2.4 Electrolysis and rechargeable cells

Summary notes

Electrolysis

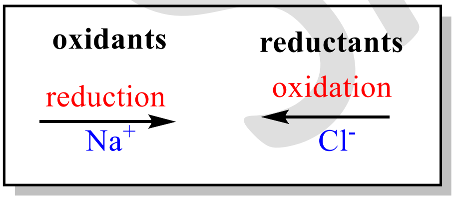
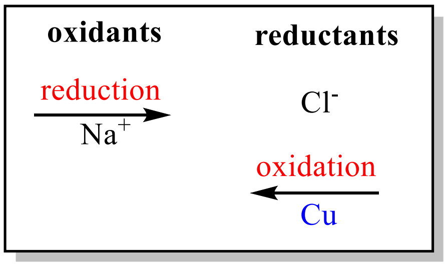
Electrolysis is a technique that uses current to cause a non-spontaneous redox reaction to occur.

Comparing electrolytic cells with galvanic cells

Electrolytic cells	Galvanic cells
Non-spontaneous redox reaction occurs	Spontaneous redox reaction occurs
Oxidation at anode, positive terminal	Oxidation at anode, negative terminal
Reduction at cathode, negative terminal	Reduction at cathode, positive terminal
Electrical energy → chemical energy	Chemical energy → electrical energy
Electrons flow from anode to cathode, positive to negative terminal	Electrons flow from anode to cathode, negative to positive terminal
Ions flow: cations towards the cathode and anions towards the anode	Ions flow: cations towards the cathode and anions towards the anode

Predicting products of electrolysis

- **Top left reactant (strongest oxidant) gets reduced**
- **Bottom right (strongest reductant) gets oxidized**

Electrolysis of molten liquids using inert electrodes	Electrolysis of molten liquids using active electrodes
Eg: electrolysis of NaCl(l) using carbon electrodes Species present: Na^+ and Cl^-  Anode: $2Cl^-(l) \rightarrow Cl_2(g) + 2e^-$ Cathode: $Na^+(l) + e^- \rightarrow Na(l)$ Overall: $2Na^+(l) + 2Cl^-(l) \rightarrow 2Na(l) + Cl_2(g)$	Eg: electrolysis of NaCl(l) using copper electrodes Species present: Na^+, Cl^- and Cu  Anode: $Cu(s) \rightarrow Cu^{2+}(l) + 2e^-$ Cathode: $Na^+(l) + e^- \rightarrow Na(l)$ Overall: $2Na^+(l) + Cu(s) \rightarrow 2Na(l) + Cu^{2+}(l)$

<table>
<tr><th>Electrolysis of aqueous solutions using inert electrodes</th><th>Electrolysis of aqueous solutions using active electrodes</th></tr>
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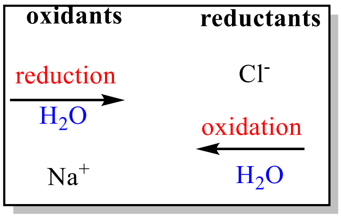
Eg: electrolysis of dilute NaCl using carbon electrodes
Species present: Na^+, Cl^- and H_2O



Anode: $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$
Cathode: $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$
Overall: $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

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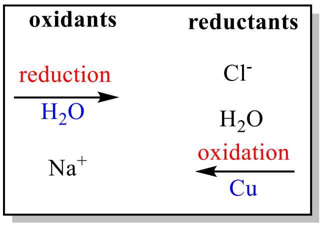
Eg: electrolysis of dilute NaCl using copper electrodes
Species present: Na^+, Cl^-, Cu and H_2O



Anode: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$
Cathode: $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$
Overall: $2H_2O(l) + Cu(s) \rightarrow 2H_2(g) + 2OH^-(aq) + Cu^{2+}(aq)$

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Note: Electrolysis is a non-spontaneous process and products should not come into contact with each other as they can react spontaneously.

