PART 1   (60 marks = 30% of paper)

Answer ALL questions in Part 1 on the separate Multiple Choice Answer Sheet provided. Each question in this part is worth 2 marks.

1	[A]	[B]	[C]	X
2	X	[B]	[C]	[D]
3	[A]	[B]	[C]	X
4	[A]	[B]	[C]	X
5	X	[B]	[C]	[D]
6	[A]	[B]	[C]	X
7	[A]	[B]	[C]	X
8	[A]	X	[C]	[D]
9	[A]	X	[C]	[D]
10	[A]	[B]	[C]	X
11	[A]	[B]	X	[D]
12	[A]	[B]	[C]	X
13	[A]	[B]	[C]	X
14	[A]	[B]	X	[D]
15	[A]	[B]	[C]	X

16	[A]	[B]	X	[D]
17	X	[B]	[C]	[D]
18	[A]	X	[C]	[D]
19	[A]	[B]	[C]	X
20	[A]	X	[C]	[D]
21	X	[B]	[C]	[D]
22	[A]	X	[C]	[D]
23	[A]	[B]	[C]	X
24	[A]	X	[C]	[D]
25	[A]	X	[C]	[D]
26	[A]	[B]	X	[D]
27	[A]	[B]	[C]	X
28	X	[B]	[C]	[D]
29	X	[B]	[C]	[D]
30	[A]	[B]	X	[D]

PART 2   (70 marks = 35% of paper)
Answer ALL questions in Part 2 in the spaces provided below.

___

1.   Write equations for any reactions that occur in the following procedures. If no reaction occurs, then write 'no reaction'.

In each case describe in full what you would observe, including any: colours; odours; precipitates (give the colour); or gases evolved (give the colour or describe as colourless). If a reaction occurs but the change is not visible, then you should state this.

a)   Propane is bubbled through bromine water while exposed to sunlight.

Equation   **$C_3H_8 + Br_2 \rightarrow C_3H_7Br + HBr$**   ✓✓

Observation   **Red-orange colour of solution slowly fades. (or NVR)**   ✓

b)   Solutions of barium hydroxide and propanoic acid are mixed.

Equation   **$CH_3CH_2COOH + OH^- \rightarrow CH_3CH_2COO^- + H_2O$**   ✓✓

Observation   **NVR**   ✓

c)   Excess ammonia solution is added to solid zinc hydroxide.

Equation   **$Zn(OH)_2 + 4\,NH_3 \rightarrow Zn(NH_3)_4^{2+} + 2\,OH^-$**   ✓✓

Observation   **White solid dissolves forming a colourless solution.**   ✓

d)   1.0 mol L^{-1} sodium chloride in acid is added to 1.0 mol L^{-1} sodium permanganate

Equation   **$2\,MnO_4^- + 10\,C\ell^- + 16\,H^+ \rightarrow 2\,Mn^{2+} + 5\,C\ell_2 + 8\,H_2O$** ✓✓

Observation   **Purple solution fades to colourless**   ✓
                  (and a yellow-green gas evolves)
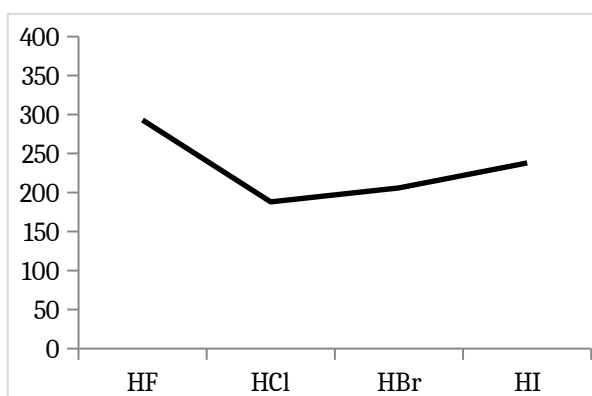
[3 x 3 = 12 marks]

2.   Draw electron dot diagrams for the following, showing all valence electrons
     as either .. or − .

a) NH_4CN	b) H_2SO_4 molecule

a) NH_4CN

$$\left[\begin{array}{c} \text{H} \\ | \\ \text{H}-\text{N}-\text{H} \\ | \\ \text{H} \end{array} \right]^+$$

✔

$[\; | \; C \equiv N \; | \;]^-$

✔

b) H_2SO_4 molecule

$$\begin{array}{c} :\ddot{O}: \\ | \\ H-\ddot{O}-S-\ddot{O}-H \\ | \\ :\ddot{O}: \end{array}$$

✔✔

[4 marks]

3.   Consider the following graph, which depicts the boiling points (in Kelvin) of the
     group VII hydrides.

Briefly account for the shape of the graph.

