Edexcel GCSE Physics

Your notes

Atomic Structure

Contents

Inside the Atom

Your notes

Inside the Atom

- Atoms are the building blocks of **all matter**
- Atoms have a tiny, dense, **positively charged nucleus** at their centre, with **negatively charged electrons** orbiting around the nucleus
- The radius of the nucleus is over 10,000 times smaller than the whole atom, but it contains almost **all of the mass** of the atom

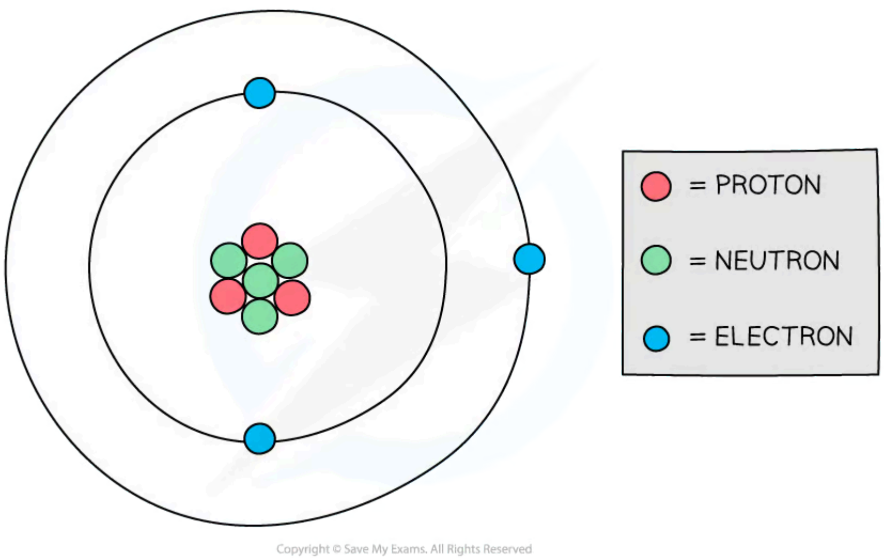


Diagram showing the structure of a Lithium atom. If drawn to scale then the electrons would be around 100 metres away from the nucleus!

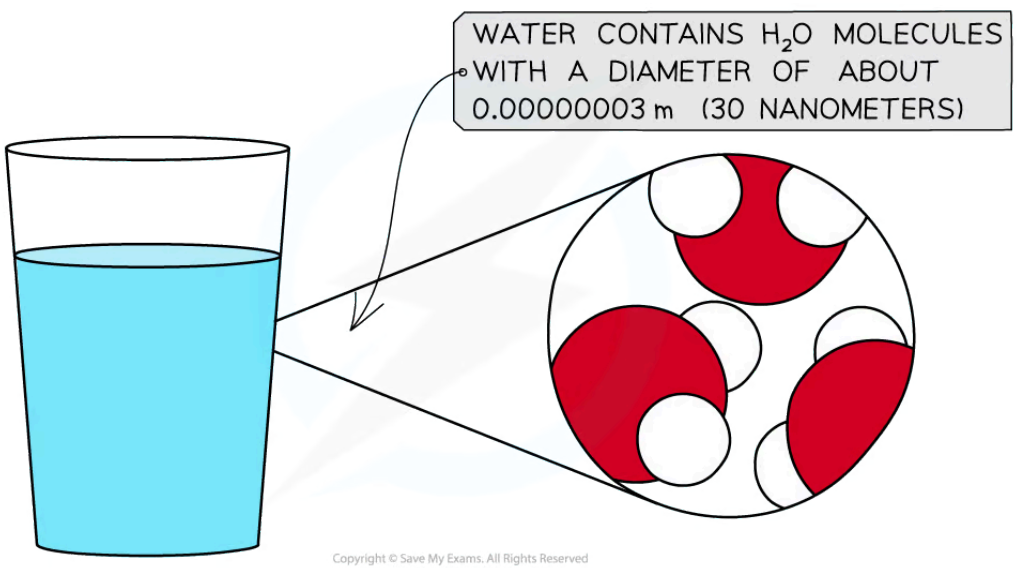
Parts of the Atom

- The nucleus contains:
  - **Protons** - positively charged particles with a relative atomic mass of one unit
  - **Neutrons** – no charge, and also with a relative atomic mass of one unit
- Almost all of the atom is empty space, but moving around the nucleus there are:
  - **Electrons** – negative charge with almost no mass (1/2000 the mass of a proton or neutron)

Your notes

The Size of the Atom

- Atoms are incredibly **small**, with a radius of only 1×10^{-10} m
- This is **0.0000000001 m** when written without standard form
  - This means that about one hundred million atoms could fit side by side across your thumbnail
- A group of atoms can bond together to make molecules, such as water
  - A water molecule is comprised of two hydrogen atoms and one oxygen atom



A 200 ml glass of water will contain approximately 7,000,000,000,000,000,000,000,000 water molecules!

Examiner Tips and Tricks

There are many different models of the atom. As you progress through the topic you will discover that the atom can be described in many different ways, such as the Plum Pudding Model that is covered later, but for your exam, make sure to only use the model and descriptions described here.

Protons, Neutrons & Electrons

Your notes

Relative Mass & Charge

Properties of Sub-atomic particles

- The different particles that make up atoms have different properties
- Relative **mass** is a way of comparing particles. It is measured in **atomic mass units** (amu)
- A relative mass of 1 is equal to mass of 1.67×10^{-27} kg
- **Charge** can be positive or negative
- Relative charge is, again, used to compare particles
- The fundamental charge is equal to the **size** of the charge on a proton and an electron, however the electron's charge is negative
- The properties of each of the particles are shown in the table below:

