PiXL KnowIT!

GCSE Physics

Edexcel Radioactivity

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The PiXL Club Ltd, Company number 07321607

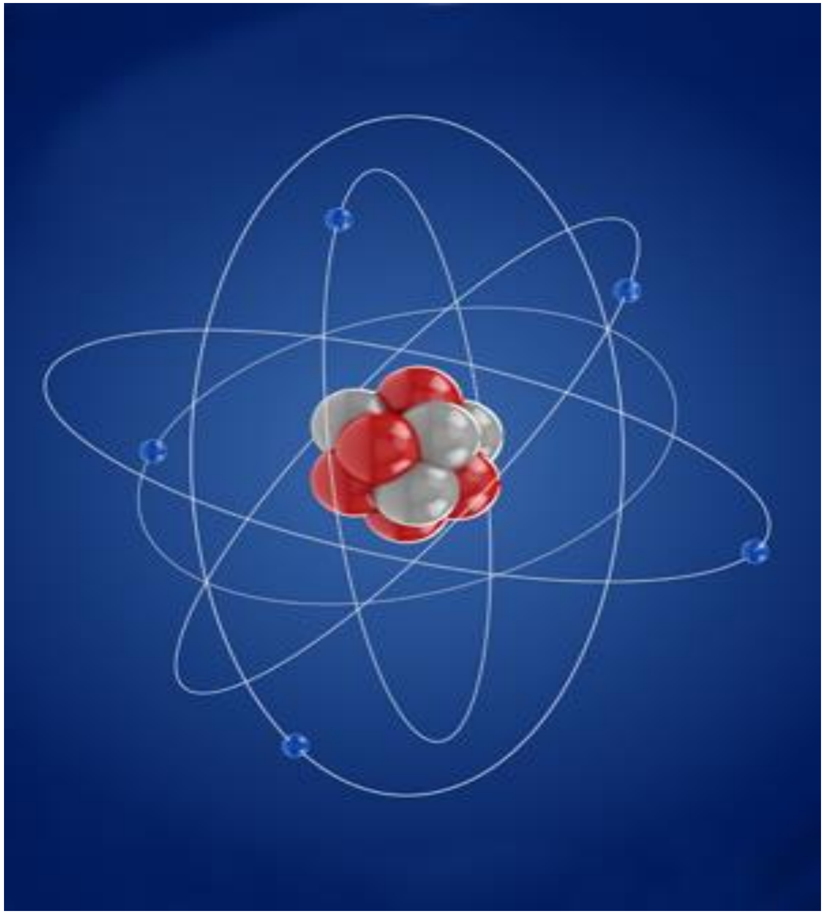
Overview
Edexcel Topic 6

Radioactivity

Part 1
- Atoms
- Types of radiation
- Background radiation

Part 2
- Radioactive decay and half life
- Uses and dangers of radioactivity

Part 3
- Nuclear reactions



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LearnIT!
KnowIT!

Part 1

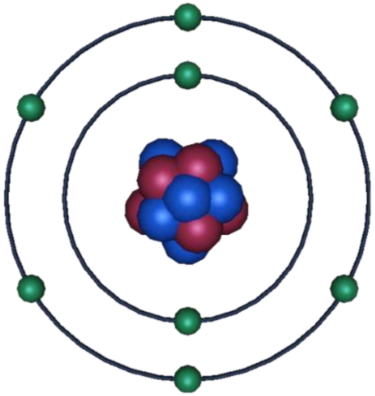
- Atoms
- Types of radiation
- Background radiation

Structure of the atom - subatomic particles

- An **atom** has a positively charged **nucleus** containing **protons and neutrons**, surrounded by negatively charged **electrons in shells**.
- The nuclear radius much smaller than that of the atom and with almost all mass **of an atom** is **concentrated in the nucleus**.
- An atom contains **equal numbers of protons and electrons**.
- Atoms have **no overall electrical charge** because the number of positive protons equals the number of negative electrons.

number of protons = atomic number

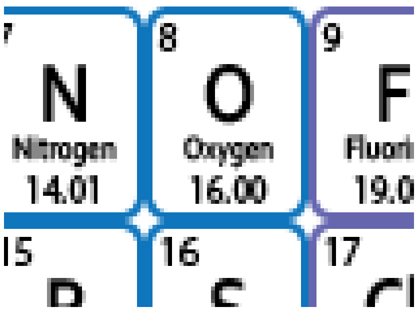
- All atoms of an element have the **same number of protons in the nucleus**. This number is **unique to that element**.



	Mass	Charge	Location
Proton	1	+ (positive)	nucleus
Neutron	1	no charge	nucleus
Electron	1/1835 negligible	- (negative)	shells

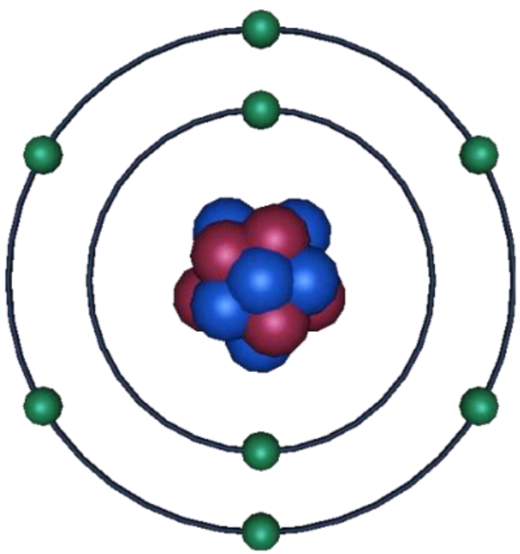
Mass number and atomic number

All atoms of a particular element have the **same number of protons**. The number of protons in an element is called its **atomic number**.



