GROUP 2 – ALKALINE EARTH METALS

Elements	Be	Mg	Ca	Sr	Ba
Atomic Radius	• ↑ down group (outermost e are further away from the nucleus) • **Shielding effect** increases is more significant than the increase **in Nuclear Charge** (outermost e further away from nucleus with more fully filled electron shells) • **Effective Nuclear Charge** ↓ down group				

Ionisation energy	• Generally ↓ down group as
	   • **Shielding effect** increases is more significant than increase **in Nuclear Charge**
	   • ↑ in atomic radius as a fully filled electron shell is added for every element
	   • larger shielding effect coupled with a larger atomic radius outweighs the increase in nuclear charge
	   • **Effective Nuclear Charge** ↓ down group				

Electronegativity is tendency of an atom to attract bonding electrons to itself in a covalent bond	• Generally ↓ down group as
	   • **Shielding effect** increases is more significant than increase **in Nuclear Charge**
	   • ↑ in atomic radius as a fully filled electron shell is added for every element
	   • larger shielding effect coupled with a larger atomic radius outweighs the increase in nuclear charge
	   • **Effective Nuclear Charge** ↓ down group				

Melting Point	• Decreases from Ca to Ba due to
	   • Same no. of delocalised electrons : 2
	   • Atomic size increases down group
	 • **Mg** do not conform to the trend because of high charge density that affects the number of electrons to be delocalised				

Good reducing agents	• E value becomes more negative down group • **Reactivity** increases down group • Elements become **more easily oxidised** down group • Elements become **more powerful reducing agents** down group • **Strength of reducing agent increases** down group		$E^{\ominus}$ $Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$ −2.37 V $Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$ −2.87 V $Sr^{2+}(aq) + 2e^- \rightleftharpoons Sr(s)$ −2.89 V $Ba^{2+}(aq) + 2e^- \rightleftharpoons Ba(s)$ −2.91 V		
Reaction with Oxygen	• React with oxygen to produce Oxides: $2M + O_2 \rightarrow 2MO$				
Reaction with Water	hardly any reaction, even with steam [due to high IE that makes loss of electron difficult; protected by inert impermeable BeO layer]	reacts very slowly with cold water, but rapidly with steam to form the oxide and H_2 $Mg(s) + H_2O(g) \Leftrightarrow MgO(s) + H_2(g)$	React with cold water with increasing vigour down the group to form the hydroxide and H_2 $M(s) + 2H_2O(l) \Leftrightarrow M(OH)_2 (aq/s) + H_2(g)$ $Ca(OH)_2$ (**aq/s**); $Sr(OH)_2$ (**aq**); $Ba(OH)_2$ (**aq**) Effervescence, heat released, sinks in water		

Elements	Be	Mg	Ca	Sr	Ba
Reaction of Oxides with Water	amphoteric and does not react/dissolve in water [due to small ionic radius of Be and high lattice energy]	reacts very slowly with water $MgO\ (s) + H_2O\ (l) \Leftrightarrow Mg(OH)_2\ (aq)$ Sparingly soluble	react vigorously with water $MO\ (s) + H_2O\ (l) \Leftrightarrow M(OH)_2$ (aq/s) heat released, sinks in water, precipitate may/may not be produced		

Thermal decomposition of Carbonates, Nitrates and Hydroxides	• **Thermal stability increases (thermal stability decreases)** down the group → **thermal decomposition temperature** increases down the group • Group 2 carbonates, nitrates and hydroxides are thermally unstable; they decompose on heating to form **oxides**. 　• **$2M(NO_3)_2 \rightarrow 2MO + 4NO_2$ (acidic/brown) $+ O_2$** 　• **$MCO_3 \rightarrow MO + CO_2$ (acidic)** 　• **$M(OH)_2 \rightarrow MO + H_2O$** • Thermal decomposition of these compounds occurs as a result of **polarization effect** exerted **by the cation (of high charge density) of the large anion** • **Down group, ionic radius of the cation increases** • **Charge density decreases down group causes → Polarizing power of cation decreases** • Ability to distort electron cloud of the anion decreases & **bond energy C-O bond increases** → Stability increases down the group • Weaken the C-O or O-H or N-O bonds

oxygen atom on the way to becoming the O^{2-} anion

delocalised electrons being pulled towards the positive charge, weakening C–O bond

The electron cloud of CO_3^{2-} ion before polarisation.

The electron cloud of CO_3^{2-} ion is greatly distorted by the smaller Mg^{2+} ion.

The electron cloud of CO_3^{2-} ion is less distorted by the larger Ba^{2+} ion.

Reaction of Gp II Peroxides with Water	• Unable to form stable peroxide ($^-O\text{-}O^-$), which has large electron cloud size, due to high charge density of the cation • Small cation size/**high polarizing ability** • Ability to distort electron cloud of the anion decreases → Stability increases down the group • Weaken the O-O bonds	$BaO_2 + 2H_2O \rightarrow Ba^{2+} + 2OH^- + H_2O_2$ $BaO_2 + H_2SO_4 \rightarrow H_2O_2 + BaSO_4$

Atypical Behaviour of Beryllium	*Theory* Beryllium differs from the other Group II elements; it has properties closer to that of aluminium - THE DIAGONAL RELATIONSHIP. Being the **head element** of a Group...
	
	it has • a much **smaller ionic size** (a greater charge/size ratio - highly polarising)
	     • a much **larger ionisation energies** than those elements below it
	
	so • is less likely to form ions
	     • compounds ($BeCl_2$) show covalent character - often soluble in organic solvents
	                                        - have lower melting points
	                                        - often hydrolysed by water
	