Faraday's laws

$Q = I \times t$ **$Q = n(e^-) \times F$**

Q= charge in coulomb, I= current in amps, t= time in seconds, $n(e^-)$= moles of electros, F= 96,500 C/mol

Rechargeable batteries

Primary cells: cells that cannot be recharged are called primary cells**.** They stop producing electricity when the cell reaction comes to an equilibrium.

Secondary cells: are the cells that can be recharged. During the recharging process, an external power supply forces a non spontaneous reaction to occur. The applied potential difference must be greater than the potential difference of the cell.

<table>
<tr><th>Cell discharging</th><th>Cell recharging</th></tr>
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- Galvanic process
- Chemical energy to electrical energy
- Spontaneous reaction
- Anode is the negative terminal

Eg: lead-acid battery discharging
Anode (-):
$Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$
Cathode (+):
$PbO_2(s) + SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$
Overall reaction
$Pb(s) + PbO_2(s) + 2SO_4^{2-}(aq) + 4H^+(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

</td><td>

- Electrolytic process
- Electrical energy to chemical energy
- Non spontaneous reaction
- Cathode is the negative terminal

Eg: lead-acid battery recharging
Anode (+):
$PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + SO_4^{2-}(aq) + 4H^+ + 2e^-$
Cathode (-):
$PbSO_4(s) + 2e^- \rightarrow Pb(s) + SO_4^{2-}(aq)$
Overall reaction
$2PbSO_4(s) + 2H_2O(l) \rightarrow Pb(s) + PbO_2(s) + 2SO_4^{2-}(aq) + 4H^+(aq)$

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</table>

Batteries life

- Battery life usually refers to the number of charge-discharge cycles until the end of useful life.
- Higher temperature can cause the life time of a battery to decrease. This is because at higher temperatures rate of side reactions which decreases the life time of a battery is greater.

Lower temperatures can cause the performance of a battery to decrease. This is because at lower temperatures rate of reaction is slow and the battery can produce less electric charge at a specific discharge rate.

Multiple choice questions

Question 1

Which of the following is **not** true about an electrolytic cell?

A. non-spontaneous reaction occurs
B. anode is the negative terminal
C. oxidation happens at the anode
D. electrical energy is converted to chemical energy

Question 2

Which of the following is common for electrolytic and galvanic cell?

A. reduction is happening at the cathode
B. cathode is the negative terminal
C. reaction is spontaneous
D. anode is the negative terminal

Question 3

Which of the following is **no**t true for electrolytic and fuel cells?

A. in electrolytic cells non-spontaneous reaction occurs and in fuel cells spontaneous reaction occurs
B. in electrolytic cells cathode is negative and in fuel cells cathode is positive
C. in both cells cations move towards the cathode
D. in electrolytic cell electrons move from anode to cathode and in fuel cells electrons move from cathode to anode

Question 4

Why sodium metal **cannot** be extracted from electrolysis of sodium chloride solution?

A. sodium metal is very reactive
B. water is a stronger oxidant than sodium ion
C. water is a stronger reductant than sodium metal
D. electrolysis is a non-spontaneous process

Question 5

When current is passed through molten magnesium chloride using carbon electrodes, product produced at the anode is,

A. chlorine gas
B. oxygen gas
C. magnesium metal
D. hydrogen gas

Question 6

When current is passed through lithium chloride solution using carbon electrodes, product produced at the cathode is,

A. chlorine gas
B. oxygen gas
C. lithium metal
D. hydrogen gas

Question 7

When current is passed through molten sodium iodide using copper electrodes, product produced at the anode is,

A. iodine liquid
B. oxygen gas
C. sodium metal
D. copper ions

Question 8

When current is passed through sodium iodide solution using carbon electrodes, product produced at the anode is,

A. iodine liquid
B. oxygen gas
C. sodium metal
D. copper ions

Question 9

When current is passed through water using carbon electrodes, the products formed at negative and positive electrode respectively are,

A. hydrogen gas and oxygen gas
B. hydroxide ions and hydrogen gas
C. oxygen gas and hydrogen gas
D. water cannot give any products

Use the following information to answer questions 10-12

A metallic key to be plated with copper metal was placed in an ionic solution and current of 0.2 A was passed through the cell for 30 minutes.

