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VCE Chemistry ¾
Introduction to Electrolysis [0.12]
Workshop Solutions

Error Logbook:

New Ideas/Concepts	Didn't Read Question
Pg / Q #: _____ Notes:	Pg / Q #: _____ Notes:
Algebraic/Arithmetic/ Calculator Input Mistake	**Working Out Not Detailed Enough**
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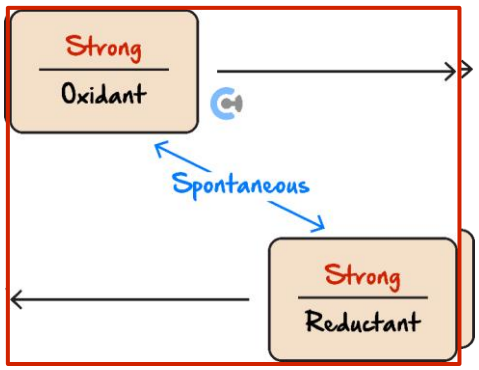
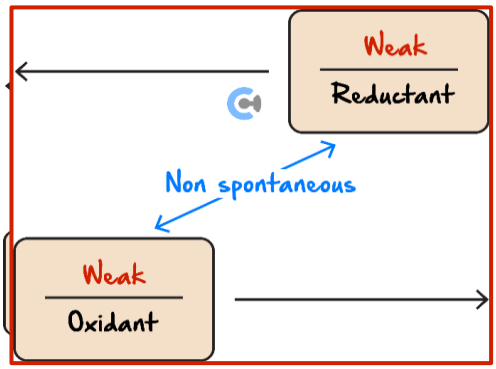
Section A: Recap (5 Marks)

Learning Objective: [2.1.1] – Identify differences between galvanic & electrolysis for electrodes, energy conversions, and electron flow

	Galvanic Cells	Electrolytic Cells
Spontaneous Reaction	[Yes] / [No]	[Yes] / [No]
Energy Conversion	Chemical → Electrical	Electrical → Chemical
Type of Reaction	[Exothermic] / [Endothermic]	[Exothermic] / [Endothermic]
Oxidant / Reductant Relative Strength		
Electron Flow	Anode → Cathode	Anode → Cathode
Anode	AO –	AO +
Cathode	RC +	RC –
Salt-Bridge / Electrolyte Ion Flow	Cations → [cathode] / [anode]	Cations → [cathode] / [anode]

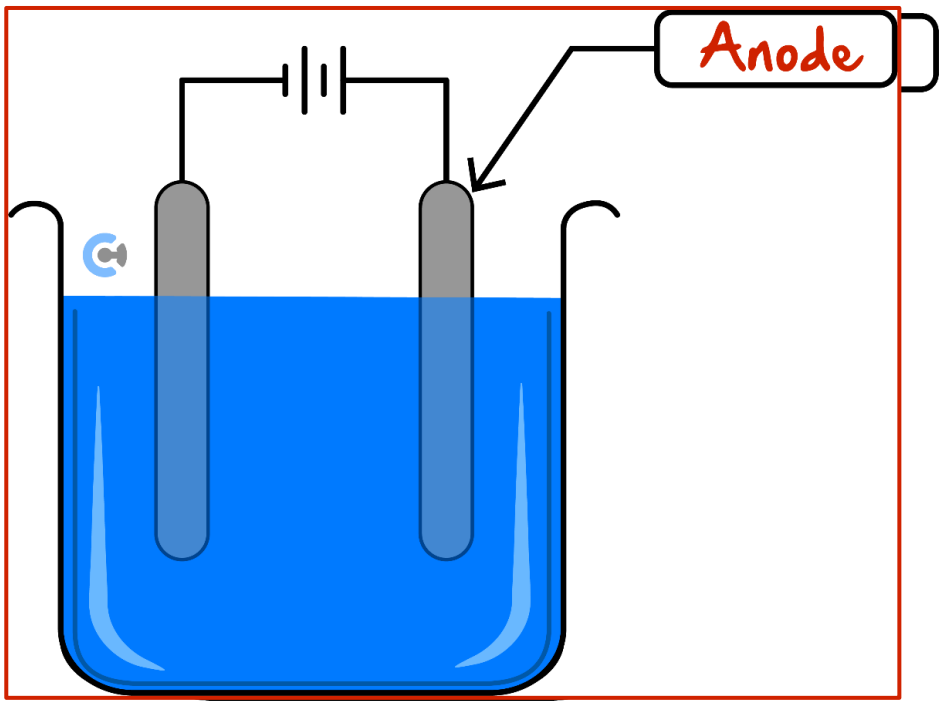
Learning Objective: [2.1.2] – Write equations & calculate EMF required for electrolytic reactions

- When predicting electrolytic reactions, do not forget to include ___ water ___.
- Metals at the cathode are ___ unreactive ___.
- Voltage required is _____ greater than the difference _____.

