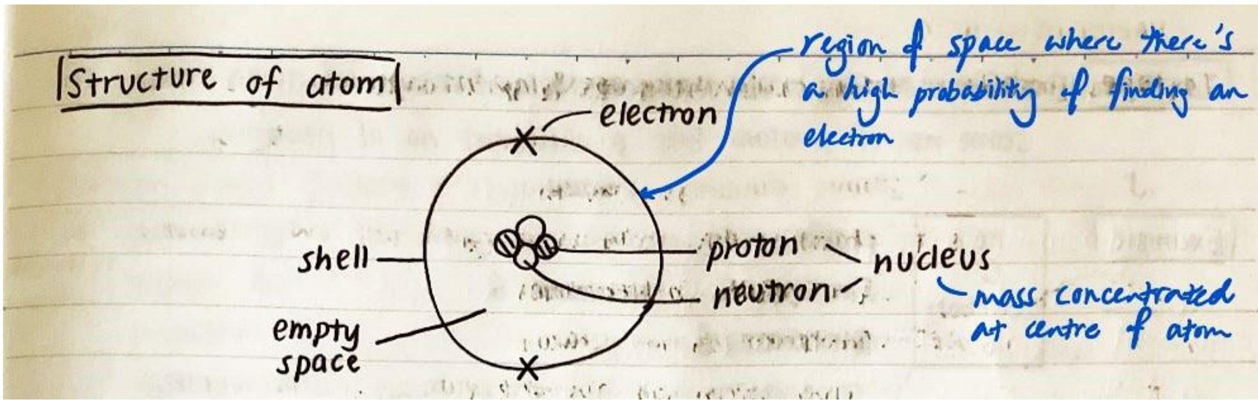
Topic 5 – Atomic physics

Table of Content

5.1 The nuclear atom

5.1.1 Atomic model



Rutherford – 'Alpha Particle Scattering Experiment'

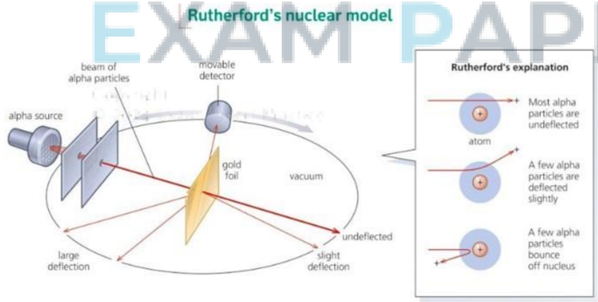
Experiment

- Fired +ve alpha particle beams on extremely thin gold foil

Results

a) Straight through → most atom is empty spaced
b) Slightly deflected → nucleus is +ve charged
c) Deflected by >90° → nucleus is +ve charged

- +ve nucleus concentrate mass of atom at centre of atom
- -ve e^- exist in cloud around nucleus



43 The scattering of α-particles by a thin metal foil supports the nuclear model of an atom.

Why are α-particles used rather than neutrons?

A because they always travel more slowly
B because they are heavier
C because they are larger in diameter
D because they have a positive charge

5.1.2 Nucleus

Name of particle	Relative mass	Electric charge
Proton	1	+1
Neutron	1	0
Electron	0 or $\frac{1}{1836}$	-1

Why doesn't an atom have charge?

- Relative electrical charge ○ Electrons: -1, protons :+1

- No of electrons = no of protons

Atom radius = 0.1nm (1×10^{-10}m)

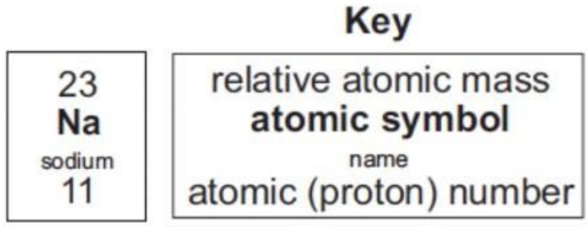
Nucleus radius = $\frac{1}{10000}$ of an atom (1×10^{-14}m)

Formulae

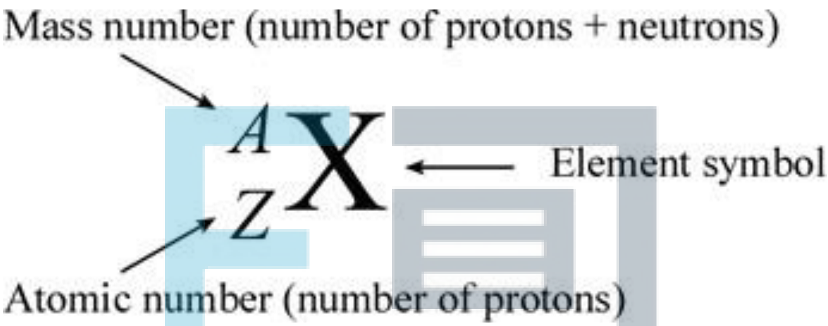
No of neutrons = mass no – atomic no = 23-11 = 12

