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VCE Chemistry ¾

AOS 2 Revision (Electrolysis) [2.0]

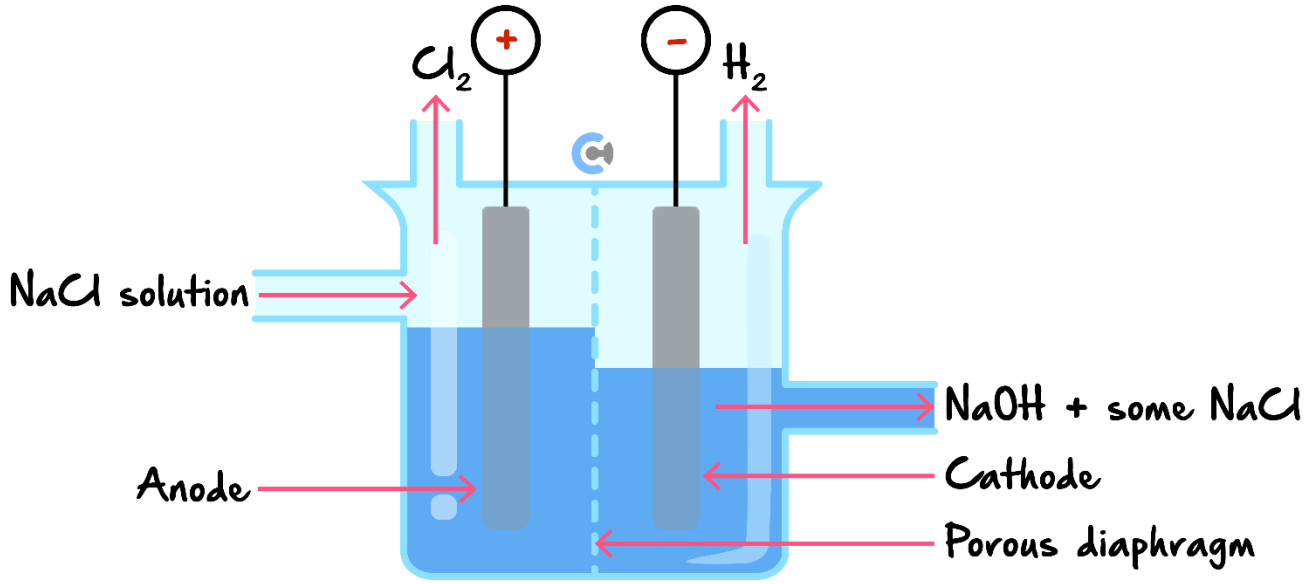
SAC 3 Solutions

50 Marks. 5 Minutes Reading. 60 Minutes Writing.

Section A: Multiple Choice Questions (5 Marks)

Question 1 (1 mark)

Some industrial chlorine production methods make use of electrolytic cells. The following is one such apparatus.



Which of the following is false?

A. The concentration of NaCl solution is very high.

B. The porous diaphragm facilitates the transfer of ions.

C. The minimum voltage required for this cell to function is $4.07\ V$.

D. Oxidation occurs at the positive electrode.

Question 2 (1 mark)

Four solutions are used in four independent electroplating circuits, all with inert anodes. The circuits are connected in series and are all run for two hours. The cathodes from each circuit are dried and weighed.

The solution in the electroplating circuit with the least mass deposited on the cathode is:

A. $Ni(NO_3)_2$

B. $AgNO_3$

C. $ZnSO_4$

D. $CuSO_4$

Question 3 (1 mark)

In a nickel metal hydride cell, the following reaction is occurring at the positive electrode:

$$Ni(OH)_2(s) + OH^-(aq) \rightarrow NiOOH(s) + H_2O(l) + e^-$$

The positive electrode in this cell is:

A. Currently undergoing discharge.

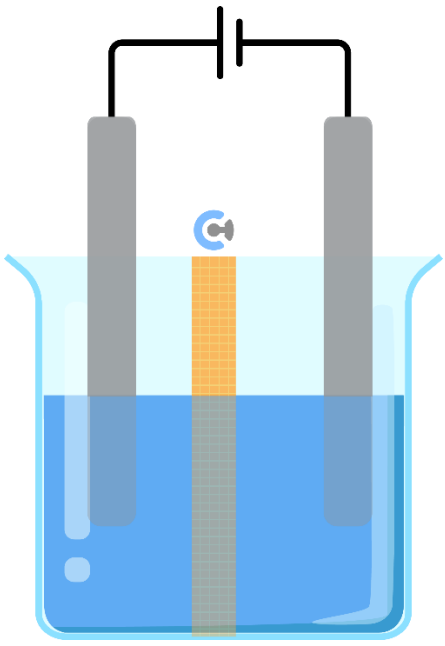
B. The cathode.