Question 1 (5 marks) **Walkthrough.**

A cell involves the electrolysis of a solution of nickel (II) nitrate with a tin cathode and copper anode.

The diagram of the cell is shown below.



a. Label the right electrode as the cathode or anode in the diagram provided above. (1 mark)

b. Write the balanced half-equation for the reaction which occurs at the: (2 marks)

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

Negative electrode: $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

c. As the reaction progresses, multiple observations are seen to occur.

$$Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$$

List **two** observations which occur in the electrolyte. Justify your answer. (2 marks)

Intensity of the blue colour of the electrolyte increases due to formation of copper (II) ions.

pH increases due to hydroxide forming.

Section B: Warm Up (12 Marks)

INSTRUCTION: 12 Marks. 8 Minutes Writing.

Question 2 (2 marks)

Complete the following table regarding the **type of reaction** occurring and the **polarity** for each electrode.

	Galvanic Cells	**Electrolytic Cells**
Anode	[reduction] / [oxidation] [positive] / [negative]	[reduction] / [oxidation] [positive] / [negative]
Cathode	[reduction] / [oxidation] [positive] / [negative]	[reduction] / [oxidation] [positive] / [negative]

Question 3 (1 mark)

Which statement is true for both a galvanic cell and an electrolytic cell?

A. Oxidation occurs at the negative electrode.

B. The anode is negatively charged.

C. The strongest oxidant will react with the weakest reductant.

D. Electrons flow from the anode to the cathode.

Space for Personal Notes

Question 4 (1 mark)

Select the alternative that would only react in an electrolytic cell.

A. $Zn(s) + AgNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + Ag(s)$

B. $Mg(s) + H_2O(l) \rightarrow Mg(OH)_2(aq) + H_2(g)$

C. $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

D. $Cl_2(g) + FeI_2(aq) \rightarrow FeCl_2(aq) + I_2(g)$

Question 5 (1 mark)

Inspired from VCAA Chemistry Exam 2021
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2021/2021chem-w.pdf#page=4

Consider the following characteristics of electrolytic cells and galvanic cells:

Characteristic Number	Electrolytic Cells	Galvanic Cells
1	Cathode is negative.	Cathode is positive.
2	Have non-spontaneous reactions.	Have spontaneous reactions.
3	Reduction occurs at the anode.	Reduction occurs at the cathode.
4	Produce electricity.	Consume electricity.

Which of the following combinations of characteristics of electrolytic cells and galvanic cells are correct?

A. Only 1 and 2.

B. Only 2 and 3.

C. Only 3 and 4.

D. Only 1, 2, and 4.

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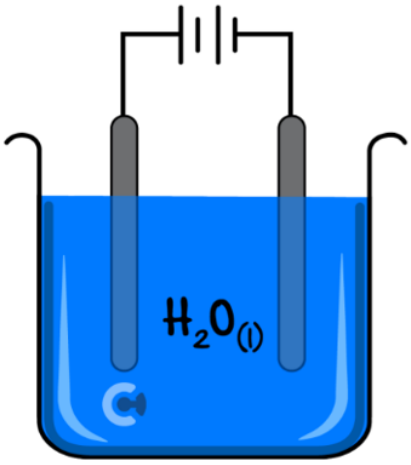
Question 6 (7 marks)

Electricity is run through some water according to the following setup using inert electrodes.



a.

i. State whether the left electrode is the anode or the cathode. (1 mark)

Anode

ii. Hence, write the appropriate half-equation occurring at the positive electrode. (1 mark)

Oxidation: $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$

b. Write the other half-equation occurring in this cell. (1 mark)

Reduction: $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

c. Hence, list 3 things that would be observed as this cell operates. (3 marks)

1.

2.

3.

- Bubbles produced at the positive electrode/anode ($O_2(g)$).
- Bubbles produced at the negative electrode/cathode ($H_2(g)$).
- Overall volume of solution would decrease (can also say how pH changes at each electrode and/or no pH change overall though).

d. Find the voltage which needs to be inputted for the electrolytic cell to operate. (1 mark)

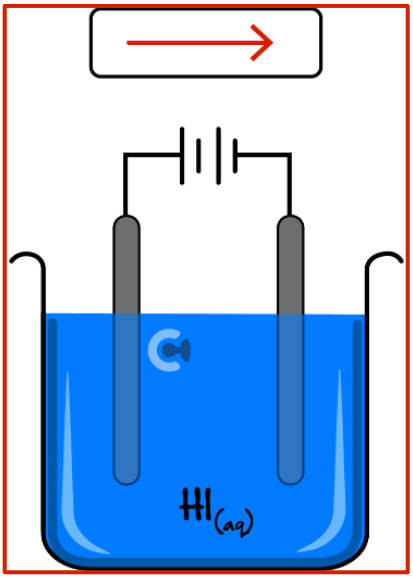
$-0.83 - 1.23 = -2.06\ V$
$> 2.06\ V$ needed.

