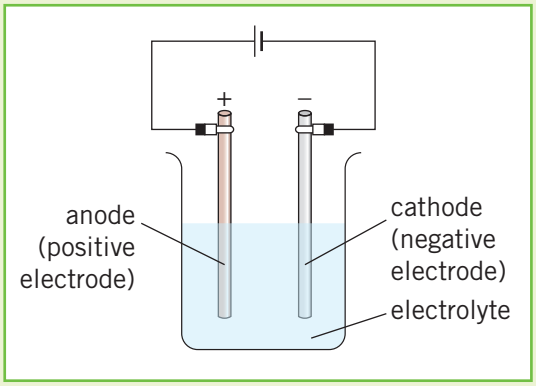
C5 Electrolysis

Electrolysis

In the process of **electrolysis**, an electric current is passed through an **electrolyte**. An electrolyte is a liquid or solution that contains ions and so can conduct electricity. This causes the ions to move to the **electrodes**, where they form pure elements.



Electrolysis of molten compounds

Solid ionic compounds do not conduct electricity as the ions cannot move. To undergo electrolysis they must be molten or dissolved, so the ions are free to move.

When an ionic compound is molten:

- the positive metal ions are *attracted* to the **cathode**, where they will *gain* electrons to form the pure metal
- the negative non-metal ions are *attracted* to the **anode**, where they will *lose* electrons and become the pure non-metal.

For example, molten sodium chloride, NaCl, can undergo electrolysis to form sodium at the cathode and chlorine at the anode.

Half equations

sodium chloride → sodium + chlorine

$2NaCl(l) \rightarrow 2Na(s) + Cl_2(g)$

- at the cathode: $2Na^+(l) + 2e^- \rightarrow 2Na(s)$
- at the anode: $2Cl^-(l) \rightarrow Cl_2(g) + 2e^-$

Electrolysis of aqueous solutions

Solid ionic compounds can also undergo electrolysis when dissolved in water. It requires less energy to dissolve ionic compounds in water than it does to melt them. However, in the electrolysis of solutions, the pure elements are not always produced. This is because the water can also undergo ionisation:

$H_2O(l) \rightarrow H^+(aq) + OH^-(aq)$

Products at the anode

In the electrolysis of a solution, if the non-metal contains oxygen then oxygen gas is formed at the anode:

- The $OH^-(aq)$ ions formed from the ionisation of water are attracted to the anode.
- The $OH^-(aq)$ ions lose electrons to the anode and form oxygen gas.
- $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$

If the non-metal ion is a halogen in high concentration, then the halogen gas is formed at the anode.

- $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$

potassium
sodium
calcium
magnesium
aluminium
(carbon)
zinc
iron
tin
lead
(hydrogen)
copper
silver
gold
platinum

most reactive

least reactive

Products at the cathode

In the electrolysis of a solution, if the metal is *more* **reactive** than hydrogen then hydrogen gas is formed at the cathode:

- The H+(aq) ions from the ionisation of water are attracted to the cathode and react with it.
- The H+(aq) ions gain electrons from the cathode and form hydrogen gas.
- $2H^+(aq) + 2e^- \rightarrow H_2(g)$
- The metal ions remain in solution.

Electrolysis of sodium chloride solution

When sodium chloride solution (brine) is electrolysed, it makes three commercially valuable products:

- hydrogen used in many chemical processes
- chlorine used to make bleach and plastic
- sodium hydroxide used to make soap

Electroplating

Electroplating uses **electrolysis** to coat one metal with a thin layer of another, more precious and less reactive metal. This makes the object more desirable, more durable, or protect it from corrosion. For example, cheap jewellery can be silver-plated using electroplating.

Electrolysis of aluminium oxide

Electrolysis can be used to extract metals from their ionic compounds. Electrolysis is used if the metal is more reactive than carbon. Aluminium is extracted from aluminium oxide by electrolysis:

1 The aluminium oxide is mixed with a substance called **cryolite**, which lowers the melting point.
2 The mixture is then heated until it is molten.
3 The resulting molten mixture undergoes electrolysis.