Atomic no = no of protons = 11

Mass no = protons + neutrons



Nuclide notation for atoms



Isotope

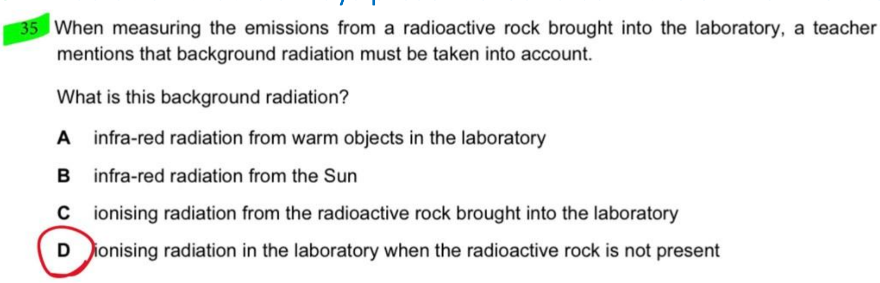
Explain why $^{1111}{}_{66}CC$ and $^{1111}{}_{66}CC$ are isotopes of carbon. You should refer to the numbers of sub-atomic particles in the nucleus of each isotope. (3)

- Isotope is different forms of the same element, which have the same no of protons but different no of neutrons
- They both have 6 protons
- 12C has 6 neutrons, 14C has 8 protons

5.2 Radioactivity

5.2.1 Detection of radioactivity

Background radiation – radiation that is always present around us in the environment eg soil, rocks


35 When measuring the emissions from a radioactive rock brought into the laboratory, a teacher mentions that background radiation must be taken into account.

What is this background radiation?

A infra-red radiation from warm objects in the laboratory

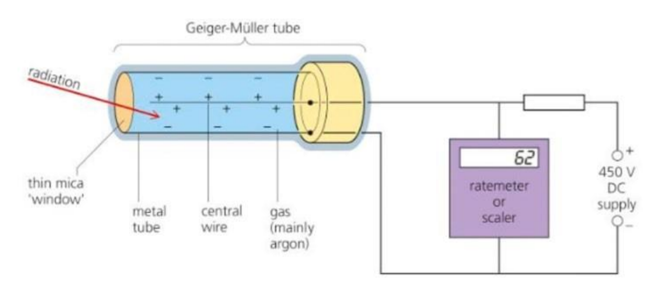
B infra-red radiation from the Sun

C ionising radiation from the radioactive rock brought into the laboratory

D ionising radiation in the laboratory when the radioactive rock is not present

Detecting radioation

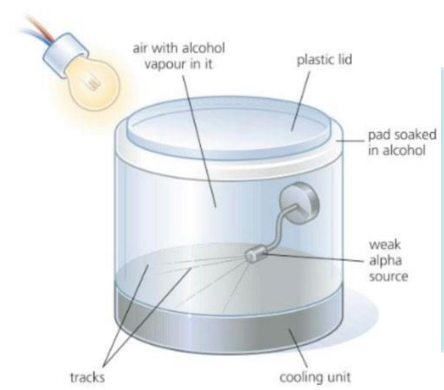
Geiger-Müller (GM) tube – detect alpha, beta & gamma radiation

	Ratemeter – gives a reading in counts per sec Scaler – counts total no of particles / bursts of gamma radiation Amplifier/loudspeaker – makes 'click' when each particles / bursts of gamma radiation detected

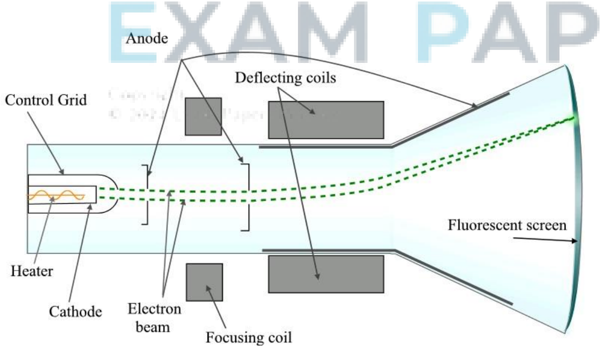
1. Particles pass through the thin mica 'window'
2. They ionised the gas inside → set off high-voltage spark & conduct electric current
3. When radiation from radiation source measured, reading includes background radiation

Cloud chamber

- Useful for studying alpha particles coz makes track visible

	1. Chamber has cold alcohol vapour in the air inside it 2. Alpha particles makes vapour condense → can see trails of droplets where each particle passes through

Cathode-ray tube



23 In a cathode-ray tube, a hot tungsten cathode releases particles by thermionic emission.

What are these particles?