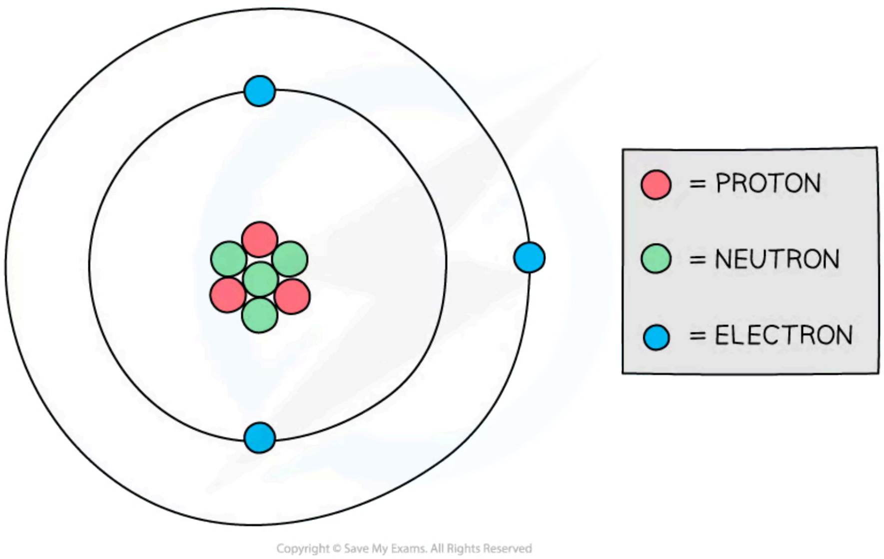
Particle	Location	Relative Charge	Relative Mass
Proton	In the nucleus	+1	1
Neutron	In the nucleus	0	1
Electron	Orbiting the nucleus	−1	1/2000 (Negligible)

Positrons

- A positron is the **antiparticle** of an electron
- It has the same mass as an electron, and the same size of charge, however it has a **positive charge**
- Positrons can be produced during nuclear **beta-plus decay**
  - a proton spontaneously changes into a neutron and a positron
- They only exist in normal conditions for a fraction of a second before they react with electrons and are destroyed

Electrons & Protons

- Although atoms contain particles of different charge, the **total charge** within an atom is **zero**
  - This is because the number of **electrons** is **equal** to the number of **protons**



A Lithium atom has three protons, four neutrons and three electrons

- The following table sets out the calculation of the total charge in the Lithium atom:

Total Charge Calculation Table

	Relative Charge	Number of Particles in the Lithium atom	Number x charge	Total Charge
Protons	+1	3	+3	(+3) + 0 + (−3) = 0
Neutrons	0	4	0	
Electrons	−1	3	−3	

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- If an atom loses electrons, then it is said to be **ionised**

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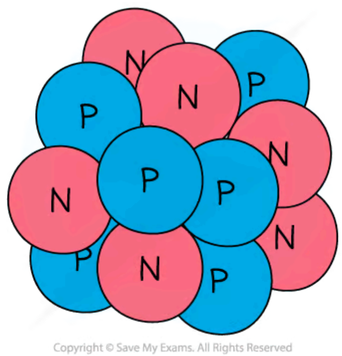
Worked Example

A nucleus of carbon-12 is shown below.



How many electrons are there in an atom of carbon-12?

Answer:

Step 1: Count the number of protons in the carbon nucleus

- There are 6 protons in the carbon atom

Step 2: Determine the number of electrons

- Remember, the number of electrons in an atom is **equal** to the number of protons
- Therefore there must be **6** electrons in the carbon atom

Atomic & Mass Number

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Atomic & Mass Number

Atomic Number

- The **number of protons** in an atom is called its **atomic number** (it can also be called the proton number)
  - Elements in the periodic table are ordered by their atomic number
  - Therefore, the number of protons determines which element an atom is
- **The atomic number of a particular element is always the same**
- For example:
  - Hydrogen has an atomic number of 1. It always has just one proton
  - Sodium has an atomic number of 11. It has 11 protons
  - Uranium has an atomic number of 92. It has 92 protons
- The atomic number is also **equal** to the number of **electrons** in an atom
  - This is because a neutral atom has the same number of electrons and protons in order to have **no overall charge**

Mass Number

- The total number of particles in the nucleus of an atom is called its **mass number** (it is also called the **nucleon** number)
  - The mass number is the total number of protons **and** neutrons in the atom
- The number of neutrons can be found by **subtracting** the **atomic** number from the **mass** number

Number of Neutrons = Mass Number – Atomic Number

- For example, if a sodium atom has a mass number of 23 and an atomic number of 11, then the number of neutrons would be 23 – 11 = 12
- The mass number of an element can change, which means they are are isotopes

Nuclear Notation

- The mass number and atomic number of an atom are shown by writing them with the atomic symbol
  - This is called **nuclear notation**

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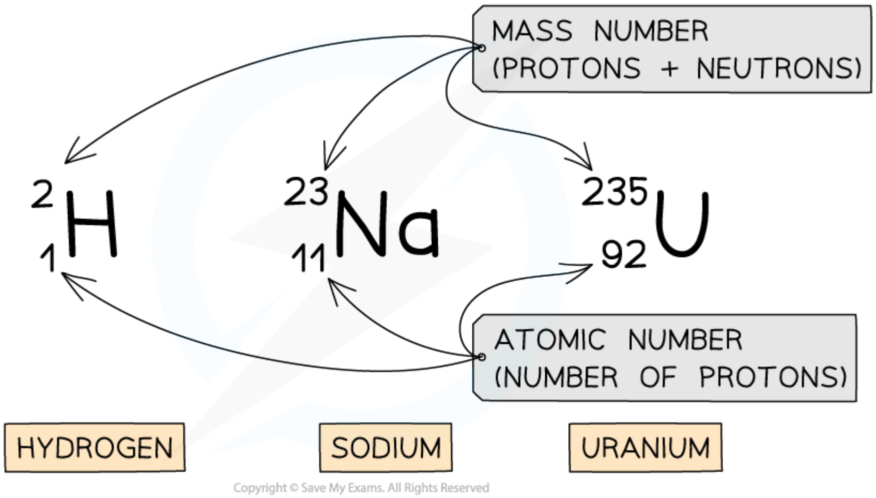
- Here are three examples:



Examples of nuclear notation for atoms of Hydrogen, Sodium and Uranium

- The top number is the **mass number**
  - This is equal to the total number of particles (**protons and neutrons**) in the nucleus
- The lower number is the **atomic number**
  - This is equal to the total number of **protons** in the nucleus
- The atomic and mass number of each type of atom in the examples above is shown in this table:

Protons, Neutrons & Electrons Table

Atom	Number of protons (Atomic Number)	Number on Neutrons (Mass number − Atomic number)	Number of electrons (same as the number of protons)
Hydrogen	1	1	1
Sodium	11	12	11
Uranium	92	143	92

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Worked Example

The element symbol for gold is Au. How many protons, neutrons and electrons are in the gold atom?

$$^{197}_{79}Au$$

	Protons	Neutrons	Electrons
A	79	79	79
B	197	79	118
C	118	118	79
D	79	118	79

Answer: D

Step 1: Determine the atomic and mass number

- The gold atom has an atomic number of 79 (lower number) and a mass number of 197 (top number)

Step 2: Determine the number of protons

- The **atomic** number is equal to the number of **protons**
- The atom has 79 protons

Step 3: Calculate the number of neutrons

- The mass number is equal to the number of protons and neutrons
- The number of neutrons is equal to the mass number minus the atomic number

$$197 - 79 = 118$$

- The atom has 118 neutrons

Step 4: Determine the number of electrons

- An atom has the **same** number of **protons and electrons**
- The atom has 79 electrons

Worked Example

State the number of protons, neutrons and electrons in Chlorine-35 and Chlorine-36 atoms.

