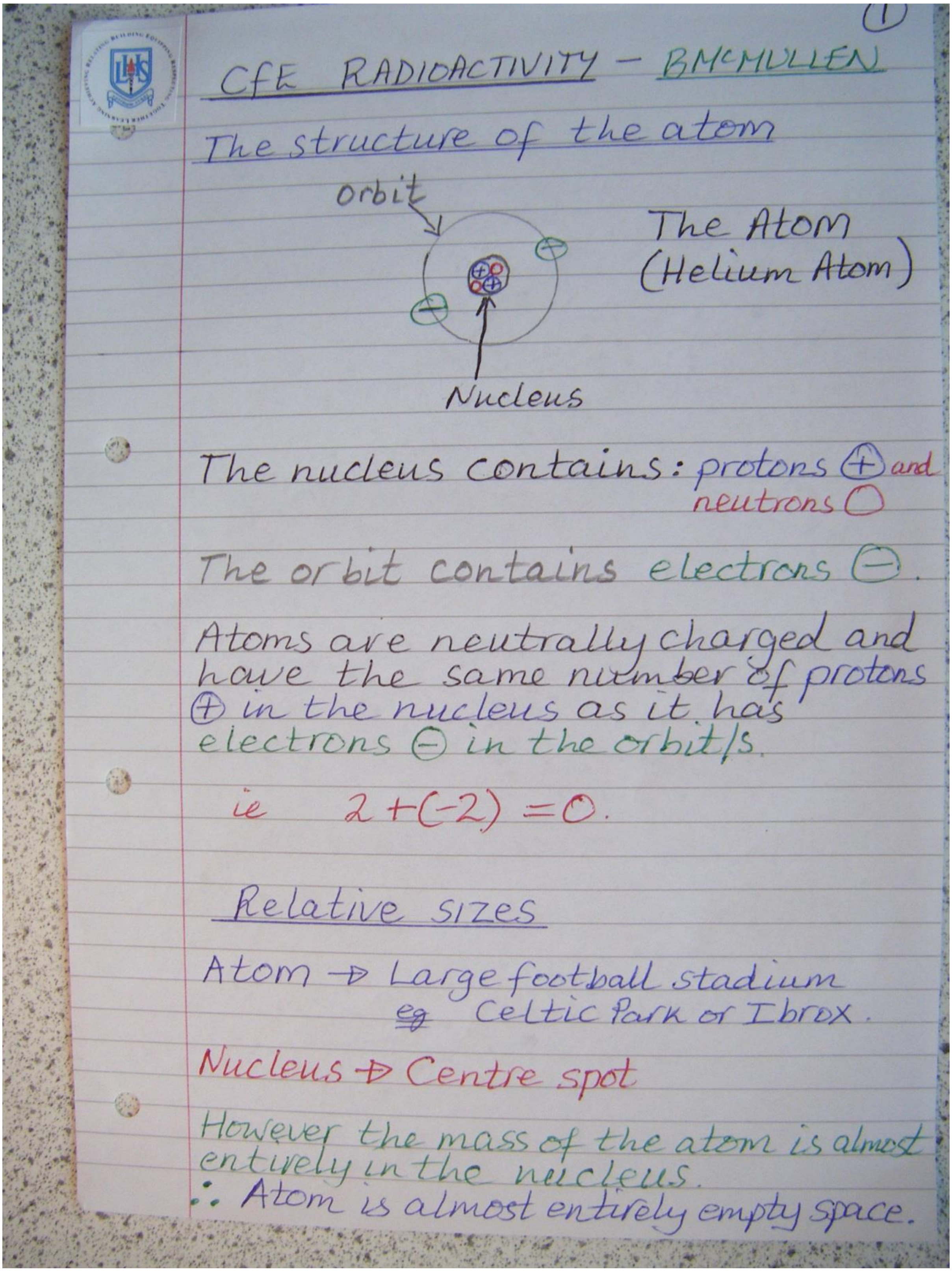


CfE RADIOACTIVITY – BMcMULLEN

The structure of the atom

orbit

The Atom
(Helium Atom)

Nucleus

The nucleus contains: protons ⊕ and neutrons ○

The orbit contains electrons ⊖.

Atoms are neutrally charged and have the same number of protons ⊕ in the nucleus as it has electrons ⊖ in the orbit/s.

ie $2+(-2)=0$.

Relative sizes

Atom → Large football stadium
eg Celtic Park or Ibrox.

Nucleus → Centre spot

However the mass of the atom is almost entirely in the nucleus.
∴ Atom is almost entirely empty space.

