Alpha, beta and gamma radiations are all capable of knocking electrons out of atoms, i.e. ionising them, and so are called ionising radiation. Ultra-violet (UV) and X-rays are also ionising.

Visible light, radio waves, microwaves and heat radiation are non-ionising radiations.

Americium-241 is an alpha-emitter used in smoke detectors.

Strontium-90 is a beta-emitter used in forensic analysis of bones.

Heavy radioisotopes decay via a series of stages that form a radioactive series. There are four series in total. E.g. $^{238}_{92}$U (uranium-238) $\alpha$-decays to $^{234}_{90}$Th (thorium-234) which is a beta-emitter. After a series of stages of successively lighter or less energetic nuclei each series terminates in a stable isotope of lead, except for the $^{237}_{93}$Np (neptunium-237) series which ends in an isotope of bismuth (Bi).
Radioactive Half-Life ($t_{1/2}$)

• Recall that the term half-life refers to the time taken for half the radioactive nuclei in a sample to decay and that the half-life is fixed for any given isotope; carry out half-life calculations:
  
  • Radioactive decay is a statistical process which is almost entirely independent of external physical factors (such as temperature and pressure).
  
  • As the particles decay there are fewer radioactive atoms left in a sample - the radioactivity of a given sample diminishes with time.
  
  • Half-life ($t_{1/2}$): the time taken for half of the radioactive nuclei to decay.
  
  • The half-life is a characteristic of the particular radioisotope, for example the half-life of iodine-131 is 8.1 days, whilst that of uranium-238 is 4.5 billion years.

\[ \text{Decay of iodine-131} \]

\[ \text{Decay of uranium-238} \]

• Notice that starting with an initial sample, say 100 g, the radioactivity falls to half after one half-life, then it halves again (to a quarter) after two half-lives, then after three half-lives we have an eight of the original sample left, and so on.

• As time progresses, the rate of decline in radioactivity diminishes (the curve becomes less steep).

• Exponential decay: the mass of radioisotope declines exponentially since the number of atoms decaying depends upon the number of radioactive atoms present.

Calculations involving half-life:

Example 1: Iodine-131 has a half-life of about 8 days. If we start with 8 g of the radioisotope, then how much of it will be left after 24 days?

  Number of half-lives = 24/8 = 3.
  Initial mass: 8 g.
  After one half-life, \( \frac{1}{2} \) mass remaining = \( \frac{8}{2} = 4 \) g.
  After 2 half-lives, \( \frac{1}{4} \) mass remaining = \( \frac{8}{4} = 4/2 = 2 \) g.
  After 3 half-lives, \( \frac{1}{8} \) mass remaining = \( \frac{8}{8} = 2/2 = 1 \) g.

Or use: \( N = N_0 \cdot \exp(-\ln(2)/t_{1/2} \times t) = 8 \times \exp(-0.693/8 \times 24) = 1 \) g.

Where: \( N \equiv \) mass of substance to be found, \( N_0 \equiv \) initial mass, \( \ln(2) \approx 0.693 \), and \( t_{1/2} \) and \( t \) are in the same units (days, years, etc.).
• Understand the use of radioisotopes in the dating of archaeological and geological material

Carbon-14 ($^{14}$C) dating:

$^{14}$C is formed in the atmosphere by bombardment of atoms by energetic cosmic rays (mostly protons) causing disintegration of the nuclei and secondary neutron emission. The neutrons collide with $^{14}$N to form $^{14}$C:

$$^{14}_7\text{N} + n \rightarrow ^{14}_6\text{C} + ^1_1\text{H}$$

Assumes that the relative abundance of carbon isotopes has remained unchanged for the last few thousand years. Plants assimilate this $^{14}$C into sugars, oils and proteins by photosynthesis and animals consume the plants and $^{14}$C enters the food chain. When an organism dies it ceases to accumulate new $^{14}$C and its $^{14}$C beta-decays:

$$^{14}_6\text{C} \rightarrow ^{14}_7\text{N} + \beta^- + \nu$$

Thus the ratio of radioactive $^{14}$C to stable $^{12}$C and $^{13}$C isotopes gives us an estimate of the age since death of the sample. $^{14}$C has a half-life of about 5730 years and can usefully be used on samples up to 50 thousand years old.

Other radiometric dating methods:

Dating older materials and inorganic materials requires different radioisotope methods. Uranium-lead radioisotope dating is used to date rocks that are billions of years old. For example when the mineral zircon, ZrSiO$_4$, forms, it incorporates some uranium atoms into its crystal structure in place of some of the zirconium atoms, but lead is strongly ejected from the lattice. This method uses the decays: $^{235}$U to $^{207}$Pb, $t_{1/2} = 700$ million years and $^{238}$U to $^{206}$Pb, $t_{1/2} = 4.5$ billion years and measures the U/Pb ratios.

Detecting Radiation

Geiger counters are used to detect radiation ($\alpha$, $\beta$ and $\gamma$). This device consists of a Geiger-Müller tube filled with an inert gas (such as He, Ne or Ar) which conducts a pulse of electricity when ionised by a particle of ionising radiation. The device amplifies the signal to produce a meter-reading and/or audible click.

Scintillation counters also detect ionising radiation ($\alpha$, $\beta$ and $\gamma$) and use a scintillator which contains a crystal that fluoresces when struck by ionising radiation. These devices are used to detect the gamma-ray photons in PET.