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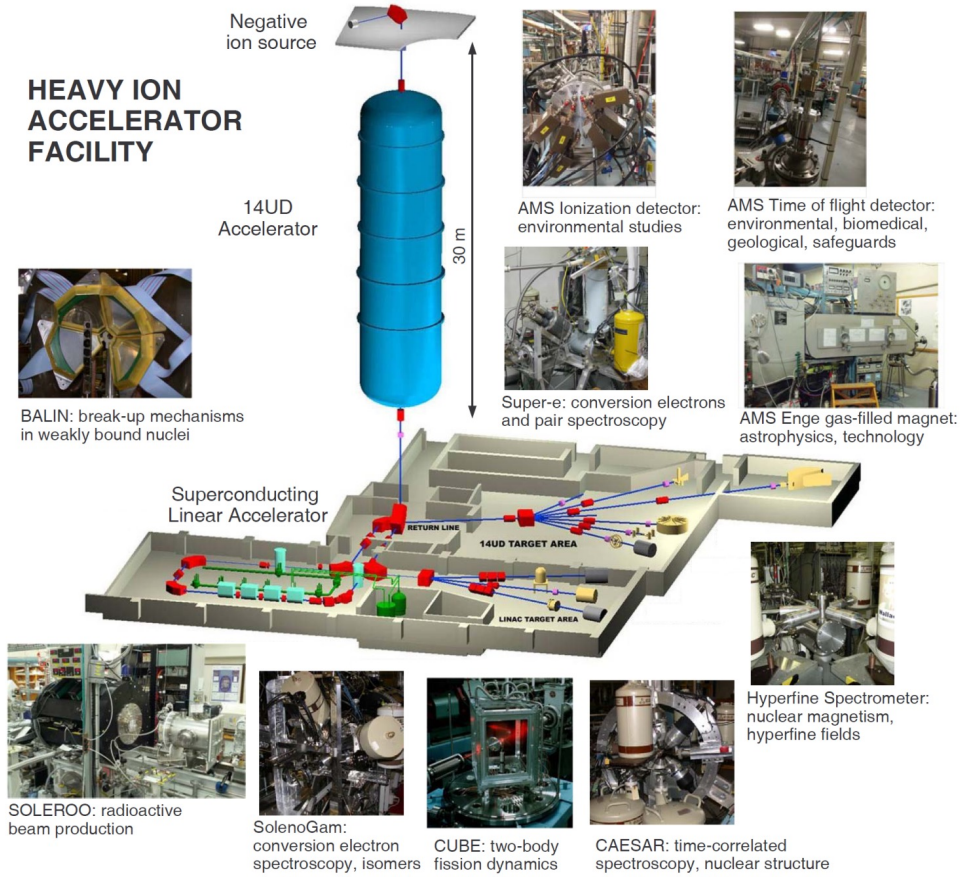
Internal conversion coefficients, BrIcc, BrIccMixing and decay scheme normalisation

T. Kibèdi (ANU)

Heavy Ion Accelerator Facility - ANU



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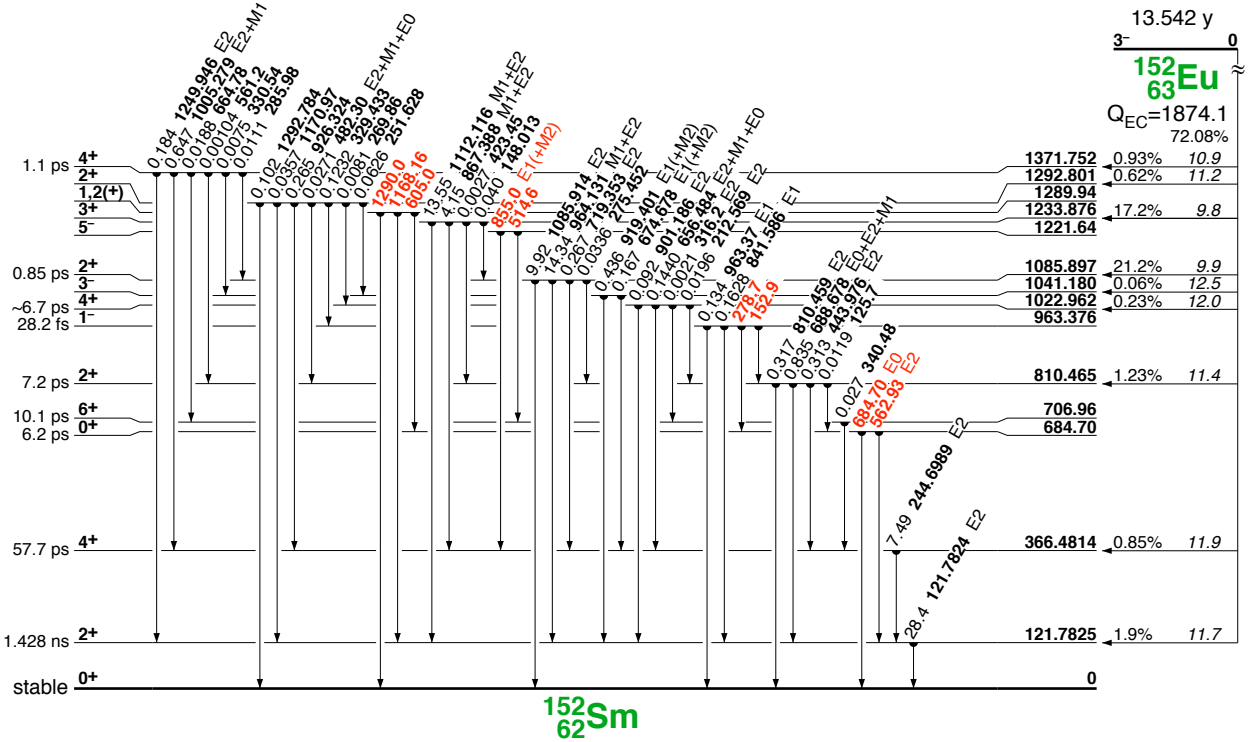
Overview

- Electromagnetic decays in atomic nuclei
- Internal conversion coefficients, mixed multipolarities
- Electric monopole transitions
- BrIcc - Calculation of conversion coefficient
- BrIccMixing – multipole mixing ratios from conversion electron data
- GABS – normalisation of decay scheme

Afternoon practice session by Filip Kondev on installation and detailed use of the codes

Electromagnetic Decay Processes

EM decay: energy and momentum carried away



Electromagnetic Decay Processes
γ-ray emission

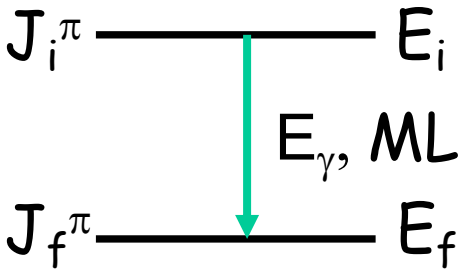
EM decay: energy and momentum carried away

Selection *rules* (πL)

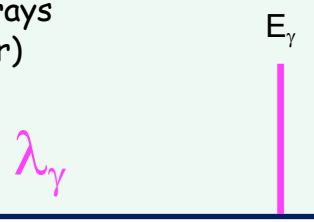
$|L-j_i| \lesssim j_f \lesssim L+j_i$

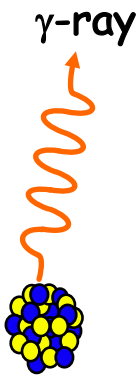
$\pi = (-1)^L$ for EL

$\pi = (-1)^{L+1}$ for ML



Gamma-rays (1^{st} order)





Energetics

Gamma $E_\gamma = E_i - E_f + T_r$

CE $E_{CE_i} = E_i - E_f - E_{BE_i} + T_r$

PF $E^+ + E^- = E_i - E_f - 2m_0c^2 + T_r$

Electromagnetic Decay Processes Multipolarity

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EM decay: energy and momentum carried away

Selection *rules* (πL)

$|L-j_i| \lesssim j_f \lesssim L+j_i$

$\pi = (-1)^L$ for EL

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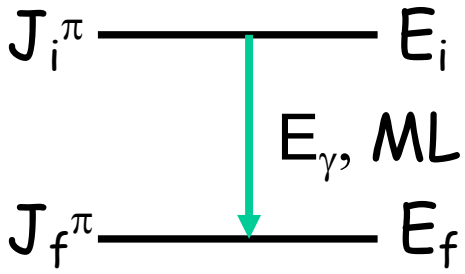

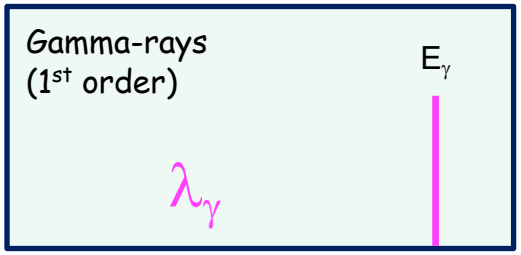

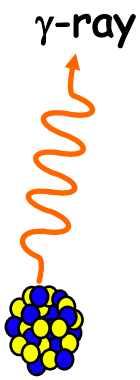

	ΔL	Δπ
E1	−1, 0, +1	yes
M1	−1, 0, +1	no
E2	−2, −1, 0, +1, +2	no
M2	−2, −1, 0, +1, +2	yes
E3	−3, −2, −1, 0, +1, +2, +3	yes
M3	−3, −2, −1, 0, +1, +2, +3	no

Energetics

Gamma $E_\gamma = E_i - E_f + T_r$

CE $E_{CE_i} = E_i - E_f - E_{BE_i} + T_r$

PF $E^+ + E^- = E_i - E_f - 2m_0c^2 + T_r$

Electromagnetic Decay Processes
Conversion electron emission

EM decay: energy and momentum carried away

Selection *rules* (πL)

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$\pi = (-1)^L$ for EL

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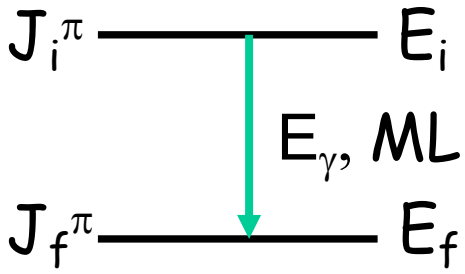

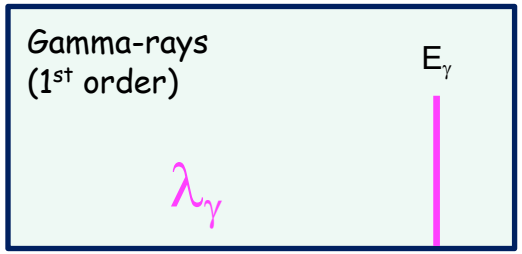

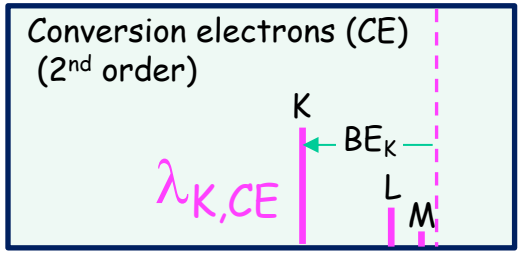

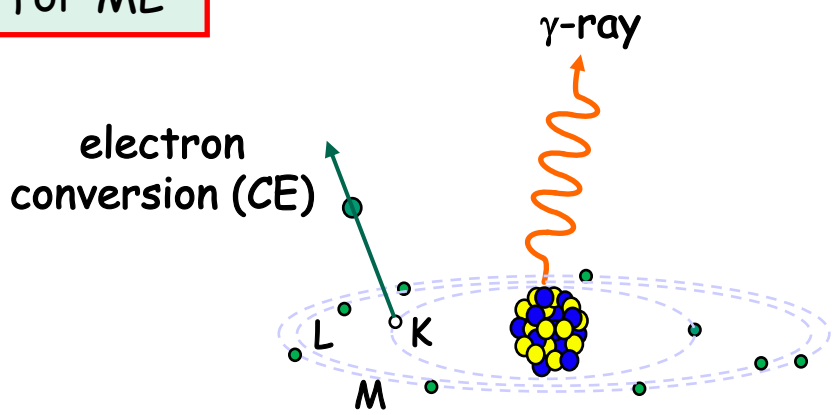

Energetics

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Electromagnetic Decay Processes
Electron-positron pair emission