Protons
On the periodic table, **oxygen** is shown as having an **atomic number** of eight, therefore **8 protons**.

Protons
Neutrons
Electrons



Neutrons
The total number of **protons and neutrons** in an atom is called its **mass number**.
Oxygen has a mass number of 16. If it has 8 protons it must therefore have **8 neutrons** to make a mass number of 16.

Electrons
Atoms are electrically neutral so there must be the **same number** of electrons (-) as protons (+); **8 electrons**.

Oxygen has: 8 protons, (16 – 8) = 8 neutrons, and 8 electrons

Structure of an atom

- An **atom** has a positively charged **nucleus** containing **protons and neutrons**, surrounded by negatively charged **electrons in shells**.
- The nuclear radius much smaller than that of the atom and with almost all mass **of an atom** is **concentrated in the nucleus**.

Electrons are arranged in **orbits or energy levels** around the nucleus. Energy levels can hold a maximum of:

2 e^- in the first level

8 e^- in the second level

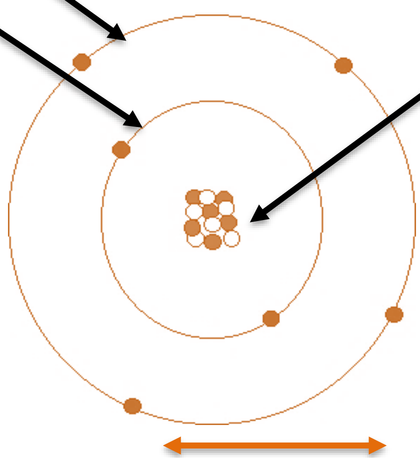
8 e^- in the third level

Electrons change **orbit** when there is **absorption** or **emission** of **electromagnetic radiation.**

Atom of Carbon 12

$^{12}_{6}C$

. ← 9 x 10^{13} atoms in this dot of ink



Radius of an atom **1 x 10 $^{-10}$m**

Nucleus made up of nucleons, these can be protons or neutrons

Protons: charge +1

Neutrons: charge 0

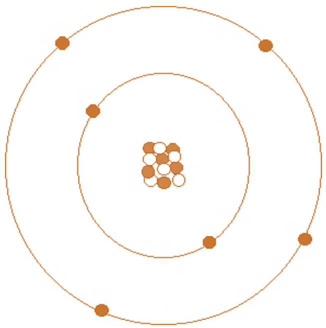
The radius of the nucleus is less than **1/10 000** the radius of the atom – the atom is **99.9999999%** empty space!

The nucleus holds **99%** of the mass of the atom

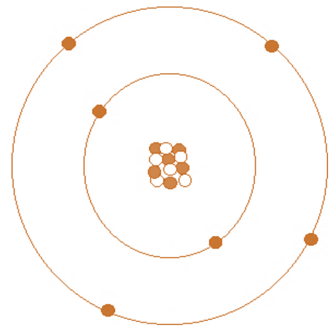
Mass number, atomic number and isotopes

Isotopes are elements with **different atomic masses (nucleon number)**.
The number of **protons** can not change or it would not be the same element so **an isotope is an element with different numbers of neutrons**.

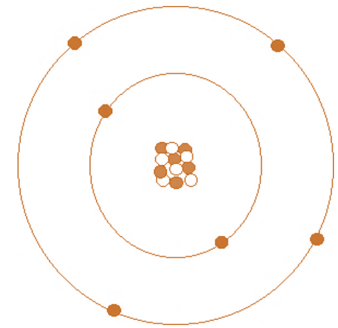
Carbon 12	Carbon 13	Carbon 14
$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$