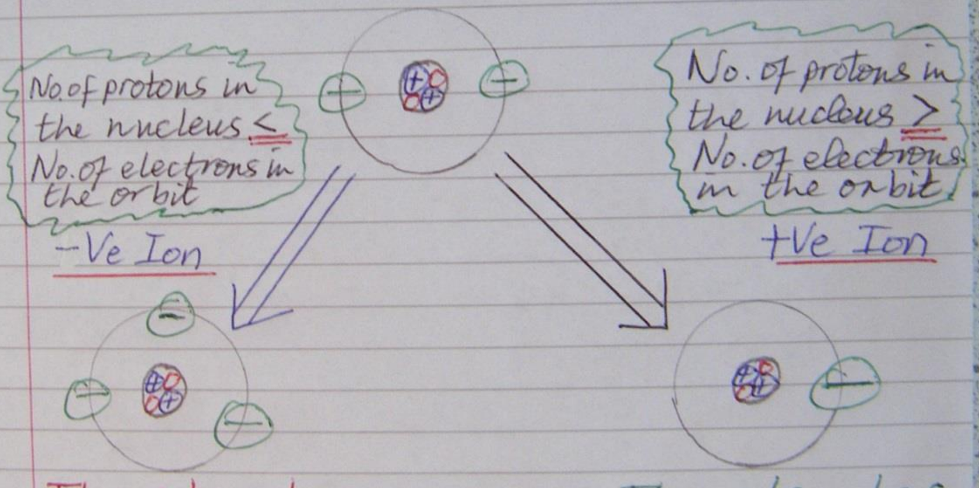
Ionisation

Ionisation is defined as the loss or gain of an electron from an atom.

* If an atom has an electron knocked off its orbit it will become a positive ion. *

* If an atom has an electron added to its orbit it will become a negative ion. *

Atom



No. of protons in the nucleus < No. of electrons in the orbit

-Ve Ion

No. of protons in the nucleus > No. of electrons in the orbit

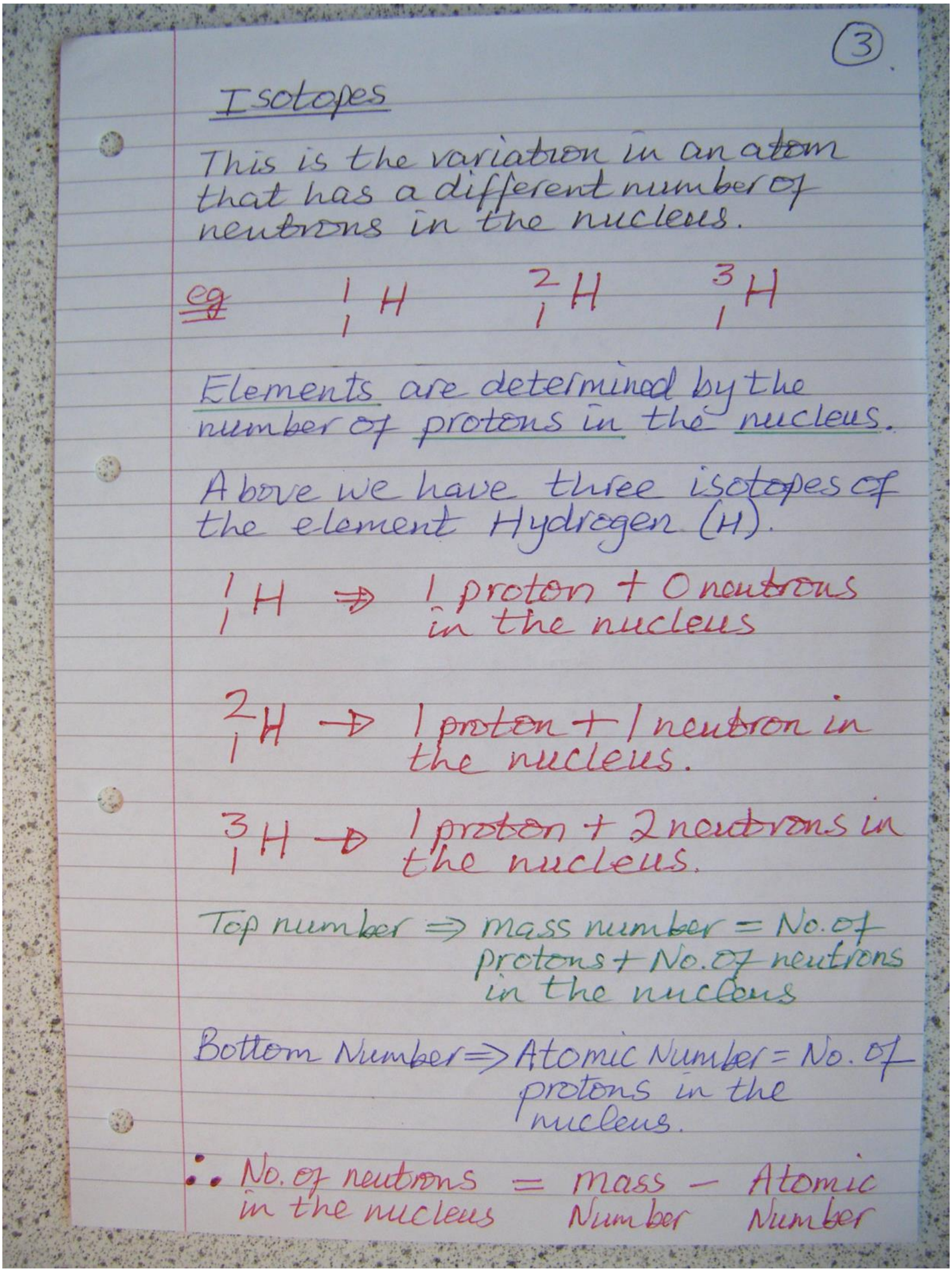
+Ve Ion

The atom has an electron added to the orbit. $2+(-3)=-1$

∴ Overall negative charge.

The atom has an electron knocked off the orbit. $2+(-1)=+1$

∴ Overall positive charge.



Isotopes

This is the variation in an atom that has a different number of neutrons in the nucleus.