	     • maximum co-ordination number of 4 - due to small size
	
	     • beryllium hydroxide is AMPHOTERIC - dissolves in both acids and bases
	
	$$Be(OH)_{2(s)} + 2H^+_{(aq)} + 2H_2O_{(l)} \longrightarrow [Be(H_2O)_4]^{2+}_{(aq)}$$
	$$Be(OH)_{2(s)} + 2OH^-_{(aq)} \longrightarrow [Be(OH)_4]^{2-}_{(aq)}$$

Similar behaviour of Be and Al	1. Both Be and Al dissolve in alkali to liberate hydrogen gas 2. Both $BeCl_2$ and $AlCl_3$ are <u>covalent</u>; high charge density of cation $\Rightarrow$ significant polarization on the large anion 3. Both $BeCl_2$ and $AlCl_3$ are acidic when hydrolyses in water with pH of about 3-4. 4. $BeCO_3$ is unstable at room temperature and $Al_2(CO_3)_3$ does not exist 5. Both $Be(OH)_2$ and $Al(OH)_3$ are <u>amphoteric</u> (react with acid/base but not water) 6. Both BeO and Al_2O_3 are <u>amphoteric</u>
State 2 physical properties of iron that differ from calcium	**Both** (m.pt. and density) of Fe are higher than those for Ca [1] m.pt.: (due to:) stronger lattice/bonding *or* more delocalised electrons [1] density:(due to:) heavier atoms/larger A_r but (roughly) the same/smaller radius/size *or* closer packing [**both** mass and size need to be referred to] [1]

Similar behaviour of Mg and Li	1. Both Li_2CO_3 and $MgCO_3$ are relatively insoluble in water. (group I carbonate soluble in water) 2. Li_2CO_3 and $MgCO_3$ thermally decompose to produce carbon dioxide. (group I carbonate does not thermally decompose) 3. $LiNO_3$ and $Mg(NO_3)_2$ decompose to produce nitrogen dioxide and oxygen. High charge density of Li^+ polarizes and distorts e cloud of nitrate (group I nitrate → nitrite(NO_2^-)/smaller anion (KNO_3→KNO_2 + ½ O_2) less easily polarised + oxygen) 4. Li_2O_2 and MgO_2 are unstable due to the high charge density of Li^+ and Mg^{2+}. (group I peroxide stable due to low polarizing ability of cation) 5. Li^+ and Mg^{2+} in aqueous state form complex ions, but with different coordination number. $[Li(H_2O)_4]^+$; coordination number = 4 $[Mg(H_2O)_6]^{2+}$; coordination number = 6
Atypical behaviour of Li as a group I metal	1. Li_2CO_3 is insoluble in water as compared to other group I carbonates which are soluble in water. 2. Li_2CO_3 thermally decomposes to produce carbon dioxide, unlike other group I carbonates which are stable and do not decompose under normal heating $$Li_2CO_{3(s)} ==> Li_2O_{(s)} + CO_{2(g)}$$ 3. $LiNO_3$ decomposes to produce nitrogen dioxide and oxygen, unlike other group I nitrate which decomposes to produce group I nitrite (MNO_2) and oxygen $$4LiNO_{3(s)} ==> 2Li_2O(s) + 4NO_{2(g)} + O_{2(g)}$$ $$2MNO_{3(s)} ==> 2MNO_{2(s)} + O_{2(g)}$$ 4. Li_2O_2 is unstable due to the high charge density of Li^+, unlike other group I peroxides which are stable $$2M_{(s)} + O_{2(g)} ==> M_2O_{2(s)}$$ $$M_2O_{2(s)} + 2H_2O_{(l)} ==> 2MOH_{(aq)} + H_2O_{2(aq)}$$ 5. Li^+ in aqueous state forms complex ions ($[M(H_2O)_4]^{n+}$), unlike other aqueous group I cations which form ion-dipole attraction forces with polar water molecules

Summary / Study the Row

Complete the table below and state the trend for the examining the **trend down group 2**:
Down group 2 elements,

Relative ease of losing electron	↑	Standard electrode potential becomes **more**/less **–ve**/+ve	↓	Becomes **stronger**/weaker oxidizing/**reducing** agent		
Reactivity of metal	↑	Reactivity of metal with water (Be no rxn; Mg - slow)	↑	Reactivity of metal with steam (Be no rxn)	↑	
Size of metal atom	↑	Melting point **(exception Mg)**	↓	Enthalpy of atomization becomes more/**less** –ve/**+ve (exception Mg)** $M(s) \rightarrow M(g)$	↓	
Size of cation	↑	Charge density of cation or polarizing ability of cation	↓	Enthalpy of hydration becomes more/**less –ve**/+ve; $M^{2+}(g) \rightarrow M^{2+}(aq)$ (ΔH_{hyd} proportional to charge density)		
Electronegativity (ability to gain electron)	↓	Ionic character of oxide **(diff in En of metal and oxygen increases)** **BeO – predominantly ionic with covalent character; amphoteric/not soluble MgO – predominantly ionic with covalent character; base; partially soluble**	↑	Covalent character of chloride **(diff in En of metal and Cl increases; charge density of cation decreases therefore lower polarizing ability to distort e cloud of Cl⁻)**	↓	
Electropositivity (ability to lose electron)	↑	Summation of 1st and 2nd IE becomes more/**less** –ve/**+ve**	↓	pH of chlorides (acidic towards neutral; covalent chlorides are acidic and ionic chlorides are neutral) $BeCl_2$ – pH 3-4 $MgCl_2$ – pH 6.5	↑ to 7	