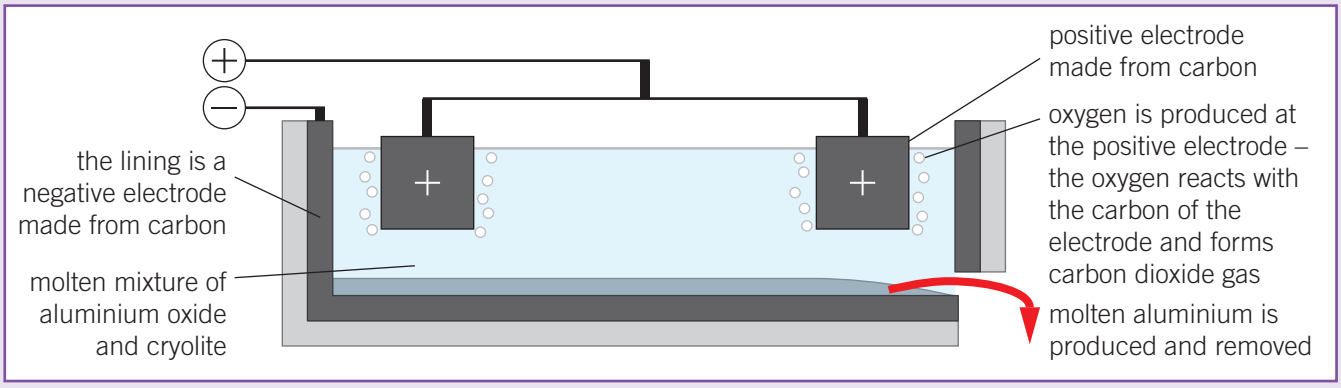
aluminium oxide → *aluminium* + *oxygen*

$2Al_2O_3(l) \rightarrow 4Al(l) + 3O_2(g)$

cathode: pure aluminium is formed $Al^{3+}(l) + 3e^- \rightarrow Al(l)$

anode: oxygen is formed $2O^{2-}(l) \rightarrow O_2(g) + 4e^-$

In the electrolysis of aluminium, the anode is made of graphite. The graphite reacts with the oxygen to form carbon dioxide and so slowly wears away. It therefore needs to be replaced frequently.



Revision tips

Extraction of aluminium by electrolysis makes a good six mark question. It's a bit different from the other example of electrolysis that you need to learn. Make sure you can do the half equations, know the key words, and know what the electrodes are made of.

Revision tips

In an exam, don't PANIC.

Here is an easy way to remember which electrode is which:

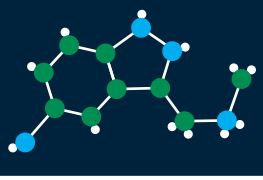
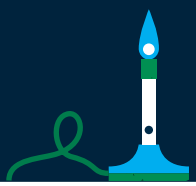
Positive
Anode
Negative
Is
Cathode

Key terms

Make sure you can write a definition for these key terms.

anode *cathode* *cryolite* *electrode* *electrolysis*
electrolyte *electroplating* *oxidation* *reactivity* *reduction*

Retrieval


Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	C5 questions	Answers
1	What is electrolysis?	process of using electricity to extract elements from a compound
2	What is an electrode?	the end of a circuit which is placed in the electrolyte
3	What is an electrolyte?	the liquid or solution that electrolysis is carried out in
4	What is the cathode?	the negative electrode
5	What is the anode?	the positive electrode
6	Where are metals formed?	at the cathode
7	Where are non-metals formed?	at the anode
8	How can ionic substances be electrolysed?	by melting or dissolving them
9	Why can solid ionic substances not be electrolysed?	they do not conduct electricity
10	In the electrolysis of aluminium oxide, why is the aluminium oxide mixed with cryolite?	to lower the melting point
11	In the electrolysis of aluminium oxide, why do the anodes need to be replaced?	they react with the oxygen being formed
12	In the electrolysis of solutions, when is the metal not produced at the cathode?	when the metal is more reactive than hydrogen
13	In the electrolysis of solutions, what is produced at the anode?	a halogen or oxygen
14	What are the three products of the electrolysis of sodium chloride solution?	hydrogen, sodium hydroxide, chlorine
15	What are the reasons for electroplating a metal?	increase durability, improve desirability, reduce corrosion

Now go back and use the questions below to check your knowledge from previous chapters.

