Test of internal-conversion theory with a measurement in ^{111}Cd

TEXAS A&M PROGRAM TO MEASURE ICC
N. NICA

Internal Conversion Coefficients (ICC):

- **Big impact on quality of nuclear science**
- **Central for NSDD-USNDP and other nuclear data programs**
- **Intensely studied by theory and experiment**
- **Important result for nuclear data communities:**

The calculations including the atomic vacancy are now standard!

Survey of ICC's theories and measurements

S.Raman, C.W.Nestor, Jr., A.Ichihara, M.B.Trzhaskovskaya, *Phys.Rev. C66, 044312 (2002)*

Theory: ***Relativeistic Hartree Fock Slater*** **and** ***Relativestic Dirac Fock*** **comparison**

Exchange interaction, Finite size of nucleus, ***Hole treatment***

- **Experiment:**

  100 ***E2, M3, E3, M4, E5*** **ICC values, 0.5%-6% precision,**

  very few <1% precision!

- **Conclusions, Δ(exp:theory)%:**

  No hole**: +0.19(26)%** ***BEST*** ***(bound and continuum states - SCF of neutral atom***

  Hole-SCF**: -0.94(24)%** ***(continuum - SCF of ion + hole (full relaxation of ion orbitals)***

  Hole-FO**: -1.18(24)%** ***(continuum - ion field from bound wave functions of neutral atom (no relaxation of ion orbitals))***

