Chemical changes

Model answers and marking points

GCSE science 6-mark questions

This topic online

1 Mei tested four metals, labelled A, B, C and D, with cold water and with dilute hydrochloric acid.

Metal	Cold water	Dilute hydrochloric acid
A	fizzes quickly and moves around the surface	too dangerous to test
B	no reaction	a few slow bubbles
C	no reaction	no reaction
D	a few bubbles after several minutes	fizzes quickly

Use the results to put the metals in order of reactivity. Explain how you decided, and explain what makes one metal more reactive than another. Identify the gas produced and give a test for it. (6 marks)

Model answer

The order from most reactive to least reactive is A, D, B, C.

A is the most reactive because it fizzes quickly even in cold water, so it would be too dangerous to add to acid. D only gives a few bubbles with cold water after several minutes, but fizzes quickly with acid, so it is reactive but less so than A. B does not react with water and gives only a few slow bubbles with acid, so it is less reactive than D. C does not react with water or acid, so it is the least reactive and must be less reactive than hydrogen. I decided by looking at how fast the bubbles formed: the faster the bubbles, the more reactive the metal.

When metals react, their atoms lose electrons and form positive ions. A more reactive metal has a greater tendency to lose electrons and form positive ions, so it reacts more readily.

The gas made in these reactions is hydrogen. To test for it, hold a lit splint at the mouth of the test tube. Hydrogen burns with a squeaky pop.

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

- Order from most to least reactive: A, D, B, C
- A is most reactive: it reacts quickly even with cold water
- D reacts slowly with water but quickly with acid, so it is less reactive than A
- B does not react with water and only slowly with acid, so it is below D
- C does not react with either, so it is least reactive (less reactive than hydrogen)
- The faster the bubbles form, the more reactive the metal
- Metals react by losing electrons to form positive ions
- A more reactive metal has a greater tendency to form positive ions
- The gas is hydrogen
- Test: a lit splint gives a squeaky pop

How it is marked

- 5-6 marks: gives the correct order with reasons that use both columns, links reactivity to the tendency to form positive ions, and identifies hydrogen with its test.
- 3-4 marks: gives the correct order with some reasons, plus either the gas test or the ions explanation.
- 1-2 marks: gives a partly correct order or identifies the gas, with little explanation.

What loses marks

- Using only one column of results, which cannot separate B and D from each other
- Saying reactive metals gain electrons
- Giving the test for oxygen (relights a glowing splint) instead of hydrogen

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2 **Higher tier**

Kwame adds magnesium powder to blue copper sulfate solution and stirs. The temperature rises, a brown solid forms and the blue colour fades.

Explain these observations. Your answer should include an ionic equation and should explain the reaction in terms of oxidation and reduction. (6 marks)

Model answer

Magnesium is more reactive than copper, so it displaces copper from copper sulfate solution. The brown solid is copper metal. The blue colour fades because the blue copper ions are being removed from the solution and replaced by magnesium ions, and magnesium sulfate solution is colourless. The temperature rises because the reaction is exothermic and transfers energy to the surroundings.

The sulfate ions do not change, so they are spectator ions and are left out of the ionic equation:

$Mg + Cu^{2+} \rightarrow Mg^{2+} + Cu$

Each magnesium atom loses two electrons to form a magnesium ion: $Mg \rightarrow Mg^{2+} + 2e^-$. Loss of electrons is oxidation, so magnesium is oxidised. Each copper ion gains two electrons to form a copper atom: $Cu^{2+} + 2e^- \rightarrow Cu$. Gain of electrons is reduction, so the copper ions are reduced. Because oxidation and reduction happen at the same time, this is a redox reaction.

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

- Magnesium is more reactive than copper, so it displaces copper from the solution
- The brown solid is copper metal
- The blue colour fades because blue Cu^{2+} ions are removed and replaced by colourless Mg^{2+} ions
- Magnesium sulfate solution is colourless
- The temperature rises because the reaction is exothermic
- Ionic equation: $Mg + Cu^{2+} \rightarrow Mg^{2+} + Cu$
- Sulfate ions are spectator ions: they do not change
- Magnesium atoms lose two electrons, so magnesium is oxidised: $Mg \rightarrow Mg^{2+} + 2e^-$
- Copper ions gain two electrons, so they are reduced: $Cu^{2+} + 2e^- \rightarrow Cu$
- Oxidation and reduction happen at the same time, so this is a redox reaction

How it is marked

- 5-6 marks: explains each observation, gives a correct ionic equation with spectator ions identified, and correctly states which species is oxidised and which is reduced in terms of electrons.
- 3-4 marks: explains displacement and most observations, with either the ionic equation or the redox explanation correct.
- 1-2 marks: says magnesium is more reactive or names the products, with little explanation.