Previous questions		Answers
1	What is the relative mass of a proton?	1
2	What is the relative mass of a neutron?	1
3	What is the relative mass of an electron?	0
4	How are covalent bonds formed?	atoms sharing electrons
5	How many electrons go into a covalent bond?	2 for a single bond, 4 for a double bond
6	Between which kinds of atom does covalent bonding occur?	non-metals
7	What are the three main types of covalent structure?	giant covalent, small molecules, large molecules
8	Describe the structure and bonding of a giant covalent substance.	billions of atoms bonded together with strong covalent bonds
9	What is an ion?	an atom that has lost or gained electrons

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Required Practical Skills

Practise answering questions on the required practicals using the example below. You need to be able to apply your skills and knowledge to other practicals too.

Electrolysis

You need to be able to describe the method of electrolysis, and label the experimental set-up for electrolysis.

Electrolysis uses electricity to break ionic compounds down into simpler compounds or elements. Metals or hydrogen are made at the negative electrode, and non-metal molecules are made at the positive electrode.

You will need to be able to apply the principles of electrolysis to any example, as many solutions can undergo electrolysis. This includes predicting the products of electrolysis for different solutions, identifying which ions move to each electrode, and writing equations for the reactions at the two electrodes.

Worked Example

The electrolysis of aqueous sodium chloride gives three products. Identify these products and state how we can test for them.

Answer:

The three products are chlorine gas (Cl_2), hydrogen gas (H_2), and sodium hydroxide solution ($NaOH$).

To test for hydrogen gas, collect the gas in a test tube and insert a glowing splint – it should burn with a squeaky pop noise.

To test for chlorine gas, collect the gas in a test tube and insert damp litmus paper – the litmus paper will bleach white.

Sodium hydroxide can be tested for using universal indicator – the solution will turn purple as sodium hydroxide is an alkali.

Practice

1 State what you would observe at each electrode during the electrolysis of copper(II) chloride.

2 Give the products of the electrolysis of sodium sulfate.

3 Explain why the electrodes must not touch each other during electrolysis.

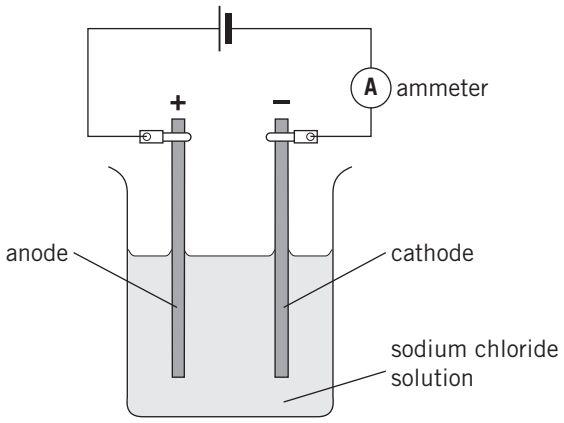
Practice

Exam-style questions

01 A student investigated the electrolysis of sodium chloride solution.

Figure 1 shows the apparatus used.

Figure 1



Exam Tip

It's not sodium. Use the reactivity series and the formula of salty water to work out the other product.

01.1 Name the substance that is produced at the cathode. **[1 mark]**

_____

01.2 Write a half equation, including state symbols, for the reaction that occurs at the anode. **[3 marks]**

_____

01.3 The student wanted to investigate if changing the concentration of sodium chloride solution affects the current that flows.

