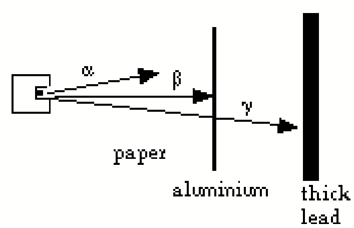
Radioactive Rays 9.1

Unstable nuclei cause radioactivity.
Radioactivity is caused by unstable nuclei trying to become stable by emitting particles and/or energy .The nuclei of radioactive substances are unstable due to an unstable ratio of protons to neutrons. In stable atoms of relatively low atomic mass there are approximately equal numbers of protons and neutrons i.e. a proton to neutrons ratio of about 1:1.In stable atoms of higher atomic mass more neutrons than protons are needed to keep the nucleus stable.

Types of radiation.
There are three types of radiation: -

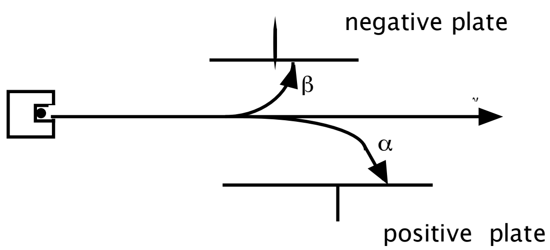
Type	Nature	Symbol	Charge	Mass(amu)
alpha	He nucleus		2+	4
beta	electron		1-	0
gamma	electro- magnetic radiation		0	0

Penetrating power



Alpha( ) particles are absorbed by thin paper and can travel only a few centimetres in air. Beta particles ( ) are absorbed by thin aluminium and can travel a metre or so in air. Gamma radiation ( ) is absorbed by a few centimetres of lead and can travel many metres in air.

Deflection in an electric field.



Alpha particles ( ) are positively charged and so deflect towards the negatively charged plate.

Beta particles ( ) are negatively charged and deflect towards the positively charged plate.

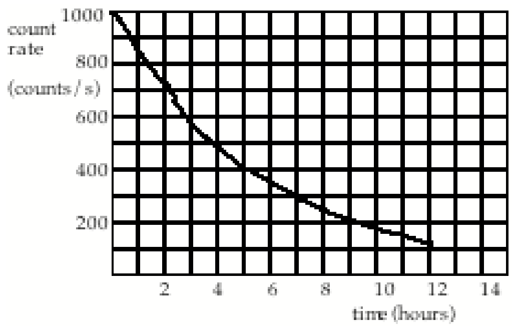
Gamma radiation ( ) has no charge and so is not deflected.

Note: - The beta particles deflect more than alpha particles, as they are lighter than the alpha particles.

Half-life. 9.2

The half -life of a radioisotope is the time it takes for the activity of the radioisotope to decay to half its original value. In one half- life, half of the radioisotopes atoms present at the start will decay into other nuclei.

- **Radioactive decay curves.**



The graph show the curve obtained when a radioisotope with a half life of 4 hours and an initial count rate of 1000 counts/s decays. In the first 4 hours the count rate falls from 1000 counts/s to 500 counts/s. In the next 4 hours the count rate falls from 500 counts/s to 250 counts/s etc.

Calculations involving half-life.

1) A 1.2 g sample of tritium (^{3}H) was placed in a sealed jar and left for 8 days. After this time it was found that 0.075 g of tritium remained. Calculate the half-life of the sample.

$$1.2\text{ g} \xrightarrow{1/2\text{life}} 0.6\text{ g} \xrightarrow{1/2\text{life}} 0.3\text{ g} \xrightarrow{1/2\text{life}} 0.15\text{ g} \xrightarrow{1/2\text{life}} 0.075\text{ g}$$

In four half lives the mass decreases from 1.2 g to 0.075 g.
As 4 half lives = 8 days then 1 half-life = 2 days.

