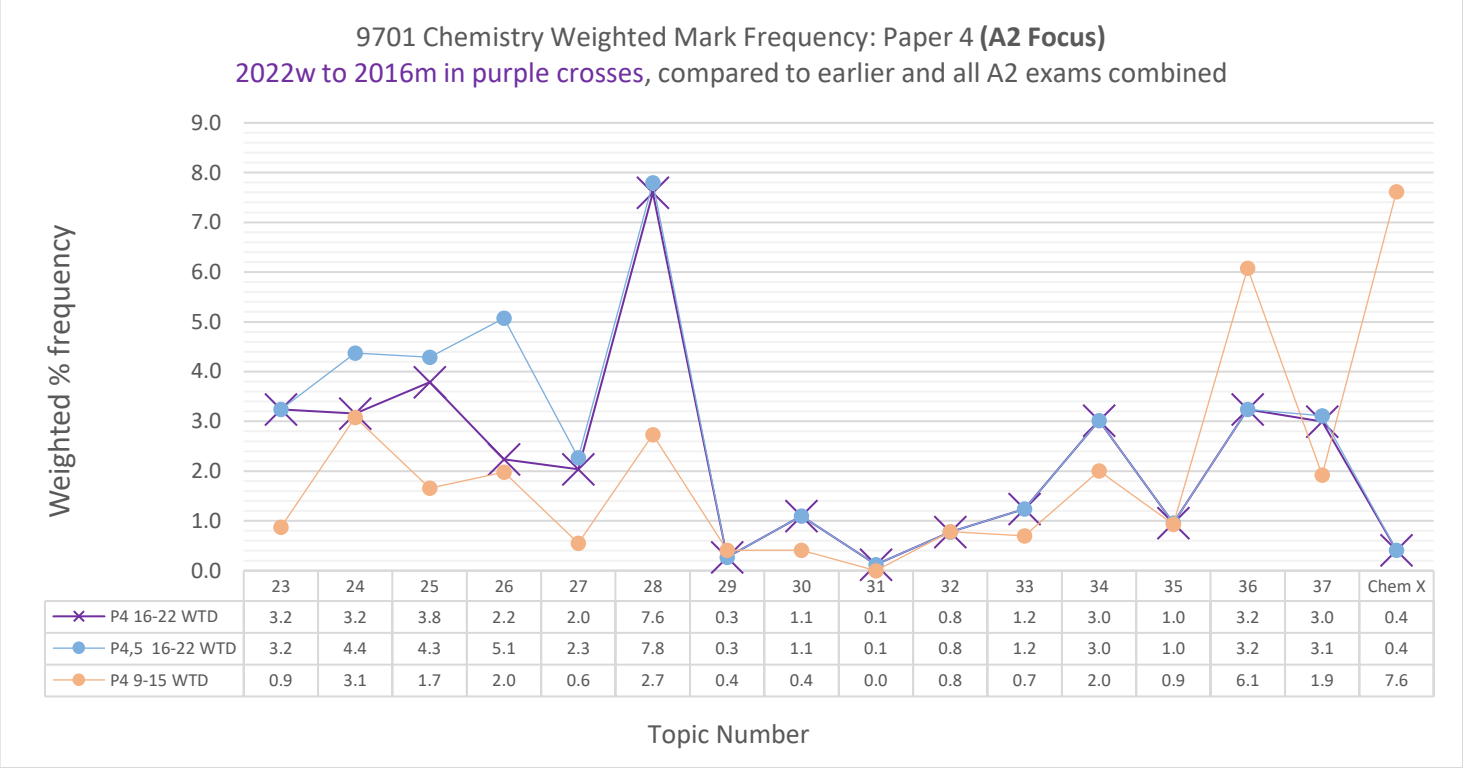
Name: Class: Date:

A Level Chem 23 EQ 22m to 09w **Paper 4** Chemical energetics 189marks

As you start and work through this worksheet you can tick off your progress to show yourself how much you have done, and what you need to do next. The first task is just to read the first question and should take you less than 3 minutes to complete.

Paper 4 Topic Checklist Tick each task off as you go along	RANK: Marks	P4 Noob 1 Q Started	P4 Novice 1 Q done	P4 Bronze 10% of marks	P4 Silver 25% of marks	P4 Gold 40% of marks	P4[1] Winner 50% of marks	P4 Hero 75% of marks	P4 Legend 100% of marks
Topic 23/marks	189		6	19	47	76	95	142	189
Time (72seconds per mark)/minutes	230	3	8	23	57	92	115	172	230



	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	Chem X
P4 16-22 WTD	3.2	3.2	3.8	2.2	2.0	7.6	0.3	1.1	0.1	0.8	1.2	3.0	1.0	3.2	3.0	0.4
P4,5 16-22 WTD	3.2	4.4	4.3	5.1	2.3	7.8	0.3	1.1	0.1	0.8	1.2	3.0	1.0	3.2	3.1	0.4
P4 9-15 WTD	0.9	3.1	1.7	2.0	0.6	2.7	0.4	0.4	0.0	0.8	0.7	2.0	0.9	6.1	1.9	7.6

What the most thoughtful students will get out of their extensive studying will be a capacity to do meaningful brain-based work even under stressful conditions, which is a part of the self-mastery skillset that will continue to deliver value for the whole of their lives. Outstanding grades will also happen, but the most important outcome from skillful action in study is being better at any important tasks even if circumstances are do not feel ideal.

Learning how to manage oneself so we can more reliably get ambitious and successful outcomes out of our challenges in a productive and positive way is one aspect of life's most valuable pursuit summarised and inscribed on the Temple of Apollo at Delphi: "know thyself".

1. To complete these questions, as important as your answer, is checking your answer against the mark scheme.
2. For each question, or page, convert your mark score into a percentage. This will allow you to see (and feel) your progress as you get more experience and understanding with each topic.
3. If you find you get a higher percentage answering short answer questions than multiple choice questions that often means you are using the marking scheme correctly; your correct answer might not be fully complete. The marks easiest to miss rely on providing more details.

[1] **DO NOT** work on these higher levels of completion unless you have also achieved at least a "Silver" (25%) in the same topic in Paper 5, if it exists.

Physical chemistry

23 Chemical energetics

23.1 Lattice energy and Born-Haber cycles

Learning outcomes

Candidates should be able to:

1 define and use the terms:
   (a) enthalpy change of atomisation, ΔH_{at}
   (b) lattice energy, ΔH_{latt} (the change from gas phase ions to solid lattice)
2 (a) define and use the term first electron affinity, EA
   (b) explain the factors affecting the electron affinities of elements
   (c) describe and explain the trends in the electron affinities of the Group 16 and Group 17 elements
3 construct and use Born–Haber cycles for ionic solids
   (limited to +1 and +2 cations, –1 and –2 anions)
4 carry out calculations involving Born–Haber cycles
5 explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of a lattice energy

23.2 Enthalpies of solution and hydration

Learning outcomes

Candidates should be able to:

1 define and use the term enthalpy change with reference to hydration, ΔH_{hyd}, and solution, ΔH_{sol}
2 construct and use an energy cycle involving enthalpy change of solution, lattice energy and enthalpy change of hydration
3 carry out calculations involving the energy cycles in 23.2.2
4 explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of an enthalpy change of hydration

23.3 Entropy change, ΔS

Learning outcomes

Candidates should be able to:

1 define the term entropy, S, as the number of possible arrangements of the particles and their energy in a given system
2 predict and explain the sign of the entropy changes that occur:
   (a) during a change in state, e.g. melting, boiling and dissolving (and their reverse)
   (b) during a temperature change
   (c) during a reaction in which there is a change in the number of gaseous molecules
3 calculate the entropy change for a reaction, ΔS, given the standard entropies, $S^{\ominus}$, of the reactants and products, $\Delta S^{\ominus} = \Sigma S^{\ominus}$ (products) – $\Sigma S^{\ominus}$ (reactants)
   (use of $\Delta S^{\ominus} = \Delta S surr^{\ominus} + \Delta S sys^{\ominus}$ is not required)

23.4 Gibbs free energy change, ΔG

Learning outcomes

Candidates should be able to:

1 state and use the Gibbs equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$
2 perform calculations using the equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$
3 state whether a reaction or process will be feasible by using the sign of ΔG
4 predict the effect of temperature change on the feasibility of a reaction, given standard enthalpy and entropy changes

2 Silicon is the second most abundant element by mass in the Earth's crust.

(a) In industry, silicon is extracted from SiO_2 by reaction with carbon at over 2000 °C.

reaction 1 $SiO_2(s) + 2C(s) \rightarrow Si(l) + 2CO(g)$

(i) Explain why the entropy change, ΔS, of reaction 1 is positive.

.....

..... [1]

(ii) Reaction 1 is highly endothermic.

Suggest the effect of an increase in temperature on the feasibility of this reaction.
Explain your answer.

.....

.....

..... [2]

(b) Silicon is purified by first heating it in a stream of $HCl(g)$ to form $SiHCl_3$. The $SiHCl_3$ formed is then distilled to remove other impurities.

reaction 2 $Si(s) + 3HCl(g) \rightarrow SiHCl_3(g) + H_2(g)$

(i) Table 2.1 shows some standard entropy data.

Table 2.1

compound	standard entropy, $S^\ominus$ / $JK^{-1}mol^{-1}$
Si(s)	19
$HCl(g)$	187
$SiHCl_3(g)$	314
$H_2(g)$	131

Use the data in Table 2.1 to calculate $\Delta S^\ominus$ for reaction 2.

$\Delta S^\ominus$ = ... $JK^{-1}mol^{-1}$ [2]

(ii) Reaction 3 is the reverse of reaction 2 and is used to obtain pure silicon.

reaction 3 $SiHCl_3(g) + H_2(g) \rightarrow Si(s) + 3HCl(g)$ $\Delta H = +219.3\,kJ\,mol^{-1}$

Use this information and your answer to **(b)(i)** to calculate the temperature, in K, at which reaction 3 becomes feasible.
Show your working.

[If you were unable to answer **(b)(i)**, you should use $\Delta S^{\ominus} = -150\,J\,K^{-1}\,mol^{-1}$ for reaction 2. This is not the correct answer to **(b)(i)**.]

temperature = ... K [2]

Q# 2/ ALvl Chemistry/2022/m/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(b) The Group 1 iodides all form stable ionic lattices and are soluble in water.

(i) Define enthalpy change of solution.

.....

.....

..... [1]

(ii) Use the data in Table 1.1 to calculate the enthalpy change of solution of potassium iodide, KI.

