THE BRITISH SCHOOL OF KUWAIT

IGCSE Physics

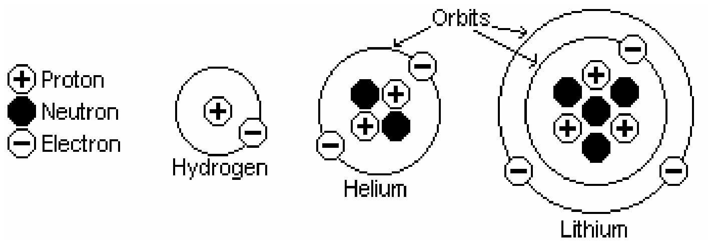
RADIOACTIVITY AND THE ATOM

INTRODUCTION

This unit will detail the structure of the atom is terms of electrons, protons and neutrons as well as studying isotopes and their uses. It will also investigate why certain atoms are radioactive, what happens during decay and the types and nature of particles given off in decay. Know the term half-life and how to calculate it as well as the safety precautions needed for radioactive materials.

THE MODEL OF THE ATOM

Consists of a central nucleus with electrons orbiting far distant from it. For atoms or Molecules, which are neutral then:
No. of Electrons = No. of protons
The nucleus contains only two types of particles - Protons and Neutrons.



The ratio of protons to neutrons depends upon which atom we consider.

Protons = symbol **p** positively charged (**+**)
Electrons = symbol **e** negatively charged (**-**)
Neutrons = symbol **n** no charge

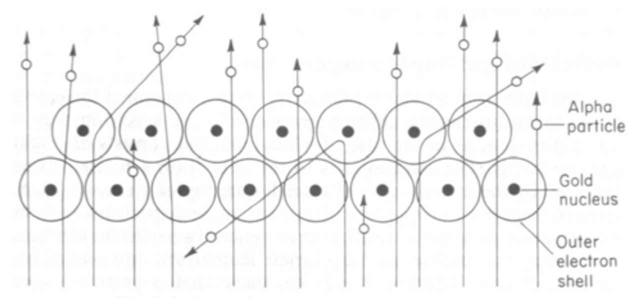
ATOMIC NUMBER AND MASS NUMBER

For each element, there is: An atomic number = number of protons, symbol Z;
A mass (or nucleon) number = number of nucleons (number of p + n), symbol A.
For any given atom we define it by its number of protons and nucleus.
All of these are contained in the nucleus.
We can refer to an atom as a NUCLIDE.
Each nuclide can be written in notation as follows: $^{A}_{Z}X$
Where: X = Chemical symbol, A = Mass number, Z = Atomic number
e.g. $^{7}_{3}Li$ $^{4}_{2}He$ N.B Since A = p + n and Z = p
Then number of neutrons = A – Z

EVIDENCE FOR ATOMIC MODEL

The scintillator is a special screen, which when attached to a microscope, produces a flash of light for each α particle that strikes it. If a stream of α particles is fired at a very thin sheet of gold leaf, a scintillator can be used to detect what happens to these α particles.

It was found that most of the particles passed straight through the foil, some were deflected downwards, upwards and left to right. This helps to support the model of the atom because:



1. Since most (+vely charged) α particles pass straight through the foil it suggests that most of the atom is empty space, with most of its mass concentrated in the nucleus.
2. It also suggests that the nucleus is +vely charged since it manages to repel some of the particles and therefore scatter them.

ISOTOPES

Some elements (nuclides) have different forms. They have the same chemical properties, but may have different physical properties.

$^{35}_{17}Cl$ $^{37}_{17}Cl$

$^{12}_{6}C$ $^{14}_{6}C$

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

Each form has the same Z number (number of p) but a different A number (number of neutrons) which causes this difference.
These forms are called Isotopes of each other.
Isotopes of an element are atoms that have the same number of protons, but a different number of neutrons.
Most of these isotopes have forms that are radioactive.