2) The remains of an ancient fire found in a cave had a carbon-14 count rate of 15.3 counts per minute per gram of carbon. The carbon-14 count in a newly cut piece of wood is 122.4 counts per minute. Given that carbon-14 has a half-life of 5730 years, calculate the age of the remains.

$$122.4 \xrightarrow{1/2\text{life}} 61.2 \xrightarrow{1/2\text{life}} 30.6 \xrightarrow{1/2\text{life}} 15.3$$

Three half-lives have passed. This gives an age of 3 x 5730 = 17190 years.

Half-life and reaction conditions.

The half-life of a radioisotope is independent of
a) the mass of sample taken.
b) the state of the sample - solid, liquid or gas.
c) The temperature or pressure.

The 1/2 life is only dependant on the isotope present it makes no difference what its chemical and physical states are.

e.g. 1 g of carbon-14 has a half-life of 5730 years. 10kg of carbon-14 has a half-life of 5730 years. 1kg of carbon dioxide gas containing 0.003% carbon-14 has a half-life of 5730 years.

No mass loss overall.

Consider the decay process shown below. If at the start of the reaction we had 1.0g of Po-210 present and no products then after one half-life we would have 0.5 g of Po-210 left and a total of 0.5 g of lead and helium formed.
i.e. there is no overall loss in mass - law of conservation of mass prevails.

Background Radiation
Even when not measuring the radioactivity of a radioisotope, a Geiger Muller Tube will always register a small amount of radioactivity. This is called background radiation and there are three main causes.

1. Naturally Occurring Radiation
   These are found in tiny amounts in nearly all materials including living things. For example carbon -14 is present in all living plants and animals. It only starts to disintegrate on death(See carbon dating)
   Granite rocks contain uranium isotopes, which give off radioactive radon gas which seep up through cracks in rocks into the atmosphere.
2. Artificial Radioisotopes.
   These are pollution products from nuclear bombs and accidents like Chernobyl. They also include leakages from nuclear submarines and power stations.
3. Cosmic Rays
   These are high-energy gamma rays from outer space, which bombard our planet continuously.

Uses of Radioisotopes 9.3

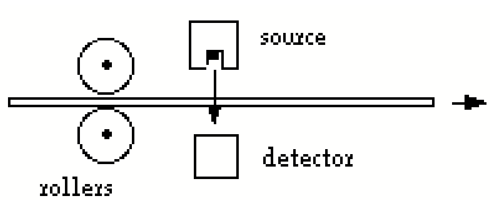
Medical uses of radioisotopes.
Radioisotopes are widely used in medicine e.g.

a) Gamma radiation from a cobalt-60 source is used to destroy deep-seated cancerous tumours. The gamma rays are concentrated on the tumour.
b) Less penetrating beta radiation from phosphorus-32 can be used to treat skin cancer by direct application to the affected area.
c) Radioisotopes can be used a 'tracers' used to monitor the processes occurring in different parts of the body. One such tracer is Iodine-131, which is taken up by the thyroid gland and can be used to monitor the workings of the thyroid.

Industrial uses of radioisotopes.
a) The very penetrating gamma radiation from a Cobalt-60 source can be used to inspect metal for cracks which would be invisible to the naked eye. This technique is widely used to test aircraft components for cracks caused by metal fatigue. A photographic plate is used to show any cracks - the gamma rays will be to penetrate more easily where there is a crack and so it will show up as a darker area on the photographic film.

b) Leaks in gas and oil pipelines can be detected by using radioactive 'tracers' in the pipeline.

c) The thickness of sheet material such as paper, thin metal and plastics can be automatically controlled using a beta emitter and detector. For thicker metals a gamma source would be used.



If the sheet thickens the amount of radiation will fall and a signal will be sent to the rollers to move closer together until the radiation level rises to the correct reading.

Radiocarbon dating.
Carbon-14 is constantly being produced in the upper atmosphere by neutron bombardment of nitrogen atoms. (The neutrons come from the Sun as part of the 'solar wind').

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}P$$

The carbon-14 like the more abundant carbon-12 is in the carbon dioxide gas that is constantly being absorbed by growing plants. It is also absorbed by animals, which eat the plants. As long as the organism is alive there is a fairly constant ratio of carbon-14 to carbon-12 in the organism. However, when the organism dies the amount of carbon-14 will start to fall as the carbon-14 decays by beta emission.
The half-life for this process is 5730 years and so by measuring the ratio of carbon-14 to carbon-12 in the sample its age can be determined.

