St Ninian's High School

Chemistry Department

National 5 Chemistry

Unit 3: Chemistry in Society

Nuclear Chemistry

Summary Notes

Name ___________________________________

Learning Outcomes

After completing this topic you should be able to :

1	state that there are many unstable isotopes
2	state that unstable isotopes become more stable by emitting radiations
3	state that isotopes which emit radiations are known as radioactive isotopes or radioisotopes
4	state that the three types of radiation emitted from nuclei are alpha (α) particles , beta (β) particles and gamma (γ) rays
5	state that alpha and beta radiations change an isotope of one element to an isotope of another element
6	state that gamma emissions are due to nuclei losing energy
7	state that alpha particles are helium nuclei and are heavy positively charged particles which are slow moving and have low penetration, they travel only a few centimetres through the air
8	state that beta particles are fast moving electrons and are negatively charged and are more penetrating than alpha particles but are stopped by thin aluminium
9	explain that beta particles are emitted when a neutron changes to a proton in the nucleus
10	state that gamma rays have no mass or charge and travel at the speed of light, gamma rays are stopped by 10 cm of lead or thick concrete
11	state that the time for half of the nuclei of a particular isotope to decay is fixed and is called the half-life
12	carry out half-life calculations
13	state that the age of materials can be determined using the half-lives of radioisotopes
14	produce nuclear equations to describe the transitions which produce radiations, mass numbers and atomic numbers of isotopes are shown in nuclear equations
15	give examples of uses of radioisotopes, e.g. medical use, industrial use, scientific use.

Background Radiation

Background radiation is all around us. It can be natural or artificial. Most background radiation comes from **natural** sources such as:

i) cosmic rays from space   ii) rocks and soil   iii) gases in the atmosphere such as radon.

Artificial sources are due to human activity such as:

i) radioactive waste   ii) X-rays in medicine   iii) nuclear testing.

Background radiation can be measured using a Geiger-Muller tube and counter.

What is Radioactivity?

The nucleus of all atoms (apart from some atoms of hydrogen) contains both protons and neutrons. The nuclei of some atoms are unstable, i.e. they spontaneously break up (**decay**) with the emission of radiation. This 'happening' is known as **radioactivity**. Most elements exist as isotopes. Radioisotopes are radioactive isotopes of elements. Most isotopes are stable but some are not and will therefore decay in order to become more stable. As they decay they emit particles and energy until they form stable isotopes. Radioactive decay is spontaneous. There are three types of nuclear radiations:

i) alpha (α)   ii) beta (β)   iii) gamma (γ).