RADIOACTIVITY AND RADIOACTIVE DECAY

A material is 'radioactive' if it gives out 'Ionising Radiation'. This occurs because the nucleus of the atom is 'unstable' in some way. It has:

1. An imbalance between its number of protons and number of neutrons and will emit a particle from the nucleus to adjust this imbalance and become stable – this causes α and β
2. An excess of energy in the nucleus from process 1, this causes γ rays

This giving out of ionising radiation in order for the nucleus to become stable leads to a change in the nucleus, so that it is no longer the same element. In other words it has undergone **transmutation**.
The whole process of giving out radiation and the nucleus charging is called "**Radioactive Decay** ".

RADIOACTIVE EMISSIONS / IONISING RADIATION

There are three main types of radioactive emission:

1 The Alpha particle (α)
Emitted from the nucleus and is the same as a helium nucleus — $^{4}_{2}\alpha$ or $^{4}_{2}He$

2 The Beta particle (β)
Also emitted from the nucleus and is the same as an electron — $^{0}_{-1}\beta$ or $^{0}_{-1}e$

3 The gamma ray (γ)
Also from the nucleus, but never emitted alone, only with Alpha or Beta. — $^{0}_{0}\gamma$
It is not a particle. It is a wave of pure energy.

DECAY SCHEMES

To achieve stability, a nucleus will often undergo several decays and these can be represented in a series of diagrams like these.

Alpha Decay $^{226}_{88}Ra \longrightarrow ^{222}_{86}Rn + ^{4}_{2}\alpha$

Beta Decay $^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}\beta$

Gamma Decay $^{226}_{88}Ra \longrightarrow ^{226}_{88}Ra + ^{0}_{0}\gamma$

A larger decay scheme: $^{232}_{90}Th \longrightarrow ^{4}_{2}\alpha + ^{228}_{88}Ra \longrightarrow ^{0}_{-1}\beta + ^{228}_{89}Ac \longrightarrow$

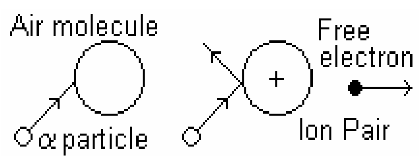
This could be also the represented in words rather than chemical symbols.

PROPERTIES OF IONISING RADIATION

<u>**Properties**</u>	<u>**α - particle**</u>	<u>**β - particle**</u>	<u>**γ Gamma Ray**</u>
Nature	+ve charge Helium nucleus	-ve charge Electron No mass	No charge E–M waves No mass
Affected by magnetic field	Yes	Yes	No
Affected by electric field	Yes	Yes	No
Penetration	Stopped by paper or skin	Stopped by 3mm of Al	Reduced, but not stopped by thick lead.
Ionising effect	Strong Ionisation	Weak Ionisation	Very weak Ionisation
Detectors	Photographic film, cloud chamber, spark counter, g–m tube.	Photographic film, cloud chamber, g–m tube	Photographic film, cloud chamber, g–m tube.

IONISING EFFECT

As alpha and beta travel through a medium, they collide with the molecules of that medium. If they collide hard enough they will knock an electron out of the mediums molecule to from a free electron and a +ve ion. In other words they form an “ion pair”.



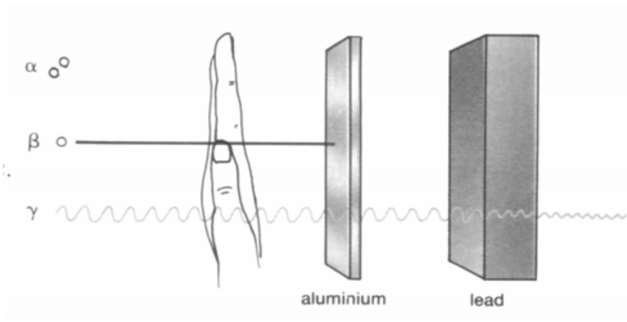
Ionising effect is a measure of how much Ionisation each emission causes. γ achieves the same results (but less effectively) as an electron in the molecules absorbs some of the energy of the γ ray and breaks completely free.