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

Nuclear and fossil fuels compared.
There are advantages and disadvantages for both nuclear and fossil fuels being used as a source of energy.

Advantages of fossil fuels.
Fossil fuels are widely available and are a cheap source of energy.

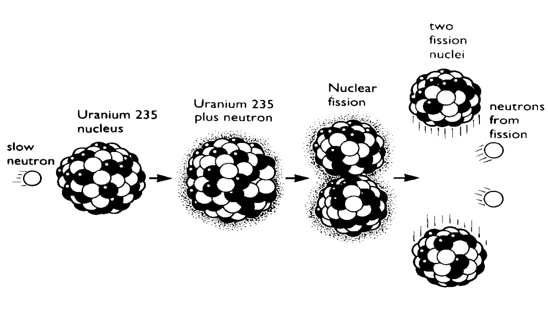
Disadvantages of fossil fuels.
Fossil fuels are in finite supply and will be totally exhausted some time in the future.
The burning of fossil fuels causes atmospheric pollution e.g. carbon dioxide (a Greenhouse gas), sulphur dioxide and oxides of nitrogen (both acid rain gases.

Advantages of nuclear fuels.
Only small quantities of nuclear fuel are required to produce as much energy as much more fossil fuel.
e.g. One mole (235 g) of uranium-235 can produce as much energy as 60 tonnes (60 000 000 g) o f coal.
Nuclear fuels do not produce Greenhouse gases and acid rain gases.

Nuclear Energy 9.4

Nuclear fission.
Worldwide, large amounts of electrical energy are generated by nuclear fission of fuels such as uranium-235. The heat produced by the fission of the fuel being used to generate steam to turn the steam turbines.In nuclear fission, heavy nuclei such as uranium-235 are split into lighter nuclei by bombarding the uranium-235 with slow moving neutrons. One such fission process is

$$^{235}U + ^{1}n \longrightarrow ^{140}Xe + ^{94}Sr + 2\ ^{1}n$$



The neutrons that are released in this process will react with other atoms of uranium-235 causing them to fission and so a self-sustaining chain reaction is brought about.
Note: - the reaction is controlled by absorbing some of the neutrons released in the fission reaction by inserting control rods of a non-fissile material into the reactor. Both carbon and boron rods can be used to absorb neutrons and so moderate the reaction.

Nuclear fusion.

In nuclear fusion light nuclei are joined together to form a heavier nucleus with energy being released in the process.

e.g.

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

The difficulty with nuclear fusion as a source of energy is that the process requires extremely high temperatures - millions of degrees Celsius and it has not been possible so far to bring about controlled nuclear fusion. The reactions take place in stars where the high temperatures and gravitational forces are sufficient to overcome the repulsion of small positive nuclei.

e.g.

$$^{2}H + ^{3}H \longrightarrow ^{4}He + ^{1}n + 1.9 \times 10^{9} \text{ kJ}$$

This type of reaction takes place in the stars and is thought to have given rise to all the elements as we now know them. e.g. carbon, oxygen etc.

Nuclear Equations 9.5

Alpha and Beta Decay

The most common forms of radioactive decay involve the emission of alpha ( ) particles and beta ( ) particles.

Example 1 Thorium -230 decays by alpha emission to radium

$$^{230}Th \longrightarrow ^{226}Ra + ^{4}He$$

The sum of both atomic and mass numbers are conserved.

Example 2 Phosphorus - 32 decays by beta emission to sulphur

$$^{32}P \longrightarrow ^{32}S + ^{0}e$$

Complete the following equations

1 a) $^{234}Th \longrightarrow \quad + \quad ^{0}e$

b) $^{6}Li + {}^{1}n \longrightarrow {}^{3}H + $

c) $^{234}U \longrightarrow \quad + \quad ^{4}He$

d) $\longrightarrow {}^{212}Bi + {}^{0}e$

2 The isotope uranium- 239 was produced by neutron bombardment. A sample of this material gave Evidence of different radioactive processes of short half-life. Among these were alpha and beta emissions.

