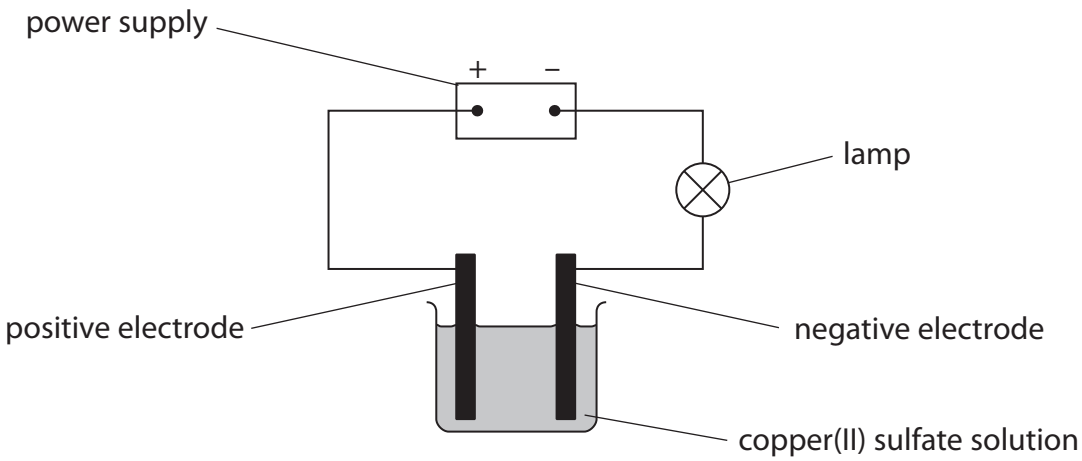
1 Most experiments involving electrolysis use inert electrodes, which do not take part in the reactions. However, in some experiments the electrodes do take part in the reactions.

A student investigates the electrolysis of copper(II) sulfate solution using copper electrodes which do take part in the reaction. She uses this apparatus.



She uses this method.

- weigh two clean strips of copper
- use one strip as the positive electrode and the other as the negative electrode
- after electrolysis wash the strips of copper with ethanol (a liquid that boils at 78 °C)
- dry the strips of copper and reweigh them

The ionic half-equations for the reactions at the electrodes are

Positive electrode $Cu(s) - 2e^- \rightarrow Cu^{2+}(aq)$

Negative electrode $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

(a) Suggest why the copper strips would dry more quickly when washed with ethanol rather than with water.

(1)

.....

(b) The student's results are shown in the table.

	Positive electrode	Negative electrode
Mass of electrode before electrolysis in g	8.78	7.95
Mass of electrode after electrolysis in g	8.46	8.25

The table shows that the decrease in mass of the positive electrode was 0.32 g.

(i) Calculate the increase in mass, in grams, of the negative electrode.

(1)

Increase in mass = ... g

(ii) The ionic half-equations show that the increase in mass of the negative electrode should be the same as the decrease in mass of the positive electrode.

Suggest two reasons why the increase in mass of the negative electrode in the student's experiment was less than expected.

(2)

1 .....

.....

2 .....

.....

(c) Another student investigated the effect of changing the electrical charge, in faradays, passed during the electrolysis.

He wanted to find how this affected the increase in mass of the negative electrode.

One faraday is the electrical charge of one mole of electrons.

