Decay Types and Conversion of Nuclides in Radioactivity

In general, radioactive decays can be divided into alpha, beta, and gamma decays. However, other process may also be considered as types of decay.

• **Alpha decay**

  In an alpha, α, decay, a helium nucleus \(^4\text{He}\) is emitted from an atomic nucleus. Since \(^4\text{He}\) consists of 2 protons and 2 neutrons (mass number = 4), the parent nuclide \(^M\text{P}^Z\) becomes a daughter nuclide \(^{M-4}\text{D}^{Z-2}\) after the emission of an alpha.

  \[
  \text{M}_P^Z \rightarrow \text{M}^{-4}_D^{Z-2} + 4\text{He}^2
  \]

  Some typical examples of alpha decays are:

  \[
  \begin{align*}
  ^{235}\text{U}^{92} & \rightarrow ^{231}\text{Th}^{90} + 4\text{He}^2 \\
  ^{238}\text{U}^{92} & \rightarrow ^{234}\text{U}^{90} + 4\text{He}^2 \\
  ^{208}\text{Po}^{84} & \rightarrow ^{204}\text{Pb}^{82} + 4\text{He}^2
  \end{align*}
  \]

  Many isotopes of elements with atomic number greater than 83 are alpha emitters. Some rare earth elements (\(^{114}\text{Nd}\), \(^{146}\text{Sm}\), ... \(^{174}\text{Hf}\)) and some light elements (\(^8\text{Li}\), \(^9\text{Li}\) etc) also emit alpha particles.

• **Beta decay** The emission of a negative electron, a positive electron (positron), or the capture of an atomic orbital electron (EC) is called a **beta decay process**

  - Negative electron emission
    A *free* neutron (n) outside a nucleus is unstable, and it emits an electron and becomes a proton (p). The proton and the electron are the components of a hydrogen atom. A company particle in the emission of electron is the antineutrino \(\nu^*\).

    \[
    \text{n} \rightarrow \text{p}^+ + \text{e}^- + \nu^*
    \]

    The antineutrino is the antiparticle of *neutrino*.

    When a nuclide \(^M\text{P}^Z\) emits an electron, we may consider one of the neutron in the nucleus being converted to a proton. For example,

    \[
    \begin{align*}
    ^{14}\text{C}^6 & \rightarrow ^{14}\text{N}^7 + \text{e}^- + \nu^* \\
    ^{40}\text{Ca}^{19} & \rightarrow ^{40}\text{Ca}^{20} + \text{e}^- + \nu^* \\
    ^{50}\text{V}^{23} & \rightarrow ^{50}\text{Cr}^{24} + \text{e}^- + \nu^* \\
    ^{87}\text{Rb}^{37} & \rightarrow ^{87}\text{Sr}^{38} + \text{e}^- + \nu^*
    \end{align*}
    \]

  - Positive electron (positron) emission
    A positive electron is called *positron*, which is the antiparticle of electron. The company particle for positron
emission is a neutrino (\(v\)). Some examples are given here to illustrate the process:

\[
\begin{align*}
22\text{Na}^{11} & \rightarrow 22\text{Ne}^{10} + e^+ + \nu \\
21\text{Na}^{11} & \rightarrow 21\text{Ne}^{10} + e^+ + \nu \\
30\text{P}^{15} & \rightarrow 30\text{Si}^{14} + e^+ + \nu \\
34\text{Cl}^{17} & \rightarrow 34\text{S}^{16} + e^+ + \nu \\
116\text{Sb}^{51} & \rightarrow 116\text{Sn}^{50} + e^+ + \nu
\end{align*}
\]

