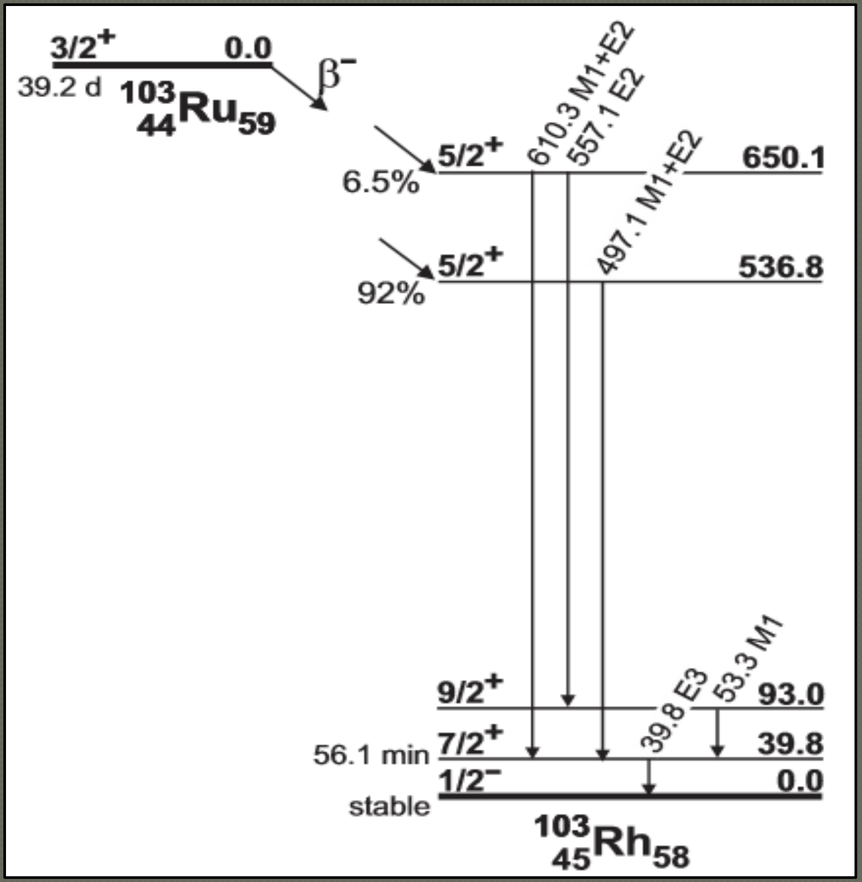
- $\alpha_K \equiv \frac{I_{ek}}{I_\gamma}$
- $\alpha_K = \frac{1}{\omega_k} \times \frac{I_{kx}}{I_\gamma}$
- $\frac{A_\gamma}{\varepsilon_\gamma} = I_\gamma$ – Intensity of the gamma–ray
- $\omega_k \times I_{ek} = I_{kx}$ - Intensity of the K x-ray
- ε_γ - Photopeak detector efficiency

Experimental formula used to determine α_K :

$$\alpha_K = \frac{1}{\omega_k} \times \frac{A_{kx}}{\varepsilon_{kx}} \times \frac{\varepsilon_\gamma}{A_\gamma}$$

Basic Formulas cont'd

$$\alpha_{T39.8\gamma} = [\frac{A_{53.1\gamma}}{\varepsilon_{53.1\gamma}}(1+\alpha_{T53.1\gamma}) + \frac{A_{497.3\gamma}}{\varepsilon_{497.3\gamma}}(1+\alpha_{T497.3\gamma}) + \frac{A_{610.6\gamma}}{\varepsilon_{610.6\gamma}}(1+\alpha_{T610.6\gamma})] \times \frac{\varepsilon_{39.8\gamma}}{A_{39.8\gamma}} - 1$$



Motivation

- Measure ICCs to a high precision and investigate the accuracy of the theoretical calculations that either include or exclude the atomic vacancy.
- Previous measurements with heavier nuclei demonstrated that the atomic vacancy must be taken into account.
- Gain a better understanding of α_K values used in science and their applications to balance intensities in decay-schemes, assign multipolarities, spins, etc.