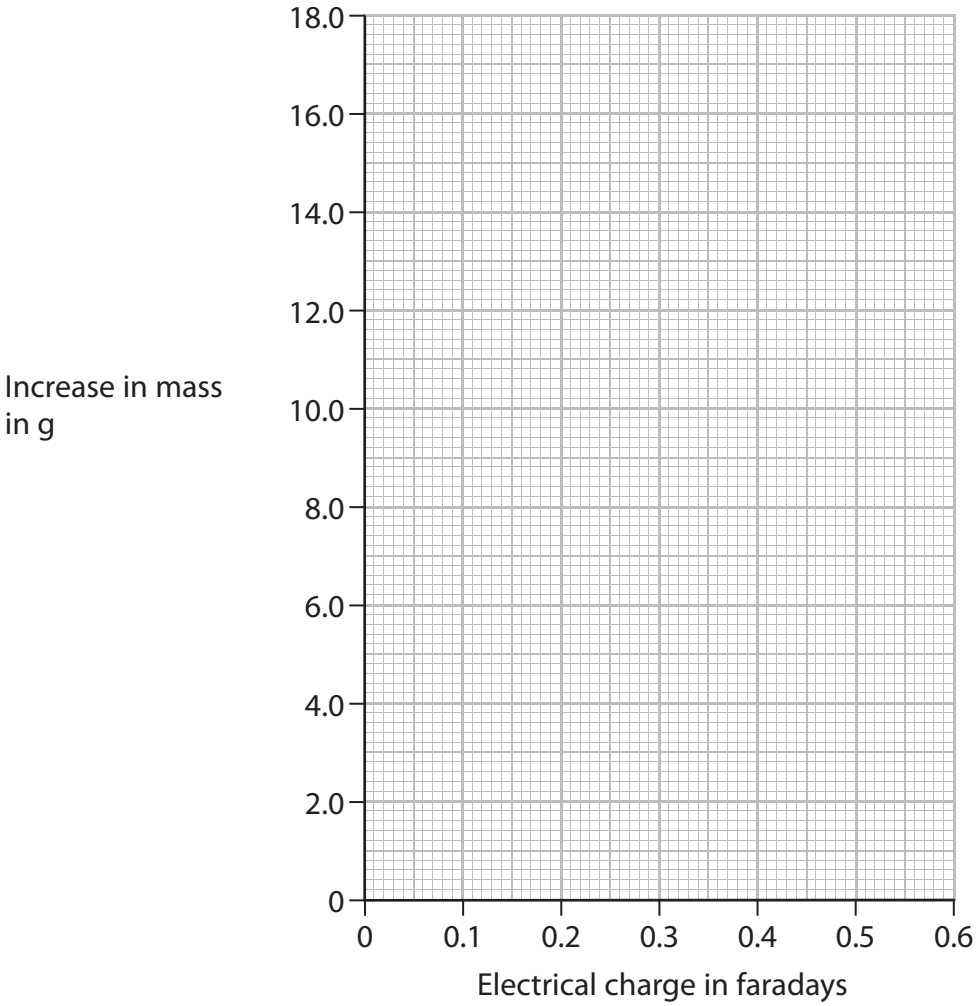
His results are shown in the table.

Experiment	1	2	3	4	5	6	7	8	9
Electrical charge in faradays	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Increase in mass in g	3.20	4.80	7.40	8.00	9.60	11.20	12.80	14.40	16.00

(i) On the grid, plot a graph of increase in mass against electrical charge.

Draw a straight line of best fit. Start your line at the origin (0,0).

(3)



&gg' Draw a circle around the anomalous result

(1)

(iii) Suggest why the straight line should go through the origin.

(1)

.....

.....

(iv) Explain why the graph shows that the increase in mass is directly proportional to the electrical charge passed.

(1)

.....

.....

