Nuclear Physics and Astrophysics

PHY-302

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Lecture 13 - Gamma Radiation

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Material For This Lecture

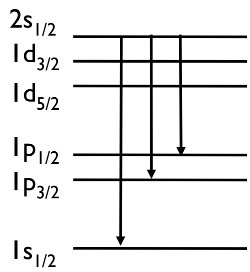
Gamma decay:

Definition

Quantum interpretation

Uses of gamma spectroscopy

Turn to γ decay - last of three radioactive decay modes
opens field of discussion to nuclear spectroscopy
Then move on to applications of what we have learned!



- Many α and β decays leave daughter in excited state
- Often decay to ground state is via gamma emission - high energy photon
- Study of gamma emission → deduce spin / parity of excited states
- Photon energy ~ 0.1 - 10 MeV reflects energy difference of nuclear states
  wavelengths ~ 100 - 10^3 fm
  10^6 shorter than visible light $E_\gamma = hc/\lambda \qquad hc = 1239 \text{ MeV fm}$
- Many details of nuclear structure are revealed through knowledge of excited states
- Thus gamma ray emission - standard tool of nuclear spectroscopy
- Also, photons attenuated less in matter than α and β particles

Consider decay of excited nucleus: N* → N + γ
From E_i to E_f : $E_i = E_f + E_\gamma + T_R$
T_R = non relativistic recoil of nucleus = $P_R^2/2m$
$0 = \mathbf{P_R} + \mathbf{P_\gamma}$
If $\Delta E = E_i - E_f$ and $E_\gamma = cp_\gamma$

$$\Delta E = E_\gamma + \frac{E_\gamma^2}{2mc^2}$$

Second term is a small nuclear recoil correction to maximum allowed photon energy

This recoil correction ~ 10^{-5} since $E_{\neq}$ ~1 MeV but M ~ A x 1000 MeV

Generally take $\Delta E = E_\gamma$ (except for the Mossbauer Effect, see later)

For low E_γ recoil energy < 1 eV (very small, mostly negligible)

If E_γ ~ 5-10 MeV, recoil ~100 eV
possibly large enough to move atom from position in lattice
radiation damage e.g. in semi-conductor devices

Internal conversion

competing process for nuclear energy emission:
Atomic electron wavefunctions can penetrate into nucleus
Excited nuclear state interacts with such electrons
"collision" of excited nucleon and an atomic electron
nucleon de-excites to lower energy state
electron is ionised
Transition energy converted into T_e kinetic energy of electron

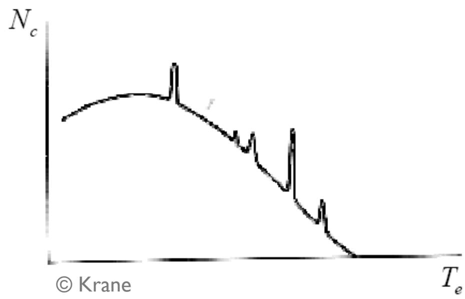
$$^A_Z X \rightarrow ^A_Z X^+ + e^-$$

This is different from beta decay!
No change in N or Z

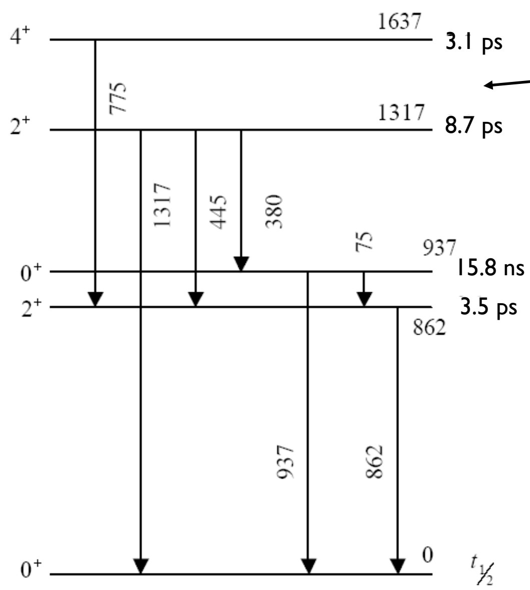
$$T_e = \Delta E - B$$

ΔE = transition energy
B = electron binding energy
T_e = electron kinetic energy

Following conversion there is a vacancy in electronic shells
Filled rapidly by cascade of electrons from higher shells
Characteristic X-ray emission is observed
Note: X-ray photons ~ keV & nuclear excitations ~ MeV



Many nuclei exhibit internal conversion & beta decay
These show peaks above continuous beta spectrum in low energy region



Consider lifetimes of nuclear excitations

1317 KeV level measured to have $t_{1/2}$ = 8.7ps

Thus decay const $\lambda = \ln 2/t_{1/2} = 8 \times 10^{-10}\ s^{-1}$

Total decay rate is sum of all rates:

$$\lambda_{tot} = \lambda_{1317} + \lambda_{445} + \lambda_{380}$$

Note: Approximation pure gamma emission dominates!
If e capture is competing process then need to account for this
$\lambda_{tot} = \lambda_\gamma + \lambda_e = \lambda_\gamma (1+\alpha)$ α is internal conversion coefficient = λ_e/λ_γ