6 protons
6 neutrons



6 protons
7 neutrons



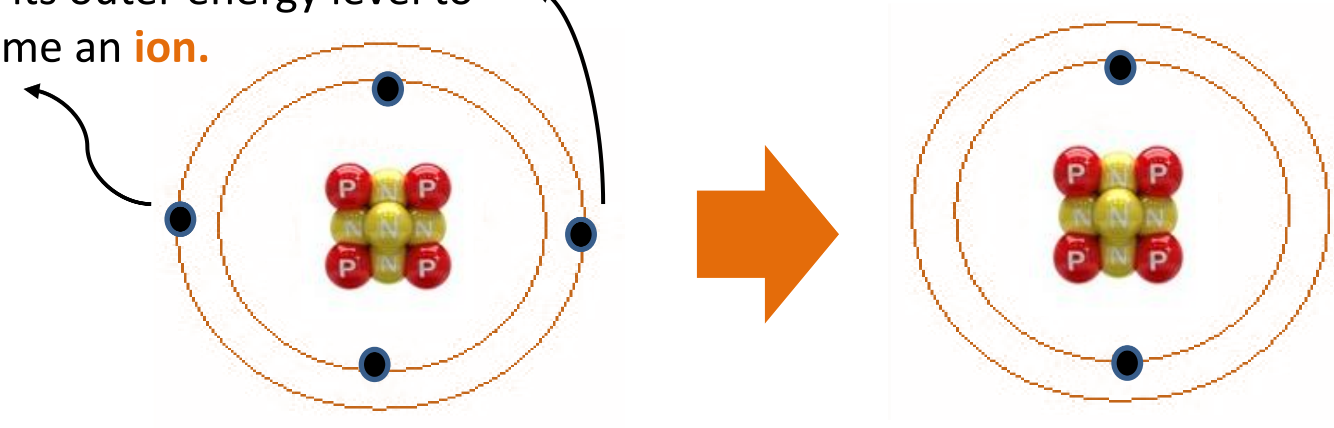
6 protons
8 neutrons

The isotopes have the **same number of protons** and the **same number of electrons**. Only the number of **neutrons changes** in an isotope.

Mass number, atomic number and isotopes

Atoms can form **ions** if they gain or lose **electrons.** Atoms do this so they have **full outer energy levels.**

Beryllium **can lose 2 electrons** from its outer energy level to become an **ion.**



If Beryllium
loses 2 e$^-$
it now has:

4 protons 4+
2 electrons 2-
2+

Berylium $^{2+}$

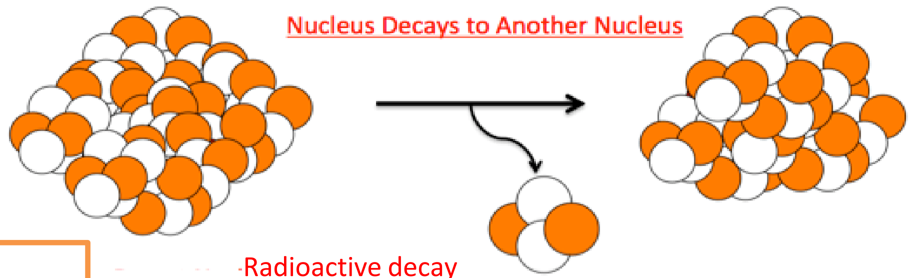
$${}^{9}_{4}\mathrm{Be} \rightarrow {}^{9}_{4}\mathrm{Be}^{2+}$$

Atoms can **lose (-) electrons** to become **positive (+) ions** or **gain (-) electrons** to become **negative (-) ions**.

Radioactive decay and nuclear radiation

The nuclei of some atoms are unstable. To become more stable these nuclei give out radiation. This process is called radioactive decay.

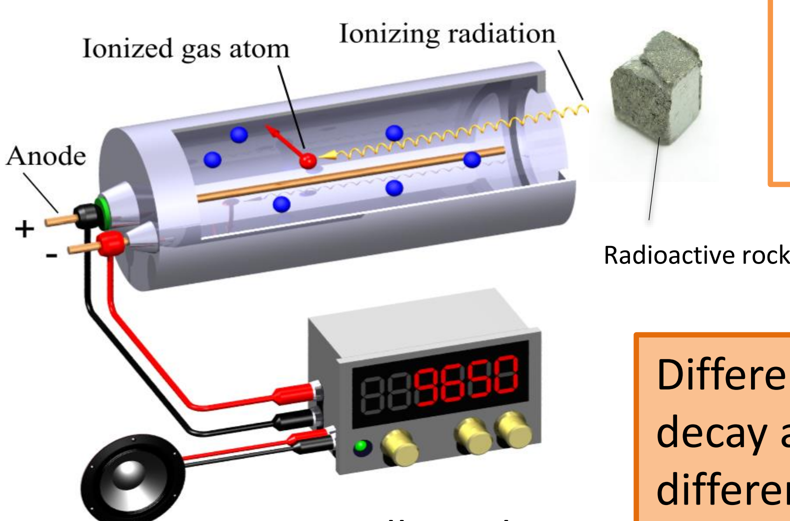
Unstable atom



Stable atom

Activity = **rate at which a source of unstable nuclei decays**, measured in **becquerels (Bq).**

Count-rate = **number of decays recorded each second by a detector**



Geiger–Müller tube

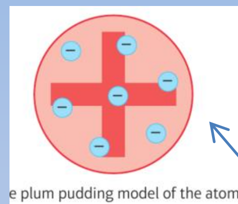
Radioactivity can be detected by using Geiger–Müller tube or photographic film.

Different radioactive isotopes decay at different rates and emit different types of radiation.