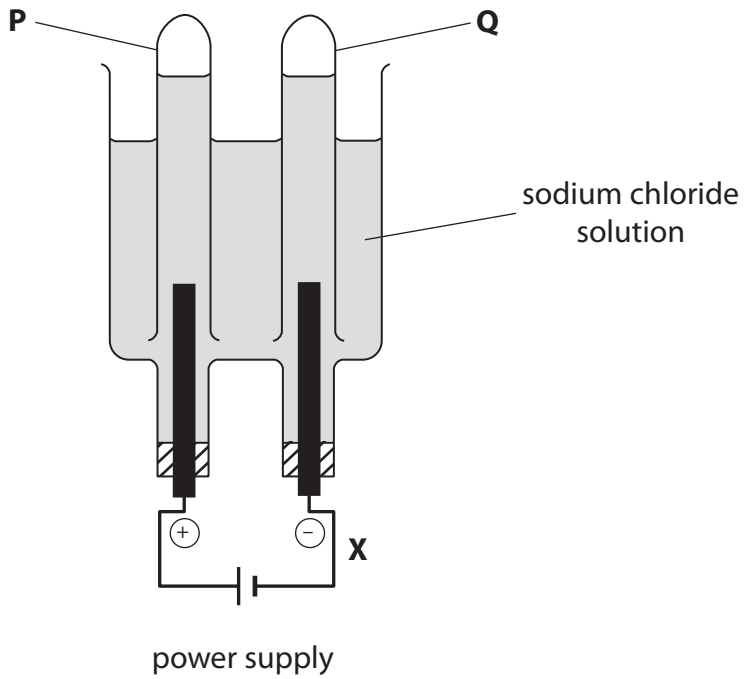
(v) Use your graph to estimate the increase in mass, in grams, of the copper electrode that would be produced by passing an electrical charge of 0.55 faradays.

(2)

Increase in mass = ... g

(Total for Question 1 = 12 marks)

2 The diagram shows how sodium chloride solution can be electrolysed and the products of electrolysis collected.



(a) (i) Draw an arrow on the diagram to show the direction of electron flow at point **X**.

(1)

(ii) The diagram shows one of the gases being collected in test tube **Q**.

Identify this gas.

(1)

.....

(iii) When the concentration of the sodium chloride solution is low, the gas collected in test tube **P** is mostly oxygen. The formation of this gas can be represented by an ionic half-equation.

Balance the equation.

(1)

$$\text{.....}OH^- \rightarrow \text{.....}H_2O + \text{.....}O_2 + \text{.....}e^-$$

(b) When the concentration of sodium chloride solution is high, the gas that collects in test tube **P** is mostly chlorine. The equation for its formation is:

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

In one experiment, the volume of chlorine gas collected was 18 cm^3.

(i) Calculate the amount, in moles, of chlorine gas in 18 cm^3.

(The volume of 1 mol of a gas at room temperature and pressure is 24 000 cm^3)

(2)

Amount = ... mol

(ii) Calculate the quantity of electricity, in coulombs, needed to produce this volume of chlorine gas.

(1 faraday = 96 500 coulombs)

(2)

Quantity = ... C

(c) Chlorine reacts with potassium bromide solution. The equation for this reaction is:

$$Cl_2(g) + 2Br^-(aq) \rightarrow 2Cl^-(aq) + Br_2(aq)$$

This reaction can be described as both a displacement reaction and a redox reaction.

(i) Identify the element that is displaced in this reaction.

(1)

.....

(ii) State the meaning of the term **redox**.

(1)

.....

.....

(d) Chlorine is used in the manufacture of phosphorus pentachloride, PCl_5

The equation for the reaction is:

$$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g) \qquad \Delta H = -124 \text{ kJ/mol}$$

(i) What does the $\rightleftharpoons$ symbol indicate about this reaction?

(1)

.....

(ii) Predict and explain the effect of increasing the pressure on the equilibrium position of this reaction.

(2)

Prediction .....

Explanation .....

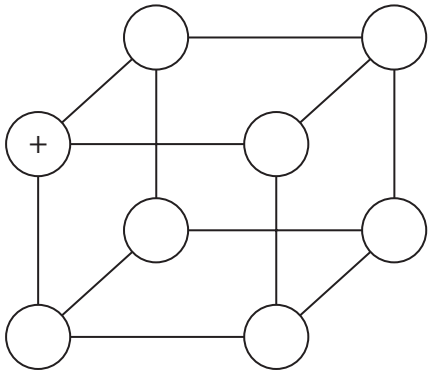
.....

.....

(Total for Question 2 = 12 marks)

3 Potassium chloride, KCl, is very similar to sodium chloride, NaCl. They have the same type of crystal structure, and their aqueous solutions can be electrolysed to give similar products.