Table 1.1

process	enthalpy change, ΔH / kJ mol^{-1}
$K^+(g) + I^-(g) \rightarrow KI(s)$	–629
$K^+(g) \rightarrow K^+(aq)$	–322
$I^-(g) \rightarrow I^-(aq)$	–293

enthalpy change of solution = ... kJ mol^{-1} [1]

(iii) Suggest the trend in the magnitude of the lattice energies of the Group 1 iodides, LiI, NaI, KI.
Explain your answer.

.....

.....

.....

..... [2]

Q# 3/ ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 **(a)** Define the term *electron affinity*.

.....

..... [2]

(b) Write an equation for the process corresponding to the **second** ionisation energy of calcium. Include state symbols.

..... [1]

Some data relating to calcium and oxygen are listed. Select relevant data from this list for your answers to parts **(c)**, **(d)** and **(e)**.

process	value / kJ mol^{-1}
first ionisation energy of oxygen	+1310
second ionisation energy of oxygen	+3390
first electron affinity of oxygen	–142
second electron affinity of oxygen	+844
enthalpy change for $\frac{1}{2}O_2(g) + 2e^- \rightarrow O^{2-}(g)$	+951
enthalpy change for $Ca(s) \rightarrow Ca^{2+}(g) + 2e^-$	+1933
lattice energy of CaO(s)	–3517

(c) Oxygen exists as O_2 molecules.

Use the data in this question to calculate a value for the bond energy of the O=O bond.
Show all your working.

bond energy = ... kJ mol^{-1} [3]

(d) (i) Suggest why the first electron affinity of oxygen is negative.

.....

..... [1]

(ii) Suggest why the second electron affinity of oxygen is positive.

.....

..... [1]

(e) Calculate the enthalpy of formation of calcium oxide, CaO(s).

enthalpy of formation = ... $kJ\,mol^{-1}$ [2]

(f) The lattice energy of lithium fluoride, LiF(s), is $-1022\,kJ\,mol^{-1}$.

Identify the factor that causes the lattice energy of calcium oxide to be more exothermic than that of lithium fluoride. Explain why this factor causes the difference in lattice energies.

.....

..... [2]

[Total: 12]

Q# 4/ ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1 When dilute sulfuric acid is electrolysed, water is split into hydrogen and oxygen.

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

(e) The standard entropies, $S^{\ominus}$, of three species are given in the table.

species	$S^{\ominus}/J\,K^{-1}\,mol^{-1}$
$H_2O(l)$	+70
$H_2(g)$	+131
$O_2(g)$	+205

(i) Calculate $\Delta S^{\ominus}$ for the reaction $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$.

$\Delta S^{\ominus}$ = ... $J\,K^{-1}\,mol^{-1}$ [1]

(ii) $\Delta H^{\ominus}$ for the reaction $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$ is $+572\,kJ\,mol^{-1}$.

Calculate $\Delta G^{\ominus}$ for this reaction at 298 K.

$\Delta G^{\ominus}$ = ... $kJ\,mol^{-1}$ [2]

(iii) Predict the effect of increasing temperature on the spontaneity of this reaction.
Explain your answer.

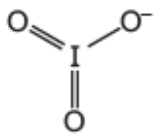
.....

..... [1]

Q# 6/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 Iodates are compounds that contain the IO_3^- anion.

(a) The IO_3^- anion is shown.



(f) NH_4IO_3 is an unstable compound that readily decomposes when warmed. The decomposition reaction is shown.

$$NH_4IO_3(s) \rightarrow \tfrac{1}{2}N_2(g) + \tfrac{1}{2}O_2(g) + \tfrac{1}{2}I_2(g) + 2H_2O(l) \qquad \Delta H = -154.6\,kJ\,mol^{-1}$$

(i) Use the data in the table to calculate the entropy change of reaction, ΔS, of the decomposition of $NH_4IO_3(s)$.

compound	$S / J\,K^{-1}\,mol^{-1}$
$NH_4IO_3(s)$	42
$N_2(g)$	192
$O_2(g)$	205
$I_2(g)$	261
$H_2O(l)$	70

ΔS = ... $JK^{-1}\,mol^{-1}$ [2]

(ii) This reaction is feasible at all temperatures.

Explain why, using the data in **(f)** and your answer to **(f)(i)**.

.....

.....

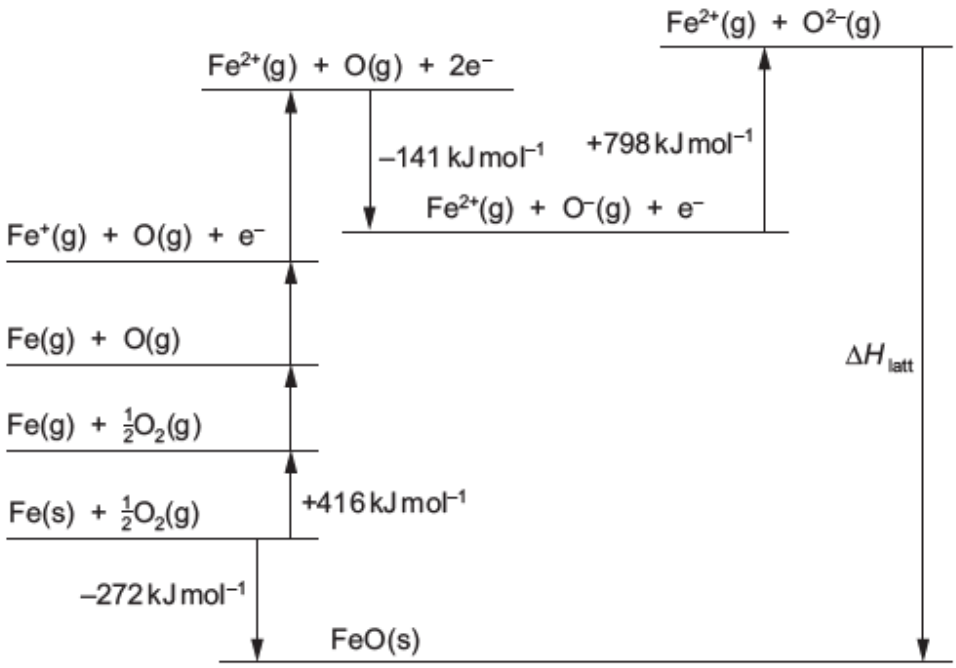
..... [1]

Q# 7/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 **(a)** Iron(II) compounds are generally only stable in neutral, non-oxidising conditions.

It is difficult to determine the lattice energy of FeO experimentally.

(i) Use data from the *Data Booklet* and this Born–Haber cycle to calculate the lattice energy, ΔH_{latt}, of FeO(s) in $kJ\,mol^{-1}$.



ΔH_{latt}FeO(s) = ... $kJ\,mol^{-1}$ [2]

(iii) State and explain how the lattice energy of FeO(s) compares to the lattice energy of CaO(s).

.....

.....

.....

.....

..... [2]

Q# 8/ ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 **(a)** The lattice energies of three ionic compounds are given.

compound	lattice energy / kJ mol^{-1}
LiF(s)	–1022
CaO(s)	–3513
SrO(s)	–3310

(i) Define the term *lattice energy*.

.....

.....

..... [2]

(ii) Explain why the lattice energy of CaO is more exothermic than the lattice energy of LiF.

.....

.....

..... [1]

(iii) Use the data in the table to estimate approximate values for the lattice energies of magnesium oxide and barium oxide.

ΔH_{latt}MgO(s) = ... kJ mol^{-1}

ΔH_{latt}BaO(s) = ... kJ mol^{-1}

[1]

(c) Use the following data and relevant data from the *Data Booklet* to calculate a value for the lattice energy of magnesium fluoride, $MgF_2(s)$.

You might find it helpful to construct an energy cycle.
Show your working.

electron affinity of F(g)	$= -348\,kJ\,mol^{-1}$
enthalpy change of atomisation of Mg(s)	$= +147\,kJ\,mol^{-1}$
enthalpy change of formation of $MgF_2(s)$	$= -1102\,kJ\,mol^{-1}$

$\Delta H_{latt} MgF_2(s)$ = ... [3]

(d) (i) Define the term *electron affinity*.

.....

..... [2]

(ii) The electron affinity of carbon, C(g), is $-120\,kJ\,mol^{-1}$.

Suggest an explanation for the difference between the electron affinity of fluorine and the electron affinity of carbon.

.....

.....

.....

..... [1]

[Total: 15]

Q# 9/ ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 7 /www.SmashingScience.org :o)

(b) Silver chloride, AgC*l*, is sparingly soluble in water. The equation for the enthalpy change of solution is shown.

$$AgCl(s) \rightarrow Ag^+(aq) + Cl^-(aq) \qquad \Delta H^{\ominus}_{sol} = +65.5\,kJ\,mol^{-1}$$

Standard entropies are shown in the table.

species	AgC*l*(s)	Ag^+(aq)	Cl^-(aq)
$S^{\ominus}$/$JK^{-1}mol^{-1}$	+96.2	+72.7	+56.5

(i) Calculate the standard entropy change of solution, $\Delta S^{\ominus}$.

$\Delta S^{\ominus}$ = ... $JK^{-1}mol^{-1}$ [1]

(ii) Explain, with the aid of a calculation, why AgC*l* is insoluble in water at 25 °C.

You should use data from this question and your answer to **(b)(i)**.

.....

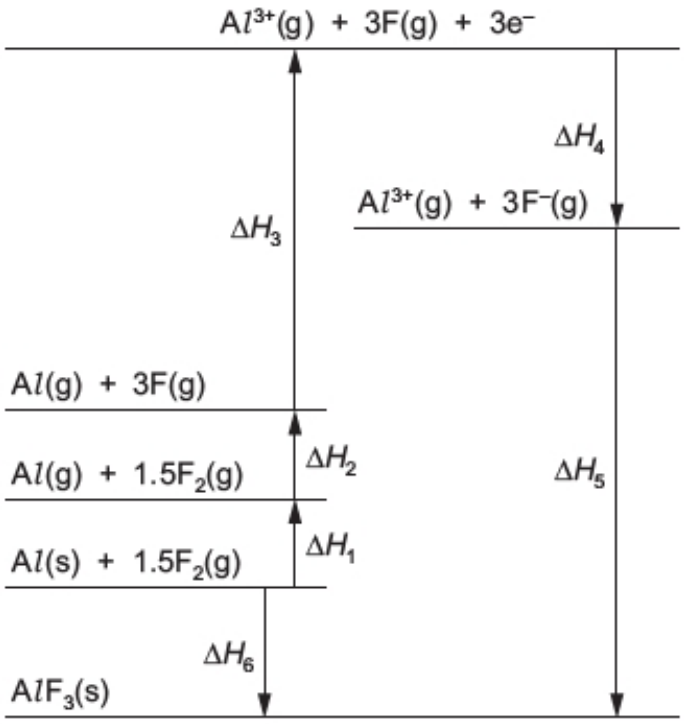
..... [3]

[Total: 10]

3 Gold is an unreactive metal that can only be oxidised under specific conditions.

(c) $Al F_3$ is an ionic compound.