Label with ↑ or ↓ or cancel
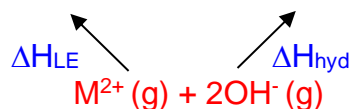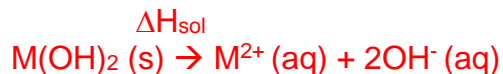**Study the Column**
Down group 2 compounds,

Charge density of cation or polarizing ability of cation	↓	Peroxide, nitrate, hydroxide and carbonate becomes <u>more</u> stable <u>stability</u>	↑	Peroxide, nitrate, hydroxide and carbonate becomes <u>less</u> unstable <u>instability</u>	↓
Stability of compound	↑	Relative ease of thermal decomposition of peroxide, nitrate, hydroxide and carbonate	↓	Decomposition temperature of peroxide, nitrate, hydroxide and carbonate	↑
Size of cation	↑	Lattice enthalpy of ionic compound becomes more/**less –ve**/+ve $\Delta H_{latt} \propto \dfrac{Q^+ Q^-}{r^+ + r^-}$		Enthalpy of hydration becomes more/**less –ve**/+ve $\Delta H_{latt} \propto \dfrac{Q^+}{r^+}$ or $\dfrac{Q^-}{r^-}$	
Reactivity of oxides **(weaker ionic bonds btw cation & O^{2-})**	↑	Solubility of oxide in water **(BeO – not soluble and MgO – poor solubility)**	↑	Reactivity with water becomes **more**/less exothermic Better solubility of the hydroxide	
pH of aqueous chloride solution **(higher charge density of cation & its effect on water)** (BeCl$_2$: 3-4, MgCl$_2$: 6.5)	↑ to 7	Acidity of aqueous chloride solution (alkalinity increases)	↓		
Enthalpy of solubility of hydroxide becomes more exo/less endo		Solubility of hydroxide (memorise)	↑		
Enthalpy of solubility of sulfate/chloride becomes more endo/less exo		Solubility of sulfate/chloride (memorise)	↓		

Label with ↑ or ↓ or cancel

Reaction involving metal		
Mg (s) + H_2O (g)	→	MgO (s) + H_2 (g)
M (s) + $2H_2O$ (l)	→	$M(OH)_2$ (aq/s) + H_2 (g)
Reaction involving metal oxide		
2M (s) + O_2 (g)	→	2MO (s)
MO(s) + H_2O (l)	→	$M(OH)_2$ (aq)
Reaction involving metal peroxide (O_2^{2-})		
M (s) + O_2 (g)	→	MO_2 (s)
MO_2 (s) + $2H_2O$ (l)	→	**$M(OH)_2$ (aq/s) + H_2O_2 (aq)**
MO_2 (s) + $2H^+$ (aq)	→	**M^{2+}(aq) + H_2O_2 (aq)**
Reaction involving metal nitride		
3M (s) + N_2 (g)	→	**M_3N_2 (s)**
M_3N_2 (s) + $3H_2O$ (l)	→	**3MO (s) + $2NH_3$ (g)**
M_3N_2 (s) + $6H_2O$ (l)	→	**$3M(OH)_2$ (aq/s) + $2NH_3$ (g)**
Thermal decomposition reactions		
$M(OH)_2$ (s)	→	MO (s) + H_2O (l)
MCO_3 (s)	→	MO (s) + CO_2 (g)
$2M(NO_3)_2$ (s)	→	2MO (s) + $4NO_2$ (g) + O_2 (g)
MO_2 (s)	→	**MO (s) + ½ O_2 (g)**

All metal oxides are basic oxides except Pb, Zn, Al oxides are amphoteric.

Q1. Which of the following group 2 compounds when reacted with water releases a gas that turns red litmus paper blue?

a. Nitride (N^{3-})	b. carbonate
c. peroxide	d. nitrate (NO_3^-)

Q2. Which of the following group 2 compounds when heated would produce a coloured gas?

a. hydroxide	b. carbonate
c. peroxide	d. nitrate

Q3 Which of the following group 2 compounds when thermally decomposed would not produce a basic oxide?

a. Beryllium hydroxide	b. magnesium carbonate
c. Barium peroxide	d. calcium hydroxide

Q4 Which of the following group 2 compounds when thermally decomposed produce greater number of moles of gases when compared to itself?

a. Hydroxide	b. Carbonate
c. Peroxide (1mol: ½ mol of gas)	d. Nitrate (1mol: 2.5 moles of gases)

Q5. Which of the following magnesium compounds when thermally decomposed produce a basic oxide and an acidic oxide? **Neutral oxides: CO, H_2O, NO, N_2O**

(1) Nitrate	
(2) Carbonate	
(3) Hydroxide	

Group 2 Notes (FOR INFO)

$$\Delta H_{sol}$$

$M(OH)_2\ (s) \rightarrow M^{2+}\ (aq) + 2OH^-\ (aq)$

ΔH_{LE} \qquad\qquad ΔH_{hyd}

$\qquad M^{2+}\ (g) + 2OH^-\ (g)$

$\Delta H_{sol} = (-\Delta H_{LE}) + \Delta H_{hyd}$

$(-\Delta H_{LE})$: breaking of ionic bond

ΔH_{hyd}: formation of ion-dipole attraction force

$$\Delta H_{sol}$$

$MSO_4\ (s) \rightarrow M^{2+}\ (aq) + SO_4^{2-}\ (aq)$

ΔH_{LE} \qquad\qquad ΔH_{hyd}

$\qquad M^{2+}\ (g) + SO_4^{2-}\ (g)$
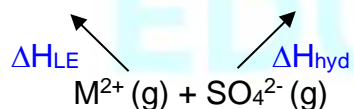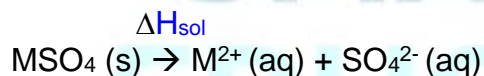
Magnitude of Hydration Energy $\propto \dfrac{Q^+}{r^+}$ **or** $\dfrac{Q^-}{r^-}$