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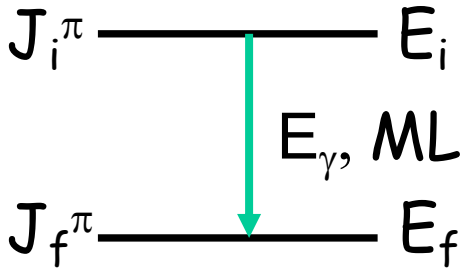
EM decay: energy and momentum carried away

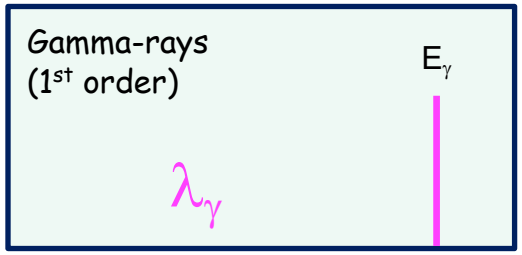
Selection *rules* (πL)

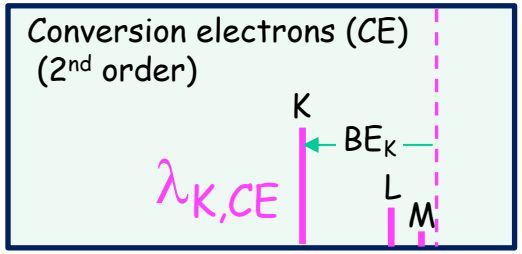
$|L-j_i| \lesssim j_f \lesssim L+j_i$

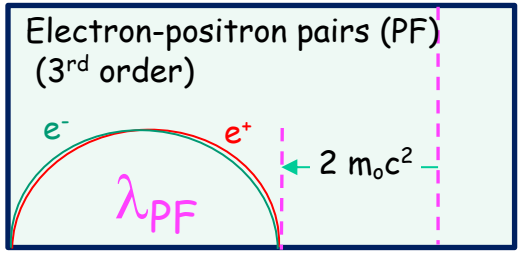
$\pi = (-1)^L$ for EL

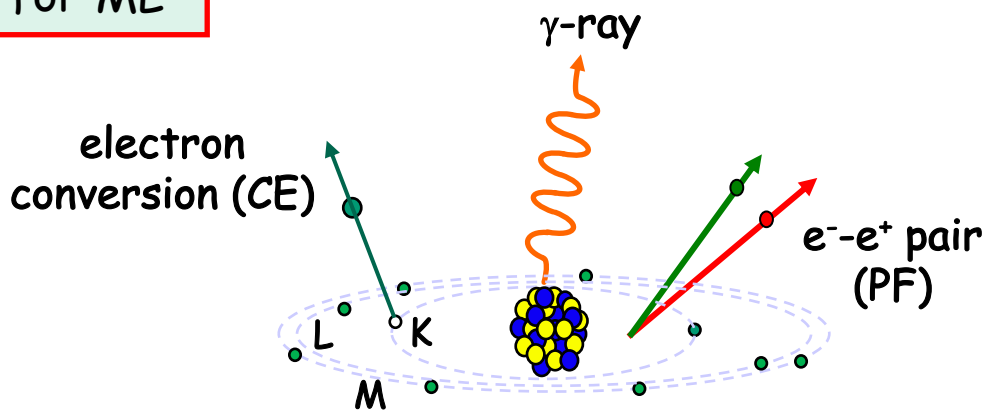
$\pi = (-1)^{L+1}$ for ML











Transition probability

$\lambda_T = \lambda_\gamma + \lambda_K + \lambda_L + \lambda_M \ldots\ldots + \lambda_{PF}$

Conversion coefficient

$\alpha_{CE,PF} = \lambda_{CE,PF} / \lambda_\gamma$

$\lambda_{CE,PF} = \lambda_\gamma \times \alpha_{CE,PF}$

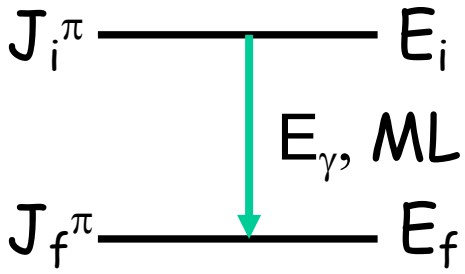
Energetics

Gamma $E_\gamma = E_i - E_f + T_r$

CE $E_{CE,i} = E_i - E_f - E_{BE,i} + T_r$

PF $E^+ + E^- = E_i - E_f - 2m_oc^2 + T_r$

Transition probabilities and conversion coefficients



Transition probability

$$\lambda_T = \lambda_\gamma + \lambda_K + \lambda_L + \lambda_M \ldots\ldots + \lambda_{PF}$$

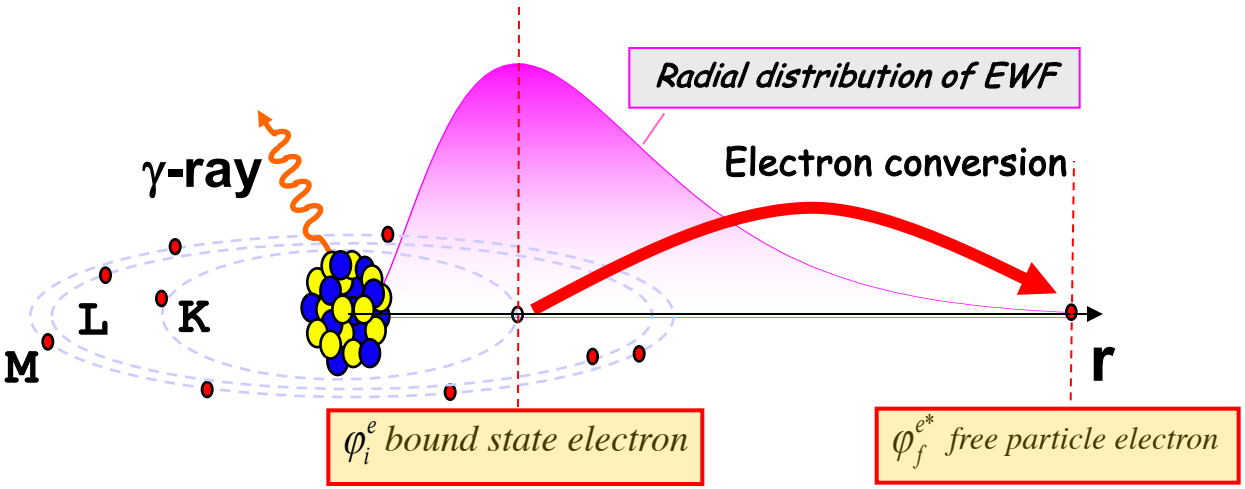
$$\lambda_T = \lambda_\gamma \times (1 + \alpha_{total})$$

Conversion coefficient and total intensity

$$I_{total} = I_\gamma \times (1+\alpha_{total})$$

The knowledge of conversion coefficients essential to evaluate the total transition probabilities

BrIcc - Calculation of theoretical conversion coefficients



Fermi's golden rule

$$\alpha_e = \frac{\lambda_e}{\lambda_\gamma} \Rightarrow \lambda_e = \frac{2\pi}{\hbar}|m_{fi}|^2 \frac{d\rho}{dE}$$

Density of the final electron state (continuum)

$$m_{fi} = \psi_f^{N*}\ \varphi_f^{e*}\ F_{\ell,m}\ \psi_i^{N}\ \varphi_i^{e}$$

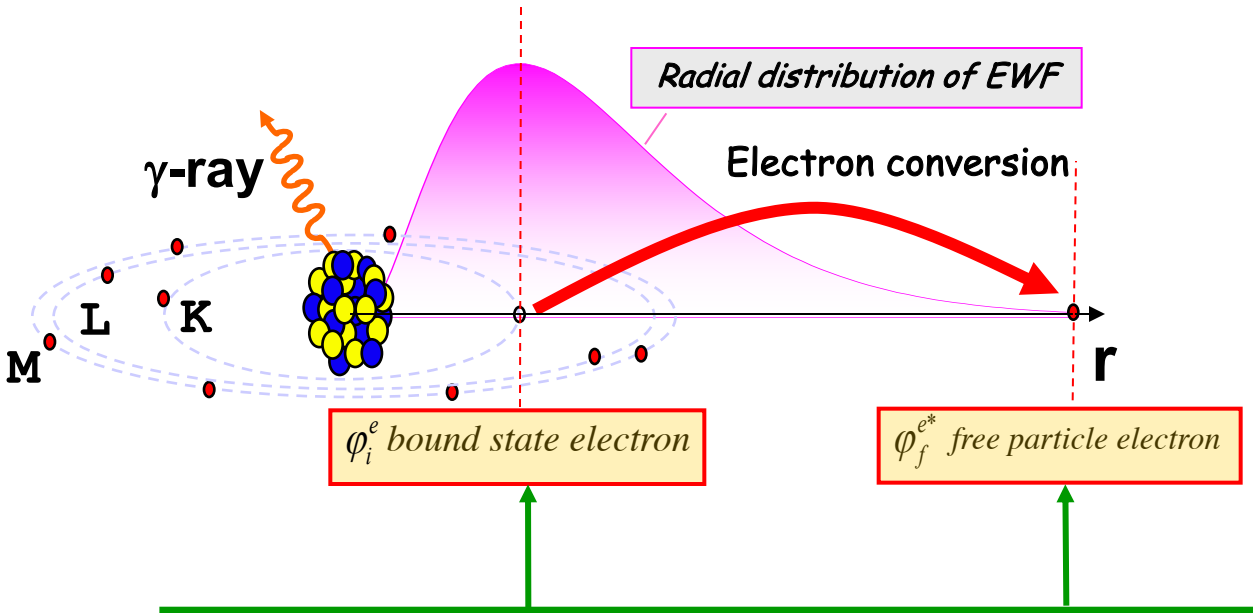
Nuclear

Electron

Multipolar source

Same for γ and CE

ICC calculations
Atomic model



SCF of a neutral atom

Constructed from the WF of a neutral atom, not SCF

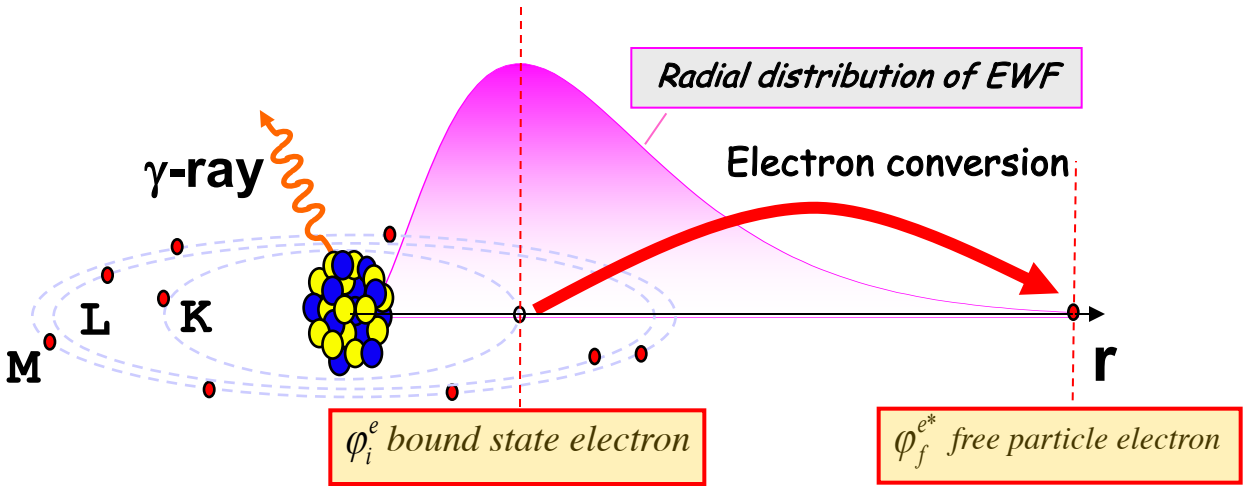
"Frozen Orbitals" – RNIT(2)

