Cambridge Assessment International Education

Teaching Pack

The electrolysis of acidified water using a Hofmann voltameter

Cambridge International AS & A Level Chemistry 9701

Version 1

Cambridge Pathway

Contents

Icons used in this pack:

Briefing lesson

Planning lesson

Lab lesson

Debriefing lesson

Introduction

This pack will help you to develop your learners' experimental skills as defined by assessment objective 3 (AO3 Experimental skills and investigations) in the course syllabus.

> **Important note**
> Our *Teaching Packs* have been written by **classroom teachers** to help you deliver topics and skills that can be challenging. Use these materials to supplement your teaching and engage your learners. You can also use them to help you create lesson plans for other experiments.
>
> ***This content is designed to give you and your learners the chance to explore practical skills. It is not intended as specific practice for Paper 3 (Advanced Practical Skills) or Paper 5 (Planning, Analysis and Evaluation).***

This is one of a range of *Teaching Packs* and each pack is based on one experiment. The packs can be used in any order to suit your teaching sequence.

The structure is as follows:

Briefing lesson (1 hour*)
This lesson reinforces the key concepts, relevant skills, knowledge and understanding linked to the experiment.

↓

Planning lesson (1 hour*)
This lesson focuses on planning an experiment.
It ends with a demonstration video of the experiment.

↓

Lab lesson (1 hour*)
This lesson focuses on carrying out the experiment including the collection and recording of observations, measurements and estimates.

↓

Debriefing lesson (1 hour*)
This lesson focuses on the analysis and interpretation of data.
This includes making conclusions, evaluating methods and the quality of data and how improvements could be made.

** the timings are a guide only; you may need to adapt the lessons to suit your circumstances.*

In this pack you will find lesson plans, worksheets and teacher resource sheets.

Experiment: The electrolysis of acidified water using a Hofmann voltameter

This *Teaching Pack* focuses on an electrolysis experiment.

Electrolysis employs electricity to cause a non-spontaneous reaction to occur in molten or aqueous electrolytes. It results in substances being split up into simpler components.

This experiment has links to the following syllabus content (see syllabus for detail):

- 24.1 Electrolysis

The experiment covers the following experimental skills, as listed in **AO3: Experimental skills and investigations:**

- Plan experiments and investigations
- Collect, record and present observations, measurements and estimates
- Analyse and interpret data to reach conclusions
- Evaluate methods and quality of data and suggest improvements.

Prior knowledge

Knowledge from the following syllabus topics is useful for this experiment.

- 3 Chemical bonding
- 2 Atoms, molecules and stochiometry

Briefing lesson: Background knowledge quiz

Resources	• Worksheet A and corresponding answer sheet

Learning objectives	By the end of the lesson: • all learners should be able to answer questions 1–7 with minor assistance. • most learners should be able to answer questions 1–7 of the quiz questions correctly without assistance. • some learners will be able to answer all the quiz questions correctly, including question 8 about aqueous electrolysis.

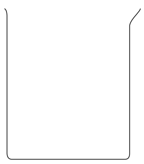
Timings	Activity
10 min	**Starter/Introduction** Ask learners to reflect on what they can remember about electrolysis from previous learning. They could for example try to draw a concept map. **Please note** that there is an electrolysis experiment in Resource Plus for Cambridge IGCSE Chemistry 0620. Ask if any of the learners can define electrolysis? [It is the chemical decomposition of a substance caused by passing an electric current through it]
35 min	**Main lesson** Learners may have a significant difference in their background knowledge regarding electrolysis. The focus of this lesson is to ensure that by the end of it, learners know the rudimentary terms and understand the basic ideas surrounding this topic. Divide learners into pairs for the following activity. Handout Worksheet A which is a series of quiz questions. **Questions 1–7** Most learners should find questions 1–7 quite straight forward. In question 5 you may wish to expand on the answer. Most metals can be produced by electrolysis but only some are. Aluminium is a reactive metal and can only be produced this way economically. Iron could be produced by electrolysis, but it is not since it is much more economically viable to obtain it by extraction from its ores. In question 6 some learners may write ‘Cl’ instead of ‘Cl_2’ as the formula for one of the electrode products. You may wish to discuss half-equations for reactions at this stage, but half-equations are discussed in the Debriefing lesson later on. **Question 8** This sub-topic may not be so well remembered or understood by learners. Regarding the electrolysis of aqueous solutions, learners may need some extra input to bring them all to a similar level of understanding.