Atomic models

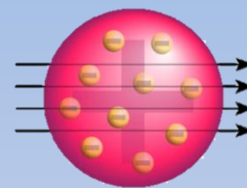
words:……

Particle theory(or kinetic theory) helps explain the properties of solids liquids and gasses

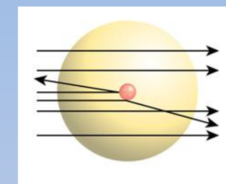


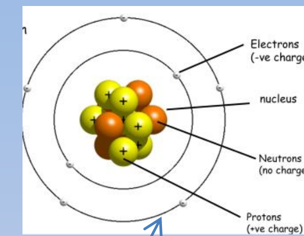
Rutherford bombarded gold foil with alpha particles

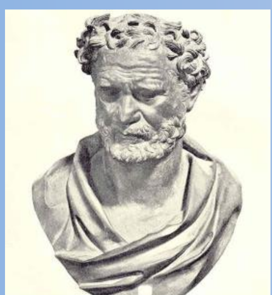
Expected results



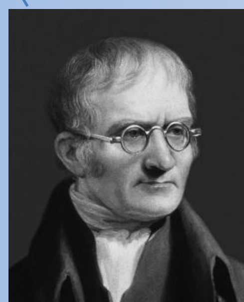
Actual results





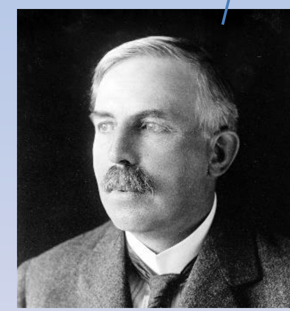


Democritus



John Dalton

JJ Thompson



Ernest Rutherford

Niels Bohr

All matter is made from tiny particles

All matter is made from tiny ‘ultimate’ particles which can’t be broken into anything smaller

Atoms are like plum puddings, positive charges with smaller negative charges

Most of the atom is empty space; It has a positive centre and a negative electrons in shells

The nucleus is made from protons and neutrons. The electrons must exist is specific ‘shells’

WALT…

Rutherford

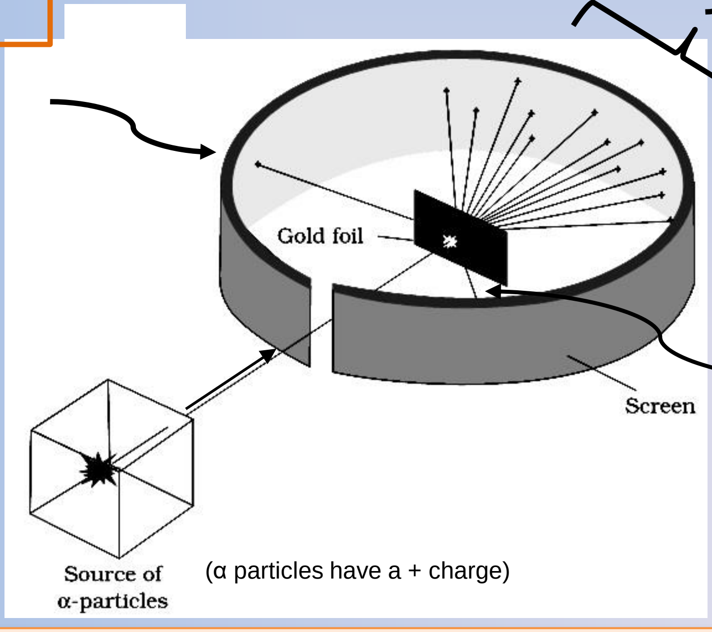
words:……

Rutherford's alpha scattering experiment

A beam of alpha particles are directed at a very thin gold foil screen.

A few (+) alpha particles are deflected by a positive nucleus within the gold atoms.

Most (99.99%) of the alpha particles pass straight through the gold foil unaffected by its presence.



A tiny number of alpha particles are reflected because they collide with the nucleus of the gold atoms.

Rutherford concluded that the gold atoms are mostly empty space with a positively charged nucleus that contains nearly all the mass of the atom.

WALT…

Key words:..

- The nuclei of the two isotopes can be re … are these two isotopes of cobalt (2) $^{60}_{27}Co$ $^{59}_{27}Co$

Same number of protons (1)

Different number of neutrons (1)

Cobalt-60 is unstable (1)

- Insert the correct numbers into this sentence. A nucleus of uranium-235 contains . 92 . Protons and . 143 . Neutrons (2) $^{235}_{92}U$

Here

- … (2)

Same number of protons/atomic number, different number of neutrons/mass number

- Rutherfo … m as a result of his scatterin … nodel that this replaced (2)

Plum pudding model(1) this model describes an atom as a sphere of positive with electrons through it (1)

- Sta … be the obs … vided evi …

Property- most atom empty space **observation-** most alpha particles went straight through.

Property- most mass in nucleus **observation**- some alpha particles hit nucleus and bounced back.

Property- nucleus positive charge **observation**- some alpha particles changed direction repelled by positive.

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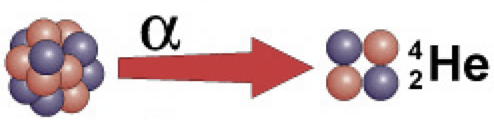
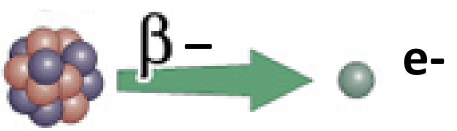
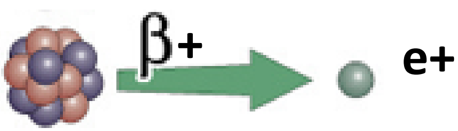
Radioactive decay and nuclear radiation

There are three types of radioactive decay, **alpha, beta (β– beta minus and β+ positron) and gamma**. All come from an unstable **nucleus of an atom**.
In the examples below, only the nucleus is shown. This is a random process



Alpha decay (symbol ^4_2He or) consist of **2 protons and 2 neutrons** emitted from the nucleus. They have a **positive** charge as they contain 2 (+) protons.