Identify A, B, C and D.

a) $^{239}U \longrightarrow {}^{235}A + {}^{4}He$

b) $^{235}A \longrightarrow {}^{231}B + {}^{4}He$

c) $^{231}B \longrightarrow {}^{231}C + {}^{0}e$

d) $^{231}C \longrightarrow {}^{231}D + {}^{0}e$

A =

B =

C =

D =

3. A slow moving neutron reacts with N-14 to give either
i a c-14 nucleus and a proton or
ii a B-11 nucleus and an alpha particle

A fast moving neutron gives
iii a C-12 nucleus and a tritium nucleus

Write nuclear equations for

i

ii

iii

4. Write nuclear equations for

a) alpha decay of i $^{232}Th \longrightarrow$

ii $^{238}U \longrightarrow$

b) beta decay of i $^{14}C \longrightarrow$

ii $^{3}H \longrightarrow$

c) neutron capture of i $^{238}U \longrightarrow$

ii $^{40}Ar \longrightarrow$

Radioisotopes and dating. 9.6

Things, which were once alive, such as wood or bones, can be dated using an isotope of carbon i.e. carbon-14. It has to be assumed that the proportion of carbon-14 to carbon-12 was the same years ago as it is today.
Carbon-14 is constantly being produced in the upper atmosphere by neutron bombardment of nitrogen atoms. (The neutrons come from the Sun as part of the 'solar wind').

$$^{14}N \quad + ^{1}n \longrightarrow ^{14}C \quad + ^{1}P$$

Growing plants, are constantly absorbing the carbon-14 which like the more abundant carbon-12 is in the carbon dioxide gas that is being used for photosynthesis. It is also absorbed by animals, which eat the plants.
As long as the organism is alive there is a fairly constant ratio of carbon-14 to carbon-12 in the organism. However, when the organism dies the amount of carbon-14 will start to fall as the carbon-14 decays by beta emission.

$$^{14}C \longrightarrow ^{14}N \quad + \quad ^{0}e$$

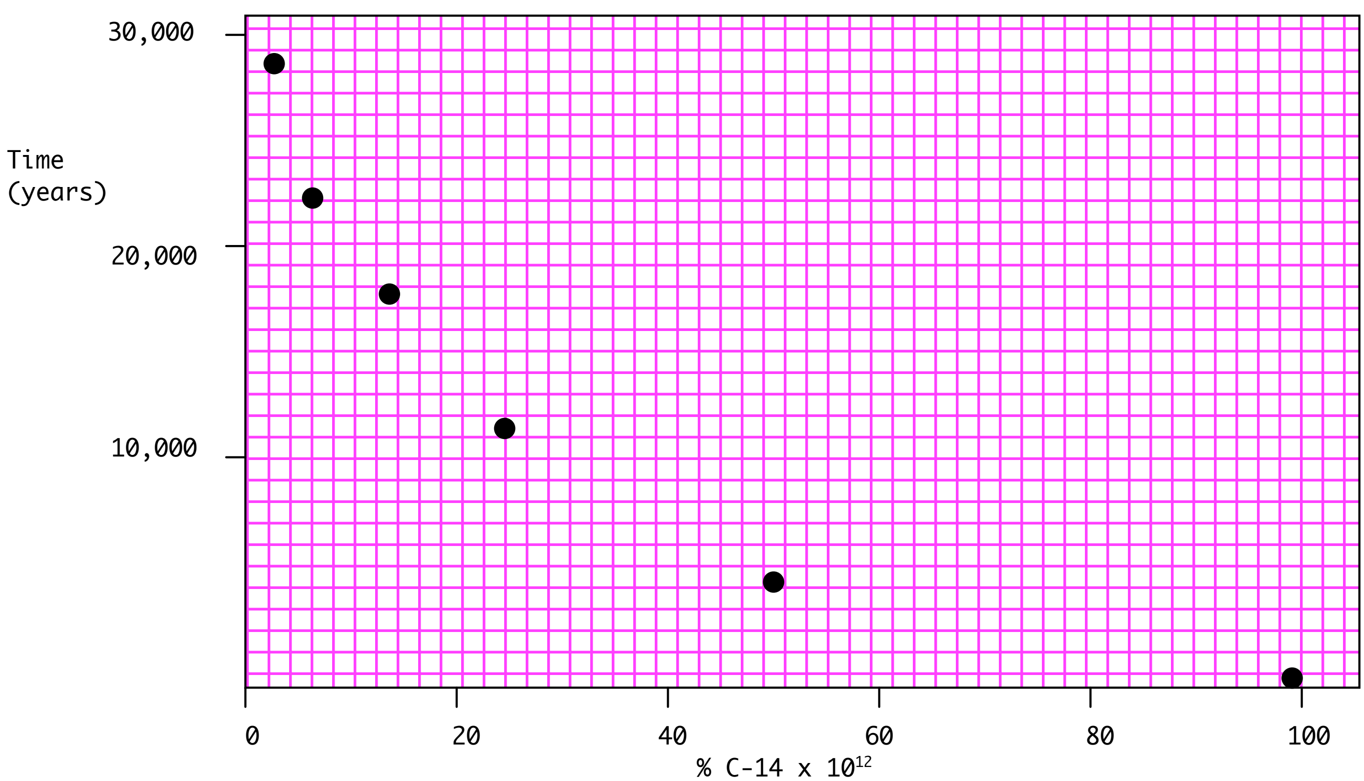
The half-life for this process is 5730 years and so by measuring the ratio of carbon-14 to carbon-12 in the sample its age can be determined.