**HI > HBr > HCℓ due to increasing dispersion forces with increasing
molar mass.**   ✔

HF > HCℓ due to hydrogen bonding between HF molecules.   ✔

[2 marks]

4. Complete the following table using the list of substances below. Whilst there may be more than one possible answer, only one answer per box is required. You may use the same substance more than once.

    HCHO H_2O_2 HCN SiO_2 SO_3 O_3 CO_2 CH_4 $NC\ell_3$

a) a polar linear molecule	**HCN**
b) a substance with hydrogen bonds between its molecules	**H_2O_2**
c) a substance with only dispersion forces between its molecules	**CH_4, SO_3, CO_2**
d) a polar trigonal planar molecule	**HCHO**
e) a polar molecule with non-polar bonds	**H_2O_2, O_3**
f) a non-polar molecule with polar bonds	**CO_2, SO_3**

✓ **each**   [6 marks]

5. Ammonium acetate (ethanoate) is soluble in water. Explain, with the aid of equations, why it would be difficult to predict whether a 0.100 mol L^{-1} solution of ammonium acetate is acidic or basic.
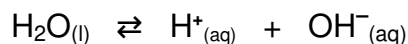
    NH_4^+ is acidic $NH_4^+ + H_2O \rightleftarrows NH_3 + H_3O^+$ ✓

    CH_3COO^- is basic $CH_3COO^- + H_2O \rightleftarrows CH_3COOH + OH^-$ ✓

    One cannot predict whether the solution will be acidic or basic without knowing the position of the equilibria.   ✓✓

[4 marks]

6.   Water self-ionises as follows:

$$H_2O_{(l)} \rightleftarrows H^+_{(aq)} + OH^-_{(aq)}$$

The value of K_w varies with temperature as follows:

   25ºC $K_w = 1.0 \times 10^{-14}$

   50ºC $K_w = 5.5 \times 10^{-14}$

Use the above information to answer and explain the following:

a)   In the self-ionisation of water, is the forward reaction endothermic or exothermic? Explain your answer.

   As T increases, K_w increases   ✓

   Since $K_w = [H^+].[OH^-]$, $[H^+]$ and $[OH^-]$ increases   ✓

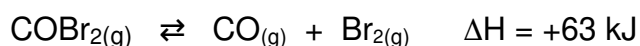   **This is a shift to the right so, applying LCP, forward reaction must be endothermic.**   ✓

b)   Calculate the pH of water at 50ºC.

   $[H^+] = \sqrt{5.5 \times 10^{-4}} = 2.345 \times 10^{-4}$ mol L^{-1}   ✓

   pH $= -\log [H^+] = -\log (2.345 \times 10^{-4}) = 6.63$ ✓

                                                          (3,2 = 5 marks)

7.   The decomposition of carbonyl bromide is given by the following equation:

$$COBr_{2(g)} \rightleftharpoons CO_{(g)} + Br_{2(g)} \qquad \Delta H = +63 \text{ kJ}$$

a)   Write the equilibrium law expression for this reaction.

K = [CO].[Br$_2$] / [COBr$_2$]   ✓

[1 mark]

b)   Complete the following table:

Change in equilibrium system	Effect on the rate of the forward reaction when equilibrium is reestablished (increase, decrease or no change)	Effect on the number of moles of COBr$_2$ (increase, decrease, or no change)	Effect on the equilibrium constant, K (increase, decrease, or no change)
a) carbon monoxide is added to the reaction vessel at constant volume and temperature	**increase**	**increase**	**no change**
b) the temperature is increased at constant volume	**increase**	**decrease**	**increase**
c) argon is added at constant pressure and temperature	**decrease**	**decrease**	**no change**
d) ethene is introduced to the flask at constant volume and temperature **Note - ethene reacts with Br$_2$**	**decrease**	**decrease**	**no change**

✓ **each**   [12 marks]