Vacancy incorporated

BrIccFO data table

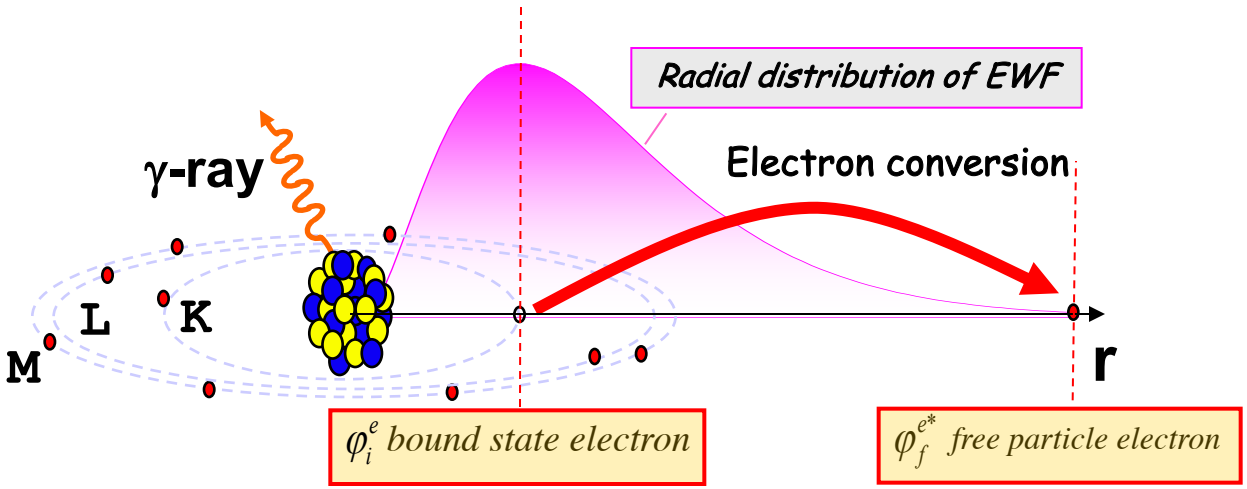
2002Ba85 *Band et al., ADNDT 81 (2002) 1*

ICC calculations
Atomic model



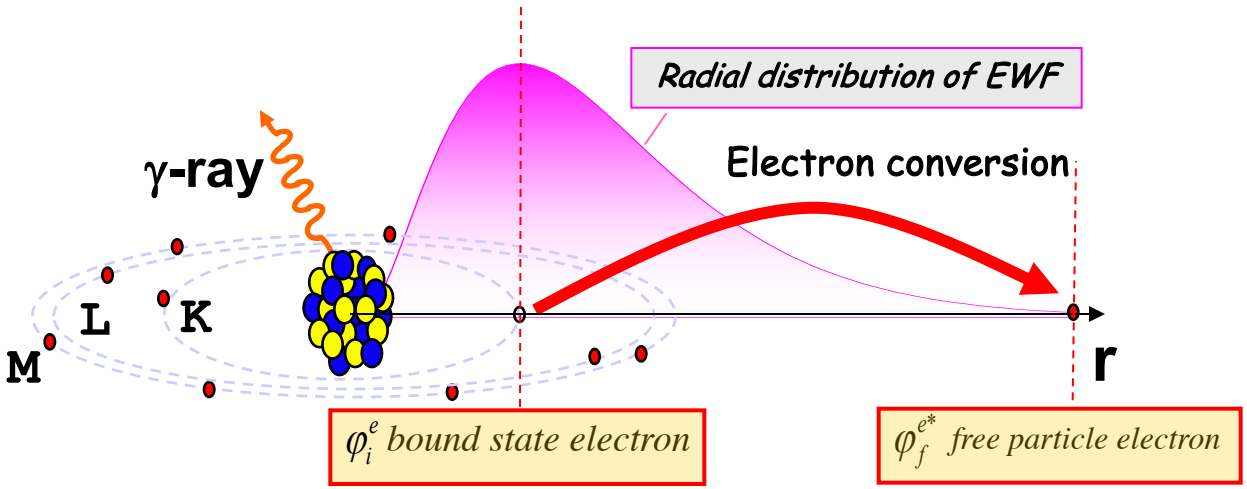
- Relativistic Dirac-Fock method
- One-electron approximation
- Free neutral atom
- Screening of the nuclear field by the atomic electrons
- Spherically symmetric atomic potential
- Relativistic electron wave functions
- Experimental electron binding energies

ICC calculations
Nuclear model



- Finite nuclear size
- Dynamic (penetration) effects incorporated using the Surface Current model
- Spherically symmetric nucleus; most abundant isotope

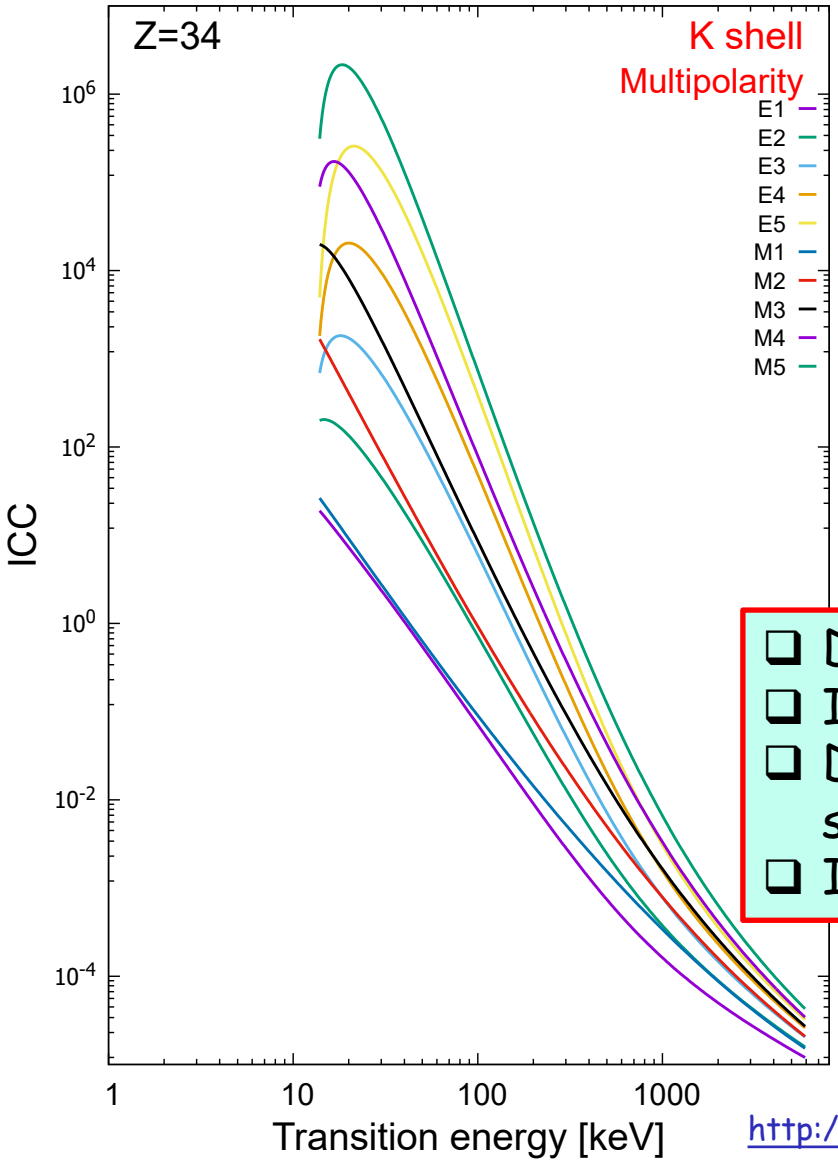
ICC calculations
Higher order effects

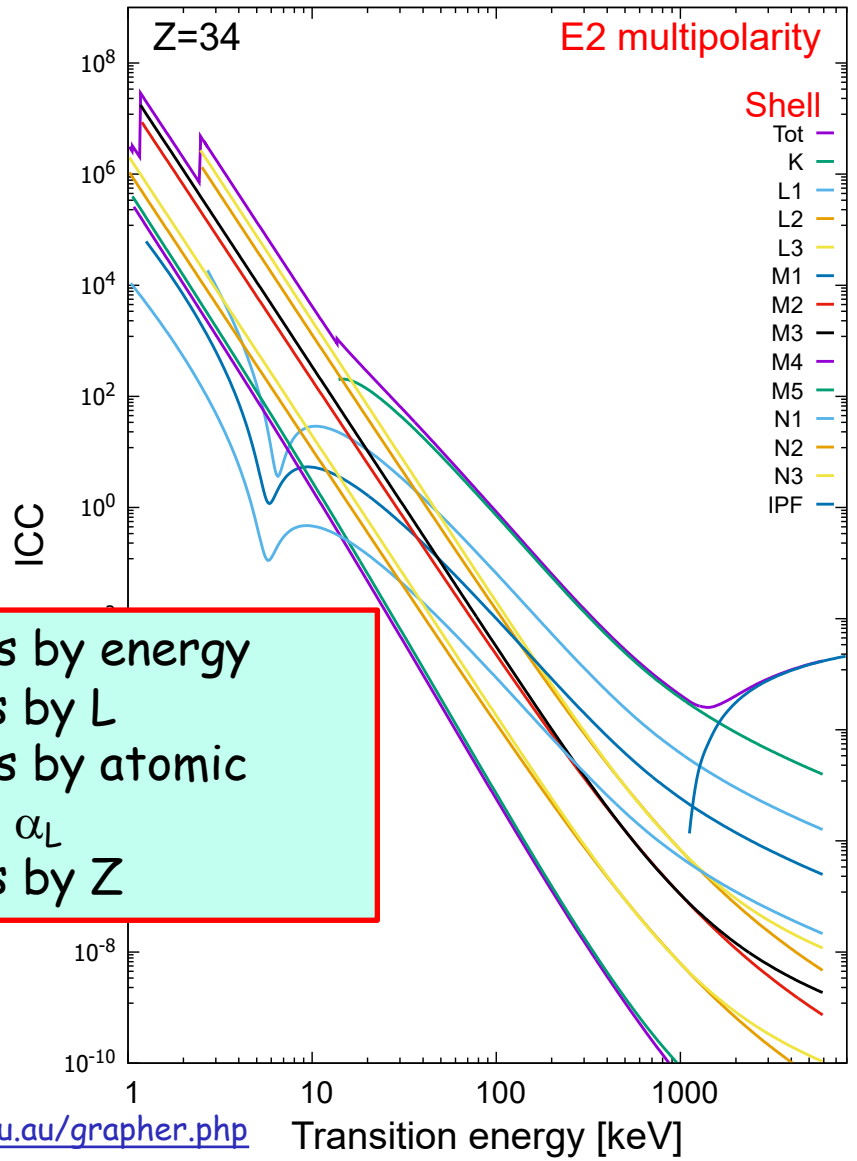


- Atomic many body correlations: factor ~2 for $E_{kin}(ce) < 1$ keV
- Partially filled valence shell: non-spherical atomic field
- Binding energy uncertainty: <0.5% for $E_{kin}(ce) > 10$ keV
- Chemical effects: <<1%