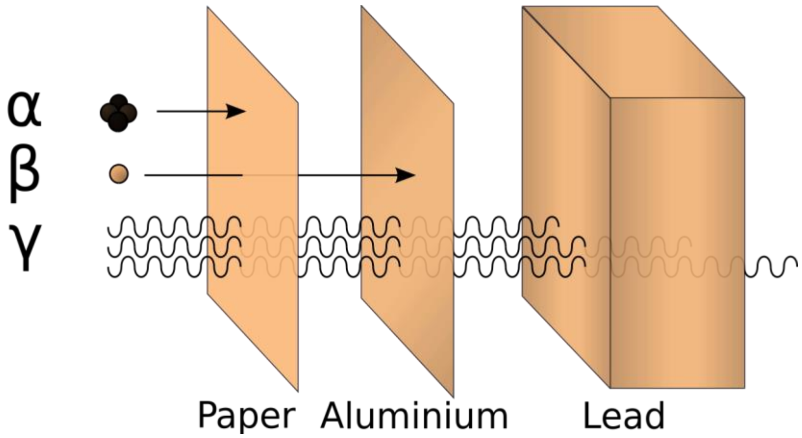




β– (beta minus) decay , consist of an **electron** emitted from the nucleus. This results from a neutron splitting into a proton and an electron.
β+ (positron) decay , consist of an **positron** emitted from the nucleus. This results from a proton splitting into a neutron and an positron.
(A positron is has the same mass as an electron).

Gamma rays (symbol γ) are **electromagnetic radiation** emitted from the nucleus. Gamma radiation has **no mass** and **no electrical charge.**

Properties of alpha, beta and gamma radiation.



Alpha, beta and gamma radiation can penetrate different materials due to their differing nature.

Alpha – easily stopped by **a few sheets of paper**.

Beta – penetrates paper but stopped by a thin **sheet of aluminium**.

Gamma – only stopped by **thick lead** or several metres of **concrete**.

All three types of radiation cause **ionisation** of other atoms. If these atoms are in **living cells** it can cause damage which could lead to **cancer.**

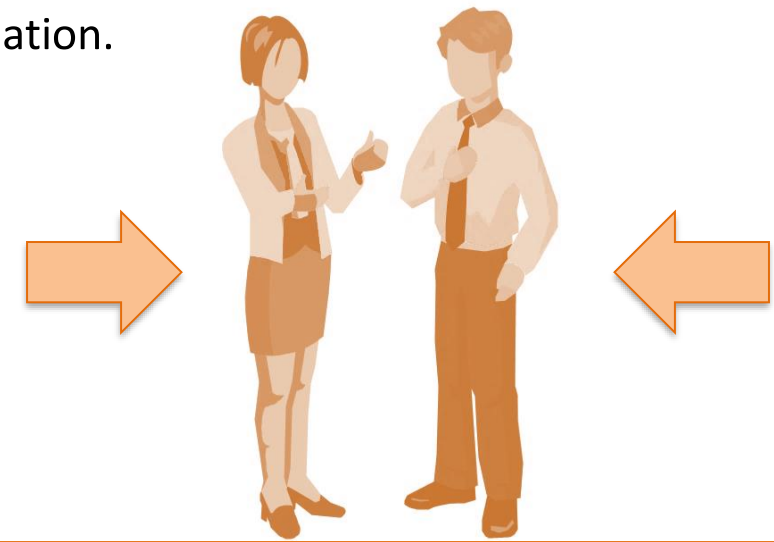
Name	Symbol	Speed	Range in air	Ionising power
Alpha	α	Slowest	6 - 8 cm	High
Beta	β	Medium	1 – 2 m	Medium
Gamma	γ	Fastest	300 - 500 m	Low

Background radiation

Background radiation is the constant , low level radiation in the environment. This can be natural radiation from rocks, building materials, cosmic rays etc. **Radioactive pollution** from nuclear testing, nuclear power and industrial/medical waste also contributes to background radiation.

Sources of radioactive exposure and contamination.

- 14% Medicine
- 1% Nuclear Industry
- 42% Radon
- 18% Buildings/Soil
- 14% Cosmic
- 11% Food/Drinking Water
- 85% Natural Radiation



Radiation dose is measured in: **sieverts (Sv)**

1 Sv = 1000 millisieverts

Everyone receives background radiation but people who **work or live** in locations with high levels of radiation **receive additional doses of radiation**.
Some nuclear workers, medical staff, military and industrial workers may have higher doses due to working with radioactive sources.

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QuestionIT!

Part 1

- Atoms
- Types of radiation
- Background radiation

1. The diameter of an atom is about 0.000 000 000 2 m. What is this distance in standard form?

2. What is the nucleus of an atom composed of?

3. Describe what happens when an electron drops to a lower energy level in an atom.

4. An atom of sodium is represented by: $^{23}_{11}Na$

   Use this information to determine the number of protons, neutrons and electrons in an atom of sodium.