Answer:

Step 1: Determine the number of protons

- The atomic number is the number of protons
- Both Chlorine-35 and Chlorine-36 have 17 protons

Step 2: Determine the number of neutrons

- The mass number is the number of protons and neutrons
- Chlorine-35 neutrons: 35 - 17 = 18 neutrons
- Chlorine-36 neutrons: 36 - 17 = 19 neutrons

Step 3: Determine the number of electrons

- The number of electrons is equal to the number of protons
- Both Chlorine-35 and Chlorine-36 have 17 electrons

Examiner Tips and Tricks

You may have noticed that the number of electrons is not part of the mass number. This is because electrons have a **tiny** mass compared to neutrons and protons. We say their mass is negligible when compared to the particles in the nucleus.

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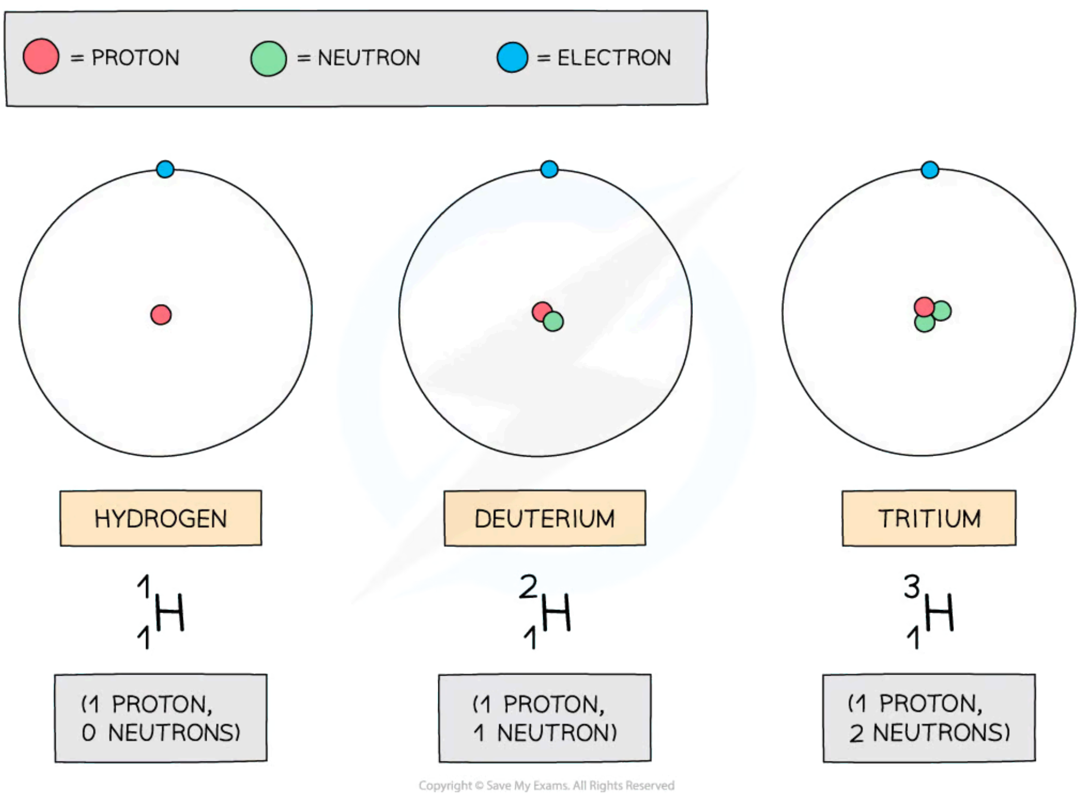
Isotopes

Your notes

Isotopes

- Although the number of protons in a particular element is always the same, the number of **neutrons** can be different
- **Isotopes** are atoms of the same element that have an equal number of protons but a **different** number of **neutrons**
- In the diagram below are three isotopes of Hydrogen:



Hydrogen has three isotopes, each with a different number of neutrons

- Isotopes occur naturally, but some are more rare than others
- For example, about 2 in every 10,000 Hydrogen atoms is Deuterium
  - Tritium is even more rare (about 1 in every billion billion hydrogen atoms)

Differences Between Isotopes

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- The number of neutrons in an atom does not affect the chemical properties of an atom, such as its charge, but only its mass
  - This is because neutrons have no charge but do have mass
- The charge of the nucleus of a particular element is **always the same**
- In the periodic table, the mass number of Chlorine is often given as 35.5

			4 He HELIUM 2
14 N NITROGEN 7	16 O OXYGEN 8	19 F FLUORINE 9	20 Ne NEON 10
31 P PHOSPHORUS 15	32 S SULFUR 16	35.5 Cl CHLORINE 17	40 Ar ARGON 18

This section of a periodic table shows Chlorine as having a mass number of 35.5, but other elements have an integer mass number

- The mass number of chlorine is given as 35.5 because it has 2 isotopes, one with a mass number of 35 and the other with a mass number of 37
- Chlorine-35 is about three times more abundant than chlorine-37, so the given mass number of chlorine is closer to 35 than 37
- The number of electrons and protons in different isotopes remains the **same**
- Some isotopes are **unstable** as they have an imbalance of protons and neutrons

Worked Example

One of the rows in the table shows a pair of nuclei that are isotopes of one another.

	Nucleon number	Number of neutrons
A	39 35	19 22
B	37 35	20 18
C	37 35	18 20
D	35 35	20 18

Which row is correct?