Table 1 shows the student's results.

Table 1

Concentration of sodium chloride solution in mol/dm^3	Current in amps
0.2	0.20
0.4	0.33
0.6	0.43
0.8	0.47
1.0	0.52

Identify the independent variable and the dependent variable in the investigation. **[2 marks]**

independent variable: _____

dependent variable: _____

Exam Tip

'Independent' is the one we change and 'dependent' is the one we measure. A good way to remember this is that your results *depend* on the dependent variable.

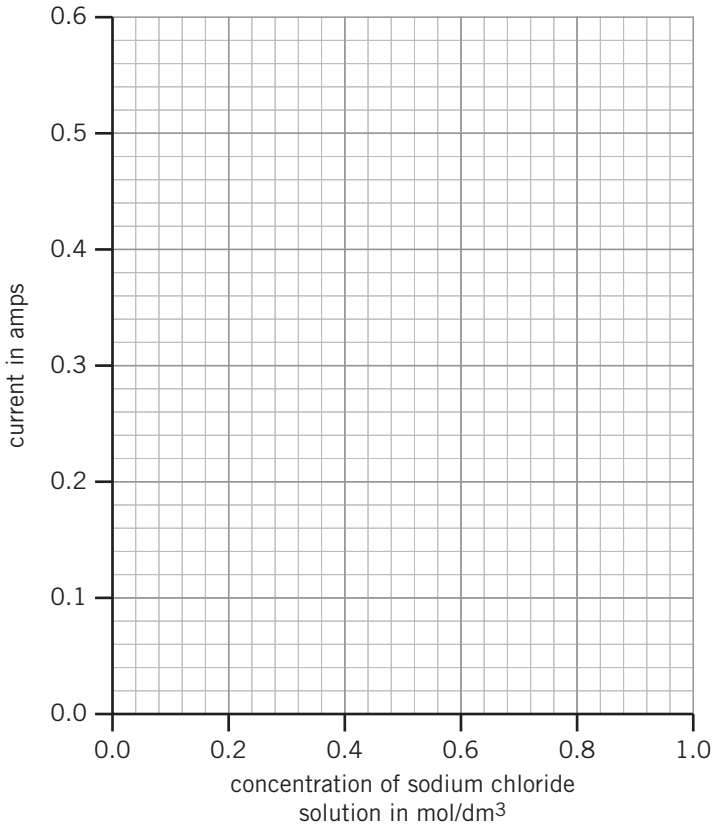
01.4 Suggest **one** control variable in the investigation. **[1 mark]**

_____

01.5 Plot the data from **Table 1** on **Figure 2**.

Draw a line of best fit. **[3 marks]**

Figure 2



Exam Tip

Use crosses to plot your points because this clearly shows the examiners which point you are aiming for. Circles can easily be misinterpreted as they can cover a range of points or be too small to be seen by the examiner. Crosses are the best way to ensure you get the mark.

01.6 Describe the pattern shown on your graph.

Suggest **one** reason for this pattern. **[2 marks]**

pattern: _____

_____

reason: _____

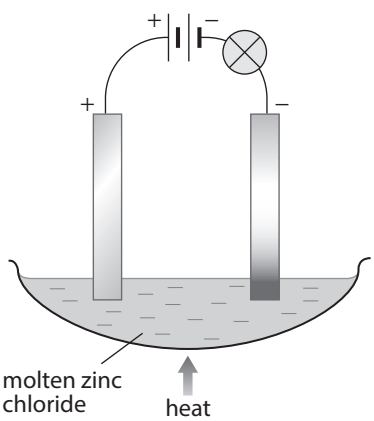
_____

Exam Tip

Use data from the graph to support your reason.

