



**Q1.**

(a) Lead chloride ( $\text{PbCl}_2$ ) is an ionic salt with relatively low aqueous solubility; it has a  $K_{\text{sp}}$  value of  $1.17 \times 10^{-5}$  at  $25^\circ\text{C}$ .

(i) Write an equation showing the equilibrium established between solid  $\text{PbCl}_2$  and its ions in solution. (2 marks)

(ii) Calculate its molar solubility in pure water at  $25^\circ\text{C}$ . Hence distinguish between the  $K_{\text{sp}}$  and the *molar solubility* of a sparingly soluble ionic salt. (7 marks)

(iii) Would you expect  $\text{PbCl}_2$  to be more soluble in water or in a solution of sodium chloride ( $\text{NaCl}$ )? Explain your answer. (3 marks)

(b) When a fuel is burned in a cylinder fitted with a piston, the volume expands from 0.255L to 1.45L against an external pressure of 1.02 atm. and 875J of heat are released. What is the change in the energy ( $\Delta E$ ) for the burning of the fuel? Express your answer in joules (J) where 101.3J is equivalent to 1L·atm. (6 marks)

(c) What do you understand by the term *reaction order*? Sulfuryl chloride ( $\text{SO}_2\text{Cl}_2$ ) decomposes according to the equation



Describe how one might determine the order of this decomposition reaction.

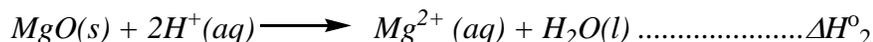
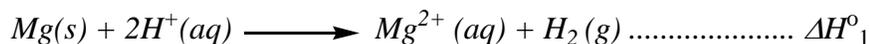
(7 marks)

**Q2.**

(a) Write a laboratory procedure which could be used to measure the amount of heat absorbed or released in a chemical reaction. In your answer describe the reaction equipment and state the precautions which must be taken to minimize errors

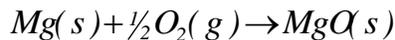
(9 marks)

(b) When solid magnesium (0.6g) was added to an aqueous solution of acid (60cm<sup>3</sup>), the temperature of the solution increased from 15°C to 53°C. Calculate the heat released by the 0.6g sample of Mg; hence determine the reaction enthalpy ( $\Delta H^\circ_1$ ). Express your answer in kJ mol<sup>-1</sup>. In a second experiment, a temperature increase of 12°C was observed when a 1g sample of MgO was added to 60cm<sup>3</sup> of an aqueous acid solution. Determine a value for  $\Delta H^\circ_2$ . *Specific heat capacity water: 4.180 J g<sup>-1</sup> K<sup>-1</sup>.*



(7 marks)

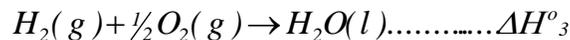
(c) The *standard enthalpy of formation* of MgO is the enthalpy change for the reaction



(i) What do you understand by the term *standard enthalpy of formation*?

(3 marks)

(ii) Calculate the standard enthalpy of formation ( $\Delta H^\circ_f$ ) of MgO from its elements using the thermochemical equations and enthalpies from part (b) and the enthalpy of formation of water (– 285.5kJ mol<sup>-1</sup>)



(6 marks)

**Q3.**

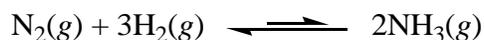
- (a) Give a brief account of the main principles underlying the collision model theory. (7 marks)
- (b) What does the term  $A$  in the Arrhenius equation  $k = Ae^{-E_a/RT}$  represent? (3 marks)
- (c) The decomposition of ozone  $O_3(g) \rightarrow O_2(g) + O(g)$  is important to many atmospheric reactions. A study of the kinetics of the reaction over a range of temperatures resulted in the data shown in the table

<b>T (K)</b>	700	900	1100	1300	1600	1900
<b>k (M<sup>-1</sup>s<sup>-1</sup>)</b>	4.85 x 10 <sup>4</sup>	1.70 x 10 <sup>6</sup>	1.63 x 10 <sup>7</sup>	7.83 x 10 <sup>7</sup>	3.93 x 10 <sup>8</sup>	1.19 x 10 <sup>9</sup>

- (i) Deduce the order of the reaction from the rate constant units and write the rate law for the decomposition. (3 marks)
- (ii) Using the natural log of the Arrhenius equation  $\ln k = -E_a/RT + \ln A$ , construct the appropriate plot and determine the activation energy ( $E_a$ ) for the decomposition reaction. ( $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$ ) (12 marks)

**Q4.**

- (a) Distinguish between *homogeneous* and *heterogeneous* equilibria. Give an example of each type (5 marks)
- (b) State and explain Le Châtelier's Principle (5 marks)
- (c) Under normal conditions, the reaction for the synthesis of ammonia (NH<sub>3</sub>) from N<sub>2</sub> and H<sub>2</sub> is slow, low yielding, and exothermic ( $-92 \text{ kJ mol}^{-1}$ ).



The optimum conditions for the industrial (Haber) process are 400–500°C, ~200atm pressure, iron catalyst and removal of NH<sub>3</sub> on formation. Discuss how these reaction conditions may have been chosen and found suitable for the process.