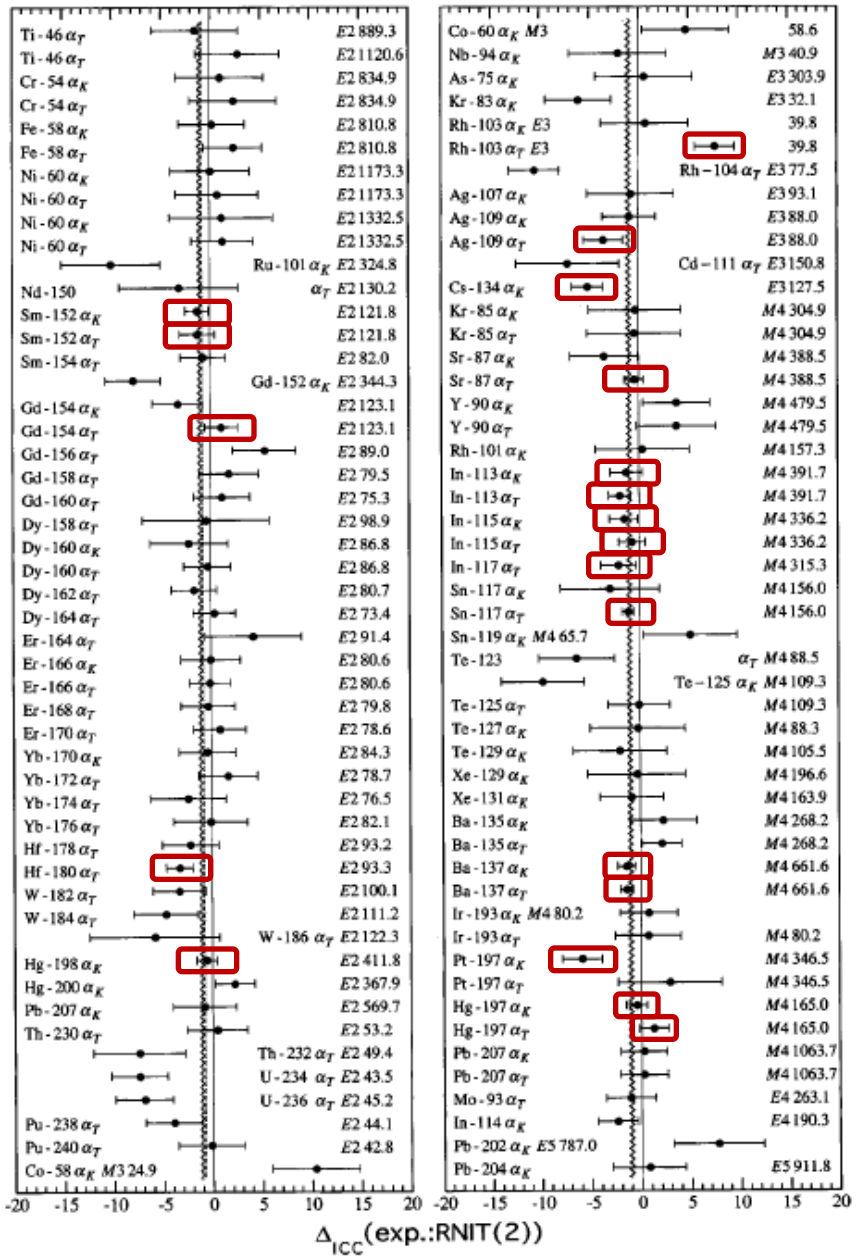
PHYSICAL ARGUMENT

K-shell filling time vs. time to leave atom

~10^{-15} – 10^{-17} s » ~10^{-18} s

S.Raman, C.W.Nestor, Jr., A.Ichihara, M.B.Trzhaskovskaya, *Phys.Rev. C66, 044312 (2002)*

100 α_K(exp) cases compared with 'hole FO' calculations



KX to γ rays ratio method

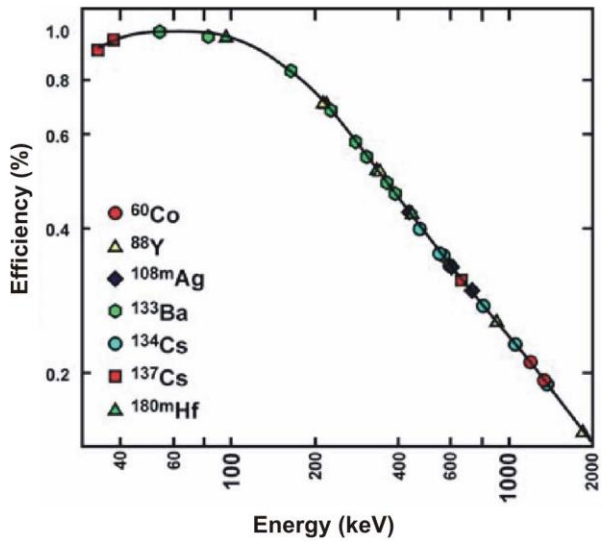
- Single-transition level scheme (or dominated by a strong transition)
- Sources for n_{th} activation
  - Small selfabsorption (< 0.1%)
  - Dead time (< 5%)
  - Statistics (> 10^6 for γ or x-rays)
  - High spectrum purity
  - Minimize activation time (0.5 h)
- Impurity analysis - *essentially based on ENSDF*
  - Trace and correct impurity to 0.01% level
  - Use decay-curve analysis
  - Especially important for the K X-ray region
- Voigt-shape (Lorentzian) correction for X-rays
  - Done by simulation spectra, analyzed as the real spectra
- Coincidence summing correction (including angular correlation)

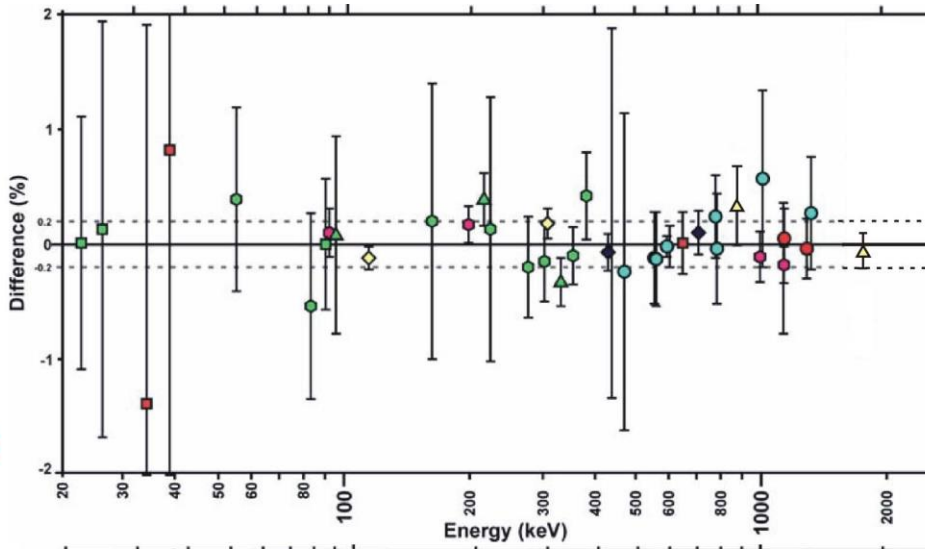
DETECTOR EFFICIENCY
50 keV < E_γ < 1.4 MeV