Timings	Activity
	It is essential that learners appreciate that, since H^+ and OH^- ions are also present in the electrolyte, preferential discharge occurs at the anode and cathode. The rules are summarised on the answer sheet.
15 min	**Plenary** Handout Worksheet A - answers. Go through each answer highlighting the rules in question 8.

Planning lesson: Planning an aqueous electrolysis

Resources	• Sheets B and corresponding answer sheet B • Display the equipment as in the sheet above if available

Learning objectives	By the end of the lesson: • ***all*** learners should be able to draw the set-up correctly with some guidance. They should be able to offer basic annotations suggesting the functions of the equipment used. • ***most*** learners should be able to will be able to draw a scientific diagram of the apparatus correctly and annotate it with only a few mistakes • ***some*** learners will be able to draw a scientific diagram of the apparatus correctly and annotate it fully in correct English

Timings	Activity
5 min	**Starter/Introduction** Before handing out/ displaying the equipment for the exercise below, elicit from learners what equipment would be necessary to carry out the electrolysis experiment.
30 min	**Main lesson** Learners can work in pairs to complete this planning activity. Handout Worksheet B If the equipment is available is would be beneficial to learners to display it at the front of the class for reference. At this stage of their Chemistry education, learners should be aware of how to draw simple scientific apparatus For example: a beaker =  The sheet requires learners not only do draw and name the equipment, but to fully annotate the functions of each in English.
10 min	**Plenary** Handout or project answer Worksheet B - answers, so that learners can check their plan. Check that learners have used the correct English in their annotations. The answer sheet gives guidelines only and answers may vary. Ensure that learners have drawn the diagram as if viewed from the side. Sometimes learners waste time drawing artistic 3-D diagrams. Do not accept beakers drawn without a ruler.

Lab lesson: The electrolysis of acidified water using a Hofmann voltameter

Resources	• Equipment as described in the Teacher notes • Worksheet C and Worksheet C answers

Learning objectives	By the end of the lesson: • ***all*** learners should be able show that they appreciate that the stochiometric gas volume ratio of hydrogen:oxygen is 2:1 by being able to answer questions 1–5 on worksheet C correctly. • ***most*** learners should be able to demonstrate competence in understanding of the experiment, practically and theoretically by being able to answer most of the questions 1–7 on Sheet C correctly. • ***some*** learners will be able to demonstrate full understanding of the experiment, practically and theoretically by answering all the questions, 1–7 on Sheet C correctly.

Timings	Activity
5 min	**Starter/Introduction** Explain to learners that they are going to watch and take part in a demonstration to electrolyse acidified water. [note that this experiment is often described as the electrolysis of water – however, since the self-ionisation of water produces such a small quantity of ions, pure water alone cannot be used]. Thus, 'The electrolysis of acidified water' is a more accurate description. Since the acid normally used is sulfuric acid, the title of the experiment could also be described 'The electrolysis of dilute sulfuric acid'. In this experiment, the apparatus used will be different from what learners planned in the previous section. The reason they will use a Hofmann voltameter is mainly because they are going to estimate the volume of gases, collect and test them. Since most schools have only one Hofmann voltameter, this is most likely to be a demonstration experiment in which learners can take an active part.
20 min 20 min	**Main lesson** Seat learners in clear view of the Hofmann voltameter. Explain to them that they should observe carefully and ask questions during the experiment. Ask for assistance in setting up the external circuit and elicit from learners which metal the electrodes might be made from and why. Fill the central reservoir with dilute sulfuric acid in front of learners so they can see how this is done and explain that this is the 'acidified water'. After the experiment is finished, handout question Worksheet C. Learners can work in pairs to answer the questions.
	Plenary

Timings	Activity
15 min	Handout Worksheet C - answers. If any difficulties are encountered, they will most likely be with questions 4 and 6, and so extra guidance and explanation may be necessary.

Teacher notes

Watch the 'Electrolysis of acidified water using a Hofmann voltameter' (teacher version) and read these notes.

This demonstration will require:

- A Hofmann voltameter equipped with platinum electrodes
- 1 mol dm^{-3} sulfuric acid (acidified water). Enough to fill the apparatus
- DC power supply set to 12V
- Connecting leads and crocodile clips
- A clamp stand to hold the voltameter securely
- 2 x test tubes
- A splint and matches
- A short length of rubber tube (to fit onto the apparatus to direct gas into a test tube).