The Born–Haber cycle for the formation of $Al F_3$ is shown.



(i) Name the enthalpy changes labelled ΔH_4 and ΔH_6.

ΔH_4 = ...

ΔH_6 = ...

[2]

(ii) Use the data in the table and data from the *Data Booklet* to calculate the lattice energy of $Al F_3$.

process	enthalpy change / kJ mol^{-1}
$Al(s) \rightarrow Al(g)$	+326
$Al(g) \rightarrow Al^{3+}(g)$	+5137
$F(g) \rightarrow F^-(g)$	–328
$Al(s) + 1.5F_2(g) \rightarrow AlF_3(s)$	–1504

lattice energy of $Al F_3$ = ... kJ mol^{-1} [2]

(iii) Scandium fluoride, ScF_3, is an ionic compound.

Use data from the *Data Booklet* to suggest how the lattice energy of AlF_3 compares with the lattice energy of ScF_3.

Explain your answer.

.....

.....

..... [2]

Q# 11/ ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 **(a)** Explain what is meant by the term *entropy of a system*.

.....

..... [1]

(b) State and explain whether the entropy change of each of the following processes is positive or negative. Do not consider the entropy change of the surroundings.

- liquid water at 80 °C is cooled to 60 °C

The entropy change is ..... because .....

.....

- solid calcium chloride is added to water and the mixture is stirred

The entropy change is ..... because .....

.....

- the change corresponding to the lattice energy of calcium chloride, ΔH_{latt} $CaCl_2(s)$, takes place

The entropy change is ..... because .....

.....

[3]

(c) The reaction $ZnCO_3(s) \rightarrow ZnO(s) + CO_2(g)$ is not spontaneous at room temperature.

(i) Give the full name for the term $\Delta G^{\ominus}$.

..... [1]

(ii) Describe how the temperature at which the reaction becomes spontaneous can be calculated. Include an equation in your answer.

equation .....

.....

.....

.....

[2]

Q# 12/ ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 6 /www.SmashingScience.org :o)

6 **(a)** Complete the table by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

energy change	always positive	always negative	either negative or positive
bond energy			
enthalpy change of formation			

[1]

(b) Explain what is meant by the term *enthalpy change of atomisation*.

.....

..... [1]

(c) The overall reaction for the atomisation of liquid bromine molecules, $Br_2(l)$, is shown.

$$Br_2(l) \rightarrow 2Br(g)$$

This happens via a two-step process.

- Construct a **labelled** energy cycle to represent this atomisation process, including state symbols.
- Use your cycle and relevant data from the *Data Booklet* to calculate the enthalpy change of vaporisation of $Br_2(l)$, $\Delta H^{\ominus}_{vap}$.
  The enthalpy change of atomisation of bromine, ΔH_{at}, = +112 kJ mol^{-1}.

$\Delta H^{\ominus}_{vap}$ = ... kJ mol^{-1} [3]

6 **(a)** Complete the table by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

energy change	always positive	always negative	either negative or positive
bond energy			
enthalpy change of formation			

[1]

(b) Explain what is meant by the term *enthalpy change of atomisation*.

.....

..... [1]

(c) The overall reaction for the atomisation of liquid bromine molecules, $Br_2(l)$, is shown.

$$Br_2(l) \rightarrow 2Br(g)$$

This happens via a two-step process.

- Construct a **labelled** energy cycle to represent this atomisation process, including state symbols.
- Use your cycle and relevant data from the *Data Booklet* to calculate the enthalpy change of vaporisation of $Br_2(l)$, $\Delta H^{\ominus}_{vap}$.
  The enthalpy change of atomisation of bromine, ΔH_{at}, = +112 kJ mol^{-1}.

$\Delta H^{\ominus}_{vap}$ = ... kJ mol^{-1} [3]

(d) Suggest how the $\Delta H^{\ominus}_{vap}$ of iodine, $I_2(l)$, would compare to that of bromine, $Br_2(l)$. Explain your answer.

.....

..... [1]

(e) (i) Explain what is meant by the term *enthalpy change of hydration*.

.....

..... [1]

(ii) Suggest why the enthalpy change of hydration of $Br^-(g)$ is **more** exothermic than that of $I^-(g)$.

.....

.....

..... [2]

[Total: 9]

Q# 13/ ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 (a) The following table lists the solubilities of the hydroxides and carbonates of some of the Group 2 elements, **M**, at 25 °C.

element **M**	solubility / mol dm^{-3}	
	$M(OH)_2$	MCO_3
Mg	2.0×10^{-4}	1.5×10^{-3}
Ca	1.5×10^{-2}	1.3×10^{-4}
Sr	3.4×10^{-2}	7.4×10^{-5}
Ba	1.5×10^{-1}	9.1×10^{-5}

(c) The equation for the formation of the gaseous hydroxide ion is shown.

$$\tfrac{1}{2}H_2(g) + \tfrac{1}{2}O_2(g) + e^- \rightarrow OH^-(g) \qquad \Delta H = \Delta H_f^{\ominus}(OH^-(g))$$

Use data in the table and from the *Data Booklet* to calculate $\Delta H_f^{\ominus}(OH^-(g))$. You might find it useful to construct a Born-Haber cycle.

enthalpy change	$\Delta H^{\ominus}$ / kJ mol^{-1}
atomisation of Mg(s)	+148
formation of $Mg(OH)_2(s)$	–925
lattice energy of $Mg(OH)_2(s)$	–2993

$\Delta H_f^{\ominus}(OH^-(g))$ = ... kJ mol^{-1} [3]

1 **(a)** State **one** natural and **one** man-made occurrence of oxides of nitrogen.

.....

..... [1]

(b) Under conditions of high pressure and a catalyst, nitrogen monoxide, NO, forms two other oxides of nitrogen, dinitrogen monoxide, N_2O, and dinitrogen trioxide, N_2O_3.

..... $NO(g) \rightarrow$ ..... $N_2O(g)$ + ... $N_2O_3(g)$ $\quad \Delta H^\ominus = -195.2\,kJ\,mol^{-1}$ $\quad \Delta G^\ominus = -102.8\,kJ\,mol^{-1}$

(i) Balance the equation above for the formation of N_2O and N_2O_3 from NO. [1]

(ii) State how the oxidation number of nitrogen changes during this reaction.

$NO \rightarrow N_2O$ from ..... to .....

$NO \rightarrow N_2O_3$ from ..... to .....

[1]

(iii) Calculate the entropy change for the reaction at 298 K. Include the units in your answer.

$\Delta S^\ominus$ = ...

units = ...

[2]

(iv) State whether the sign of $\Delta S^\ominus$ calculated in **(iii)** agrees with that predicted from your balanced equation in **(i)**. Explain your answer.

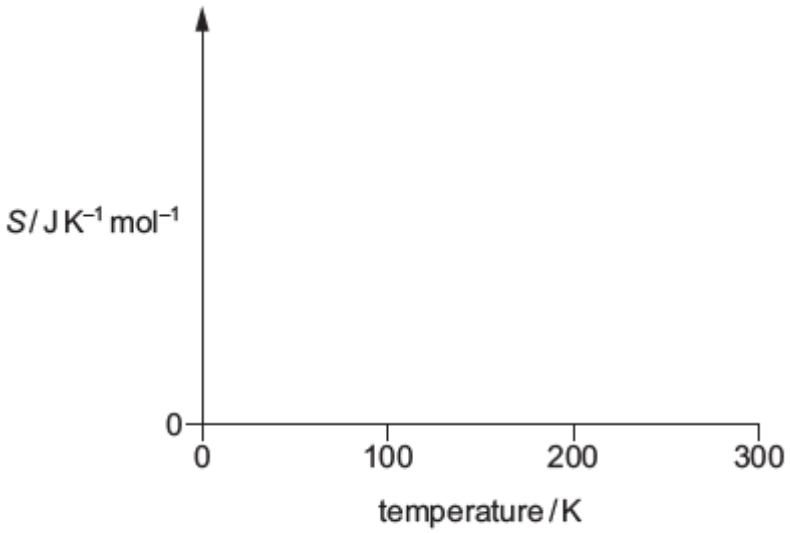
.....

..... [1]

8 Entropy is a measure of the disorder of a system.

(a) Assume the entropy, S, for H_2O is zero at 0 K.

Sketch a graph on the axes to show how the entropy changes for H_2O between 0 K and 300 K.



[2]

(b) Place **one tick** (✓) in **each row** of the table to show the sign of the entropy changes, ΔS.

	ΔS is negative	ΔS is positive
solid dissolving in water		
water boiling to steam		

[1]

(c) The equation for a reaction that produces methanol is shown.

$$CO_2(g) + 3H_2(g) \rightarrow CH_3OH(g) + H_2O(g)$$

Use relevant bond energies from the *Data Booklet* to calculate the enthalpy change, ΔH, for this gas phase reaction.

ΔH = ... kJ mol^{-1} [2]

(d) At 298 K, both products of this reaction are liquid.

$$CO_2(g) + 3H_2(g) \rightarrow CH_3OH(l) + H_2O(l) \qquad \Delta H^\ominus = -131\,kJ\,mol^{-1}$$

Standard entropies are shown in the table.

substance	$CO_2(g)$	$H_2(g)$	$CH_3OH(l)$	$H_2O(l)$
$S^\ominus / J\,K^{-1}\,mol^{-1}$	+214	+131	+127	+70

(i) Calculate the standard entropy change, $\Delta S^\ominus$, for this reaction.

$\Delta S^\ominus$ = ... $J\,K^{-1}\,mol^{-1}$ [2]

(ii) Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, for this reaction at 298 K.

$\Delta G^\ominus$ = ... $kJ\,mol^{-1}$ [2]

(iii) Predict the effect of increasing the temperature on the feasibility of this reaction.

.....