- **Electron capture (EC)**

  The electron capture process is in competition with positron emission. Both processes reduce the number of proton in the nucleus. Examples of EC are:

\[
\begin{align*}
48\text{V}^{23} & \rightarrow 48\text{Ti}^{22} + e^+ + \nu (50\%) \\
48\text{V}^{23} & \rightarrow 48\text{Ti}^{22} + \nu (+\text{X-ray}) (50\%) \\
40\text{K}^{19} & \rightarrow 40\text{Ar}^{18} + e^- + \nu (+\text{X-ray}) \\
65\text{Zn}^{30} & \rightarrow 65\text{Cu}^{29} + e^- + \nu (+\text{X-ray}) \\
7\text{Be}^4 & \rightarrow 7\text{Li}^3 + e^- + \nu (+\text{X-ray})
\end{align*}
\]

- **Gamma decay**

  Gamma rays (\(\gamma\)) are high-energy photons emitted from atomic nuclei.

  After alpha or beta emission, some daughter nuclei have excess energy, and they become stable after emission of gamma photons. Thus, gamma rays are emitted almost at the same time beta or alpha rays are emitted.

\[
\begin{align*}
60\text{Co}^{27} & \rightarrow 60\text{Ni}^{28} + e^- + \nu^* + \gamma \\
24\text{Na}^{11} & \rightarrow 24\text{Mg}^{12} + e^- + \nu^* + \gamma
\end{align*}
\]

Nuclei not releasing the excess energy immediately are called **isomers**, which are represented by a superscript m following the mass number. These isomers emit gamma rays.

\[
\begin{align*}
99m\text{Tc} & \rightarrow 99\text{Tc} + \gamma \\
99m\text{Tc} & \rightarrow 99\text{Tc} + \gamma \\
60\text{Co}^{27} & \rightarrow 60m\text{Ni}^{28} + e^- + \nu^* \\
60m\text{Ni} & \rightarrow 60\text{Ni} + \gamma
\end{align*}
\]

This two-step process is in competition with the immediate release of gamma rays.
An isomer may also undergo an internal conversion to release its energy. In this process, an electron from the inner atomic orbital is ejected, and the electron so ejected may be as energetic as beta particles. This is another mode of gamma decay.

- **Other decay processes**
  Several recently discovered processes are given below:
  - **Proton decay** is rare, but an example is
    \[
    ^{53m}\text{Co}^{27} \rightarrow ^{52}\text{Fe}^{26} + p \ (1.5\%)
    \]
    \[
    ^{53m}\text{Co}^{27} \rightarrow ^{53}\text{Fe}^{26} + e^+ + \nu \ (98.5\%)
    \]
  - **Spontaneous fission** is often overshadowed by alpha decay, but nuclides $^{235}\text{U}$, $^{238}\text{U}$, $^{231}\text{Th}$, $^{208}\text{Po}$, $^{258}\text{Fm}$, $^{256}\text{Fm}$, $^{254}\text{Fm}$, $^{254}\text{Cf}$, $^{252}\text{Fm}$, $^{250}\text{Cm}$ undergo spontaneous fission. Alpha decays are much more dominant for these nuclides, however.
    
    As an example, the fission $^{256}\text{Fm}$ may be represented by
    \[
    ^{256}\text{Fm}^{100} \rightarrow ^{140}\text{Xe}^{54} + ^{112}\text{Pd}^{46} + 4 \text{n}.
    \]
    
    The fission process splits the nucleus into two large fragments and some neutrons.
  - **Beta-delayed Alpha and Proton Emissions** have been observed. For example,
    \[
    ^{8}\text{B} \rightarrow ^{8}\text{Be} + b^+ + n
    \]
    \[
    ^{8}\text{Li} \rightarrow ^{8}\text{Be} + b^- + n
    \]
    \[
    ^{8}\text{Be} \rightarrow 2 \ a
    \]
    
    These processes can be represented as $b^+a$, and $b^-a$, respectively. Another example of $b^+a$, is,
    \[
    ^{20}\text{Na} \rightarrow ^{20}\text{Ne} + b^+ + \nu
    \]
    \[
    ^{20}\text{Ne} \rightarrow ^{16}\text{O} + a
    \]

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