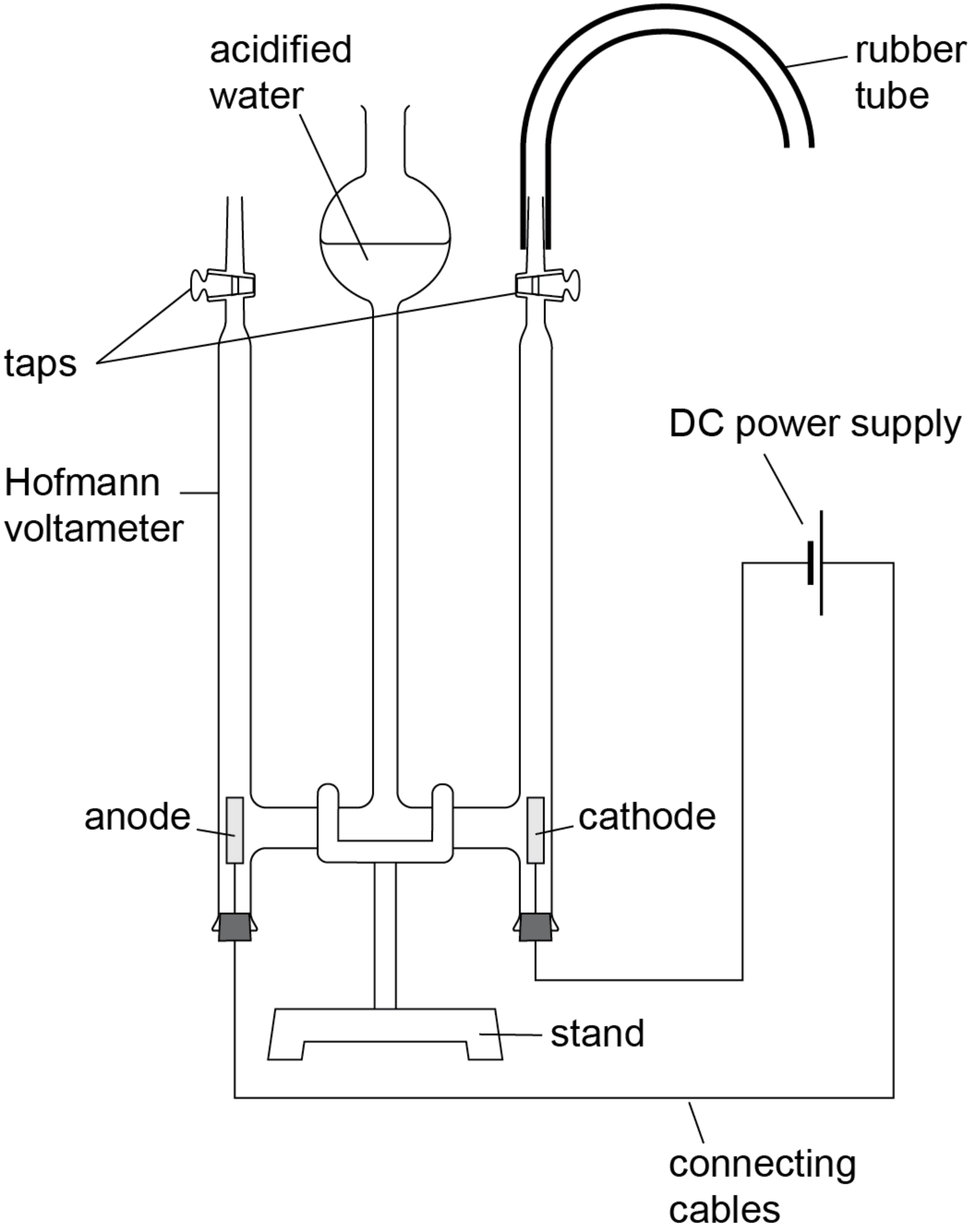
Safety

The information in the table below is a summary of the key points you should consider before undertaking this experiment with your learners.

It is your responsibility to carry out an appropriate risk assessment for this experiment.