Question 10

Which of the following shows the species used as the cathode, anode and the solution?

	cathode	anode	Solution
A	Copper rod	key	Copper sulfate
B	key	Copper rod	Copper sulfate
C	key	Coper rod	Copper oxide
D	Copper rod	key	Copper oxide

Question 11

The mass of copper metal deposited on the key is,

A. 0.12 g
B. 0.24 g
C. 0.002 g
D. 0.004 g

Question 12

If the above key needed to be coated with 0.3 g of copper metal, for how long a current of 0.2 A must passed through the cell?

A. 76 minutes
B. 38 minutes
C. 30 minutes
D. 50 minutes

Question 13

current of 0.1 A was passed through solutions of $AgNO_3$, NaCl and $CuSO_4$, for same length of time. The ratio for moles of metal deposited respectively is,

A. 1: 1: 2
B. 2: 2: 1
C. 2: 0: 1
D: 1:1: 0

Question 14

During the electrolysis of molten sodium chloride 50 mL of chlorine gas was collected at SLC. The mass of sodium metal produced is,

A. 0.093 g
B. 0.046 g
C. 93 g
D. 46 g

Question 15

A current of 2 A was passed through acidified water for 10 minutes at standard laboratory conditions. What is the volume of oxygen gas produced?

A. 77 mL
B. 154 mL
C. 308 mL
D. 19 mL

Question 16

Which of the following is true for recharging a car battery

A. a spontaneous reaction is happening during the recharge
B. oxidation happens at the cathode
C. cathode is the negative terminal
D. anode is the negative terminal

Use the following information to answer questions 17-21

The equation below represents the cell reaction occurring when a lead-acid battery producing electrical energy.

$Pb(s) + PbO_2(s) + 2SO_4^{2-}(aq) + 4H^+(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

Above reaction can produce a voltage of about 2 volts. A car battery has six of these cells giving a total voltage of 12 V.

Question 17

The reaction happens at the negative terminal of the battery when the cell discharge is,

A. $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$ B. $PbO_2(s) + SO_4^{2-}(aq) + 4H^+ + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$

C. $PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + SO_4^{2-}(aq) + 4H^+ + 2e^-$ D. $PbSO_4(s) + 2e^- \rightarrow Pb(s) + SO_4^{2-}(aq)$

Question 18

The reaction occurring at the electrode connected to the negative terminal of the battery when cell is recharging is,

A. $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$ B. $PbO_2(s) + SO_4^{2-}(aq) + 4H^+ + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$

C. $PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + SO_4^{2-}(aq) + 4H^+ + 2e^-$ D. $PbSO_4(s) + 2e^- \rightarrow Pb(s) + SO_4^{2-}(aq)$

Question 19

What will happen to the pH of the cell, when it is recharging

A. pH will not change as there is no acid or base present

B. pH will increase as the H^+ concentration is increasing

C. pH will increase as the H^+ concentration is decreasing

D. pH will decrease as the H^+ concentration is increasing

Question20

The above battery has a limited life time. Which of the following does **not** explain the reason for this?

A. loss of reactant or products from the electrodes

B. formation of other chemicals by side reactions

C. battery is operating in hot climates

D**.** battery is operating in cold climates

Question 21

What is the voltage needed to recharge this cell?

A. 12 V B. 14 V C. 10 V D. 2 V

Short Answer Questions

Question 1

Write half equations and full reactions for electrolysis of following electrolytes

Electrolyte	electrodes	Anode reaction	Cathode reaction	Overall reaction
Molten lithium chloride	Both anode and cathode are carbon			
Potassium bromide solution	Both anode and cathode are carbon			
Calcium iodide solution	Both anode and cathode are copper			
Molten magnesium fluoride	Both anode and cathode are copper			

Question 2

Electrolysis of concentrated solution of sodium chloride produced chlorine gas.
a. At which electrode chlorine gas was produced?
b. Write the equation for the production of chlorine gas at the above mentioned electrode.
c. Write the equation for the reaction occurring at the other electrode.
d. During the commercial production of chlorine gas, a membrane cell is used to carry out the electrolysis of sodium chloride solution.
i. What is the function of membrane?
ii. Besides chlorine gas, what other two useful chemicals can be obtained in this membrane cell?
e. What volume of chlorine gas measured at SLC, can be obtained by passing current of 2.00 A for 1.00 hour?