Magnitude of Lattice Energy $\propto \dfrac{Q^+\ Q^-}{r^+ + r^-}$

$\Delta H_{sol} \quad = \quad \Delta H_{hyd} \quad + \quad (-\Delta H_{latt})$
$\qquad\qquad\quad$ Exothermic $\qquad$ Endothermic

Down group 2 sulfate, r+ increases, rest are the same

Magnitude of Lattice Energy $\propto \dfrac{Q^+\ Q^-}{r^+ + r^-} = \dfrac{+2.\ -2}{r^+ + r_{SO_4^{2-}}}$

$r_{SO_4^{2-}} >> r^+$

Down group 2 hydroxide, solubility increases and ΔH_{sol} becomes more exothermic/-ve

r+ ↓, ΔH_{hyd} & ΔH_{LE} less exo [*due to the square factor, the lattice enthalpy decreases faster than the hydration enthalpy*]

Final Revision Exercise

Q1.

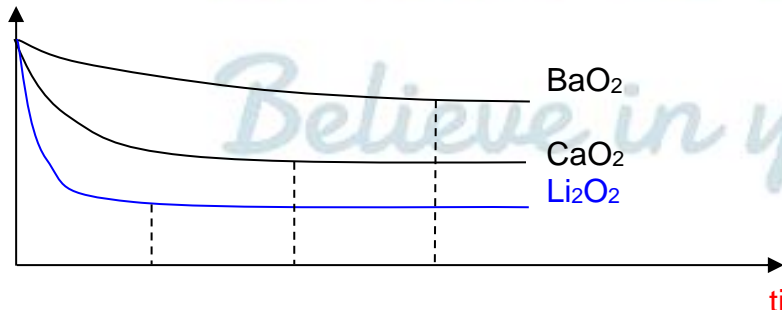|	
a.	Rank the thermal decomposition temperature on the following compounds: Li_2O_2, CaO_2 and BaO_2. (Hint: remember the diagonal relationship between Li and Mg) Briefly explain the trend. [4]
b.	Given 10 gram of each compound, which of them would have the largest decrease in mass when thermally decomposed. Briefly explain your answer. [2]
c.	Given 3 metals: Mg, Ca and Ba, describe the laboratory tests that can be conducted to identify the metals. [4]
d.	Suggest an explanation for an unusually low melting point for magnesium by interpreting the data provided below. <table><tr><td></td><td>Melting point /K</td><td>Atomic size / 10^{-10}m</td><td>resisitivity / $m\Omega$ cm</td></tr><tr><td>Be</td><td>**1560**</td><td>**1.40**</td><td>**4.0**</td></tr><tr><td>Mg</td><td>**923**</td><td>**1.72**</td><td>**4.4**</td></tr><tr><td>Ca</td><td>**1115**</td><td>**2.23**</td><td>**3.4**</td></tr></table> [2]

Q1.

a.	Rank the thermal decomposition temperature on the following compounds: Li_2O_2, CaO_2 and BaO_2. (Hint: remember the diagonal relationship between Li and Mg) Briefly explain the trend. • Higher charge density of cation: $Mg^{2+} > Ca^{2+} > Ba^{2+}$ • Higher polarizing ability • Charge density of Li^+ is comparable to Mg^{2+} (diagonal relationship) • Distort the large electron cloud of peroxide resulting in unstable peroxide • In terms of thermal stability: $Li_2O_2 < CaO_2 < BaO_2$ • In terms of decomposition temperature: $BaO_2 > CaO_2 > Li_2O_2$ [4]
b.	Given 10 gram of each compound, which of them would have the largest decrease in mass when thermally decomposed. Briefly explain your answer. • Larger Mr, fewer moles; less amount of oxygen produced • $Li_2O_2 \rightarrow Li_2O + \frac{1}{2} O_2$; $MO_2 \rightarrow MO + \frac{1}{2} O_2$ • In terms of Mr: $Li_2O_2 < CaO_2 < BaO_2$ • number of moles of oxygen released: $Li_2O_2 > CaO_2 > BaO_2$ • decrease in mass of 10g sample: Li_2O_2 (largest decrease) > $CaO_2 > BaO_2$ Sketch the graph to reflect the change in mass of the solid peroxide against time during thermal decomposition. [2]
c.	Given 3 metals: Mg, Ca and Ba, describe the laboratory tests that can be conducted to identify the metals.

	• Add water • No/poor: effervescence – Mg; Vigorous effervescence – Ca or Ba • Gradually add more water and observed which dissolve • White precipitate/poor solubility – $Ca(OH)_2$; Colourless solution – $Ba(OH)_2$ Or • Add dilute nitric acid • Separate each mixture solution into 2 samples • To each sample, add either aq NaOH or aq ammonia in excess

Add in excess	Mg^{2+}	Ca^{2+}	Ba^{2+}
Aq NaOH	White ppt	White ppt	No ppt
Aq ammonia	White ppt	No ppt	No ppt
knowledge	$Mg(OH)_2$ – highly insoluble	$Ca(OH)_2$ – sparingly soluble	$Ba(OH)_2$ – completely soluble

[4]

d.	Suggest an explanation for an unusually low melting point for magnesium by interpreting the data provided below.