C. Porous and catalytic.

D. Always in contact with NiOOH(s).

Question 4 (1 mark)

Consider the cell depicted in the diagram below.



Based on the diagram, which of the following must be true?

A. The electrodes in this cell are inert.

B. This cell converts electrical energy into chemical energy and heat.

C. A spontaneous reaction is occurring in this cell.

D. This cell can power a light bulb.

Question 5 (1 mark)

Artificial photosynthesis converts sunlight into chemical energy using electrolysis. One student is experimenting with the use of artificial photosynthesis to generate 'green hydrogen', for which they require a particular component.

This component must be a:

A. Photocathode.

B. Proton exchange membrane.

C. Photoanode.

D. Power supply.

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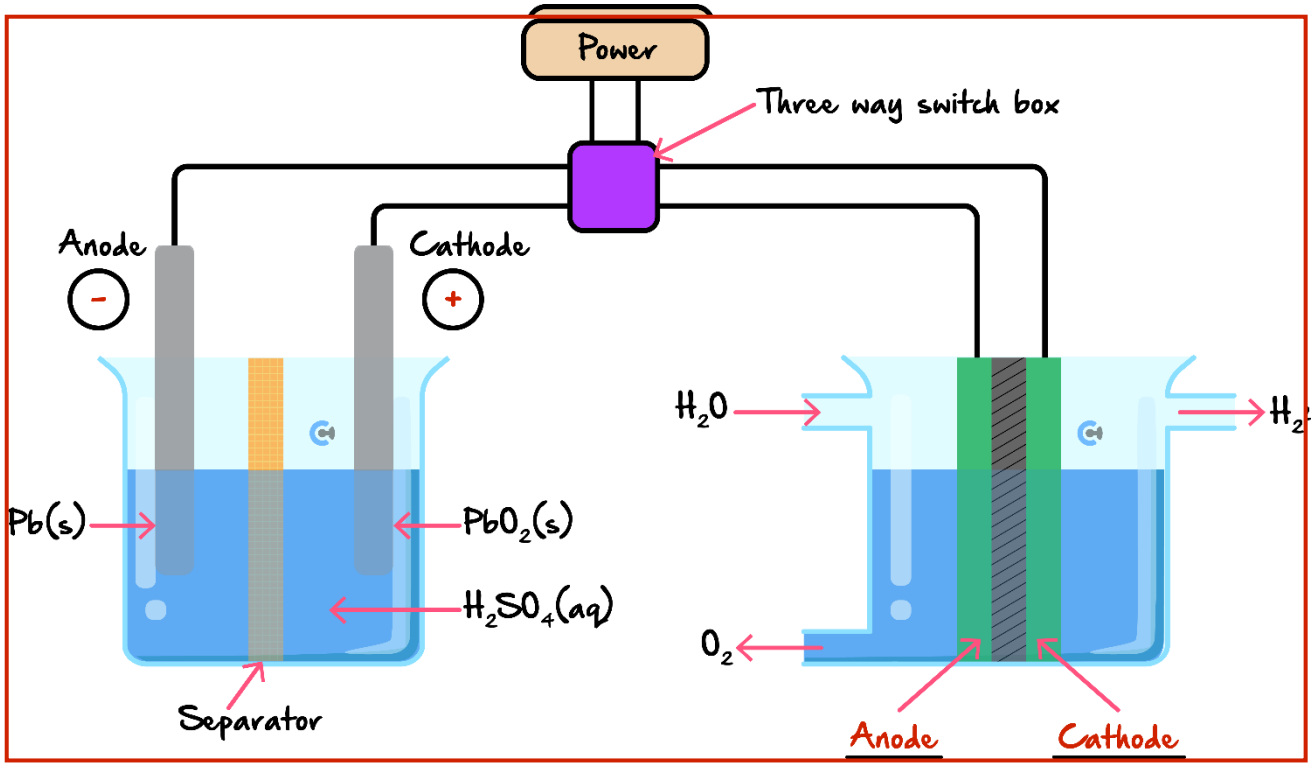
Section B: Short Answer Questions (45 Marks)

Question 6 (19 marks)

Mikhail runs a PEM electrolyser using electricity from a lead-acid car battery to produce hydrogen gas. The apparatus he uses includes a three-way switch box that allows him to simultaneously charge the car battery from the mains power and run the electrolyser. His setup is shown below.