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

Elements are determined by the number of protons in the nucleus.

Above we have three isotopes of the element Hydrogen (H).

$^{1}_{1}H \Rightarrow$ 1 proton + 0 neutrons in the nucleus

$^{2}_{1}H \rightarrow$ 1 proton + 1 neutron in the nucleus.

$^{3}_{1}H \rightarrow$ 1 proton + 2 neutrons in the nucleus.

Top number ⇒ mass number = No. of protons + No. of neutrons in the nucleus

Bottom Number ⇒ Atomic Number = No. of protons in the nucleus.

∴ No. of neutrons in the nucleus = Mass Number − Atomic Number

Types of Radiation

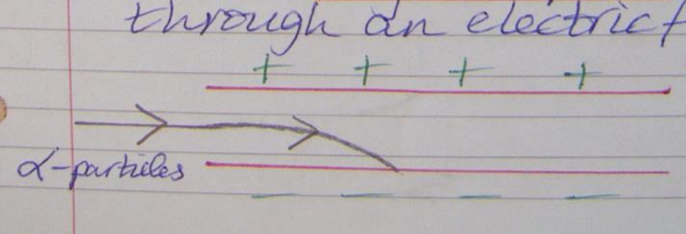
The three types of radioactive source that we will look at are:

- Alpha (α)
- Beta (β)
- Gamma (γ)

Helium atom ↓ Helium nucleus ↓

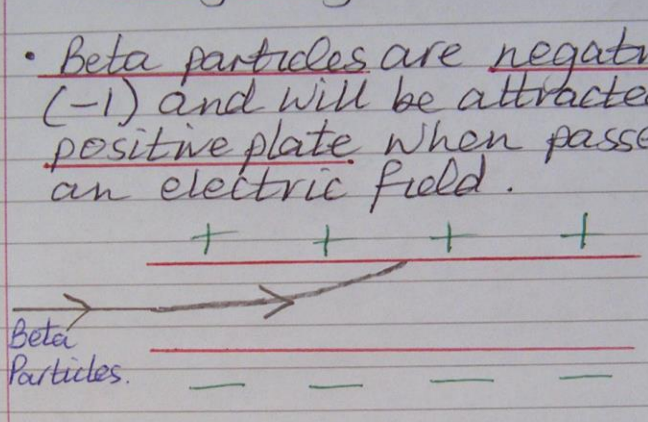
* 1) Alpha (α) $\Rightarrow$ $^{4}_{2}He$ $(^{4}_{2}He^{2+})$

- This consists of a Helium nucleus. (atom with no outer electrons)
- Alpha particles do not travel far and are absorbed by a thin piece of paper or a few cm's of air.
- Alpha particles are much more ionising than any other form of radiation and have a Weighting Factor, $W_R = 20$.
- Alpha particles are positively charged (+2) and will be attracted to the negative plate when passed through an electric field.



* 2) Beta (β) ⇒ $^{0}_{-1}e$

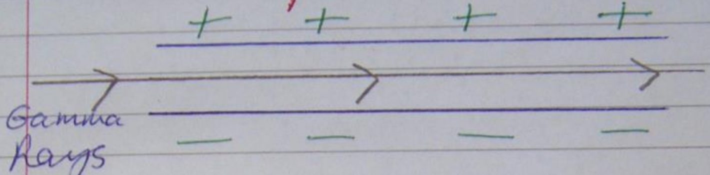
- This is a fast moving electron
- Beta particles can pass through air and paper but will be absorbed by a few mm's of Aluminium (AL)
- Beta particles ionise but not as much as alpha particles. They have a weighting Factor, $W_R = 1$.
- Beta particles are negatively charged (−1) and will be attracted to the positive plate when passed through an electric field.



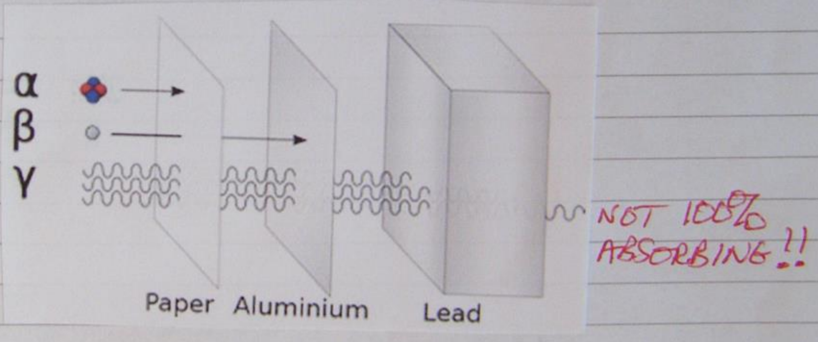
* 3) Gamma (γ) ⇒ $^{0}_{0}\gamma$

- This is high frequency e.m radiation. (high energy radiation)
- Gamma rays can pass through air, paper and aluminium. However they will be absorbed by cm's of Lead (Pb). {But this is not 100% absorbing}
- Gamma rays can pass straight through your body so are very useful as radioactive tracers.

- Gamma rays are much less ionising than alpha or beta particles.
- Gamma rays have no mass and no charge. Therefore they will not deviate when passing through an electric field.



Absorption of α, β and γ radiation



Alpha particles (α)

Absorbed by a piece of paper or a few cm's of air.

