

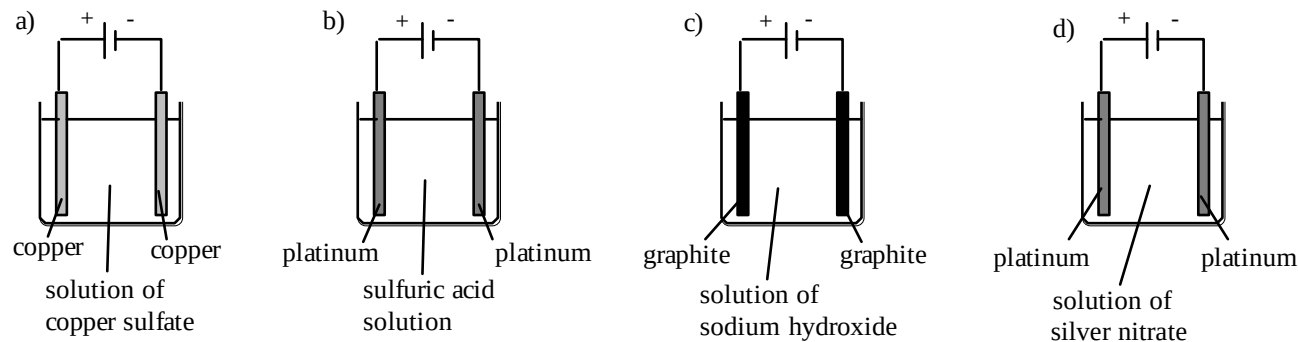
**OXIDATION & REDUCTION - 3 - PROBLEM SHEET**

1. For the following four cells:

i) Show the direction of electron and ion flow.

ii) Label the cathode and anode.

iii) Write equations for the reactions that occur at the electrodes.



2. Predict the minimum applied voltage required to bring about the electrolysis reactions in the cells b), c) and d) described in question 1.

3. Given the cathode, anode and overall cell reactions for the following cells:

a) the electrolysis of a solution of potassium iodide using nickel electrodes.

b) the electrolysis of 1 mol L<sup>-1</sup> NaCl solution using graphite electrodes.

c) the electrolysis of an aluminium nitrate solution using lead electrodes.

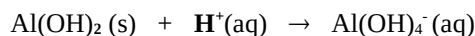
d) the electrolysis of molten sodium chloride, using platinum electrodes.

e) the electrolysis of molten aluminium oxide, using platinum electrodes.

4. Correct the many mistakes (at least 27) in the following passage concerning the extraction and purification of alumina from bauxite i.e. the Bayer process. The mistakes are printed in **BOLD**.

#### The Bayer process

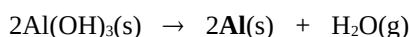
The purpose of the Bayer process is to prepare pure **aluminium** from bauxite. Bauxite is composed of aluminium **nitrate** and impurities such as **coal** and iron oxide. After mining, the bauxite is added to a solution of **hydrochloric acid** and heated. Because aluminium hydroxide is **basic** it reacts with the hydroxide ions to form **aluminium oxide**.



The **aluminate** complex ion is **insoluble** in water. The impurities in the bauxite **react** with the sodium hydroxide solution and so remain **soluble** in the mixture. The hot mixture is **distilled** to remove the insoluble impurities. The soluble tetrahydroxoaluminate ion remains in the **sediment**. The filtrate is heated and seed crystals of **aluminium** are added. Crystals of aluminium **nitrate** form in the cooled solution.