..... [1]

1 Sodium oxide, Na_2O, is a white crystalline solid with a high melting point.

(d) Use the data below, and other suitable data from the *Data Booklet*, to calculate the lattice energy of sodium oxide, $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$.

energy change	value / kJ mol^{-1}
standard enthalpy change of formation of sodium oxide, $\Delta H^{\ominus}_{f}$ $Na_2O(s)$	–416
standard enthalpy change of atomisation of sodium, $\Delta H^{\ominus}_{at}$ Na(s)	+109
electron affinity of O(g)	–142
electron affinity of O^-(g)	+844

$\Delta H^{\ominus}_{latt}$ $Na_2O(s)$ = ... kJ mol^{-1} [4]

(e) State how $\Delta H^{\ominus}_{latt}$ $Na_2S(s)$ differs from $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$.
Indicate this by placing a tick (✓) in the appropriate box in the table.

$\Delta H^{\ominus}_{latt}$ $Na_2S(s)$ is more exothermic than $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$	$\Delta H^{\ominus}_{latt}$ $Na_2S(s)$ is the same as $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$	$\Delta H^{\ominus}_{latt}$ $Na_2S(s)$ is less exothermic than $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$

Explain your answer.

.....

.....

..... [2]

The table lists the standard enthalpy changes of formation, $\Delta H_f^{\ominus}$, for some compounds and aqueous ions.

species	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$Ba^{2+}(aq)$	–538
$OH^-(aq)$	–230
$CO_2(g)$	–394
$BaCO_3(s)$	–1216
$H_2O(l)$	–286

(b) (i) Reaction 1 occurs when $CO_2(g)$ is bubbled through an aqueous solution of $Ba(OH)_2$.

Use the data in the table to calculate the standard enthalpy change for reaction 1, $\Delta H_{r1}^{\ominus}$.

$$Ba(OH)_2(aq) + CO_2(g) \rightarrow BaCO_3(s) + H_2O(l) \qquad \text{reaction 1}$$

$\Delta H_{r1}^{\ominus}$ = ... kJ mol^{-1} [2]

If $CO_2(g)$ is bubbled through an aqueous solution of $Ba(OH)_2$ for a long time, the precipitated $BaCO_3(s)$ dissolves, as shown in reaction 2.

$$BaCO_3(s) + CO_2(g) + H_2O(l) \rightarrow Ba(HCO_3)_2(aq) \qquad \text{reaction 2}$$

The standard enthalpy change for reaction 2, $\Delta H_{r2}^{\ominus}$, = –26 kJ mol^{-1}.

(ii) Use this information and the data in the table to calculate the standard enthalpy change of formation of the $HCO_3^-(aq)$ ion.

$\Delta H_f^{\ominus}$ $HCO_3^-(aq)$ = ... kJ mol^{-1} [2]

(iii) The overall process is shown by reaction 3.

Use your answer to **(ii)**, and the data given in the table, to calculate the standard enthalpy change for reaction 3, $\Delta H^{\ominus}_{r3}$.

$$Ba(OH)_2(aq) + 2CO_2(g) \rightarrow Ba(HCO_3)_2(aq) \qquad \text{reaction 3}$$

$\Delta H^{\ominus}_{r3}$ = ... kJ mol^{-1} [1]

(iv) How would the value of $\Delta H^{\ominus}_{r3}$ compare with the value of $\Delta H^{\ominus}_{r4}$ for the similar reaction with $Ca(OH)_2(aq)$ as shown in reaction 4?
Explain your answer.

$$Ca(OH)_2(aq) + 2CO_2(g) \rightarrow Ca(HCO_3)_2(aq) \qquad \text{reaction 4}$$

.....

.....

..... [2]

(c) The standard entropy change for reaction 1 is $\Delta S^{\ominus}_{r1}$.

Suggest, with a reason, how the standard entropy change for reaction 3 might compare with $\Delta S^{\ominus}_{r1}$.

.....

.....

..... [2]

[Total: 13]

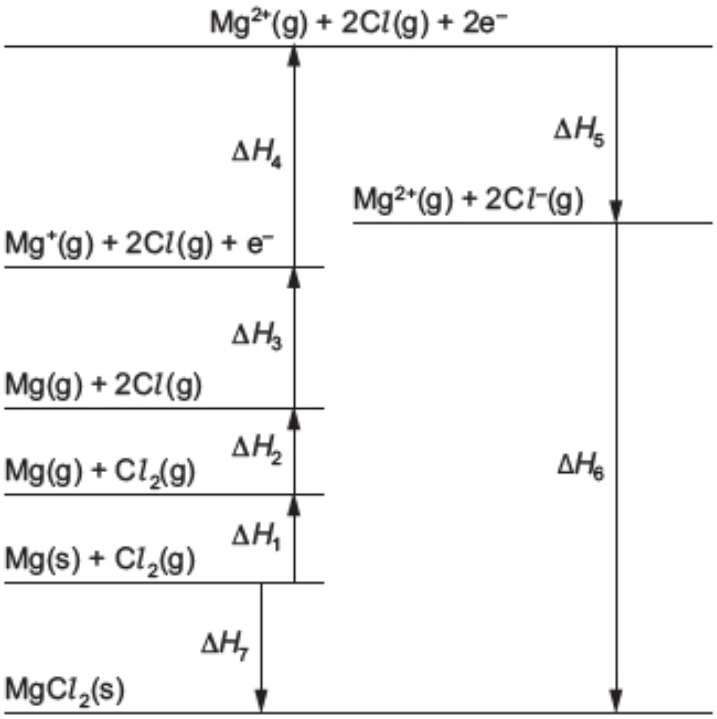
Q# 18/ ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 **(a)** Complete the table using ticks (✓) to indicate whether the sign of each type of energy change, under standard conditions, is always positive, always negative or could be either positive or negative.

energy change	always positive	always negative	either positive or negative
electron affinity			
enthalpy change of atomisation			
ionisation energy			
lattice energy			

[2]

(b) The Born-Haber cycle for magnesium chloride is shown.



(i) Explain why ΔH_4 is greater than ΔH_3.

.....

..... [1]

(ii) What names are given to the enthalpy changes ΔH_6 and ΔH_7?

ΔH_6 .....

ΔH_7 .....

[1]

(c) Chlorine is in Group 17.

Suggest the trend in the first electron affinity of the elements in Group 17. Explain your answer.

.....

.....

..... [2]

(d) The equation for the formation of magnesium oxide from its elements is shown.

$$Mg(s) + \tfrac{1}{2}O_2(g) \rightarrow MgO(s) \qquad \Delta H^\ominus = -602\,kJ\,mol^{-1}$$

substance	$S^\ominus$ / J K^{-1} mol^{-1}
Mg(s)	32.7
O_2(g)	205
MgO(s)	26.9

Use the equation and the data given in the table to calculate $\Delta G^{\ominus}$ for the reaction at 25 °C.

$\Delta G^{\ominus}$ = ... units .....

[4]

Q# 19/ ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 The spontaneity (feasibility) of a chemical reaction depends on the standard Gibbs free energy change, $\Delta G^{\ominus}$. This is related to the standard enthalpy and entropy changes by the equation shown.

$$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$$

(d) The solubility of Group 2 sulfates decreases down the Group.

Explain this trend.

.....

.....

.....

..... [2]

Q# 20/ ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 The spontaneity (feasibility) of a chemical reaction depends on the standard Gibbs free energy change, $\Delta G^{\ominus}$. This is related to the standard enthalpy and entropy changes by the equation shown.

$$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$$

(a) State and explain whether the following processes will lead to an increase or decrease in entropy.

(i) the reaction of magnesium with hydrochloric acid

entropy change .....

explanation .....

[1]

(ii) solid potassium chloride dissolving in water

entropy change .....

explanation .....

[1]

3 The spontaneity (feasibility) of a chemical reaction depends on the standard Gibbs free energy change, $\Delta G^{\ominus}$. This is related to the standard enthalpy and entropy changes by the equation shown.

$$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$$

(a) State and explain whether the following processes will lead to an increase or decrease in entropy.

(i) the reaction of magnesium with hydrochloric acid

entropy change .....

explanation .....

[1]

(ii) solid potassium chloride dissolving in water

entropy change .....

explanation .....

[1]

(iii) steam condensing to water

entropy change .....

explanation .....

[1]

(b) Magnesium carbonate can be decomposed.

$$MgCO_3(s) \rightarrow MgO(s) + CO_2(g) \qquad \Delta H^{\ominus} = +117\,kJ\,mol^{-1}$$

Standard entropies are shown in the table.

substance	$MgCO_3(s)$	$MgO(s)$	$CO_2(g)$
$S^{\ominus}$ / $J\,mol^{-1}\,K^{-1}$	+65.7	+26.9	+214

(i) Calculate $\Delta G^{\ominus}$ for this reaction at 298 K.
Include a relevant sign and give your answer to **three** significant figures.

$\Delta G^{\ominus}$ = ... $kJ\,mol^{-1}$ [3]

(ii) Explain, with reference to $\Delta G^{\ominus}$, why this reaction becomes more feasible at higher temperatures.

.....

..... [1]

(c) On heating, sodium hydrogencarbonate decomposes into sodium carbonate as shown.

$$2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g) \quad \Delta H^{\ominus} = +130\,kJ\,mol^{-1}$$
$$\Delta S^{\ominus} = +316\,J\,mol^{-1}\,K^{-1}$$

Calculate the **minimum** temperature at which this reaction becomes spontaneous (feasible). Show your working.

temperature = ... K [2]

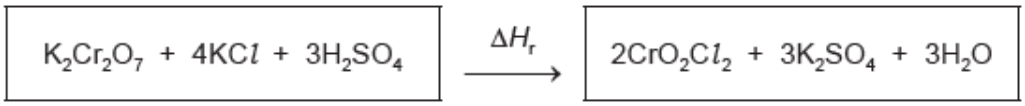
Q# 21/ ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 8 /www.SmashingScience.org :o)

8 **(a)** Chromyl chloride, CrO_2Cl_2, can be prepared by heating a mixture of potassium dichromate(VI) and potassium chloride with concentrated sulfuric acid.

$$K_2Cr_2O_7 + 4KCl + 3H_2SO_4 \rightarrow 2CrO_2Cl_2 + 3K_2SO_4 + 3H_2O$$

Use the following data to complete the Hess' Law cycle and calculate the enthalpy change of the reaction, ΔH_r.

compound	enthalpy change of formation, $\Delta H_f^{\ominus}$ / kJ mol^{-1}
$K_2Cr_2O_7$	–2061
KCl	–437
H_2SO_4	–814
CrO_2Cl_2	–580
K_2SO_4	–1438
H_2O	–286



ΔH_r = ... kJ mol^{-1} [2]

Q# 22/ ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 8 /www.SmashingScience.org :o)

8 **(a)** Chromyl chloride, CrO_2Cl_2, can be prepared by heating a mixture of potassium dichromate(VI) and potassium chloride with concentrated sulfuric acid.

$$K_2Cr_2O_7 + 4KCl + 3H_2SO_4 \rightarrow 2CrO_2Cl_2 + 3K_2SO_4 + 3H_2O$$

(b) There are two isomeric complex ions with the formula $[Cr(NH_3)_4Cl_2]^+$. One is green and the other is violet.