PENETRATION

This is a measure of how easy it is to stop the ionising radiation, by allowing a material to absorb it. The order is as follows: α particles β < particles < γ rays

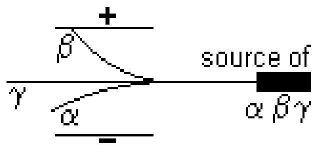
An experiment to show this is as follows:

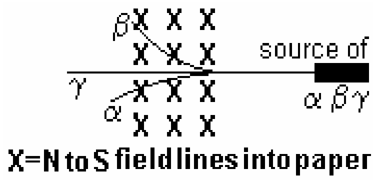
Place a radioactive source a set distance from a detector and in turn place paper, aluminium sheet and lead sheet between the source and detector and record the count rate on the detector.



Alpha particles are absorbed by thin paper or skin.
Beta particles are absorbed by a thin sheet of aluminium.
Gamma rays are reduced by thick lead.
So a drop in count rate (greater than background fluctuation) when paper is used shows that α - particles were present. If no drop in count rate occurs till Al is used then β - particles were present and so on.

EFFECT OF ELECTRIC / MAGNETIC FIELDS





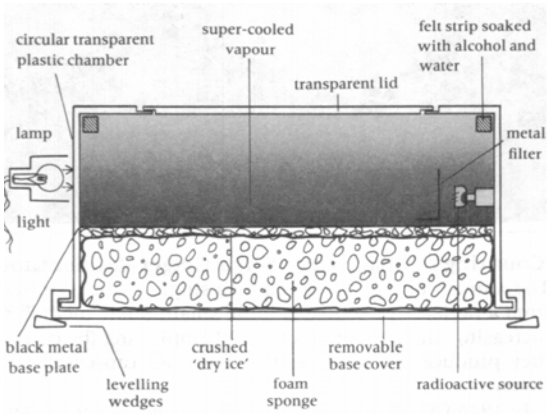
Electric field Since α is +vely charged and β -vely charged they would be affected by the electric field, but γ rays will not because they have no charge. β curves more than α since β are more easily deflected as they are is much lighter than α particles.

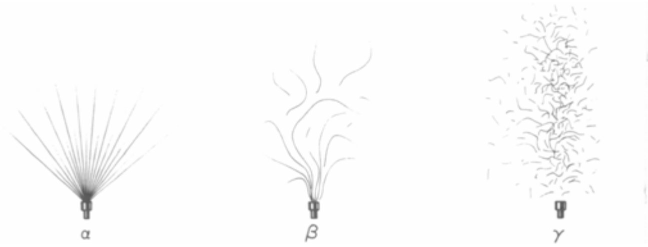
Magnetic field γ rays are undeflected since they have no charge. By Fleming's left hand rule, in this case β will be deflected upwards and α downwards.

DETECTION OF IONISING RADIATION

Cloud chamber

As the ionising radiation passes through the chamber it causes ionisation of the air inside it. The dry ice causes the alcohol vapour to condense on the ion pairs formed by the ionising radiation. This shows as sets of bright patterns on the dark surface.

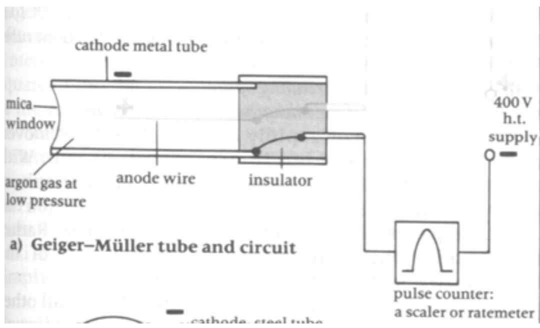




Each pattern is specific to the type of radiation, so the cloud chamber can be used to not only detect radiation but also to discover its type.

The Geiger – Muller tube

This is a tube containing a gas at low pressure. The radiation passes through the thin window at the front and ionises the gas inside. These ion pairs are attracted to the cathode and anode so that an electric current flows.



