BM-3252 MEDICAL PHYSICS

UNIT II

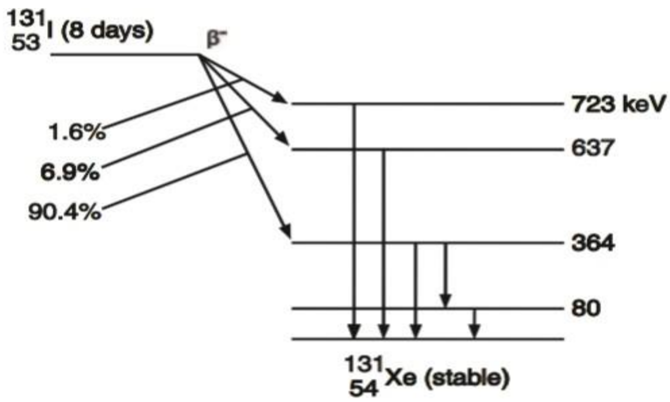
Beta decay

- When a radionuclide is neutron rich, that is, the N/Z ratio is greater than that of the nearest stable nuclide, it decays by the emission of a β^--particle and an antineutrino, $\overline{\nu}$.
- In the β^- decay process, a neutron is converted to a proton, thus raising the atomic number

$$n \rightarrow p + \beta^- + \overline{\nu}$$

  Z of the product by 1.
- The difference in energy between the parent and daughter nuclides is called the transition or decay energy, denoted by Emax.
- The β^--particles carry Emax or part of it, exhibiting a spectrum of energy. The average energy of the β^- particles is about one-third of Emax.
- This observation indicates that β^--particles often carry only a part of the transition energy, and energy is not apparently conserved in β^- decay.
- To satisfy the law of energy conservation, a particle called the antineutrino, with no charge and a negligible mass has been postulated, which carries the remainder of Emax in each β^--decay.
- After β^--decay, the daughter nuclide may exist in an excited state, in which case, one or more γ-ray emissions or internal conversion will occur to dispose of the excitation energy.
- In other words, β^--decay is followed by isomeric transition if energetically permitted.
- Beta-minus decay can be described by the following equation:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \underset{\text{(negatron)}}{\beta^-} + \underset{\text{(antineutrino)}}{\overline{\nu}} + \text{energy}$$



- It should be noted that in β−-decay, the atomic number of the daughter nuclide is increased by 1 and the mass number remains the same. Decay modes in which the mass number remains constant are called isobaric transitions.

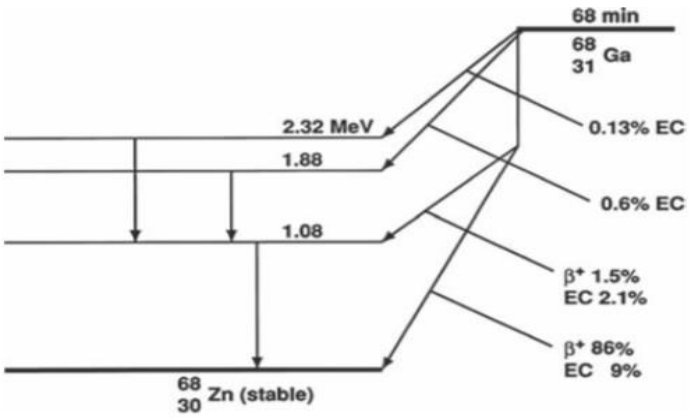
Positron (β^+) decay

- When a radionuclide is proton rich, that is, the N/Z ratio is low relative to that of the nearest stable nuclide; it can decay by positron (β^+) emission accompanied by the emission of a neutrino (ν), which is an opposite entity of the antineutrino.
- Positron emission takes place only when the energy difference (transition energy) between the parent and daughter nuclides is greater than 1.02MeV.
- In β^+-decay, essentially a proton is converted to a neutron plus a positron, thus, decreasing