(a) The diagram shows part of the structure of potassium chloride.

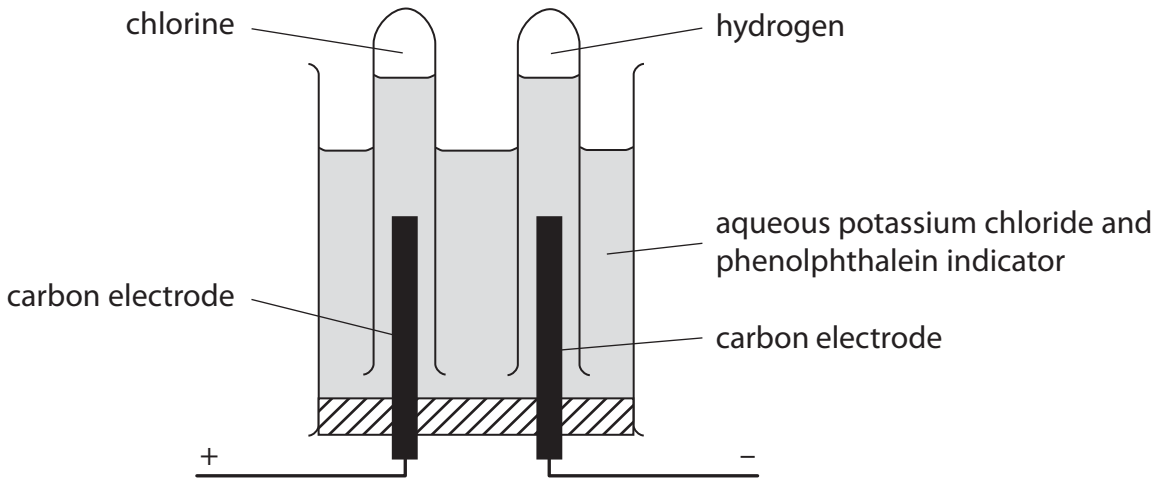


The plus (+) sign shows the position of one potassium ion.

Complete the diagram using a plus (+) sign to show the position of each potassium ion, and a minus (–) sign to show the position of each chloride ion.

(2)

(b) The diagram shows apparatus used to electrolyse aqueous potassium chloride in the laboratory.



(i) Chlorine is formed at the positive electrode.

Describe a test for chlorine gas.

(2)

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.....

.....

.....

(ii) Hydrogen gas is formed at the negative electrode.

Write an ionic half-equation for the formation of hydrogen.

(2)

.....

(iii) The solution used in this electrolysis contains phenolphthalein. During the electrolysis, the colour of the solution around the negative electrode goes pink.

Explain why the solution goes pink, and give the formula of the ion responsible for causing the colour change.

(2)

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.....

(c) The ionic half-equation for the formation of chlorine at the positive electrode is

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

In one experiment a charge of 0.0250 faraday is passed through an aqueous solution of potassium chloride.

(i) Calculate the amount, in moles, of chlorine formed.

(1)

amount of chlorine = ... mol

(ii) Calculate the volume of chlorine formed at room temperature and pressure (rtp). [The molar volume of a gas is 24 dm^3 at rtp.]