This current can be used to drive -

- A scalar - records the bursts of current as numbers on a digital display in counts per minute or per second.
- A ratemeter - records the current as a needle deflection on an ammeter.
- A loud speaker – this converts the electricity into a series of clicks. The rate of clicks given an indication as to the amount of radiation present.

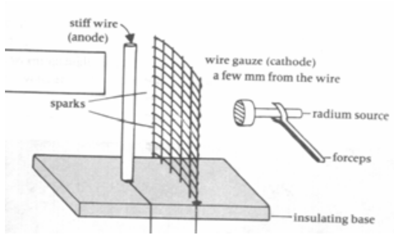
In all cases only the presence and quantity of charge is identified, not the type.

Photographic film

Used on badges to monitor levels of radiation. The film in the badge will lighten as it is exposed to radiation.

The spark counter

As the air is ionised by the radiation, the ion pairs produced are attracted to the wire gauze and sparks are produced. The number of sparks represents the intensity of the radiation. Type of radiation is not identified.



THE RANDOMNESS OF DECAY

There is no way to predict which nucleus in a sample will decay first, or when it will decay. This means that any "counting" of decay will have a random factor because only the same number of nuclei will decay each minute or second.

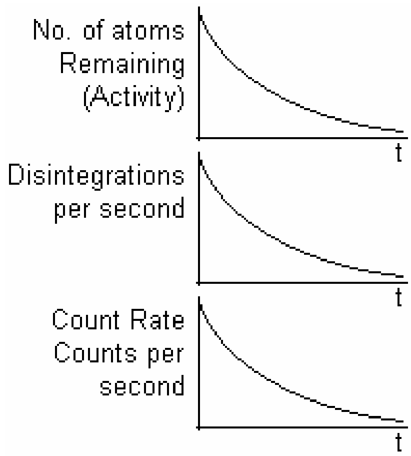
To reduce this randomness in our results we repeat the count per minute over a period of time and average our results. If we did not, we would not get the smooth carve shown in the next section, but could have random points through which we would have to draw our best curve.

DECAY GRAPHS AND HALF-LIFE

We can monitor how the radioactivity of a sample changes with time, in several ways.

1. Activity = number of radioactive nuclei / atoms that have not decayed.
2. Disintegration's / second or minute = number of nuclei decaying each minute or each second.
3. Count rate = equivalent to number of nuclei decaying per second or minute.

All of these can be shown on graphs ==>



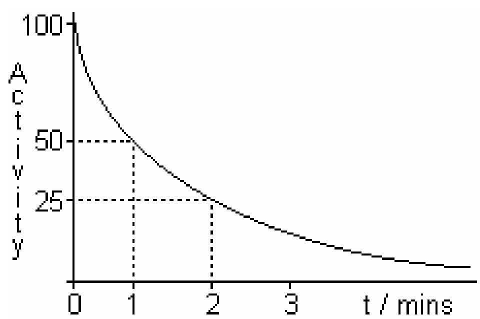
In each case, it can be seen that the decay is "exponential" this means that there will never be a time when the radioactivity of a sample will reach zero.

The " Half–Life "is the time taken for half of the original number of atoms to decay.

The half–life can be calculated from ANY decay curve as follows:

1. Time taken for activity to halve (e.g. 100 to 50) is found => half-life.
2. Time taken for activity to fall from 50 to 25 is found => half life

In this example the half-life is one minute



BACKGROUND RADIATION

There is a natural low-level radiation that is constantly around us. This is called the "Background Radiation" with an average count rate of 25 c.p.m. (counts per minute). It is so low that it is at a safe level. All measurements taken will include this value, so in the experiment on "penetration", for example, the count rate can never reach zero even if all of the radiation from the source were absorbed.

STORAGE AND HANDLING OF RADIOACTIVE MATERIAL

The damage from α particles (due, like all radiation, to their ionising properties) is small unless the source enters the body. β and γ rays can cause radiation burns (i.e. redness and sores on the skin) and delayed effects such as cancer and eye cataracts. Fall out from atomic explosions contains highly active elements (such as Strontium), with long half lives, which are absorbed by bones.