$$p \rightarrow n + \beta^+ + \nu$$

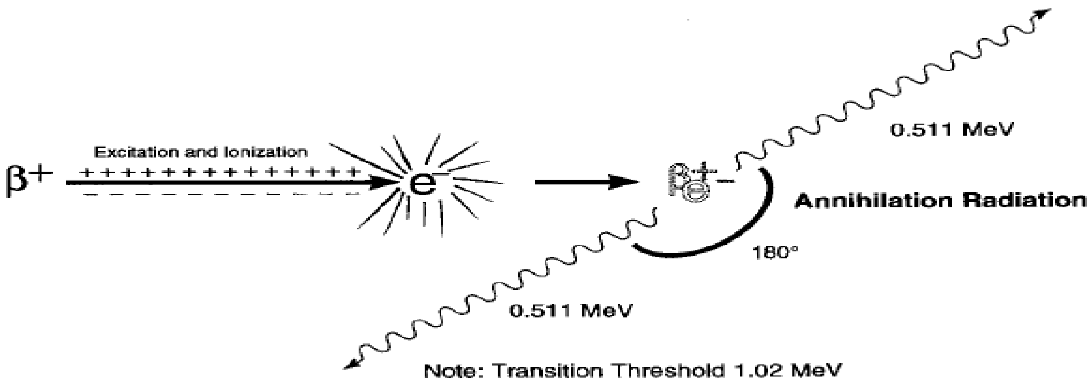
  the atomic number Z of the daughter nuclide by 1.
- The requirement of 1.02MeV for β^+-decay arises from the fact that one electron mass has to be added to a proton to produce a neutron and one positron is created.

- Since each electron or positron mass is equal to 0.511MeV, one electron and one positron are equal to 1.02MeV, which is required as a minimum for β^+-decay.



- The energetic β^+-particle loses energy while passing through matter. The range of positrons is short in matter.
- When it loses almost all of its energy, it combines with an atomic electron of the medium and is annihilated, giving rise to two photons of 511 keV emitted in opposite directions. These photons are called **annihilation radiations**.
- Beta-plus decay can be described by the following equation:

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \underset{(positron)}{\beta^+} + \underset{(neutrino)}{\nu} + \text{energy} $$



Some examples of β^+-decay:

$$^{18}_{9}F \rightarrow {}^{18}_{8}O + \beta^+ + \nu$$
$$^{68}_{31}Ga \rightarrow {}^{68}_{30}Zn + \beta^+ + \nu$$
$$^{13}_{7}N \rightarrow {}^{13}_{6}C + \beta^+ + \nu$$
$$^{15}_{8}O \rightarrow {}^{15}_{7}N + \beta^+ + \nu$$

Electron Capture

- Decay by electron capture (EC) is an alternative to the β^+-decay for proton rich radionuclides with N/Z lower than that of the stable nuclide.
- In EC decay, an electron from an extranuclear shell, particularly the K shell because of its proximity, is captured by a proton in the nucleus, forming a neutron accompanied by the emission of a neutrino for conservation of energy.

$$p + e^- \rightarrow n + \nu$$

- In this process, the atomic number of the daughter nuclide is lowered by 1. The EC process occurs usually in nuclides having excitation energy less than 1.02MeV.
- In nuclides having excitation energy greater than 1.02MeV, both EC and β^+-decay can occur, although the probability of β^+-decay increases with higher excitation energy.
- In EC decay, analogous to the situation in internal conversion, a vacancy is created inthe shell from which the electron is captured.
- It is filled in by the transition of an electron from the next upper shell, in which case the difference in energy between the two shells appears as a characteristic x-ray of the daughter nuclide. Instead of characteristic x-ray emission, the Auger process can occur, whereby an Auger electron is emitted.
- Electron capture decay can be described by the following equation:

$$^{A}_{Z}X + e^- \rightarrow {}_{Z-1}^{A}Y + \underset{\text{(neutrino)}}{\nu} + \text{energy}$$