8. For the following pairs of chemicals, give a simple test and observation by which you can distinguish between them.

    a) two colourless liquids: 3-methyl-2-butanol and 2-methyl-2-butanol

    Test: **add H^+/MnO_4^- or $H^+/Cr_2O_7^{2-}$** ✔

    Observations:

    3-methyl-2-butanol **purple to c/less or orange to green** ✔

    2-methyl-2-butanol **NVR** ✔

    b) two colourless liquids: hydrogen peroxide solution and water

    Test: **add a catalyst (e.g. MnO_2) or a suitable oxidant (e.g. $C\ell_2$) or reductant (e.g. I^-)** ✔

    Observations: **depends on test, but for most:**

    $H_2O_{2(aq)}$ **c/less, o/less gas evolved** ✔

    $H_2O_{(l)}$ **NVR** ✔

[6 marks]

9. Write the anode and cathode reactions for the following cells:

    a) electrolysis of $AgNO_{3(aq)}$ using a Pt anode and Ag cathode

    anode **$2\,H_2O \rightarrow O_2 + 4\,H^+ + 4\,e^-$** ✔

    cathode **$Ag^+ + e^- \rightarrow Ag$** ✔

    b) the H_2/O_2 fuel cell in acidic conditions

    anode **$H_2 \rightarrow 2\,H^+ + 2\,e^-$** ✔

    cathode **$O_2 + 4\,H^+ + 4\,e^- \rightarrow 2\,H_2O$** ✔

    c) recharging the lead-acid accumulator (car battery)

    anode **$PbSO_4 + 2\,H_2O \rightarrow PbO_2 + SO_4^{2-} + 4\,H^+ + 2\,e^-$** ✔
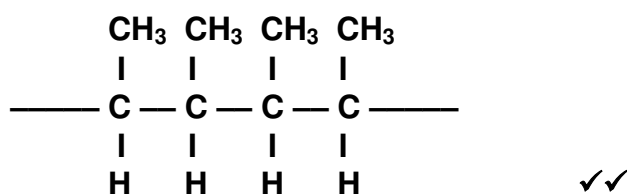
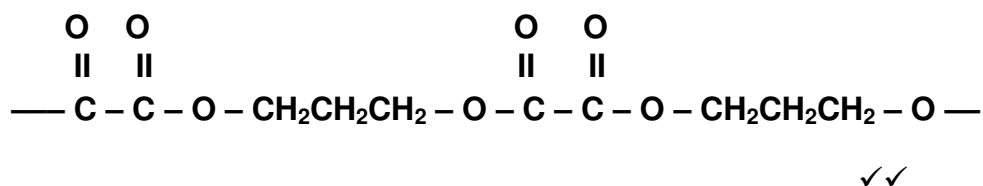   cathode **$PbSO_4 + 2\,e^- \rightarrow Pb + SO_4^{2-}$** ✔

[6 marks]

10.   a)   Use one or more of the following molecules to sketch a section of the appropriate polymer. Your sketch should show at least two repeating units.
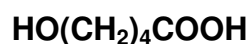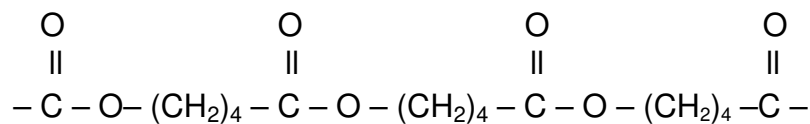
- *cis*-2-butene

- $HOCH_2CH_2CH_2OH$

- $HOOCCOOH$

Addition polymer

$$\begin{array}{cccc} CH_3 & CH_3 & CH_3 & CH_3 \\ | & | & | & | \\ ---C & ---C & ---C & ---C--- \\ | & | & | & | \\ H & H & H & H \end{array}$$ ✓✓

Condensation polymer

$$\begin{array}{cccc} O & O & O & O \\ \| & \| & \| & \| \\ ---C-C-O-CH_2CH_2CH_2-O-C-C-O-CH_2CH_2CH_2-O--- \end{array}$$ ✓✓
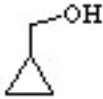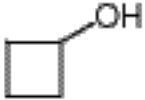
b)   Sketch the monomer/s that would be used to make the polymer whose structure is shown below.

$$\begin{array}{cccc} O & O & O & O \\ \| & \| & \| & \| \\ -C-O-(CH_2)_4-C-O-(CH_2)_4-C-O-(CH_2)_4-C- \end{array}$$