RAINE code by Band et al., 2002Ba85
Overall accuracy ~1% 2008KiZV

Theoretical conversion coefficients (L>0)





- Decreases by energy
- Increases by L
- Decreases by atomic shell; $\alpha_K > \alpha_L$
- Increases by Z

http://bricc.anu.edu.au/grapher.php

Mixed transitions

Selection *rules* (πL)

$|L-j_i| \lesssim j_f \lesssim L+j_i$

$\pi = (-1)^L$ for EL

$\pi = (-1)^{L+1}$ for ML

Example: 2^+ to 1^+ transition, $\Delta J=-1$

- pure M1 ($\Delta J=-1,0,+1$)
- pure E2 ($\Delta J=-2,-1,0,+1,+2$)
- mixed M1+E2 ($\Delta J=-1,0,+1$)

	$\Delta\pi=+1$		$\Delta\pi=-1$	
πL	M1	M3	E1	E3
$\pi' L'$	E2	E4	M2	M4

Special case: mixed transitions with 3 multipolarities:

^{184}W 536.674(15) keV

E1+M2+E3,

ME(M2/E1)=+0.070(6),

MR(E3/M2)=-0.025(4)

λ=-2.1(2);

γ-ray transition probability:

$$\lambda_\gamma(\pi' L'/\pi L) = \lambda_\gamma(\pi` L`) + \lambda_\gamma(\pi, L)$$

Mixing ratio (MR)

$$\delta^2(\pi' L'/\pi L) = \frac{\lambda_\gamma(\pi' L')}{\lambda_\gamma(\pi L)}$$

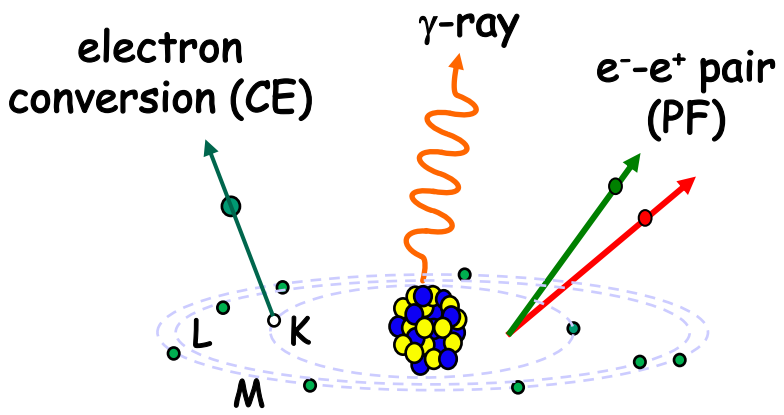
Conversion coefficient for CE and PF

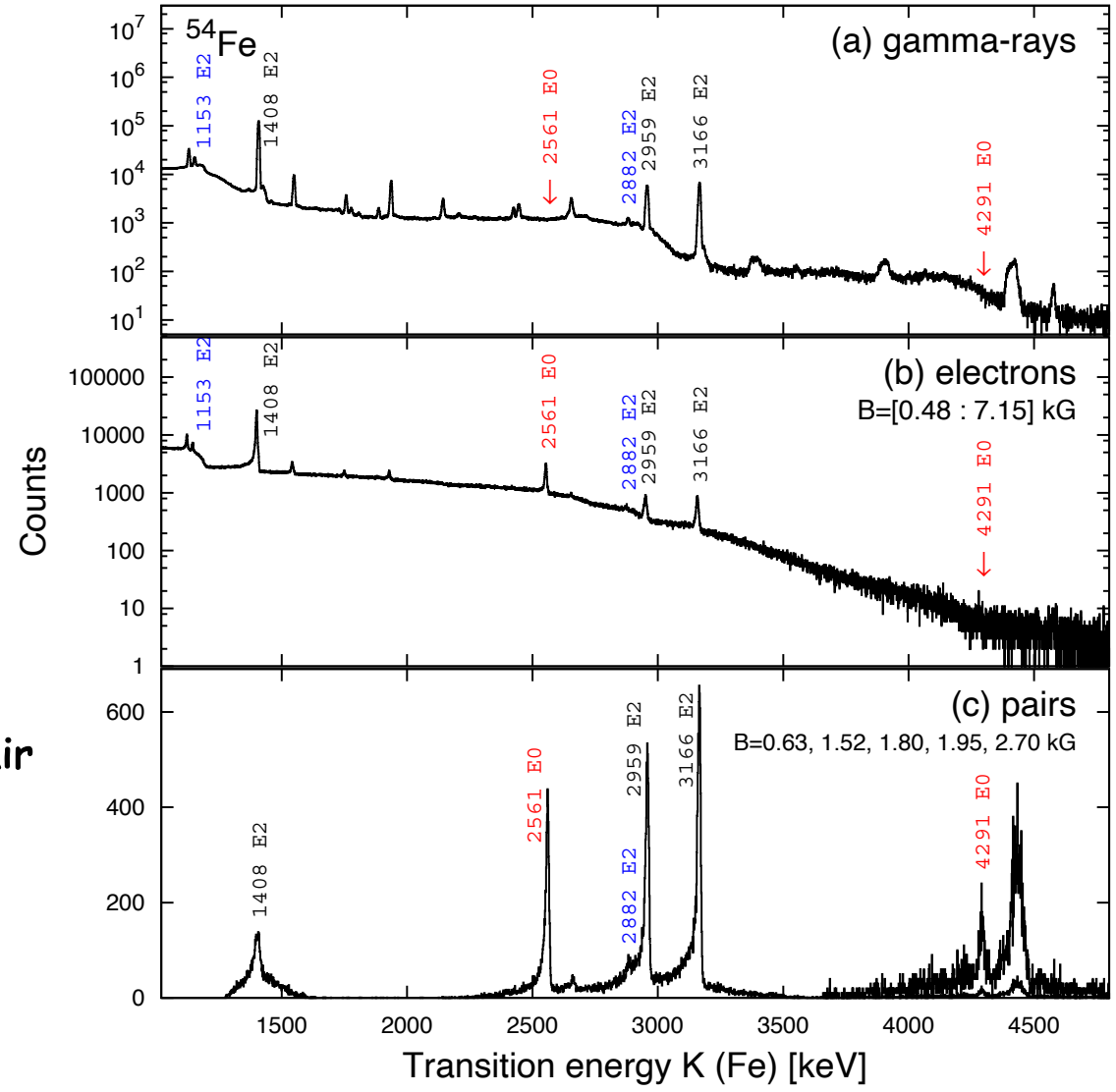
$$\alpha(\pi' L'/\pi L) = \frac{\alpha(\pi L) + \delta^2 \alpha(\pi' L')}{1+\delta^2}$$

Measuring conversion coefficients

Experimental determination of ICC

$$\alpha_{exp} = I_{CE \text{ or } IPF} / I_{\gamma}$$





T.K. Eriksen PhD (2018, ANU)

Experimental determination of ICC

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Definition: $\alpha_{exp} = \frac{I_{CE,PF}}{I_\gamma}$

Review of methods (~16): J.H. Hamilton 1975, Ch 11, The Electromagnetic Interaction in Nuclear Spectroscopy, North-Holland

NPG: - normalised relative CE or PF ($I_{CE,PF}$) and γ (I_γ)intensities; normalisation factor, N from a known transition multipolarity, using theoretical ICC

$$\alpha_{exp} = N \times \frac{I_{CE,PF}}{I_\gamma}$$

Check if the most recent theoretical ICC was used!

XPG: - X-ray (I_{KX}) to γ-ray (I_γ) intensity ratio, using K-shell fluorescence yield (ω_K)

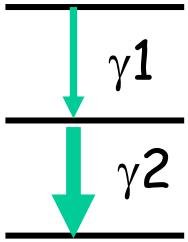
$$\alpha_{exp} = \frac{I_{KX}}{I_\gamma} \times \frac{\epsilon_\gamma}{\epsilon_{KX}} \times \frac{1}{\omega_K}$$

Check if the most recent ω_K was used!

Intensity balance of two cascading transitions ($I_{\gamma 1}$, $I_{\gamma 2}$)

$$I_{\gamma 1} \times (1 + \alpha_{tot1}) = I_{\gamma 2} \times (1 + \alpha_{tot2})$$

Check if the most recent theoretical ICC was used!



Higher order Electromagnetic Decay Processes

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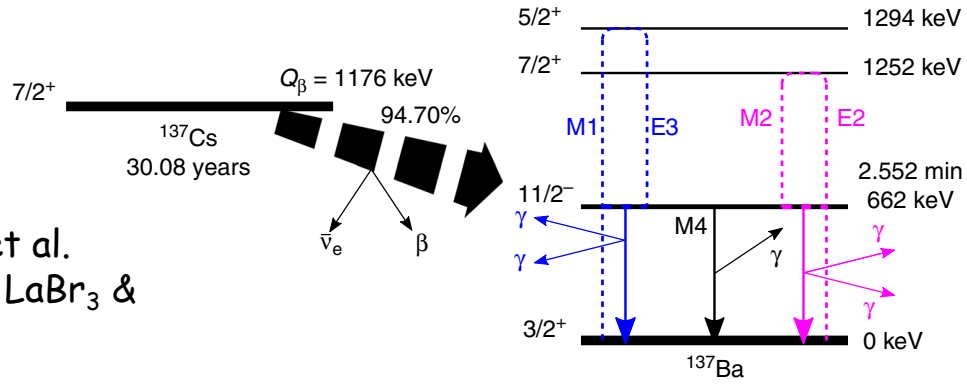
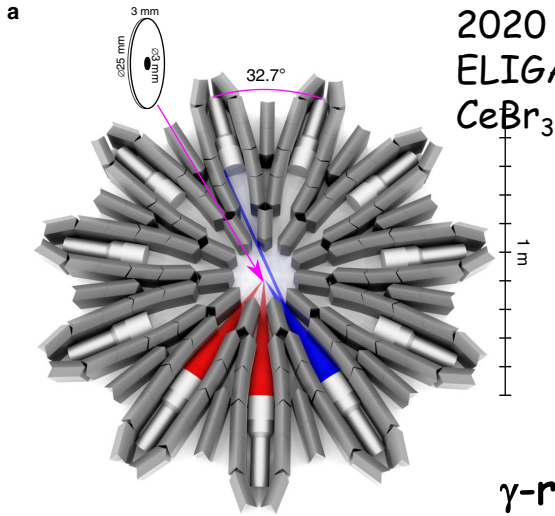
nature COMMUNICATIONS