Question 3

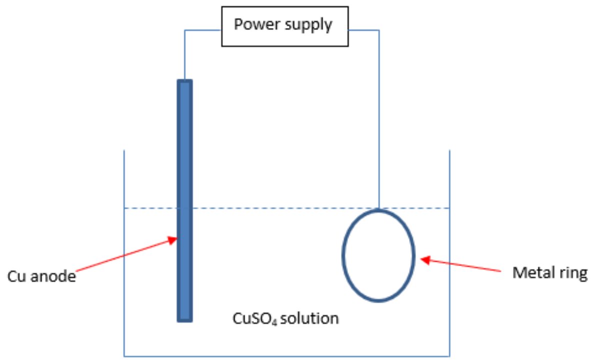
Aluminium metal can be obtained by electrolysis of molten aluminium oxide dissolved in cryolite. Both anode and cathode consist of carbon. Oxygen gas produced at the anode reacts with carbon to produce carbon dioxide at the operating temperature of this cell.
a. Give equations of the reactions occurring at anode and the cathode.
b. Give the overall reactions occurring in the cell.
c. The products of this electrolysis must be separated from each other. What is the reason for this?
d. Why aluminium oxide needs to be dissolves in cryolite?
e. Give one advantage and disadvantage of using carbon as the anode in this cell.
f. Calculate the volume of carbon dioxide (measured at SLC) produced, if 2.5 tonnes of aluminium was extracted from this cell?

Question 4

A student was given a task to investigate the Faradays firs law of electrolysis: **The mass of a substance produced by electrolysis is proportional to the quantity of electricity used.**

She then setup the following experiment.

Step 1: A metal ring was weighed, connected to a power supply and placed in a solution of 0.1 M copper sulfate as shown in the diagram below.



Step 2: A current of 1.0 A, was passed through the cell for 30 minutes at a potential of 1.5 V.

Step 3: The metal ring was removed from the solution, washed, dried thoroughly and re-weighed.

Above steps were repeated two more times using different metal rings with similar masses at following combination of current and voltage.
Current 2.0 A and voltage 2 V
Current 3.0 A and voltage 2.5 V.

The results of the experiment are shown in the table below.

Trial number	Initial mass of the ring (g)	Final mass of the ring (g)	Mass of metal deposited (g)	Current (A)	Voltage (V)
1	2.565	2.693	0.128	1.0	1.5
2	2.595	2. 847	0.252	2.0	2.0
3	2.581	2.874	0.293	3.0	2.5

Student's conclusion: It can be proved from the above experiment that the mass of a substance produced by electrolysis is proportional to the quantity of electricity used.

a. Evaluate the student's experimental procedure and conclusion. In your response:

- identify and explain one strength of the experimental procedure
- suggest three improvements or modifications that you would make to the experimental procedure
- comment on the validity of the conclusion based on the results obtained.

Question 5

Electrolysis can be used to calculate the value of Avogadro's number experimentally. A current of 0.6 A was passed through a solution of sulfuric acid for 30 minutes. The electrodes of this cell were made from copper metal. The mass of anode before and after electrolysis was record.

Mass of anode before electrolysis: 22.352 g

Mass of anode after electrolysis: 22.001 g

a. What mass of copper was oxidized at the anode?

b. Write the equation for the reaction occurring at the anode?

c. What is the charge pass through this cell?

d. If the charge on one electron is 1.6×10^{-19} C, how many electrons were passed through the cell?

e. Calculate the number of copper atoms that were oxidized at the copper anode

f. Calculate the number of copper atoms that were oxidized per gram of copper

g. If one mole of copper equals 63.5 g and Avogadro's constant is the number of copper atoms present in one mole of copper, calculate the Avogadro's constant.