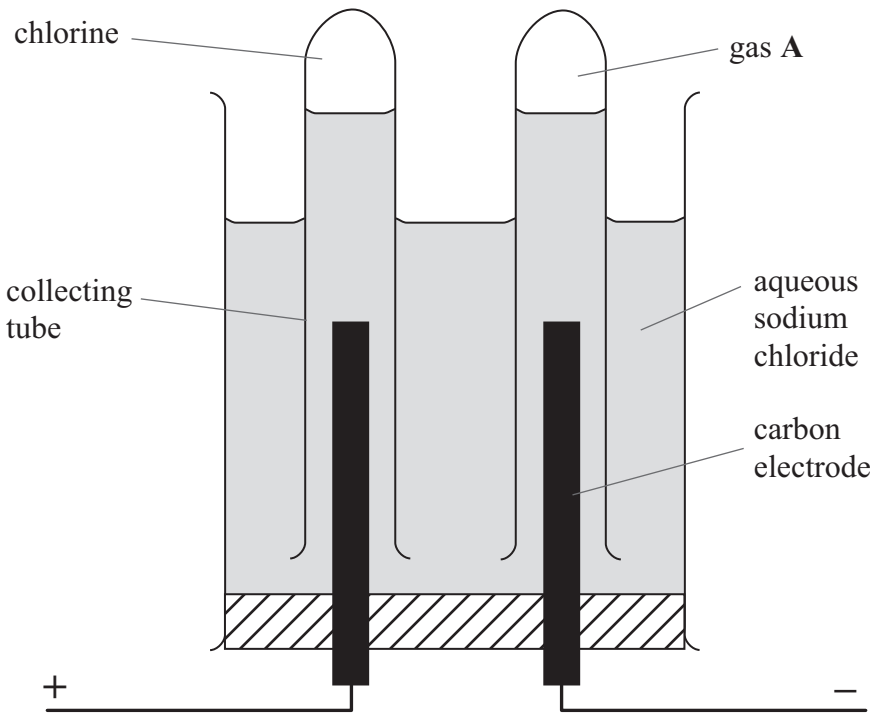
Give the unit in your answer.

(2)

volume of chlorine = ... unit .....

(Total for Question 3 = 11 marks)

4 The apparatus shown can be used to electrolyse aqueous sodium chloride in the laboratory.



(a) Gases are evolved at both electrodes.

(i) Describe a chemical test to show that the gas evolved at the positive electrode is chlorine.

(2)

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.....

.....

(ii) Identify gas **A**.

(1)

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(b) Some of the solution formed after the electrolysis was tested with the indicator phenolphthalein. The indicator turned pink

Explain this result.

(1)

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.....

(c) The equation for the reaction taking place at the positive electrode is:

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

Ten faradays (10 F) of electricity were passed through an aqueous solution of sodium chloride.

(i) Calculate the amount, in moles, of chlorine formed.

(1)

(ii) Calculate the volume of chlorine formed.

(One mole of a gas occupies 24 dm^3 at this temperature and pressure)

(2)

(Total for Question 4 7 marks)

5 Iron and aluminium are two important metals extracted from their ores on a large scale.

(a) In the extraction of iron, three different raw materials are put into the top of a blast furnace.

Name the main compound present in the following raw materials.

(i) Haematite

(1)

.....

(ii) Limestone

(1)

.....

(b) The following equations represent reactions in the blast furnace.

A $C + O_2 \rightarrow CO_2$

B $CaCO_3 \rightarrow CaO + CO_2$

C $C + CO_2 \rightarrow 2CO$

D $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

E $CaO + SiO_2 \rightarrow CaSiO_3$

Choose from the letters **A**, **B**, **C**, **D** or **E** to answer parts (i) – (iv).

Each letter may be used once, more than once or not at all.

(4)

(i) A reaction that is used to produce heat .....

(ii) A neutralisation reaction .....

(iii) A decomposition reaction .....

(iv) A reaction that forms a reducing agent .....

(c) Molten iron and another molten substance collect at the bottom of the blast furnace.

What is the common name of this other molten substance?

(1)

.....

(d) Aluminium is extracted from its ore by electrolysis. This is a more expensive process than using a blast furnace.

(i) Why is a different method used for aluminium?

(1)

.....

.....

(ii) State the major reason for the high cost of extracting aluminium.

(1)

.....

.....

(e) Coke used in the blast furnace contains carbon. Carbon is also used in the extraction of aluminium, but for a different purpose.

What is this purpose?

(1)

.....

.....

(f) The extraction of aluminium can be represented by the chemical equation:

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

Write the two ionic half-equations that can also be used to represent this extraction.

(3)

Half-equation 1 .....

Half-equation 2 .....

(Total for Question 5 = 13 marks)