When an unstable nucleus undergoes radioactive decay, it may eject a particle. The two particles are alpha and beta particles, gamma radiation may also be emitted, but this is not a particle. The three decay processes all come from the nucleus; the electron cloud does not give of radiation.

**Alpha decay**  \[ ^4_2\alpha \]

These are helium nuclei, and so consist of two protons and two neutrons. When a nucleus emits an alpha particle, it loses two protons and two neutrons. Alpha particles are ejected with high speeds and are relatively easily absorbed by matter. Range in air at ordinary pressure is < 100 mm, they are almost completely absorbed by a sheet of paper. Most alpha-emitters have high atomic numbers.

The symbol for an alpha particle is \[ ^4_2\alpha , \text{He}^2_4, \alpha^2_2 \]

When an atom changes into a different element, it is said to have undergone a **nuclear transmutation**. The new element formed is called the **daughter nucleus**. In any nuclear reaction, including radioactive decay, atomic and mass numbers are conserved.

\[
\begin{align*}
^{238}_{92}\text{U} & \rightarrow ^{234}_{90}\text{Th} + ^4_2\alpha + \text{energy} \\
238_{92}\text{U} & \rightarrow 234_{90}\text{Th} + 4_2\alpha + \text{energy}
\end{align*}
\]

**Beta decay**  \[ ^0_{-1}\beta \]

Beta particles are electrons; they carry away a negative charge equal in magnitude to the charge of a proton. They emanate from the nucleus of radioactive nuclei that has too many neutrons for stability. A neutron spontaneously decays into a proton and an electron, and the electron (and an uncharged, massless particle, called an antineutrino \( \bar{\nu} \)) are emitted to restore the nucleus to a more stable state.

The isotopes of carbon are \( ^{12}_{6}\text{C} , ^{13}_{6}\text{C} , ^{14}_{6}\text{C} \). Carbon-12 and carbon-13 are both stable but carbon-14 has extra neutrons, as so is unstable.
The nuclear decay equation is  

\[ {}^3\text{He} \rightarrow {}_2^3\text{He} + {}^0\beta + \gamma + \text{energy.} \]

Both the atomic and mass numbers are conserved.

**Gamma decay**  
Gamma rays are electromagnetic waves, similar in nature to light waves and x-rays. They have no charge and do not alter the mass number of the nucleus that emits them.

A common example of a gamma ray emitter is iodine-131. Iodine-131 decays by beta and gamma emission to form xenon-131.

\[ {}^{131}_{53}\text{I} \rightarrow {}^{131}_{54}\text{Xe} + {}^0\beta + {}^0\gamma \]

Gamma ray decay alone occurs when a nucleus is left in an energised or excited state following an alpha or beta decay. This excited state is known as the **metastable state** and it usually only lasts a very short time. The equation above can be more strictly written as:

\[ {}^{131}_{53}\text{I} \rightarrow {}^{131m}_{54}\text{Xe} + {}^0\beta \]

\[ {}^{131m}_{54}\text{Xe} \rightarrow {}^{131}_{54}\text{Xe} + {}^0\gamma \]

The 'm' denotes an unstable or metastable state. Cobalt-60 and technetium-99 also exist in metastable states.

**Artificial transmutation**
Artificial radioisotopes are manufactured by bombarding stable nuclei with neutrons. This process is known as artificial transmutation.

The nuclear transformation is:  

\[ {}_0^1\text{n} + {}^{59}_{27}\text{Co} \rightarrow {}^{60}_{27}\text{Co} \].

The artificial radioisotope cobalt-60 is used extensively in the treatment of cancer. It decays by emitting a beta particle.