Method 1: MAESTRO-32

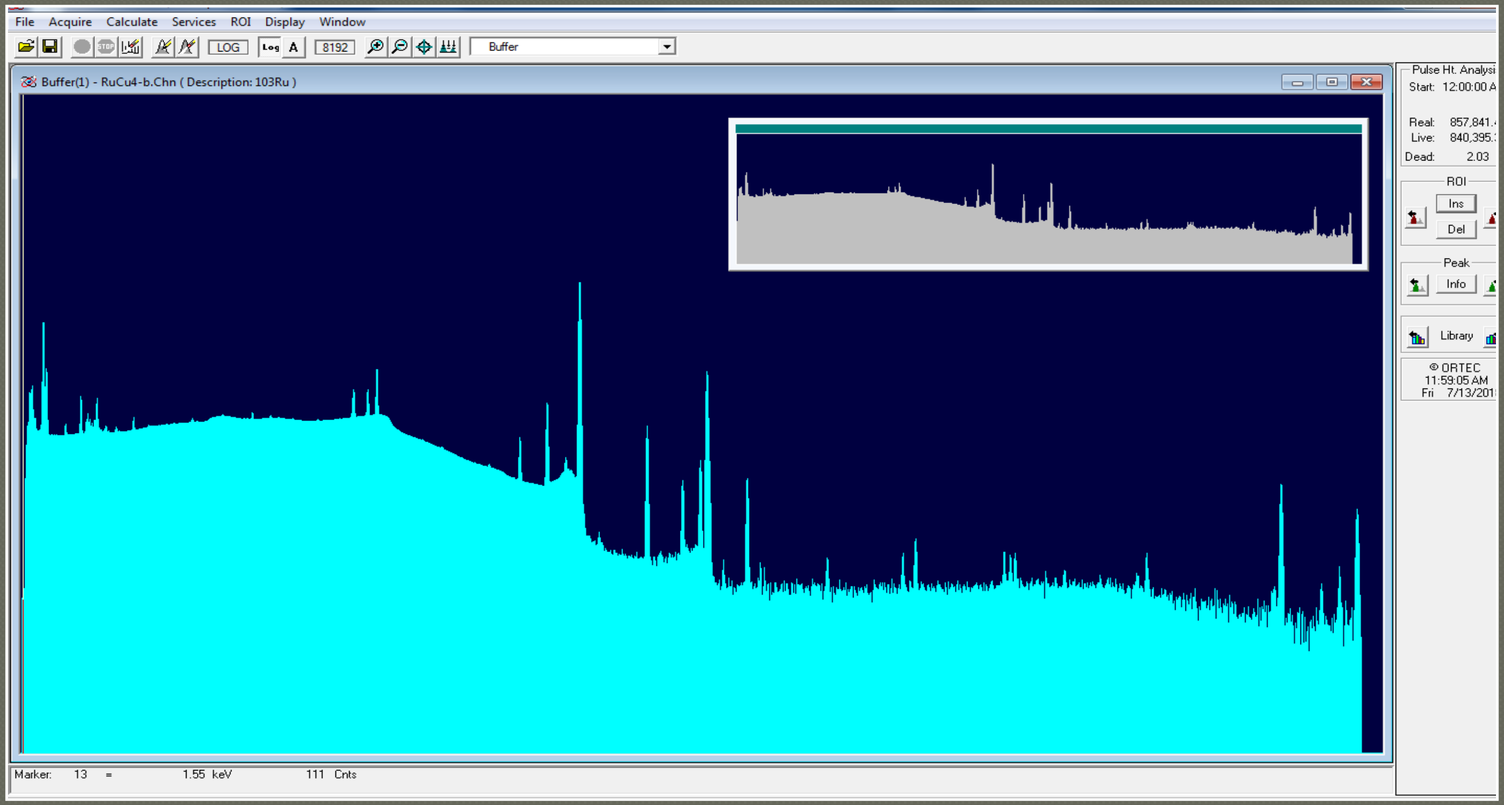