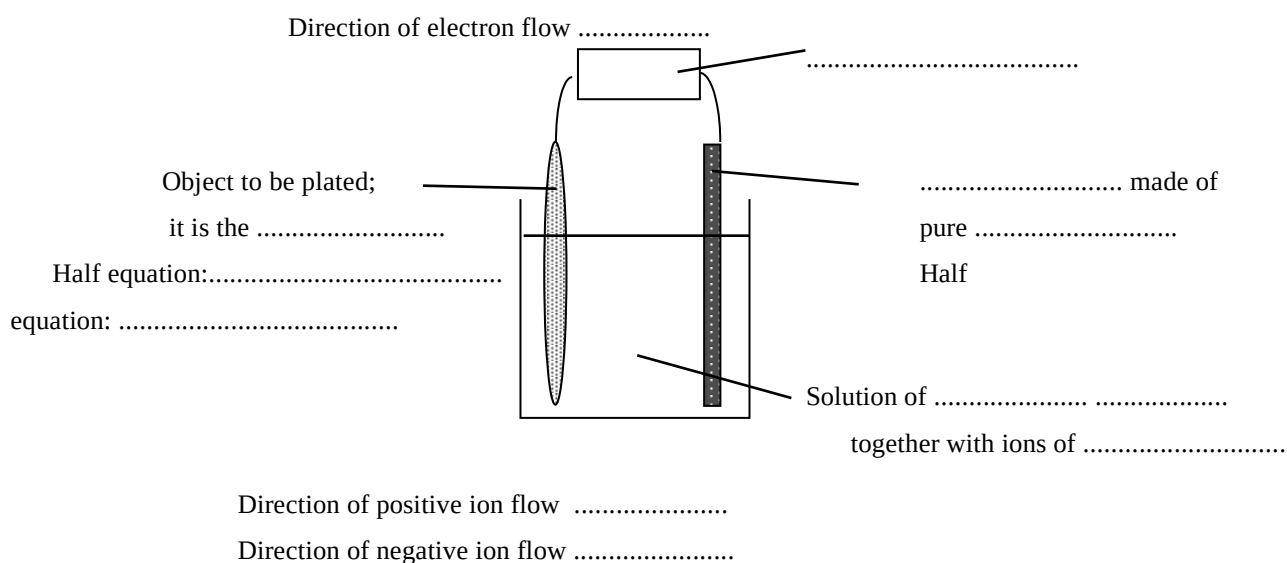
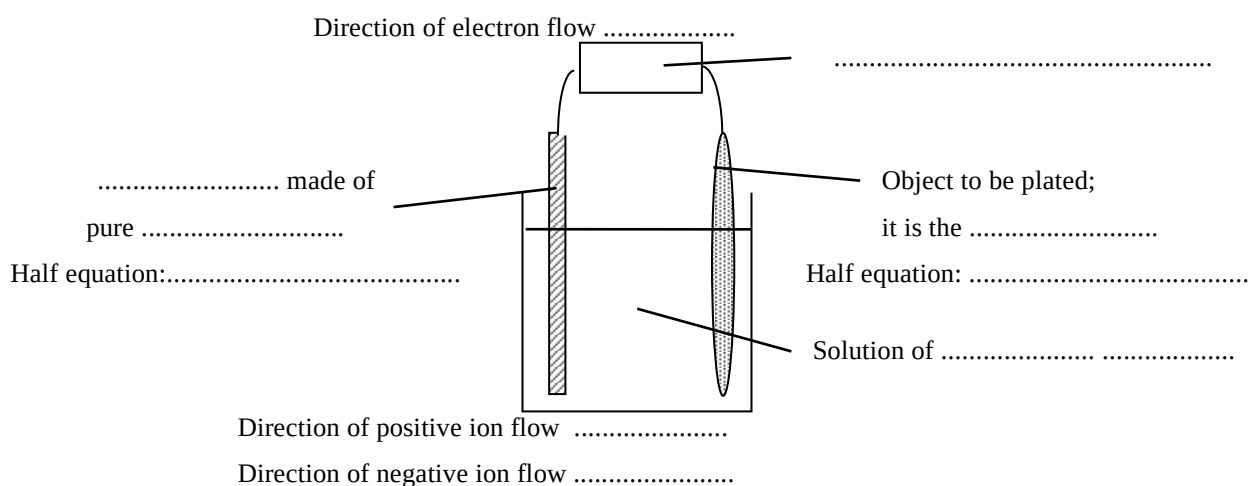
The **aluminium** crystals are removed by filtration and the filtrate is treated and then **tossed away**. The solid aluminium **nitrate** is then **cooled** to **0°C** to remove most of the **sand impurities**.



Alumina, or pure **aluminium**, is formed.

5. The following statements concern the manufacture of aluminium from alumina by the Hall-Heroult process. Identify each statement as true or false.
- Alumina is pure aluminium oxide.
  - In the Hall-Heroult process, alumina is oxidised to form aluminium.
  - Aluminium is produced by passing an electric current through an aqueous solution containing aluminium ions.
  - An electric current cannot be passed through solid aluminium oxide (alumina).
  - To produce aluminium, it would be too expensive to pass the electricity through molten aluminium oxide.
  - One of the electrodes in the Hall-Heroult cell is made of cryolite.
  - In the Hall-Heroult process, cryolite acts as an oxidant.
  - Cryolite is sodium hexafluoroaluminate and it has the formula of  $\text{NaAlF}_6$ .
  - The electrolyte in this process is aluminium oxide dissolved in cryolite.
  - The melting point of the cryolite/alumina mixture is higher than the melting point of alumina.
  - In the cell both the anode and the cathode are composed of carbon.
  - In this process, the aluminium ions are oxidised at the anode.
  - The carbon cathode lines the electrolytic Hall-Heroult cell.
  - The reaction  $\text{Al}^{3+}(\text{l}) + 3\text{e}^- \rightarrow \text{Al}(\text{l})$  occurs at the carbon cathode.
  - Cryolite is oxidised at the anode to form carbon dioxide.
  - The carbon anodes are oxidised in the electrolytic process.

5. q) The reaction that occurs at the anode is  $\text{C(s)} + \text{O}^{2-}(\text{l}) \rightarrow \text{CO(g)} + 2\text{e}^-$   
 r) The carbon cathode is used up in the electrolytic cell.  
 s) The aluminium that forms is less dense than cryolite and so it floats to the top of the cell.  
 t) Solid aluminium forms in the electrolytic process and it sinks to the bottom of the cell. It is then filtered off.  
 u) Aluminium must have a melting point lower than about  $1000^\circ\text{C}$ .  
 v) Only a small amount of electricity is needed to manufacture aluminium.  
 w) It is economically worthwhile to recycle aluminium because it is very expensive to extract aluminium from bauxite.
6. Complete the labels and equations in the following diagrams which show the equipment and chemicals required to plate an object with silver and an object with copper.

**Electroplating with silver:****Electroplating with copper:**

7. a) You are required to produce some copper that is 99.9% pure. You are given a slab of “blister” copper (impure copper), a thin sheet of pure copper, an acidified solution of copper sulfate and a power source. Draw a diagram of the equipment and chemicals you would use to produce the pure copper.
- b) Give the equations for the main reactions that would occur at the anode and the cathode.
- c) Give two examples of other reactions that occur at the anode.
- d) At the completion of the process, name two substances that could be collected from underneath the anode.
- e) Give two examples of positive ions, apart from copper ions, that would be in the electrolytic solution at the completion of the process.
8. Complete the following table showing the reactions of aluminium, zinc and copper with water, acids and bases. Record, with a tick, if a reaction occurs and give the products.