What loses marks

- Including sulfate ions in the ionic equation
- Saying copper is oxidised because it changes
- Defining oxidation only as gaining oxygen when the question asks about electrons

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3 **Higher tier**

Hannah has two acid solutions, both with a concentration of 0.1 mol/dm^3:

- hydrochloric acid, pH 1
- ethanoic acid, pH 3

She adds the same mass of magnesium ribbon to equal volumes of each acid. The acid is in excess.

Compare the two acids. Explain the difference in pH and predict how their reactions with magnesium would compare.

(6 marks)

Model answer

Both acids have the same concentration, 0.1 mol/dm^3, but they are not equally strong. Hydrochloric acid is a strong acid, so it is completely ionised in water. Ethanoic acid is a weak acid, so only some of its molecules ionise. This means hydrochloric acid has a much higher concentration of H^+ ions, so its pH is lower.

Each decrease of one pH unit means the H^+ ion concentration is ten times higher. Hydrochloric acid is two pH units lower than ethanoic acid, so its H^+ concentration is 10 × 10 = 100 times greater.

Both acids react with magnesium to make hydrogen gas and a salt: magnesium chloride with hydrochloric acid and magnesium ethanoate with ethanoic acid. Magnesium will fizz much faster in hydrochloric acid because there are more H^+ ions, so collisions between the ions and the magnesium happen more often. However, the mass of magnesium is the same and the acid is in excess, so both reactions will finally produce the same volume of hydrogen. The ethanoic acid reaction just takes longer.

This shows that strong and weak are about how much an acid ionises, not about concentration.

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

- Both solutions have the same concentration of acid
- Hydrochloric acid is a strong acid: it is completely ionised in water
- Ethanoic acid is a weak acid: it is only partially ionised in water
- So hydrochloric acid has a much higher concentration of H^+ ions, giving a lower pH
- A decrease of one pH unit means H^+ concentration is 10 times greater
- pH 1 compared with pH 3 means hydrochloric acid has 100 times the H^+ concentration
- Magnesium fizzes faster in hydrochloric acid because there are more frequent collisions with H^+ ions
- Both reactions make hydrogen and a salt (magnesium chloride or magnesium ethanoate)
- Same mass of magnesium and acid in excess, so the same total volume of hydrogen is produced
- Strong and weak are not the same as concentrated and dilute

How it is marked

- 5-6 marks: explains the pH difference by full versus partial ionisation, uses the factor of 10 per pH unit to give 100 times, and compares both rate and final amount of gas with reasons.
- 3-4 marks: explains strong versus weak with some link to H^+ ions and says hydrochloric acid reacts faster, but misses the factor or the final volume.
- 1-2 marks: states hydrochloric acid is stronger or reacts faster, with little explanation.

What loses marks

- Saying ethanoic acid is weak because it is more dilute
- Saying pH 1 has three times or twice as many H^+ ions as pH 3
- Predicting less hydrogen from ethanoic acid even though magnesium is the limiting reactant

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4 Aluminium is extracted from aluminium oxide by electrolysis. Both electrodes are made of carbon.

Describe how aluminium is extracted by electrolysis. Include why cryolite is used, what happens at each electrode, and why the positive electrodes need to be replaced. (6 marks)

Model answer

Aluminium is more reactive than carbon, so it cannot be extracted by heating its oxide with carbon. Electrolysis is used instead.

Aluminium oxide has a very high melting point, so it is mixed with molten cryolite. This lowers the melting point of the mixture, so a lower temperature is needed and energy and money are saved. The mixture must be molten so that the ions are free to move.

When the current flows, the positive aluminium ions move to the negative electrode, the cathode. Here they gain electrons and become aluminium atoms. The molten aluminium collects at the bottom of the cell and is tapped off.