Unstable Nuclei

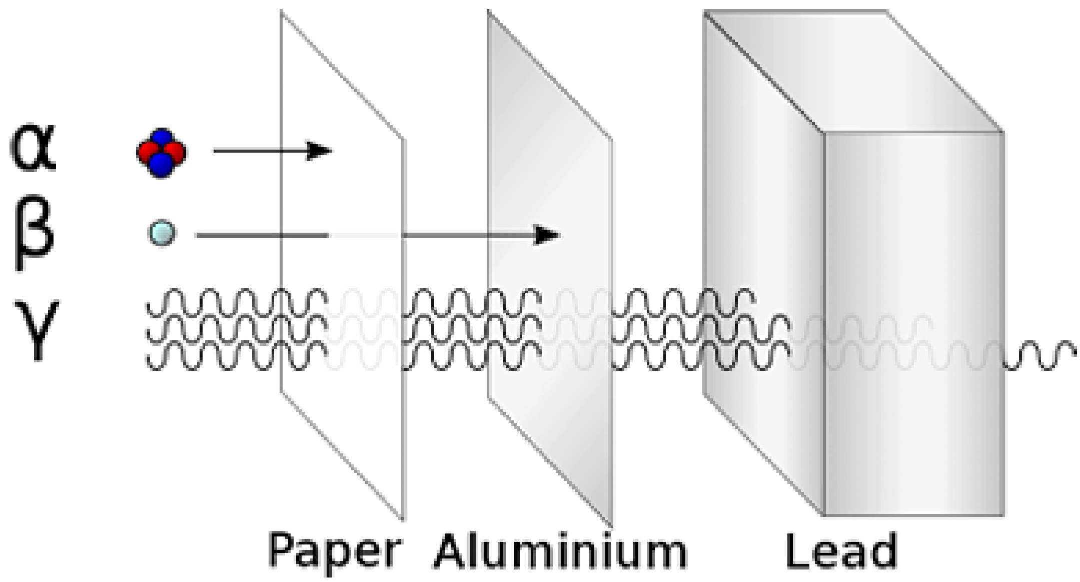
Types of Radiation

Alpha particles consist of 2 protons and 2 neutrons i.e. the nucleus of a helium atom.

Beta particles are fast moving electrons emitted from the nucleus. They are produced when a neutron in the nucleus breaks up to form a proton and electron.

Gamma radiation is a type of electromagnetic wave similar to X-rays but of higher energy.

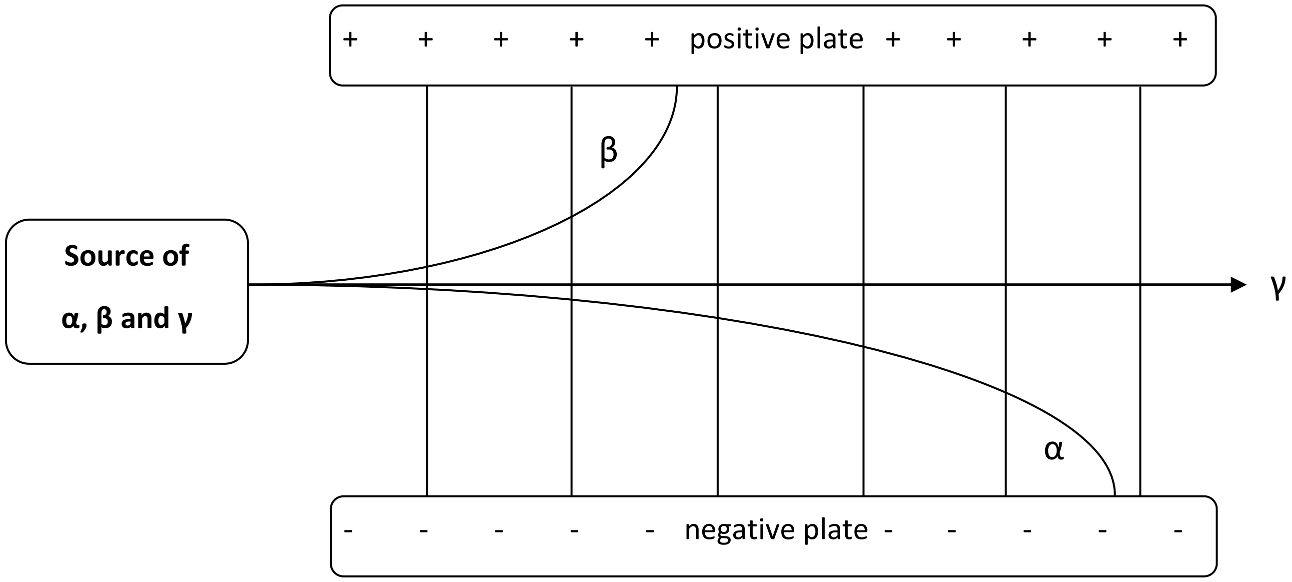
The different types of radiation have different penetrating power. Alpha is the least penetrating as it is stopped by paper or 2-3 cm of air. Beta is the next least penetrating and is stopped by thin aluminium or about 10 cm of air. Gamma radiation is the most penetrating but is stopped by 10 cm thick lead or concrete as summarised in the diagram below.