Substance	Hazard	First aid
Sulfuric acid (1 mol dm^{-3})	 GHS07 (*moderate hazard* **MH**)	**In the eye:** flood the eye with gently-running tap water for at least 10 minutes. See a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Sips of water may help cool the throat and help keep the airway open. See a doctor. **Spilt on the skin or clothing:** remove contaminated clothing and rinse it. Wash off the skin with plenty of water. **Spilt on the floor, bench, etc.** Wipe up small amounts with a damp cloth and rinse it well. For larger amounts, and especially for (moderately) concentrated acid, cover with mineral absorbent (e.g, cat litter) and scoop into a bucket. Neutralise with sodium carbonate. Rinse with plenty of water.
Naked flame (matches)	Since a match will be used to light splints in this experiment ensure that there are no flammable organic substances nearby	

Experiment set-up



Teacher method

This is your version of the method for this experiment that accompanies the *Teacher walkthrough* video.

Do not share this method with learners.

Before you begin

Plan where you will seat your learners so that they can clearly observe this demonstration experiment.

Experiment

Before you start make sure that the bungs carrying the platinum electrodes are firmly in place.

Steps	Notes
1. Fill the Hofmann voltameter with 1 mol dm^{-3} sulfuric acid through the central reservoir at the top of the apparatus.	*There is no need to explain what concentration the acid is. The only important detail for learners to grasp is that pure water will not undergo electrolysis.* *It is good to do this in the presence of learners, but make sure none are seated too close in case any spillages occur.*
2. Connect a red cable from one of the electrodes to the positive terminal of the power supply set to 12V. Connect the other lead to the other electrode.	It is not essential to use red and black leads – this is just convention and nice if you have them.
3. Switch the power on (set to 12V).	*Bubbles should be formed at both electrodes. Discuss the rate of production of bubbles with learners.*
4. After discussing the rate of bubble formation at each electrode, leave the electrolysis to run for a few minutes.	
5. Shift learners' focus to the volumes of gas produced at the top of the apparatus.	The volume ratio at the top of the apparatus anode: cathode should be 1:2. This can be estimated or done using a ruler.
6. Collect the gas at the cathode: place an inverted test tube over the tap at the cathode.	The gas will be collected using this inverted test tube because hydrogen is much less dense than air and will displace the air in it. Be careful to open the tap slowly, else dilute acid will come out of the tap.
7.Test this gas: place a lighted splint under the inverted test tube. A characteristic squeaky pop should be heard.	Make sure that there are no organic solvents close by. Make sure that the splint is extinguished afterwards.

Steps	Notes
8. Collect the gas formed at the anode: place the tube in a test tube and turn the tap carefully.	The gas will displace the air in the tube. Be careful to open the tap slowly, else dilute acid will come out of the tap.
9. Test this gas: plunge a glowing splint into the tube. The splint relights	Make sure that the splint is extinguished afterwards.

Clean-up

After the experiment learners should:

- empty chemical waste into the main chemical waste bottle in a central location.

Debriefing lesson: Quantitative electrolysis

Resources	• Worksheet D and corresponding answer sheet
Learning objectives	By the end of the lesson: • ***all*** learners should be able to solve the calculations with stepwise guidance. • ***most*** learners should be able to solve the calculations with limited assistance. • ***some*** learners will be able to solve all the calculations correctly without assistance.

Timings	Activity
5 min	**Starter/Introduction** Open with a discussion with learners about how they know what the products of the electrolysis were and what the significance of the experiment was. [Learners will hopefully mention the volume ratio of gases and tests for hydrogen and oxygen.] Ask learners if there is another way that they can theoretically show that the volume ratio of hydrogen to oxygen must be 2:1. Lead the discussion in the direction of half-equations for the reactions at the electrodes.
45 min	**Main lesson** The focus of this lesson is for learners to extend their qualitative treatment regarding the Hofmann voltameter experiment in the previous lab section, to quantitative chemistry considerations detailed in the Chemistry course syllabus. Handout Worksheet D. Learners can work in pairs for this activity. Though able learners may be able to complete this sheet independently, it is intended that you will provide significant guidance for most learners. In question 1, learners construct half-equations for the reactions which occur at the electrodes during the electrolysis using the Hofmann voltameter. Despite having probably come across the reaction at the anode before, learners may still need help developing this. One way of doing this could be to partially construct the equation for them: $OH^- \longrightarrow O_2$ At the cathode water molecules are stripped of their hydrogen ions, which are then discharged, releasing hydrogen molecules and hydroxide ions $2H_2O(l) + 2e^- = H_2(g) + 2OH^-(aq)$ Water molecules at the anode yield up their hydroxide ions, which are discharged as oxygen, while releasing the remaining hydrogen ions into solution. $2H_2O(l) = O_2(g) + 4H^+(aq) + 4e$