METAL	ALUMINIUM	ZINC	COPPER
Reaction with steam			
Reaction with dilute hydrochloric acid			
Reaction with dilute sulfuric acid			
Reaction with dilute nitric acid			
Reaction with concentrated nitric acid			
Reaction with solution of sodium hydroxide			

9. Write ionic equations for the following reactions. Give observations.
- a) dilute hydrochloric acid is added to aluminium
- b) superheated steam is passed over some zinc
- c) dilute sulfuric acid is added to zinc
- d) a hot solution of sodium hydroxide is added to aluminium
- e) dilute nitric acid is added to copper
- f) aluminium is added to a solution of copper sulfate

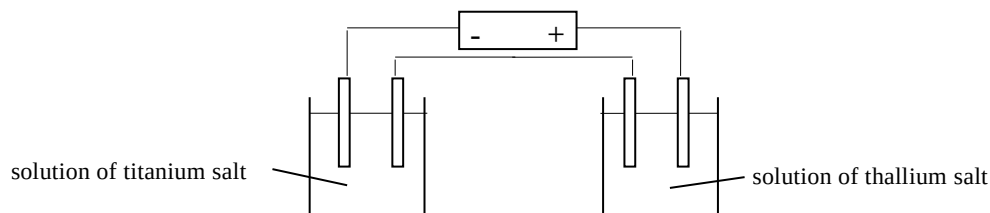
10. What mass of nickel is deposited at the cathode when a current of 5.00 amps flows for 30.0 minutes through an electrolysis cell containing nickel (II) sulfate solution?
11. A passage of a steady current through a solution of cobalt (II) sulfate for one hour caused the deposition of 10.0 g of cobalt metal on the cathode. What was the magnitude of the current?
12. In an electrolytic cell containing silver nitrate solution and using inert electrodes, silver is deposited at the cathode and oxygen evolved at the anode.
- a) Provide equations to explain the products.
- b) If 10.8 g of silver is deposited at the cathode, what volume of oxygen, at STP, will be liberated at the anode?
13. The solution of a certain gold compound was electrolysed for exactly one hour. The average current flow was measured at 1.24 A. During the electrolysis, 3.026 g of gold was deposited. What was the charge on the gold ions involved?
14. A given quantity of electricity passes through two electrolytic cells connected in series. One cell contains a solution of silver nitrate and the other contains a solution of tin (II) chloride. If 2.00 g of silver is deposited in one cell, what mass of tin is deposited in the other?
15. In an electrolytic cell, both electrodes are platinum, and the electrolyte is copper (II) sulfate and, during a certain run, the mass of the cathode increased by 1.27 g. Identify the gaseous product produced at the anode and calculate its volume at 25°C and 100 kPa pressure.
16. 50.0 mL of 0.600 mol L<sup>-1</sup> HCl is electrolysed between inert electrodes by a current of 2.00 A flowing for 15.0 minutes. What volume of 0.200 mol L<sup>-1</sup> NaOH would be needed to neutralise the residual solution?

17. 500 mL of  $0.0200 \text{ mol L}^{-1} \text{ AgNO}_3$  solution is placed in an electrolytic cell and 96.5 C of electricity is passed through. What is the final concentration, in  $\text{mol L}^{-1}$ , of the solution with respect to  $\text{Ag}^+$ ?
18. A steady current is passed through two electrolysis cells connected in series. One cell contains a solution of  $\text{ZnCl}_2$  and the other a solution of  $\text{CrCl}_3$ . After 50 minutes, it is found that 1.87 g of zinc has been deposited in one cell.
- What mass of chromium is simultaneously deposited in the second cell?
  - What was the strength of the current used?

### **TEE Questions**

19. Blister copper may contain iron, cobalt, nickel, zinc, silver, platinum and gold as impurities. When blister copper is refined by electrolysis, what happens to the cobalt and the platinum impurities?
- Both the cobalt and the platinum finish up as ions in the electrolyte solution.
  - Both the cobalt and the platinum fall to the bottom of the electrolysis vessel as part of the anode mud.
  - Both the cobalt and the platinum remain in the blister copper anode which becomes increasingly impure.
  - The cobalt finishes up as  $\text{Co}^{2+}$  in the electrolyte solution and the platinum falls to the bottom
  - The cobalt falls to the bottom and the platinum finishes up as  $\text{Pt}^{2+}$  in the electrolyte solution.

20. One solution contains a titanium (Ti) salt, and a second solution contains a thallium (Tl) salt. When a quantity of electricity is passed through the two solutions as shown in the diagram below, 0.20 mol of Ti is deposited on one cathode and 0.40 mol of Tl on the other cathode.



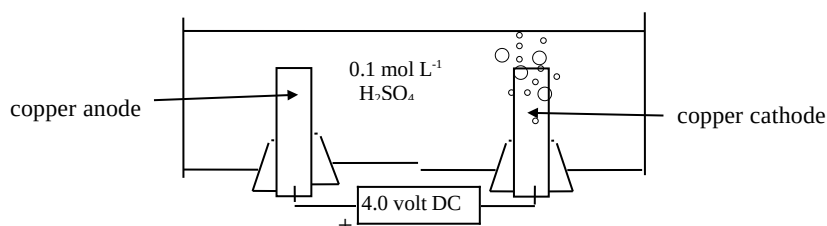
Which of the following conclusions can be drawn from these observations **alone**?

- I Both the Ti and Tl ions are positively charged  
 II The charge on the Ti ion is double that on the Tl ion  
 III The Ti ion has a 2+ charge  
 IV The Tl ion has +1 charge
- A I and II only                      B II only                      C II, III and IV only  
 D All of I, II, III and IV              E None of I, II, III and IV

21. There are several general industrial methods for obtaining metals. Which of the following is not one of these? In other words, which one of the following statements is false?