Name	Nature	Symbol	Charge
Alpha	2 protons 2 neutrons	${}^{4}_{2}\alpha$	2+
Beta	fast moving electron	${}^{0}_{-1}\beta$	1-
Gamma	electromagnetic waves	γ	no change

Unstable Nuclei

If alpha, beta and gamma radiation are passed through an electric field there is a distinct pathway each will take based on the charges present in each. (Remember like charges repel and opposite attract.)



Nuclear Equations

Nuclear equations are used to summarise nuclear decay. Note that when writing nuclear equations the total mass number of the left hand side is equal to the total mass number on the right hand side. The total atomic number on the left hand side is also equal to the total atomic number on the right hand side.

Alpha Decay

During alpha decay the nucleus emits 2 protons and 2 neutrons (an alpha particle). This means the atomic number of the product is smaller by 2 and the mass number smaller by 4.

Example 1: An americium isotope emits an alpha particle producing a neptunium isotope.

$$^{241}_{95}Am \rightarrow ^{237}_{93}Np + ^{4}_{2}\alpha$$

Example 2: The alpha decay of radium to form radon.

$$^{222}_{88}Ra \rightarrow ^{4}_{2}He + ^{218}_{86}Rn$$

Beta Decay

During beta decay a high energy electron is emitted from the nucleus and the atomic number increases by 1. The mass number remains constant.

Example 1: Beta decay of carbon-14.

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

Example 2: Beta decay of iodine-131.

$$^{131}_{53}I \rightarrow ^{0}_{-1}e + ^{131}_{54}Xe$$

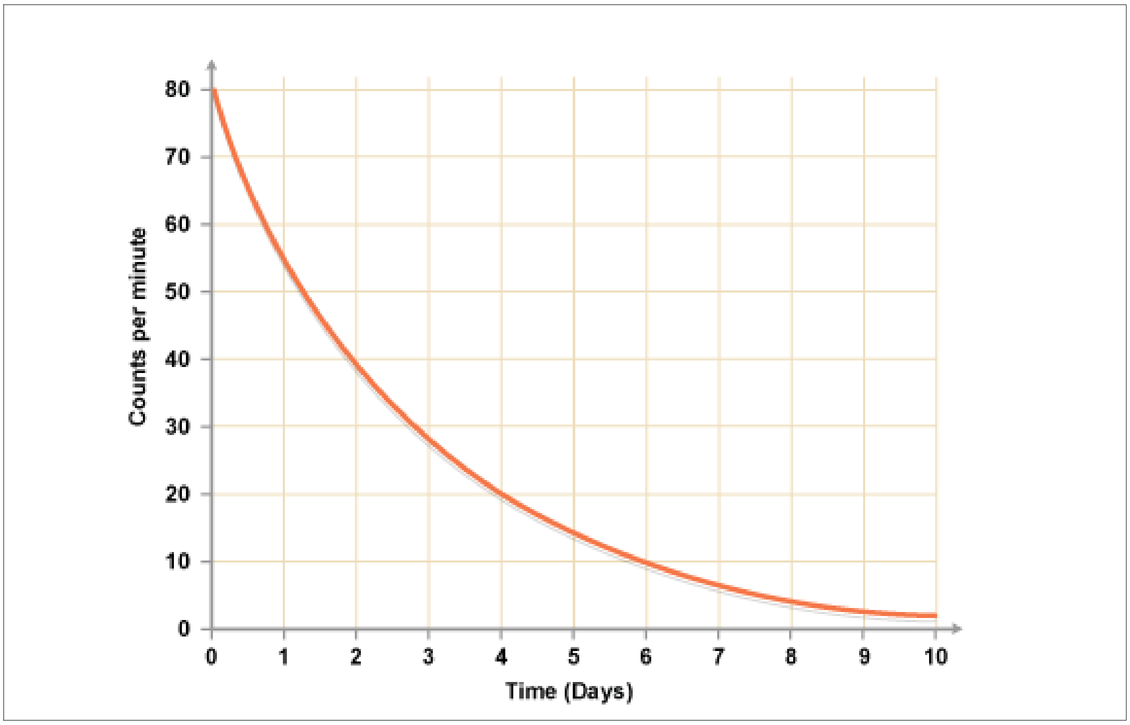
Half-life

When a sample of a radioisotope decays the decay process is random. However when the random events are averaged out the decay of a radioisotope follows a definite pattern.