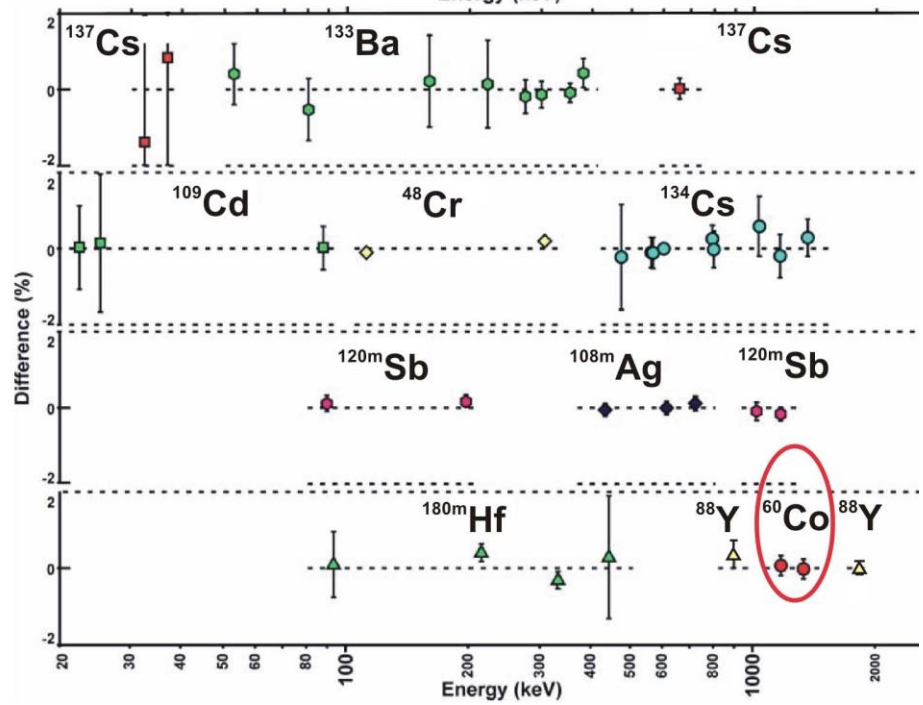
Coaxial 280-cc n-type Ge detector:

- Measured absolute efficiency (^{60}Co source from PTB with activity known to + 0.1%)
- Measured relative efficiency (9 sources)
- Calculated efficiencies with Monte Carlo (Integrated Tiger Series - CYLTRAN code)

0.2% uncertainty for the interval 50-1400 keV







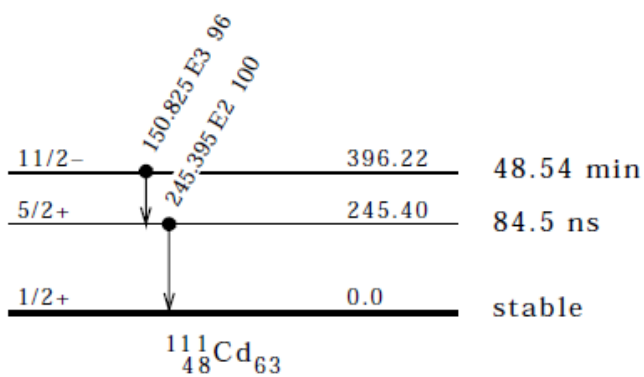
^{111m}Cd 150.8 keV, E3 transition

- **α(K)exp = 1.29 *11*, %unc=8.5 (Zs.Nemeth, A.Veres, *Phys.Rev. C35, 2294 (1987*)**
- **$\alpha(K)_{hole\_FO}$ = 1.450, $\alpha(K)_{no\_hole}$ = 1.425, Δ_K = 1.7%**

^{111}Cd IT Decay (48.54 min)