5. What is the electrical charge attached to:

   a neutron
   an electron
   a proton

6. What is the mass number and the atomic number for fluorine?

$^{19}_{9}F$

7. Beryllium has the chemical symbol:

$^{9}_{4}Be$

Use this information to draw a representation of an atom of beryllium.

8. A different isotope of beryllium has an extra neutron. Give the chemical symbol of this new isotope of beryllium.

9. The radioactive element Uranium has two common isotopes.

$^{236}_{92}U$ and $^{238}_{92}U$

Complete the table to show the number of protons, neutrons and electrons in each isotope.

Isotope	Protons	Neutrons	Electrons
$^{236}_{92}U$			
$^{238}_{92}U$			

10. Sodium can lose its outer electron to have a full outer energy level. What will the atom now become?

11. Which part of an atom is involved with radioactive decay?

12. Explain the meaning of the term activity, as applied to radioactive materials and state the units of activity.

13. What is meant by the term “count rate”?

14. Copy and complete the table to show the nature of alpha, beta and gamma radiations.

Radiation	Symbol	Composition	Electrical charge
Beta	β		
Gamma		Electromagnetic wave	
Alpha			+2

15. A piece of radioactive rock shows a reading of 350 counts/min. When covered in aluminium foil, this drops down to 4 counts/min. Explain which type of radiation this rock is emitting.

16. Radioactive emissions are often described as ionising radiations. What does this mean?

17. Smoke detectors use americium-241 which is an alpha emitter. Explain why an alpha source is used in these detectors.

18. Why is an alpha particle often described as a helium nuclei?

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AnswerIT!

Part 1

- Atoms
- Types of radiation
- Background radiation

1. The diameter of an atom is about 0.000 000 000 2 m. What is this distance in standard form?

   2×10^{-10} m

2. What is the nucleus of an atom composed of?

   Protons and neutrons (except Hydrogen which has no neutrons).

3. Describe what happens when an electron drops to a lower energy level in an atom.

   It releases a photon of electromagnetic radiation.

4. An atom of sodium is represented by: $^{23}_{11}Na$

5. Use this information to determine the number of protons, neutrons and electrons in an atom of sodium.

   Protons = 11 Neutrons = 12 Electrons = 11

6. What is the electrical charge attached to:

   a neutron **Neutral**
   an electron **Negative**
   a proton **Positive**

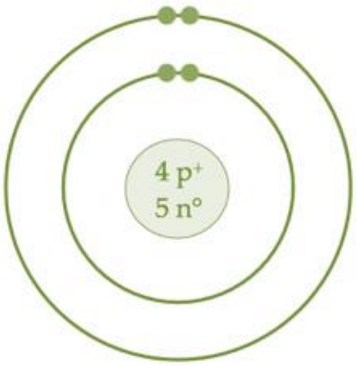
6. What is the mass number and the atomic number for fluorine?

$^{19}_{9}F$

Mass number = 19; atomic number = 9

7. Beryllium has the chemical symbol:

$^{9}_{4}Be$



Use this information to draw a representation of an atom of beryllium.

8. A different isotope of beryllium has an extra neutron. Give the chemical symbol of this new isotope of beryllium.

$^{10}_{4}Be$

9. The radioactive element Uranium has two common isotopes.

$^{236}_{92}U$ and $^{238}_{92}U$

Complete the table to show the number of protons, neutrons and electrons in each isotope.

Isotope	Protons	Neutrons	Electrons
$^{236}_{92}U$	92	144	92
$^{238}_{92}U$	92	146	92

10. Sodium can lose its outer electron to have a full outer energy level. What will the atom now become?

An ion with a charge of 1+

11. Which part of am atom is involved with radioactive decay?
    The nucleus only.
12. Explain the meaning of the term activity as applied to radioactive materials and state the units of activity.
    The rate at which a source of unstable nuclei decays. Units Bq.
13. What is meant by the term “count rate”?
    The number of radioactive decays recorded in a given time.
14. Copy and complete the table to show the nature of alpha, beta and gamma radiations.

Radiation	Symbol	Composition	Electrical charge
Beta	β	an electron	-1
Gamma	γ	Electromagnetic wave	0
Alpha	α	2 protons and 2 neutrons	+2

Part 1 - AnswerIT

15. A piece of radioactive rock shows a reading of 350 counts/min. When covered in aluminium foil, this drops down to 4 counts/min. Explain which type of radiation this rock is emitting.

    Could be alpha or beta as both would be stopped by the foil and gamma would not be stopped by the foil.

16. Radioactive emissions are often described as ionising radiations. What does this mean?

    The emissions knock off electrons from atoms which then become ions.

17. Smoke detectors use americium-241 which is an alpha emitter. Explain why an alpha source is used in these detectors.

    Alpha particles are easily stopped by smoke.

    They do not travel far in air so are safe for the user.

18. Why is an alpha particle often described as a helium nuclei?

    It contains 2 protons and 2 neutrons, the same as the nucleus of a helium atom.

