24.1 ELECTROLYSIS

Initial assessment

1. Heating of FeO results in the formation of Fe_3O_4, as shown.

   Reaction 1: $4\ FeO \rightarrow Fe + Fe_3O_4$

   Each formula unit of Fe_3O_4 contains one Fe^{2+} and two Fe^{3+} ions.
   Show how reaction 1 can be described as a disproportionation reaction.

   ……

   ……

   …… [1]

2. Chlorate(V) ions are powerful oxidising agents.
   (a) The reduction of chlorate(V) ions, ClO_3^-, with SO_2 forms chlorine dioxide, ClO_2, and sulfate ions, SO_4^{2-}, as the only products.
   Construct an equation for this reaction.

   ..... [1]

   (b) (i) Chlorine dioxide, ClO_2, disproportionates with hydroxide ions, $OH^-(aq)$, to form a mixture of ClO_2^- and ClO_3^- ions.
   $2\ ClO_2 + 2\ OH^- \rightleftharpoons ClO_2^- + ClO_3^- + H_2O$

   Explain, using this reaction as an example, what is meant by disproportionation.

   .....

   ..... [1]

   (ii) Deduce the ionic half-equations for the reaction in (b)(i).

   .....

   …… [2]

3. The manganate(VII) ion, MnO_4^-, is used in chemistry as an oxidising agent.
   Three reactions each involve MnO4– as a reagent.
   reaction 2 $MnO_4^- + 5Fe^{2+} + 8H^+ \ Mn^{2+} + 5Fe^{3+} + 4H_2O$
   reaction 3 $C_6H_5CH_3 + 3[O]\ C_7H_6O_2 + H_2O$
   reaction 4 $MnO^{4-} + 4Mn(OH)_2 + 16H^+\ 5Mn^{3+} + 12H_2O$
   Reaction 4 is called a reverse disproportionation reaction.
   Suggest the meaning of reverse disproportionation. Use oxidation numbers to explain your reasoning.

   .....

   .....

   .....

   ..... [2]

Calculation applying the relationship F = Le

4. A molten magnesium salt is electrolysed for 15.0 minutes by a constant current.
   4.75×10^{22} magnesium atoms are produced at the cathode.
   Calculate the value of the current used.

current = ... A [2]

5. A solution containing $[Cu(H_2O)_6]^{2+}$ is electrolysed for 5.00 hours using a constant electric current. 0.764 g of copper metal is formed at the cathode. No other reduction reaction takes place.
   Calculate the electric current, in A, used. Give your answer to three significant figures.

current = ... A [3]

6. When molten sodium chloride is electrolysed, chlorine is liberated at the anode and sodium is liberated at the cathode.
   A sample of molten sodium chloride is electrolysed for 1.50 hours using a current of 4.50 A.
   Calculate the volume of chlorine and the mass of sodium that are liberated under room conditions.

volume of chlorine = ... (ans = 3.02)..... dm^3 mass of sodium = ... (ans = 5.79) ..... g [4]

7. Aluminium is produced industrially by electrolysis of a melt containing large amounts of Al^{3+} ions.
   Calculate the mass of aluminium that is obtained when a current of 300 000 A is passed for 24 hours. Give your answer to three significant figures.

mass = ... units = ...[4]

8. Heating of FeO results in the formation of Fe_3O_4, as shown.

   Reaction 1: $4\ FeO \rightarrow Fe + Fe_3O_4$

   Each formula unit of Fe_3O_4 contains one Fe^{2+} and two Fe^{3+} ions.

   (i) Fe_3O_4 (l) can be electrolysed using inert electrodes to form Fe. (ii) Write the half-equation for the reaction that occurs at the anode during the electrolysis of Fe_3O_4 (l).

   ..... [1]

   (ii) Calculate the maximum mass of iron metal formed when Fe_3O_4 (l) is electrolysed for six hours using a current of 50 A. Assume the one Fe^{2+} and two Fe^{3+} ions are discharged at the same rate.

   mass of iron = ... g [3]

9. When a solution of Al_2O_3 in molten cryolite is electrolysed, aluminium metal is formed at the cathode. The equation is shown.
   $Al^{3+} + 3e^- \rightleftharpoons Al$
   Calculate the maximum mass of aluminium produced when a current of 1.5 A is passed through this solution for 30 minutes.
   Give your answer to two significant figures.

   mass of aluminium = ... g [4]

10. When dilute sulfuric acid is electrolysed, water is split into hydrogen and oxygen.
$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$
A current of x A is passed through the solution for 14.0 minutes. 462 cm^3 of hydrogen are produced at the cathode, measured under room conditions.
(a) Calculate the number of hydrogen molecules produced during the electrolysis.

number of hydrogen molecules = ... [2]

(b) Calculate the total number of electrons transferred to produce this number of hydrogen molecules.

total number of electrons = ... [1]

(c) Calculate the quantity of charge, in coulombs, of the total number of electrons calculated in (b).

quantity of charge = ... C [1]

(d) Calculate the current, x, passed during this experiment.

x = ... A [1]

Calculation of mass and volume

11. When dilute sulfuric acid is electrolysed, oxygen is liberated at the anode.
Dilute sulfuric acid is electrolysed for 15.0 minutes using a current of 0.750 A.
Calculate the volume of oxygen that is liberated under room conditions.

volume of oxygen = ...(ans = 41.969 or 42.047) ..... cm^3 [3]

12. A student electrolyses a solution of KI(aq) for 8 minutes using a direct current.
The half-equation for the reaction that occurs at the anode is given.
$2I^-(aq) \rightarrow I_2(aq) + 2e^-$
(i) Write a half-equation for the reaction that occurs at the cathode.
Include state symbols.