Beta Particles (β)

Absorbed by mm's of Aluminium (Al).

Gamma Rays (γ)

Absorbed by cm's of Lead (Pb) but this is not 100%. (Also absorbed by Concrete!!)

Detection of Radiation

A Geiger-Muller tube (GM tube) is used to detect α, β and γ radiation

Ions are produced in a GM tube when α, β and γ radiation are detected.

The ions produced will allow a current flow, with a greater number of ions produced providing a larger current.

Applications of radioactive sources in medicine

- Treating malignant tumours

A Gamma source is rotated around a patient. The source is centred on the cancerous tissue, so it receives a large dose.

The healthy tissue will only receive a much lower dose of gamma radiation.

- Radioactive tracers

They emit gamma radiation and can be detected outside the body. They allow doctors to find out if there is a blockage or if any organ is not working properly.

- Ionisation

In terms of Health Physics it can kill, damage or change the nature of healthy cells or tissue.

- Sterilisation

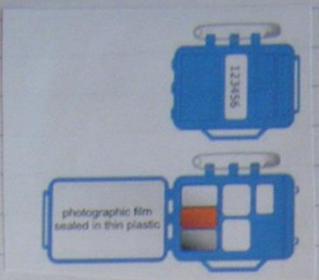
Medical instruments can be sterilised using radiation inside a sealed bag. This will kill the bacteria, but will not make the instrument radioactive

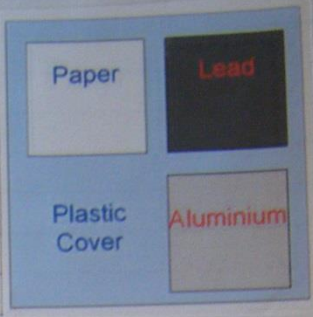
- Radioactive tracers in Industry

These can be used to track leaks from underground pipes, without having to dig up the ground or roads.

Radiation can also be used in Agriculture during research to look at how plants absorb fertilisers.

Film Badges.





Workers who use radioactive materials, such as Health Physicists or Nuclear Physicists in power stations, are required to wear film badges throughout their working day.

When radiation hits the photographic film it will fog ie change colour from white to grey/black shades.

From the fogging of the film:

1) The type of radiation exposed to can be identified. This depends on which windows the radiation passes through in the film badge.

2) The quantity of radiation exposure can be worked out by the degree of the fogging on the photographic film.

Dosimetry

This is the part of the Radioactivity unit which Health and Nuclear Physicists perform calculations to measure the radioactive dose to workers, patients etc.

Activity of a radioactive source

$$\boxed{A = \frac{N}{t}}$$

→ No. of decays/ Counts/ disintegrations of atoms

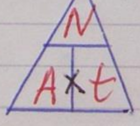
Activity (Becquerels)

→ time (seconds)

Definition of Activity

* The number of atoms in a source that decay per second. *

Becquerels have the symbol Bq.



1/ $A = \frac{N}{t}$

2/ $N = At$

3/ $t = \frac{N}{A}$

- 1Bq = 1 Count per second
- 1Bq = 1 decay per second
- 1Bq = 1 disintegration per second

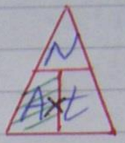
Atoms

Ex 1

A radioactive source produces 2400 decays of atoms in 2 minutes.

Calculate the activity of the source

A = ?
N = 2400 decays
t = 2 minutes = 120 s



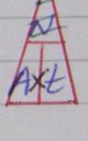
$A = \frac{N}{t} = \frac{2400}{120}$

$\underline{\underline{A = 20\,Bq}}$

Ex2

The activity of a radioactive source is 4MBq. How many disintegrations of atoms will take place in 2hours.

$A = 4MBq = 4 \times 10^6\,Bq$
N = ?
t = 2 hours = 2×60×60 = 7200 s



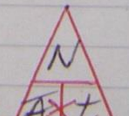
$N = At$
$\Rightarrow N = 4 \times 10^6 \times 7200$
$\Rightarrow N = 2.88 \times 10^{10}$ disintegrations

Ex3

A pupil measures the background activity at 45 counts per minute using a Geiger-Müller tube and a counter.

Calculate the background activity in Bq.

A = ?
N = 45 counts
t = 1 minute = 60 s



$A = \frac{N}{t} = \frac{45}{60} = \underline{\underline{0.75\,Bq}}$

Absorbed Dose (D)

This is the radiation energy absorbed per kilogram of absorbing tissue.

Absorbed dose is measured in Grays (Gy) or Joules per kilogram (JKg^{-1}).

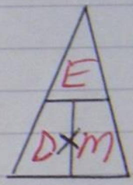
$$\text{Absorbed Dose} = \frac{\text{Radiation Energy}}{\text{Mass of absorbing tissue}}$$

$$\boxed{D = \frac{E}{m}}$$

$E \rightarrow (J)$

$m \rightarrow (Kg)$.

$D \rightarrow$ Gy or JKg^{-1}



1. $D = \frac{E}{m}$
2. $E = Dm$
3. $m = \frac{E}{D}$.

Ex4

Calculate the absorbed dose received by a radiation worker of mass 90kg who absorbs 0·45J of radiation energy.