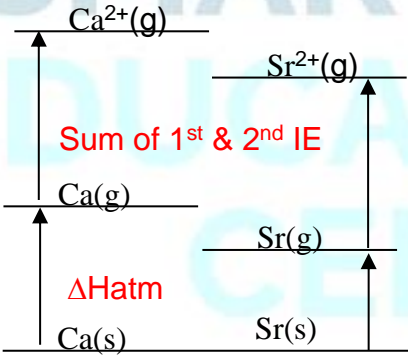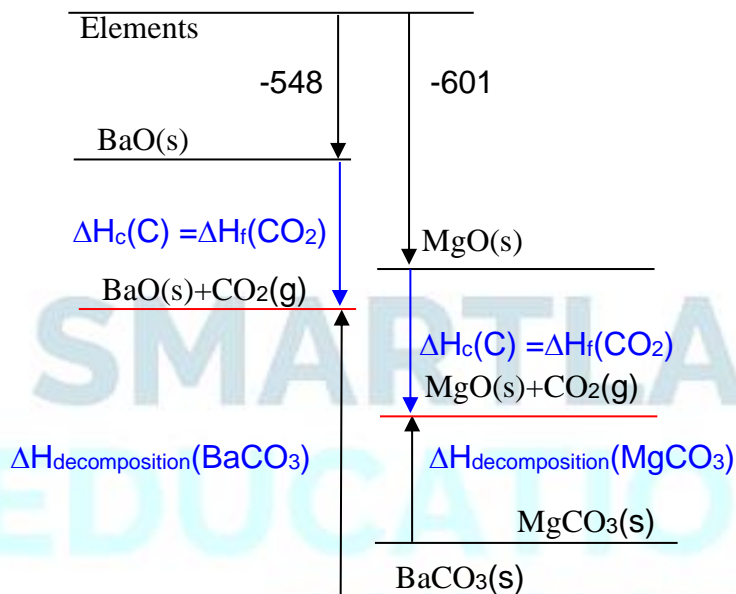|	Melting point /K	Atomic size / 10^{-10}m	resisitivity / $m\Omega\ cm$
Be	1560	1.40	4.0
Mg	923	1.72	4.4
Ca	1115	2.23	3.4

[2]

• High resistivity – poor delocalisation of valence electrons in Mg
• Weaker metallic bond than usual
• since lower density of delocalised electrons are available

Q2.

a.	On the same enthalpy level diagram, draw the enthalpies of formation for $Ca^{2+}(g)$ and $Sr^{2+}(g)$ using the data given below and relevant data sheet values. <table><tr><td>Element</td><td>Enthalpy of atomization</td></tr><tr><td>Ca</td><td>178</td></tr><tr><td>Sr</td><td>164</td></tr></table> [2]
b.	Compare and explain the magnitudes of enthalpies of formation of CaO and MgO. [6]
c.	Thermal decomposition of carbonate is an endothermic reaction. Explain with use of an energy level diagram which of the following has a higher enthalpy of decomposition of 1mole of $BaCO_3$ or 1 mole of $MgCO_3$ given that the standard enthalpy of formation of BaO is $-548 kJmol^{-1}$ and MgO is $-601 kJmol^{-1}$. Explain your answer in details. [4]
d.	The table below gives some information about the solubility of Group 2 sulfates. Construct a relevant energy cycle and suggest values for X and Y. <table><tr><td></td><td>Solubility / moldm^{-3}</td><td>Lattice energy / kJmol^{-1}</td><td>Hydration energy / kJ mol^{-1}</td></tr><tr><td>CaSO$_4$</td><td>**4.6 ×10^{-2}**</td><td>-2480</td><td>-1650</td></tr><tr><td>SrSO$_4$</td><td>**7.1 × 10^{-4}**</td><td>-2484</td><td>X = -1600</td></tr><tr><td>BaSO$_4$</td><td>**9.4 × 10^{-6}**</td><td>-2374</td><td>Y = -1450</td></tr></table> [4]

Q2.

a.	On the same enthalpy level diagram, draw the enthalpies of formation for $Ca^{2+}(g)$ and $Sr^{2+}(g)$ using the data given below and relevant data sheet values. Melting point of Sr < Ca; larger ionic radius and lower charge density Higher melting point means more positive enthalpy change of atomisation | Element	Enthalpy of atomization
Ca	178
Sr	164 | [2]
b.	Compare and explain the magnitudes of enthalpies of formation of CaO and MgO. (consider metal burning in excess oxygen) Ca more reactive than Mg/Ca a stronger reducing agent standard electrode potential being more -ve more exothermic for CaO [6]
c.	Thermal decomposition of carbonate is an endothermic reaction. Explain with use of an energy level diagram which of the following has a higher enthalpy of decomposition of 1mole of $BaCO_3$ or 1 mole of $MgCO_3$ given that the standard enthalpy of formation of BaO is –548 kJmol^{-1} and MgO is –601kJmol^{-1}. Explain your answer in details.

Energy cycle diagram showing:
- Elements at top
- -548 and -601 arrows down to BaO(s) level
- $\Delta H_c(C) = \Delta H_f(CO_2)$
- BaO(s), MgO(s) levels
- BaO(s)+CO_2(g), MgO(s)+CO_2(g)
- $\Delta H_{decomposition}(BaCO_3)$, $\Delta H_{decomposition}(MgCO_3)$
- $MgCO_3$(s), $BaCO_3$(s)

Red box notes:
- Thermal stability: $BaCO_3$ > $MgCO_3$; lower charge density of Ba^{2+}
- Enthalpy level lower for $BaCO_3$
- Enthalpy of decomposition: $BaCO_3$ > $MgCO_3$

[4]

d.	The table below gives some information about the solubility of Group 2 sulfates. Construct a relevant energy cycle and suggest values for X and Y.