(15 marks)

**Q5.**

(a) Explain the term *amphoteric*. Write equations that demonstrate the amphoteric character of the hydrogen carbonate ion ( $\text{HCO}_3^-$ ) in aqueous solution.

(5 marks)

(b) Calculate the pH of the following solutions:

(i) 0.025M  $\text{HNO}_3$

(ii) A solution prepared by dissolving 12.5g of solid NaOH in water and diluting to a volume of  $750\text{cm}^3$

(6 marks)

(c) Write an equation which shows the ionization of a weak acid (HA) in aqueous solution and give an expression for the corresponding acid dissociation constant,  $K_a$ .

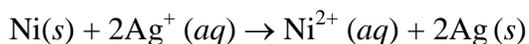
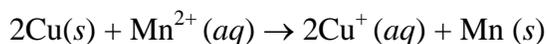
(4 marks)

(d) Summarize the main characteristics of a buffer solution. Derive an equation which relates the pH of a buffer solution to its  $\text{p}K_a$  and its composition. Hence or otherwise, determine the pH of a buffer at  $25^\circ\text{C}$  that is 0.05M in benzoic acid ( $\text{C}_6\text{H}_5\text{COOH}$ ) and 0.15M in sodium benzoate ( $\text{C}_6\text{H}_5\text{COONa}$ ). The  $K_a$  value for benzoic acid at  $25^\circ\text{C}$  is  $6.5 \times 10^{-5}$ .

(10 marks)

**Q6.**

- (a) Name and distinguish between two types of electrochemical cells which utilize redox reactions. (4 marks)
- (b) Write a note on the function of salt bridges in electrochemical cells. Give examples of two types of salt bridge. (5 marks)
- (c) What do you understand by the term *cell potential*? What units are used to measure cell potential? (4 marks)
- (d) With the aid of a fully labelled diagram, describe the standard hydrogen electrode. (6 marks)
- (e) Use the Standard Reduction Potential Tables provided to calculate  $E^\circ_{\text{cell}}$  for the following redox reactions: hence determine which one of the two reactions is spontaneous



Identify the oxidizing and reducing agents in each reaction

(6 marks)

TABLE 18.1 Standard Electrode Potentials at 25 °C

Reduction Half-Reaction	$E^\circ$ (V)
$F_2(g) + 2 e^- \longrightarrow 2 F^-(aq)$	2.87
$H_2O_2(aq) + 2 H^+(aq) + 2 e^- \longrightarrow 2 H_2O(l)$	1.78
$PbO_2(s) + 4 H^+(aq) + SO_4^{2-}(aq) + 2 e^- \longrightarrow PbSO_4(s) + 2 H_2O(l)$	1.69
$MnO_4^-(aq) + 4 H^+(aq) + 3 e^- \longrightarrow MnO_2(s) + 2 H_2O(l)$	1.68
$MnO_4^-(aq) + 8 H^+(aq) + 5 e^- \longrightarrow Mn^{2+}(aq) + 4 H_2O(l)$	1.51
$Au^{3+}(aq) + 3 e^- \longrightarrow Au(s)$	1.50
$PbO_2(s) + 4 H^+(aq) + 2 e^- \longrightarrow Pb^{2+}(aq) + 2 H_2O(l)$	1.46
$Cl_2(g) + 2 e^- \longrightarrow 2 Cl^-(aq)$	1.36
$Cr_2O_7^{2-}(aq) + 14 H^+(aq) + 6 e^- \longrightarrow 2 Cr^{3+}(aq) + 7 H_2O(l)$	1.33
$O_2(g) + 4 H^+(aq) + 4 e^- \longrightarrow 2 H_2O(l)$	1.23
$MnO_2(s) + 4 H^+(aq) + 2 e^- \longrightarrow Mn^{2+}(aq) + 2 H_2O(l)$	1.21
$IO_3^-(aq) + 6 H^+(aq) + 5 e^- \longrightarrow \frac{1}{2} I_2(aq) + 3 H_2O(l)$	1.20
$Br_2(l) + 2 e^- \longrightarrow 2 Br^-(aq)$	1.09
$VO_2^+(aq) + 2 H^+(aq) + e^- \longrightarrow VO^{2+}(aq) + H_2O(l)$	1.00
$NO_3^-(aq) + 4 H^+(aq) + 3 e^- \longrightarrow NO(g) + 2 H_2O(l)$	0.96
$ClO_2(g) + e^- \longrightarrow ClO_2^-(aq)$	0.95
$Ag^+(aq) + e^- \longrightarrow Ag(s)$	0.80
$Fe^{3+}(aq) + e^- \longrightarrow Fe^{2+}(aq)$	0.77
$O_2(g) + 2 H^+(aq) + 2 e^- \longrightarrow H_2O_2(aq)$	0.70
$MnO_4^-(aq) + e^- \longrightarrow MnO_4^{2-}(aq)$	0.56
$I_2(s) + 2 e^- \longrightarrow 2 I^-(aq)$	0.54
$Cu^+(aq) + e^- \longrightarrow Cu(s)$	0.52
$O_2(g) + 2 H_2O(l) + 4 e^- \longrightarrow 4 OH^-(aq)$	0.40
$Cu^{2+}(aq) + 2 e^- \longrightarrow Cu(s)$	0.34
$SO_4^{2-}(aq) + 4 H^+(aq) + 2 e^- \longrightarrow H_2SO_3(aq) + H_2O(l)$	0.20
$Cu^+(aq) + e^- \longrightarrow Cu^0(aq)$	0.16
$Sn^{4+}(aq) + 2 e^- \longrightarrow Sn^{2+}(aq)$	0.15
$2 H^+(aq) + 2 e^- \longrightarrow H_2(g)$	0
$Fe^{3+}(aq) + 3 e^- \longrightarrow Fe(s)$	-0.036
$Pb^{2+}(aq) + 2 e^- \longrightarrow Pb(s)$	-0.13
$Sn^{2+}(aq) + 2 e^- \longrightarrow Sn(s)$	-0.14
$Ni^{2+}(aq) + 2 e^- \longrightarrow Ni(s)$	-0.23
$Cd^{2+}(aq) + 2 e^- \longrightarrow Cd(s)$	-0.40
$Fe^{2+}(aq) + 2 e^- \longrightarrow Fe(s)$	-0.45
$Cr^{3+}(aq) + e^- \longrightarrow Cr^{2+}(aq)$	-0.50
$Cr^{3+}(aq) + 3 e^- \longrightarrow Cr(s)$	-0.73
$Zn^{2+}(aq) + 2 e^- \longrightarrow Zn(s)$	-0.76
$2 H_2O(l) + 2 e^- \longrightarrow H_2(g) + 2 OH^-(aq)$	-0.83
$Mn^{2+}(aq) + 2 e^- \longrightarrow Mn(s)$	-1.18
$Al^{3+}(aq) + 3 e^- \longrightarrow Al(s)$	-1.66
$Mg^{2+}(aq) + 2 e^- \longrightarrow Mg(s)$	-2.37
$Na^+(aq) + e^- \longrightarrow Na(s)$	-2.71
$Ca^{2+}(aq) + 2 e^- \longrightarrow Ca(s)$	-2.76
$Ba^{2+}(aq) + 2 e^- \longrightarrow Ba(s)$	-2.90
$K^+(aq) + e^- \longrightarrow K(s)$	-2.92
$Li^+(aq) + e^- \longrightarrow Li(s)$	-3.04