A α-particles
B electrons
C protons
D tungsten atoms

5.2.2 Characteristics of the three kinds of emission

Nuclear radiation

- Some materials contain atoms with unstable nuclei
- Unstable nucleus disintegrates (radioactive decay) & shoots out a tiny particle & sometimes burst wave energy
- See 5.2.3 Radioactive decay

Radioactive materials

- Materials which emit nuclear radiation

Isotopes that are radioactive		
Stable nuclei	Unstable nuclei, radioactive	Found in
Carbon-12 Carbon-13	Carbon-14	Air Plants, animals – absorbs & gives out carbon
Potassium-39	Potassium-40	Rocks, plants, sea water
	Uranium-234 Uranium-235 Uranium-238	Rocks

Ionising radiation

- Radioactive emission
- UV/X-rays

Ions – charged atoms when lose/gain e^-

Nuclear radiation can remove e^- from atoms in its path → has an ionising effect

If gas becomes ionized

- Conduct electric current
- Sometimes burst gamma radiation

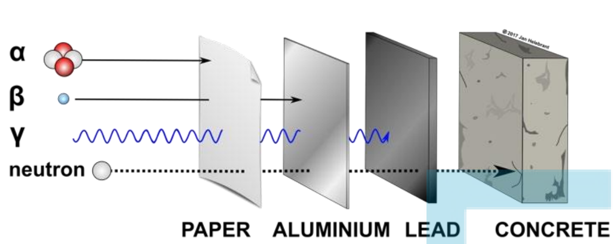
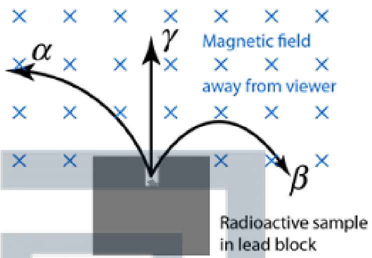
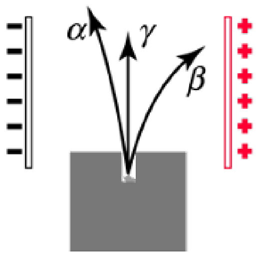
If living things become ionized

- Damage / destroy cells
- Disrupt chemical instructions in cell → cells grow abnormally → cancer
- ↑ intensity / exposure time, ↑ risk

Types of nuclear radiation

Type of radiation	**Alpha particles (α)**	**Beta particles (β)**	**Gamma rays ($\gamma\gamma$)**
Representation			 γ
Description	Each particle is 2 protons + 2 neutrons (Helium nucleus)	Each particle is an electron (created when nucleus decays)	Electromagnetic waves
Relative charge	+2	-1	0
Mass	High, compared with β	Low	-
Speed	0.1 × speed of light Slower → speed more time close to any e^- they pass	0.9 × speed of light	Speed of light
Ionising effect	Strong Coz have greater charge → exert more force on e^-	Weak	Very weak

Penetrating effect	Not very penetrating Stopped by a thick sheet of paper, or by skin, or by few cm of air	Penetrating Stopped by few mm of aluminium or other metals	Very penetrating Never completely stopped
Effects of fields	+2 charged → equivalent to electric current → deflect by magnetic & electric fields	-1 charged, light → deflected more in opposite direction	Uncharged → not deflected by magnetic & electric fields

Penetrating effect	Effects of fields
Penetrating power of different types of radiation  	 

(b) Ionisation smoke detectors contain americium and two small electrodes with a small voltage between them. The air between the electrodes is ionised by α-particles so that there is a small electric current between the electrodes.

(i) Suggest and explain the effect of smoke on the current between the electrodes in the smoke detector.

Suggestion: Current decreases

Explanation: a-particles absorbed by smoke [1]

(ii) Suggest **two** reasons for using an α-particle emitter in a smoke detector.

Reason 1 a-particles highly ionising

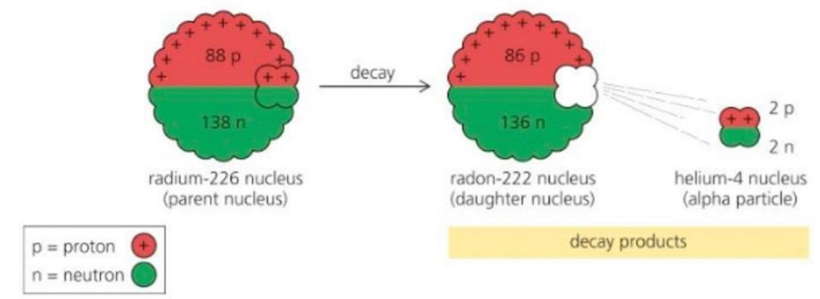
Reason 2 a-particles aren't very penetrating Stop by a few cm in air [2]