Question 6

The nickel-cadmium battery is secondary battery that is suited for low-temperature conditions with a long shelf life. When the cell is delivering current the reactions occurring at the cathode and the anode are given below.

Cathode:

$2NiO(OH)(s)+2H_2O(l)+2e^- \rightarrow 2Ni(OH)_2(s)+2OH^-(aq)$

Anode:

$Cd(s)+2OH^-(aq) \rightarrow Cd(OH)_2(s) + 2e^-$

a. Give the overall reaction of the cell during cell discharge

b. Give the overall reaction of the cell during cell recharge

c. Give the reaction occurring at negative terminal of the cell during cell discharge

d. Give the reaction occurring at the electrode connected to the positive terminal during cell recharge

e. What will happen to the pH of the cell during discharge

f. Give 3 reasons why this battery has a limited life time.

Answers for Multiple Choice Questions

1	B	In electrolysis, anode is the positive terminal where oxidation occurs
2	A	In both electrolytic and galvanic cells, oxidation happens at the anode and reduction happens at the cathode
3	D	In both electrolytic and fuel cells (galvanic cells) electrons travel from anode to cathode
4	B	In electrochemical series water is above sodium ion. So, water is a stronger oxidant than sodium ion and it get reduced preferentially.
5	A	Species present: Mg^{2+} and Cl^-. Cl^- is a reductant and it get oxidized at the anode to produce chlorine gas.
6	D	Species present: Li^+, Cl^- and H_2O. Both Li^+ and H_2O are oxidants. However, water is a stronger oxidant than Li^+ and it get reduced preferentially at the cathode to produce hydrogen gas.
7	D	Species present: Na^+, I^- and Cu. Both I^- and Cu are reductants. However, Cu is a stronger reductant than I^- and it get oxidized preferentially at the anode to produce copper ions.
8	A	Species present: Na^+, I^- and H_2O. Both I^- and H_2O are reductants. However, I^- is a stronger reductant than water and it get oxidized preferentially at the anode to produce iodine.
9	A	In electrolysis negative electrode is cathode and when water reduced at the cathode it produces hydrogen gas. When water oxidized at the positive anode product formed is oxygen gas.
10	B	Deposition of the metal (reduction) occurs at the cathode. So, the object (key) must be the cathode. Solution is copper sulfate which can provide copper ions for the reduction process. Copper oxide cannot be used as it is insoluble and cannot provide copper ions. Anode is made from copper rod.
11	A	$Q = It$, $Q = 0.2\ A \times (30 \times 60) s = 360\ C$ $Q = n_eF$, $n_e = 360 / 96{,}500 = 0.0037$ mol $Cu^{2+}{}_{(aq)} + 2e \rightarrow Cu(s)$ n(Cu) = 0.0037/2 = 0.0019 mol, m(Cu) = 0.0019 x 63.5 = 0.118 g = 0.12 g
12	A	n(Cu) = 0.3/63.5 = 0.0047 mol, n_e = 0.0047x 2 = 0.0094 mol Q = 0.0094 x 96,500 = 911.8 C, t= 911.8/0.2 = 4559 s, 4559/60 = 76 min
13	C	Deposition of metal is a reduction process. In aqueous solutions Na^+ will not get reduce as water is a stronger oxidant than Na^+. $Cu^{2+}{}_{(aq)} + 2e \rightarrow Cu(s)$ $Ag^+{}_{(aq)} + e \rightarrow Ag(s)$ To deposit 1 mol of Cu, 2 moles of electrons are required. Which means when the same amount of charge (same number of electrons) passed through the solutions of $AgNO_3$ and $CuSO_4$, moles of coper metal deposited will be half of silver metal.
14	A	Anode: $2Cl^-(l) \rightarrow Cl_2(g) + 2e^-$ Cathode: $Na^+(l) + e^- \rightarrow Na(l)$ Overall: $2Na^+(l) + 2Cl^-(l) \rightarrow 2Na(l) + Cl_2(g)$ $n(Cl_2)$ = V/Vm = 0.05 / 24.8 = 0.002 mol, n(Na) = 0.002 x 2 = 0.004 mol, m(Na) = 0.004 x 23 = 0.093 g
15	A	$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$ Q = It = 2 A x (10 x 60)s = 1200 C, n_e = 1200 / 96500 = 0.0124 mol, $n(O_2)$ = 0.0124/4 = 0.0031 mol, V= 0.0031 x 24.8 = 0.077 L = 77 mL
16	C	Cell recharge is a non spontaneous electrolytic process in which cathode is the negative terminal.
17.	A	During the cell discharge, galvanic process occurs and the negative terminal is the anode where the oxidation of Pb happens.
18	D	The reaction occurring at the negative terminal when cell discharge is, $Pb(s) + SO_4{}^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$ When the cell is recharging this reaction will occur in reverse direction at the same electrode.
19	D	During the recharge, the following reaction is occurring $2PbSO_4(s) + 2H_2O(l) \rightarrow Pb(s) + PbO_2(s) + 2SO_4{}^{2-}(aq) + 4H^+$ As the concentration of H^+ is increasing pH will decrease.
20	D	Reactants and the products may become detached from the electrode with time. For the cell reactions to happen, reactants and products must remain contact with the electrodes. Formation of other chemicals by side reactions can decreases the efficiency and the life time of the cell. Higher temperature can cause the life time of a battery to decrease. This is because at higher temperatures rate of side reactions which decreases the life time of a battery is greater. Lower temperatures cause the performance of a battery to decrease but not the life time.
21	B	The applied potential difference must be greater than the potential difference of the cell.