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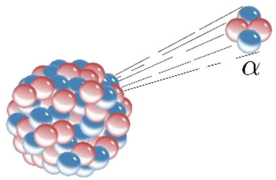
Part 2

- Radioactive decay and half life
- Uses and dangers of radioactivity

Nuclear equations

Nuclear equations show the changes to an atom when it emits radiation.

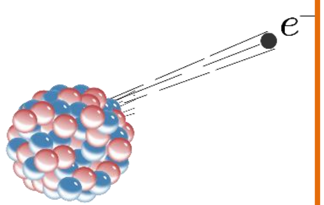
Alpha emission



Nucleus **loses 2 protons** and **2 neutrons**.
Atomic number will reduce by 2 and atomic mass by 4.

$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

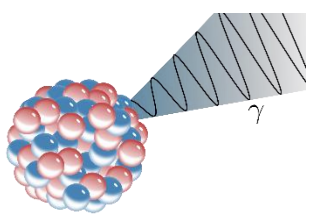
Beta emission



Nucleus **loses an electron** which is produced when a neutron turns into a proton. So **mass stays the same** but **atomic number of the product increases by one**.

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

Gamma emission



No particles are emitted so there is **no change to the nucleus**. Atomic mass and atomic number stay the same.

$$^{99}_{43}Tc \longrightarrow {}^{99}_{43}Tc + \gamma$$

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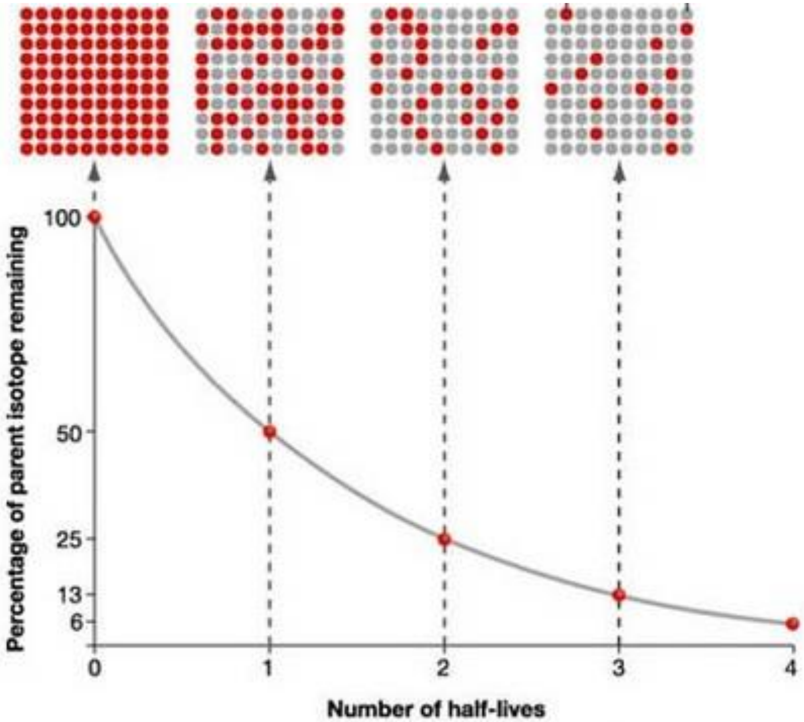
Half life and the random nature of radioactive decay

Radioactive decay is a random process so the likelihood of a decay taking place is a probability problem. For this reason, the **half-life** of an isotope is given rather than saying how long it will take to fully decay.

The **half-life** of a radioactive isotope is the time it takes for the **number of nuclei** of the isotope in the sample to halve, or the time it takes for the **count rate** from a sample containing the isotope to fall to half its initial level.

The net decline of the isotope is the fraction remaining after a number of half lives.
E.g. 100 → 50 → 25
After 2 half lives net decline is 75/100 = **3/4**



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Different half lives of isotopes

Radioactive isotopes have an enormous range of half-lives.

Examples of the range of half-lives of radioactive materials

Radioactive nuclide	Nuclide notation	Half-life
Lithium-8	$^{8}_{3}Li$	0.838 s
Krypton-89	$^{89}_{36}Kr$	3.16 minutes
Sodium-24	$^{24}_{11}Na$	15 hours
Iodine-131	$^{131}_{53}I$	8 days
Cobalt-60	$^{60}_{27}Co$	5.27 years
Radium-228	$^{226}_{88}Ra$	1600 years
Uranium-235	$^{235}_{92}U$	703 million years

Half-life and hazard (Physics only)

Radioactive isotopes with a **short half-life** often give **high doses** of radiation in a short period of time so are often dangerous.

Long half-life isotopes are **low dose** hazards but they are around for a very **long time**. Uranium-238 is the main fuel producer for the nuclear industry but is so slow at emitting radiation it is often considered quite safe by scientists.

Products of the nuclear industry such as Iodine-131 are much more dangerous as they emit radiation at a much faster rate and are soluble so they get into the food chain much more easily.

Half life and the random nature of radioactive decay

Calculating the half life of a radioactive isotope.

If you know the start and finish count rate and the time taken, you can calculate the half life.

Example:

The count rate of an isotope is 1008 Bq. This falls to a count rate of 126 over a period of 21 days.