02 A teacher passed an electric current through molten zinc chloride. **Figure 3** shows the apparatus.

Figure 3



02.1 Predict the observations at the positive and negative electrodes. **[2 marks]**

02.2 Write a half equation for the reaction that occurs at the negative electrode. **[3 marks]**

02.3 The teacher passes an electric current through an aqueous zinc chloride solution. Predict the products formed at the positive and negative electrodes. Zinc is more reactive than hydrogen. **[2 marks]**

Exam Tip

Start by working out the ions that will be in zinc chloride and to which electrode they will be attracted.

03 Molten zinc chloride is electrolysed using inert electrodes.

03.1 Name the electrode that positively charged ions move towards during electrolysis. **[1 mark]**

03.2 What are the products at the anode and cathode? **[1 mark]**

Tick **one** box.

anode	cathode	
zinc	chlorine	☐
chlorine	zinc	☐
zinc	hydrogen	☐
chlorine	hydrogen	☐

Exam Tip

The first step is to work out the charges on the ions within zinc chloride.

03.3 Explain why solid zinc chloride cannot be used for electrolysis. **[3 marks]**

03.4 The symbol equation for the reaction is:

$$ZnCl_2 \rightarrow Zn + Cl_2$$

Complete the symbol equation by adding state symbols. **[1 mark]**

04 Potassium is extracted from its ores by electrolysis.

04.1 Suggest why electrolysis is used to extract potassium. **[1 mark]**

04.2 In the electrolysis of molten potassium sulfate, name the electrode that solid potassium metal will form at. **[1 mark]**

04.3 The electrolysis of molten potassium sulfate is an expensive industrial process. Give a reason why. **[1 mark]**

04.4 Aqueous potassium sulfate solution can also be electrolysed. Write the half equations for the electrolysis of aqueous potassium sulfate. **[6 marks]**

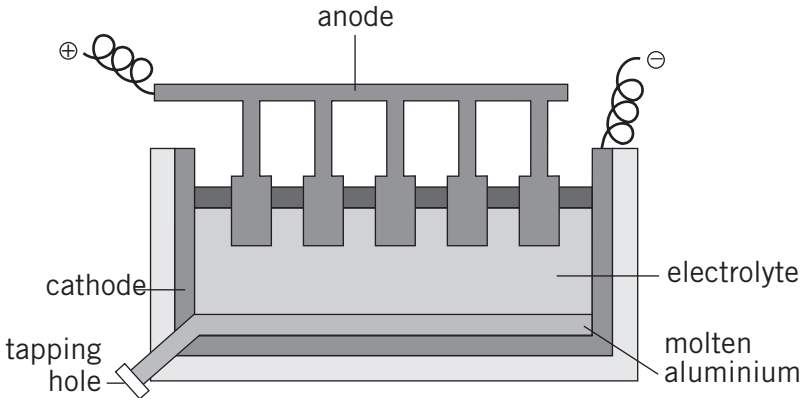
04.5 Suggest why an aqueous solution of potassium sulfate cannot be used to extract potassium. **[1 mark]**

Exam Tip

Look at the reactivity series to help you answer this.

05 **Figure 4** shows an electrolysis cell for the industrial extraction of aluminium.

Figure 4



05.1 Explain why aluminium cannot be extracted by heating its ore with carbon. **[1 mark]**

05.2 Name the material that the anode and cathode are made from. **[1 mark]**

05.3 Explain why the anode must be replaced regularly. **[1 mark]**

Exam Tip

Think about the element that the electrodes are made from.

05.4 Name the **two** substances that are mixed together in the electrolyte. **[2 marks]**

05.5 Write a half equation, including state symbols, for the reaction that occurs at the cathode. **[3 marks]**

05.6 Suggest why industrial aluminium electrolysis cells are often sited near power stations that generate electricity from renewable sources. **[1 mark]**

Exam Tip

Make sure the number of electrons matches the charge on the ions, and that the equation is balanced.