Major reason for gamma ray study:

obtain information on excited nuclear states

Gamma rays easily detected

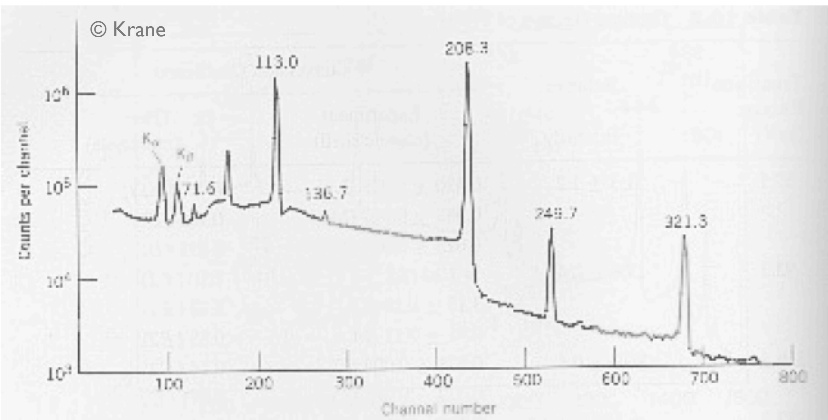
Energy resolution ~ 2 keV

Allows precision comparisons to theory

Most direct , precise, & easiest way to obtain properties of excitations

In ideal experiment:

gamma ray spectrum provides us energies & intensities of transitions
co-incidence measurements informs us about arrangement of states
absolute transition probabilities determined from half-lives of levels



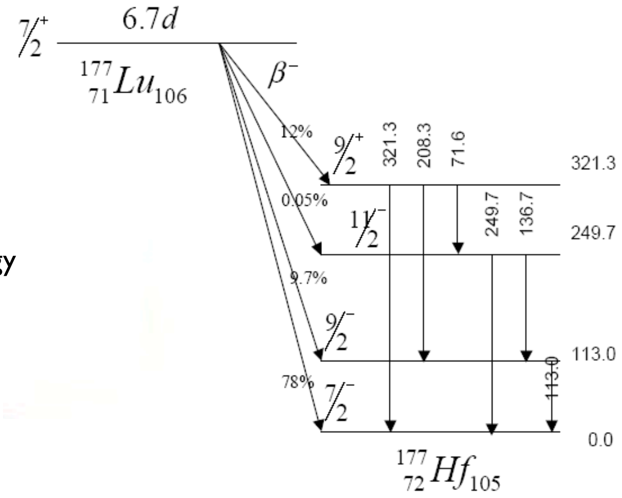
Gamma ray energy spectrum of ^{177}Lu (lutetium)

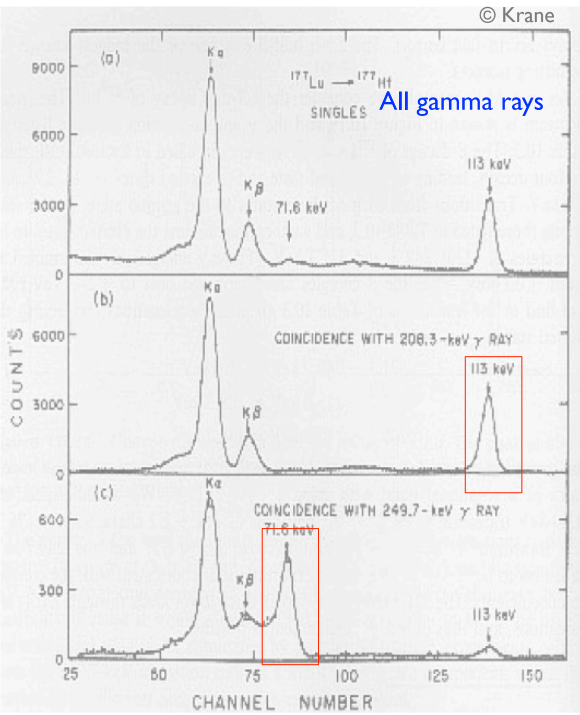
Gamma spectroscopy can be combined with beta spectroscopy

$$^{177}_{71}\mathrm{Lu}_{106} \rightarrow \, ^{177}_{72}\mathrm{Hf}_{105} + e^- + \bar{\nu}_e$$

Hf = Hafnium

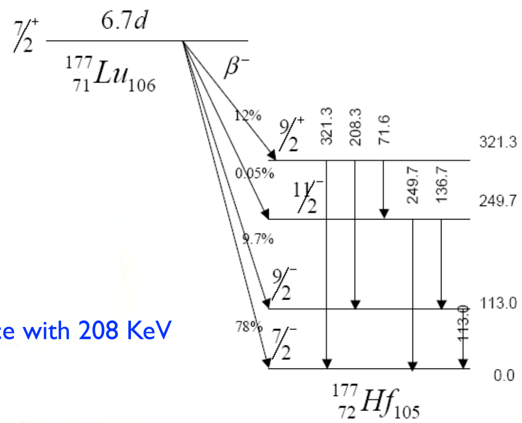
End point of beta energy spectrum
tells us of Q for the decay to lowest energy
state of daughter





coincidence with 208 KeV

coincidence with 249 KeV



Coincidence technique helps determine structure

We have now covered all fundamental aspects of nuclear physics

Will now move on to discover applications & study some in detail

- e.g. fusion / fission reactions
- medical applications

Summary

Gamma spectroscopy - deduce nuclear structure

Gamma absorbtion

Next Lecture

Neutron Physics