ARTICLE

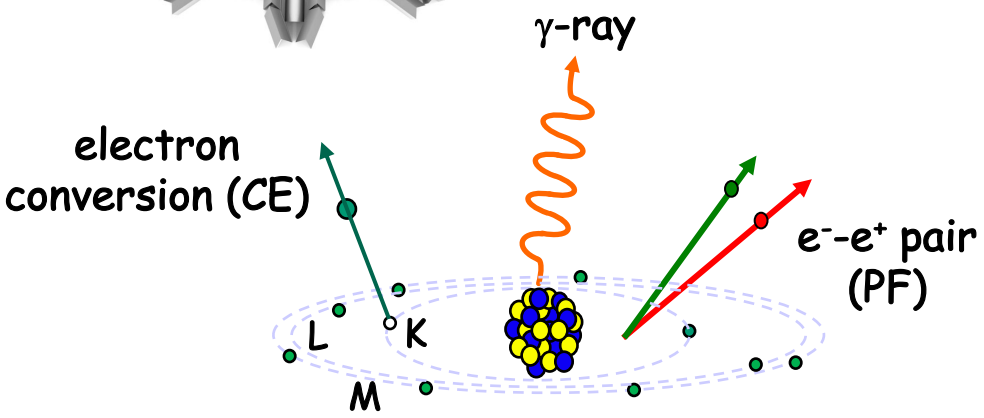
https://doi.org/10.1038/s41467-020-16787-4 OPEN

Electromagnetic character of the competitive $\gamma\gamma/\gamma$-decay from ^{137m}Ba





2020 Söderström et al.
ELIGANT array: 11 $LaBr_3$ & $CeBr_3$



$11/2^- \rightarrow 3/2^+$ transition through virtual states,
Pairs of E2 & M2 or M1 & E3

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma}} = 2.62(30)\times10^{-6}$$

More higher order possibilities:
γ-CE γ-PF CE-CE ……
<u>Not considered in ENSDF</u>

E0 - electric monopole transitions

EM decay: energy and momentum carried away

Selection *rules* (πL)

$j_i = j_f$

$\Delta\pi = 0$

Pure E0

- NO gamma-ray
- Only CE or PF

References:

1997Wo07 J.L. Wood et al., NP **A651** (1999) 323

2022Ki03 T. Kibèdi, A.B. Garnsworthy, J.L. Wood, Prog. Part. Nucl. Phys. 123 (2022) 103930

E0 conversion coefficient NOT DEFINED

$\alpha(E0) = \lambda_{CE,PF}(E0) / \lambda_{\gamma}(E0)$

E0 transition rate

$\lambda_{CE,PF}(E0) = \rho^2(E0)\, \Omega_{CE,PF}(E0)$

$\rho(E0)$ – monopole strength parameter, contains all nuclear structure information

$\Omega_{CE,PF}(E0)$ – theoretical E0 electronic factor (BrIcc)

E0 reduced transition rate

$B(E0) = \rho^2(E0)\, e^2 R_o^4$

Experimental determination

$\rho^2(E0) = 1/[\Omega_{CE}(E0) + \Omega_{PF}(E0)] \times \tau(E0)$

Conversion coefficients vs. E0 electronic factors

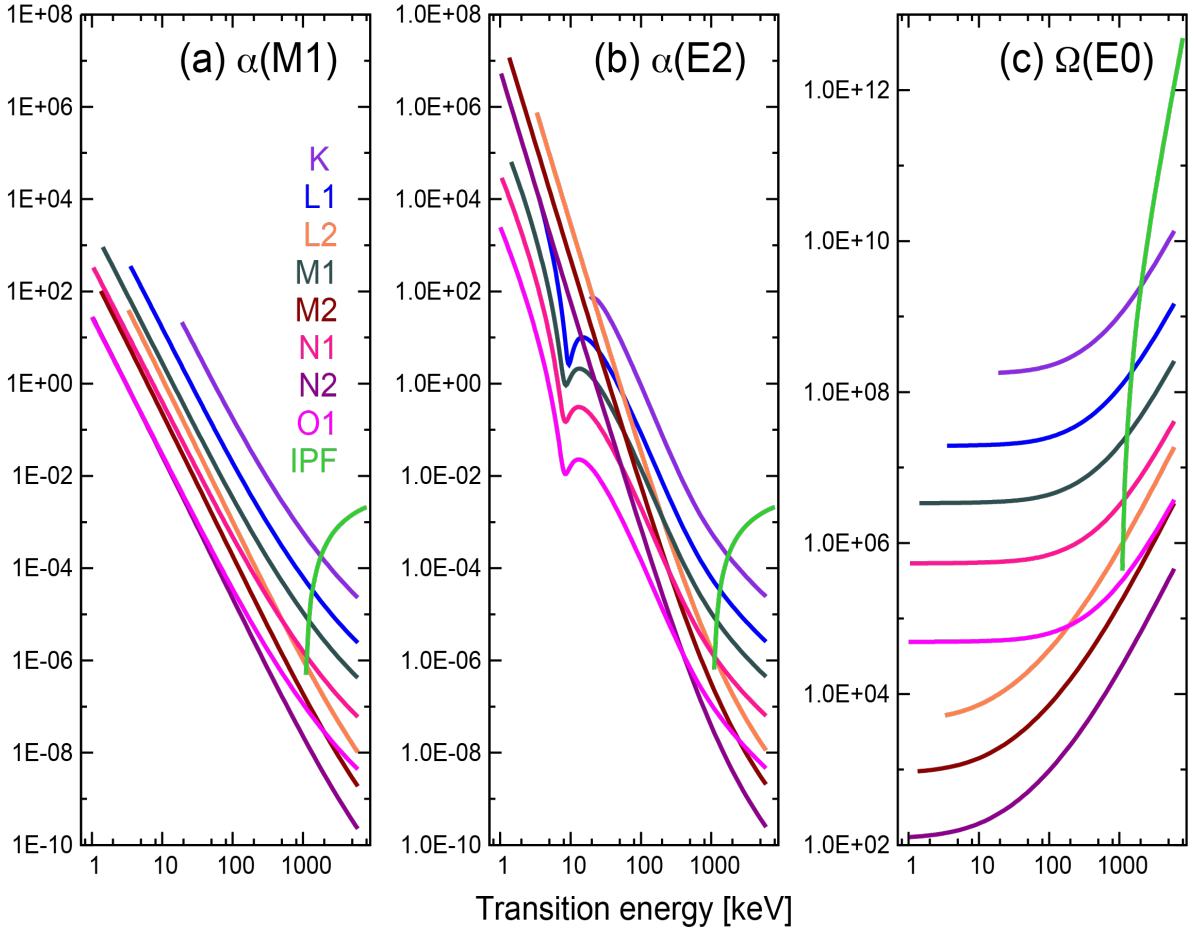
- E0 conversion on $nS_{1/2}$ and $nP_{1/2}$ shells only
- Energy dependence
  - α(M1,E2): ⬇ up 14 orders of magnitude
  - Ω(E0): ⬆ 2-3 orders of magnitude
  - Opposite for pair conversion
- Atomic shells (K, L, M):

  Always decreasing
- Transition rates

$$I_{CE}(E0) = \rho^2(E0) \times \Omega(E0)$$

$$I_{CE}(M1+E2) = I_\gamma(M1+E2) \times \alpha(M1+E2)$$

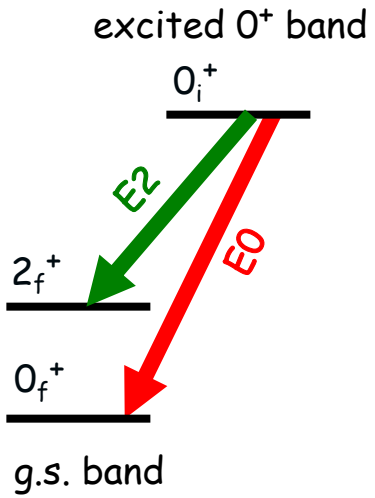
Z=40; α(M1,E2): from BrIcc (2008Ki07); $W_{CE,PF}$(E0): (2020Do01)



$\rho^2(E0)$ from experiments Pure E0

From level half life and E0 branching

$$\varrho^2(E0) = \frac{1}{[\Omega_{CE}(E0) + \Omega_{PF}(E0)] \times \tau(E0)}$$



From E2 absolute transition rate and E0/E2 branching

$$\varrho^2(E0) = q_K^2(E0/E2) \times \frac{\alpha_K(E2)}{\Omega_K(E0)} \times \frac{1}{\tau_\gamma(E2)}$$

MR(E0/E2) mixing ratio – defined for a particular shell (K)

$$q_K^2(E0/E2) = \frac{\lambda_K(E0)}{\lambda_K(E2)}$$

Remember:
$\Omega_{CE,PF}(E0) \sim \lambda_{CE,PF}(E0)$

$$q_K^2(E0/E2) = q_{PF}^2(E0/E2) \frac{\Omega_K(E0)}{\Omega_{PF}(E0)}$$

ρ^2(E0) from experiments E0+E2+M1 mixed transitions

EM decay: energy and momentum carried away

Selection *rules* (πL)

$j_i = j_f$

$\Delta\pi = 0$

2^+ to 2^+ transition

E0 competite with E2+M1

Transition probability:

$$\lambda(E0+E2+M1) = \lambda_{CE}(E0)+\lambda_{PF}(E0) + \lambda_\gamma(E2) + \lambda_{CE}(E2)+\lambda_{PF}(E2) + \lambda_\gamma(M1) + \lambda_{CE}(M1)+\lambda_{PF}(M1)$$

MR(E2/M1) mixing ratio

$$\delta^2(E2/M1) = \frac{\lambda_\gamma(E2)}{\lambda_\gamma(M1)}$$

MR(E0/E2) mixing ratio

$$q_K^2(E0/E2) = \frac{\lambda_K(E0)}{\lambda_K(E2)}$$

Conversion coefficient (K-shell)

$$\alpha_K(E0+E2+M1) = \frac{\alpha_K(M1) + \delta^2 \times [1+q_K^2] \times \alpha_K(E2)}{1+\delta^2}$$

ρ^2(E0) can be determined if both E2/M1 and E0/E2 mixing ratios and level half life are known (E0/E2 mixing ratio from α_K)

THE AUSTRALIAN NATIONAL UNIVERSITY

BrIcc

2008Ki07

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Nuclear Instruments and Methods in Physics Research A 589 (2008) 202–229
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

- Aims: to calculate theoretical conversion coefficients
- Data tables:

Evaluation of theoretical conversion coefficients using *BrIcc*

T. Kibédi[a,*], T.W. Burrows[b], M.B. Trzhaskovskaya[c], P.M. Davidson[a], C.W. Nestor Jr.[d]

Data Table	Reference	Z	Shells or IPF	L	Transition energy [keV][a]
Internal Conversion Coefficient (ICC)					
BrIccFO	Based on the model using the *'Frozen Orbitals'* approximation of 2002Ba85 and 2002Ra45	5–110	All shells	1–5	ε_{ic}+1–6000
BrIccNH	Based on the model using the *'No Hole'* approximation of 2002Ba85 and 2002Ra45	5–110	All shells	1–5	ε_{ic}+1–6000
Pair Conversion Coefficient (PCC)					
ScPcc	1979Sc31	0–100[b]	IPF	1–3	1100–8000
HoPcc	1996Ho21	50–100	IPF	1–3	1100–8000
Electronic factor Ω(E0)[c]					
HsOmg	1969Ha61	30–42	K[d],L_1[e],L_2[f]	0	ε_{ic}+6–1500
BeOmg	1970Be87	40–102	K	0	51[f]–2555
		40–102	L_1,L_2	0	51–2555
PaOmg	1986PaZM	8–40	K[e]	0	511–12775
		8–40	IPF	0	1431–12775