Section C: Ramping Up (14 Marks)

INSTRUCTION: 14 Marks. 11 Minutes Writing.

Question 7 (8 marks)

The following cell was set up by Athena using platinum electrodes. She inputs a voltage of 2 V.



a. Label the direction of electron flow by placing an arrow in the box above. (1 mark)

b. Write the relevant balanced anode half-equation occurring. (1 mark)

$2I^-(aq) \rightarrow I_2(s) + 2e^-$

c. Write the balanced overall equation taking place in this cell. (1 mark)

$2HI(aq) \rightarrow I_2(s) + H_2(g)$

d. State the minimum voltage required to be inputted for the cell to operate. Hence, explain whether a reaction will occur, given Athena has inputted 2 V and state any other observations that would be made due to this. (2 marks)

$> 0.54\ V$. As she has inputted 2 V, which is greater than 0.54 V so a reaction will occur. However, due to significantly more voltage inputted, overpotential will occur, producing a lot of heat.

e. Describe the colour change that would be observed within the electrolyte by Athena as this cell operates. Justify your answer. (1 mark)

HI(aq) is colourless but as $I_2(s)$ is produced within an aqueous solution, the electrolyte will become brown over time.

f. After some time, all the ions in the solutions are exhausted. Explain what would happen in the cell. (2 marks)

Only water is left, so the new strongest oxidant (water) would react with the new strongest reductant (water), BUT the voltage supplied is only 2 V, which is not enough to electrolyse water, and as such, no reaction would occur after HI(aq) has been exhausted.

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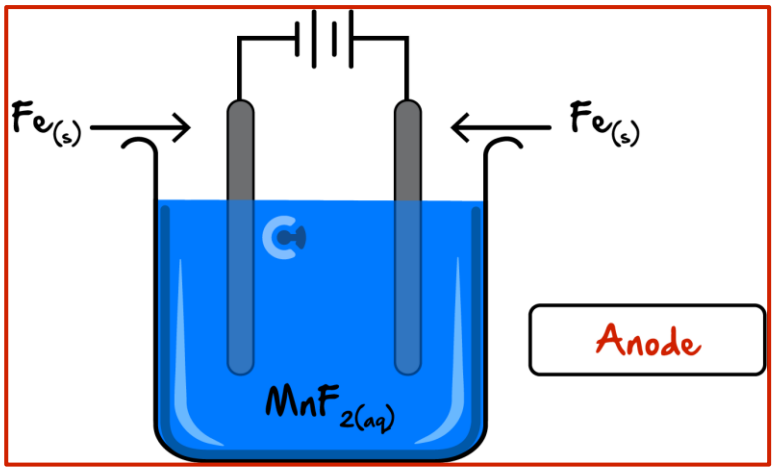
Question 8 (6 marks)

Daniel has a few iron rods lying around so he decides to put them to use by constructing the following setup:



a. Label the electrode on the right as either the anode or cathode in the box provided. (1 mark)

b. Hence, write the relevant half-equation taking place at the right electrode. (1 mark)

$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$

c. Write the equation for the reaction taking place at the other iron electrode. (1 mark)

$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

d.

i. Outline what colour the electrolyte is before any of the reactions take place. (1 mark)

Pale pink due to $Mn^{2+}(aq)$.

ii. Using your answers from **part b.** and **part c.,** explain four different things that would be observed for this cell as it operates. (2 marks)

1.
2.
3.
4.

1. Bubbles formed at the cathode/negative electrode/left electrode due to $H_2(g)$.
2. pH increase at the cathode/negative electrode/left electrode due to OH^- production.
3. Anode/right electrode gets thinner/pitted.
4. Colour of electrolyte will become more green/will be a combination of green and pink due to Fe^{2+} being produced and mixing with Mn^{2+}.

Section D: Getting Trickier I (10 Marks)

INSTRUCTION: 10 Marks. 8 Minutes Writing.

Question 9 (1 mark)

When 1 M $CuSO_4$ is electrolysed using a copper anode and platinum cathode, the products formed are:

A. O_2, H^+, H_2, OH^-

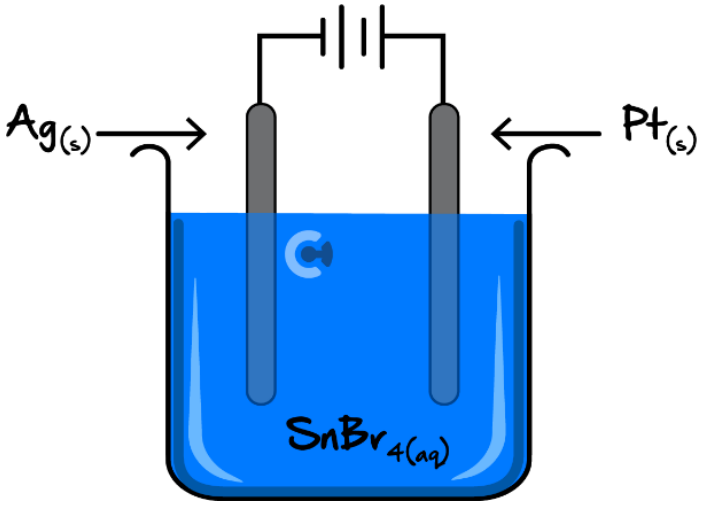
B. $O_2,\ H^+, Cu$

C. Cu^{2+}, Cu

D. Cu^{2+}, H_2, OH^-

Question 10 (9 marks)