06.1 Define the term inert electrode. **[2 marks]**

06.2 The charge on a lead ion is 2+. Deduce the formula of lead bromide. **[1 mark]**

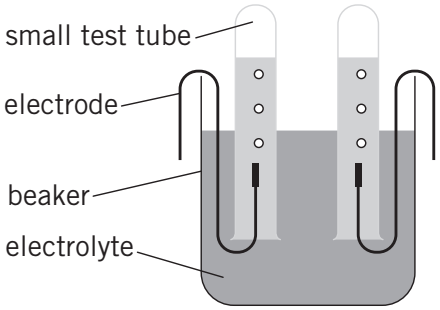
06.3 An electrolysis reaction happens when electricity is passed through molten lead bromide using inert electrodes. Describe what happens in this reaction. Include in your answer the name of the products of the electrolysis reaction and an explanation of how the products are made. **[6 marks]**

Exam Tip

Split your answer into two parts: what happens at the anode and then what happens at the cathode.

07 A student investigates electrolysis cells. **Figure 5** shows the apparatus used.

Figure 5



The student used the following method:

1. Set up the electrolysis cell as shown, with a battery to supply the current.
2. Pour the first electrolyte into the beaker.
3. Switch on the current and record any observations.

07.1 Suggest a reason for investigating the electrolysis of aqueous solutions of salts instead of the electrolysis of molten salts. **[1 mark]**

07.2 Explain why test tubes are placed over the electrodes. **[1 mark]**

Exam Tip

Look at what is happening at the electrodes in Figure 5.

07.3 **Table 2** shows some of the students' results.

Table 2

Experiment	Electrolyte	Observations at anode	Observations at cathode
1	copper chloride solution	bubbles	
2	copper sulfate solution	bubbles	cathode coated in reddish metal
3	potassium bromide solution	yellow-brown liquid	bubbles

Exam Tip

Base your predictions on the other results in the table.

Predict what the student would observe at the cathode in experiment **1**. **[1 mark]**

07.4 Describe how to test the gas in the bubbles in experiment **2**. In your answer, give the results you would expect. **[2 marks]**

07.5 Explain how the gas in the bubbles in experiment **3** are formed. Include a half equation in your answer. **[5 marks]**

Exam Tip

The gas formed is not sulfur or sulfur dioxide. There are only four gases you are expected to know how to test for in this exam; make sure you know them.

08 A chemist tried to pass an electric current through a solid, a liquid, and a solution. **Table 3** shows the chemist's results.

Table 3

Substance	State	Observations at anode	Observations at cathode
sodium chloride	solid	no change (did not conduct electricity)	

sodium chloride	liquid	smell of chlorine	silver-coloured liquid produced
sodium chloride	concentrated solution	gas produced did not relight glowing splint smell of chlorine	gas produced lit splint gives a squeaky pop
sodium chloride	dilute solution	gas produced relit glowing splint smell of chlorine	gas produced lit splint gives a squeaky pop

08.1 Explain the observations in solid and liquid sodium chloride. **[3 marks]**

08.2 Write a half equation, including state symbols, for the reaction that occurs at the cathode for concentrated sodium chloride. **[3 marks]**

08.3 Suggest an explanation for the observations at the anode and cathode for dilute sodium chloride solution. **[6 marks]**

Exam Tip

There are two gases produced here, not one gas that gives two positive results.

09 Aluminium is manufactured by electrolysis.

09.1 Suggest why reduction with carbon is not an appropriate method to manufacture aluminium. **[1 mark]**

09.2 In the electrolysis of aluminium, what is the cathode made of? **[1 mark]**

09.3 A mixture of aluminium oxide and cryolite forms the electrolyte. Explain the purpose of the cryolite. **[3 marks]**

09.4 Explain why aluminium is produced at the cathode. **[2 marks]**

09.5 In the electrolysis of aluminium oxide, explain why the anode has to be replaced regularly. **[2 marks]**

Exam Tip

The electrodes are made of carbon.