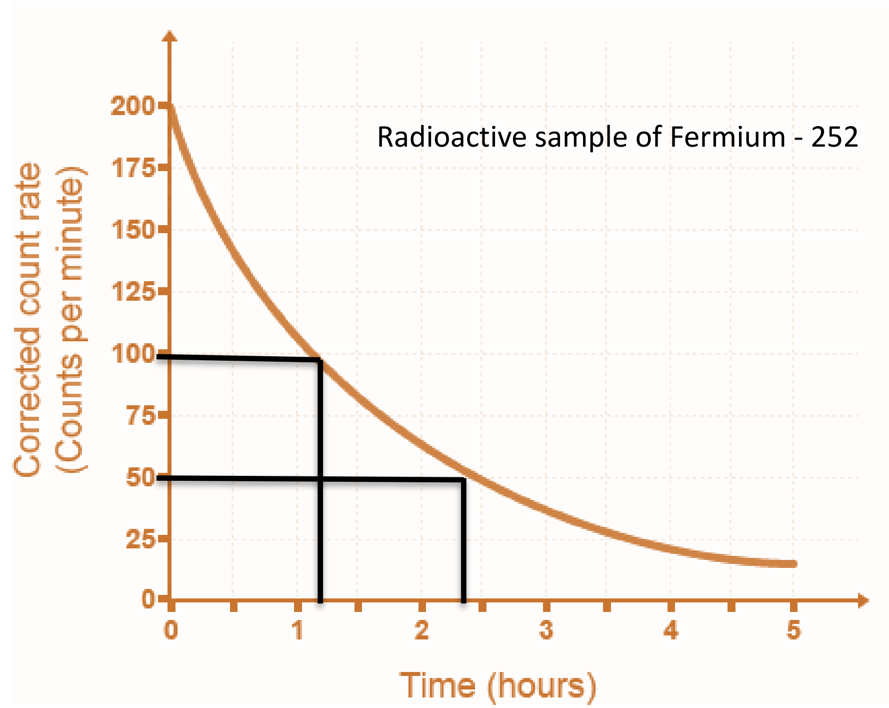
1008 → 504 → 252 → 126

1 2 3

3 half lives for count rate to fall to 126.

These 3 half lives took 21 days so each half life took 7 days.

Half life if this isotope = 7 days



200 counts / min at the beginning.

100 counts/min occurred after 1.2 hours.

50 counts/min occurred after 2.4 hours.

It always takes 1.2 hours for the count rate to halve.

Half life of Fermium - 252 = 1.2 hours.

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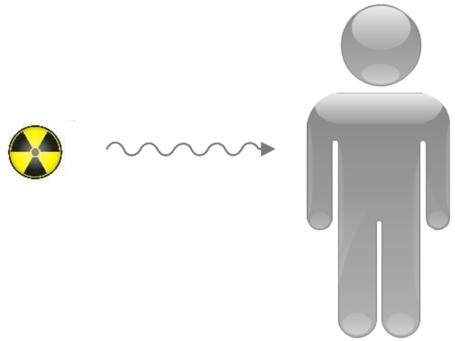
Radioactive materials are **hazardous** to **life**. **Nuclear radiation** can **ionise** (add or remove electrons) substances **within** the human body. This can **change** the way cells behave, **damage** DNA or **destroy** human cells.

Body part	Effect of ionising radiation
Hair	Hair loss
Skin	Can cause burns or lead to skin cancers
Reproductive organs	High doses can cause sterility or mutations in offspring
Thyroid	Exposure to radioactive iodine can destroy the cells in the thyroid or cause cancers
Bone marrow	Can cause leukaemia or other blood cancers

Rapidly dividing cells like cells that produce hair or those in the reproductive organs are most **susceptible** to **ionising radiation.**

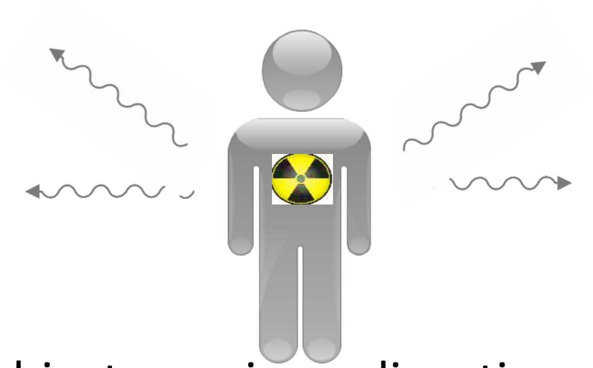
Radioactive irradiation and contamination

Irradiation is when an object or person is **exposed** to radiation. Protection from irradiation means stopping the radiation from reaching you.



Medical dressings are often irradiated but present no danger to the user.

Contamination is when a radioactive source is in **contact** with an object or person. The radioactive substance rather than the emissions are present.



The object remains radioactive until the contamination is removed or decays naturally.

Radioactive materials are hazardous, so certain **precautions** can be taken to reduce the risk when using radioactive sources. These include:

- wear **protective clothing** to prevent the body becoming contaminated should radioactive isotopes leak out
- limit the **dose** and monitor **exposure** using detector badges, etc