The weak sources used by schools should always be lifted with forceps, never held near the eyes and should be kept in their boxes when not in use. In industry, sources are handled using long tongues and transported in thick lead containers. Workers are protected by lead and concrete walls.

USES OF RADIATION

Radioactive isotopes, or radioisotopes, can be made by bombarding substances inside a nuclear reactor. Handled with care, they have many uses.

Radioactive tracers

Radioactive fertiliser can be fed to plants and then traced through the plant using a Geiger counter. This method is used to develop better fertiliser.

Radioisotopes have important medical uses. For example, a doctor might suspect that a patient has a blocked kidney. To find out, the patient sits with a Geiger country over each kidney. A small amount of iodine-123 is injected into the patient. Within 5 minutes both the kidneys should extract the iodine from the blood stream, and then within 20 minutes, pass it with urine into the bladder. The difference in readings from the two counters will show which of the kidneys is blocked.

The most common tracer is called technetium–99.

This is very useful, and safe because:

- It emits only gamma rays; the γ rays can be detected outside the body by a "gamma-camera". It is also safer because γ rays do not cause much ionisation. Ionisation can damage cells and cause cancer (it is alpha-radiation, strongly ionising, that is the most dangerous if it gets inside your body. Perhaps from a radioactive gas like radon).
- It has a short half-life (of 6 hours). How much of it remains after one day?

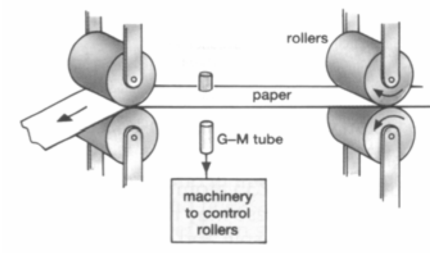
Tracers are also used in industry. If radioactive pistons are fitted to a car, then a Geiger counter can be used to test the oil for traces of wear from the piston. Different piston designs can be tested.

Leaks from a pipeline carrying oil or gas can be traced by injecting a radioisotope into it. This saves digging up all the pipe. The right isotope is chosen so that:

- It has a half-life of only a few hours or days. This is so that it remains long enough to be detected but not so long that it remains a safety problem.
- It is a beta-emitter. Alpha particles would be absorbed by the soil, whereas gamma rays would pass through the metal pipe anyway.

Sterilising
Gamma rays can be used to kill bacteria, mould and insects in foods, even after the food has been packaged. This prolongs the shelf life of the food, but it sometimes changes the taste.
Gamma rays are also used sterilise hospital equipment, especially plastic syringes that would be damaged by heating them.
Cancer cells in a patient's body can be killed by careful use of γ rays.

Thickness control
In paper mills, the thickness of the paper can be controlled by measuring how much beta-radiation passes through the paper to a Geiger counter.



The counter controls the pressure of the rollers to give the correct thickness.
With paper, or plastic, or aluminium foil, β rays are used. In a sheet-steel factory γ rays are used. Why is this? Why should the source have a long half-life?

Smoke detection
Many homes are fitted with a smoke alarm. This contains a weak source made of Americium-241. This emits alpha particles, which ionise the air. So that it conducts electricity and a small current flows.
If smoke enters the alarm, it absorbs the α particles, the current reduces and the alarm sounds. Am-241 has a half-life of 460 years. Why is this useful?

Checking Welds
If a gamma source is placed on one side of the welded metal, and a photographic film on the other side, weak points, or air bubbles, will show up on the film because more radiation will have passed through the weak weld.

Radioactive dating
The Uranium-238 in rocks decays steadily with a very long half-life of 4500 million years. It changes slowly into lead. By measuring how much of the uranium has changed into lead, it is possible to calculate the age of the rock.
The U-238 acts as a kind of clock.
With once-living material (like Egyptian mummies) Carbon-14 is used instead.

Homework p 351: q 4, 5, 6; p 353: q 3, 4.