Answer: B

Step 1: Properties of isotopes

Isotopes are nuclei with the same number of protons but different number of neutrons

The nucleon number is the sum of the protons and neutron

Therefore, an isotope has a different nucleon number too

Step 2: Calculate protons in the first nucleus

Nucleon number: 37

Neutrons: 20

Protons = 37 – 20 = 17

Step 3: Calculate protons in the second nucleus

Nucleon number: 35

Neutrons: 18

Protons = 35 – 18 = 17

Step 4: Conclusion

Therefore, they have the same number of protons but different numbers of neutrons and are isotopes of each other

The correct answer is therefore option **B**

Your notes

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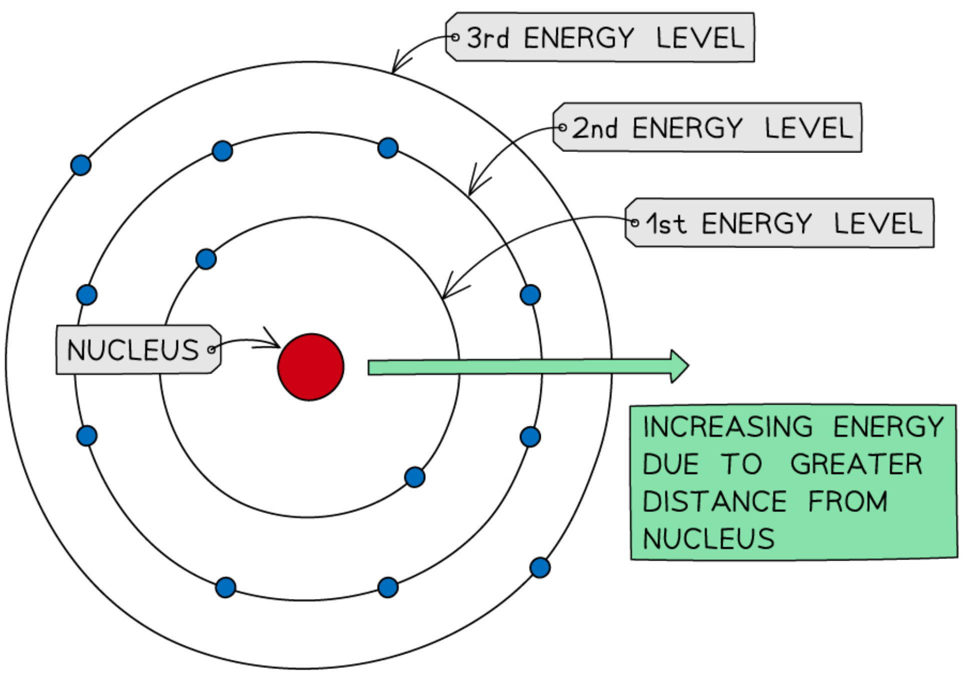
Electron Structure

Electron Structure

- Electrons in an atom orbit around the nucleus at particular distances, known as **energy levels**
- A certain number of electrons can occupy each energy level
  - For example, only two electrons can orbit in the first energy level
  - Only eight electrons can fit in the second energy level, and eight in the third as well
- The **higher the energy level, the further the distance** of the electron from the nucleus



In this diagram the first two energy levels are full. Electrons further from the nucleus have more energy

- Like moving up a ladder, electrons in higher energy levels have greater potential energy because they have more distance between them and the nucleus

Examiner Tips and Tricks

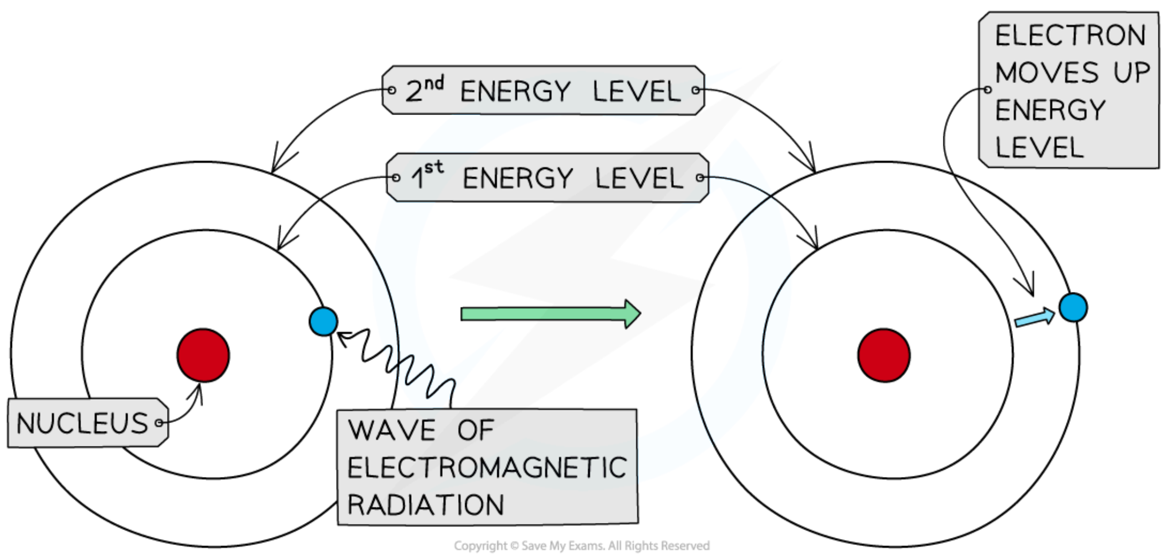
Your notes

> If you are studying for your Chemistry GCSE then you will need to know the number of electrons that fit into the different energy levels. They may also be called **electron shells**.

The Absorption and Emission of EM Radiation

Absorption of Electromagnetic Radiation

- Electrons are able to temporarily move between energy levels when they **absorb** or **emit** energy
  - This means that they change their **orbit**
- When electrons **absorb** electromagnetic radiation, they move to a **higher energy level**
  - This happens when waves of electromagnetic radiation (such as **light** and **heat**) hit them