$D = ?$

$E = 0{\cdot}45J$

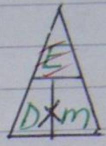
$m = 90kg$

$$\therefore D = \frac{E}{m} = \frac{0{\cdot}45}{90} = \underline{\underline{5 \times 10^{-3} Gy}}$$

Ex 5

Calculate the energy (radiation) absorbed by a Health Physicist in a hospital, if they have a mass of 60Kg with an absorbed dose of 25mGy.

$D = 25mGy = 25 \times 10^{-3} Gy$
$E = ?$
$m = 60Kg.$



$E = DM$
$\Rightarrow E = 25 \times 10^{-3} \times 60$
$\Rightarrow \underline{\underline{E = 1.5J}}$

Equivalent Dose (H)

This is a measure of the risk of the biological harm of radiation on living tissue due to the exposure of radiation.

This depends on 3 factors:

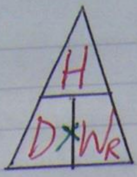
1) Absorbed Dose (D)
2) The type of radiation (W_R)
3) The body tissue or organs affected.

$$\boxed{H = D W_R}$$

W_R → Weighting Factor (No units!!)

H → Equivalent Dose (Sieverts) ⇓ Sv

D → Absorbed Dose (Grays) ⇓ Gy



1. $H = DW_R$

2. $D = \frac{H}{W_R}$

3. $W_R = \frac{H}{D}$

* Values of Weighting factor lie between 1 and 20. (ie $1 \leq W_R \leq 20$).

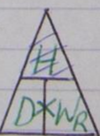
TYPES OF RADIATION	WEIGHTING FACTOR (W_R)
X-Rays	1
γ-Rays	1
Beta particles	1
slow (thermal) neutrons	3
Fast neutrons	10
Protons	10
Alpha Particles	20

Ex6

A radiation worker receives 100μGy of fast neutrons.

Calculate the Equivalent Dose received by the worker.

$H = ?$
$D = 100\mu Gy$
$W_R = 10$



$H = DW_R$

$\Rightarrow H = 100 \times 10^{-6} \times 10$

$\Rightarrow \underline{\underline{H = 1000 \times 10^{-6} Sv}}$

or

$\underline{\underline{H = 1 \times 10^{-3} Sv}}$

Equivalent Dose Rate ($\dot{H}$)

The Equivalent Dose Rate is the Equivalent Dose per unit of time.

$$\boxed{\dot{H} = \frac{H}{t}}$$

$H \rightarrow$ Equivalent Dose (Sv)

$t \rightarrow$ time (h)

$\dot{H} \rightarrow$ Equivalent Dose Rate (Svh^{-1}).

* Technically the Equivalent Dose Rate can be measured in Sieverts per minute or Sieverts per second *

Ex 7

A radiation worker receives an absorbed dose of 40μGy of alpha particles during a 32 hour working week.

Q Calculate or find:

a) Equivalent Dose (H)