It is possible to calculate how much of a radioisotope has decayed and how much remains after a given time using the half-life of the isotope.

Half-life is defined as the time it takes for half of the sample to decay or the time it takes for the activity to reduce to half its original value. Some half-life values are a matter of seconds while others are millions of years. The half-life is **not** affected by temperature or concentration unlike normal chemical reactions.

Half-life can be found from a graph of activity against time as shown below.



In this graph the initial activity is 80 counts per minute. After one half life the activity will be reduced to 40 counts per minute. It is therefore seen that the half-life is 2 days. After another 2 days the activity is seen to have reduced by half again.

Half-life can be shown as a percentage of the original sample or as a fraction of the original sample.

After		**1st**	**2nd**	**3rd**	**half-lives**
As a percentage:	100% ⟶	50% ⟶	25% ⟶	12·5%	etc
Or as fractions:	1/1 ⟶	1/2 ⟶	1/4 ⟶	1/8	etc

Half-Life Calculations

Example 1: Lead-210 decays to 6·25% of its original radioactivity after 84 years. What is the half-life of this isotope?

After 1 half-life there would be 50% of the original sample remaining.
After 2 half-lives there would be 25% of the original sample remaining.
After 3 half-lives there would be 12·5% of the original sample remaining.
After 4 half-lives there would be 6·25% of the original sample remaining.

So 84 ÷ 4 = 21 years for each half-life.

Example 2: A radioisotope of phosphorus has a mass of 80 g and a half-life of 14 days. Calculate the mass of the isotope remaining after 56 days.

56 ÷ 14 = 4 half-lives

80 g ⟶ 40 g ⟶ 20 g ⟶ 10 g ⟶ 5 g

5 g remains.

Example 3: A radioisotope has a half-life of 7000 years. How long will it take for the 48 g of the radioisotope to decay to leave 6 g?

Find how many half-lives this requires.

48 g ⟶ 24 g ⟶ 12 g ⟶ 6 g

3 half-lives are required.

Total time = 7000 x 3 = 21 000 years.

Example 4: Carbon-14 is a naturally occurring radioisotope. It has a half-life of 5730 years and is found in the remains of living things and is therefore used to date objects.

A sample of wood was found to have 12·5% of the carbon-14 content of living wood. Calculate the age of the wood.

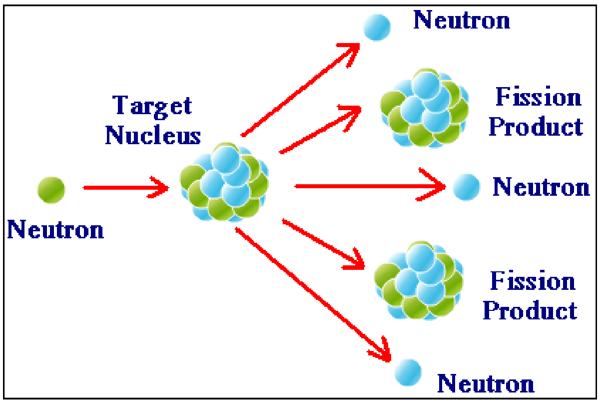
100% ⟶ 50% ⟶ 25% ⟶ 12·5%

0 years ⟶ 5730 years ⟶ 11 460 years ⟶ 17 190 years

Nuclear Fission & Fusion

Nuclear Fission

Nuclear fission occurs when the nucleus of an atom splits to produce smaller nuclei with the release of energy. Nuclear fission occurs in the reactor of a nuclear power station when it is normally uranium-235 nuclei which split. Each fission reaction occurs when a neutron hits a uranium nucleus causing it to split with the release of further neutrons which can then cause further fission reactions and ultimately a chain reaction is established.