$HO(CH_2)_4COOH$ ✓✓

[2,2,2 = 6 marks]

11.   There are several isomers with molecular formula C_4H_8O. Draw full structural formula(e) of isomer(s) that fit the following descriptions;

Description	Structural Formula(e)
a) the product of oxidising 2-butanol using acidified sodium dichromate	$CH_3COCH_2CH_3$ ✓
b) it can be oxidised to 2-methylpropanoic acid using acidified potassium permanganate	$(CH_3)_2CHCHO$ ✓
c) a saturated primary alcohol	✓
d) a saturated secondary alcohol	✓

e) a pair of geometric isomers	H CH₂OH H₃C CH₂OH
	  \ / \ /
	   C = C and C = C
	  / \ / \
	H₃C H H H
	
	or
	
	HO CH₃ H₃C CH₃
	  \ / \ /
	   C = C and C = C
	  / \ / \
	H₃C H HO H
	
	or
	
	HO H HO CH₂CH₃
	  \ / \ /
	   C = C and C = C
	  / \ / \
	H CH₂CH₃ H H
	
	✓✓

[6 marks]

END OF PART 2

PART 3   (50 marks = 25% of paper)

1.   a)

P	$C\ell$	S

m(P) = $\dfrac{2 \times 30.97 \times 0.562}{222.56}$
 	
     = 0.1564 g
 	
% (P) = $\dfrac{0.1564 \times 100}{0.847}$
 	
     =   18.47 %
 	
✓✓
	n(Ag^+) = n($C\ell^-$)
	     = 0.5 x 0.0225
	     = 0.01125 mol
	
	m($C\ell$) = 0.01125 x 35.45
	     = 0.3988 g
	
	%($C\ell$) = $\dfrac{0.3988 \times 100}{0.639}$
	
	    = 62.41 %
	
	✓✓
		%(S) = 100 − [%P + % $C\ell$]
		
		    = 19.12 %
		
		✓

n(P) = 18.47/30.97
     = 0.5964
 	
ratio :   **1**
(/0.5962)
	n($C\ell$) = 62.41/35.25
	     = 1.760
	
	3
		n(S) = 19.12/32.06
		     = 0.5964
		
		1
		
		        ✓

<u>**EF :   PS$C\ell_3$**</u>   ✓

b)   n(compound) = PV/RT = $\dfrac{41.33 \times 0.3}{8.315 \times 523.1}$ =   0.002851 mol   ✓✓

M(compound) = m/n   = 0.482/0.002851   = <u>**169.1 g mol^{-1}**</u>   ✓

c)   **M(PS$C\ell_3$) x n   =   169.1**

169.4 x n   = 169 .1   n = 1

MF :   <u>PS$C\ell_3$</u>   ✓

2. $n(Br_2)_{total}$ = c.V = 0.3 x 0.020 = 0.006000 mol   ✓

$n(Na_2S_2O_3)_{reacted}$ = c.V = 0.0314 x 0.01742 = 0.0005470 mol   ✓

$n(Br_2)_{excess}$ = 4 x $n(Na_2S_2O_3)$ = 4 x 0.000547 = 0.002188 mol   ✓

$n(Br_2)_{reacted}$ = 0.006000 − 0.002188 = 0.003812 mol   ✓

$n(C_2H_4)$ = $n(Br_2)$ = 0.003812 mol   ✓

$V(C_2H_4)$ = nRT/P = $\underline{0.003812 \ x \ 8.315 \ x \ 298.1}$ = 0.09573 L   ✓✓
                                    98.7

%(C_2H_4) by volume = $\underline{0.09573 \ x \ 100}$ = $\underline{9.57 \ \%}$ ✓
                                        1.00

3   a)

Solution X	Solution Y	Solution Z

$[H_2SO_4]$ = 0.210 x 50/250
 	
      = $\underline{0.0420 \ mol \ L^{-1}}$
 	
                                    ✓
	$n(HC\ell)$ = V/22.41
	      = 0.585/22.41
	      = 0.0261 mol
	
	                    ✓
	
	$[HC\ell]$ = n/V
	      = 0.0261/0.50
	      = $\underline{0.0522 \ mol \ L^{-1}}$
	                    ✓
		$n(NaOH)$ = c.V
		      = 0.557/39.998
		      = 0.01393 mol
		