	Solubility / moldm^{-3}	Lattice energy / kJmol^{-1}	Hydration energy / kJ mol^{-1}
$CaSO_4$	**4.6 ×10^{-2}**	-2480	-1650
$SrSO_4$	**7.1 × 10^{-4}**	-2484	X ?
$BaSO_4$	**9.4 × 10^{-6}**	-2374	Y ?

- Lower Ksp, lower solubility of sulfate
- Less exothermic/more endothermic the enthalpy of solution
- $SrSO_4$: Larger positive number than 830 (ΔH_{sol} of $CaSO_4$ = -(-2480)-1650);
    X has to be less exothermic than −1650 [1]; e.g. **X = −1600**; ΔH_{sol} = 884 [1]
- $BaSO_4$:Larger positive number than $\Delta H_{sol}(SrSO_4)$;
    Y has to be less exothermic than −1600; e.g. −1550; ΔH_{sol} = 824 (WRONG)
    e.g. **Y = −1450**; ΔH_{sol} = 924 > 884 [1]

Down the group 2 sulfate, ΔH_{sol} **MORE positive** / LESS negative

For $CaSO_4$, ΔH_{sol} = ΔH_{hyd} + $(-\Delta H_{latt})$ = -1650 – (-2480) = 830 kJmol^{-1}
                         Exothermic   Endothermic

ΔH_{sol}

$MSO_4 (s) \rightarrow M^{2+} (aq) + SO_4^{2-} (aq)$

ΔH_{LE} ΔH_{hyd}

$M^{2+} (g) + SO_4^{2-} (g)$

1000(W) = ΔH_{hyd} + -(-2484); X = -1484 kJmol^{-1}(U)
[1] ΔH_{sol} ($SrSO_4$) > 830   [1] ΔH_{hyd} ($SrSO_4$) less negative than −1600
                                        charge density of cation decreases
1100 = ΔH_{hyd} + -(-2374); Y = -1274 kJmol^{-1}
[1] ΔH_{sol} ($BaSO_4$) > (W)   [1] ΔH_{hyd} ($BaSO_4$) less negative than (U)
                                        charge density of cation decreases

[4]

Q3. The table below gives some information regarding the solubility of lead(II) halides.

	Colour	Ksp
PbI_2	Yellow	9.8×10^{-9}
$PbBr_2$	White	6.6×10^{-6}
$PbCl_2$	White	1.7×10^{-5}

a.	Write an expression of the Ksp for dissolution of lead(II) halides. Represent halogen with "X". [1]
b.	Which of the lead(II) halides, PbX_2, is the most soluble in water? Calculate its solubility in (1) 1dm^3 of distilled water (2) 50cm^3 of 0.10moldm^{-3} of BaX_2(aq)/barium halide solution. [5]
c.	If there is a mixture of equimolar concentration of I$^-$ and Cl$^-$ present in a solution, state and explain the observations when small amount of solid lead(II) nitrate granules are being gradually dissolved in the solution. [2]
d.	Explain the observations made by a student in the school laboratory. "When concentrated aq HCl is being gradually being added to an aqueous solution of lead(II) nitrate solution, white precipitate that is initially formed dissolved to form a colourless solution." [2]

a.	Write an expression of the Ksp for dissolution of lead(II) halides. Represent halogen with "X". $PbX_2(s) \Leftrightarrow Pb^{2+} (aq) + 2X^- (aq)$; $Ksp = [Pb^{2+}][X^-]^2$ [1]
b.	Which of the lead(II) halides, PbX_2, is the most soluble in water? Calculate its solubility in (1) $1dm^3$ of distilled water. (2) $50cm^3$ of $0.10 moldm^{-3}$ of $BaX_2(aq)$/barium halide solution. (1) $PbX_2(s) \Leftrightarrow Pb^{2+} (aq) + 2X^- (aq)$ x x 2x Larger Ksp most soluble is $PbCl_2$, $Ksp = [Pb^{2+}][X^-]^2 = [x][2x]^2 = 4x^3 = 1.7 \times 10^{-5}$; $x = 0.0162$ $moldm^{-3}$ (2) common ion, lower solubility $Ksp = [Pb^{2+}][X^-]^2 = x (0.10)^2 = 1.7 \times 10^{-5}$ (WRONG) $Ksp = [Pb^{2+}][X^-]^2 = y (2y + \underline{0.20})^2 = y (\sim 0.20)^2 = 1.7 \times 10^{-5}$ Assumption: $y << 0.10$; $y = 0.000452$ $moldm^{-3}$ (assumption validated) [5]
c.	If there is a mixture of equimolar concentration of I^- and Cl^- present in a solution, state and explain the observations when small amount of solid lead(II) nitrate granules are being gradually dissolved in the solution. Yellow ppt observed lower Ksp of PbI_2, lead (II) iodide precipitated first Followed by white ppt being produced larger Ksp of $PbCl_2$, lead (II) chloride precipitated next [2]
d.	Explain the observations made by a student in the school laboratory. "When concentrated aq HCl is being gradually being added to an aqueous solution of lead(II) nitrate solution, white precipitate that is initially formed dissolved to form a colourless solution." Precipitation: $Pb^{2+} (aq) + 2Cl^- (aq) \rightarrow PbCl_2 (s)$ Ionic complex (soluble): $PbX_2 (s) + 2X^- (aq) \rightarrow [PbX_4]^{2-} (aq)$ [2]

Q4. 10.0 grams of solid barium amide, $Ba(NH_2)_2$ decomposes when heated to give barium nitride and a pungent gas that turns damp red litmus blue. Upon adding water to barium nitride, more of the pungent gas is produced.

