Radioisotopes

All naturally occurring elements were formed in the stars. Some isotopes have unstable nuclei. We call these radioisotopes.

In a stable nucleus:

No. of protons ${}^{1}_{1}\mathrm{H}$ = No. of neutrons ${}^{1}_{0}\mathrm{n}$

There are three reasons for unstable nuclei :

A. No. of protons < no. of neutrons

The nucleus stabilises itself by converting a neutron into a proton

and a negative electron which is emitted as a β particle ${}^{0}_{-1}\mathrm{e}$ e.g.

$${}^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$$

B. No. of protons > no. of neutrons

The nucleus stabilises itself by converting a proton into a neutron

and a positive electron which is emitted as a positron ${}^{0}_{1}\mathrm{e}$ e.g.

$${}^{11}_{6}\mathrm{C} \longrightarrow {}^{11}_{5}\mathrm{B} + {}^{0}_{1}\mathrm{e}$$

β particles and positrons have a range of a few metres in air and are stopped by a sheet of Aluminium.

C. No. of neutrons + no. of protons 140

Repulsions occur between the protons in heavy nuclei. The nucleus stabilises itself by emitting an α particle : a particle consisting of two neutrons and two protons bound together.

This is just a Helium nucleus ${}^{4}_{2}\mathrm{He}$

e.g. $${}^{237}_{92}\mathrm{U} \longrightarrow {}^{233}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$

α particles have a range of a few centimetres in air and are stopped by a sheet of paper.

N.B. Rearrangement of the particles in the nucleus after particle emission results in the emission of energy - γ radiation.

γ radiation has a range of about 100 metres in air and is stopped by about 5 cms of Lead.

Half-life

The decay of radioisotopes is random : it is not possible to predict the time of decay of an individual atom. With larger numbers of atoms, the time taken for half the isotopes to decay is called the half-life ($t_{1/2}$) e.g.

$^{32}_{15}P$ has a half-life of 14 days.

The half-life of a particular isotope is constant: it does not vary with temperature or pressure and is unaffected by the compound which contains the isotope

e.g. $^{32}_{15}P$ has a half-life of 14 days whether present in

Phosphoric acid H_3PO_4, Phosphorus oxide P_2O_5 or a solution of Ammonium hydrogen phosphate $(NH_4^+)_2HPO_4^{2-}$ in Water !

Problem 1

7/8 of the atoms of a radioisotope decay in 30 minutes. Calculate the half-life of the isotope.

Answer : Say we start with 8 atoms. Half decay every $t_{1/2}$ minutes.

$$8 \xrightarrow{t_{1/2}} 4 \xrightarrow{t_{1/2}} 2 \xrightarrow{t_{1/2}} 1$$

After $3t_{1/2}$ minutes 1 atom is left and 7 have decayed (7/8)

=> $3t_{1/2} = 30$

=> $t_{1/2}$ = 10 mins

Problem 2

5g of Sodium iodide containing the radioisotope $^{131}_{53}I$, half-life 8 days, has an activity of 320 counts per minute (cpm) on a Geiger counter. How long would it take for the activity to drop to 20 cpm ?

Answer : $320 \xrightarrow{8\ \text{days}} 160 \xrightarrow{8\ \text{days}} 80 \xrightarrow{8\ \text{days}} 40 \xrightarrow{8\ \text{days}} 20$

=> Time = 4 x 8 = 32 days

When using a Geiger counter we must always take background radiation into account. This is radiation due to cosmic rays (protons, electrons, positrons etc) which are emitted by the Sun, Radon gas which is produced by the decay of Uranium in rocks and artificial sources e.g. leaks from power stations.

Problem 3

^{42}Ar is a β emitter, half-life 34 years. Calculate the number of β particles given off by 4.2g ^{42}Ar in 102 years.