Devon sets up the following cell with the intention of reacting to all of the silver.



a. Explain, with appropriate justification, why the cell constructed will **not** achieve his goal. (2 marks)

Because the silver is the cathode (connected to negative terminal of battery) and thus, it is receiving electrons and unable to oxidise, despite being the strongest reductant present.

b.

i. For the cell shown, write the appropriate half-equation which involves an increase in oxidation number for the species reacting. (1 mark)

$2Br^-(aq) \rightarrow Br_2(l) + 2e^-$

ii. Write the other half-equation taking place. (1 mark)

$Sn^{4+}(aq) + 2e^- \rightarrow Sn^{2+}(aq)$

c. State the one major change that would be observed by Devon as this cell operates. (1 mark)

Electrolyte will become brown due to the production of $Br_2(l)$.

d.

i. Propose what change Devon should make in order to realise his goal of using up the silver, using the same chemicals. (1 mark)

Connect the silver to the positive terminal of the battery/make it the anode.

ii. Hence, with the change proposed in **part d.i.,** such that the silver is able to be consumed, state how the EMF supplied would differ from that in Devon's original set-up. (1 mark)

Before it was $0.15 - (1.09) = -0.94$, so $> 0.94\ V$ were needed to be supplied, but now only $> 0.65\ V$ are needed $(0.15 - 0.80)$.

iii. State 2 other differences – in terms of physical observations – as this new cell operates, in comparison to the original cell shown. (2 marks)

1. **2.**

1. The silver electrode/anode will become thinner/pitted, whereas before it did not react.
2. Since $Br_2(l)$ is no longer being produced, the solution will remain colourless as the cell operates now.

Section E: Getting Trickier II (16 Marks)

INSTRUCTION: 16 Marks. 14 Minutes Writing.

Question 11 (9 marks)

Simran places solutions of potassium dichromate, hydrochloric acid, and sodium hydroxide together in a beaker.

a. State what the strongest oxidant and the strongest reductant present are. (1 mark)

Strongest oxidant: $Cr_2O_7^{2-}(aq)$

Strongest reductant: $OH^-(aq)$

b. Explain whether she would observe a reaction upon mixing these chemicals together. If so, write the relevant overall equation taking place. (2 marks)

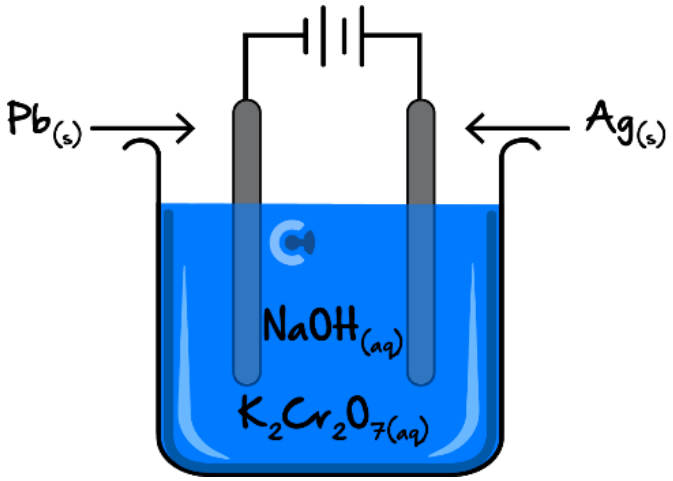
Yes, a spontaneous reaction would occur as the strongest oxidant is higher up on the ECS than the strongest reductant.

$$2Cr_2O_7^{2-}(aq) + 16H^+(aq) \rightarrow 4Cr^{3+}(aq) + 8H_2O(l) + 3O_2(g)$$

c. As Simran's friend, you advised her that she should not have added hydrochloric acid to the beaker. Explain what effect this would have had on the scenario. (2 marks)

Because now there are no $H^+(aq)$ available for the dichromate to react with, so the strongest oxidant which can now react is just water. Thus, no spontaneous reaction will occur if H^+ is not present/if HCl was not added.

Following your advice, she finds a clean, new beaker and only adds in solutions of potassium dichromate and sodium hydroxide. She also adds in electrodes and connects the whole thing to a power supply, as shown below:



d.

i. Write the half-equation occurring at the negative electrode. (1 mark)

$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

ii. Write the other half-equation taking place. (1 mark)

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$

iii. Hence, or otherwise, if Simran were to place a pH meter in the electrolyte, outline what she would observe before she turns the power supply on, and when she turns it off at the conclusion of the experiment. (2 marks)

(1). As the solution is initially basic, she would observe a high pH (close to 14).
(2). As the cell operates, since the overall equation does not feature OH^-, there is no change in pH, and therefore it will stay constant but basic.