a.	Draw the dot and cross diagram for $Ba(NH_2)_2$. State the types of chemical bonding present in the compound. [3]
b.	(1) Write a balanced equation for the decomposition of barium amide. (2) Write a balanced equation for the reaction of barium nitride and excess water. (3) Hence calculate the **maximum** volume of the pungent gas that can be produced given 10.0 grams of solid barium amide. [4]
c.	Suggest the hydrolysis that takes place when barium amide is dissolved in water. [1]
d.	With the aid of the data booklet, arrange the following amides: $NaNH_2$, $Mg(NH_2)_2$ and $Ba(NH_2)_2$ in order of increasing ease of thermal decomposition. Explain your answer. [3]

a.	Draw the dot and cross diagram for $Ba(NH_2)_2$. State the types of chemical bonding present in the compound. • Ba^{2+}; NH_2^- • $[Ba]^{2+}$; 2 $[H-N-H]^-$ (remark: N has a foreign e) • Ionic bonds between ions • Covalent bonds within complex anion: NH_2^- [3]
b.	(1) Write a balanced equation for the decomposition of barium amide. $3Ba(NH_2)_2 \rightarrow Ba_3N_2 + 4NH_3$ (2) Write a balanced equation for the reaction of barium nitride and excess water. Excess water: $Ba_3N_2 (s) + 6H_2O (l) \rightarrow 3 Ba(OH)_2 (aq) + 2NH_3 (g)$ Limited water: $Ba_3N_2 (s) + 3H_2O (l) \rightarrow 3 BaO (s) + 2NH_3 (g)$ (3) Hence calculate the **maximum** volume of the pungent gas that can be produced given 10.0 grams of solid barium amide. Number of moles of amide = 0.0592 mol Ref to equ in (1), number of mole of ammonia produced = $^4/_3$ x 0.0592 mol Ref to equ in (2), number of mole of ammonia produced = $^2/_3$ x 0.0592 mol At rtp, volume of ammonia = 2 x 0.0592 mol x 24 = $2.84 dm^3$ [4]
c.	Suggest the hydrolysis that takes place when barium amide is dissolved in water. $Ba(NH_2)_2 + 2H_2O \rightarrow Ba(OH)_2 + 2NH_3$ [1]
d.	With the aid of the data booklet, arrange the following amides: $NaNH_2$, $Mg(NH_2)_2$ and $Ba(NH_2)_2$ in order of increasing ease of thermal decomposition. Explain your answer. • Ionic radius Ba^{2+} = 0.135nm, Na^+ = 0.095nm (data booklet) • Charge density: $Mg^{2+} > Ba^{2+} > Na^+$ • Ease of thermal decomposition: $Mg(NH_2)_2 > Ba(NH_2)_2 > NaNH_2$ [3]

Q5.

This question involves the chemistry of 2 group 2 metals and their carbonates found in another planet. Given below are some data of the two metals and their carbonates.

group 2 metals	E^θ/V	K_{sp} of carbonates/ mol^2dm^{-6}	Decomposition temperature of carbonates / K
X	-2.8	1.0×10^{-5}	A
Y	-3.9	5.0×10^{-5}	1630

a.	Which of the metal has a smaller proton number?	[1]
b.	Which carbonate has a higher solubility?	[1]
c.	Is value of A larger or smaller than 1630K? Explain your answer.	[2]
d.	Is the lattice enthalpy of the carbonate of X more or less exothermic than Y? Explain your answer.	[2]

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X	-2.8	1.0×10^{-5}	A
Y	-3.9	5.0×10^{-5}	1630

a.	Which of the metal has a smaller proton number? X More negative standard electrode potential indicates metal Y is more reactive, lower in the group	[1]
b.	Which carbonate has a higher solubility? YCO_3 Higher Ksp, more soluble the salt	[1]
c.	Is value of A larger or smaller than 1630K? Explain your answer. Smaller than 1630K higher charge density of X^{2+} due to smaller ionic radius higher polarizing ability to destabilize carbonate carbonate thermally less stable/lower decomposition temperature	[2]
d.	Is the lattice enthalpy of the carbonate of X more or less exothermic than Y? Explain your answer. **Magnitude of Lattice Energy $\propto \dfrac{Q^+ Q^-}{r^+ + r^-}$** More exothermic; X^{2+} has smaller ionic radius	[2]

Q6. Barium reacts with oxygen under different conditions to give either barium oxide or barium peroxide (BaO_2).

In an experiment, a mixture of these oxides was treated with an excess of dilute sulfuric acid. 1.63 g of a white solid was precipitated, and a solution of hydrogen peroxide was produced. On the addition of 24.5 cm^3 of 0.02 mol dm^{-3} potassium manganate (VII) to the solution, a faint permanent pink was observed.

a.	Write an equation for the reaction of each of the oxides with dilute sulfuric acid.	[1]
b.	Name the white solid and calculate the number of moles formed.	[2]
c.	Find the number of moles of hydrogen peroxide formed in the solution.	[2]
d.	Calculate the masses of the two oxides of barium in the mixture.	[2]
e.	Calculate the number of moles of dilute sulfuric acid required to neutralize the mixture of barium oxides.	[1]
f.	Calculate the maximum volume of gases that are produced when heated strongly at stp.	[1]

