Atomic structure and the periodic table

Model answers and marking points

GCSE science 6-mark questions

This topic online

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1 A science museum in Leeds is making a wall display called *How our picture of the atom changed*.

Describe how the model of the atom developed from the plum pudding model to the model used today. Include the evidence that led to each change.

(6 marks)

Model answer

Before electrons were discovered, atoms were thought of as tiny spheres that could not be divided. After the electron was discovered, the plum pudding model was suggested. This pictured the atom as a ball of positive charge with negative electrons spread through it.

In the alpha scattering experiment, positive alpha particles were fired at a very thin sheet of gold foil. Most of them went straight through, which showed that most of the atom is empty space. A small number were deflected through large angles and a few bounced back. This showed that the positive charge and most of the mass are concentrated in a tiny, dense centre. This led to the nuclear model, with a small positive nucleus and electrons outside it.

Niels Bohr then suggested that electrons orbit the nucleus in shells at fixed distances. His calculations agreed with what was observed in experiments. Further experiments showed that the positive charge of the nucleus is shared out between smaller particles called protons. Later, James Chadwick showed that the nucleus also contains neutrons, which have no charge, and this explained why atoms have more mass than their protons alone.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Early idea: atoms were tiny spheres that could not be split
- Discovery of the electron led to the plum pudding model: a ball of positive charge with negative electrons spread through it
- In the alpha scattering experiment, positive alpha particles were fired at very thin gold foil
- Most alpha particles passed straight through, so most of the atom is empty space
- A few were deflected through large angles or bounced back, so there is a tiny, dense, positive centre
- This gave the nuclear model: mass concentrated in a small nucleus with electrons outside it
- Bohr suggested electrons orbit the nucleus at fixed distances (shells); his calculations agreed with experimental observations
- Later work showed the positive charge of the nucleus is carried by smaller particles called protons
- Chadwick later showed the nucleus also contains neutral particles, neutrons, explaining the extra mass

How it is marked

- 5-6 marks: gives the models in the correct order and links each change to the evidence, including what both the straight-through and the deflected alpha particles showed, and mentions shells and neutrons.
- 3-4 marks: describes the plum pudding and nuclear models and the scattering experiment, but the evidence for later changes (shells, protons or neutrons) is thin or missing.
- 1-2 marks: names one or two models or describes one model without saying what evidence changed it.

What loses marks

- Saying the deflected alpha particles were attracted to the nucleus: they were repelled because both are positive
- Describing the models with no evidence for why each one replaced the last
- Putting the discovery of the neutron before the nuclear model

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2 Oliver investigated three group 1 metals. He dropped a 0.1 g piece of each metal into a large trough of water and timed how long it took to react completely.

Metal	Melting point in °C	Time to react completely in s
lithium	181	85
sodium	98	22
potassium	63	3

Use the data to describe the trends in group 1. Predict the results for rubidium, which is below potassium. Explain the trend in reactivity in terms of the structure of the atoms. (6 marks)

Model answer

The data show that the melting point decreases going down group 1, from 181 °C for lithium to 63 °C for potassium. The time to react completely also gets shorter, from 85 s to 3 s, so the metals get more reactive further down the group.

I predict rubidium will have a melting point below 63 °C and will react completely in less than 3 s, more violently than potassium. Like the others it will react with water to form a metal hydroxide and hydrogen gas.

All group 1 atoms have one electron in their outer shell, and they react by losing this electron to form an ion with a 1+ charge. Going down the group, each atom has an extra shell of electrons, so the outer electron is further from the nucleus. There are also more inner shells shielding it. This means the attraction between the positive nucleus and the outer electron is weaker, so the electron is lost more easily. Therefore the metals further down the group react more readily.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Melting point decreases going down the group
- Time to react decreases down the group, so reactivity increases down the group
- Rubidium: melting point lower than 63 °C
- Rubidium: reacts in less than 3 s, more violently than potassium
- All group 1 atoms have one electron in their outer shell and react by losing it to form a 1+ ion
- Going down the group the atoms have more shells, so the outer electron is further from the nucleus
- The outer electron is more shielded by inner shells, so the attraction to the nucleus is weaker
- So the outer electron is lost more easily and the metal is more reactive
- Each metal reacts with water to make a metal hydroxide and hydrogen