b) Equivalent Dose Rate ($\dot{H}$), from the radiation

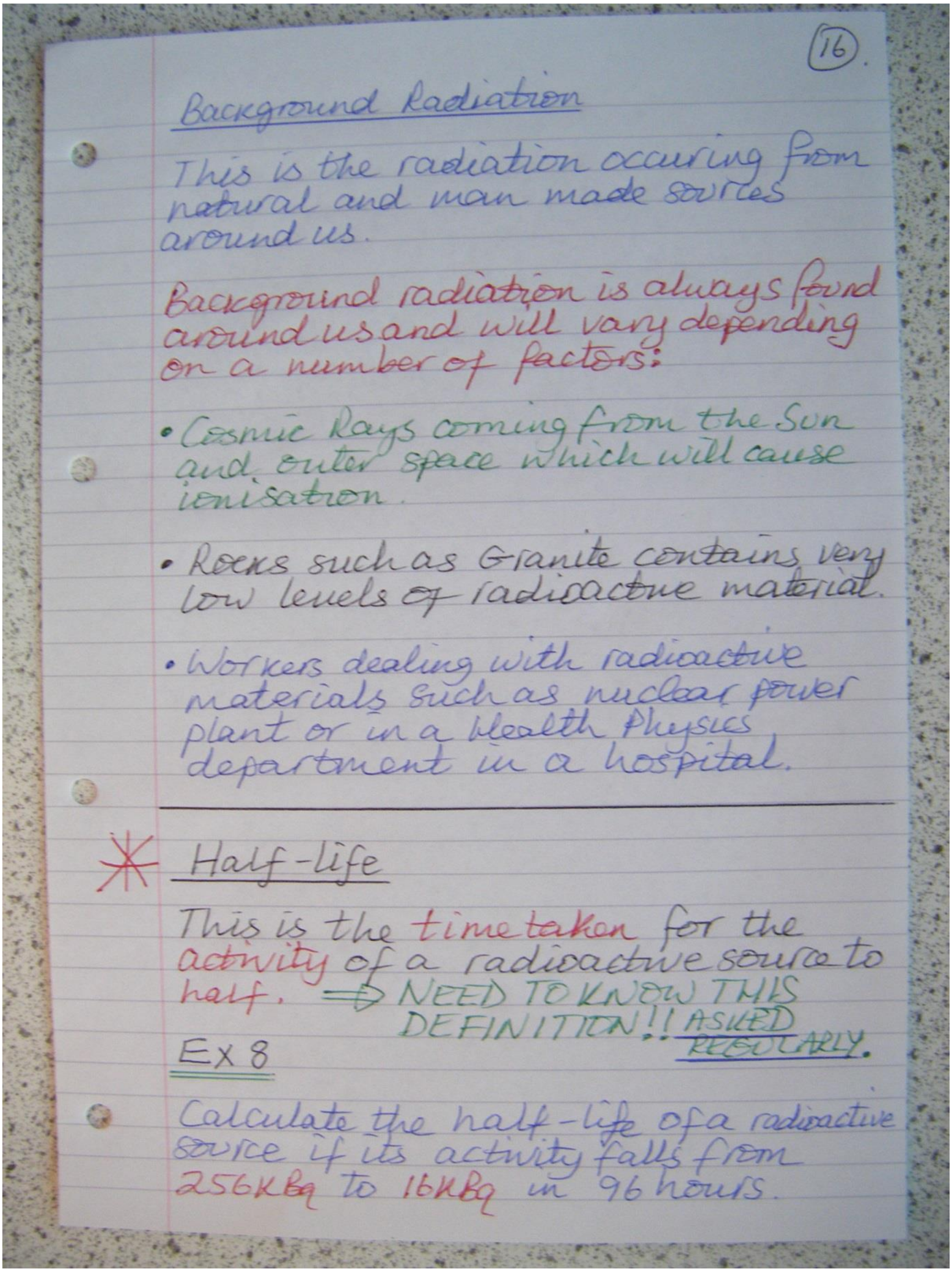
A a) $H = D W_R$

$\Rightarrow H = 40 \times 10^{-6} \times 20$

$\Rightarrow \underline{\underline{H = 800 \times 10^{-6} Sv}}$

b) $\dot{H} = \frac{H}{t} = \frac{800 \times 10^{-6}}{32}$

$\underline{\underline{\dot{H} = 25 \times 10^{-6} Svh^{-1}}}$



Background Radiation

This is the radiation occuring from natural and man made sources around us.

Background radiation is always found around us and will vary depending on a number of factors:

- Cosmic Rays coming from the Sun and outer space which will cause ionisation.
- Rocks such as Granite contains very low levels of radioactive material.
- Workers dealing with radioactive materials such as nuclear power plant or in a Health Physics department in a hospital.

✳ Half-life

This is the time taken for the activity of a radioactive source to half. ⇒ NEED TO KNOW THIS DEFINITION!! ASKED REGULARLY.

Ex 8

Calculate the half-life of a radioactive source if its activity falls from 256kBq to 16kBq in 96 hours.

$$256 \xrightarrow{\textcircled{1}} 128 \xrightarrow{\textcircled{2}} 64 \xrightarrow{\textcircled{3}} 32 \xrightarrow{\textcircled{4}} 16$$

4 half-lives = 96 hours

$\therefore$ half-life $= \frac{96}{4} = \underline{\underline{24 \text{ hours}}}$.

Ex9

Calculate the half-life of a radioactive source if its activity falls to $\frac{1}{32}$ of its original activity in 45 minutes.

$$1 \xrightarrow{\textcircled{1}} \frac{1}{2} \xrightarrow{\textcircled{2}} \frac{1}{4} \xrightarrow{\textcircled{3}} \frac{1}{8} \xrightarrow{\textcircled{4}} \frac{1}{16} \xrightarrow{\textcircled{5}} \frac{1}{32}$$

5 half-lives = 45 minutes

$\therefore$ half-life $= \frac{45}{5} = \underline{\underline{9 \text{ minutes}}}$

Ex10

Iodine-131 has a half-life of 8 days. If its current activity is 20kBq then calculate its activity 40 days ago.

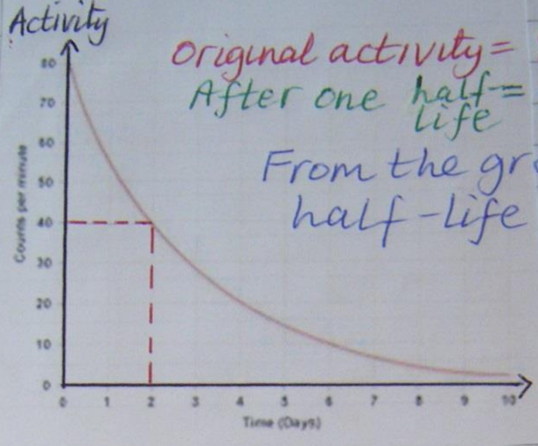
$$20 \xrightarrow{\textcircled{1}} 40 \xrightarrow{\textcircled{2}} 80 \xrightarrow{\textcircled{3}} 160 \xrightarrow{\textcircled{4}} 320 \xrightarrow{\textcircled{5}} 640$$

8 days = 1 half-life

$\therefore$ 40 days = 5 half-lives before

$\therefore$ Original activity = $\underline{\underline{640 \text{KBq}}}$

Finding half-life from a graph



Original activity = 80 counts per minute

After one half-life = 40 counts per minute

From the graph the half-life = <u>2 days</u>.

Safety in handling radioactive sources

- Do not handle radioactive sources with bare hands. Use tongs or forceps
- In Scotland, pupils under 16 are not allowed to handle radioactive sources.
- Always point radioactive sources away from your body and in particular away from your eyes.
- Always wash your hands thoroughly with soap and water particularly before consuming food.
- Wear protective clothing such as goggles, gloves etc.

Protection for radiation workers.