Believe in yourself

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a.	Write an equation for the reaction of each of the oxides with dilute sulfuric acid.
	$BaO + H_2SO_4 \rightarrow BaSO_4 (s) + H_2O$
	    x x
	$BaO_2 + H_2SO_4 \rightarrow BaSO_4 (s) + H_2O_2$
	   y y y
		[1]

b.	Name the white solid and calculate the number of moles formed. $BaSO_4$; 0.007 mols (x+y)	[2]
c.	Find the number of moles of hydrogen peroxide formed in the solution. 2 moles of MnO_4^- reacts with 5 moles of H_2O_2 y = 0.001225 mols	[2]
d.	Calculate the masses of the two oxides of barium in the mixture. BaO_2: y = 0.001225 mols; 0.207g BaO: x = 0.007-0.001225 mols; 0.884g	[2]
e.	Calculate the number of moles of dilute sulfuric acid required to neutralize the mixture of barium oxides. 0.007 (x+y)	[1]
f.	Calculate the maximum volume of gases that are produced when heated strongly at stp. $BaO_2 \rightarrow BaO + ½ O_2(g)$ volume of oxygen = 0.001225/2 x 22.4 mols = 0.01372 dm^3	[1]

Q7.   Barium reacts with oxygen under different conditions to give either barium oxide or barium peroxide (BaO_2). Potassium reacts with oxygen to produce superoxide (KO_2). Potassium superoxide dissolves in water to produce hydrogen peroxide, potassium hydroxide and oxygen.

In an experiment, a mixture of these 3 oxides: **KO_2**, BaO and BaO_2, was treated with 100cm^3 of distilled water and a total of 480 cm^3 of oxygen is produced at rtp. Thereafter, 2 samples of 25.0cm^3 of the mixture solution were extracted and titrated respectively with 25.0 cm^3 of 0.480 mol dm^{-3} acidified potassium manganate (VII) to the solution, where a faint permanent pink was observed and 47.5 cm^3 of **2**.00 mol dm^{-3} of aqueous HCl, where phenolphthalein turns colourless.

a.	(1) Write an equation for the reaction of each of the oxides with water. (2) Which of the following equation is redox? Explain using oxidation states. [5]
b.	Write a balanced equation for the reaction of between acidified potassium manganate(VII) and hydrogen peroxide. Hence calculate the number of moles of hydrogen peroxide present in the 100cm^3 of mixture solution. [3]
c.	Calculate the number of moles of OH- present in the 100cm^3 of mixture solution. [3]
d.	Calculate the number of moles of KO_2 and hence or otherwise determine the number of moles of BaO and BaO_2 in the mixture of the 3 oxides. [3]

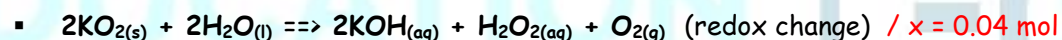Oxidation state of O in **KO₂** is –½.

Number of moles of H_2O_2 = $\dfrac{25.0 \times 0.480 \times 5}{25.0 \times 2} \times 0.100$ = 0.12 mol

Number of moles of O_2 = $\dfrac{480}{24000}$ = 0.02 mol

Number of moles of OH^- = $\dfrac{47.5 \times 2.00}{25.0} \times 0.100$ = 0.38 mol

Disproportionation reaction

$$-\tfrac{1}{2} \qquad\qquad -2 \qquad\quad -2 \qquad\quad -1 \qquad 0$$

- $2KO_{2(s)} + 2H_2O_{(l)} ==> 2KOH_{(aq)} + H_2O_{2(aq)} + O_{2(g)}$ (redox change) / x = 0.04 mol

  x = 0.04   x   0.5 x   0.5x = 0.02 (480/24000); x = 0.04mol

Non-redox

- $BaO_{2(s)} + 2H_2O_{(l)} ==> Ba(OH)_{2(aq)} + H_2O_{2(aq)}$ / y = 0.10 mol

  y   y   y   (y + 0.5x = 0.12; y = 0.10 mol)

- $BaO_{(s)} + H_2O_{(l)} ==> Ba(OH)_{2(aq)}$ / z = 0.07 mol
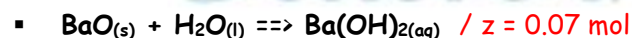
  z   z   (2z + 2y + x = 2z + 0.20 + 0.04 = 0.38

  ; z = 0.07 mol)

Q8.   A 0.400g of a mineral $AB(CO_3)_2$, where A and B are group 2 elements was heated strongly until no further change in mass.
A white powder weighing 0.275g was collected and shaken with $0.2dm^3$ of water.
A portion of the white powder remains insoluble and
was then filtered.
The residue was dried and it weighed 0.057g.

(i) Assuming that the products on heating consist of the oxides of A and B
and carbon dioxide, write balanced equation for the
thermal decomposition of $AB(CO_3)_2$.

(ii) Calculate the mass of carbon dioxide produced.

(iii) Hence, or otherwise, identify the metals A and B showing your working clearly.

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(i) Assuming that the products on heating consist of the oxides of A and B
and carbon dioxide, write balanced equation for the
thermal decomposition of $AB(CO_3)_2$.

$AB(CO_3)_2 \rightarrow AO + BO + 2CO_2$

(ii) Calculate the mass of carbon dioxide produced.

Mass of carbon dioxide = 0.400g – 0.275g = 0.125g
Number of mole of carbon dioxide = 0.002841 mol

(iii) Hence, or otherwise, identify the metals A and B showing your working clearly.

Number of mole of AO = BO = ½ x 0.002841 = 0.00142 mol

Mr of $AB(CO_3)_2$ = 0.400g /0.00142 = 281.6
Ar of A + Ar of B = 161.6
a + b = 161.6 --- Equation (1)

(16+a) 0.00142 + (16+b) 0.00142 = 0.275
a + b = 161.6 --- Equation (1)

Hence A and B are Ba and Mg respectively.