(i) Suggest the *type of isomerism* shown by these complex ions.

..... [1]

(ii) Explain why these two complex ions

- are coloured, ...

.....

.....

.....

- have **different** colours. .....

.....

.....

.....

[4]

Q# 23/ ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

(c) (i) Predict the sign of $\Delta S^{\ominus}$ for this reaction. Explain your answer.

$$2H_2S(g) + CH_4(g) \rightleftharpoons CS_2(g) + 4H_2(g) \qquad \Delta H^{\ominus} = +241\,kJ\,mol^{-1}$$

.....

..... [1]

The free energy change, $\Delta G^{\ominus}$, for this reaction at 1000 K is $+51\,kJ\,mol^{-1}$.

(ii) Calculate the value of $\Delta S^{\ominus}$ for this reaction, stating its units.

$\Delta S^{\ominus}$ = ... units ..... [2]

(d) How would the value of $\Delta G^{\ominus}$, and hence the spontaneity (feasibility) of this reaction change as the temperature increases? Explain your answer.

.....

.....

..... [2]

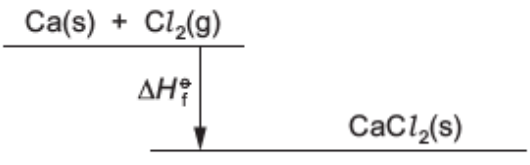
Q# 24/ ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 (a) Calcium metal reacts with chlorine gas to form calcium chloride, $CaCl_2$.

(i) Write an equation, including state symbols, to represent the lattice energy of calcium chloride, $CaCl_2$.

..... [1]

(ii) Complete a fully labelled Born-Haber cycle that could be used to calculate the lattice energy, $\Delta H^{\ominus}_{latt}$, for calcium chloride.



[2]

(iii) Use your answer to **(ii)** and the following data, together with relevant data from the *Data Booklet*, to calculate a value for $\Delta H^{\ominus}_{latt}$ for calcium chloride.

standard enthalpy change of formation of $CaCl_2(s)$, $\Delta H^{\ominus}_f$	–796 kJ mol^{-1}
standard enthalpy change of atomisation of Ca(s), $\Delta H^{\ominus}_{at}$	+178 kJ mol^{-1}
electron affinity of chlorine atoms	–349 kJ mol^{-1}

$\Delta H^{\ominus}_{latt}$ = ... kJ mol^{-1} [3]

(b) Entropy is a measure of the disorder of a system.

Describe and explain what happens to the entropy of a gas when the temperature is increased.

.....

.....

..... [2]

(c) The table shows four reactions.

(i) For each reaction, predict the sign of the entropy change, $\Delta S^{\ominus}$. If you predict no entropy change, write 'no change' in the table below. The first one has been done for you.

reaction	sign of $\Delta S^{\ominus}$
$CO(g) + O_2(g) \rightarrow CO_2(g)$	negative
$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$	
$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4.5H_5O(s)$	
$NaHCO_3(s) + H^+(aq) \rightarrow Na^+(aq) + CO_2(g) + H_2O(l)$	

[2]

(ii) Explain why the entropy change for the first process is negative.

.....

..... [1]

(d) Calculate the standard entropy change, $\Delta S^{\ominus}$, for this reaction.

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

Standard entropies, $S^{\ominus}$, in $JK^{-1}mol^{-1}$ are given.

$N_2(g)$	$H_2(g)$	$NH_3(g)$
+192	+131	+193

$\Delta S^{\ominus}$ ..... $JK^{-1}mol^{-1}$ [2]

(e) Whether or not a chemical reaction is spontaneous (feasible) can be deduced by calculating the change in free energy, $\Delta G^{\ominus}$, at a given temperature.

$$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$$

$\Delta H^{\ominus} = +117\,kJ\,mol^{-1}$
$\Delta S^{\ominus} = +175\,JK^{-1}mol^{-1}$

(i) Calculate the value of $\Delta G^{\ominus}$ at 298 K for the above reaction.

[2]

(ii) Use your answer to **(i)** to explain whether or not this reaction is spontaneous at 298 K.

.....

..... [1]

Q# 25/ ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(d) (i) What is meant by the term *standard enthalpy change of hydration*, $\Delta H^{\ominus}_{hyd}$?

.....

.....

..... [2]

(ii) Use the following data to calculate the lattice energy, $\Delta H^{\ominus}_{latt}$, of calcium nitrate, $Ca(NO_3)_2(s)$. You may find it helpful to construct an energy cycle.

enthalpy change	value
$\Delta H^{\ominus}_{hyd}$ $(Ca^{2+}(g))$	$-1650\,kJ\,mol^{-1}$
$\Delta H^{\ominus}_{hyd}$ $(NO_3^-(g))$	$-314\,kJ\,mol^{-1}$
enthalpy change of solution for $Ca(NO_3)_2(s)$	$-19\,kJ\,mol^{-1}$

$\Delta H^{\ominus}_{latt}$ $Ca(NO_3)_2(s)$ = ... kJ mol^{-1} [3]

(e) The standard enthalpy change of hydration for Ba^{2+}, $\Delta H^{\ominus}_{hyd}$ ($Ba^{2+}(g)$), is –1305 kJ mol^{-1}.

Suggest an explanation for why the $\Delta H^{\ominus}_{hyd}$ of the Ba^{2+} ion is **less** exothermic than the $\Delta H^{\ominus}_{hyd}$ of the Ca^{2+} ion.

.....

.....

..... [2]

[Total: 12]

Q# 26/ ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 4 /www.SmashingScience.org :o)

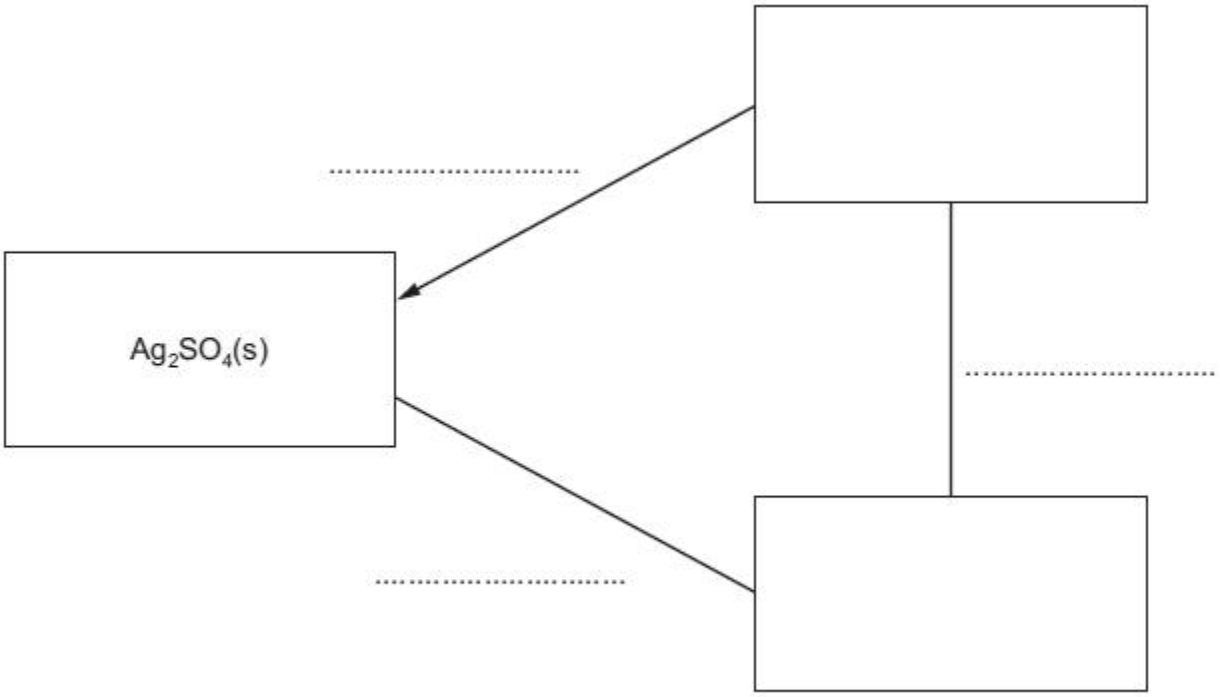
4 **(a)** Silver sulfate, Ag_2SO_4, is sparingly soluble in water. The concentration of its saturated solution is 2.5×10^{-2} mol dm^{-3} at 298 K.

(b) Using Ag_2SO_4 as an example, complete the following Hess' Law energy cycle relating the

- lattice energy, $\Delta H^{\ominus}_{latt}$,
- enthalpy change of solution, $\Delta H^{\ominus}_{sol}$, and
- enthalpy change of hydration, $\Delta H^{\ominus}_{hyd}$.

On your diagram:

- include the relevant species in the two empty boxes,
- label each enthalpy change with its appropriate symbol,
- complete the remaining two arrows showing the correct direction of enthalpy change.



[4]

Q# 27/ ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

(e) (i) What is meant by the term *lattice energy*?

.....

.....

(ii) Explain why the lattice energy of calcium phosphate is **less** exothermic than that of magnesium phosphate.

.....

.....

[3]

Q# 28/ ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1 (a) (i) What is meant by the term *lattice energy*?

.....