Time (years)	% C-14
0	1.0×10^{-10}
5730	5.0×10^{-11}
11460	2.5×10^{-11}
17190	1.2×10^{-11}
22920	6.2×10^{-12}
28650	3.1×10^{-12}

Use the graph below to determine the age of

a) A skull containing 8.5×10^{-11} % C-14

b) A tree containing 3 .0 x 10^{-12} % C-14



Dating Rocks

The half-life of carbon-14 is 5730 years which makes it suitable only to date living organisms that are less than about 10 half-lives old i.e. about 50,000 years.
Objects older than this can be dated using other radioactive isotopes. Some rocks, for example, contain uranium-238 which has a half-life of 4.51 x 10^9 years. The uranium -238 finally decays to give lead-206. By studying the proportions of these scientists can date very old rocks.
Note:- One of the products in the decay series U-238 to Pb-206 is radon-222 (See page 8 of data book) Radon being a gas can escape to the atmosphere which reduces the final mass of Pb-206 making process less accurate.

Short Term Dating

To date objects that are less than 100 years old a radioisotope with a shorter half-life can be used. This will give more accurate results.
Hydrogen-3 [Tritium], which is a beta emitter, has a half-life of 12 years

$$^{3}H \longrightarrow {}^{3}He + {}^{0}e$$

Tritium is produced in the upper atmosphere. All water taking part in the Water Cycle will have a constant proportion of H-3. By measuring the proportions of H-1 to H-3 it will be possible to determine the age of the substance containing water.

e.g. Water found in an underwater cavern is found to have only 1/8th the ratio of ^{3}H to ^{1}H as fresh water. Taking the half-life of ^{3}H as 12 years. Calculate how long the water has been there.

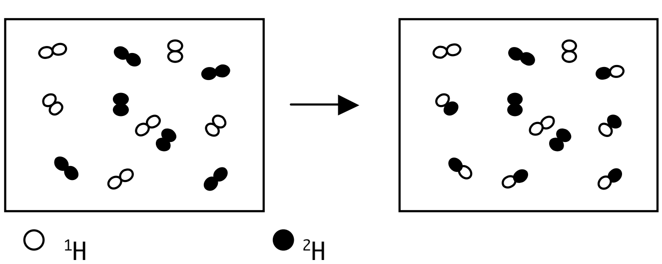
$$1 \xrightarrow{12years} 1/2 \xrightarrow{12years} 1/4 \xrightarrow{12years} 1/8$$