[a] ε_{ic} is the binding energy for the ic-shell
[b] Used for Z < 50
[c] Electronic factors are only calculated for even Z values at present
[d] Not used
[e] Used for Z < 40
[f] For Z=40–58: 51.1 keV; for Z=60–82: 102.2 keV; for Z=84–96: 1

Under development

2012Ki04: extension of BrIccFO (Z=111–126)

2020Do01: new Electronic factor tables (Z=4-100)

BrIcc

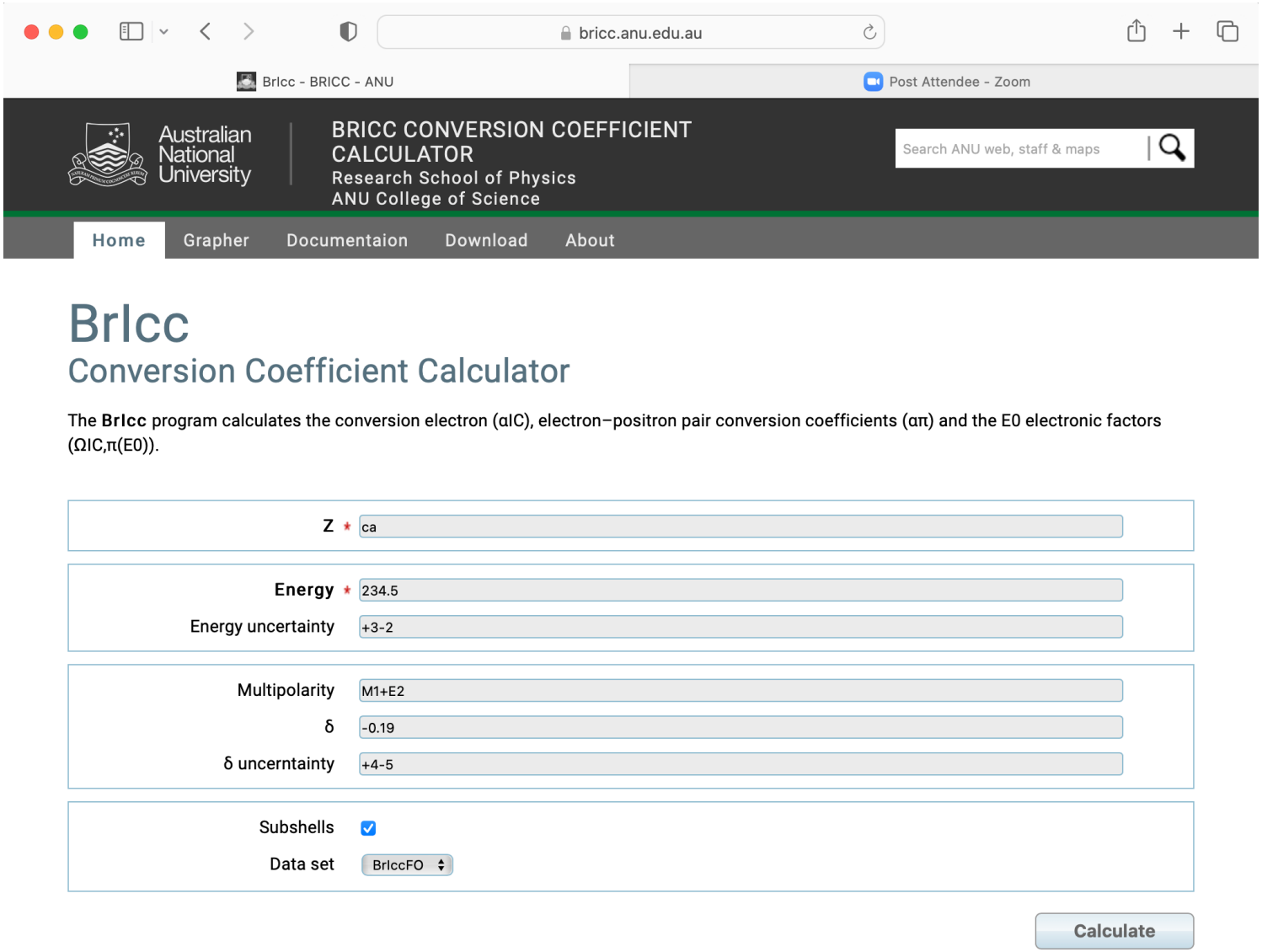
2008Ki07

- Install files (code, data files, manual) into one directory, defined with the **BrIccHome** environment variable
- Working with ENSDF files is a TWO step process
  1) Bricc <ENSDF file> - creates calculation report BrIcc.lst) and new G-records (Cards.new)
  2) Bricc <ENSDF file> merge – insert/replace/delete G, S_G records
- Always check ENSDF file for errors (use FMTCHK) before running BrIcc
- Uncertainty on theoretical ICC: 1.4% (1% theory, 0.4% interpolation)
- If MR is empty, BrIcc uses assumed mixing ratios:

  for E2/M1: MR= 1.00

  for M3/E2, E4/M3, M5/E4, M2/E1, M4/E3, E5/M4: MR= 0.10

  for E3/M2: MR= 1.00
- Installation and use: talk by Filip Kondev this afternoon
- More information in NimA 589 (2008) 202 and BrIcc Manual
- Report problems and or comments: Tibor.Kibedi@anu.edu.au
- Web interface: https://bricc.anu.edu.au


bricc.anu.edu.au
BrIcc - BRICC - ANU
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Australian National University
BRICC CONVERSION COEFFICIENT CALCULATOR
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BrIcc
Conversion Coefficient Calculator
The BrIcc program calculates the conversion electron (αIC), electron–positron pair conversion coefficients (απ) and the E0 electronic factors (ΩIC,π(E0)).
Z * ca
Energy * 234.5
Energy uncertainty +3-2
Multipolarity M1+E2
δ -0.19
δ uncerntainty +4-5
Subshells
Data set BrIccFO
Calculate

BrIccS v2.3 (9-Dec-2011)

Z=20 (Ca, Calcium)

γ-energy: 234.5 *(+3 -2)* keV

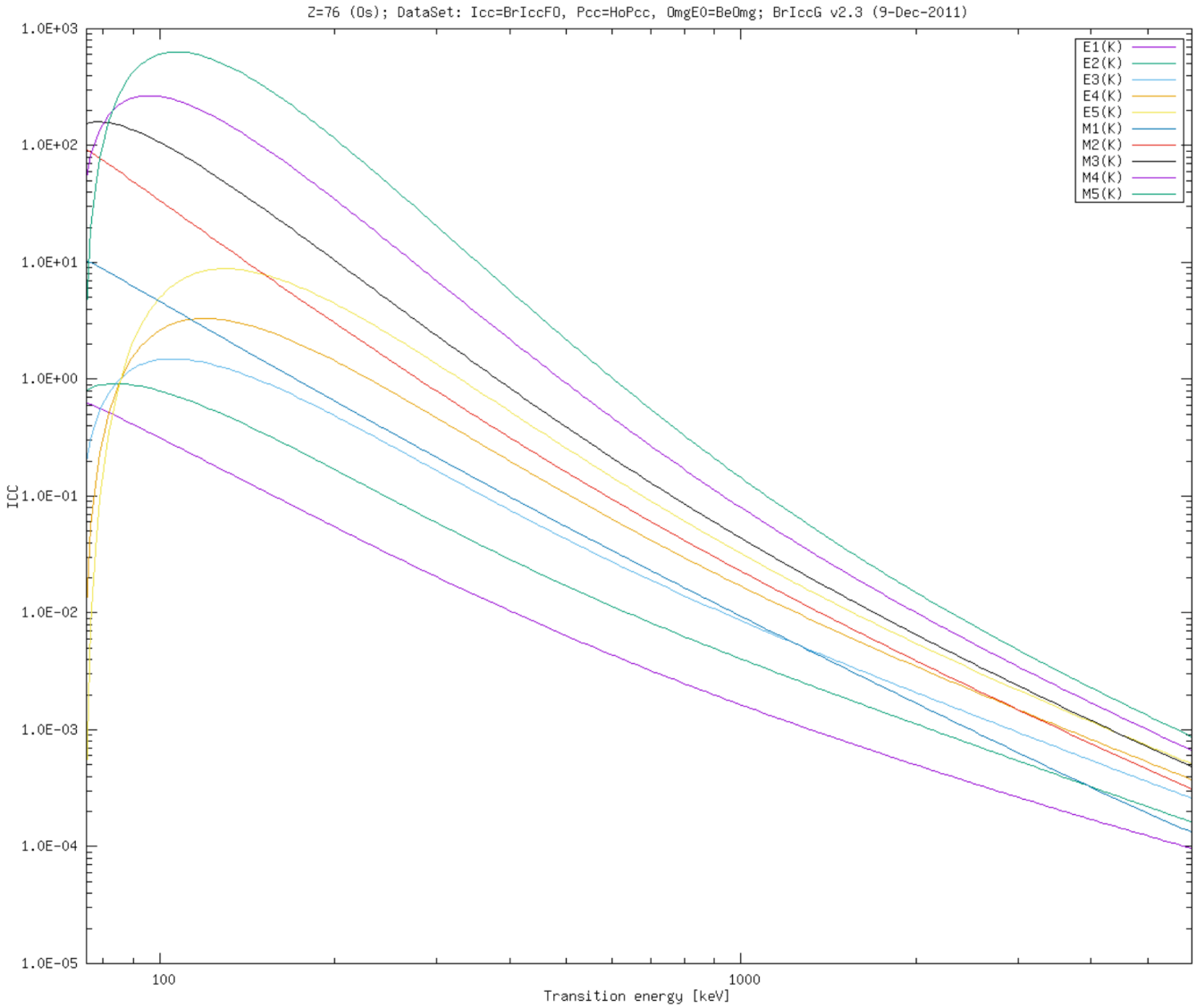
Mixing Ratio δ: -0.19 *(+4 -5)*

Data Sets: BrIccF0

Shell	E(ce)	M1	E2	Mixed ICC
Tot		1.587E-03	9.932E-03	0.00188 (17)
K	230.46	1.445E-03	9.044E-03	0.00171 (16)
L1	234.06	1.235E-04	7.579E-04	0.000146 (13)
L2	234.15	1.345E-06	1.347E-05	1.77E-6 (24)
L3	234.15	7.731E-07	1.832E-05	1.4E-6 (4)
L-tot	234.06	1.257E-04	7.897E-04	0.000149 (14)
K/L		1.150E+01	1.145E+01	11.5 (15)
M1	234.46	1.469E-05	8.990E-05	1.73E-5 (15)
M2	234.47	1.425E-07	1.425E-06	1.9E-7 (3)
M3	234.47	8.180E-08	1.939E-06	1.5E-7 (4)
M-tot	234.46	1.491E-05	9.327E-05	1.76E-5 (16)
L/M		8.428E+00	8.466E+00	8.4 (11)
N1	234.50	8.393E-07	5.136E-06	9.9E-7 (9)
N-tot	234.50	8.393E-07	5.136E-06	9.9E-7 (9)
L/N		1.497E+02	1.537E+02	150 (19)