Answer : No. of moles ^{42}Ar at start = $\frac{4.2}{42}$ = 0.1 mol

$$0.1 \xrightarrow{34\ \text{years}} 0.05 \xrightarrow{34\ \text{years}} 0.025 \xrightarrow{34\ \text{years}} 0.0125$$

After 102 years, no.of moles ^{42}Ar remaining = 0.0125 mol

.. ..decayed = 0.1 - 0.0125

= 0.0875 mol

One mole ^{42}Ar emits 1 mole β particles :

$$^{42}_{18}Ar \longrightarrow {}^{42}_{19}K + {}^{0}_{-1}e$$

=> 0.0875 mol ^{42}Ar emits 0.0875 mol β particles

=> no. of β particles given off = $0.0875 \times 6.023 \times 10^{23}$

= 5.27×10^{22}

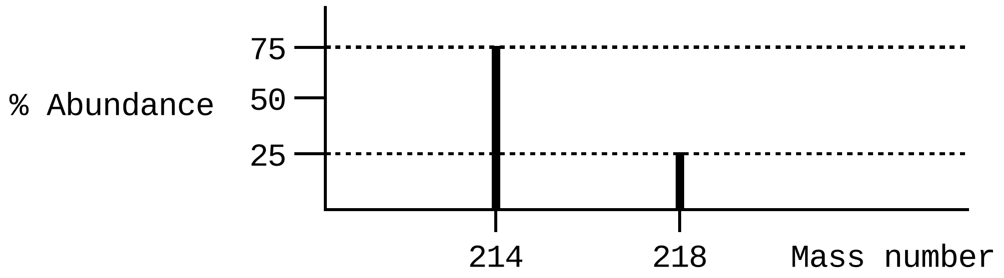
Problem 4

(a) Write an equation to show the decay of ^{218}Po - an α emitter

Answer:

$$^{218}_{84}Po \longrightarrow {}^{214}_{82}Pb + {}^{4}_{2}He$$

(b) The following chart shows the percentages of ^{218}Po and ^{214}Pb in a sample of ^{218}Po which is 6 minutes old:



Calculate the half-life of ^{218}Po.

Answer : Say we start with 8 ^{218}Po atoms.

$$8 \xrightarrow{t_{1/2}} 4 \xrightarrow{t_{1/2}} 2$$

After $2t_{1/2}$ minutes, 2 ^{218}Po atoms are left (25%)

=> $2t_{1/2}$ = 6

=> $t_{1/2}$ = 3 mins

Examples of Uses of Radioisotopes

1. In industry

γ radiation from ^{60}Co is used to examine castings and welds for cracks.

2. In medicine

(a) γ emission from the decay of ^{60}Co is used to treat deep-seated tumours.

(b) The uptake of Iodine by the thyroid gland can be traced with ^{131}I (β emitter).

3. Nuclear fission

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3\,^{1}_{0}n + \text{energy}$$

This is a chain reaction : the rate increases with time as the neutrons formed strike more $^{235}_{92}U$ nuclei.

Nuclear fuel, unlike fossil fuels, causes little pollution but, like fossil fuels, it will not last forever and is considered by some to be unsafe.

N.B. Nuclear fusion involves :

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n + \text{energy}$$

4. Radiocarbon dating

^{14}C (β emitter, half-life 5720 years) is produced in the upper atmosphere by bombardment of ^{14}N by the neutrons in cosmic rays:

$$^{14}_{7}N + ^{1}_{0}n \longrightarrow ^{14}_{6}C + ^{1}_{1}H$$

The ^{14}C is constantly taken up by living things through photosynthesis. The ^{14}C : ^{12}C ratio in living things can be measured.

When the living thing dies, ^{14}C is no longer taken up. Over the years ^{14}C decays. The ^{14}C : ^{12}C ratio drops. The age of the remains can be estimated from the change in the ^{14}C : ^{12}C ratio.

5. Tracers in Chemical Reactions

If Na_2SO_3 containing the radioisotope ^{35}S (β emitter) is used in the following reaction :

$$Na_2SO_3 + H_2SO_4 \rightarrow Na_2SO_4 + SO_2 + H_2O$$

only the resulting SO_2 is radioactive. If the H_2SO_4 is labelled with ^{35}S, only the Na_2SO_4 is radioactive. This suggests that the Sulphur in the SO_2 must have come form the Na_2SO_3 and that the Sulphur in the Na_2SO_4 must have come from the H_2SO_4.