Timings	Activity
	Please note: the equations used in the video are the correct equations at this level.**** Question 3a develops ideas/ revise quantitative aspects of electrolysis as described in the syllabus. If learners are doing this for the first time, they may need considerable teacher input. Question 3b is like part a., in that it asks learners to find the volume of oxygen produced in the experiment. Learners should therefore need less teacher input this time. Question 3c: it is probable that the calculated value of $150cm^3 : 75cm^3 = 2 : 1$, will be the same (or approximately so) as the ratio found by experiment in the previous section. If the class demonstration did not yield similar results, you will need to explain what should have happened or show the video of this experiment showing the 2:1 ratio of gases. Question 4 uses the same ideas in reverse. In this question it may be necessary to guide learners to the half-equation to get them started. Once they have calculated the charge needed, they can use the equation. $Q = I \times t$
10 min	**Plenary** Handout Worksheet D - answers to learners. Ensure that learners have included and used units correctly and that they have shown each step of their calculations clearly. Finish by explaining that in electrolyses where the products are non-gaseous, similar calculations can be performed, but this time regarding the masses of substances formed. The example of the familiar electrolysis of copper (II) sulfate could be sited, in which copper is deposited at the cathode.

Worksheets and answers

	Worksheet	Answers
For use in *Briefing lesson*:		
A: Quiz questions	**18**	**25**
For use in *Planning lesson*:		
B: Design an experiment to electrolyse a dilute sulfuric acid	**20**	**27**
For use in *Lab lesson*:		
C: Questions about the electrolysis	**22**	**28**
For use in *Evaluation lesson*:		
D: Quantitative Electrolysis	**24**	**30**

Worksheet A: Quiz questions

Answer the following questions to help refresh your mind about electrolysis.

1.
   a. What are the names and charges of the 2 electrodes used in electrolysis?

   b. Which non-metal are they made from?

2. In an electrolysis experiment, the external circuit consists of a power supply, connecting leads, electrodes and sometimes a bulb and/or an ammeter.

   What travels round the external circuit?

3.
   a. What is the name of the melt or aqueous solution which is electrolysed?

   b. Which species move within it?

   c. What type of chemical bonding exists in a molten electrolyte?

   d. Why do these materials, in c. above, usually have high melting points?

4. What effect does an increase of the electric current have in an electrolysis experiment?

Worksheet A: Quiz questions, *continued*

5.

a. Name a metal which is usually produced by electrolysis.

b. Name a metal not produced by extraction from its ores.

6. Give the chemical formulae of the following substances and the formulae of the products formed after electrolysis of their molten salts.

a. Lithium chloride

b. Lead bromide

c. Aluminium oxide

d. Zinc chloride

7. In aqueous electrolyses, which additional ions are present in the electrolyte and where do they come from?

8. Detail the rules that determine which ions are preferentially discharged at each electrode during an aqueous electrolysis?

Worksheet B: Design an experiment to electrolyse a dilute sulfuric acid solution

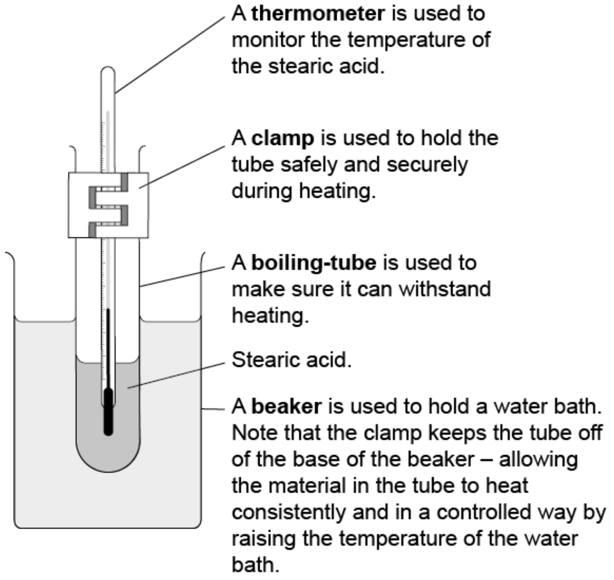
This is the list of equipment and materials you would require for the experiment.