		                    ✓
		
		$[NaOH]$ = n/V
		      = 0.01393/0.100
		      = $\underline{0.139 \ mol \ L^{-1}}$
		                    ✓

b) H^+ + OH^- → H_2O

$n(H^+)$ from H_2SO_4 = 2 x 0.03 x 0.0420 = 0.002520 mol   ✓

$n(H^+)$ from $HC\ell$ = 0.03 x 0.0522 = 0.001566 mol   ✓

$n(H^+)_{total}$ = 0.001566 + 0.00252 = 0.004086 mol   ✓

$n(OH^-)$ = 0.03 x 0.1393 = 0.004170 mol   ✓

$n(OH^-)_{excess}$ = 0.004170 − 0.004086 = 0.00008400 mol   ✓

$[OH^-]$ = 0.00008400 / 0.0900 = 0.0009333 mol L^{-1} ✓

pOH = − log$[OH^-]$ = 3.02   ✓

pH = 14 − pOH = $\underline{11.0}$ ✓

4.   a) $n(H_2C_2O_4) = 4.277/90.036 = 0.04750$ mol   ✓

      $[H_2C_2O_4] = n/v = 0.04750 \times 20//250 = 0.003800$ mol L^{-1} ✓

      $n(Cr_2O_7^{2-}) = 1/3 \times 0.003800 = 0.001267$ mol   ✓

      $[Cr_2O_7^{2-}] = n/v = 0.001267/0.02555 = \underline{0.0496\ mol\ L^{-1}}$ ✓

      b) $n(Cr_2O_7^{2-}) = c \times v = 0.0496 \times 0.03546 = 0.001758$ mol   ✓

      $n(CH_3CH_2OH) = 3/2 \times 0.001758 = 0.002637$ mol   ✓

      $m(CH_3CH_2OH) = 0.002637 \times 46.068 = 0.1215$ g   ✓

      % (alcohol) by mass = $\underline{\dfrac{0.1215 \times 100}{25}} = \underline{0.486\ \%}$ ✓

5.   a) $n(Au) = 0.124/197.0 = 0.0006294$ mol   ✓

      $n(e) = n(Au) = 0.0006294$ mol   ✓

      since cathode reaction is $Au(CN)_2^- + e^- \rightarrow Au + 2\ CN^-$

      $Q = n(e) \times 96490 = 0.0006294 \times 96490 = 60.73$ C   ✓

      With % efficiency $Q = 100/68.1 \times 60.73 = 89.18$ C   ✓

      $t = Q/I = 89.18/5.20 = \underline{17.1\ seconds}$ ✓

      b) $Hg_2^{2+} + 2\ e^- \rightarrow 2\ Hg$

      $Q = 34.30 \times 5.20 = 178.37$ C   ✓

      $n(e^-) = 178.37/96490 = 0.001848$ mol   ✓

      $n(Hg) = n(e^-) = 0.001848$ mol   ✓

      $m(Hg) = 0.001848 \times 200.6 = 0.3708$ g   ✓

      true m(Hg) obtained $= 0.813 \times .3708 = \underline{0.301\ g}$ ✓

END OF PART 3

PART 4   (20 marks = 10% of paper)

There is no single correct response to this question.

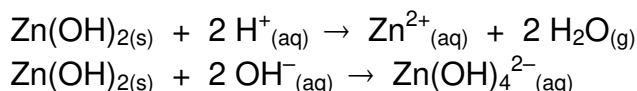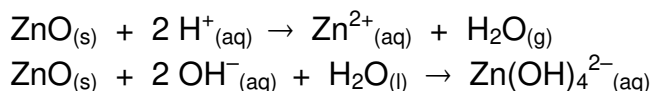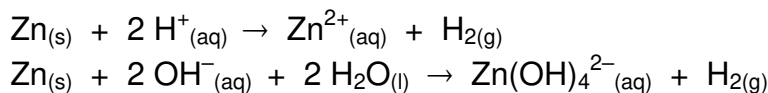*In order to achieve high marks, responses would need to:*
- be relevant to the topic/s referred to in the question
- make specific reference to the material/information presented
- provide equations where appropriate
- link evidence to theory
- contain no errors

Listed below are some points that could have been addressed.