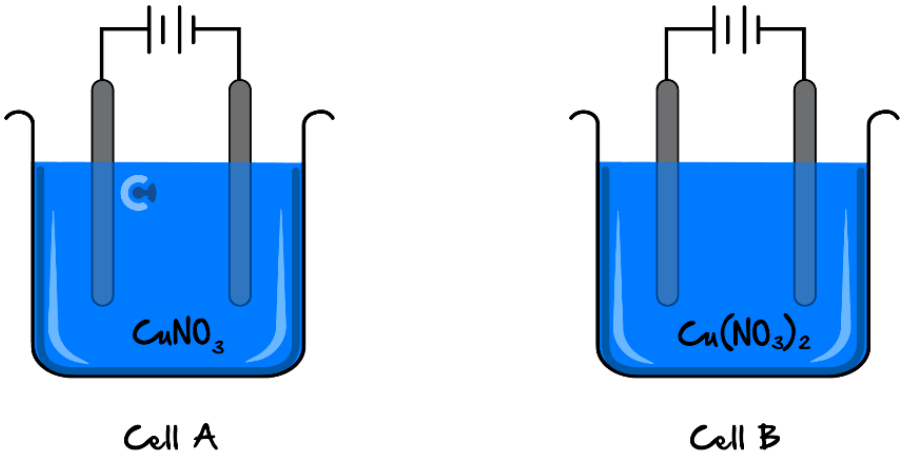
Space for Personal Notes

Question 12 (7 marks)

Leviana decides to set up an electrolytic cell *A* which comprises of a solution of both copper (I) nitrate, whereas Jody decides to set up an electrolytic cell *B* which comprises copper (II) nitrate. They both use platinum electrodes.

The half-equation for Cu^+ ions can be found below:

$$Cu^+(aq) + e^- \rightarrow Cu(s) \qquad E^0 = +0.54\,V$$



a. Write the half-equations which occur at the cathode for:

i. Cell *A*. (1 mark)

$Cu^+ + e^- \rightarrow Cu$

ii. Cell *B*. (1 mark)

$Cu^{2+} + 2e^- \rightarrow Cu$

b. As both cells react, different things are observed to happen in each cell in terms of colour change. Explain the difference in colour observed between the two cells. (2 marks)

Cell *A* – turns less red as Cu^+ is red.
Cell *B* – turns less blue as Cu^{2+} is blue.

c. Both cells are run for 10.0 minutes at a voltage of 0.89 V and an electric current of 1.00 A. The mass of the electrodes from each cell weighs exactly 10.0 g.

When both the **electrodes** from each cell are weighed before and after electricity is run through the cell, it is found that one of the cells (Cell A or B) has much heavier electrodes than the other cell. State which cell is likely to have heavier electrodes, giving justification for your reasoning. (3 marks)

Cell A
Voltage is 0.89 V, which is not enough for cell B which requires at least 0.89 V. As a result, no reaction takes place in cell B.
In cell A, the mass of the cathode increases, resulting in a greater final mass.

Let's take a BREAK!

Space for Personal Notes

Section F: VCAA-Level Questions I (9 Marks)

INSTRUCTION: 9 Marks. 30 Seconds Reading. 9 Minutes Writing.

Question 13 (9 marks)

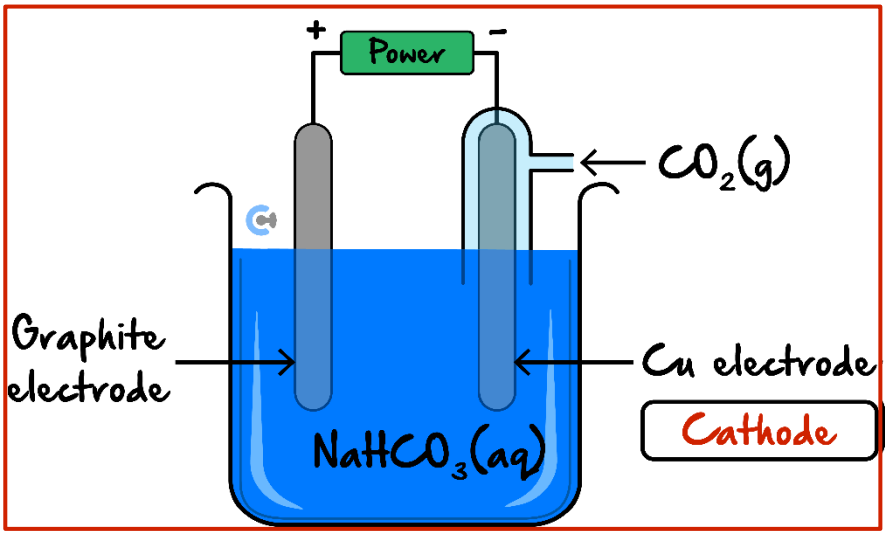
To produce ethanol, the electrolysis of carbon dioxide gas $CO_2(g)$ in alkaline water is often used. The half-equation involving $CO_2(g)$ and some other relevant species are as follows:

$$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l) \qquad E^0 = +1.23\ V$$

$$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq) \qquad E^0 = +0.40\ V$$

$$2CO_2(g) + 9H_2O(l) + 12e^- \rightleftharpoons C_2H_5OH(l) + 12OH^-(aq) \qquad E^0 = -0.33\ V$$

$$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq) \qquad E^0 = -0.83\ V$$



a. Describe the requirements for an electrolytic cell to operate. (1 mark)

Input of electrical energy is required to force a non-spontaneous redox reaction to occur.

b. Identify whether the Cu electrode is the anode or the cathode in the box above. (1 mark)

c. Write the balanced half-equation for the reaction occurring at:

i. The cathode. (1 mark)

$2CO_2(g) + 9H_2O(l) + 12e^- \rightarrow C_2H_5OH(l) + 12OH^-(aq)$

ii. The anode. (1 mark)

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$

d. Hence, determine the applied voltage required for the electrolysis of the cell to operate after some time has passed. (1 mark)

$> 0.76\ V$

e. Describe the expected change in pH as the cell runs providing justification for your reasoning. (2 marks)

No change in pH – as OH^- used at the anode, but the same amount of OH^- is produced at the cathode.

f. Identify the oxidising agent in this reaction. Give reasoning using oxidation numbers. (2 marks)

CO_2.
The oxidation number of C in CO_2 is $+4$ & oxidation number of C in C_2H_5OH is -2. As there is a decrease in oxidation number, CO_2 is reduced, and thereby causes the other species (OH^-) to oxidise. As such, CO_2 is the oxidising agent.

Space for Personal Notes

Section G: Multiple Choice Questions (7 Marks)

INSTRUCTION: 7 Marks. 7 Minutes Writing.

Question 14 (1 mark)

Which one of the following pairs of statements is correct for both electrolysis cells and galvanic cells?

	Electrolysis Cell	Galvanic Cell
A.	Both electrodes are always inert.	Both electrodes are always made of metal.
B.	Electrical energy is converted to chemical energy.	The voltage of the cell is independent of the concentration.
C.	Chemical energy is converted to electrical energy.	The products are dependent on the half-cell components.
D.	The products are dependent on the half-cell components.	Chemical energy is converted to electrical energy.

Question 15 (1 mark)

When a direct current of electricity is conducted by an aqueous solution of an electrolyte in an electrolytic cell:

A. The movement of electrons accounts for the current flow through the solution.

B. The solution remains electrically neutral.

C. Electrons always flow towards the positive electrode.

D. The number of positive ions moving toward one electrode is always equal to the number of negative ions moving toward the other electrode.

Space for Personal Notes

Question 16 (1 mark)

In the electrolysis of very dilute sodium chloride solution using platinum electrodes, a product at the anode is most likely to be:

A. Chlorine.

B. Oxygen.

C. Sodium.

D. Hydrogen.

Question 17 (1 mark)

A direct electric current is passed through 1.0 M K_2SO_4 solution using inert electrodes. The following standard reduction potential is provided in addition to those in the Data Book.

$$S_2O_8{}^{2-}(aq) + 2e^- \rightleftharpoons 2SO_4{}^{2-}(aq) \qquad E^0 = 2.01\ V$$

Which one of the following equations represents the reaction that occurs at the anode?

A. $2SO_4{}^{2-}(aq) \rightarrow S_2O_8{}^{2-}(aq) + 2e^-$

B. $2H_2O(l) \rightarrow O_2(g) + 4H^+ + 4e^-$

C. $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

D. $K^+(aq) + e^- \rightarrow K(s)$

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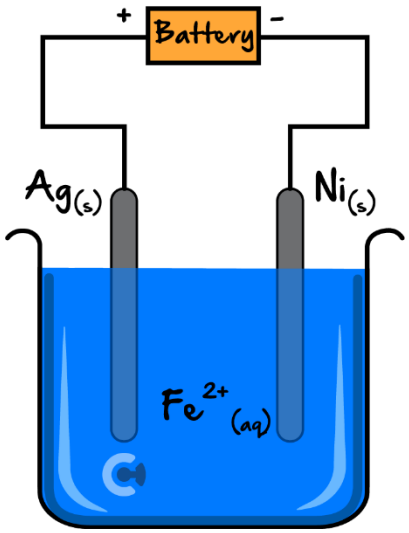
Question 18 (1 mark)

Consider the following electrolytic cell.