How it is marked

- 5-6 marks: states both trends from the table, makes a sensible prediction for both columns, and explains reactivity using distance of the outer electron and weaker attraction to the nucleus.
- 3-4 marks: describes the trends and predicts for rubidium, with a partial explanation such as 'bigger atoms' without linking it to attraction for the outer electron.
- 1-2 marks: reads off one trend or makes a prediction with no explanation.

What loses marks

- Saying atoms lower down have more outer electrons: every group 1 atom has one
- Predicting a number for rubidium without saying it fits the trend
- Saying the outer electron is 'harder to gain' instead of easier to lose

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3 A heritage railway in Cornwall uses iron for its rails, bolts and wheels. Sodium is also a metal, but it could never be used to build anything like this.

Sodium is in group 1. Iron is a transition metal. Compare the physical and chemical properties of sodium and iron.

Separate science only

(6 marks)

Model answer

Sodium and iron are both metals, so both conduct electricity and heat. However, iron has a much higher melting point than sodium. Iron is also much denser, while sodium is so light it floats on water. Iron is hard and strong, but sodium is soft enough to cut with a knife.

Chemically, sodium is far more reactive. It reacts vigorously with cold water and tarnishes quickly in air, so it is stored under oil. Iron reacts only slowly, for example when it rusts in damp air.

Sodium always forms ions with a 1+ charge, but iron can form ions with different charges, Fe^{2+} and Fe^{3+}. Sodium compounds are white or form colourless solutions, whereas iron compounds are coloured, for example green or orange-brown. Iron is also used as a catalyst, for example when making ammonia, but sodium is not used as a catalyst.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Both are metals: both conduct electricity and heat
- Iron has a much higher melting point than sodium
- Iron has a higher density than sodium; sodium floats on water
- Iron is hard and strong; sodium is soft and can be cut with a knife
- Sodium reacts vigorously with cold water and quickly tarnishes in air, so it is stored under oil; iron reacts only slowly (rusting)
- Sodium only forms 1+ ions; iron can form ions with different charges, Fe^{2+} and Fe^{3+}
- Sodium compounds are white or colourless; iron compounds are coloured, e.g. green or orange-brown
- Iron and its compounds are useful catalysts, e.g. iron in making ammonia; sodium is not used this way

How it is marked

- 5-6 marks: makes at least five clear point-by-point comparisons covering both physical and chemical properties, including ion charges and coloured compounds or catalysis.
- 3-4 marks: makes three or four comparisons, mostly physical, or lists properties of each metal without directly comparing them.
- 1-2 marks: one or two simple differences, such as 'sodium is more reactive'.

What loses marks

- Listing facts about each metal separately with no comparison words such as 'whereas' or 'but'
- Only giving physical properties and leaving out ion charges, colour or catalysis
- Saying iron does not react at all

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4 **Higher tier**

Priya added a few drops of halogen solutions to solutions of potassium halides.

Halogen added	potassium chloride	potassium bromide	potassium iodide
chlorine	-	turns orange	turns brown
bromine	no change	-	turns brown

Explain these results. In your answer include the trend in reactivity in group 7 in terms of electrons, an ionic equation for one reaction, and which species are oxidised and reduced. (6 marks)

Model answer

Chlorine displaces both bromine and iodine from their salts, and bromine displaces iodine but not chlorine. The orange colour shows bromine has formed and the brown colour shows iodine has formed. A more reactive halogen displaces a less reactive one, so the order is chlorine, then bromine, then iodine, and reactivity decreases down group 7.

Halogen atoms have seven outer electrons and react by gaining one electron. Further down the group the atoms are larger, so the outer shell is further from the nucleus and more shielded by inner shells. This means the attraction for an extra electron is weaker, so the halogen is less reactive.