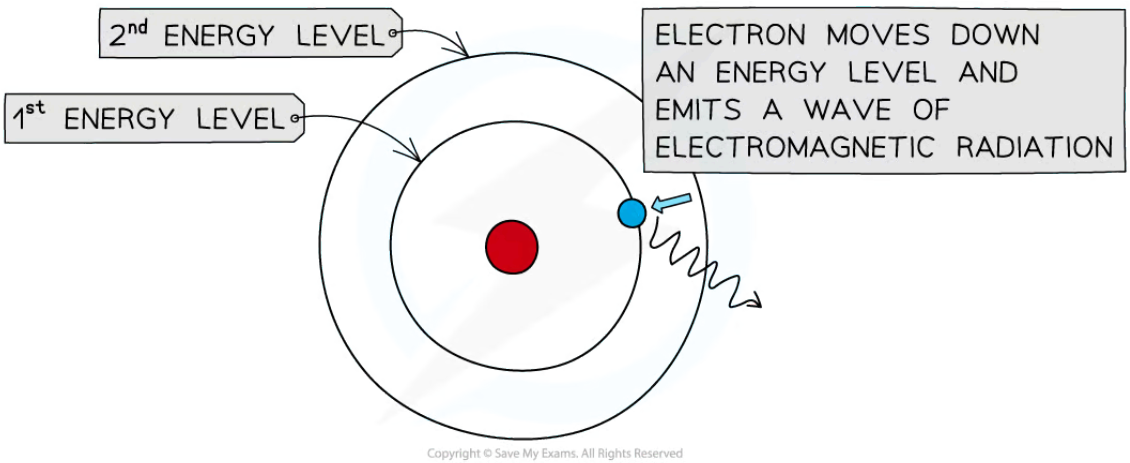


The electron absorbs electromagnetic radiation which causes it to move up an energy level

- Dark coloured objects are good absorbers of radiation
  - They appear dark because they do not reflect the energy that hits them

Emission of Electromagnetic Radiation

- When an electron has moved up an energy level, it will be in an **excited state**
- Eventually, it will move back down to its **original** energy level, which will be closer to the nucleus
  - As it moves back down, it **emits** a wave of electromagnetic radiation



The electron emits a wave of electromagnetic radiation and moves down an energy level

- **All** of the colours in the visible spectrum are produced in this way
- The light waves come from electrons moving down energy levels and emitting electromagnetic radiation

Examiner Tips and Tricks

Whilst you are expected to know about energy levels and the absorption and emission of electromagnetic waves, you are not expected to know about the number of electrons in each energy level or the way in which they fill up – that's all part of Chemistry.

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Positive Ions

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Positive Ions

- Electrons in the outer energy level can be knocked out from an atom
- This can happen in a number of ways:
  - When objects are rubbed together, electrons can be removed by **friction**
  - When electrons absorb electromagnetic radiation they can gain enough energy to **leave** the atom
  - From **chemical reactions**
- When one or more electrons are removed from an atom, it becomes **positively charged**
  - This is because an electron is negatively charged
- The atom becomes a **positive ion**
  - An ion is an atom or particle with a **non-zero charge**

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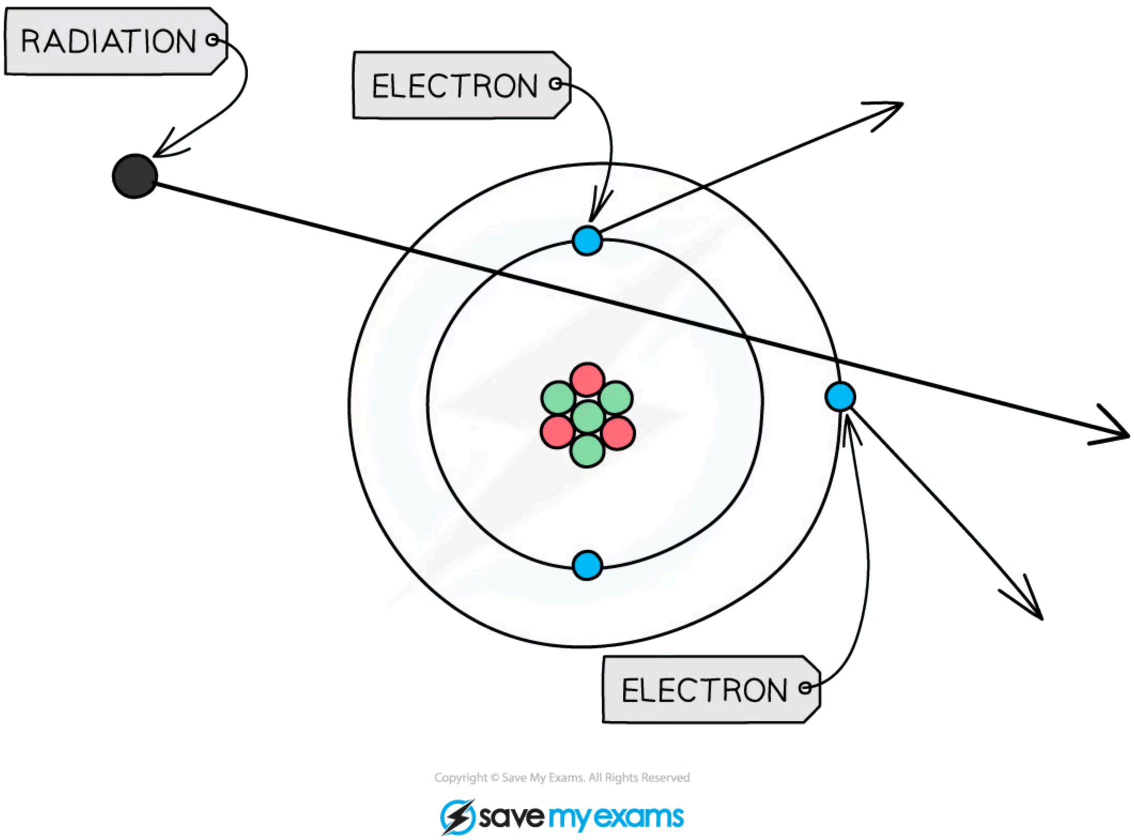


When radiation passes close to atoms it can knock electrons out, leaving the atom with an overall positive charge

- Ions are more chemically reactive than atoms because of their positive charge

Worked Example

Which option describes the change that a Ca (Calcium) atom would undergo in order to form a Ca^{2+} ion?

A. The atom has gained two protons

B. The atom has lost two protons

C. The atom has gained two electrons

Your notes

D. The atom has lost two electrons

Answer: D

- The answer is **not A** because a change in the number of protons would cause the element symbol to change
- The answer is **not B** because a change in the number of protons would cause the element symbol to change and losing protons would result in a more negatively charged particle
- The answer is **not C** because gaining electrons would make a particle more negatively charged
- The answer is D because an electron carries a charge of -1
    - The charge on an atom is 0
    - When 2 electrons are lost from an atom then it will lose two lots of -1 charge
    - The new charge can be worked out as:

$$0 - 2(-1) = +2$$

Examiner Tips and Tricks

Definitions are very important for picking up marks on this topic. Be clear with your definitions such as ions and isotopes, and remember that ions have different numbers of **electrons**, whereas isotopes have different numbers of **neutrons**.

