

# RADIATION DETECTION AND MEASUREMENT

## *Lecture 1*

### RADIATION SOURCES

- Radiation differs in hardness, the ability to penetrate through a thickness of material
- Range includes soft ( $\alpha$ , low E x-rays), which requires sources to be deposited in thin layers.
- Physically thicker sources are subject to “self – absorption” which affect the quality (energy spectrum) and quality of the radiation.

### RADIOACTIVITY

Activity of a radioisotope is defined by its rate of decay

$$\left. \frac{dN}{dt} \right|_{\text{decay}} = -\lambda N$$

where  $N$  is the number of radioactive nuclei and  $\lambda$  is the decay constant

Units: SI: Becquerel (Bq), traditional Curie (Ci)

$$1\text{Bq} = 2.703 \times 10^{-11} \text{Ci}$$

$$1\text{Ci} = 3.7 \times 10^{10} \text{Bq}$$

$\text{Bq}$  is disintegrations per second

$\text{Ci}$  is activity of 1 gm pure Ra-226

Specific activity ( $sa$ ) is the activity per unit mass of the radioisotope sample. Pure or “carrier-free” sample is obtained free from other nuclear species

$$sa = \frac{\text{activity}}{\text{mass}} = \frac{\lambda N}{NM / A_v} = \frac{\lambda A_v}{M}$$

$M$ : molecular weight of sample

$A_v$ : Avogadro's # =  $6.02 \times 10^{23}$  particles/mole

$\lambda$  = decay constant ( $= \ln 2 / T_{1/2}$ )

- radioisotopes tend to be diluted in larger concentrations of stable nuclei; and thus are not carrier-free
- for sources with high self absorption, one requires high specific activity to maximize the number of radioactive nuclei in a given thickness
- high  $sa$  is acquired from samples with large decay constant

## ENERGY

- eV is defined as the kinetic energy gained by an electron ( $e^-$ ) by its acceleration through a potential difference of 1V
- for ionizing radiation keV & MeV are the magnitudes of interest
- # of charges accelerates through potential multiplies energy;  
 $\alpha^{2+}$  through 1000V = 2 keV
- SI unit is joule [J];  $1\text{eV} = 1.602 \times 10^{-19} \text{ J}$
- Energy and frequency of quanta (photon)
- 

$$E = h\nu$$

$h$  : planck's constant (  $6.626 \times 10^{-34} \text{ J}\cdot\text{s}$ ,  $4.135 \times 10^{-15} \text{ eV}\cdot\text{s}$ )

$\nu$  : frequency

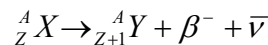
- Energy wavelength relation

$$\lambda[m] = \frac{1.240 \times 10^{-6}}{E[eV]} \Rightarrow \frac{1.240}{E[keV]} = \lambda[nm]$$

## FAST ELECTRON SOURCES

Includes:  $\beta^-$ , IC, Auger electron

### Beta decay, $\beta^-$



$X$ ,  $Y$  are the initial and final nuclear species and  $\bar{\nu}$  is the anti neutrino (lepton conservation)

- anti-neutrino and neutrino's have a small interaction probability with matter, we consider them undetectable
- Fig 1.1 shows the decay scheme and resulting  $\beta^-$  spectrum with a defined end point energy (peak)
- end point is defined since average energy is  $1/3 E_{\text{peak}}$

### Internal Conversion, IC

$$E_{e^-} = E_{ex} - E_b$$

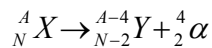
- starts with de-excitation of parent species (often  $\beta^-$  decay), nucleus
- emission of  $\gamma$ -particle ( $E_{ex}$ ) which interacts with an internal shell electron through transfer
- the electron then is ejected at  $E_{e^-}$  where  $E_b$  is the binding energy of the shell
- table 1.2 shows some common sources

## Auger Electron

- similar to IC only the energy originates from the electron shells not the nucleus
- a preceding process leaves a vacancy
- the resulting x-ray may leave the atom or transfer energy to outer electron, x-ray is characteristic and monochromatic
- the release of the outer electron is an Auger electron

## HEAVY CHARGED PARTICLE SOURCES

### Alpha decay ( $\alpha^{2+}$ )



- $\alpha$  particles appear in quasi mono energetic groups
- these groups are produced due to the requirement of conservation of angular momentum between wave functions for the initial and final nuclei
- generally, this leaves the daughter nuclei in some excited state, where a  $\gamma$  decay will shortly follow to de-excite the daughter to the ground state
- this requirement produces a unique Q value and thus several peaks, characterized by Q

### Digression:

$$m_x c^2 = m_{x'} c^2 + T_{x'} + m_\alpha c^2 + T_\alpha \quad \text{conservation of energy}$$

$$(m_x - m_{x'} - m_\alpha) c^2 = T_{x'} + T_\alpha = Q$$

$$p_\alpha = p_{x'} \quad \text{conservation of momentum}$$

Since decay of  $\alpha \sim 5$  MeV we can use non-relativistic momentum values  $T = p^2/2m$

$$2m_\alpha T_\alpha = 2T_{x'} m_{x'}$$

$$T_{x'} = T_\alpha (m_\alpha / m_{x'})$$

$$T_\alpha = Q - T_{x'} = Q - T_\alpha (m_\alpha / m_{x'})$$

$$T_\alpha = Q / (1 + m_\alpha / m_{x'})$$

since  $m_\alpha / m_{x'}$  is small ( $m_{x'}$  is a heavy nucleus)

we can  $\approx$  with  $4/A-4$  ( as long as  $A \gg 4$ )

$$\therefore T_\alpha = Q / (A / A - 4) = Q(A - 4) / A$$

- note the branching ratios in Fig 1.3, the relative abundance of each of the decays during emission.

## SPONTANEOUS FISSION

- this will only occur when  $Q > 0$ , thus there is free energy from the charge in rest mass and promotes a spontaneous reaction
- this is not significant, except in the transuranic isotopes with a large mass #
- this process of fracturing results in fragments of medium weight positive ions with a mass distribution shown in fig 1.4a
- fragments fall into clusters of “light group” ( $\bar{m} \sim 108$ ) and “heavy group” ( $\bar{m} \sim 143$ )
- Fragments also have T with a bimodal distribution where higher T is associated with lighter group and lower T with heavy group.