The car battery has almost completely discharged.

a. Label the polarities of the car battery's electrodes. (1 mark)

b. Label the anode and the cathode on the electrolyser. (1 mark)

c. Write the overall equation for the reaction occurring at the PEM electrolyser. (1 mark)

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

After a short time, Mikhail notices that the PEM electrolyser is barely functioning.

d. State the minimum voltage required for the PEM electrolyser to function. (1 mark)

$V_{min} = E^0_{cathode} - E^0_{anode} = 1.23 - 0 = 1.23\ V$
$V > 1.23\ V.$

e. Using the electrochemical series, find the maximum output voltage of the car battery. (1 mark)

$V = E^0_{cathode} - E^0_{anode} = 1.47 - (-0.13) = 2.00\ V$
$V = 2.00\ V$ (from Data Book).

f. Suggest a reason for Mikhail's observation. Justify your answer. (2 marks)

As secondary cells discharge, their voltage decreases as a result of reactant concentration decreasing (1).

The output voltage of the lead-acid battery is not sufficient for the electrolysis of water (2); that is, the lead-acid battery is outputting less than $1.23\ V$.

To keep the electrolyser running, he switches the three-way switch box so that it now runs using the mains power. The car battery then also undergoes recharge.

g. Write the overall equation for the reaction occurring at the car battery. (2 marks)

$2Pb^{2+}(aq) + 2H_2O(l) \rightarrow Pb(s) + PbO_2(s) + 4H^+(aq)$
OR
$2PbSO_4(s) + 2H_2O(l) \rightarrow Pb(s) + PbO_2(s) + 2H_2SO_4(aq)$
Note: the state of Pb^{2+} or $PbSO_4$ must be **solid** because it is insoluble in water.
Correct reactants including states (1). Correct products including states (2).

h. Explain **two** features of the lead-acid car battery that allow for it to be recharged. (2 marks)

Separator keeps spontaneous reactants apart while allowing for the transfer of ions (1).

Reactants stay in contact with the electrodes during discharge so that recharge redox reactions can occur (2).

A couple of hours later, Mikhail switches the three-way switch box again to reconnect the electrolyser and the car battery.

i. The electrolyser produces hydrogen gas. Identify two safety risks present when working with hydrogen gas and suggest precautions Mikhail should take. (2 marks)

Hydrogen is highly flammable. Mikhail should run his electrolyser away from naked flames. (1)
Hydrogen can cause asphyxiation by replacing oxygen in closed spaces. Mikhail should run his electrolyser in a well-ventilated area (2).
Note: Other solutions are acceptable.

j. Explain the function of a proton exchange membrane. (2 marks)

A proton exchange membrane is a semi-permeable membrane that only allows protons through. It facilitates the transfer of protons (1) needed for electrolysis of water and prevents the products, H_2 and O_2, to spontaneously react (2).

To cut costs, Mikhail decides to manufacture the electrodes for his electrolyser by himself.

k. Compare the features of galvanic fuel cells and Mikhail's PEM electrolyser. (3 marks)

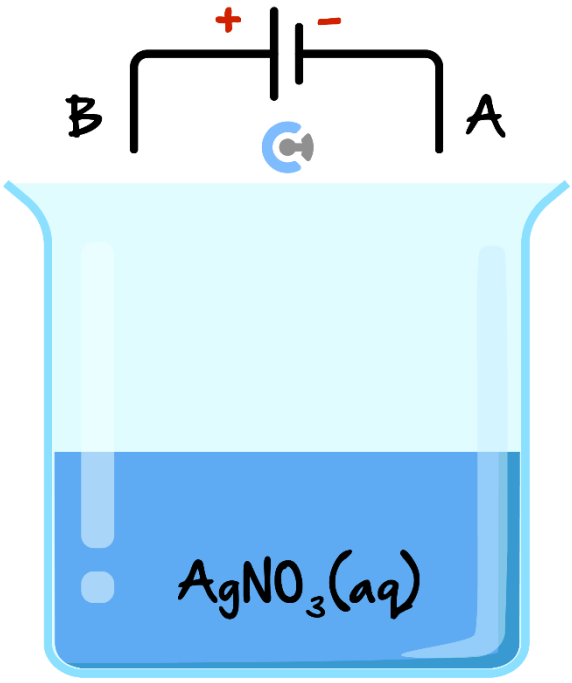
Fuel cells convert chemical energy into electrical energy whereas the electrolyser converts electrical energy into chemical energy (1).
Both fuel cells and the electrolyser use electrodes that are porous, catalytic, and inert (2).
Both fuel cells and the electrolyser require a constant supply of reactants and constant evacuation of products (3).
Note: Both similarities **AND** differences must be present to obtain all marks. A maximum of two marks is available without either a similarity or difference.