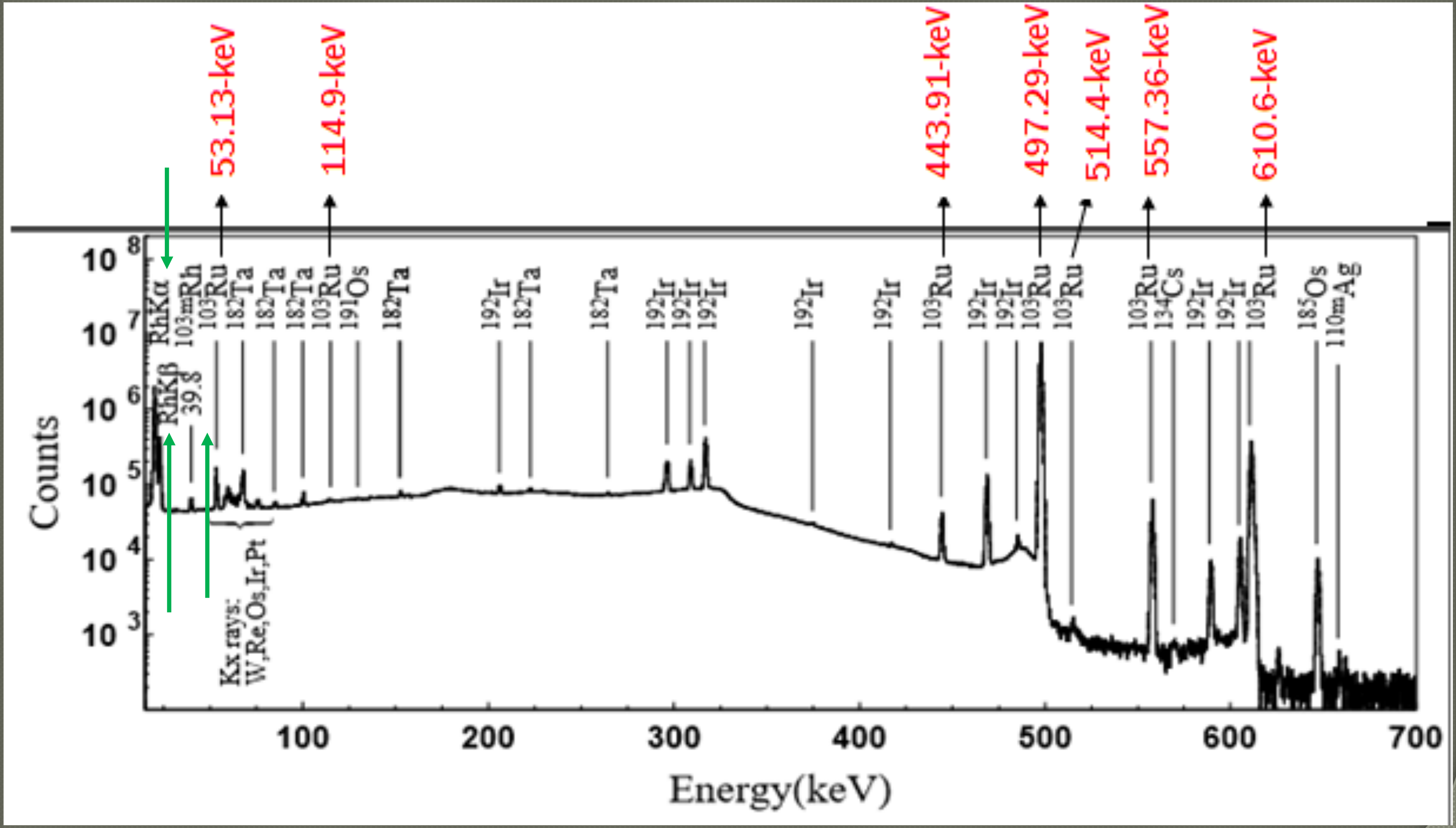