Nuclear Fission

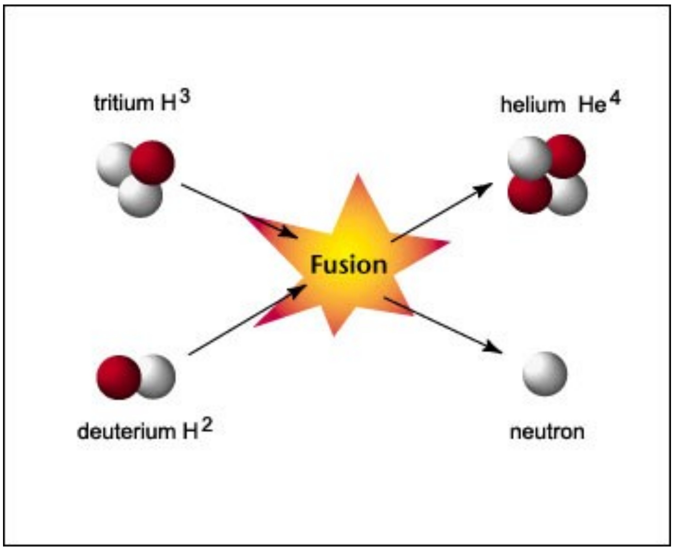
A fission reaction can be shown as a nuclear equation e.g.

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{90}_{38}\mathrm{Sr} + {}^{144}_{54}\mathrm{Xe} + 2\,{}^{1}_{0}\mathrm{n}$$

A neutron is seen to split a uranium-235 atom into two smaller nuclei with the release of 2 further neutrons.

Nuclear Fusion

Nuclear fusion involves the small nuclei combining to form larger nuclei with the release of energy. Fusion reactions occur in stars including the sun where very light nuclei fuse to produce heavier nuclei.



In this example two hydrogen isotopes fuse together to produce a helium nucleus with the release of a neutron.

$$^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

Uses of Radioisotopes

Radioisotopes are widely used in medicine and industry. They are often manufactured by bombarding stable isotopes with neutrons in a nuclear reactor. Since neutrons have no charge they are not repelled by the positive nucleus. Some radioisotopes are used in medical applications such as treatment of cancer cells. Radioisotopes can be injected into the body to help destroy the cancerous cells which cause a cancer tumour.

Radioisotopes are found in household smoke detectors. The radioisotope causes the smoke particles to ionise creating a small electrical current which then sets of an alarm.

Summary Statements

- ☐ Unstable isotopes become more stable by emitting radiations.
- ☐ Isotopes which emit radiations are known as radioactive isotopes or radioisotopes.
- ☐ The three types of radiation emitted from nuclei are alpha (α) particles , beta (β) particles and gamma (γ) rays.
- ☐ Alpha and beta radiations change an isotope of one element to an isotope of another element.
- ☐ Gamma emissions are due to nuclei losing energy.
- ☐ Alpha particles are helium nuclei and are heavy positively charged particles which are slow moving and have low penetration, they travel only a few centimetres through the air.
- ☐ Beta particles are fast moving electrons and are negatively charged and are more penetrating than alpha particles but are stopped by thin aluminium.
- ☐ Beta particles are emitted when a neutron changes to a proton in the nucleus.
- ☐ Gamma rays have no mass or charge and travel at the speed of light, gamma rays are stopped by 10 cm of lead or thick concrete.
- ☐ The time for half of the nuclei of a particular isotope to decay is fixed and is called the half-life.
- ☐ The age of materials can be determined using the half-lives of radioisotopes
- ☐ Nuclear equations are used to describe the transitions which produce radiations, mass numbers and atomic numbers of isotopes are shown in nuclear equations.
- ☐ Radioisotopes have a wide range of uses, e.g. medical use, industrial use, scientific use.
- ☐ Carry out calculations involving half-lives.