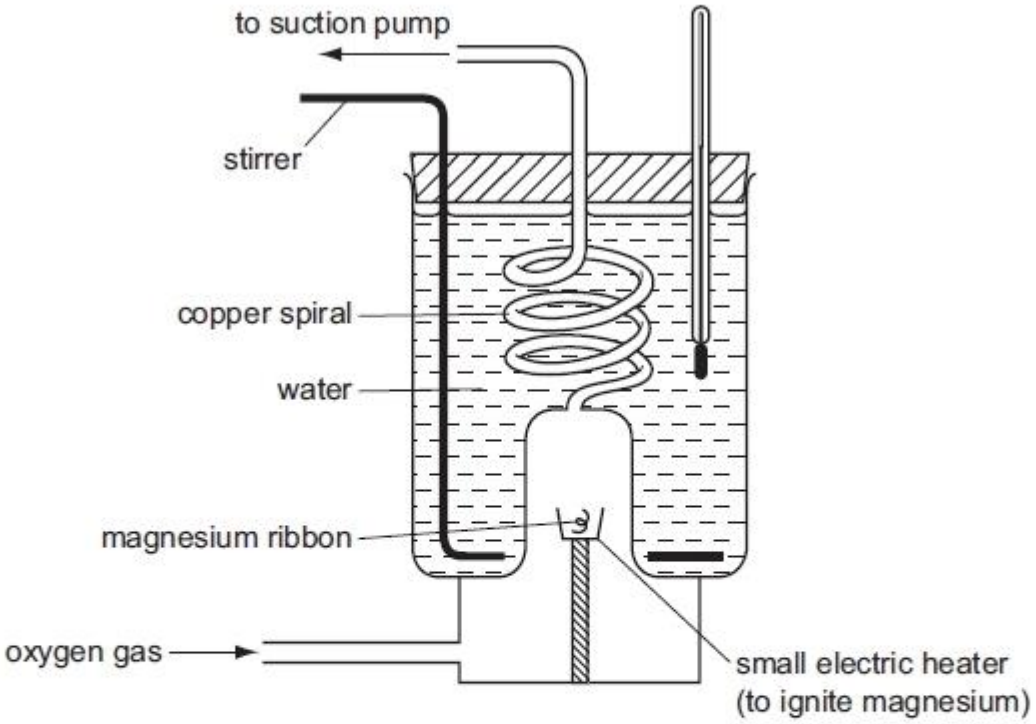
.....

(ii) Write an equation to represent the lattice energy of MgO.

.....

[3]

(b) The apparatus shown in the diagram can be used to measure the enthalpy change of formation of magnesium oxide, $\Delta H_f^{\ominus}(MgO)$.



List the measurements you would need to make using this apparatus in order to calculate $\Delta H_f^{\ominus}(MgO)$.

.....

.....

.....

..... [3]

Q# 29/ ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1 Taken together, nitrogen and oxygen make up 99% of the air. Oxygen is by far the more reactive of the two gases, and most of the substances that react with air combine with the oxygen rather than with the nitrogen.

Despite the apparent lack of reactivity of N_2, nitrogen atoms have been found to form bonds with almost all of the elements in the Periodic Table. Lithium metal reacts with nitrogen gas at room temperature to give lithium nitride, Li_3N. Magnesium produces magnesium nitride, Mg_3N_2, as well as magnesium oxide, when heated in air.

(b) Calculate the lattice energy of magnesium nitride using the following data, in addition to relevant data from the *Data Booklet*.

enthalpy change	value/kJ mol^{-1}
atomisation of Mg(s)	+148
total of electron affinities for the change $N(g) \longrightarrow N^{3-}(g)$	+2148
enthalpy of formation of $Mg_3N_2(s)$	–461

lattice energy = ...kJ mol^{-1} [3]

2 Calcium chloride, $CaCl_2$, is an important industrial chemical used in refrigeration plants, for de-icing roads and for giving greater strength to concrete.

(a) Show by means of an equation what is meant by the lattice energy of calcium chloride.

..... [1]

(b) Suggest, with an explanation, how the lattice energies of the following salts might compare in magnitude with that of calcium chloride.

(i) calcium fluoride, CaF_2

.....

.....

(ii) calcium sulfide, CaS

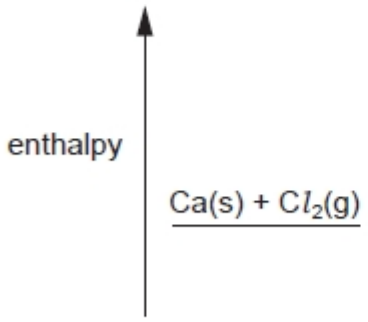
.....

.....

[3]

(c) Use the following data, together with additional data from the *Data Booklet*, to calculate the lattice energy of $CaCl_2$.

standard enthalpy change of formation of $CaCl_2$	–796 kJ mol^{-1}
standard enthalpy change of atomisation of Ca(s)	+178 kJ mol^{-1}
electron affinity per mole of chlorine atoms	–349 kJ mol^{-1}



lattice energy = ... kJ mol^{-1} [3]

Q# 1/ ALvl Chemistry/2022/m/TZ 1/Paper 4/Q# 2 /www.SmashingScience.org :o)

2(a)(i)	1 mol liquid and 2 mol gas formed from 3 mol solid OR two solid compounds converted to a liquid and a gas	1
2(a)(ii)	M1: (as T increases) $T\Delta S$ becomes greater (than ΔH) OR (as T increases) $T\Delta S$ becomes more positive M2: (as T increases) feasibility will increase as ΔG becomes more negative	2
2(b)(i)	M1: = 314 + 131 – (19 + 3 × 187) use of values and correct stoichiometry M2: = –135 (J K^{-1} mol^{-1})	2
2(b)(ii)	M1: $\Delta G = 0 \therefore T = \Delta H / \Delta S$ = +219.3 × 10^3 ÷ –(b)(i) M2: = **1624**(.4) (K)	2

Q# 2/ ALvl Chemistry/2022/m/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1(b)(i)	enthalpy change when one mole of a solute **AND** dissolves **in water** to form a solution of infinite dilution	1
1(b)(ii)	–(–629) + (–322) + (–293) = (+)**14** (kJ mol^{-1})	1
1(b)(iii)	(cationic) charge density decreases Li^+ to K^+ [1] so lattice energies become less negative / less exothermic **AND** because less **attraction** between ions [1]	2

Q# 3/ ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(a)	• enthalpy/energy change • one mole of electrons gained • by one mole of atoms • gaseous (atoms)	2
3(b)	$Ca^+(g) \rightarrow Ca^{2+}(g) + e^-$ [1]	1
3(c)	M1: selecting correct data 951, 844, 142 only M2: evaluation to give 249 (ΔH_{atom}) OR 2(951) = BE – 2(142) + 2(844) M3: evaluation to 498 (2 × 249) ecf M2 951 = ΔH_{atom} –142 + 844 ΔH_{atom} = 249 BE = 498 (kJ mol^{-1}) [3]	3
3(d)(i)	**attraction** between nucleus / protons / nuclear charge **and** electron [1]	1
3(d)(ii)	**repulsion** between 1– ion / electrons of O^- **and** electron [1]	1
3(e)	M1: selecting correct data 951, 1933, 3517 only (ignore signs) M2: evaluation to give –633 (ΔH_f) ecf ΔH_f = 951 + 1933 – 3517 = –633 (kJ mol^{-1}) [2]	2
3(f)	ionic charge / charge density (of the ions) [1] greater (attractive) force between the ions [1]	2

Q# 4/ ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

2(b)	M1 $[H^+] = 10^{-5}$ OR 1×10^{-5} $K_a = [H^+][A^-] / [HA]$ OR pH = pKa + log $[A^-] / [HA]$ • ✓ [1] M2 moles of A^- = (1.35 × 10^{-5})(5 / 74) / (1 × 10^{-5}) moles of A^- = 0.0912 [1] ecf M3 mass of sodium propanoate = 0.0912 × 96 = **8.76** [1] min 2sf ecf	3
2(c)	all of the (sodium) **propanoate** (ion) has been protonated / converted to (propanoic) acid / neutralised [1] H^+ is in excess / H^+ is 0.1 mol dm^{-3} (from the H_2SO_4) [1]	2

Q# 5/ ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

2(a)(i	$K_a = \frac{[H^+][Cl(CH_2)_3CO_2^-]}{[Cl(CH_2)_3CO_2H]}$ [1]	1
2(a)(ii)	$pK_a = -\log K_a$ OR $K_a = 10^{-pKa}$ [1]	1
2(a)(iii)	$[H^+] = 10^{-4.0} = 1 \times 10^{-4}$ [1]	1
2(a)(iv)	• $[HCl] = 1 \times 10^{-4}$ ecf 2(a)(iii) • $K_a = 10^{-4.52} = 3.02 \times 10^{-5}$ • $[Cl(CH_2)_3CO_2H] = (1 \times 10^{-4})^2 / 3.02 \times 10^{-5}$ $= 3.3 \times 10^{-4}$ ecf • $\frac{[HCl]}{[Cl(CH_2)_3CO_2H]} = \frac{1\times10^{-4}}{3.3\times10^{-4}} = 0.302$ min 2sf ecf	2

Q# 6/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(f)(i)	**M1**: ΔS = ½(192) + ½(205) + ½(261) + 2(70) – 42 **M2**: (+)427 (J K^{-1} mol^{-1}) ecf	2
3(f)(ii)	ΔG (always) negative because • $\Delta H < 0$ / negative **OR** exothermic **AND** • $\Delta S > 0$ / positive **OR** $-T\Delta S < 0$ for all T	1

Q# 7/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2(a)(i)	**M1** the only number extracted: 762, 1560, 496 **M2** correct multiplier, other four numbers used and calculation to the answer –272 = +416 + ½(496) + 762 + 1560 –141 + 798 + $\Delta H_{lattice}$ ∴ $\Delta H_{lattice}$ = **–3915** (kJ mol^{-1}) ecf	2
2(a)(iii)	• FeO more exothermic/more negative • Fe^{2+} has smaller radius/higher charge density (also same charge) • greater attraction/ stronger ionic bonds (between Fe^{2+} and O^{2-}) **All three for two marks**	2

Q# 8/ ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2 /www.SmashingScience.org :o)

2(a)(i)	**M1** energy released when 1 mole of an ionic compound is formed [1] **M2** from gaseous ions (under standard conditions) [1]	2
2(a)(ii)	Ca^{2+} & O^{2-} have a higher charge / charge density (than Li^+ and F^-) [1]	1
2(a)(iii)	MgO –3600 or more negative **AND** BaO –3200 or less negative **BOTH** [1]	1
2(c)	**M1:** Use of 2 × –348 (EA F) and +158 (bond energy of F_2) [1] **M2:** Use of +147 (at Mg) and +736 and +1450 (IEs of Mg) [1] **M3:** evaluation and calculation of their answer (–1102 – (147 + 158 + 736 + 1450 – 696)) = **–2897** (kJ mol^{-1}) [1] ecf	3
2(d)(i)	• (energy change) when an / one electron is added to • each atom / ion in one mole of • gaseous atoms / ions mark as • ✓ ✓ [2]	2
2(d)(ii)	F has greater nuclear charge / more protons **AND** greater attraction between F atom / nucleus and the electrons • ✓ **BOTH** [1]	1