Figure 1: Energy spectrum of RuCu4 using an HPGe detector

Impurity Analysis



Impurity Analysis cont'd

Isotope	$T_{1/2}$
^{103}Ru	39.2 d
^{97}Ru	2.83 d
^{97m}Tc	91.0 d
^{96}TC	4.28 d
^{60}Co	1925.28 d
^{65}Zn	243.93 d
^{110m}Ag	249.76 d
^{134}Cs	2.07 y
^{182}Ta	114.74 d
^{185}Os	93.6 d
^{191}Os	15.4 d
^{192}Ir	73.8 d

Nuclear Data Search Database

Gammas from ^{103}Ru (39.26 d 2)

Eγ (keV)	Iγ (%)	Decay mode
497.080 *7*	90.9 *10*	β^-
610.33 *20*	5.75 *5*	β^-
443.799 *19*	3.27 *9*	β^-
557.039 *20*	0.8672 *9*	β^-
53.285 *7*	0.443 *10*	β^-
294.978 *20*	0.303 *5*	β^-
612.02 *3*	0.107 *3*	β^-
39.757 *6*	0.089 *8*	β^-
317.77 *22*	0.019 *9*	β^-
241.88 *4*	0.0180 *13*	β^-
514.46 *19*	0.0114 *15*	β^-
357.47 *5*	0.0094 *6*	β^-
114.970 *20*	0.0074 *5*	β^-
651.8 *4*	0.0069 *23*	β^-
292.70 *20*	0.0057 *3*	β^-
42.63 *4*	0.0052 *6*	β^-
113.25 *7*	0.0035 *7*	β^-
567.87 *13*	0.00282 *9*	β^-
317.72 *5*	0.00006	β^-
62.41 *3*	0(calc)	β^-

X-rays from ^{103}Ru (39.26 d 2)

E (keV)	I (%)	Assignment
2,377	0.106 *21*	Rh L_l
2,519	0.063 *11*	Rh L_η
2,692	0.28 *5*	Rh $L_{\alpha2}$
2,697	2.5 *5*	Rh $L_{\alpha1}$
2,834	1.6 *3*	Rh $L_{\beta1}$
2,891	0.0084 *22*	Rh $L_{\beta4}$
2,916	0.013 *3*	Rh $L_{\beta3}$
2,923	0.017 *3*	Rh $L_{\beta6}$
3,001	0.26 *5*	Rh $L_{\beta2}$
3,144	0.15 *3*	Rh $L_{\gamma1}$
3,364	0.0015 *4*	Rh $L_{\gamma2}$
3,364	0.0026 *7*	Rh $L_{\gamma3}$
19,808	9.99E-05 *9*	Rh $K_{\alpha3}$
20,074	3.1 *3*	Rh $K_{\alpha2}$
20,216	5.9 *5*	Rh $K_{\alpha1}$
22,699	0.49 *4*	Rh $K_{\beta3}$
22,724	0.94 *8*	Rh $K_{\beta1}$
22,911	0.0059 *6*	Rh $K_{\beta5}$
23,172	0.226 *20*	Rh $K_{\beta2}$
23,217	0.043 *4*	Rh $K_{\beta4}$

Nuclear Data Search Database cont'd

WWW Table of Radioactive Isotopes

Radiation search

Energy: 316.5 ± 0.3 keV Search

Type: ○ Alpha ◉ Gamma

Parent:

T1/2: 12 d - s

Mass number: -

Z: or Element:

N:

Sort by: ◉ Energy, Intensity ○ A, Z Reset form

Main page | Nuclide search

WWW Table of Radioactive Isotopes

Gamma energy search

Eg between 316.2 and 316.8 keV; $T_{1/2}$(parent) ≥ 12 d;

Eg (keV)	Ig (%)	Decay mode	Half life	Parent
316.200 *20*	0.00248 *10*	b^-	44.6 d *3*	^{115m}Cd
316.3 *1*	0.0021 *13*	$e+b^+$	13.537 y *6*	^{152}Eu
316.440 *6*	0.0000132 *4*	a	24110 y *30*	^{239}Pu
316.50791 *13*	82.81 *21*	b^-	73.831 d *8*	^{192}Ir
316.8 *2*	<5.00E-08	a	432.2 y *7*	^{241}Am
316.8 *2*	0.16 *3*	$e+b^+$	17.4 d *5*	^{230}Pa

Main page | Radiation search | Nuclide search

Gammas from ^{192}Ir (73.831 d *8*)

Eg (keV)	Ig (%)	Decay mode
316.50791 *13*	82.81 *21*	b^-
468.07152 *24*	47.83 *17*	b^-
308.45692 *13*	30.00 *8*	b^-
295.95827 *12*	28.67 *9*	b^-
604.41464 *21*	8.23 *6*	b^-
612.46564 *20*	5.309 *17*	b^-
588.5845 *7*	4.515 *14*	b^-
205.79549 *6*	3.300 *17*	$e+b^+$
484.5780 *4*	3.184 *11*	$e+b^+$
374.4852 *8*	0.721 *5*	$e+b^+$
416.4714 *8*	0.664 *7*	b^-
201.3112 *7*	0.472 *6*	$e+b^+$
489.039 *13*	0.443 *4*	$e+b^+$
884.5418 *8*	0.2923 *25*	b^-
283.2668 *8*	0.262 *4*	$e+b^+$
136.34348 *25*	0.183 *8*	b^-
314.8 *3*	<0.07	b^-
314.8 *3*	<0.07	$e+b^+$
420.532 *10*	0.0737 *25*	$e+b^+$
1061.48 *4*	0.0528 *8*	b^-
593.37 *5*	0.0426 *15*	b^-
280.04 *5*	0.023 *11*	b^-
329.312 *9*	0.0185 *11*	$e+b^+$
110.093 *19*	0.0126 *9*	$e+b^+$
415.4 *5*	<0.009	b^-
415.4 *5*	<0.009	$e+b^+$
703.98 *12*	0.0053 *9*	$e+b^+$
176.98 *4*	0.0043 *12*	b^-
599.35 *10*	0.0039 *17*	b^-
214.7 *5*	<0.0026	b^-