Decay Scheme

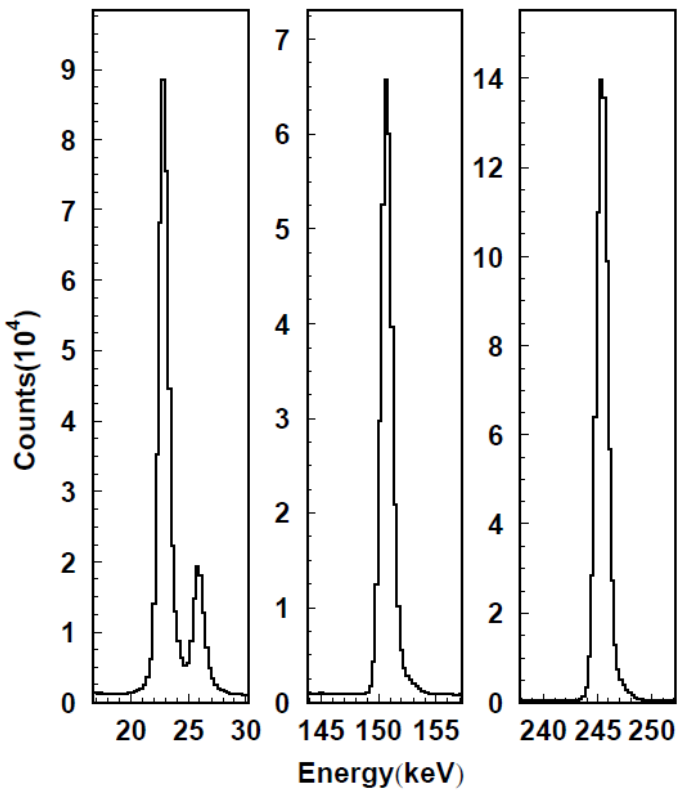
Intensities: I(γ+ce) per
100 decays by this branch
%IT=100



Data analysis and Results

Table 2. The total number of counts (or areas of the peaks) for ^{111m}Cd K x rays and the 150.8- and 245.4-keV γ rays, followed by corrections and the corrected area-ratios information required to extract the value of α_{K150}.

Quantity	Value	
	S1	S2
Cd ($K_\alpha + K_\beta$) x rays		
Total counts	$1.979(6)\times10^5$	$4.695(9)\times10^5$
Impurities	$-5.39(14)\times10^3$	$-1.66(3)\times10^4$
Lorentzian correction	+0.12(2)%	+0.12(2)%
Summing correction	+0.99(6)%	+0.99(6)%
Attenuation correction	+0.27(2)%	+0.29(2)%
Corrected counts, N_K	$1.952(6)\times10^5$	$4.593(10)\times10^5$
^{111}Cd 150.8-keV γ ray		
Total counts	$1.303(11)\times10^5$	$3.064(25)\times10^5$
Summing correction	+1.29(6)%	+1.29(6)%
Corrected counts, $N_{\gamma150}$	$1.320(12)\times10^5$	$3.104(25)\times10^5$
^{111}Cd 245.4-keV γ ray		
Total counts	$3.024(22)\times10^5$	$7.082(45)\times10^5$
Summing correction	+0.86(3)%	+0.86(3)%
Corrected counts, $N_{\gamma245}$	$3.050(22)\times10^5$	$7.143(45)\times10^5$
$N_K/N_{\gamma150}$	1.479(14)	1.480(12)
$N_{\gamma245}/N_{\gamma150}$	2.311(27)	2.301(24)