For chlorine with potassium bromide the ionic equation is:

$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$

The potassium ions are spectator ions. Chlorine gains electrons, $Cl_2 + 2e^- \rightarrow 2Cl^-$, so it is reduced.

Bromide ions lose electrons, $2Br^- \rightarrow Br_2 + 2e^-$, so they are oxidised.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Chlorine displaces bromine and iodine; bromine displaces iodine but not chlorine
- A more reactive halogen displaces a less reactive one from its salt, so reactivity decreases down the group
- Orange colour shows bromine formed; brown shows iodine formed
- Halogen atoms have seven outer electrons and react by gaining one electron
- Further down the group atoms are larger, the outer shell is further from the nucleus and more shielded
- So there is weaker attraction for an extra electron and the halogen is less reactive
- Ionic equation: $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$ (potassium ions are spectators)
- Chlorine gains electrons so is reduced: $Cl_2 + 2e^- \rightarrow 2Cl^-$
- Bromide ions lose electrons so are oxidised: $2Br^- \rightarrow Br_2 + 2e^-$

How it is marked

- 5-6 marks: uses the results to rank the halogens, explains the trend by attraction for a gained electron, gives a correct balanced ionic equation and correctly names what is oxidised and reduced in electron terms.
- 3-4 marks: ranks the halogens and explains displacement, with either the electron explanation or the equation and redox correct but not both.
- 1-2 marks: states that chlorine is the most reactive or describes the colours with little explanation.

What loses marks

- Saying reactivity increases down group 7 by copying the group 1 pattern
- Writing Br instead of Br_2 or forgetting to balance the bromide ions
- Mixing up oxidation and reduction: reduction is gain of electrons

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5 After a storm, a camping group in Snowdonia collects water from a puddle near the coast. The water contains mud and dissolved salt.

Three members suggest ways to get drinkable water:

- **Femi:** pour the water through filter paper.
- **Grace:** let the mud settle, then heat the water in an open pan until only salt is left.
- **Tariq:** filter the water, then use simple distillation, collecting the liquid that condenses.

Evaluate the three methods and decide which is best. (6 marks)

Model answer

Femi's method would remove the mud, because mud is insoluble and is trapped on the filter paper. However, the salt is dissolved, so it passes through the paper with the water. The filtered water would still be salty, so it is not safe to drink.

Grace's method lets the mud settle, but when she heats the open pan the water evaporates into the air and is lost. She would end up with salt and no drinking water at all, so this method does not do the job.

Tariq's method first filters out the mud, which stops it getting into the distillation flask. In simple distillation the water boils, the steam is cooled in a condenser and turns back into liquid water, which is collected. The salt has a very high boiling point, so it stays behind in the flask. The water collected is pure. The drawbacks are that it needs heating equipment, fuel and more time.

Overall, Tariq's method is the best because it is the only one that removes both the mud and the salt and actually collects the water.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Mud is insoluble so filtration removes it; it stays on the filter paper as residue
- Salt is dissolved so it passes through the filter paper in the filtrate
- Femi's water would still be salty, so it is not drinkable
- In Grace's method the water evaporates into the air, so no water is collected
- Grace's method only gives salt, not drinking water
- Distillation: water boils, the vapour is cooled in a condenser and turns back to liquid
- Salt has a very high boiling point so stays behind; the collected water is pure
- Filtering first stops mud clogging or contaminating the distillation flask
- Tariq's method needs heating equipment, fuel and time, but is the only one giving pure water
- Conclusion: Tariq's method is best

How it is marked

- 5-6 marks: judges all three methods, explaining why each one does or does not remove the mud and the salt, includes at least one drawback of the best method and gives a clear justified conclusion.
- 3-4 marks: explains why two methods work or fail and picks Tariq's method with a reason.
- 1-2 marks: picks a method with little or no reasoning, or describes one technique only.

What loses marks

- Saying filter paper removes dissolved salt
- Forgetting that evaporation in an open pan loses the water
- Giving a conclusion without comparing all three methods

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