The negative oxide ions move to the positive electrode, the anode. Here they lose electrons and form oxygen gas. The anodes are made of carbon and are very hot, so the oxygen reacts with them to form carbon dioxide. This means the anodes slowly wear away and have to be replaced regularly.

The process needs a very large electric current, which is one reason aluminium extraction is expensive.

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

- Aluminium is more reactive than carbon, so it cannot be extracted by heating with carbon
- Aluminium oxide is mixed with molten cryolite to lower the melting point
- This saves energy and money because a lower temperature is needed
- The mixture is molten so the ions are free to move
- Positive aluminium ions move to the negative electrode (cathode)
- At the cathode aluminium ions gain electrons and form molten aluminium, which collects at the bottom and is tapped off
- Negative oxide ions move to the positive electrode (anode), lose electrons and form oxygen
- The oxygen reacts with the hot carbon anodes to form carbon dioxide
- So the anodes wear away and must be replaced regularly
- The process uses a large electric current, which makes it expensive

How it is marked

- 5-6 marks: describes the role of cryolite, the movement of both ions and the products at each electrode, and explains why the anodes are replaced.
- 3-4 marks: describes the products at both electrodes and gives either the role of cryolite or the reason the anodes wear away.
- 1-2 marks: states that electricity is used to get aluminium, or names one product, with little detail.

What loses marks

- Saying cryolite is a catalyst or that it dissolves the aluminium
- Putting oxygen at the negative electrode
- Saying the anodes are replaced because they melt

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5 Ethan predicted the products at each electrode when three aqueous solutions are electrolysed with inert electrodes.

Solution	Ethan's prediction at negative electrode	Ethan's prediction at positive electrode
sodium chloride	sodium	chlorine
copper sulfate	copper	oxygen
potassium bromide	hydrogen	bromine

Evaluate Ethan's predictions. Explain which are correct and which are wrong, and give an overall judgement.

(6 marks)

Model answer

In an aqueous solution, the water also provides hydrogen ions and hydroxide ions, so these can be discharged as well as the ions from the compound.

At the negative electrode, the metal is only produced if it is less reactive than hydrogen. Otherwise hydrogen gas is produced. Sodium is more reactive than hydrogen, so for sodium chloride solution hydrogen forms, not sodium. Ethan's prediction is wrong. Copper is less reactive than hydrogen, so copper is deposited, which is correct. Potassium is more reactive than hydrogen, so hydrogen forms from potassium bromide solution, which is also correct.

At the positive electrode, a halogen is produced if halide ions are present. Sodium chloride contains chloride ions, so chlorine forms, and potassium bromide contains bromide ions, so bromine forms. Both are correct. Copper sulfate has no halide ions, so oxygen is produced from the hydroxide ions, which is also correct.

Overall, Ethan's predictions are mostly good: five out of six are correct. His only mistake is sodium at the negative electrode. Sodium would only be produced if molten sodium chloride were electrolysed, because then there would be no water.

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

- In aqueous solutions, water also provides hydrogen ions and hydroxide ions
- At the negative electrode, hydrogen forms if the metal is more reactive than hydrogen
- Sodium is more reactive than hydrogen, so hydrogen forms, not sodium: Ethan is wrong
- Copper is less reactive than hydrogen, so copper is deposited: correct
- Potassium is more reactive than hydrogen, so hydrogen forms: correct
- At the positive electrode, a halogen forms if halide ions are present
- Chloride ions present, so chlorine forms: correct; bromide ions present, so bromine forms: correct
- Sulfate is not a halide, so oxygen forms from hydroxide ions: correct
- Overall five of six predictions are correct; the one error is sodium at the negative electrode
- Sodium could only be produced by electrolysing molten sodium chloride

How it is marked

- 5-6 marks: judges every prediction using the rules for both electrodes, explains why sodium is wrong, and gives an overall judgement.
- 3-4 marks: identifies the incorrect prediction with a reason and checks some of the others, with partial use of the rules.
- 1-2 marks: identifies one correct or incorrect prediction with little or no reason.

What loses marks

- Assuming the metal always forms at the negative electrode
- Saying sulfur or sulfate forms at the positive electrode
- Checking only some of the predictions or giving no overall judgement

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