Q# 9/ ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 7 /www.SmashingScience.org :o)

7(b)(i)	$\Delta S^\ominus$ = 72.7 + 56.5 -96.2 = **+33.0** J K^{-1} mol^{-1}	1
7(b)(ii)	**M1** $\Delta G = \Delta H^\ominus - T\Delta S^\ominus$ **M2** ΔG = (65.5)- (298x0.033) = **+55.7** kJ mol^{-1} min 3sf **M3** ΔG = positive so not feasible/spontaneous	3

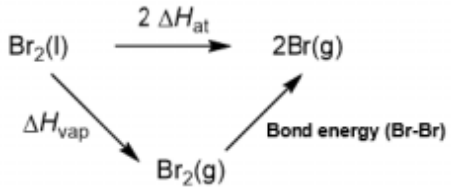
Q# 10/ ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(c)(i)	ΔH_4 = (3 ×) electron affinity of fluorine / F ΔH_5 = (enthalpy change of) formation of AlF_3	2
3(c)(ii)	**M1** +326 + 1½ × 158 + 5137 + 3 × –328 + ΔH_{lat} = –1504 **M2** ΔH_{lat} = –6220 (kJ mol^{-1})	2
3(c)(iii)	**M1** lattice energy of ScF_3 should be less exothermic ora **M2** Sc ion / Sc^{3+} larger than Al ion / Al^{3+} **AND** lesser attraction between the ions / ionic bonds are weaker	2

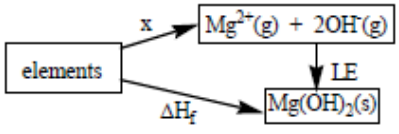
Q# 11/ ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(a)	a **measure / degree of disorder / randomness** of a system	1
3(b)	**M1:** negative – molecules have less energy in the system **M2:** positive – solid being converted into an aqueous solution **M3:** negative – gaseous ions being converted into a solid	3
3(c)(i)	(standard) Gibbs free energy change	1
3(c)(ii)	**M1:** $(\Delta)G = \Delta H - T\Delta S$ **M2:** description of calculating the minimum value of T for which ΔG is zero / becomes negative OR $T = \Delta H / \Delta S$ [1]	2

Q# 12/ ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 6 /www.SmashingScience.org :o)

6(a)	<table><tr><th>energy change</th><th>always positive</th><th>always negative</th><th>either negative or positive</th></tr><tr><td>bond energy</td><td>✓</td><td></td><td></td></tr><tr><td>enthalpy of formation</td><td></td><td></td><td>✓</td></tr></table> **both** ticks correct	1
6(b)	(energy change) when **1 mole of gaseous atoms** are formed (from an element in its standard state)	1
6(c)	 **M1**: correct cycle: formulae and state symbols **M2**: use of 1 × 193 **and** 2 × (112) **M3**: for the correct sum and answer ecf from M2 $\Delta H^{\ominus}_{vap}$ (= (2 × 112) – (193)) = +31 kJ mol^{-1} [scores M2 and M3]	3
6(d)	more endothermic **and** greater Van der Waals / London / induced dipole-dipole forces **both**	1
6(e)(i)	(energy change) when **1 mole of gaseous ions** is dissolved in (an excess of) water	1
6(e)(ii)	**M1**: Br^- has a smaller ionic radii **M2**: stronger (ion-dipole) attractions with water molecules	2

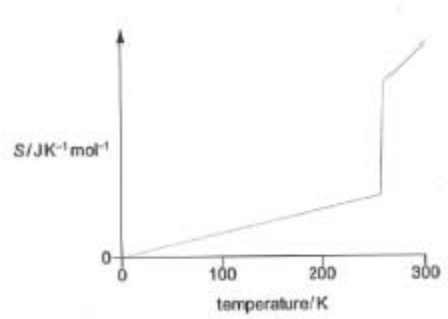
Q# 13/ ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2(c)	 –2993 + 148 + 736 + 1450 + 2ΔH_f(OH^-(g)) = –925 2ΔH_f(OH^-(g)) = –266 ΔH_f(OH^-(g)) = –133 (kJ mol^{-1})	3

Q# 14/ ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 1 /www.SmashingScience.org :o)

1(a)	natural: lightning, bacterial decomposition, volcanic emissions man-made: exhaust fumes, power stations, jet / car/ vehicle engines	1
1(b)(i)	$4NO \longrightarrow N_2O + N_2O_3$	1
1(b)(ii)	+2 to +1 **AND** +2 to +3	1
1(b)(iii)	$\Delta S = (\Delta H - \Delta G) / T$ $= (-195.2+102.8) / 298$ $= -0.310\ kJ\ mol^{-1}\ K^{-1}$ **M1** numerical answer **M2** units	2
1(b)(iv)	yes as there is a decrease in no. of moles of gas OR yes as moles of (gaseous) reactants is greater than moles of (gaseous) products	1

Q# 15/ ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 8 /www.SmashingScience.org :o)

8(a)	 **M1** continuous increase in *S* from 0–300 K (excluding m.p.) [1] **M2** **steep** vertical increase in *S* **ONLY** at the m.p. **AND** continuous increase in *S* after m.p. [1]	2
8(b)	[1] for each correct tick | | negative $\Delta S^\ominus$ | positive $\Delta S^\ominus$ | | solid dissolving in water | | ✓ | | water boiling to steam | | ✓ |	1
8(c)	$\Delta H^\ominus = (2 \times C{=}O) + (3 \times H\text{-}H) - (3 \times C\text{-}H) - (C\text{-}O) - (3 \times O\text{-}H)$ $\Delta H^\ominus = (2 \times 805) + (3 \times 436) - (3 \times 410) - (1 \times 360) - (3 \times 460)$ [1] $\Delta H^\ominus = 1610 + 1308 - 1230 - 360 - 1380 = -52\ (kJ\ mol^{-1})$ [1] ecf correct answer scores [2]	2
8(d)(i)	$\Delta S^\ominus = 127 + 70 - (214 + 3 \times 131)$ [1] $= -410\ (J\ K^{-1}\ mol^{-1})$ [1] ecf correct answer scores [2]	2
8(d)(ii)	$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$ [1] $\Delta G^\ominus = -131 - (298 \times -0.41) = -8.8(2)\ (kJ\ mol^{-1})$ [1] correct answer scores [2]	2
8(d)(iii)	(as temperature increases) feasibility decreases	1

Q# 16/ ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1(d)	use of (2 × 109) or 218 and (2 × 494) or 988	1
	use of (0.5 × 496) or 248	1
	use of 416, 142, 844	1
	evaluation of expression correctly $\Delta H_{lat} = -416 - (2 \times 109) - (0.5 \times 496) - (2 \times 494) - (-142 + 844) = -2572$	1
1(e)	the lattice energy of Na_2S is less exothermic	1
	the sulfide ion is larger than the oxide ion / S^{2-} larger than O^{2-} / ionic radii quoted 0.184 nm and 0.140 nm **AND** less attraction (between the ions)/bonds are weaker	1

Q# 17/ ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1(b)(i)	$\Delta H_{r1} - (538 + 2x230 + 394) = -(1216 + 286)$ $\Delta H_{r1} - 1392 = -1502$	1
	$\Delta H_{r1} = -110$	1

1(b)(ii)	let $\Delta H_f(HCO_3^-(aq))$ = y 2y – 538 = –1216 – 394 – 286 – 26	1
	y = –692	1
1(b)(iii)	ΔH_{r3} –538 – 2(230 + 394) = –538 – 2(692) ΔH_{r3} = –136	1
1(b)(iv)	ΔH_{r3} will be identical to ΔH_{r4}, / unchanged	1
	as the reaction is the same, or: $2OH^-(aq) + 2CO_2(g) \longrightarrow 2HCO_3^-(aq)$ or metal ions stay in solution/metal ions are unchanged / are spectators	1

1(c)	more **gaseous moles** are being consumed (in reaction 3) or more CO_2 **moles** are being consumed (in reaction 3)	1
	ΔS is therefore expected to be **more negative/less positive** for reaction 3.	1

Q# 18/ ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2(a)	<table><tr><th>enthalpy change</th><th>positive</th><th>negative</th><th>either positive or negative</th></tr><tr><td>electron affinity</td><td></td><td></td><td>✓</td></tr><tr><td>enthalpy change of atomisation</td><td>✓</td><td></td><td></td></tr><tr><td>enthalpy change of ionisation</td><td>✓</td><td></td><td></td></tr><tr><td>lattice enthalpy</td><td></td><td>✓</td><td></td></tr></table>	2
2(b)(i)	the second electron is removed from a (more) positively charged ion	1
2(b)(ii)	ΔH_6 is lattice (energy / enthalpy) **AND** ΔH_7 is (energy / enthalpy of) formation	1
2(c)	the electron affinity becomes less exothermic / negative down the Group 17	1
	electron affinity depends (mainly) on the electron-nucleus distance which increases down Group 17	1
2(d)	**M1** correct use of $\Delta G = \Delta H - T\Delta S$	1
	M2 ΔS = 26.9 – (32.7 + 102.5) = –108.3 $J K^{-1} mol^{-1}$ **OR** –0.1083 $kJ K^{-1} mol^{-1}$	1
	M3 ΔG = –602 – (298 × (–0.1083)) = –570	1
	M4 units: $kJ mol^{-1}$	1

Q# 19/ ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(d)	hydration enthalpy and lattice energy **both** more endothermic / more positive / less exothermic / less negative (down the group) ΔH_{hyd} decreases more / faster **and** ΔH_{sol} becomes (more) endothermic / (more) positive / less exothermic / less negative	1 1 2

Q# 20/ ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(a)(i)	(entropy) increases / is positive **and** H_2 / gas is formed	1 1
3(a)(ii)	(entropy) increases / is positive **and** (KCl (aq)) solution has (free) moving / mobile ions / aqueous ions	1 1
3(a)(iii)	(entropy) decreases / is negative **and** decrease in **gas**	1 1
3(b)(i)	$\Delta S^\ominus = 26.9 + 214 - 65.7 = (+)175.2\ (J K^{-1} mol^{-1})$ $\Delta G^\ominus = 117 - (298 \times 175.2/1000)$ OR $\Delta G^\ominus = 117\,000 - (298 \times 175.2)$ $\Delta G^\ominus = +64.8\ (kJ mol^{-1})$	1 1 1 3
3(b)(ii)	$T\Delta S$ is more positive than ΔH / $T\Delta S$ increases / $-T\Delta S$ more negative **and** ΔG is negative / decrease / less positive	1 1