……..... [1]

(ii) After the electrolysis, the $I_2(aq)$ produced requires 21.35 cm^3 of 0.100 mol dm^{-3} $Na_2S_2O_3(aq)$ to react completely.
$I_2(aq) + 2Na_2S_2O_3(aq) \rightarrow 2NaI(aq) + Na_2S_4O_6(aq)$
Calculate the average current used in 8 minutes during the electrolysis.

current = ...(ans = 0.429).....A [3]

13. A solution of $SnCl_2$(aq.) is electrolysed for a measured time using a steady current.
A mass of 2.95 g of tin metal is produced at the cathode.
Al_2O_3(l) is electrolysed for the same time by the same current.
Calculate the mass of aluminium metal produced at the cathode. Give your answer to three significant figures. Show your working.

mass of aluminium metal = ... g [2]

14. Pure water is a very poor conductor of electricity. However, when hydrogen chloride gas is dissolved in water, ions are formed and a current flows during electrolysis.
$HCl\ (g) + aq \rightarrow H^+(aq) + Cl^-(aq)$
The overall change after electrolysis is that hydrogen chloride gas is converted into hydrogen and chlorine.
$2HCl\ (g) \rightarrow H_2(g) + Cl_2(g)$
When a current of 3.10 A is passed through the solution for Y minutes, 351 cm^3 of chlorine are produced at the anode, measured under room conditions.
(a) Calculate the number of chlorine molecules produced during the electrolysis.

number of chlorine molecules = ... [2]

(b) Calculate the total number of electrons transferred to produce this number of chlorine molecules.

total number of electrons = ... [1]

(c) Calculate the quantity of charge, in coulombs, of the total number of electrons calculated in (b).

quantity of charge = ... C [1]

(d) Calculate the time, Y, in minutes, for which the current flows.

Y = ... minutes [1]

15. A solution of iron(II) sulfate, $FeSO_4(aq)$ is electrolyzed with iron electrodes. Under the conditions used, no gas is evolved at the cathode.
A current of 0.640 A is passed for 17.0 minutes. The mass of the cathode increases by 0.185 g.
Use these results to calculate an experimental value for the Avogadro constant, L.
Show your working.

L = ...(6.13×10^{23})..... mol^{-1} [3]

16. (a) Complete Table 5.1 to predict the substance liberated at each electrode during electrolysis of the indicated electrolyte with inert electrodes. [3]

Table 5.1

electrolyte	substance liberated at the anode	substance liberated at the cathode
$PbBr_2(l)$		
concentrated NaCl (aq)		
$Cu(NO_3)_2(aq)$		

(b) An electrolytic cell is set up to determine a value for the Avogadro constant, L. The electrolyte is dilute sulfuric acid, and both electrodes are copper.
When a current of 0.600 A is passed through the acid for 30.0 minutes, the anode decreases in mass by 0.350 g.
(i) State the relationship between the Faraday constant, F, and the Avogadro constant, L.

..... [1]

(ii) Use the experimental information in (b) and data from the table on page 23 to calculate a value for the Avogadro constant, L.
Show all working.

Avogadro constant, L = ...(ans = 6.12 x 10^{23})..... [4]

17. An aqueous solution of copper(II) sulfate is electrolysed using copper electrodes. A current of 1.50 A is passed for 3.00 hours. 5.09 g of copper is deposited on the cathode.
The charge on one electron is -1.60×10^{-19} C.
The relative atomic mass of copper is 63.5.
Use these data to calculate an experimentally determined value for the Avogadro constant, L.
Give your answer to three significant figures.

L = ...(ans= 6.32 x 10^{23})..... mol^{-1} [5]

18. Silicon can also be produced by electrolysis of SiO_2 dissolved in molten $CaCl_2$.
The relevant half-equation for the cathode is shown.
$SiO_2 + 4e^- \rightarrow Si + 2O^{2-}$
Calculate the time, in seconds, required to produce 1.00 g of Si by this electrolysis, using a current of 6.00 A.
Assume no other substances are produced at the cathode.

time = ... s [2]

19. **(i)** Identify the substances formed at the anode and at the cathode during the electrolysis of saturated $CaCl_2$(aq).

at the anode .....

at the cathode ..... [1]

(ii) Calcium can be produced by the electrolysis of molten calcium chloride, $CaCl_2$(l).
Calculate the mass, in g, of Ca formed when a current of 0.75 A passes through $CaCl_2$(l) for 60 minutes.
[*A*r: Ca, 40.1]

mass of Ca = ... g [2]

20. Identify the substances liberated at the anode and at the cathode during the electrolysis of aqueous sodium sulfate, Na_2SO_4(aq).

anode .....

cathode ..... [1]

21. Identify the substances liberated at the anode and at the cathode during the electrolysis of saturated KCl (aq).

at the anode .....

at the cathode ..... [1]

22. Aluminium is extracted from Al_2O_3 by electrolysis. Al_2O_3 is dissolved in cryolite in this process.
(i) The half-equation for the reaction at the anode is shown.

$$O^{2-} + C \rightarrow CO + 2e^-$$

Use this half-equation to write the ionic equation for the electrolysis of Al_2O_3.

..... [1]

(ii) Aluminium oxide is electrolysed for 3.0 hours using carbon electrodes and a current of 3.5×10^5 A.
Calculate the mass of aluminium that is formed.

mass of aluminium = ...(ans= 3.53×10^5)..... g [3]

(iii) Cryolite can be made from SiF_4.
The first step in this conversion is the reaction of SiF_4 with H_2O, forming H_2SiF_6 and SiO_2.
Write an equation for this reaction.

..... [1]

***... ***