	Industrial process	Examples
A	A molten salt of a very reactive metal can be electrolysed to produce the metal	$\text{Al}_2\text{O}_3(\text{l})$ to give Al $\text{NaCl}(\text{l})$ to give Na
B	A solution of a salt of a moderately reactive metal can be electrolysed to produce the metal	$\text{Ni}^{2+}(\text{aq})$ to give Ni $\text{Sn}^{2+}(\text{aq})$ to give Sn
C	A sulfide ore of a moderately reactive metal can be roasted in air to produce sulfur dioxide and the metal	$\text{MnS}(\text{s})$ to give Mn $\text{PbS}(\text{s})$ to give Pb
D	An oxide ore of a moderately reactive metal can be heated with carbon to produce a carbon oxide and the metal	$\text{Fe}_3\text{O}_4(\text{s})$ to give Fe $\text{SnO}_2(\text{s})$ to give Sn
E	The least reactive metals occur free in nature and they are obtained by methods which involve separating the metal from rock and sand	Au Pt

22. A student is asked to demonstrate the water is made from the elements hydrogen and oxygen. He decides to set up the following apparatus.



To his surprise a colourless gas is liberated from the cathode as expected, but no gas is liberated from the anode!

Write the equation for the reaction occurring at the cathode.

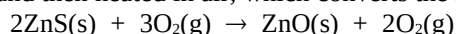
22. Write the equation for the reaction actually occurring at the anode.

Describe how this anode reaction could be observed.

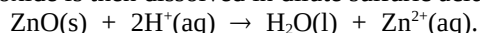
How should the student modify the apparatus so that the intended demonstration is successful?

Write the equation for the intended anode reaction.

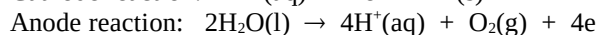
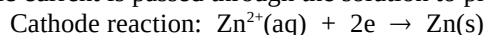
23. Zinc metal is obtained from the ore zinc blende. Zinc blende is mainly zinc sulfide, ZnS. The ore is concentrated by flotation and then heated in air, which converts the zinc sulfide into zinc oxide:



The zinc oxide is then dissolved in dilute sulfuric acid:



An electric current is passed through the solution to produce the pure metal.

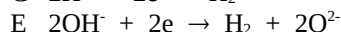
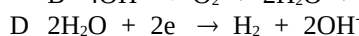
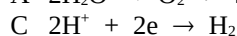
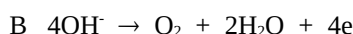
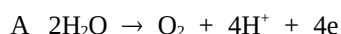


A current of 12.50 ampere is passed through a solution containing zinc ion for 7.50 hours. Calculate

- the theoretical mass of zinc deposited at the cathode and
- the theoretical volume of dry oxygen (at 1.00 atm and 25°C) produced at the anode.

24. When an electric current is passed through 1.0 mol L<sup>-1</sup> sodium hydroxide between two platinum electrodes, which one of

the following half-reactions occurs at the cathode?



25. Experiments show that a greyish blue salt of the metal M has the composition  $\text{MCl}_3 \cdot x\text{H}_2\text{O}$ .

1.5674 g of the salt was dissolved in water, and silver nitrate solution added until no further precipitation occurred.

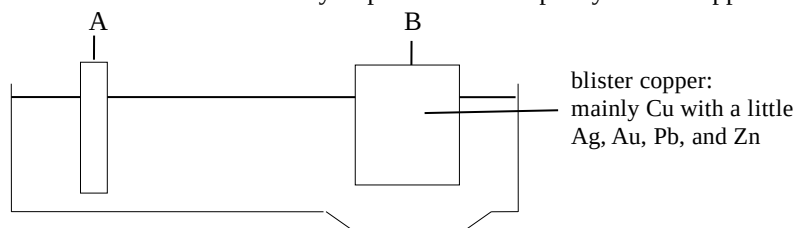
The washed and dried precipitate of silver chloride was found to weigh 2.527 g.

A second (and much larger) sample of the salt was dissolved in water and the solution electrolysed with inert electrodes. When a current of 0.750 ampere was passed through the solution for 6 hours 18 minutes and 30 seconds, the mass of the

cathode increased by 3.047 g.

- Calculate the atomic weight of M
- Calculate the value of x.
- What element could M be?

26. The diagram below represents the industrial electrolysis process used to purify blister copper.

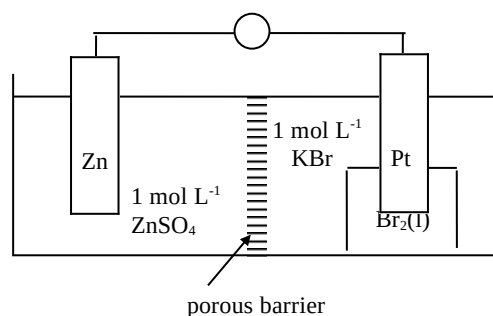


- What connects the points A and B in the external circuit?
- Which way do the electrons flow between A and B in the external circuit?
- What is the electrolyte in the solution?
- What happens to the copper in the blister copper? Where does it finish up?
- What happens to the zinc in the blister copper? Where does it finish up?
- What happens to the silver in the blister copper? Where does it finish up?

27. What is the role of cryolite ( $\text{Na}_3\text{AlF}_6$ ) in the electrolytic production of aluminium?

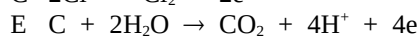
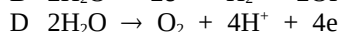
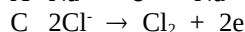
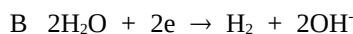
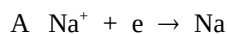