3(c)	use of $\Delta G = 0$ or $T = \frac{T\Delta S}{\Delta H} = 1$ $T = 130/(316/1000) = 410/411/412/411.4$ (K)	1 1	2

Q# 21/ ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 8 /www.SmashingScience.org :o)

8	(a)	ΔH = [2(–580) + 3(–286) + 3(–1438)] – [–2061 + 4(–437) + 3(–814)] = –81 kJ mol^{-1}	[2]

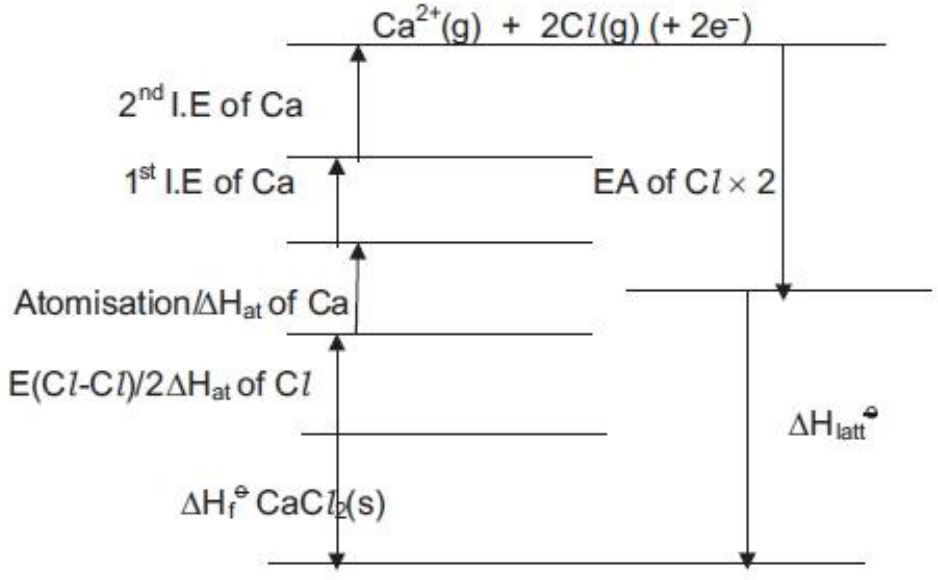
Q# 22/ ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 8 /www.SmashingScience.org :o)

	(b) (i)	*cis–trans* OR geometrical	[1]
	(ii)	in a complex the d–orbitals are split into 2 energy levels colour is due to absorption of light (in visible region) electron promotion to higher orbital absorbs a photon the d–d energy gap is different for the two complexes, hence different colours	[1] [1] [1] [1]

Q# 23/ ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3	(a)	$K_p = \{p(CS_2) \times (p(H_2))^4\} / \{(p(H_2S))^2 \times p(CH_4)\}$ units: atm^2 OR Pa^2	[1] [1]
	(b) (i)	$p(H_2S)$ = 196 atm $p(H_2)$ = 8 atm	[1] [1]
	(ii)	$K_p = (2 \times 8^4)/(196^2 \times 98) = 2.176 \times 10^{-3}$	[1]
	(c) (i)	$\Delta S^\ominus$ will be positive, because more gas moles on the RHS/products	[1]
	(ii)	$\Delta S^\ominus = (\Delta H^\ominus - \Delta G^\ominus)/T = (241 - 51)/1000 = 0.19$ OR 190 kJ mol^{-1} K^{-1} OR J mol^{-1} K^{-1}	[1] [1]
	(d)	$\Delta G^\ominus$ will become less positive/more negative as T increases, …because $\Delta S^\ominus$ is positive (*or* $-T\Delta S^\ominus$ is more negative) …therefore the reaction becomes more feasible/spontaneous as T increases	[2]

Q# 24/ ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

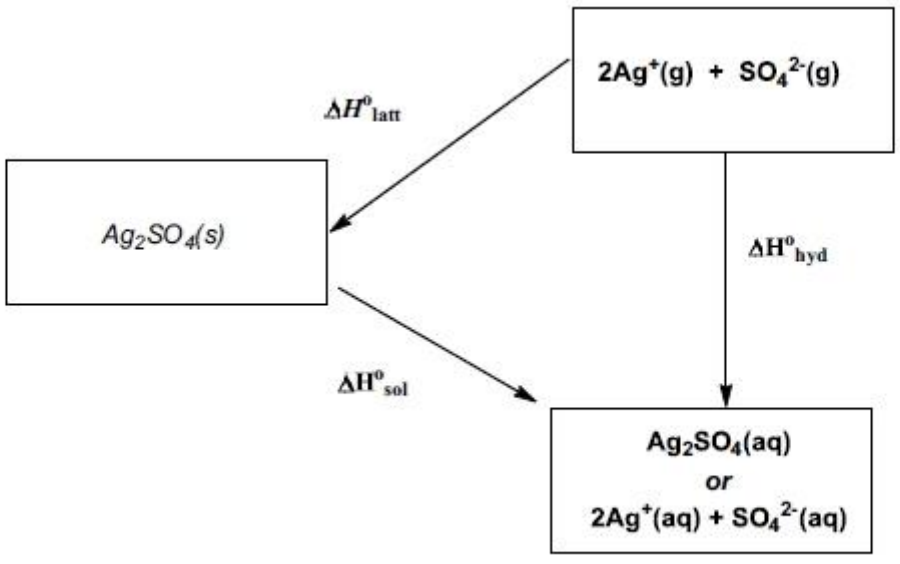
2	(a) (i)	$Ca^{2+}(g) + 2Cl^-(g) \rightarrow CaCl_2(s)$ (state symbols required)	1
	(ii)		2
	(iii)	$\Delta H_{latt}^\ominus = -796 - 242 - 178 - 590 - 1150 + (2 \times 349) = -2258$ kJ mol^{-1}	3
	(b)	(higher temperature means that) particles have more energy; entropy (of the gas/system) increases because of an increase in the amount of disorder/randomness;	2

(c) (i)	<table><tr><th>reaction</th><th>sign of $\Delta S^{\ominus}$</th></tr><tr><td>$CO(g) + O_2(g) \rightarrow CO_2(g)$</td><td>negative</td></tr><tr><td>$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$</td><td>negative</td></tr><tr><td>$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4.5H_2O(s)$</td><td>negative</td></tr><tr><td>$NaHCO_3(s) + H^+(aq) \rightarrow Na^+(aq) + CO_2(g) + H_2O(l)$</td><td>positive</td></tr></table>	2
(ii)	there is a reduction in the overall number of gaseous molecules	1
(d)	$\Delta S_f^{\ominus} = 386 - (192 + (3 \times 131))$ $= -199\ (J K^{-1} mol^{-1})$	2
(e) (i)	$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ $= 117 - ((298 \times 175)/1000)$ $= (+)\ 64.85\ (kJ\ mol^{-1})$	2
(ii)	$\Delta G^{\ominus}$ is positive and so the reaction is not spontaneous (at 298 K)	1

Q# 25/ ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(d) (i)	(energy change when) 1 mole of ions **gaseous** (ions) dissolve in **water** (to form an infinitely dilute solution) *or* **gaseous** (ions) form an **aqueous** solution	2
(ii)	$\Delta H^{\ominus}_{latt} Ca(NO_3)_2 + \Delta H^{\ominus}_{sol} Ca(NO_3)_2 = \Delta H^{\ominus}_{hyd}\ Ca^{2+} + 2\Delta H^{\ominus}_{hyd}\ NO_3^-$ $\Delta H^{\ominus}_{latt} - 19 = -1650 + (2x\ -314)$ $-2259\ kJ\ mol^{-1}$	3
1	$Ca^{(2+)}$ is a smaller (ion) ***or*** $Ca^{(2+)}$ has a larger charge density $Ca^{(2+)}$ has a stronger attraction / bond to H_2O	2
		12

Q# 26/ ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 4 /www.SmashingScience.org :o)

(b)		1 1 1 1

Q# 27/ ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

(e) (i)	(enthalpy change) when **1 mole** of an **ionic compound** is **formed** from its **gaseous ions**	1 1	
(ii)	Mg^{2+} has a smaller (ionic) radii than Ca^{2+} **OR** Mg^{2+} is smaller than Ca^{2+}	1	[3]
Total			[16]

Q# 28/ ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1 (a) (i) the enthalpy change/released when **1 mole is formed** [1]

of ionic lattice **from** the **gas** phase **ions** [1]

(ii) $Mg^{2+} + O^{2-} \longrightarrow MgO$ [1]
[3]

(b) measurements needed:
volume/mass/weight of water (in calorimeter) [1]
initial + final temperature/temperature change/temperature rise (of the water) [1]
mass of Mg (used)/mass MgO [1]
Not *volume/moles/mass of oxygen used*
[3]

(c) $\Delta H = 148 + 736 + 1450 + 496/2 - 141 + 798 - 3791$
$= \underline{-552}$ **kJ mol^{-1}** [3]
[3]

(d) $Na_2O(s) + H_2O(aq/l) \longrightarrow 2NaOH(aq)$ [1]
$MgO(s) + H_2O(aq/l) \longrightarrow Mg(OH)_2(s)$ *or* $Mg(OH)_2(aq)$ [1]
pH 12.5-14 [NaOH] **AND** 8-10.5 [$Mg(OH)_2$] respectively [1]
[3]

[Total: 12]

Q# 29/ ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(b) $3Mg(s) \rightarrow 3Mg^{2+}(g)$ $\Delta H_1 = 3 \times 148 + 3 \times 2186 = 7002$
$N_2(g) \rightarrow 2N^{3-}(g)$ $\Delta H_2 = 994 + 2 \times 2148 = 5290$

$LE = -\Delta H_1 - \Delta H_2 - 461 = \mathbf{-12{,}753}$ (kJ mol^{-1}) (–[1] for each error) [3]

Q# 30/ ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 (a) $Ca^{2+}(g) + 2Cl^-(g) \longrightarrow CaCl_2(s)$ [1]
[1]

(b) CaF_2 **and** CaS **both** have larger lattice energies (than $CaCl_2$) [1]

(i) F^- is smaller than Cl^- [1]

(ii) S^{2-} is more highly charged than Cl^- [1]
[3]

(c) $LE = -[178 + 590 + 1150] - [244 - 2 \times 349] - 796$
✓ ✓ signs✓
$= \mathbf{-2260}$ (kJ mol^{-1}) [3]
[3]