BrIcc Grapher

2008Ki07

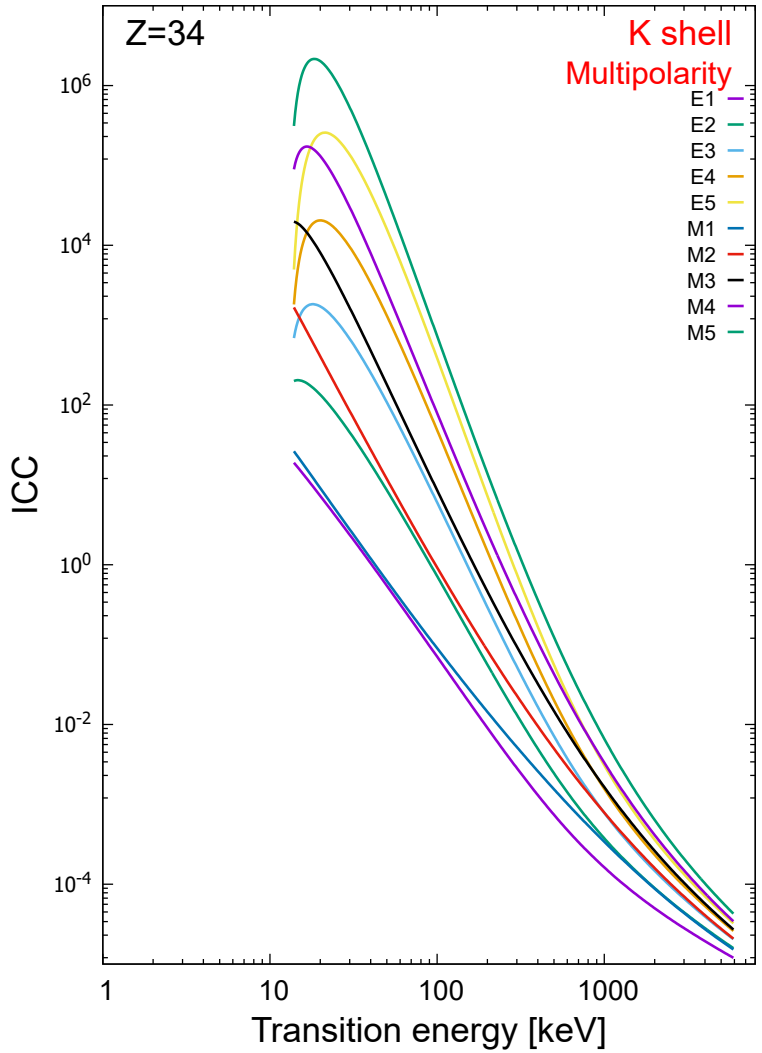


5 min break

BrIccMixing

- Aim to deduce multipole mixing ratio (MR or δ) from
  - Conversion coefficients
  - Ratios of CE intensities or ICC

$$\alpha(\pi' L'/\pi L) = \frac{\alpha(\pi L) + \delta^2 \alpha(\pi' L')}{1 + \delta^2}$$



BrIccMixing

- Aim to deduce multipole mixing ratio (MR or δ) from
  - Conversion coefficients
  - Ratios of CE intensities or ICC values (relative)

$$\alpha(\pi' L'/\pi L) = \frac{\alpha(\pi L) + \delta^2 \alpha(\pi' L')}{1 + \delta^2}$$

NOTE: CE data only gives absolute value of δ

  - Mixing ratios from γ-ray measurements (γ-ray angular distribution of $\gamma\gamma$ angular correlation)

NOTE: Not sensitive for magnetic or electric character

BrIccMixing

Input file

```
##################################################### comment
## ENSDF data
99TC  G 140.511   1  100       M1+E2      +0.13   4 ENSDF      title
#####################################################
99Tc 140.511 1          Control#1 - Z & transition energy
M1+E2 0.13  1.0         Control#2 - multipolarity, initial MR
# NsrKey     Shell    IccVal     Unc    Type
1969Ag04     L1/L2    12         4      R
1969Ag04     L1/L3    18         7      R   Input values - ratio
1969Ag04     L2/L3    1.7        7      R
1974Ga01     MR       +0.118     6      A
1981Ge05     K        0.097      3      A   Input values - ICC & MR
1981Ge05     T        0.119      3      A
*NEW ##############################################
```

Atomic shells (K, L1, L2, …, L12)
Ratios: L1/L2, L12/L3
Mixing ratio: MR

BrIccMixing – solution

Command: briccmixing <InputFile> :

- GnuPlot to create plot

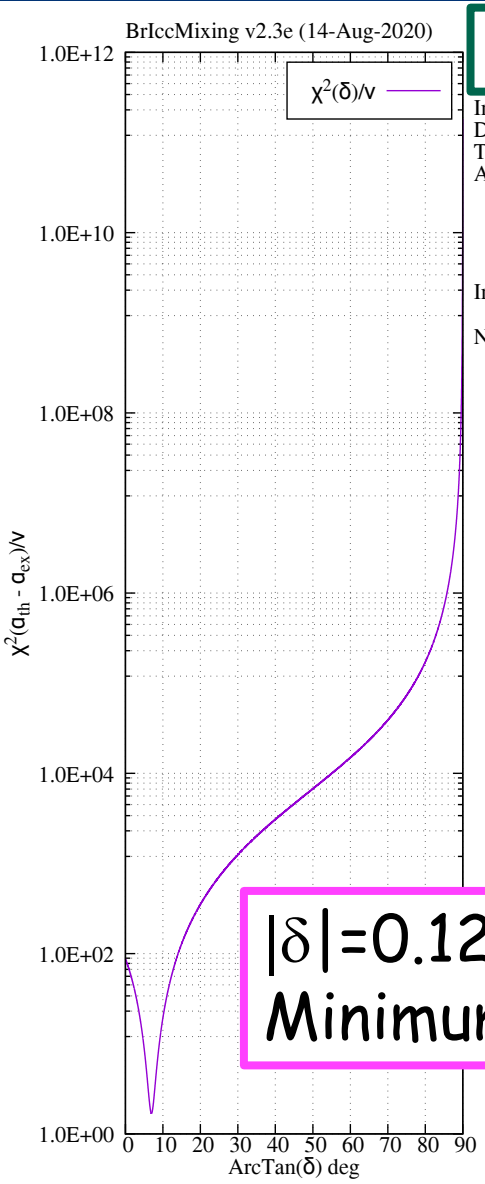
  NOTE: *ArcTan(δ)* on x-axis

- **Solution #1**

  Calculates reduced χ-squared as function of δ(MR)

  Solution: where χ-squared has a minimum

  Uncertainty: from δ values, where χ-squared risen by 1



^{99}Tc 140.5 keV M1+E2

Input file: BrIccMixingSamples.in
Data set: 99TC G 140.511 1 100 M1+E2 +0.13 4 ENSDF
Transition: 140.511 (1) keV
Adopted from fit: δ=0.122(+13-13); χ^2/ν= 1.70E+00

Input data ----------

NSRkey	Shell	Experiment Icc(Unc)	Fit Icc(Unc)	Type
1969Ag04	L1/L2	12(4)	15.84(31)	R
1969Ag04	L1/L3	18(7)	31.3(6)	R
1969Ag04	L2/L3	1.7(7)	1.98(4)	R
1974Ga01	MR	+0.118(6)	0.122	A
1981Ge05	K	0.097(3)	0.0985(14)	A
1981Ge05	T	0.119(3)	0.1129(16)	A

|δ|=0.122(13)
Minimum χ^2/N=1.7

BrIccMixing – solution

Command: briccmixing <InputFile> :

- GnuPlot to create plot

  NOTE: *ArcTan(δ)* on x-axis

- **Solution #1**

  Calculates reduced χ-squared as function of δ(MR)

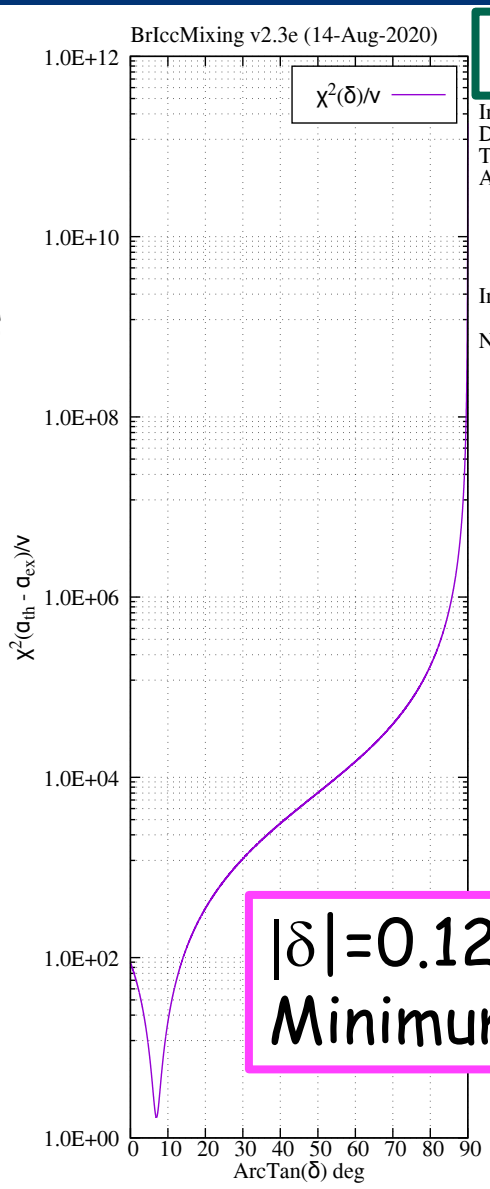
  Solution: where χ-squared has a minimum

  Uncertainty: from δ values, where χ-squared risen by 1

- Solution #2

  From quadratic fit using Minuit routines

|δ|=0.122063(19)



^{99}Tc 140.5 keV M1+E2

Input file: BrIccMixingSamples.in
Data set: 99TC G 140.511 1 100 M1+E2 +0.13 4 ENSDF
Transition: 140.511 (1) keV
Adopted from fit: δ=0.122(+13-13); χ^2/ν= 1.70E+00

Input data ----------

NSRkey	Shell	Experiment Icc(Unc)	Fit Icc(Unc)	Type
1969Ag04	L1/L2	12(4)	15.84(31)	R
1969Ag04	L1/L3	18(7)	31.3(6)	R
1969Ag04	L2/L3	1.7(7)	1.98(4)	R
1974Ga01	MR	+0.118(6)	0.122	A
1981Ge05	K	0.097(3)	0.0985(14)	A
1981Ge05	T	0.119(3)	0.1129(16)	A

|δ|=0.122(13)
Minimum χ^2/N=1.7

BrIccMixing – solution

Command: briccmixing <InputFile> :

