RADIATION DETECTION AND MEASUREMENT
Lecture 1

RADIATION SOURCES

- Radiation differs in hardness, the ability to penetrate through a thickness of material
- Range includes soft (α, 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

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

where N is the number of radioactive nuclei and λ is the decay constant

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

$$1Bq = 2.703 \times 10^{-11}\,Ci$$
$$1Ci = 3.7 \times 10^{10}\,Bq$$

Bq is disintegrations per second
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

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

M: molecular weight of sample
A_v: Avogadro's # = 6.02×10^{23} particles/mole
λ = 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 kinectic 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; α^{2+} through 1000V = 2 keV
- SI unit is joule [J]; 1eV = 1.602 x 10^{-19} J
- Energy and frequency of quanta (photon)
-

$$E = h\nu$$

h : planck's constant (6.626 x 10^{-34} J·s, 4.135 x 10^{-15} eV·s)
ν : 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: β^-, IC, Auger electron

Beta decay, β^-

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^- + \overline{\nu}$$

X, Y are the initial and final nuclear species and $\overline{\nu}$ 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 β^- spectrum with a defined end point energy (peak)
- end point is defined since average energy is 1/3 E_{peak}

Internal Conversion, IC

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

- starts with de-excitation of parent species (often β^- decay), nucleus
- emission of γ-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 (α^{2+})

$$^{A}_{N}X \rightarrow {}^{A-4}_{N-2}Y + {}^{4}_{2}\alpha$$

- α 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 γ 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:

$$m_x c^2 = m_{x'} c^2 + T_{x'} + m_\alpha c^2 + T_\alpha$$

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

conservation of energy

$$p_\alpha = p_{x'}$$

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 (*mx'* is a heavy nucleus)
we can ≈ with 4/A-4 (as long as A >> 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" ($\overline{m}$ ~ 108) and "heavy group" ($\overline{m}$ ~143)
- Fragments also have T with a bimodal distribution where higher T is associated with lighter group and lower T with heavy group.