5.2.3 Radioactive decay

Radioactive decay

- If an isotope is radioactive (becomes radioisotopes), it has unstable nuclei (neutrons & protons)
- Unstable nucleus disintegrates and emit particles (& sometimes wave energy – gamma radiation)
- When they emit alpha & beta particles ○ Makes nucleus more stable ○ Change no of neutrons & protons ○ Decay into atoms of different elements

Alpha decay by alpha emission



$AAXX \rightarrow AA-4ZZ-2YY + 42\alpha\alpha$
ZZ

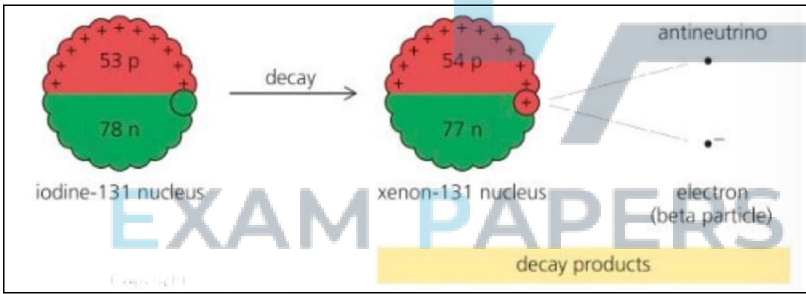
$226RRRR$
$\rightarrow 22288RRRR +$
$42\alpha\alpha$
88

- Alpha particle consists of 2 protons & 2 neutrons

When an alpha particle is emitted from nucleus

- Nucleus loses 4 nucleons → mass no ↓4
- Nucleus loses 2 protons → atomic no ↓2

Beta⁻ decay by beta emission



$AAXX \rightarrow ZZ+1AAYY + -10\beta\beta + 00VVee$
ZZ

$13153XX \rightarrow 13154XXee + -10\beta\beta + 00VVee$

When it's emitted

- Neutron changes into proton since $\beta\beta$ is -1 charged & no e⁻ inside nucleus
- e⁻ emitted at high speed as $\beta\beta$-particle is also created to balance +ve charged of protons
- An uncharged, almost massless antineutrino is created
- e⁻ & antineutrino leaves nucleus at a high speed
- A proton replace a neutron is nucleus → atomic no ↑

5.2.4 Half-life

Half-life

- Radioactive decay is a random process
- Impossible to predict when an individual nucleus will decay or in which direction a particle will emit
- Process unaffected by temp, pressure or chemical change
- On average there's a definite decay rate for each isotope
- As the process is random, there may be some small fluctuations, but with large no of atoms in a small sample, half-life is effectively constant

Define half-life

- Time for half the atoms in a sample to decay (aka decay rate)
- Time for activity of any given sample to fall to half its original value

Activity in half-life

- No of nuclei decaying per sec
- SI unit: becquerel (Bq)
- Eg 100 Bq means 100 nuclei are disintegrating per sec

State two of the social, economic or environmental issues involved in the storage of radioactive materials with very long half-lives (2)

Social	Economic	Environmental
• Cause cancer • Local objections • Ppl move away	• High cost of storage • Reduction of tourism/land	• Crop mutation • Leakage into water supplies • Pollution of atmosphere/water supply

(b) A radiation detector is set up in a laboratory where there are no radioactive samples.

On **six** separate occasions, the detector is switched on for 1.0 minute and the background count is recorded. The counts are:

23 27 25 24 20 25

(i) State why the readings are **not** all identical.

Radioactive decay is a random process [1]

(ii) Suggest a possible source for this background radiation.

Rocks [1]

(ii) The half-life of iridium-194 is 19 hours. A sample of iridium-194 has an initial count-rate of 1100 counts / min.

Calculate the count-rate from this sample after 38 hours.

$\frac{38}{19} = 2 \rightarrow$ 2 half-lives

$1100 \div 2 \div 2$

count-rate = 275 counts / min [2]

5.2.5 Safety precautions

Safety precautions

- Seal radioactive samples in casings so no radioactive material escape
- Minimize exposure time
- Store samples in lined containers in locked storerooms
- Handle samples by trained personnel & always be supervised when not in store
- Shield radioactive samples & kept in great distance from ppl
- In lab, handle them with long tongs & students kept in great distance
- In industry, handle them with remote-controlled machines. Workers protected by lead & concrete walls, and wear film badges that record amount of radiation received.
- Research, educational & industrial establishments using radioactive sources should have security measures in place and strict operational procedures to avoid accidental or deliberate misuse by staff