The reaction that occurs at the anode is:

A. $Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$

B. $Ag^{+}(aq) + e^- \rightarrow Ag(s)$

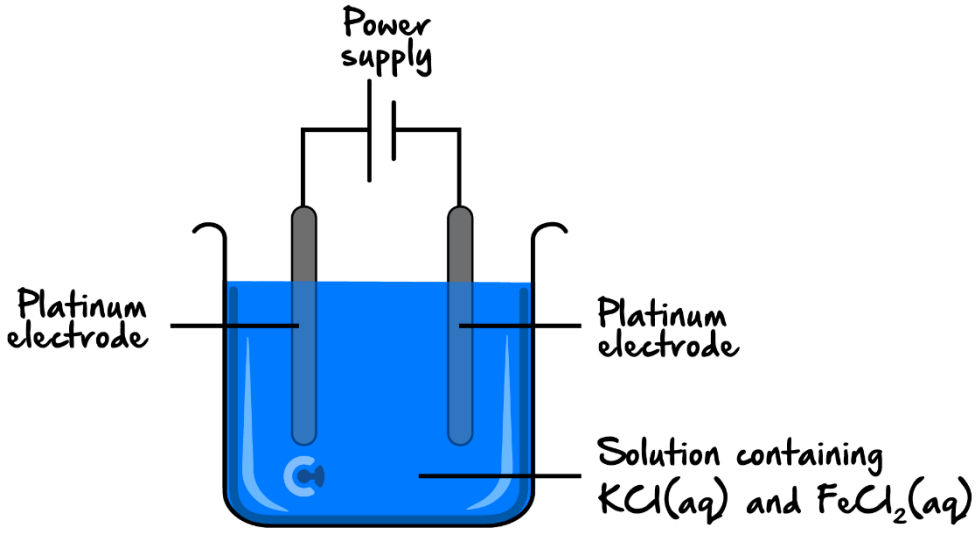
C. $Ni(s) \rightarrow Ni^{2+}(aq) + 2e^-$

D. $Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-$

Space for Personal Notes

Question 19 (1 mark)

The diagram represents an arrangement used by a student to investigate the electrolysis of a mixture containing two metal chlorides. The solution contains 0.010 *M* KCI and 0.010 *M* $FeCl_2$. The student carefully increased the voltage until the electrolysis began.



The product at the anode is most likely to be:

A. Potassium metal.

B. Iron(III) ions.

C. Oxygen gas.

D. Iron metal.

Question 20 (1 mark)

An electric current is passed through 1 *M* NaI solution. The pH in the container would:

A. Increase at the anode and decrease at the cathode.

B. Increase overall.

C. Decrease overall.

D. Increase at the cathode and decrease at the anode.

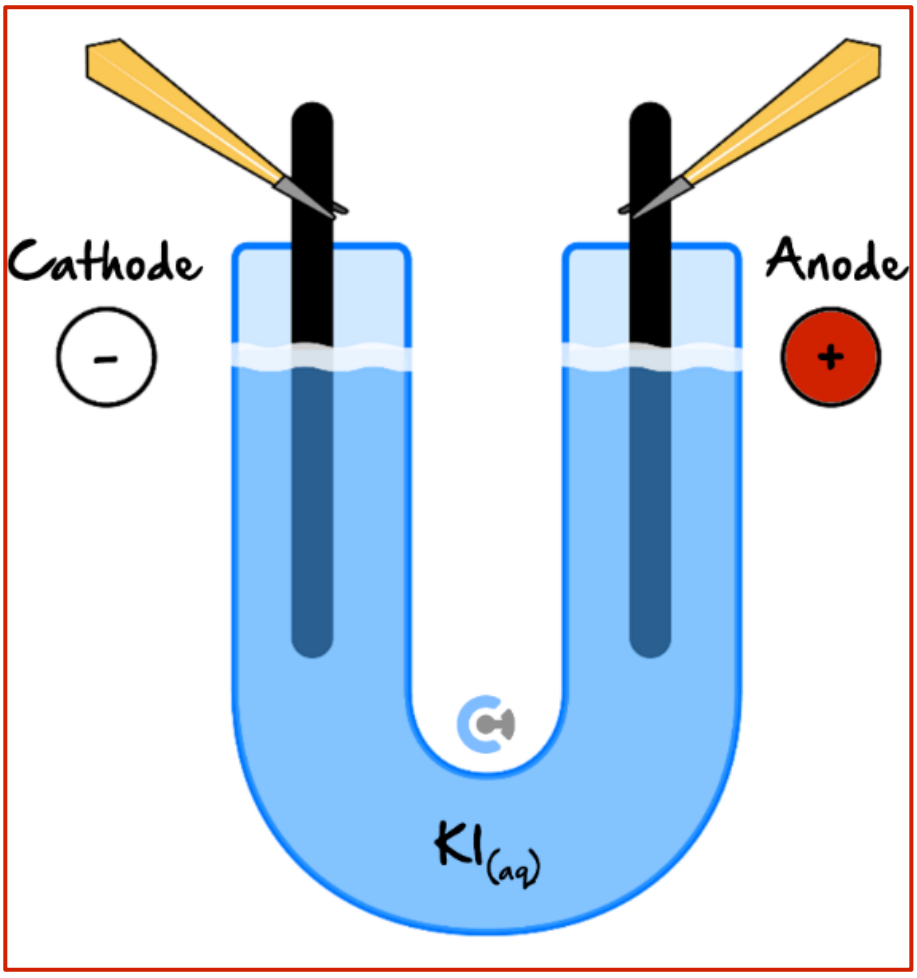
Space for Personal Notes

Section H: VCAA-Level Questions II (9 Marks)

INSTRUCTION: 9 Marks. 30 Seconds Reading. 9 Minutes Writing.