- Radiographers

They stand behind a lead-glass screen. This is so that they can observe the procedure, but will not be exposed to any of the radiation.

They also wear a lead apron to protect the trunk of their body.

- Nuclear Physicists

They wear film badges to monitor their exposure to radiation. They also have to stand as far back from the source as possible.

Radioactive Hazard Sign

When radioactive sources are in use in a classroom, then this sign must be placed on the classroom door.

The room where the radioactive sources are stored must have a permanent hazard sign on the door itself, and on the cabinet that they are held in.

Nuclear Power Stations

We would all hope that there are no charactors like Homer Simpson in charge of a Nuclear Power Station !!!

The Nuclear Power Station in Scotland used to produce electrical energy for our daily consumption is Torness. (This facility lies between Dunbar and Berwick Upon Tweed on the main A1 road south of Edinburgh.)

Advantages of Nuclear Power

- Fossil fuels such as gas and oil are running out. This will create a gap in our electrical energy requirements. Nuclear energy would be a convenient way of filling this gap.

- 1kg of Uranium will produce the same quantity of electrical energy as 180,000kg of Coal. (180 Tonnes)

- Nuclear fuels do not produce greenhouse gases such as CO_2 and SO_2 which fossil fuels do.

Disadvantages of nuclear Power

- If an accident was to occur in Britain, the entire continent of Europe would be affected.

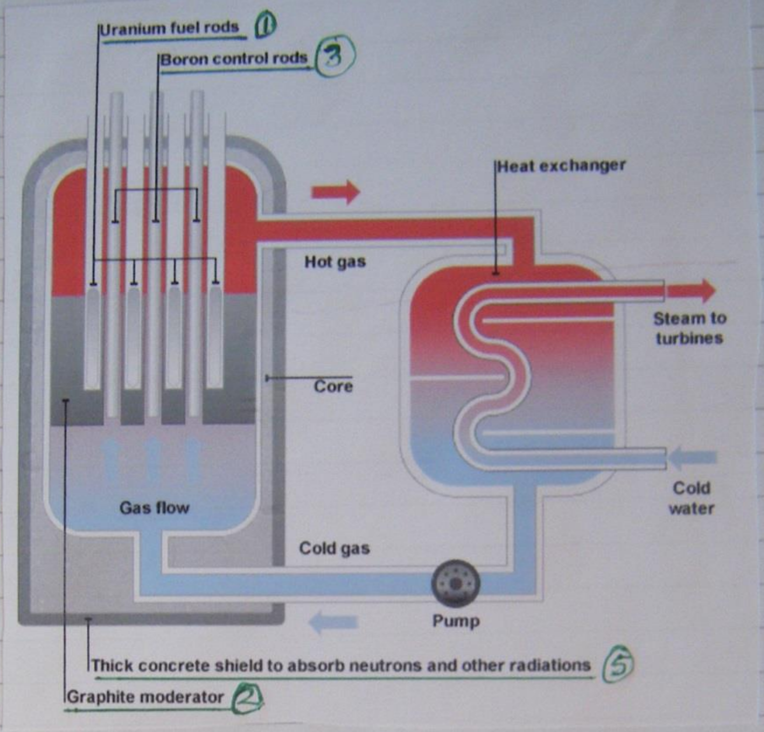
  In 1986 the Nuclear Power Plant at Chernobyl in UKRAINE had an accident, with the nuclear fallout reaching as far as Scotland. The dairy herds in Dumfries and Galloway could not supply their milk for a peried of time due to the contamination of the land.

- Nuclear power plants produce a lot of radioactive waste which is difficult to store and contain.

  The most common form of Uranium ie Uranium - 238 has a half-life of almost 5 billion years.

- Nuclear power plants are only in commission for a few decades. They then need to be de-commissioned and replaced after this peried of time.

Nuclear Reactors



1) Uranium fuel rods supply energy and neutrons to keep a nuclear fission reaction going.

2) Graphite moderator slows down the neutrons as they are going too fast.

3) Boron control rods absorb neutrons so that they cannot go on and create further nuclear fission reactions. ie They control the rate of production of energy.

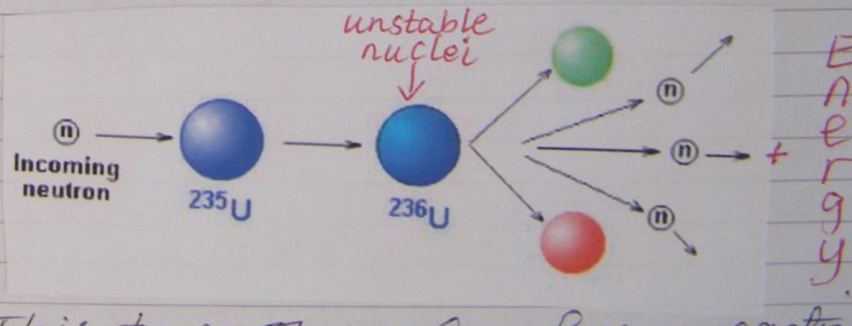
4) CO_2 gas is used as the coolant which passes between the fuel elements to extract heat energy from the core of the reactor.

5) The concrete containment vessel houses the entire reactor for safety reasons. The thick concrete shields the radiation and absorbs the neutrons.

*** Nuclear Fission (SPELLING IMPORTANT!!)

A neutron (extremely small in mass) is fired at a Uranium nuclei (extremely large in mass) to produce a very unstable Uranium nuclei (of even larger mass).