Method 2: gf3

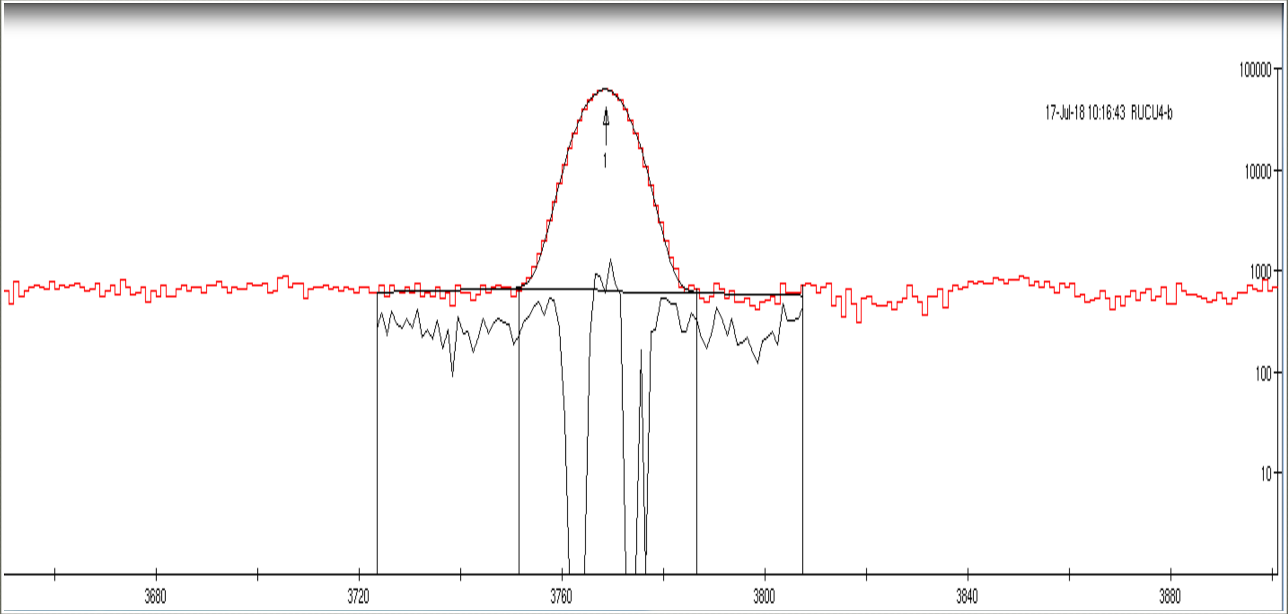


Figure 2: Identifying the area of the 557.1 γ-ray in the energy spectra of RuCu4

Results

Value for 39.8-keV

	α_K	α_T
Experimental:	142.7 (26)	1452 (25)
Theoretical:		
Vacancy	135.3 (1)	1404 (1)
No vacancy	127.5 (1)	1388 (2)

Outlook

- In comparison to the theoretical calculations, our preliminary result, although not in exact agreement with either theoretical calculation, is much closer to the hole “frozen orbital” limit but is in greater disagreement with the “no hole” limit in accordance with the previous results. It is probable that the slight discrepancy is caused by small amount of M4 mixing in the E3 transition.

Acknowledgments

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References

J.C. Hardy, *et al,* Appl.Radiat.Isot. 134, 406 (2018), Precise test of internal-conversion theory: α_k measurements for transitions in nine nuclei spanning 45 ≤ Z ≤ 78

N.Nica, *et al,* Phys.Rev. C 95, 064301 (2017), Precise measurement of α_k and α_T for the 109.3-keV M4 transition in ^{125}Te :Test of internal-conversion theory.

Questions?