Developing Models of the Atom

Your notes

Developing Models of the Atom

- The understanding of what atoms are has **changed** through time
- Different models have been developed, and then replaced as **new evidence** from experiments is discovered
  - A **model** is a way of describing something in order to explain the way it behaves

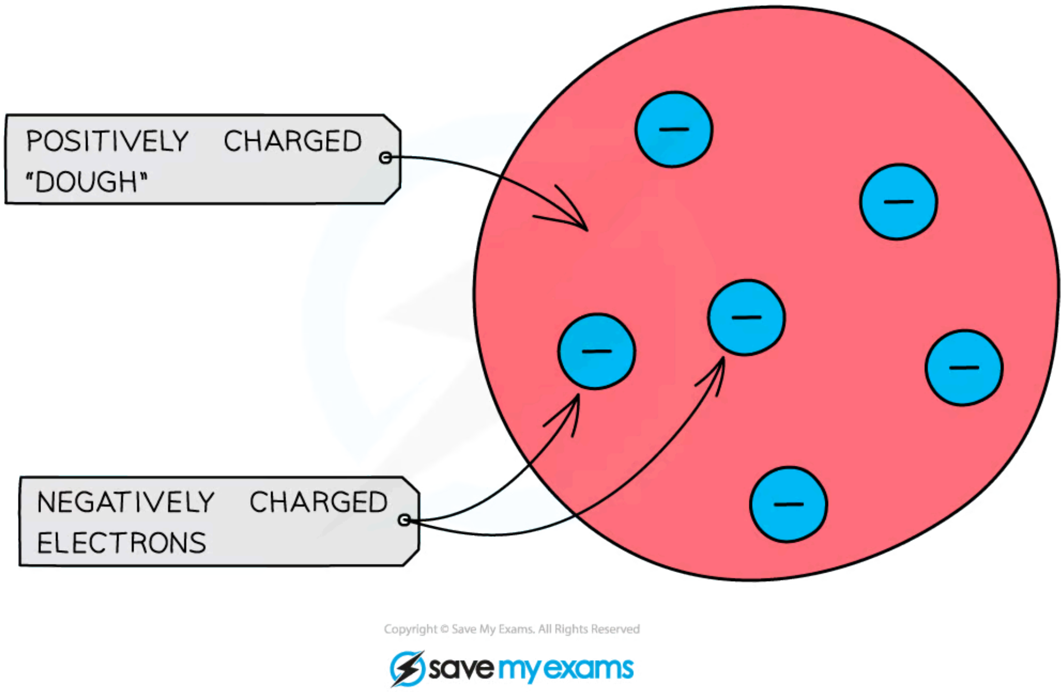
Early Models of the Atom

- Greek and Indian philosophers were the first to try and describe the idea of everything being made up of smaller parts
- The Greek philosopher, Democritus, thought that although objects could be cut into smaller pieces, the smallest possible piece would be **indivisible** (it could not be cut any further)
  - The Greek word for 'indivisible' is **atomos**
- Therefore, atoms were initially thought to be tiny spheres that could not be divided before the discovery of the electron
  - Later models described the atom as small solid spheres

JJ Thompson's Plum Pudding Model

- At the end of the 19th Century, Physicist Joseph Jon Thompson discovered the existence of **electrons**
- This new evidence meant a better model of the atom was required
- Thompson proposed the **Plum Pudding model**
  - The atom was thought to consist of negatively charged electrons (the 'plums') in a positively charged 'dough' or 'pudding'

Your notes



J J Thomson thought of the atom as being a positively charged mass embedded with small negatively charged electrons – a bit like a plum pudding

- It was known that electrons were much smaller than atoms, so it made sense that they should be embedded within the larger atom
- Since electrons have a negative charge, it was reasoned that the rest of the atom would be positive, making the atom neutral overall

Rutherford's Alpha Particle Scattering Experiment

- In 1909 a group of scientists were investigating the Plum Pudding model
  - Physicist, **Ernest Rutherford** was instructing two of his students, Hans Geiger and Ernest Marsden to carry out the experiment
- They were directing a beam of **alpha particles** (He^{2+} ions) at a thin gold foil
- They expected the alpha particles to travel through the gold foil, and maybe change direction a small amount
- Instead, they discovered that :
  - Most of the alpha particles **passed straight through** the foil

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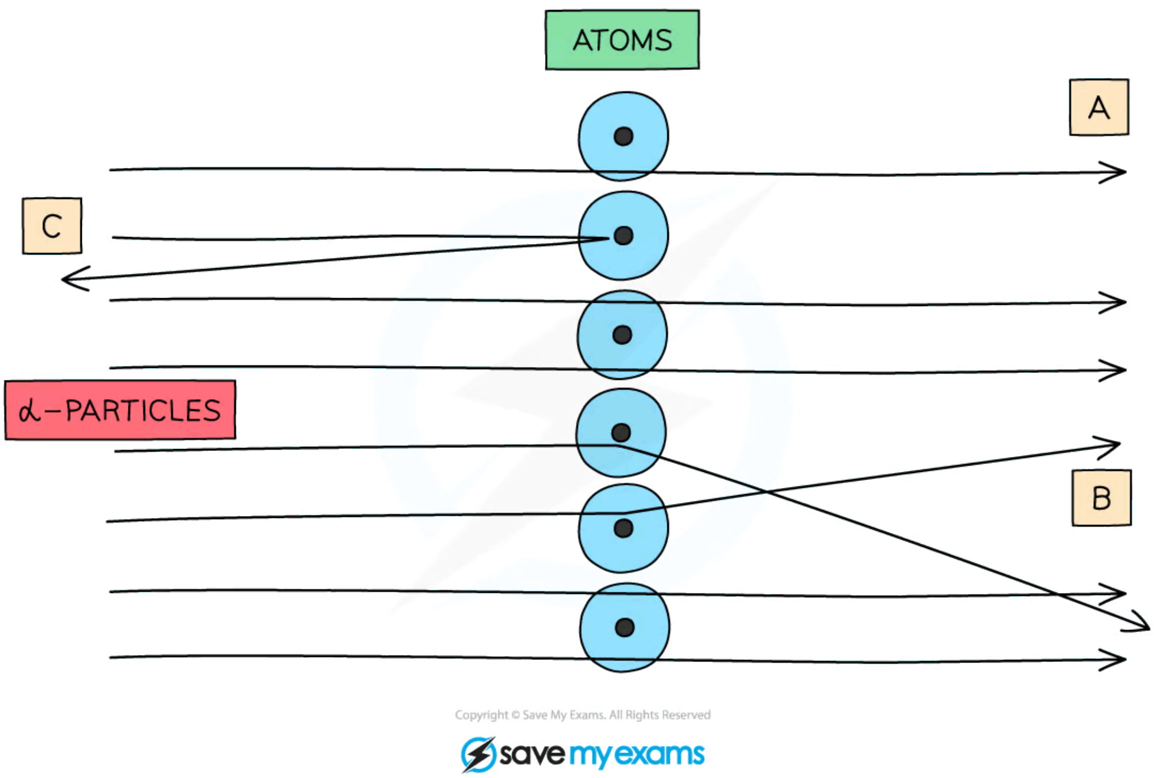
- Some of the alpha particles **changed direction** but continued through the foil
- A few of the alpha particles **bounced back** off the gold foil

