Precise Measurements of $\alpha_k$ for the 346.5 keV M4 Transition in $^{197}$Pt

By James Nolan
w/ J.C. Hardy and N. Nica
TAMU Cyclotron REU Program
1 August, 2008
Internal Conversion

- Nuclear de-excitation
  - Energy transferred to electron.
- Electron emission from atomic orbital.
- Typically observed in inner shell electrons (K, L, and M).
- Higher-shell electron moves down to fill atomic vacancy; characteristic x-ray emission results.
- Competes with gamma-ray emission.
Internal Conversion Coefficient (ICC)

\[ \alpha = \frac{\text{number of de-excitations via electron emission}}{\text{number of de-excitations via gamma-ray emission}} \]

- The ICC is the ratio of the total number of decays for a particular transition that proceed by internal conversion to those that proceed by gamma emission.
- ICC measurements are important in the study of nuclear decay schemes: branching ratios, spin and parity assignments, and transition rates.
- Precise ICC measurements are useful for detector efficiency calibration.
Theoretical ICC Calculations

Methods:
- Hager and Seltzer
- Rosel et al.
- Band and Trzhaskovskaya

Primary difference:
- Hole ("Frozen Orbital")
- No hole
A 2002 survey by Raman, et al. called into question the precision of existing ICC measurements; it also highlighted the discrepancies between existing theories.

Survey of 100 cases by Raman et al. (PRC 66, 044312 (2002))

- Number of cases
- Precision (%)
- 1 2 3 4 5 >

Difference (exp-theory) as %

- No hole (Band et al. )
- Hole (frozen orbital)

- 197Pt
- 103Rh
- 134Cs
- 137Ba

E2 E3 M4
Precision Experiments

- Precise ICCs measured for:
  - $^{193}\text{Ir}$
  - $^{134}\text{Cs}$
  - $^{137}\text{Ba}$

- These ICC measurements all suggested the “frozen orbital” (hole) approximation was a better theory.
HPGe Detector

- High Purity Germanium crystal detector
- Detects x-rays and gamma-rays
- +/- 0.15% relative efficiency uncertainty
- +/- 0.20% absolute efficiency uncertainty
346.5 keV M4 Transition in $^{197}$Pt$^m$

A 1987 paper by I.N. Vishnevsky, et al. gave the ICC of the 346.5 keV M4 Transition in $^{197}$Pt$^m$ as: 

$$\alpha = 4.02 \pm 0.08$$

The measurement’s disagreement with both theories makes this transition a good test case.
**$^{197}\text{Pt}_m$ Experiment**

- $^{196}\text{Pt}$ (97.43% pure) on Mylar backing; source covered by thin Mylar
- $^{196}\text{Pt}\rightarrow^{197}\text{Pt}_m$ by thermal neutron activation
- $^{196}\text{Pt}\rightarrow^{197}\text{Pt}_{gs}$ also occurs
- S1: Longer activation time resulted in more impurities
- S2: Shorter activation time resulted in less impurities
- X-ray and gamma-ray emissions from both sources recorded by HPGe detector.
**Impurities**

- $^{197}$Pt$^m$ IT decays to $^{197}$Pt$^g$, which beta decays to $^{197}$Au.
- In addition, the original samples of $^{196}$Pt contained traces of $^{190}$Pt, $^{192}$Pt, $^{194}$Pt, $^{195}$Pt, and $^{198}$Pt.
- The presence of these nuclides and others creates a number of small impurities which must be considered in a high precision measurement.
Radware: GF3

- Powerful, commonly used program
- Used to fit Gaussian curves to peaks on spectra
- Customized JCH version allows integration of peaks with tails and background subtraction
- Parameters adjusted manually to enhance precision of fit
Spectrum file or ID = 762_1b
Sp. 32_1b.sp 0138 chs read.
Yes
Do you want an energy calibration? (Y/N) Y
The energy calibration [in keV] is E = A + B*X + C*X^2 etc. (X = channel no.)
Current values are: 2.381 0.25502
New values = ? (rtn for old values, filename for ENCAL file) 1979T2
"Energy Calibration [first degree polynomial using 2 (E_gamma, Channel) points]."
Impurity Identification and Analysis

- S1: 1-17 spectra
- S2: 1-27 spectra
- RADWARE: GF3_JCH
  - NuDat
  - Peak Fits
  - Half-lives
  - ENSDF Tables
NuDat

- All known nuclides
- Activation creates unstable nuclides
- Unstable nuclides undergo beta decay
- Chart enables identification of theoretical impurities
- Contains half-life and gamma peak data for identifying actual impurities
Peak Fits

- Gamma-ray peaks
- Fits and JCH integration give area
- Areas give relative contribution of impurities
- Areas can be used sequentially to obtain a half-life
Half-life: $T_{1/2}$

- Plot changes in area of a gamma peak with time
- Fit to exponential trend-line
- Equation form: $Ae^{-\lambda x}$
- $T_{1/2} = \ln(2) / \lambda$
- $^{197}\text{Pt}^{m} T_{1/2} = 19.9$ h
- $T_{1/2} \neq 19.9$ h indicates the presence of an impurity.

S2: 158 Gamma Peak Time Decay

$$y = 31.73e^{-0.22x}$$

$R^2 = 1.00$
Data Comparison

Databases provide nuclide information. Gamma-ray energy, intensity, and T_{1/2} all help identify impurities.
Presence of other media en route to the detector, including the source itself, cause attenuation

- **S1**: 0.7 mg of 10 mm diameter Pt in .5 mil thick Mylar; average thickness 4.5 μm
- **S2**: 1.53 mg of 10 mm diameter Pt in .5 mil thick Mylar; average thickness 2.1 μm

\[ I_\gamma = I_\gamma^0 e^{-\mu x} \]

where μ is the attenuation coefficient.

X-rays, gamma-rays, and the Mylar cover are considered to calculate the attenuation correction

- **S1**: 0.6% attenuation
- **S2**: 1.4% attenuation
Preliminary Results

Theoretical:
- With hole:
  \[ \alpha_k = 4.275 \pm 0.0010 \]
- No hole:
  \[ \alpha_k = 4.190 \pm 0.0010 \]

Experimental:
- S1:
  \[ \alpha_k = 4.24 (13) \]
- S2:
  \[ \alpha_k = 4.26 (8) \]

Agreement of Experimental Measurements with Theoretical Calculations for the 346.5 keV M4 Transition in 197Pt(m)

- "Frozen Orbital" approximation result (4.27)
- "No hole" approximation result (4.19)
- Previous Measurement (4.02)
Conclusions

The agreement of our preliminary result with the value obtained from the “frozen orbital” (hole included) theoretical method, combined with the agreement from prior precision ICC measurements of $^{193}$Ir, $^{134}$Cs, and $^{137}$Ba, continues to support the “frozen orbital” method’s agreement with experimental measurements.

The uncertainty in the results for the $\alpha_k$ value means that this agreement is still tentative; the final result will hopefully demonstrate closer agreement with the “frozen orbital” theory.
Future Work

- Complete identification of impurities
- Subtract remaining impurity contributions from spectra
- Obtain final precision values of $\alpha_k$ for both S1 and S2.
- Compare final results with no-hole and “frozen orbital” (hole) theoretical values for $\alpha_k$.
- Publish results.
Acknowledgments

- Dr. J.C. Hardy
- Dr. N. Nica
- Hardy Research Group
- Dr. David Radford
- Faculty and staff of the Texas A&M Cyclotron Institute
- Texas A&M University
- National Science Foundation
- This work supported under grants from the National Science Foundation, the Department of Energy, and the Robert A. Welch Foundation