Answers for Short Answer Questions

Question 1

Electrolyte	electrodes	Anode reaction	Cathode reaction	Overall reaction
Molten lithium chloride	Both anode and cathode are carbon	$2Cl^-(l) \rightarrow Cl_2(g) + 2e^-$	$Li^+(l) + e^- \rightarrow Li(l)$	$2Li^+(l) + 2Cl^-(l) \rightarrow 2Li(l) + Cl_2(g)$
Potassium bromide solution	Both anode and cathode are carbon	$2Br^-(aq) \rightarrow Br_2(l) + 2e^-$	$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$	$2Br^-(aq) + 2H_2O(l) \rightarrow Br_2(l) + H_2(g) + 2OH^-(aq)$
Calcium iodide solution	Both anode and cathode are copper	$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$	$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$	$Cu(s) + 2H_2O(l) \rightarrow Cu^{2+}(aq) + H_2(g) + 2OH^-(aq)$
Molten magnesium fluoride	Both anode and cathode are copper	$Cu(s) \rightarrow Cu^{2+}(l) + 2e^-$	$Mg^{2+}(l) + 2e^- \rightarrow Mg(l)$	$Cu(s) + Mg^{2+}(l) \rightarrow Cu^{2+}(l) + Mg(l)$

Question 2

a. Anode

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

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

d. i. To separate the products of electrolysis, otherwise they can react spontaneously

ii. hydrogen gas and sodium hydroxide

e. Q = It = 2A x (1 x 60 x 60)s = 7200 C, Q= n_eF n_e= 7200/96,500 = 0.0746 mol

$n(Cl_2)$ = 0.0746/2 = 0.037 mol, $V(Cl_2)$ = 0.037 x 24.8 = **0.925 L** or **925 mL**

Question 3

a. Anode: $C(s) + 2O^{2-}$(in cryolite) $\rightarrow CO_2(g) + 4e^-$

Cathode: Al^{3+}(in cryolite) +3e$^-$ $\rightarrow$ Al(l)

b. 3C(s) + $6O^{2-}$(in cryolite) + $4Al^{3+}$(in cryolite) $\rightarrow 3CO_2(g)$ + 4Al(l)

c. If not, they can react spontaneously. So, you will lose the products of electrolysis.

