LECTURE 2

Sources of Electromagnetic Radiation

- γ-rays following β^- decay, annihilation, γ rays following nuclear reactions, bremsstrahlung, characteristic x-rays, synchrotron

Beta decay

- Includes β^-,β^+ (positron) and electron capture (competes with β^+)
- γ's are emitted after particulate radiation, where daughter nucleus is left in an excited state
- γ's are quasi-mono energetic and have a defined energy equal to the difference between the excited and stable states
- General transition reactions

$$\beta^- : n \rightarrow p^+ + e^-$$

$$\beta^+ : p \rightarrow n + e^+$$

$$ec : p + e^- \rightarrow n$$

Annihilation

- after a β^+ decay, the β^+ particle will only travel a short distance (small MFP)
- when low on T the β^+ will find an electron and the two will combine to form two γ's with E = 511 keV each
- thus there is a threshold on β^+ emission of 1.02 MeV (to allow for both photons)

γ following nuclear reaction

- i.e. ${}^4_2\alpha + {}^9_4Be \rightarrow {}^{12}_6C^* + {}^1_0n$
- the de-excitation of ${}^{12}_6C^*$ will be in the form of a γ
- also found after the absorption of thermal neutrons

Bremstrahlung (braking)

- produced when fast electron interact with matter
- fraction of energy converted to brems is proportional to the energy of the electron
- a monoenergetic group of electron produce a spectrum of γ's
- found in x-ray tubes, β particles, electrons in accelerators, cosmic rays

Characteristic x-rays

- classified by the shell with a vacancy being filled in spectroscopic notation
- i.e. K_α is the energy emitted from a vacancy filled in the K shell from an electron in the L shell

K_β would be an electron from the m shell

L_α is a vacancy filled in the L shell from an electron in the M shell, etc.

- X_α will have less energy than X_β (higher shell, more E)
- Fluorescent yield is the fraction of all cases in which the excited atom emits a characteristic γ in its de-excitation

Excitation by Radioactive Decay:

- E.C. : the nucleus captures an electron (generally a K shell) leaving a K shell vacancy
- I.C. : the nucleus emits energy which ejects an electron, leaving a vacancy
- Table 1.4 lists some low energy x-ray sources

Excitation by External radiation:

- an external radiation strikes a target creating ionized atoms (sources; x-rays, electron, α^{2+})
- target will determine energies of characteristic radiation, low Z- soft, high Z- harder
- In all cases the energy of the sources must exceed the energy of the γ's you are trying to produce.

X-ray fluorescence: where x-ray gammas interact with the target (generally through photoelectric absorption) and emit a characteristic x-ray of the target

- α^{2+} particles are a convenient way to excite a target and keep the spectrum relatively free of brems contamination, since they tend to not decay through electron modes and have little γ contributions of their own, see table 1.5 for the branching ratios of two common sources ^{210}Po & ^{244}Cm.

Synchrotron

- energetic electron are bent into circular orbits, where the change in momemtum (direction changes) causes the beam to lose some energy during each cycle.
- Allows for highly mono- chromatic beams, with monochromators, with a wide energy range ~ eV-10^4 eV

Neutron Sources

Spontaneous Fission

- most common is ^{252}Cf producing ~ 3.8 neutrons on average and 9.7 γ's
- the spectrum of neutrons is governed by

$$\frac{dN}{dE} = E^{1/2} e^{-E/T} \text{, with T = 1.3 MeV}$$

Radioisotope (α,n) sources

- (α,n) refers to the incident particle & resultant particle
  in this case $\alpha^{2+} + X \rightarrow Y + {}_0^1n$
- ${}_2^4\alpha + {}_4^9Be \rightarrow {}_6^{12}C + {}_0^1n$, this reaction produces a maximum neutron yield (irradiating Be with α) , Q value = +5.71 MeV
- All the α emitters of practical interest are actinide elements and a stable metal of the actinide can be formed by MBe_{13}, where M is the actinide element
- this metallurgical combo allows the α's to interact with the Be nucleus without intermediate energy loses
- Issue with losses are seen in Fig 1.11 where it is shown higher energy α's are required to get more neutrons
- Table 1.6 shows the characteristics of several MBe_{13} sources
- ^{239}Pu/Be is the most widely used but ^{241}Am/Be is an alternative
- when used for calibration, caution must be taken to account for impurities which may have shorter $T_{1/2}$, and α emitting daughters; this may lead to an increase in the n yield

<u>Photoneutron Sources</u>

- Photoneutron emitters are sources that emit neutrons after absorbing γ's
- ${}_4^9Be + h\nu \rightarrow {}_4^8Be + {}_0^1n$, Q = -1.66 MeV
  ${}_1^2H + h\nu \rightarrow {}_1^1H + {}_0^1n$, Q = -2.226 MeV
- Having (-Q) means hν ≥ Q to allow the reaction
- For γ's with more than this minimum, the energy of the neutron can be calculated from $E_n(\theta) \cong \frac{M(E_\gamma + Q)}{m+M} + \frac{E_\gamma[2mM(m+M)(E_\gamma + Q)]^{1/2}}{(m+M)^2}\cos\theta$

Where
θ is the angle between the γ and n
E_γ is the γ energy
M is the mass of the recoil nucleus x c^2
m is the mass of the neutron x c^2

<u>Reactions from Accelerated Charged Particles</u>

$D-D: {}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n$ Q = 3.26 MeV

$D-T: {}_1^2H + {}_1^3H \rightarrow {}_2^4He + {}_0^1n$ Q = 17.6 MeV

Aside: This is one of the only ways to get (^{3}He) which is important for cooling applications.
There are a number of the other charged particle reactions with (-Q's), but these require an accelerator to allow the reaction.