Zinc is a metallic solid. Its structure is that of Zn^{2+} ions in a sea of delocalised electrons (sketch diagram). The metallic bond is the electrostatic attraction between cations and surrounding delocalised electrons. These bonds are strong, so zinc has moderately high melting and boiling points (420ºC and 907ºC respectively). The non-directional nature of the bonds accounts for its malleability and ductility. The delocalised valance electrons provide the mobile charged particles required for electrical conductivity.

Zinc oxide is an ionic solid. Its structure is that of a three-dimensional network of alternate Zn^{2+} and O^{2-} ions (again, include a diagram). The ionic bond is the electrostatic attraction between oppositely charged ions. The bond is very strong, so zinc oxide has a high melting point (1975ºC).

Zinc, zinc oxide and zinc hydroxide are amphoteric, which means that these substances can react with both acids and bases. This is demonstrated by the equations below, which show the reaction of each with H^+ and OH^-:

$$Zn_{(s)} + 2\,H^+_{(aq)} \rightarrow Zn^{2+}_{(aq)} + H_{2(g)}$$
$$Zn_{(s)} + 2\,OH^-_{(aq)} + 2\,H_2O_{(l)} \rightarrow Zn(OH)_4{}^{2-}_{(aq)} + H_{2(g)}$$

$$ZnO_{(s)} + 2\,H^+_{(aq)} \rightarrow Zn^{2+}_{(aq)} + H_2O_{(g)}$$
$$ZnO_{(s)} + 2\,OH^-_{(aq)} + H_2O_{(l)} \rightarrow Zn(OH)_4{}^{2-}_{(aq)}$$

$$Zn(OH)_{2(s)} + 2\,H^+_{(aq)} \rightarrow Zn^{2+}_{(aq)} + 2\,H_2O_{(g)}$$
$$Zn(OH)_{2(s)} + 2\,OH^-_{(aq)} \rightarrow Zn(OH)_4{}^{2-}_{(aq)}$$

In the extraction of zinc, the sphalerite is heated strongly in air. The sulfide is oxidised to SO_2, with ZnS converted to ZnO. The zinc is recovered from zinc oxide by carbon reduction. This is similar to the recover of iron from iron(III) oxide via carbon reduction, except that the reducing agent in the latter is CO rather than C.

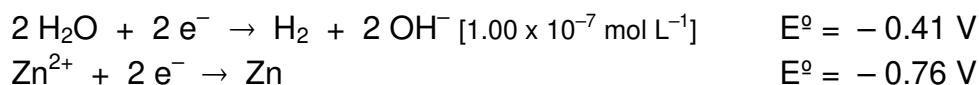In the alternative method for the extraction of zinc from zinc oxide, the zinc oxide is dissolved in sulfuric acid:

$$ZnO_{(s)} + 2\ H^+_{(aq)} \rightarrow Zn^{2+}_{(aq)} + H_2O_{(g)}$$
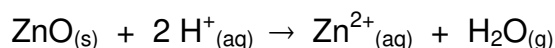
and the zinc recovered by electrolytic reduction of the solution (sketch a diagram):
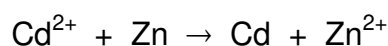
$$Zn^{2+} + 2\ e^- \rightarrow Zn$$
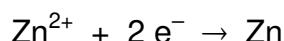
In electrolysis, electrical energy is used to drive a non-spontaneous chemical reaction. Reduction occurs at the negative electrode (connected to negative terminal of external power source) and oxidation at the positive electrode (connected to the positive terminal). The flow of charge through the solution is via movement of ions - anions towards anode, cations towards cathode.

Under standard conditions, the reduction of zinc ions would not occur because water is a stronger oxidant, as demonstrated by their standard reduction potentials

$$2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH^- \text{ [1.00 x 10}^{-7}\text{ mol L}^{-1}]\qquad E^\circ = -0.41\ V$$
$$Zn^{2+} + 2\ e^- \rightarrow Zn \qquad\qquad\qquad\qquad\qquad\qquad E^\circ = -0.76\ V$$

However, at sufficiently high concentration the reduction of Zn^{2+} becomes more likely.

In ores containing cadmium, cadmium ions are removed from solution by displacement with powdered zinc. This reaction can occur because zinc is a more reactive metal than cadmium:

$$Cd^{2+} + 2\ e^- \rightarrow Cd \qquad\qquad\qquad\qquad\qquad E^\circ = -0.40\ V$$
$$Zn^{2+} + 2\ e^- \rightarrow Zn \qquad\qquad\qquad\qquad\qquad E^\circ = -0.76\ V$$

$$Cd^{2+} + Zn \rightarrow Cd + Zn^{2+}$$

The zinc that goes into solution can be recovered via the subsequent electrolytic reduction.