10 A student sets up an electrolysis experiment in a Petri dish, as shown in **Figure 6.**

Figure 6

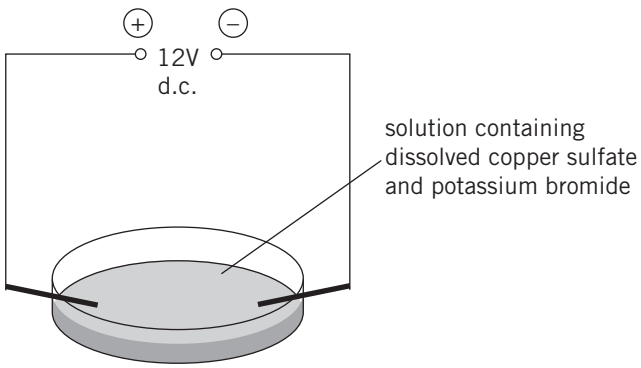


Table 4 shows the results.

Table 4

Electrode	Observations
anode	
cathode	brown flaky solid and then bubbles

10.1 Give the name of the brown flaky solid. **[1 mark]**

10.2 Predict the name of the gas that forms bubbles at the cathode. **[1 mark]**

10.3 Describe a test you could do to show that your prediction in **10.2** is correct. Include the expected results of this test. **[2 marks]**

10.4 Predict and explain the observations expected at the anode. Include half equations in your answer. **[8 marks]**

10.5 Suggest **two** reasons for carrying out the electrolysis in a Petri dish, rather than in a larger and taller electrolysis cell. **[2 marks]**

Exam Tip

Use the diagram to determine the ions in the electrolyte.

11 **Table 5** gives the diameters of some particles.

Table 5

Particle	Diameter in nm
gold atom	0.174
water molecule	0.275

11.1 Explain why a water molecule is **not** a nanoparticle. **[1 mark]**

11.2 Write the diameter of a water molecule in metres. Give your answer in standard form. **[2 marks]**

11.3 A certain gold nanoparticle has a cubic shape. The length of a side of the cube is 50 nm. Estimate the number of gold atoms that are on one face of the cube. Give your answer to one significant figure in standard form. **[4 marks]**

Exam Tip

Look at the groups that calcium and oxygen are in and determine the number of electrons in their outer shells. This will tell you how many electrons they lose or gain and then you can work out the charge.

12 This question is about the elements in Group 1 and Group 7 of the Periodic Table.

12.1 Describe the pattern in the melting points of the Group 7 elements, from the top to the bottom of the group. **[1 mark]**

12.2 Compare the patterns in the reactivity of the Group 1 and Group 7 elements, from the top to the bottom of the groups. **[2 marks]**

12.3 Name the products formed when sodium reacts with water. **[2 marks]**

Exam Tip

Make sure it's clear which group you're talking about in each part of your answer.

13 The elements calcium and oxygen react together to form an ionic compound called calcium oxide. Use the Periodic Table to help you answer this question.

13.1 Deduce the charge on a calcium ion and write its formula. **[1 mark]**

13.2 Deduce the charge on an oxide ion and write its formula. **[1 mark]**

13.3 Predict **three** properties of calcium oxide. Explain why calcium oxide has each of these properties. **[6 marks]**

14 Use the Periodic Table to answer the following questions.

14.1 Which element is most likely to be used as a catalyst? Choose **one** answer. **[1 mark]**

calcium rhodium sodium strontium

14.2 Which element will react with cold water? Choose **one** answer. **[1 mark]**

copper lithium titanium zinc

14.3 Which metal will have the highest density? Choose **one** answer. **[1 mark]**

aluminium iron magnesium potassium

14.4 Which element can form +4 ions. Choose **one** answer. **[1 mark]**

neon calcium sodium vanadium

14.5 A student has a blue metal compound. Which metal is in the compound? Choose **one** answer. **[1 mark]**

copper lead rubidium tin

Exam Tip

Only select the number of answers you're asked for in multiple choice questions: in this case, one. If you circle two answers, you won't get the marks. Equally, don't leave any blank!