NUCLEAR EXCITED STATES + EM TRANSITION

- Characterized BY EXCITATION ENERGY E_x
  (Difference in BE between level & GS

- EXITATION BY
  - nuclear reactions
  - β- decay
  - thermal excitations
  - inelastic e⁻ / particle scattering
  - Coulomb excitations (interaction with other nucleons w/o strong / E-weak interaction)
  - neutrino scattering ([neutral] + charged current)

transitions:

1) γ-ray emission
2) internal conversion

$$E = (E_i - E_f) - E_B$$

e^- is emitted from low-lying electron

3) internal pair formation

$$\Delta E > 2 m_e c^2$$

1) $E_\gamma = E_i - E_f - \Delta E_{recoil}$, $100\,keV \lesssim E_\gamma < 15\,MeV$
↑ small

Photon characterized by angular momentum $\hbar L$
→ multi-pole radiation 2^L
+ parity

$L = 1$	DIPOL	EL	$(-1)^L$
2	Quadrupol...	M_L	$(-1)^{L+1}$

But different Parity for magnetic & electric radiation pattern
→ selection rules for transition → SELECTION RULES APP B

Transition Probabilities

$$\lambda(\bar{\omega}L) = \frac{8\pi}{L[(2L+1)!!]^2} \frac{1}{\hbar} \left(\frac{E_\gamma}{\hbar c}\right)^{2L+1} B(\bar{\omega}L)$$

$\bar{\omega}$: E or M

$$(2L+1)!! = 1 \cdot 3 \cdot 5 \ldots (2L+1)$$

$B(\bar{\omega}L)$ reduced transition probability
- computed from nuclear structure model
- contain i/f wave functions

simple:
- inert nucleus core + single nucleon
- single nucleon changes from one shell state to another
- radial wave function of initial and final state constant inside nucleus & vanish outside

→ ESTIMATES (in units of eV)

$\lambda_W(E1)\hbar = 6.8\times10^{-2} A^{2/3} E_\gamma^3$

weisskopf

$E2 \quad 4.9\times10^{-8} A^{4/3} E_\gamma^5$

$E3 \quad 2.3\times10^{-14} A^2 E_\gamma^7$

⋮

$\lambda_W(M1)\hbar = 2.1\times10^{-2} E_\gamma^3$

$M2 \quad 1.5\times10^{-8} A^{2/3} E_\gamma^5$

$M3 \quad 6.8\times10^{-15} A^{4/3} E_\gamma^7$

A: MASS #

E_γ in MeV

→ FIGURE

transitions between levels of opposite parity:

$\lambda_W(E1) \gg \lambda_W(M2) \gg \lambda_W(E3)$

same parity

$\lambda_W(M1) \gg \lambda_W(E2) \gg \lambda_W(M3)$ ..

Weisskopf estimates are crude
→ nuclei are more complicated systems

Especially for M1 often orders of
of magnitude lower due to poor
overlap of i/f wave functions

But for E2 often larger
→ more nucleons participate!

→ But "Standard" for comparison
to observed transitions

$$M_W^2(\bar{\omega}L) = \frac{\lambda(\bar{\omega}L)}{\lambda_W(\bar{\omega}L)} = \frac{\Gamma(\bar{\omega}L)}{\Gamma_W(\bar{\omega}L)}$$

$$\Gamma = \lambda\hbar \sim E_\gamma^{2L+1}$$

Recommended upper limits (Endt 1993)

RUL(E1)	= 0.5	W.U.
2	100	
3	50	
M1	10	
2	5	
3	10	

BRANCHING RATIOS

in units of energy widths $\Gamma = \lambda \cdot \hbar$

$$\Gamma_{TOT} = \sum_i \Gamma_i$$

BR: $$B = \frac{\Gamma_i}{\Gamma_{TOT}} \times 100\%$$

usually only the lowest (or lowest 2) for one transition are important

Example: $2^+ \rightarrow 1^+$: M1, E2, M3

$\bar{\omega}' L$, $\bar{\omega} L+1$

$$\Gamma_j(\bar{\omega}L+1; \bar{\omega}'L) = \Gamma_j(\bar{\omega}L+1) + \Gamma_j(\bar{\omega}L)$$

DEF: multipolarity mixing for γ-rays

$$\delta^2 = \frac{\Gamma_j(\bar{\omega}L+1)}{\Gamma_j(\bar{\omega}'L)}$$

→

$$\Gamma_j(\overline{\omega}'L) = \frac{1}{1+\delta_j^2} \frac{B_j}{100\%} \Gamma_{TOT}$$

$$\Gamma_j(\overline{\omega}L+1) = \frac{\delta_j^2}{1+\delta_j^2} \frac{B_j}{100\%} \Gamma_{TOT}$$

IN Practice : compare transitions
to different final states
instead

→ FIGURE

IN HOT PLASMA

TRANSITION FROM EXCITED STATES

BOLZMANN DISTRIBUTION

$$P_\mu = \frac{N_\mu}{N} \quad \frac{g_\mu e^{-E_\mu/kT}}{\sum_\mu g_\mu e^{-E_\mu/kT}} = \frac{g_\mu e^{-E_\mu/kT}}{G}$$

$g_\mu = (2J_\mu + 1)$ statistical weight

E_μ energy (excited state) above ground

J_μ spin of state

G : partition function

^{26}Al

origin : massive stars

$^{25}Mg(p,\gamma)^{26}Al$

WR STARS, SNe

↳ eject all that is in star

(exp C burn)

obs: 1809 KeV emission (COMPTEL)

$\tau_{1/2}$ $^{26}Al^{g} \simeq 7.17 \times 10^{5}$ yr

$^{26}Al^{m} \simeq 6.34$ s

PROBLEM IN STARS: T-sensitivity of DECAY

→ DESTROY in stellar interior!

other destruction in practice

$^{26}Al(n,p)^{27}Al$