Question 21 (9 marks)

A solution of potassium iodide, KI(aq) is electrolysed using platinum electrodes according to the set-up below.



a. Label the polarities of the electrodes in the boxes provided above. (1 mark)

b. As the reaction proceeds, a solid sludge is observed to be formed, from one electrode before sinking to the bottom of the electrolyte.

i. Identify the solid and the electrode where it is being formed providing justification for your reasoning. (3 marks)

Iodide solid → formed at anode is the strongest reductant, and will thereby oxidise at the anode according to the following equation: $2I^- + 2e^- \rightarrow I_2$.
As such, we expect to see a solid sludge being formed at this anode.

ii. Explain why the solid does not coat onto the electrode, but rather, falls to the bottom of the electrolyte. (1 mark)

It is not a conductor of electricity (non-metal), and thus, cannot form metallic bonds with the metal electrode.

c. At the other electrode, bubbles are being formed and when a pH meter is inserted, its reading is not 7. Identify the gas formed and the corresponding pH change, writing a half-equation to justify your reasoning. (2 marks)

At the cathode, water reduces according to the following equation – $2H_2O + 2e^- \longrightarrow H_2\,(g) + 2OH^-$.
As such, gas produced is Hydrogen gas.
As we produce OH^-, the pH should increase.

d. Describe what would happen if a match was held above the cell. Justify your reasoning, by writing an equation to show the reaction which would take place. (2 marks)

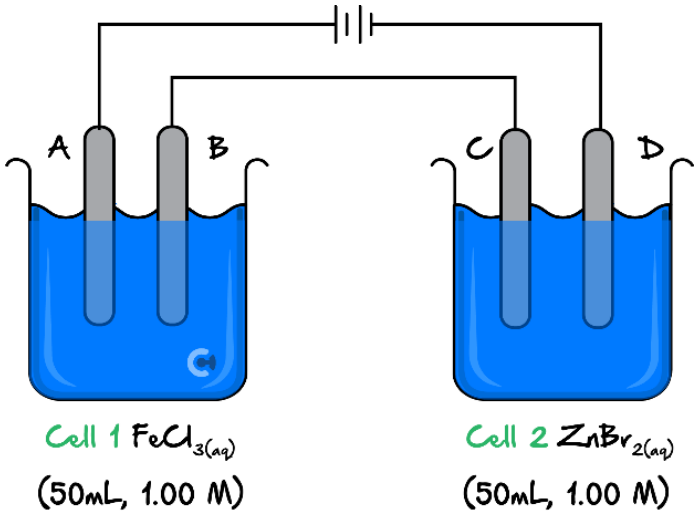
The hydrogen gas would react with the oxygen gas, and an explosion would be seen.

$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g)$$

Section I: Extension Questions (5 Marks)

Question 22 (5 marks)

Two electrolytic cells were connected in series using platinum electrodes, as shown below:



a. Predict the reactions occurring at:

i. Possible reactants in Cell 1: Fe^{3+}, Cl^-
Possible reactants in Cell 2: Zn^{2+}, Br^- and water

Cell 1:

Electrode A	Anode: $2H_2O_{(l)} \rightarrow O_{2(g)} + 4H^+_{(aq)} + 4e^-$ (1)
Electrode B	Cathode: $Fe^{3+}_{(aq)} + e^- \rightarrow Fe^{2+}_{(aq)}$

Cell 2:

Electrode C	Anode: $2Br^-_{(aq)} \rightarrow Br_{2(l)} + 2e^-$
Electrode D	Cathode: $Zn^{2+}_{(aq)} + 2e^- \rightarrow Zn_{(s)}$ (1)

Electrode *A*: _____ (1 mark)

Electrode *D*: _____ (1 mark)

b. Write an overall equation for Cell 1. (1 mark)

$$2H_2O_{(l)} + 4Fe^{3+}_{(aq)} \rightarrow O_{2(g)} + 4H^+_{(aq)} + 4Fe^{2+}_{(aq)}$$

c. Determine the voltage that would be required for the electrolysis of the two solutions. Using equations if appropriate, describe the effect, if any, that this voltage will have on the predicted reactions occurring at electrodes *A* to *D*. (2 marks)

$$0.46\,V + 1.85\,V = 2.31\,V$$

More than 2.31 *V* is required.

Space for Personal Notes

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