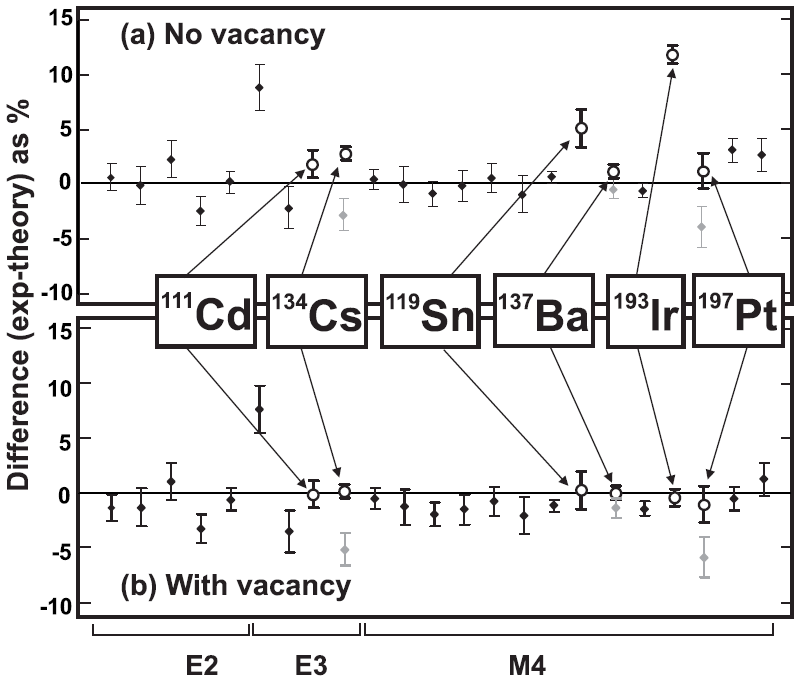
Model	α_K	$\Delta(\%)$	α_T	$\Delta(\%)$
Experiment	1.449(18)		2.217(26)	
Theory:				
No vacancy	1.425(1)	+1.7(12)	2.257(1)	−1.8(12)
Vacancy, FO	1.451(1)	−0.1(12)	2.284(1)	−2.9(12)

Current status of precision ICC measurements

Comparison of the six measured α_K values with Dirac-Fock theoretical calculations

Parent	Transition Energy(keV)	Measured α_K	Calculated α_K	
			No vacancy	Vacancy
^{197m}Pt	346.5(2)	4.23(7)	4.191	4.276
^{193m}Ir	80.22(2)	103.0(8)	92.0	103.3
^{137m}Ba	661.659(3)	0.0915(5)	0.09068	0.09148
^{134m}Cs	127.502(3)	2.742(15)	2.677	2.741
^{119m}Sn	65.66(1)	1610(27)	1544	1618
^{111m}Cd	150.853(15)	1.449(18)	1.425	1.451
χ^2			219	0.68

Percentage difference between measured and calculated ICCs for the two Dirac-Fock calculations. The measured values include our published α_K values



Conclusions:

- ***Theory calculations that include the atomic vacancy are in best agreement with measurements***
- ***As a result of our studies USNDP, NSDD, and DDEP adopted the calculations including the atomic vacancy in the databases***

Backup material

References

- **N. Nica, J. C. Hardy, V. E. Iacob, S. Raman, C. W. Nestor Jr., and M. B. Trzhaskovskaya, *Phys. Rev. C 70, 05430 (2004).***
- **N. Nica, J. C. Hardy, V. E. Iacob, J. R. Montague, and M. B. Trzhaskovskaya, *Phys. Rev. C 71, 054320 (2005).***
- **N. Nica, J. C. Hardy, V. E. Iacob, W. E. Rockwell, and M. B. Trzhaskovskaya, *Phys. Rev. C 75, 024308 (2007).***
- **N. Nica, J. C. Hardy, V. E. Iacob, C. Balonek, and M.B. Trzhaskovskaya, *Phys. Rev. C 77, 034306 (2008).***
- **J.C. Hardy, N. Nica, V.E. Iacob, C. Balonek and M.B.Trzhaskovskaya, *Appl. Rad. Isot. 66, 701 (2008).***
- **N. Nica, J. C. Hardy, V. E. Iacob, J. Goodwin, C. Balonek, M. Hernberg, J. Nolan and M. B.Trzhaskovskaya, *Phys. Rev. C 80, 064314 (2009).***
- **N. Nica, J. C. Hardy, V. E. Iacob, M. Bencomo, V. Horvat, H.I. Park, M. Maguire, S. Miller and M. B.Trzhaskovskaya, *Phys. Rev. C 89, 014303 (2014).***
- **J. C. Hardy, N. Nica, V. E. Iacob, S. Miller, M. Maguire and M. B. Trzhaskovskaya, *Appl. Rad and Isot. 87, 87 (2014).***
- **N. Nica, J. C. Hardy, V. E. Iacob, T.A. Werke, C.M.Folden, L.Pineda, and M.B.Trzhaskovskaya *Phys.Rev. C 93, 034305 (2016).***