Stronger oxidizing agent



Weaker oxidizing agent

Weaker reducing agent



Stronger reducing agent

# Periodic Table of Elements

IA	1 <b>H</b> 1.01											IIA	4 <b>Be</b> 9.01											VIIA	9 <b>F</b> 19.0	VIIIA	2 <b>He</b> 4.00	
	3 <b>Li</b> 6.94												12 <b>Mg</b> 24.3												17 <b>Cl</b> 35.5		10 <b>Ne</b> 20.2	
	11 <b>Na</b> 23.0																								16 <b>S</b> 32.1		18 <b>Ar</b> 40.0	
	19 <b>K</b> 39.1	20 <b>Ca</b> 40.1																								34 <b>Se</b> 79.0		36 <b>Kr</b> 83.8
	37 <b>Rb</b> 85.5	38 <b>Sr</b> 87.6	39 <b>Y</b> 88.9	21 <b>Sc</b> 45.0	22 <b>Ti</b> 47.9	23 <b>V</b> 50.9	24 <b>Cr</b> 52.0	25 <b>Mn</b> 54.9	26 <b>Fe</b> 55.9	27 <b>Co</b> 58.9	28 <b>Ni</b> 58.7	29 <b>Cu</b> 63.5	30 <b>Zn</b> 65.4	49 <b>In</b> 115	50 <b>Sn</b> 119	51 <b>Sb</b> 122	52 <b>Te</b> 128	53 <b>I</b> 127	54 <b>Xe</b> 131									
	55 <b>Cs</b> 133	56 <b>Ba</b> 137	57 <b>La</b> 139	72 <b>Mf</b> 179	73 <b>Ta</b> 181	74 <b>W</b> 184	75 <b>Re</b> 186	76 <b>Os</b> 190	77 <b>Ir</b> 192	78 <b>Pt</b> 195	79 <b>Au</b> 197	80 <b>Hg</b> 201	81 <b>Tl</b> 204	82 <b>Pb</b> 207	83 <b>Bi</b> 209	84 <b>Po</b> (210)	85 <b>At</b> (210)	86 <b>Rn</b> (222)										
	87 <b>Fr</b> (223)	88 <b>Ra</b> (226)	89 <b>Ac</b> (227)	104 <b>Rf</b> (261)	105 <b>Db</b> (262)	106 <b>Sg</b> (263)	107 <b>Bh</b> (264)	108 <b>Hs</b> (265)	109 <b>Mt</b> (268)	110 <b>Ds</b> (271)	111 <b>Rh</b> (272)	112 <b>Cn</b> (285)	114 <b>Fl</b> (285)	116 <b>Lv</b> (289)														