This very unstable Uranium nuclei then splits to form two nuclei of smaller mass with 2/3 neutrons and energy released in the process.



This type of nuclear fission reaction is called an Induced nuclear fission reaction.

Chain Reactions

There are two types:

1) Controlled chain Reactions (Nuclear power stations)

2) Uncontrolled chain Reactions (Nuclear bombs)

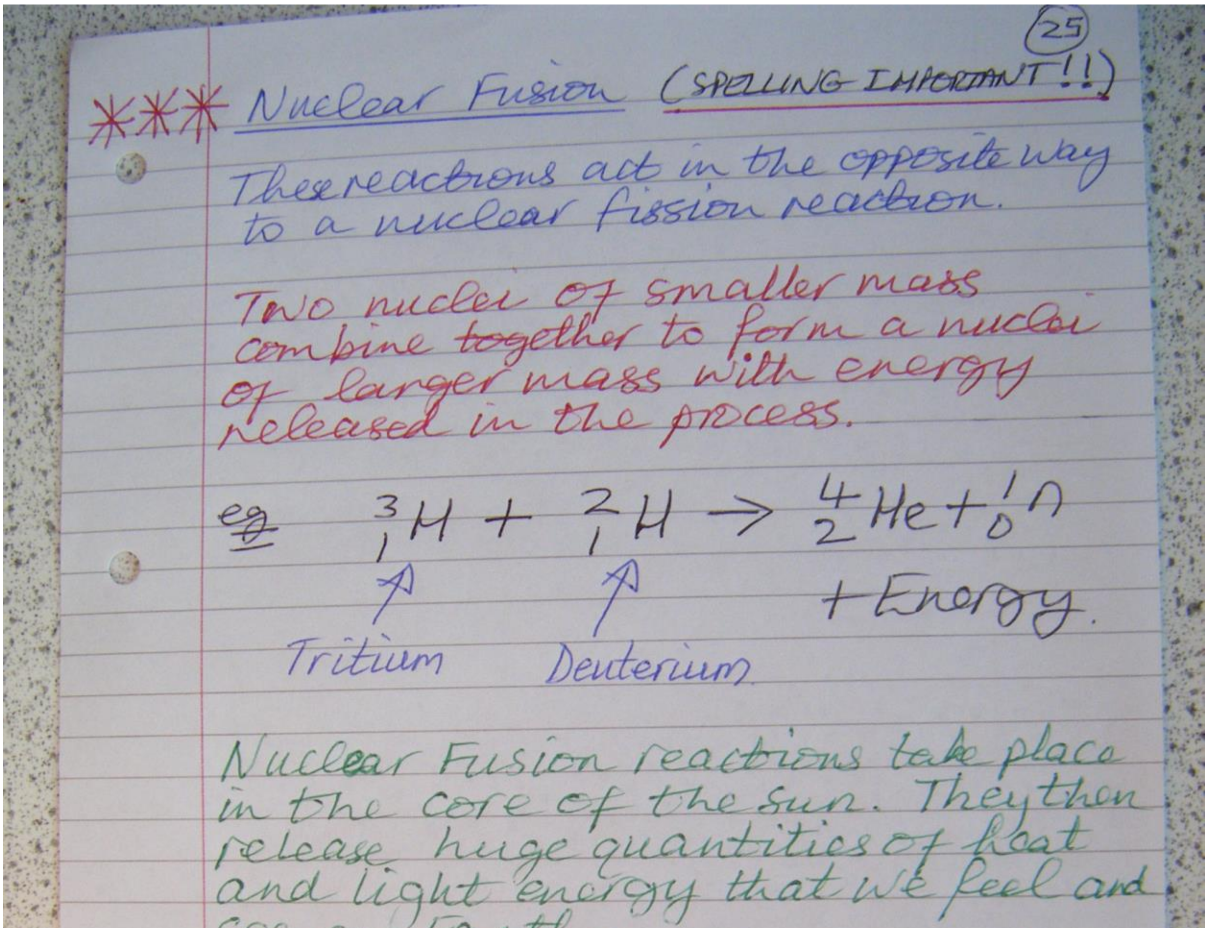
Explanation

In an uncontrolled chain reaction One neutron is fired at a Uranium nuclei which splits producing 2/3 neutrons which will provide further nuclear fission reactions.

ie 1 neutron → 3 neutrons → 9 neutrons → 27 neutrons → 81 neutrons etc etc.

The number of nuclear fission reactions possible then continually increases producing huge quantities of energy.

In controlled nuclear fission reactions the excess neutrons produced are absorbed by the Boron control rods. This means that only one neutron produced in the induced nuclear fission reaction then produces further reactions.



(25)

*** Nuclear Fusion (SPELLING IMPORTANT!!)

These reactions act in the opposite way to a nuclear fission reaction.

Two nuclei of smaller mass combine together to form a nuclei of larger mass with energy released in the process.

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

Tritium Deuterium

Nuclear Fusion reactions take place in the core of the sun. They then release huge quantities of heat and light energy that we feel and see on Earth.

(We would not think this in the Wintertime in Scotland!!!).

RECAP

- Nuclear Fission → A nuclei of large mass is split to form two nuclei of smaller mass.
- Nuclear Fusion → Two nuclei of smaller mass join together to form a nuclei of larger mass.