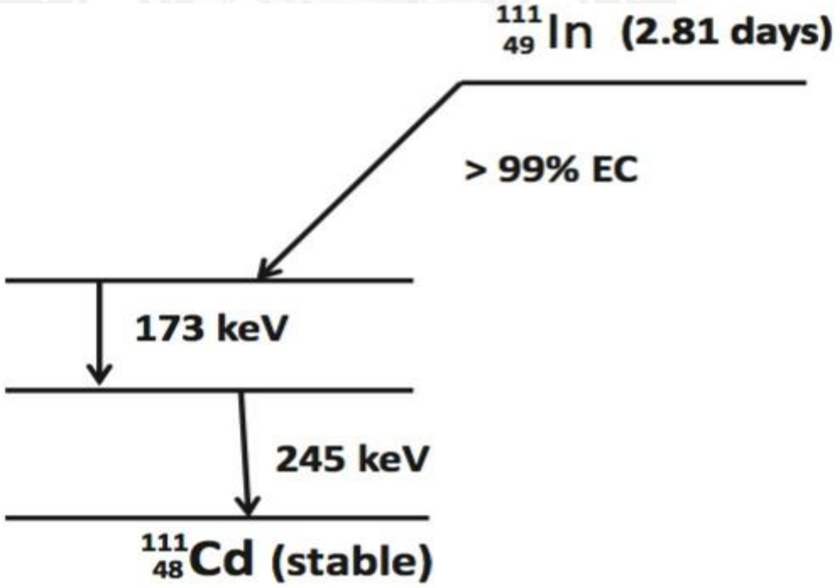
- The net effect of electron capture is the same as positron emission: the atomic number is decreased by 1, creating a different element, and the mass number remains unchanged.

- Therefore, electron capture is isobaric and results in an increase in the N/Z ratio.

Some examples of EC decay:

$$^{111}_{49}\mathrm{In} + e^- \longrightarrow {}^{111}_{48}\mathrm{Cd} + \nu$$
$$^{67}_{31}\mathrm{Ga} + e^- \longrightarrow {}^{67}_{30}\mathrm{Zn} + \nu$$
$$^{125}_{53}\mathrm{I} + e^- \longrightarrow {}^{125}_{52}\mathrm{Te} + \nu$$
$$^{57}_{27}\mathrm{Co} + e^- \longrightarrow {}^{57}_{26}\mathrm{Fe} + \nu$$
$$^{123}_{53}\mathrm{I} + e^- \longrightarrow {}^{123}_{52}\mathrm{Te} + \nu$$

The EC Process



BM-3252 MEDICAL PHYSICS

UNIT II

Sources of Radioisotopes Natural Radioactivity

- Natural sources include cosmic rays, terrestrial, and internal. **Cosmic rays** have always bombarded the earth. A typical U.S. resident receives 0.29 mSv (29 mrem) from cosmic rays.
- The earth's atmosphere provides some shielding from cosmic rays. This shielding is reduced at higher elevations, and the cosmic ray dose is increased.
- **Terrestrial background** originates from radioisotopes that are found everywhere in our surroundings. All elements found in nature have radioactive isotopes, many of which are also present in the environment.
- The exact composition of soil influences the local terrestrial background, because the

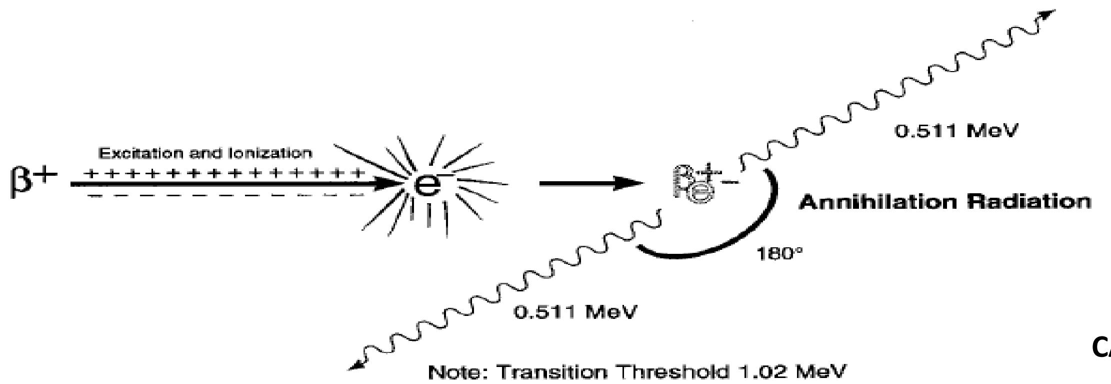


FIGURE 18-4. Annihilation radiation.