$50 cm^3$ $0.1 mol dm^{-3}$ sulfuric acid	a $100 cm^3$ glass beaker	2 x carbon electrodes	2 x crocodile clips
connecting cables	a bulb	a DC power supply set to 12V	an ammeter

Tasks

1. Use the example given for reference and draw how you think the experiment should be set-up safely.
2. Annotate each piece of equipment, explaining the function of each in short, clear sentences.

Example



Worksheet B: Design an experiment to electrolyse a dilute sulfuric acid solution, *continued*

Worksheet C: Questions about the electrolysis

Answer the following questions as you watch the electrolysis.

1. a. Which material is used for the electrodes?

b. What is the reason for its choice?

2. Why can the electrolysis not proceed without the presence of a small quantity of sulfuric acid in the electrolyte?

3.

a. As soon as the power is switched on, what do you observe at both electrodes?

b. At which electrode is the production of gas greatest?

c. What is the stochiometric ratio of the two gases?

4.

a. List all the ions present in the Hofmann voltameter

b. Which of these is present in the smallest quantity?

Worksheet C: Questions about the electrolysis, *continued*

5. Describe each of the qualitative tests and the results obtained.

i. at the anode

ii. at the cathode

6.

a. In what way does the electrolyte change chemically as the electrolysis proceeds?

b. How might we show this change?

7. How does this experiment show that the formula of water must be H_2O?

Worksheet D: Quantitative electrolysis

Answer the following questions using the following data where necessary: I Faraday (F) = 96,500 Coulombs, the volume of a gas at r.t.p. = 24dm^3.

1. Write half-equations for the reactions which occur at each electrode, during the electrolysis of acidified water.

a. at the anode:

b. at the cathode:

2. Which three factors control the amount of product formed/amount of gas produced at the electrodes during electrolysis?

3

a. In the electrolysis of acidified water using a Hofmann voltameter, calculate the volume of hydrogen produced (at r.t.p) if a current of 2A is passed for 10 minutes.

b. Consider the same electrolysis in which the same current is passed for the same time as in part a, above, find the volume of oxygen produced.

c. Compare the values obtained in a. and b. and comment on their significance in relation to the volume ratio in the main lab experiment.

4. How long, in minutes, would it take to release 2dm^3 of hydrogen gas (at r.t.p) during the electrolysis of dilute sulfuric acid if the current passed was 1.3A.

Worksheet A: Answers

Answer the following questions to help refresh your mind about electrolysis.

1.

   c. What are the names and charges of the 2 electrodes used in electrolysis?

   Anode, positively charged

   Cathode, negatively charged

   d. Which non-metal are they made from? *Carbon/graphite*

2. In an electrolysis experiment, the external circuit consists of a power supply, connecting leads, electrodes and sometimes a bulb and/or an ammeter.

   What travels round the external circuit? *electrons*

3.

   c. What is the name of the melt or aqueous solution which is electrolysed? *electrolyte*

   d. Which species move within it? *Ions/ anions and cations*

   e. What type of chemical bonding exists in a molten electrolyte? *Ionic bonding*

   d. Why do these materials in c. above, usually have high melting points? *Because ionic bonds are usually very strong.*

4. What effect does an increase of the electric current have in an electrolysis experiment?

   This would increase the rate of electrolysis meaning that the products would be produced more quickly.

5.

   a. Name a metal which is usually produced by electrolysis. *Aluminium, zinc*

   b. Name a metal not produced by extraction from its ores. *Iron, copper*

6. Give the chemical formulae of the following substances and the formulae of the products formed after electrolysis of their molten salts.

   a. Lithium chloride *$LiCl$/ Li and Cl_2*

   b. Lead bromide *$PbBr_2$ / Pb and Br_2*

Worksheet A: Answers, *continued*

c. Aluminium oxide Al_2O_3/ Al and O_2

d. Zinc chloride $ZnCl_2$ / Zn and Cl_2

7. In aqueous electrolyses, which additional ions are present in the electrolyte and where do they come from?

   Hydrogen ions (H^+) and hydroxide ions (OH^-) which are due to the very slight dissociation of water molecules.

8. Detail the rules that determine which ions are preferentially discharged at each electrode during an aqueous electrolysis?