3 x half-life = 3 x 12 years = 36 years

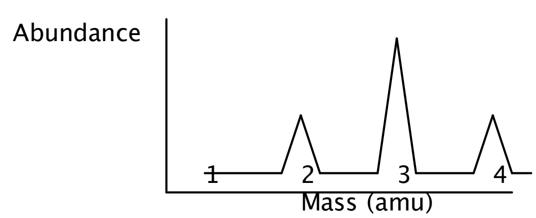
Isotopic labelling 9.7

Different isotopes of the same element undergo identical reactions and this can be used to follow the mechanisms of some reactions.

Investigating molecular collisions



Mass Spectrometer of Molecules afetr collisions



Note Peaks appear at relative masses 2, 3 and 4. The peak at 3 is twice as large as these at 2 and 4 as there will be twice as many with this mass.

Investigating Dissolving

When a solute such as sodium chloride dissolves in a solvent such as water then a solution of sodium chloride is formed.

$$NaCl_{(s)} + \text{water} \longrightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

When the solution can dissolve no more sodium chloride it is said to be **saturated.**
However the situation does not stop. Undissolved sodium chloride can dissolve displacing the dissolved sodium chloride. This can be shown to continue by isotopically labelling the sodium in solid sodium chloride.

$$^{24}NaCl_{(s)} + {}^{23}Na^{+}_{(aq)} + Cl^{-}_{(aq)} \longrightarrow {}^{23}NaCl_{(s)} + {}^{24}Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

By comparing radioactivity levels in samples of solid and dissolved sodium chloride we can show that dissolving and recrystsallisation are taking place at same time.

Investigating Ester Formation

When an alkanoic acid reacts with an alcohol, an ester and water are formed.

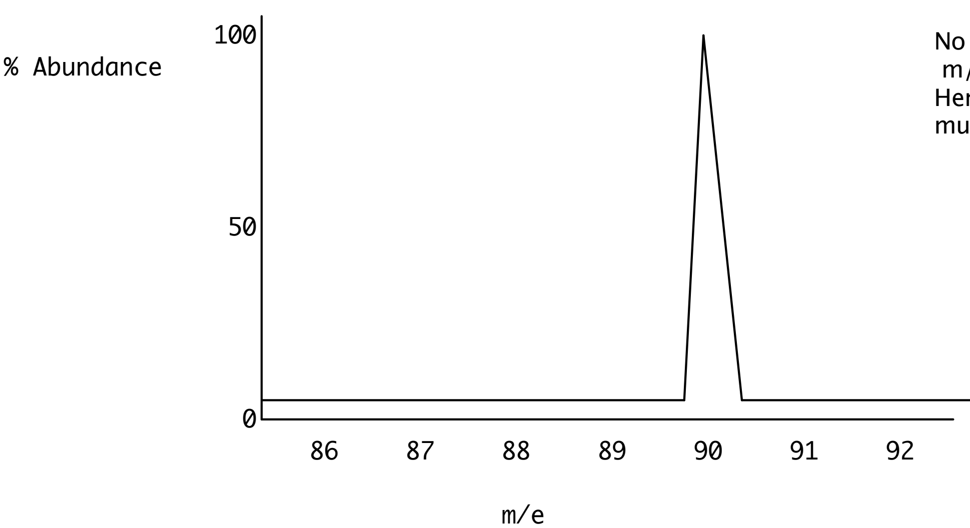
$$CH_3COOH + C_2H_5OH \longrightarrow CH_3COOC_2H_5 + H_2O$$

The question, which intrigued chemists, was did the bridging oxygen in the ester originate in the acid or the alcohol?

$$CH_3COOH + C_2H_5{}^{18}OH \longrightarrow CH_3CO^{18}OC_2H_5 + H_2O$$

As we can see the bridging oxygen originates from the alcohol.

Note That as oxygen-18 is not radioactive the product would have to be analysed in a mass spectrometer.



No peak is shown with m/e = 88
Hence all the bridging oxygens must come from the alcohol.