- The bouncing back could not be explained by the Plum Pudding model, so a new model had to be created



When alpha particles are fired at thin gold foil, most of them go straight through, some are deflected and a very small number bounce straight back

- Ernest Rutherford made different conclusions from the findings of the experiment
- The table below describes the findings and conclusions of A, B and C from the image above:

Alpha Scattering Findings and Conclusions Table

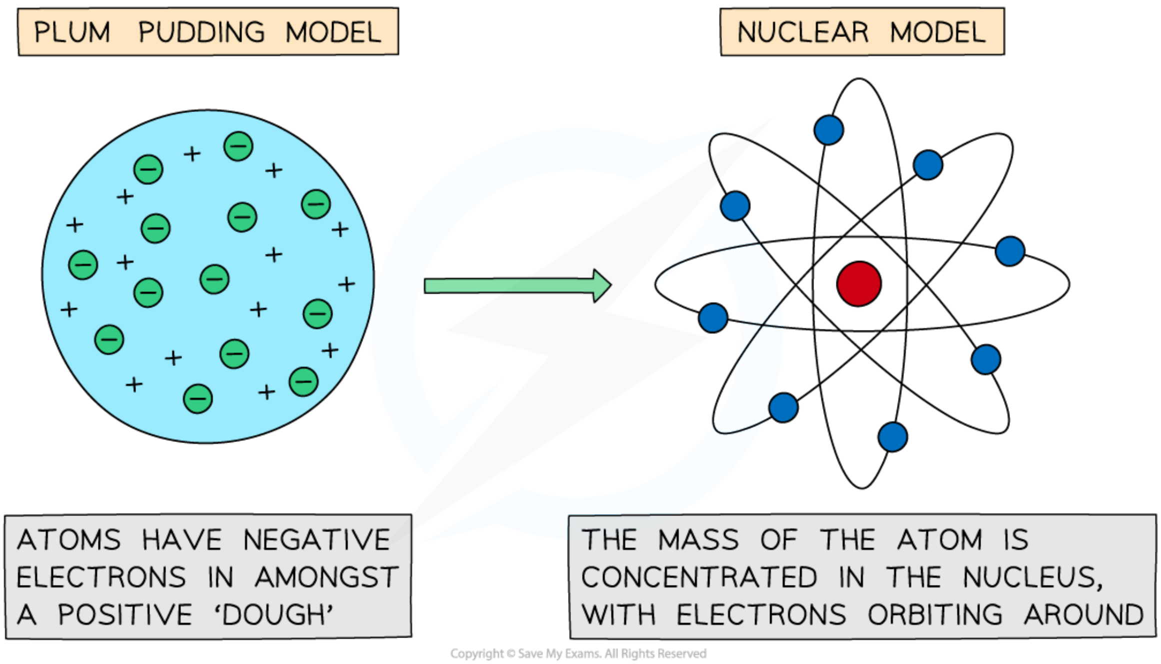
Your notes

	Finding	Conclusion
A	Most of the alpha particles passed straight through the gold foil	Atoms are mostly empty space
B	A few alpha particles were deflected from their path but continued through the gold foil	The nucleus of the atom has a strong positive charge
C	A small number of alpha particles rebounded	The atoms contains a small, heavy nucleus

The Nuclear Model

- Rutherford proposed the **nuclear model** of the atom
- In the nuclear model:
  - Nearly **all** of the mass of the atom is concentrated in the **centre** of the atom (in the nucleus)
  - The **nucleus** is **positively** charged
  - **Negatively** charged **electrons** orbit the nucleus at a distance
- Rutherford's nuclear model replaced the Plum Pudding model
  - The nuclear model could explain experimental observations better than the Plum Pudding model

Your notes

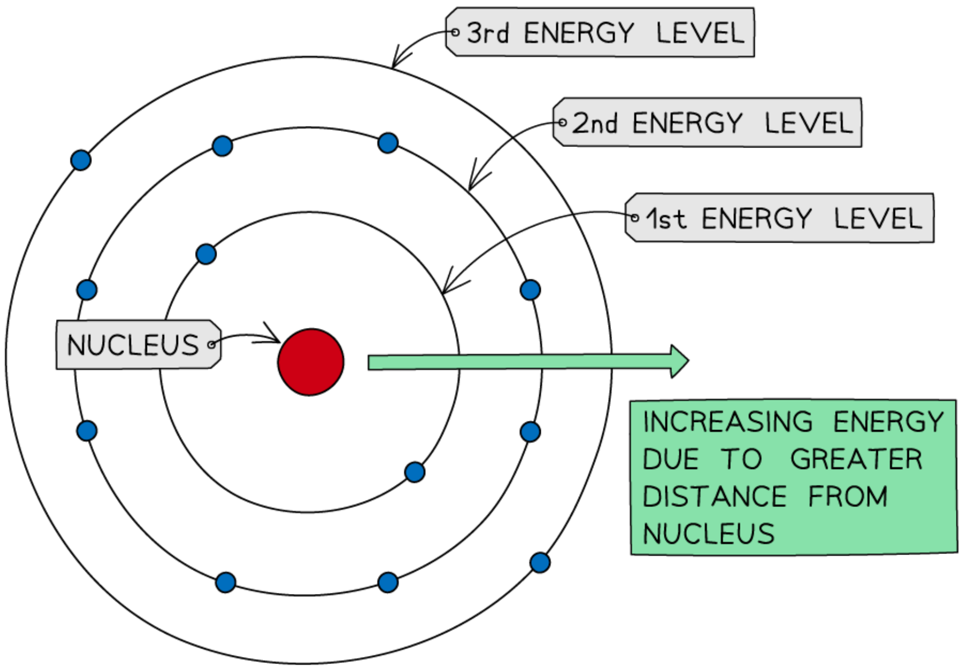


The Nuclear model replaced the Plum Pudding model as it could better explain the observations of Rutherford's Scattering Experiment