d. It has a very high melting point, and this increases the cost of the process. Dissolving in cryolite decrease the melting point.

e. Advantage: cheap disadvantage: as oxygen gas reacts with carbon at high temperature, anode needs to be replaced regularly.

f. n(Al) = 2.5 x 10^6 / 27 = 92,592.6 mol, $n(CO_2)$ = 92,592.6 x (3/4) = 69,444. 4 mol

$V(CO_2)$ = 69,444. 4 x 24.8 = **1.7 x 10^6 L**

Question 4

Strength:

- After the electrolysis the student washed and dried the ring before weighing it. This way the student can ensure that the increased mass of the ring is only due to the mass of copper deposited.
- A copper rod was used as the anode. In this way concentration of the Cu^{2+} in solution can be kept constant.
- Time was same in all trials. This reduces the number of variables.
- Same concentration of copper sulfate solution was used. This reduces the number of variables.
- Student perform three trials. This allows for better verification of results.

Improvements or modifications:

- The student needs to repeat each trial at least 3 times and use the average mass for the calculation
- In each trial, the student should keep the voltage constant and only vary the current as only one variable needs to be changed at a time. As the quantity of electricity or charge depends only on current and time (Q=It), voltage needs to be kept constant.
- A suitable concentration of copper sulfate solution needs to be used. The products of the electrolysis are dependent on the concentration of the solution.
- The student needs to ensure the copper sulfate solution is free of other metal ions. This prevents other metals being deposited on the ring.
- Current should be measured at regular intervals during the process. Variations in current can lead to inaccurate amount of charge passed through the cell. By taking an average of current readings over the 30 minutes, a more accurate value is obtained.
- Extend the time for electrolysis. This leads for greater mass of copper to be deposited, reducing weighing errors.
- Rings should have same shape and surface area. This reduces variables that could affect results.

Validity of conclusion:

According to the faradays lows greater the mass of electricity passed through the cell, greater the mass of copper deposited. Which means at higher current greater mass of copper must deposited.

Trial 1-: current 1A mass of Cu deposited: 0.128 g mass/current: 0.128
Trial 2-: current 2A mass of Cu deposited: 0.252 g mass/current: 0.126
Trial 3-: current 3A mass of Cu deposited: 0.293 g mass/current: 0.098

As shown above results shows limited consistency with Faradays laws. Results of trial 1 and 2 are consistence with the Faradays laws. However, results of trial 3 does not show any consistency. Therefore, more trials needed to be carried out.

Each trial must repeat many times and average results must be considered for the calculation. In each trial voltage, starting concentration, electrode properties needs to be same to reduce the number of variables.
When considering above facts, the students conclusion in general is not valid.

Question 5

a. 22.352 - 22.001 = **0.351 g**
b. $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$
c. Q = It = 0.6 A x (30 x 60) = **1080 C**
d. 1080/ (1.6 x 10^{-19}) = **6.75 x 10^{21}**
e. 6.75 x 10^{21}/ 2 = **3.38 x10^{21}**
f. 3.38 x10^{21}/ 0.351 = **9.62 x 10^{21}**
g. 9.63 x 10^{21} x 63.5 = **6.11 x 10^{23}**

Question 6

a. $Cd(s)+2NiO(OH)(s)+2H_2O(l) \rightarrow Cd(OH)_2(s)+2Ni(OH)_2(s)$
b. $Cd(OH)_2(s)+2Ni(OH)_2(s) \rightarrow Cd(s)+2NiO(OH)(s)+2H_2O(l)$
c. $Cd(s)+2OH^-(aq) \rightarrow Cd(OH)_2(s)+2e^-$
d. $2Ni(OH)_2(s) + 2OH^-(aq) \rightarrow 2NiO(OH)(s)+2H_2O(l)+2e^-$
e. pH will not change as there is no change in hydronium ion or hydroxide ion concentration.
f. i. With the use reactants and products can detached from the electrodes.
ii. Side reactions happening in the cell can reduce the efficiency and life time.
iii. impurities present with the cell materials can react with active materials to reduce the life time.