A similar reaction occurs in the use of powdered zinc to recover gold from the aurocyanide complex:

$$2\ Au(CN)_2^-{}_{(aq)} + Zn_{(s)} \rightarrow Zn(CN)_4^{2-}{}_{(aq)} + 2\ Au_{(s)}$$
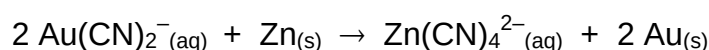
Many other uses of zinc rely on its ability to act as a reductant, such as the use of zinc in dry cells. The dry cell is an electrochemical cell or battery, in which a spontaneous reaction occurs. Since the oxidant and reductant are physically separated, the reaction will only occur if the battery is connected via an external circuit. This allows the flow of electrons to be utilised. The flow of charge within the battery is via ions; anions flow towards the anode and cations towards the cathode. Note that in the electrochemical cell the polarities of the anode and cathode are negative and positive respectively.
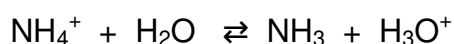
The dry cell has an outer zinc casing, which contains an NH_4Cl / MnO_2 paste and a carbon rod (sketch a diagram). The zinc serves as the anode and is oxidised:

$$Zn \rightarrow Zn^{2+} + 2\,e^-$$
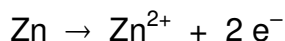
The carbon rod serves as the cathode, at which manganese is reduced:

$$2\,MnO_2 + 2\,H^+ + 2\,e^- \rightarrow Mn_2O_3 + H_2O$$
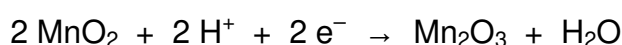
The hydrogen ions are supplied by the hydrolysis of ammonium ions, which are weakly acidic:

$$NH_4^+ + H_2O \rightleftarrows NH_3 + H_3O^+$$

The dry cell is a primary cell - meaning that it cannot be recharged - and typically generates an EMF of approximately 1.5 V.

Zinc is also used to prevent the corrosion of iron (rusting). The first stage of rusting involves the oxidation of iron by oxygen in the presence of water:

$$Fe \rightarrow Fe^{2+} + 2\,e^-$$
$$O_2 + H_2O + 4\,e^- \rightarrow 4\,OH^-$$
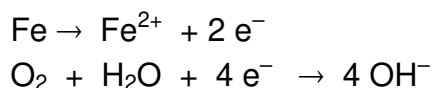
$Fe(OH)_2$ forms, which is further oxidised to $Fe(OH)_3$, which is dehydrated forming the familiar reddish-brown Fe_2O_3. Unlike the oxides of many other metals (e.g. zinc, aluminium), the oxidised layer at the surface of the iron affords no protection to the underlying metal.

Corrosion prevention targets the initial oxidation of iron.

If zinc is physically connected, either directly or indirectly (by an electrical conductor), to an iron/steel structure an electrochemical cell is established (sketch a diagram). Since zinc is a stronger reductant, it will undergo oxidation:

$$Zn \rightarrow Zn^{2+} + 2\,e^-$$
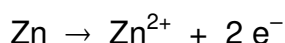
The iron/steel structure acts as the cathode where a reduction reaction occurs, possibly:

$$O_2 + H_2O + 4\,e^- \rightarrow 4\,OH^-$$
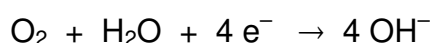
Since the zinc is consumed, it is referred to a sacrificial anode.

Zinc is used to galvanise iron/steel objects. This involves coating the object in a layer of zinc by electroplating or by immersion in a bath of molten zinc. The layer of zinc serves as a physical barrier, preventing the underlying iron/steel from contact with O_2 and H_2O. If scratched, the iron/steel continues to be protected because the zinc in the stronger reductant and is preferentially oxidised, making the exposed iron cathodic.

Zinc is a transition metal. Like many transition metals it forms complex ions - $Zn(CN)_4^{2-}$, $Zn(OH)_4^{2-}$, $Zn(NH_3)_4^{2+}$. However, unlike many transition metals it is colourless in solution.

END OF EXAMINATION