The Bohr Model of the Atom

- In 1913 the Danish Physicist, Niels Bohr, came up with an improved model of the atom
- He used the nuclear model to create his model
- In the **Bohr model** of the atom:
  - Electrons orbit the nucleus at **different distances**
  - The different orbit distances are called energy levels
  - Up to 2 electrons orbit in the first energy level
  - Up to 8 electrons can orbit in the second energy level
  - Up to 8 electrons can orbit in the third energy level

Your notes



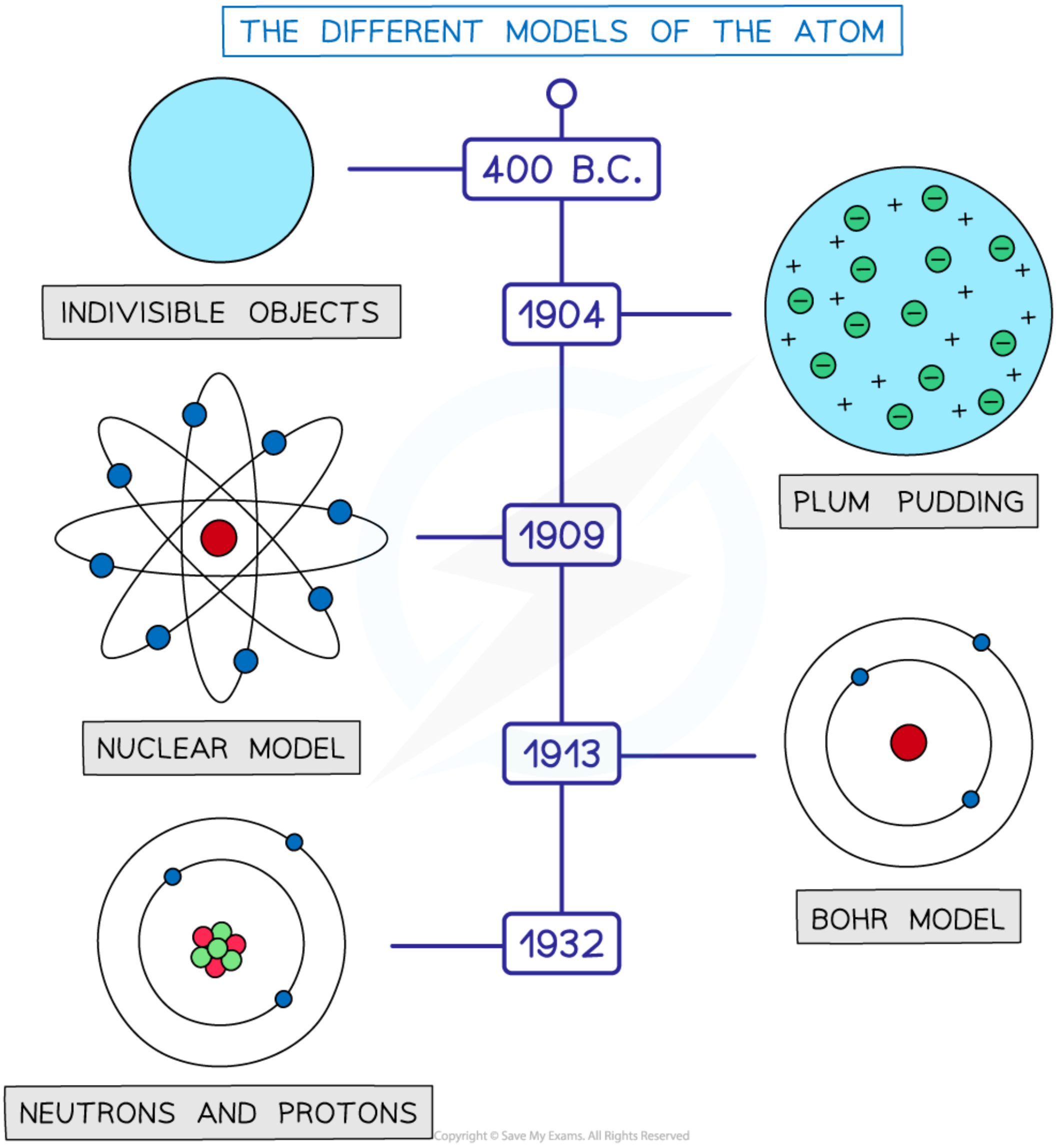
In the Bohr model of the atom electrons orbit in distinct energy levels, which are at different distances from the nucleus

Successes of the Bohr Model

- The Bohr model became the accepted model because:
  - It was able to explain the findings from different experiments better than the nuclear model of the atom
  - It was able to explain the processes of **absorption** and **emission** of electromagnetic radiation
  - Theoretical calculations made using the Bohr model agreed with experimental results

The Changing Models of the Atom

- The understanding of the structure of an atom has changed over time
- The best model of an atom is the one that can explain the evidence of experiments best
  - As more evidence has been collected, the models have improved
- The image below shows a timeline of the different models of the atom



Scientific models are used to explain observations. Models of the atom have changed and improved throughout history

Your notes

Worked Example

Explain:

Your notes

a) Why Rutherford's alpha scattering experiment lead to a new model of the atom, called the nuclear model, and replaced the 'plum pudding' model.

b) Why it is important that the experimental results and the predictions are the same.

Answer:

Part (a)

- The experimental results of the gold foil experiment could not be explained using the plum pudding model
- Therefore, the plum pudding model was disapproved and a new model, the nuclear model, was devised to match the results

Part (b)

- If the predictions are correct, then this proves that the nuclear model is correct

Examiner Tips and Tricks

For the exam you need to be able to describe the features of JJ Thompson's Plum Pudding model, but you do not need to know how electrons were discovered (this is covered at A Level), or about very early atomic models. Try to remember the different **advantages** that later models had over earlier models.