28. The following is a simplified diagram representing an electrochemical cell operating using the chemical reaction

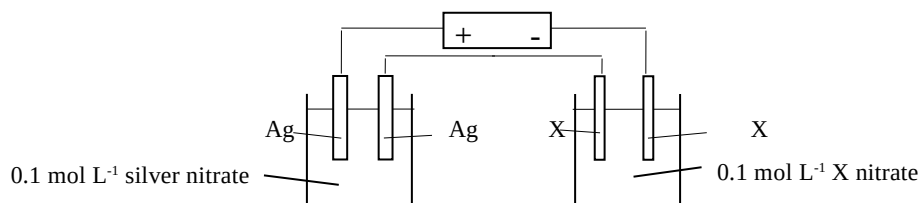
$$\text{Zn} + \text{Br}_2 \rightarrow \text{Zn}^{2+} + 2\text{Br}^-$$


- a) Write the equations for
- the half-reaction that occurs in the left-hand half-cell
  - the half-reaction that occurs in the right-hand half-cell.
- b) The cell is set up, and during its first 10.0 minutes of operation 0.639 g of zinc dissolves from the zinc electrode. calculate the mass of reactant that is consumed in the right-hand cell during this time, and state what the reactant is.
- c) Calculate the average current generated by the cell during this 10.0 minutes.

29. When an electric current is passed through 1.0 mol L<sup>-1</sup> sodium chloride between graphite electrodes, which one of the following half-reactions occurs at the cathode?



30.



In the above electrolysis cell the electrodes in the left hand cell are silver and the electrolyte 0.1 mol L<sup>-1</sup> silver nitrate. The electrodes in the right hand cell are made from a metal X and the electrolyte is 0.1 mol L<sup>-1</sup> solution of the nitrate of X.

In an experiment 0.3052 g of silver is deposited on the cathode in the left hand cell when 0.0830 g of X is deposited on the cathode in the right hand cell.

In a separate experiment a sample of metal X is treated with hot carbon monoxide to form the gaseous compound X(CO)<sub>4</sub>.

The density of this compound is found to be 5.58 g L<sup>-1</sup> at 100°C and 1.00 atm pressure.

- Determine the atomic weight of X.
- Calculate the valence of the metal X in the nitrate of X used in the first experiment.

31. Which of the following metals is commercially refined using electrolysis of an aqueous solution?

- A sodium  
D copper

- B aluminium  
E potassium

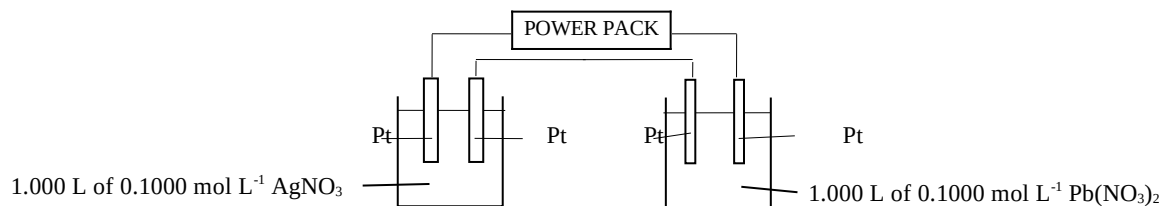
- C iron

32. In the electrolytic extraction of aluminium from its oxide, a substance called cryolite is used. Which of the following

best describes the function of cryolite in this process.

- It oxidises alumina
- It reduces alumina
- It acts as a base towards alumina
- It acts as an acid towards alumina
- It acts as a solvent for alumina.

33. Two electrolysis cells are set up in series as shown in the diagram below. The electrodes are made of inert platinum.



A low current is passed through the system for a time and then switched off. During the electrolysis 1.079 g of silver is deposited on the cathode in the left hand cell.

- Calculate the mass of lead deposited on the cathode in the right hand cell during the electrolysis.
- When the current is switched off, the contents of the right hand cell are stirred.
  - Calculate the concentration of lead ion in the 1.000 L of solution
  - Calculate the concentration of nitrate ion in the solution.
- Explain the relationship of the lead and nitrate ion concentration you calculated in part b).

**Answers - Problem Sheet**

1. i) For each cell - electron flow in external circuit - from left electrode to right electrode  
 - negative ion flow in solution - from right electrode to left electrode  
 - positive ion flow in solution - from left electrode to right electrode
- ii) **cathode** - connected to negative terminal of power supply     **anode** - connected to positive terminal of power supply
- iii) a) anode (left electrode):  $\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^-$      cathode (right electrode):  $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$   
 b) anode:  $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$      cathode:  $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$   
 c) anode:  $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$      cathode:  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$   
 d) anode:  $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$      cathode:  $\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$
2. b) 1.23 volts     c) 1.23 volts     d) 0.02 volts
3. a) cathode:  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$      anode:  $\text{Ni} \rightarrow \text{Ni}^{2+} + 2\text{e}^-$   
 overall:  $2\text{H}_2\text{O} + \text{Ni} \rightarrow \text{H}_2 + 2\text{OH}^- + \text{Ni}^{2+}$
- b) cathode:  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$   
 anode:  $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$  (predicted),      $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$  (actual)  
 overall:  $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 2\text{H}_2$  (predicted),      $2\text{H}_2\text{O} + 2\text{Cl}^- \rightarrow \text{H}_2 + 2\text{OH}^- + \text{Cl}_2$  (actual)
- c) cathode:  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$      anode:  $\text{Pb} \rightarrow \text{Pb}^{2+} + 2\text{e}^-$   
 overall:  $2\text{H}_2\text{O} + \text{Pb} \rightarrow \text{H}_2 + 2\text{OH}^- + \text{Pb}^{2+}$
- d) cathode:  $\text{Na}^+ + \text{e}^- \rightarrow \text{Na}$      anode:  $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$   
 overall:  $2\text{Na}^+ + 2\text{Cl}^- \rightarrow 2\text{Na} + \text{Cl}_2$
- e) cathode:  $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$      anode:  $2\text{O}^{2-} \rightarrow \text{O}_2 + 4\text{e}^-$   
 overall:  $4\text{Al}^{3+} + 6\text{O}^{2-} \rightarrow 4\text{Al} + 3\text{O}_2$

4.