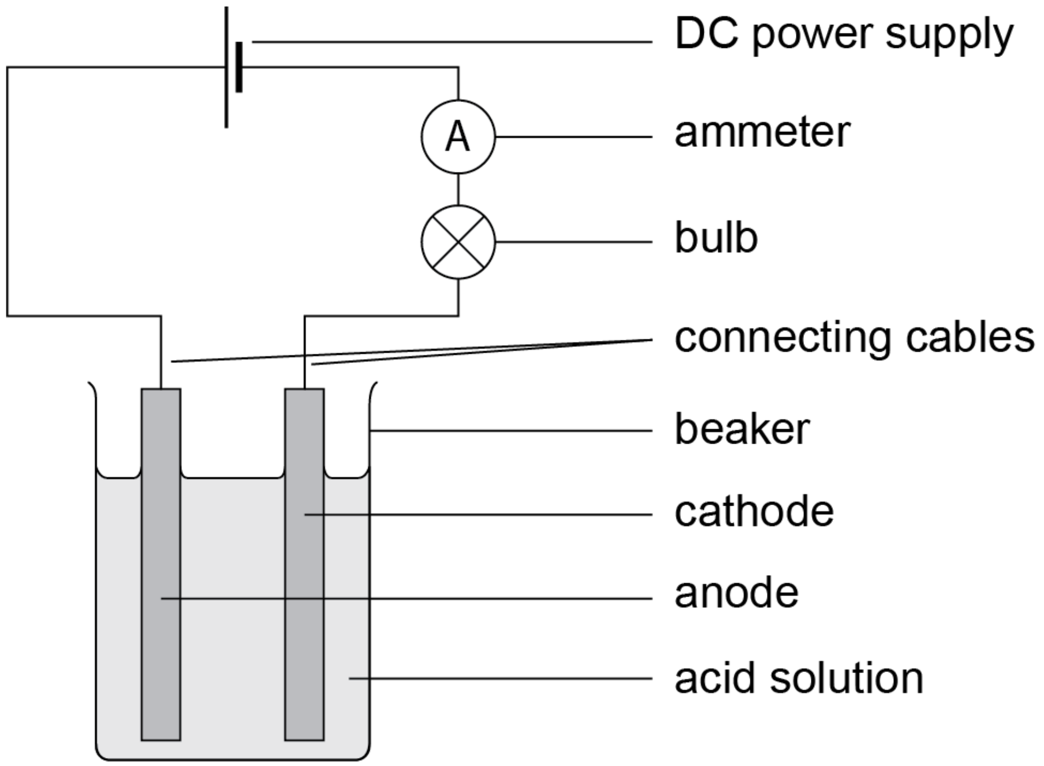
Rule 1: if a halide is present (chloride, bromide or iodide) and the solution is concentrated, the halogen is discharged at the anode.

Rule 2: if a halide is present (chloride, bromide or iodide) but the solution is dilute, oxygen is preferentially discharged.

Rule 3: In an aqueous electrolysis, with metal ions present and the metal ions are less reactive than hydrogen in the reactivity series, the metal is discharged eg. Copper

If the metal is a reactive metal, above hydrogen in the reactivity series, hydrogen ions are discharged instead, producing hydrogen gas at the cathode.

Worksheet B: Answers



Anode – this is the positive electrode to which negative ions migrate during electrolysis

Cathode – this is the negative electrode to which positive ions migrate during electrolysis

DC power supply – this supplies the electric current necessary to cause the non-spontaneous reaction to occur at the electrodes

Connecting cables – these connect the elements of the external circuit together

A bulb – a lit bulb may be used to show that the circuit is functioning properly

An ammeter – this may be used to show the size of the current flowing

The acid solution – this is the electrolyte

The glass beaker – the vessel used to hold the electrolyte

Worksheet C: Answers

Answer the following questions as you watch the electrolysis.

1.

a. Which material is used for the electrodes? *Platinum*

b. What is the reason for its choice? *Platinum is an unreactive (inert) metal*

2. Why can the electrolysis not proceed without the presence of a small quantity of sulfuric acid in the electrolyte?

The self-ionisation of pure water produces only an extremely small quantity of ions. This quantity is too small to allow significant conductivity. In other words, pure water cannot function as an electrolyte on its own. Adding a small amount of the fully dissociated acid sulfuric acid, makes the electrolyte a much better conductor.