- GnuPlot to create plot

  NOTE: *ArcTan(δ)* on x-axis

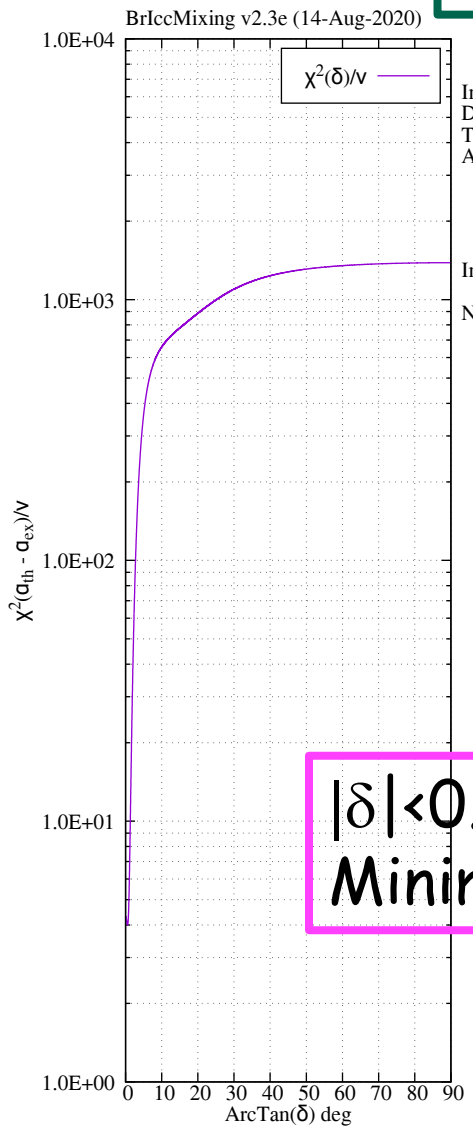
- **Solution #1**

  Calculates reduced χ-squared as function of δ(MR)

  Solution: where χ-squared has a minimum

  Uncertainty: only limit if χ-squared is NOT risen by 1 on right from δ_{min}

^{58}Co 24.889 keV M3+E4



Input file: BrIccMixing_samples.in
Data set: 58CO G 24.889 210.0389 12M3+E4 0.014 LT
Transition: 24.889 (21) keV
Adopted from fit: δ=0.010(+7); χ^2/ν= 4.00E+00

Input data

NSRkey	Shell	Experiment Icc(Unc)	Fit Icc(Unc)	Type
1950St22	K/LMN	1.9(2)	2.67(5)	R
1967St23	K/LMN	2.0(+11)	2.67(5)	R
1968Wi10	K/LMN	2.25(15)	2.67(5)	R
1968Wi10	K	1860(100)	1843(27)	A
1971Pl02	L1/L23	1.070(15)	1.054(20)	R
1971Pl02	M1/M23	1.19(6)	1.140(22)	R
1971Pl02	L/M	6.62(13)	7.02(15)	R
1971Pl02	N1/M1	0.034(10)	0.0456(9)	R

$|\delta|<0.0017$
Minimum $\chi^2/N=4.0$

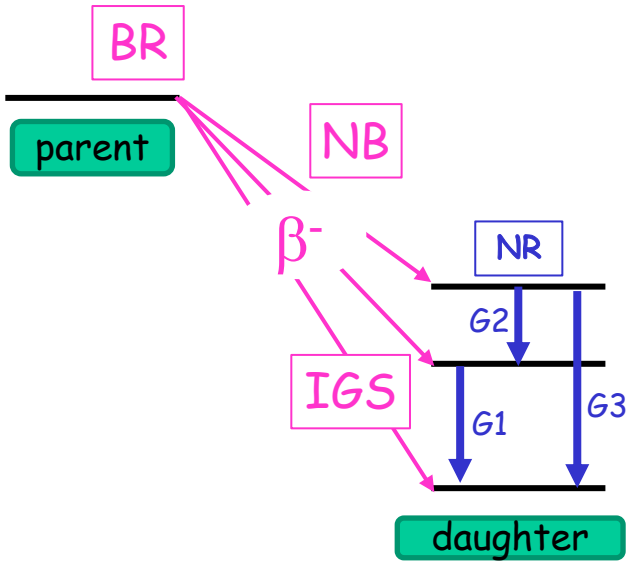
BrIccMixing Comments

Command: briccmixing <InputFile> :

- BrIcc need to be installed, put BrIccMixing executable into the same folder
- Gnuplot need to be installed and executable need to be in the PATH
- No new G-record is prepared. Document input data in G-comment record, put new MR on G-record
- Limitations:
  - Input data could not be a limit or have asymmetric uncertainties
  - Could not handle M1+E2+E0 multipolarities
  - Experimental ICC with uncertainty should not be outside of the two multipolarities
  - ICC energy dependent and there are cases, when different multipolarities overlap
  - Uncertainty may not be well defined if χ-squared minimum is >> (>10)

    Alternative method is under development
  - Minuit solution systematically underestimate uncertainty

Decay scheme normalisation and absolute intensities



NORMALISATION RECORD:

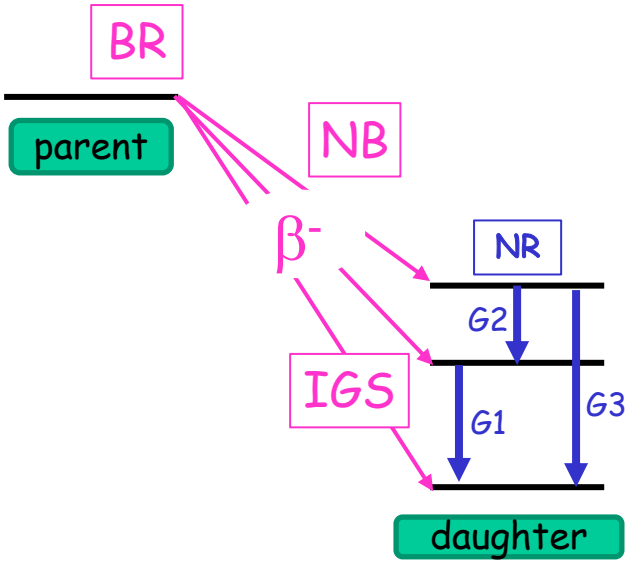
- **NR**: Multiplier for converting relative photon intensity (RI in the GAMMA record) to photons per 100 decays of the parent through the decay branch
- **BR**: Branching ratio multiplier for converting intensity per 100 decays through this decay branch to intensity per 100 decays of the parent nuclide.
- **NB**: Multiplier for converting relative β and EC intensities (IB in the B- record; IB, IE, TI in the EC record) to intensities per 100 decays through this decay branch.
- **IGS**: fraction (%) of direct β and EC feeding to the g.s.

GABS calculates

- <u>Single Data Set:</u> **NR** from **RI**, **CC**, **TI** (if given) , **BR** and **IGS**
- <u>Multiple Data Set:</u> **NR** and **BR** from **RI**, **CC**, **TI** (if given) , and **IGS**

Simple decay scheme

Simple decay scheme



1986Br21 uses G, the fraction of NOT populating the g.s.

GABS: Fractional g.s. feeding, IGS

$$G = \frac{100 - IGS}{100}$$

Definitions:

- Total transition intensity: **TI=RI*(1+CC)**
- Absolute γ-photon intensity: **%IG=NR*BR*RI** per 100 decays
- **NR** and **BR** not independent quantities:

GABS: Calculates **NR** only!

$$\mathrm{TI} = \mathrm{RI}^*(1+\mathrm{CC})$$

$$\mathrm{N} = \mathrm{NR}^*\mathrm{BR}$$

$$100 = \mathrm{BR} \times [\mathrm{IGS} + \mathrm{NR} \times \textstyle\sum_i \mathrm{TI(i)}]$$

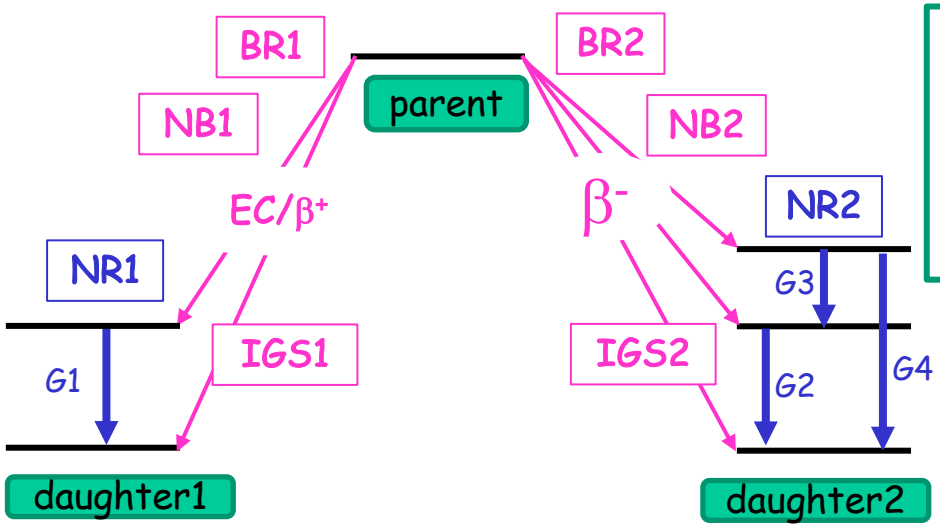
$$\mathrm{NR} = \frac{100 - \mathrm{IGS}}{100 \times \sum_i \mathrm{TI(i)}}$$

$$\%\mathrm{IG} = \mathrm{RI}^*\mathrm{NR}^*\mathrm{BR}$$

Complex decay scheme

Complex decay scheme with g.s. feeding

Assuming all RI`s are on the same scale or from the same experiment



$$100 = \sum_j BR(j) \times [IGS(j) + NR(j) \times \sum_i TI(i,j)]$$

$$\sum_j BR(j) = 1$$

$$BR(j) \times NR(j) = BR(k) \times NR(k)$$

GABS: Calculates **NR(i) & BR(i)**

Caution: Strong correlation between input parameters

New equations derived for uncertainties in **NR**, **BR** and **%IG**

$$BR(i) = \frac{\frac{100 - IGS(i)}{100} \sum_j TI(j,i)}{\sum_k \frac{100 - IGS(k)}{100} \sum_j TI(j,k)}$$

$$N = NR(i) \times BR(i) = \frac{100}{\sum_k \frac{100 - IGS(k)}{100} \sum_j TI(j,k)}$$

GABS – input ENSDF file

Gamma-rays for normalisation

- Must feed to the ground state
- RI or TI must be given; DRI or DTI could be blank, but $\Sigma(DTI(i)^2) > 0$!
- "X" in column 79
- **IGS=** on "2 N" record to specify α, β, EC decay branch **feeding to g.s.**; given in %.

GABS –normalization mode

Usage gabs –F ENSDF file

- **NR need to be blank in the input file**
- NR and BR will be obtained from a fit (using G`s marked with "X"; Ground state feeding: IGS=)
- New ENSDF & calculation report file created
- G-continuation records created with %IG=<Absolute photon Intensity>

  -C Calculate **%TI** using **NR** & **BR** from the N-record

  NOTE:

  -M Mark transitions going to the g.s. with "X" if RI>0 or TI>0

gabs ? *for quick help*

GABS – calculation mode

Usage gabs -C ENSDF file

- G-continuation records created with %IG=<Absolute photon Intensity>
- Uncertainty in %IG could be overestimated for transitions used for normalisation

GABS – marking transitions for normalisation

Usage gabs -M ENSDF file

- Transitions must have RI>0 or TI>0
- Output file created, ready to be used for normalisation

GABS – general comments

- GABS uses CC on G field to calculate TI

  Use BrIcc to populate CC on G-record before running GABS
- Put executable in a directory within the PATH.
- No additional data file needed
- No written manual, use GABS ? To get general help. Consult with sample input/output files.

Thanks