The Bayer process

The purpose of the Bayer process is to prepare pure aluminium from bauxite. Bauxite is composed of aluminium oxide (alumina) and impurities such as silicon dioxide (silica) and iron oxide. After mining, the bauxite is added to a solution of sodium hydroxide and heated. Because aluminium hydroxide is amphoteric it reacts with the hydroxide ions to form aluminium oxide tetrahydroxaluminate ions.

$$\text{Al}(\text{OH})_3(\text{s}) + \text{OH}^-(\text{aq}) \rightarrow \text{Al}(\text{OH})_4^-(\text{aq})$$

The aluminate complex ion is soluble in water. The impurities in the bauxite do not react with the sodium tetrahydroxaluminate soluble in the mixture. The hot mixture is distilled to remove the insoluble impurities. The soluble tetrahydroxaluminate ion remains in the sediment. The filtrate is heated and seed crystals of aluminium are added. Crystals of aluminium nitrate form in the cooled solution.

$$\text{Al}(\text{OH})_4^-(\text{aq}) \rightarrow \text{Al}^{3+}(\text{s}) + 4\text{OH}^-(\text{aq})$$

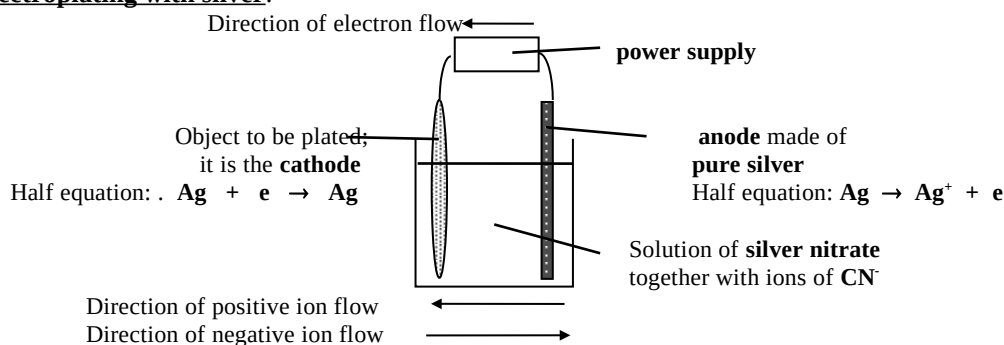
The aluminium crystals are removed by filtration and the filtrate is treated and then tossed away. The solid aluminium hydroxide is then cooled to  $0^\circ\text{C}$  to remove most of the sand impurities. moisture

$$2\text{Al}(\text{OH})_3(\text{s}) \xrightarrow{\text{heated}} 2\text{Al}_2\text{O}_3(\text{s}) + 3\text{H}_2\text{O}(\text{g})$$

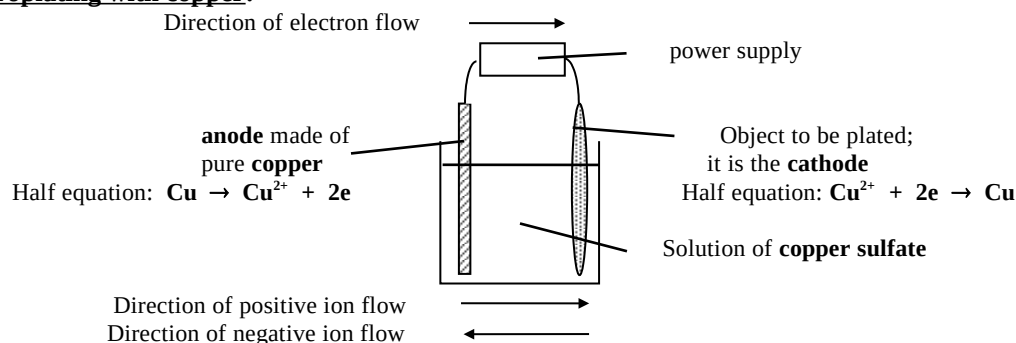
Alumina, or pure aluminium, is formed. aluminium oxide

5. a) true      b) false      c) false      d) true      e) true      f) false  
 g) false      h) true      i) true      j) false      k) true      l) false  
 m) true      n) true      o) false      p) true      q) false      r) false  
 s) false      t) false      u) true      v) false      w) true

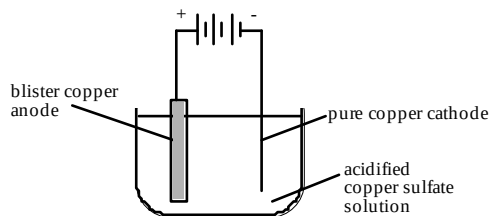
6. **Electroplating with silver:**



**Electroplating with copper:**



7. a)



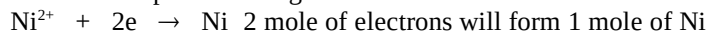
- b) anode:  $\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}$   
 cathode:  $\text{Cu}^{2+} + 2\text{e} \rightarrow \text{Cu}$
- c)  $\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}$        $\text{Ni} \rightarrow \text{Ni}^{2+} + 2\text{e}$
- d) silver, gold
- e) zinc ions, nickel ions

8.