3.

a. As soon as the power is switched on what do you observe at both electrodes? *Bubbles of gas are produced.*

b. At which electrode is the production of gas greatest? *It is greatest at the negative cathode.*

c. What is the stochiometric ratio of the two gases? *The ratio is hydrogen: oxygen 2:1*

4.

a. List all the ions present in the Hofmann Voltameter. H^+, SO_4^{2-}, OH^-

b. Which of these is present in the smallest quantity? *OH-*

5. Describe each of the qualitative tests and the results obtained.

i. at the anode

Oxygen is evolved. The gas is slightly denser than air and is collected by displacement of air using a downward facing tube. The gas is tested with a glowing splint. The splint relights confirming oxygen.

Worksheet C: Answers, *continued*

ii. at the cathode

Hydrogen is evolved. This gas is less dense than air and can be collected in an inverted test tube. A squeaky pop results from a lighted splint being brought close to it.

6.

a. In what way does the electrolyte change chemically as the electrolysis proceeds?

The sulfuric acid in the electrolyte become slightly more concentrated. This is because the hydrogen and oxygen which were evolved at the electrodes are effectively the removal of water from the electrolyte.

b. How might we show this change?

A sensitive pH meter/ a conductivity meter [accept sensitive pH paper]

7. How does this experiment show that the formula of water must be H_2O?

Since two volumes of hydrogen are produced for every volume of oxygen

Worksheet D: Answers

1. Write half-equations for the reactions which occur at each electrode, during the electrolysis of acidified water.

a. at the anode: $4OH^{-}_{(aq)} \longrightarrow O_{2(g)} + 2H_2O_{(l)} + 4e^{-}$

b. at the cathode: $2H^{+}_{(aq)} + 2e^{-} \longrightarrow H_{2(g)}$

2. Which three factors control the amount of product formed/amount of gas produced at the electrodes during electrolysis?

- *the charge on the ions*
- *the magnitude of the electric current*
- *the time the current passes for*

3

a. In the electrolysis of acidified water using a Hofmann voltameter, calculate the volume of hydrogen produced (at r.t.p.) if a current of 2A is passed for 10 minutes.

Total charge passed, Q = I x t = 2A x (10 x 60)s = 2 x 600 = 1200 Coulombs

The half-equation for the reaction at the cathode:

$2H^{+}_{(aq)} + 2e^{-} \longrightarrow H_{2(g)}$

From this, 2mol electrons produces 1mole of H_2

Now 2 mol of electrons = 2 Faradays

So, 2 x 96500 coulombs produces $24dm^3$ H_2

In the experiment, only 1200Coulombs was used

Therefore:

1200 x 24/193,000

= $0.15dm^3$ *=* **$150cm^3$** *hydrogen produced*

b. Consider the same electrolysis in which the same current is passed for the same time as in part a, above, find the volume of oxygen produced.

Charge passed = 1200 coulombs

Worksheet D: Answers, *continued*

$4OH^-_{(aq)} \longrightarrow O_{2(g)} + 2H_2O_{(l)} + 4e^-$

From the half-equation:

To produce 1 mole of oxygen, 4 moles of electrons are produced

So, producing 1 mole of oxygen releases: 4 x 96500 = 386,000 coulombs

With respect to the charge passed in this experiment:

1200 x 24/386,000 = 0.075dm³ = **75cm³** oxygen produced

c. Compare the values obtained in a. and b. and comment on their significance in relation to the predicted volume ratio in the main lab experiment.

The ratio of hydrogen to oxygen produced = 150cm³ : 75cm³ = 2 : 1

This calculation supports the qualitative findings in the main lab experiment.

4. How long, in minutes, would it take to release 2 dm³ of hydrogen gas (at r.t.p) during the electrolysis of dilute sulfuric acid if the current passed was 1.3A.

$2H^+_{(aq)} + 2e^- \longrightarrow H_{2(g)}$

From the equation, 2 mol e^- produces 1 mol of hydrogen

2mol of e^- = 2 x 96,500 = 193,000 Coulombs

Thus, 193,000 Coulombs of charge produces 1mol of hydrogen = 24dm³

But, only 2dm³ of hydrogen is released, therefore:

x/193000 = 2/24

x = 2 x 193,000/24 = 16,083 Coulombs charge required

Q = I x t

16,083 = 1.3 x t

16,083/1.3 = 12, 372s = **206 mins**

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