l. Hence, suggest a material from which PEM electrolyser electrodes can be made. (1 mark)

Platinum (1)

Question 7 (15 marks)

Robert the jeweller is working on a silver-plated ring for a client. His electroplating apparatus is incomplete as shown.



a. Robert is using a 1.0 *M* solution of silver nitrate and wants the concentration to stay the same.

i. Suggest a material that Robert should use as an electrode. Explain your suggestion. (2 marks)

Robert should use a silver electrode (1). The silver cations reduced onto the ring at the cathode (and taken out of the solution) will be replaced by the silver electrode being oxidised into the solution, and the solution's concentration will stay the same (2).

ii. Should Robert connect the ring to the wire *A* or *B*? Explain your answer. (2 marks)

Robert should connect the ring to wire *A* (1). Silver cations will be reduced onto the ring, and electrons need to be present at the ring for this to occur. For electrons to flow to the ring, the ring must be connected to the negative terminal of the power source (2).

b. Robert uses copper wires to connect the cells together. He fully submerges the ring into the solution, whereby a part of the copper wire contacts the silver nitrate electrolyte.

i. Explain why this is a bad idea. (2 marks)

The copper in the jeweller's wire will spontaneously react with silver cations and will be oxidised into the solution (1). This will reduce the mass of the wire until it breaks (which will not take long since jeweller's wire is quite thin) and the ring becomes disconnected from the circuit (2).
Note: The power supply has not been turned on yet.

ii. Suggest a material from which Robert's jeweller's wire should be made. (1 mark)

Platinum / inert material (1).

c. Finally happy with his setup, Robert turns the power on. He runs 8.00 amperes through the apparatus for half an hour.

i. Find the mass of silver that has been plated onto the ring. (3 marks)

$Q = I\,t = F\,n(e^-)$
$n(e^-) = \frac{I\,t}{F} = \frac{8.00 \times 60 \times 30}{96500} = 0.1492\ mol$ (1)
$n(\text{Ag}) = \frac{1}{1}\,n(e^-) = 0.1492\ mol$ (2)
$m(\text{Ag}) = n(\text{Ag}) \times 107.9 = 0.1492 \times 107.9 = 16.1\ g$ (3).

ii. Hence, find the change in mass for the electrode. (1 mark)

The change in mass is the same as the mass plated onto the ring: $16.1\ g$ (1).
OR
$\Delta m = -16.1g$ (1)

d. For another client, Robert uses the same setup but uses a graphite electrode. Assume the concentration of the solution is still 1.0 *M* and the solution remains at a volume of 1.00 *L*.

If Robert runs 7.00 amperes through the apparatus, find the concentration of the silver nitrate solution after exactly one hour. (4 marks)

$Q = It = 7 \times 60 \times 60 = 25200\ C$

$n(e^-) = \frac{Q}{F} = \frac{25200}{96500} = 0.2611\ mol$ (1)

$Ag^+(aq) + e^- \rightarrow Ag(s)$

$n(Ag^+) = n(e^-) = 0.2611\ mol$ (1)

$\therefore$ 0.2611 mol of $Ag^+(aq)$ deposited

$n_{initial}(Ag^+) = 1\ M \times 1\ L = 1\ mol$

$n_{final}(Ag^+) = 1\ mol - 0.2611\ mol = 0.7389\ mol$ (1)

$c_{final}(Ag^+) = \frac{n}{V} = \frac{0.7389\ mol}{1\ L} = 0.7389\ M$

$\therefore$ Concentration is 0.74M after 1 hour (1)