METAL	ALUMINIUM	ZINC	COPPER
Reaction with steam	$\text{Al}_2\text{O}_3 + \text{H}_2$	$\text{ZnO} + \text{H}_2$	no reaction
dilute hydrochloric acid	$\text{Al}^{3+} + \text{H}_2$	$\text{Zn}^{2+} + \text{H}_2$	no reaction
dilute sulfuric acid	no reaction	$\text{Zn}^{2+} + \text{H}_2$	no reaction
dilute nitric acid	no reaction	$\text{Zn}^{2+} + \text{H}_2$	no reaction
concentrated nitric acid	$\text{Al}^{3+} + \text{NO}_2 + \text{H}_2\text{O}$	$\text{Zn}^{2+} + \text{NO}_2 + \text{H}_2\text{O}$	$\text{Cu}^{2+} + \text{NO}_2 + \text{H}_2\text{O}$
solution of sodium hydroxide	$\text{Al}(\text{OH})_4^- + \text{H}_2$	$\text{Zn}(\text{OH})_4^{2-} + \text{H}_2$	no reaction

9. a)  $2\text{Al}(\text{s}) + 6\text{H}^+(\text{aq}) \rightarrow 2\text{Al}^{3+}(\text{aq}) + 3\text{H}_2(\text{g})$  - colourless solution and colourless gas formed
- b)  $\text{Zn}(\text{s}) + \text{H}_2\text{O}(\text{g}) \rightarrow \text{ZnO}(\text{s}) + \text{H}_2(\text{g})$  - white solid and colourless gas form
- c)  $\text{Zn}(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{H}_2(\text{g})$  - colourless solution and colourless gas formed
- d)  $2\text{Al}(\text{s}) + 2\text{OH}^-(\text{aq}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow 2[\text{Al}(\text{OH})_4]^- (\text{aq}) + 3\text{H}_2(\text{g})$  - colourless solution and colourless gas formed
- e)  $3\text{Cu}(\text{s}) + 2\text{NO}_3^-(\text{aq}) + 8\text{H}^+(\text{aq}) \rightarrow 3\text{Cu}^{2+}(\text{aq}) + 2\text{NO}(\text{g}) + 4\text{H}_2\text{O}(\text{l})$  - blue solution and colourless gas which goes brown in air are formed
- f)  $2\text{Al}(\text{s}) + 3\text{Cu}^{2+}(\text{aq}) \rightarrow 2\text{Al}^{3+}(\text{aq}) + 3\text{Cu}(\text{s})$  - brown solid forms, blue colour of solution fades

10. moles of electrons passed through the cell = = 0.09326 mol



i.e. mole of Ni formed =  $\times 0.09326 = 0.04663$

**Mass of nickel formed** =  $0.04663 \times 58.69 = 2.74 \text{ g}$

11. cathode reaction in cell is  $\text{Co}^{2+} + 2\text{e}^- \rightarrow \text{Co}$  mole of cobalt formed in cell = = 0.1697

therefore, mole of electrons passed through cell =  $2 \times 0.1697 = 0.3394$

so, **current** = = **9.10 ampere**

12. a) cathode:  $\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$  anode:  $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$

b) mole of Ag formed in cell = = 0.1001 = mole of electrons passed through cell

moles of  $\text{O}_2$  formed =  $\times 0.1001 = 0.02502$ , **vol of  $\text{O}_2$  at STP** =  $0.02502 \times 22.41 = 0.561 \text{ L}$

13. moles of electrons passed through the cell = = 0.04626 mol

mole of gold formed = = 0.01536

$\text{Au}^{x+} + x\text{e}^- \rightarrow \text{Au}$  1 mole of Au would form from = 3.01  $\approx$  3 mole of electrons

so, **charge** on gold ion must be +3.

14. cathode reaction in first cell is  $\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$

cathode reaction in second cell is  $\text{Sn}^{2+} + 2\text{e}^- \rightarrow \text{Sn}$

mole of silver formed in first cell = = 0.01853

therefore, mole of electrons passed through first cell = 0.01853 = mole of electrons passed through second cell

mole of Sn formed in second cell =  $\frac{1}{2} \times 0.01853 = 0.009268$

**mass of Sn formed** =  $0.009268 \times 118.7 = 1.10 \text{ g}$

15. cathode:  $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$  anode:  $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$  i.e. **oxygen** formed at anode

mass of copper formed = 1.27 g i.e. mole of Cu formed = = 0.01998

mole of electrons passed through cell =  $2 \times 0.01998 = 0.03997$

moles of  $\text{O}_2$  formed =  $\times 0.03997 = 0.009992$ ,

$PV = nRT$  **vol of  $\text{O}_2$**  = = **0.248 L**

16. moles of electrons passed through the cell = = 0.01865 mol

cathode reaction:  $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$  i.e. 1 mole of  $\text{H}^+$  reacts with 1 mole of electrons

so, mole of  $\text{H}^+$  used up = 0.01865 mol mole of  $\text{H}^+$  originally present =  $0.600 \times 0.0500 = 0.0300$

i.e. mole of  $\text{H}^+$  left after the electrolysis reaction =  $0.0300 - 0.01865 = 0.01135$

$\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$  mole of  $\text{OH}^-$  required = 0.01135 **vol of NaOH** = = **0.0568 L**

17. moles of electrons passed through the cell = = 0.00100 mol

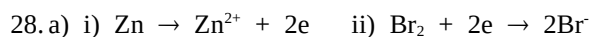
cathode reaction:  $\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$  i.e. 1 mole of  $\text{Ag}^+$  reacts with 1 mole of electrons

so, mole of  $\text{Ag}^+$  used up = 0.00100 mol mole of  $\text{Ag}^+$  originally present =  $0.500 \times 0.0200 = 0.0100$

i.e. mole of  $\text{Ag}^+$  left after the electrolysis reaction =  $0.0100 - 0.00100 = 0.00900$

**conc of  $\text{Ag}^+$**  = = **0.0180 mol L<sup>-1</sup>**

18. a) cathode reaction in first cell is  $\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn}$   
 cathode reaction in second cell is  $\text{Cr}^{3+} + 3\text{e}^- \rightarrow \text{Cr}$   
 mole of zinc formed in first cell = = 0.02860  
 therefore, mole of electrons passed through first cell =  $2 \times 0.02860$   
 = 0.05720 = mole of electrons passed through second cell  
 mole of Cr formed in second cell =  $\times 0.05720 = 0.01907$   
**mass of Cr formed** =  $0.01907 \times 52.0 = \mathbf{0.992 \text{ g}}$   
 b) mole of electrons = 0.05720 so, **current** = = **1.84 A**
19. D                                      20. A                                      21. C
22. - cathode reaction:  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$   
 - anode reaction:  $\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^-$  - observed by the solution around the anode going blue.  
 - modify apparatus by changing the anode to a graphite or platinum electrode  
 - intended anode reaction:  $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$
23. i) moles of electrons passed through the cell = = 3.497 mol  
 $\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn}$  2 mole of electrons will form 1 mole of Zn  
 i.e. mole of Zn formed =  $\times 3.497 = 1.749$   
**Mass of zinc** formed =  $1.749 \times 65.38 = \mathbf{114 \text{ g}}$   
 ii)  $2\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}^+(\text{aq}) + \text{O}_2(\text{g}) + 4\text{e}^-$  4 moles of electrons will form 1 mole of  $\text{O}_2$   
 so 3.497 moles of electrons will form  $\times 3.497 = 0.8742$ ,  
 $PV = nRT$  **vol of  $\text{O}_2$**  = = **21.4 L**
24. D
25. a) The ion of M is  $\text{M}^{3+}$ , so the reaction at the cathode is  $\text{M}^{3+} + 3\text{e}^- \rightarrow \text{M}$ , time = 22710 sec  
 moles of electrons passed through the cell = = 0.1765 mol  
 so, mole of M formed =  $\times 0.1765 = 0.05883$  - which has a mass of 3.047 g  
 i.e. **atomic weight** of M = = **51.8**  
 b) moles of AgCl formed = = 0.01763  
 moles of  $\text{MCl}_3 \cdot x\text{H}_2\text{O}$  =  $\times 0.01763 = 0.005876$  which has a mass of 1.5674 g  
 so, molar mass of  $\text{MCl}_3 \cdot x\text{H}_2\text{O}$  = =  $282.1 \text{ g mol}^{-1}$   
 i.e. formula weight =  $282.1 = 51.8 + 3 \times 35.45 + x \times 18.016$  i.e. **x = 6**  
 c) M probably is **Cr**
26. a) an electrical power supply                                      b) from B to A  
 c) solution of copper sulfate and sulfuric acid  
 d) it is oxidised to **form  $\text{Cu}^{2+}$**  which is then reduced to form **Cu at the cathode**  
 e) it is oxidised to **form  $\text{Zn}^{2+}$** , and it **remains in the solution**  
 f) it remains as **Ag** and it **settles on the bottom** in the “anodic sludge”
27. Acts as the solvent for the alumina ( $\text{Al}_2\text{O}_3$ ) or lowers the melting point of the alumina



b) **Bromine** is consumed in the right-hand cell.

moles of Zn reacted = = 0.009774

from equation, 1 mole of  $\text{Br}_2$  will react with every 1 mole of Zn i.e. moles of  $\text{Br}_2$  that react = 0.009774

**mass of  $\text{Br}_2$  that reacts** =  $0.009774 \times 159.8 = 1.56 \text{ g}$

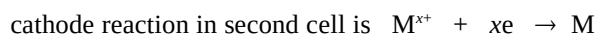
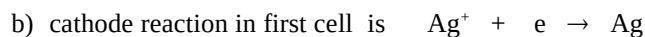
c) moles of electrons produced in the cell =  $2 \times 0.009774 = 0.01955$

average **current** that flows = = **3.14 amp**

29. B

30. a)  $P \times \text{molar mass} = D \times RT$  molar mass of  $\text{M}(\text{CO})_4 = = 170.8 \text{ g mol}^{-1}$

**atomic mass of M** =  $170.8 - 4 \times 28.01 = 58.8$



mole of Ag formed in first cell = = 0.002829

therefore, mole of electrons passed through first cell = 0.002829 = mole of electrons passed through second

cell

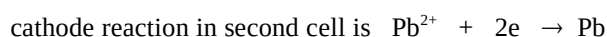
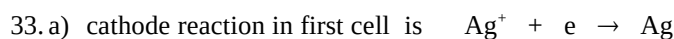
i.e. mole of M formed in second cell =  $\times 0.002829$

But, from mass of M, mole of M formed = = 0.001412 =

i.e.  $x = = 2$ , so **valence of M is +2**

31. D

32. E



mole of silver formed in first cell = = 0.0100

therefore, mole of electrons passed through first cell = 0.0100 = mole of electrons passed through second cell

mole of Pb formed in second cell =  $\frac{1}{2} \times 0.0100 = 0.00500$

**mass of Pb formed** =  $0.00500 \times 207.2 = 1.04 \text{ g}$

b) i) moles of  $\text{Pb}^{2+}$  originally present =  $0.1000 \times 1.000 = 0.1000$

moles of  $\text{Pb}^{2+}$  consumed in the cell reaction = 0.00500

so, moles of  $\text{Pb}^{2+}$  remaining in 1 L solution =  $0.1000 - 0.00500 = 0.0950$

i.e. **conc of  $\text{Pb}^{2+}$**  = **0.0950 mol L<sup>-1</sup>**

ii) **conc of nitrate** =  $2 \times 0.1000 = 0.200 \text{ mol L}^{-1}$

c) Initially the ratio of lead ions to nitrate ions would be 1:2, but some of the lead ions are consumed in the electrolysis reaction, whilst the nitrate ions do not react (to maintain neutrality in the cell, some positive ions,  $\text{H}^+$  would be formed at the anode during the electrolysis)