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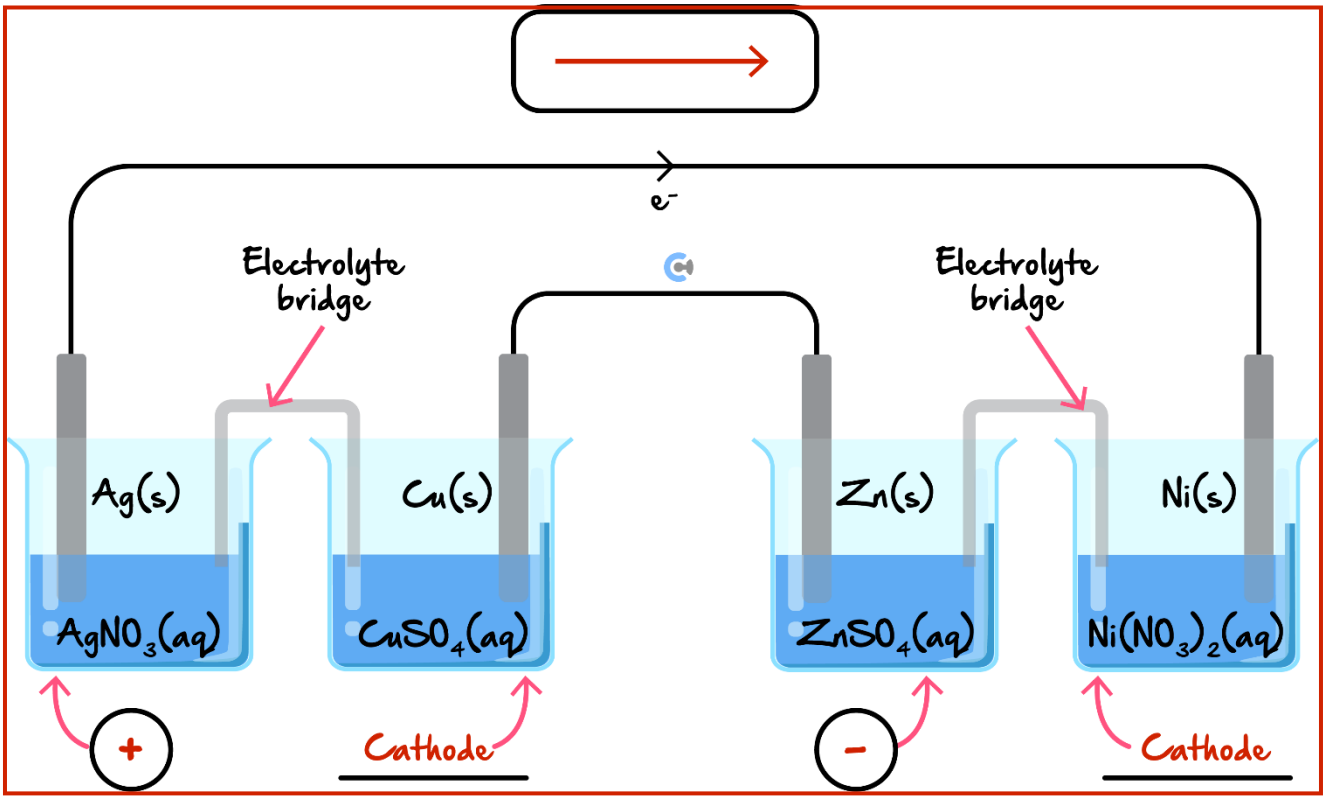
Question 8 (11 marks)

Bartholomew is at a local science fete and is studying the following apparatus.



a.

i. Label the polarities of the silver and zinc electrodes in the circles provided. (1 mark)

ii. State whether the copper and nickel electrodes are the anode or cathode of their respective cells in the spaces provided. (1 mark)

iii. Label the direction of electron flow in the box provided. (1 mark)

b. Compare the energy transformations and spontaneity of galvanic and electrolytic cells. (2 marks)

Galvanic cells convert chemical energy into electrical energy, while electrolytic cells convert electrical energy into chemical energy (1).
Galvanic cells are spontaneous, while electrolytic cells are non-spontaneous (2).

c. Explain why the zinc-nickel cell must be the galvanic cell with reference to relevant EMF values. (3 marks)

The zinc-nickel cell has a maximum electric potential of 0.51 V. The silver-copper cell has a maximum electric potential of 0.46 V (1).

Since the potential of the zinc-nickel cell is higher than the potential of the silver-copper cell, it will be able to force the non-spontaneous reaction to occur in the silver-copper cell (2).

The reverse is not possible as the required voltage is higher than the maximum output voltage of the silver-copper cell (3).

Bartholomew decides to recreate the apparatus in his garage, but discovers he has no nickel. As a substitute, he uses an iron nail and a 1.0 M solution of iron (II) sulphate.

d. Do the electrons in Bartholomew's recreation of the apparatus flow in the same direction as in the original apparatus? Explain your reasoning. (3 marks)

The maximum potential of the zinc-iron cell is 0.32 V and the potential of the silver-copper cell is 0.46 V (1).

Therefore, the zinc-iron cell must be the electrolytic cell and the silver copper cell must be the galvanic cell in this apparatus (2).

For this to occur, the electrons would have to flow in the opposite direction (3).

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