IB HL EQ P2 4Students 16w to 08s Sections A and B

IB Diploma Chemistry

Higher Level Paper 2 Exam Questions

From summer 2008 to 2016 winter

2720 marks in total

Name:_____

Contents

IB HL EQ P2 4Students 16w to 08s Sections A and B 1

Topic 5 2

Topic 5 Mark Scheme 54

Topic 5

Chem 5 9 **Q# 1/** IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

1. Ethane-1,2-diol, $HOCH_2CH_2OH$, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

(a) Ethane-1,2-diol can be formed according to the following reaction.

$$2CO(g) + 3H_2(g) \rightleftharpoons HOCH_2CH_2OH(g)$$

(iii) Calculate the enthalpy change, $\Delta H^{\ominus}$, in kJ, for this reaction using section 11 of the data booklet. The bond enthalpy of the carbon–oxygen bond in CO(g) is $1077\,kJ\,mol^{-1}$. [3]

(b) (i) Calculate $\Delta H^{\ominus}$, in kJ, for this similar reaction below using $\Delta H_f^{\ominus}$ data from section 12 of the data booklet. $\Delta H_f^{\ominus}$ of $HOCH_2CH_2OH(l)$ is $-454.8\,kJ\,mol^{-1}$. [1]

$$2CO(g) + 3H_2(g) \rightleftharpoons HOCH_2CH_2OH(l)$$

(ii) Deduce why the answers to (a)(iii) and (b)(i) differ. [1]

(iii) $\Delta S^{\ominus}$ for the reaction in (b)(i) is $-620.1\,J\,K^{-1}$. Comment on the decrease in entropy. [1]

(iv) Calculate the value of $\Delta G^{\ominus}$, in kJ, for this reaction at 298 K using your answer to (b)(i). (If you did not obtain an answer to (b)(i), use −244.0 kJ, but this is not the correct value.) [2]

(v) Comment on the statement that the reaction becomes less spontaneous as temperature is increased. [1]

(c) Ozone in the atmosphere can be formed from the combustion of methane.

(i) State the equation for this combustion reaction. *[1]*

. . . . . .

(ii) Calculate the standard enthalpy change for the reaction, $\Delta H^{\ominus}$, in $kJ\,mol^{-1}$, using the thermodynamic data in section 12 of the data booklet and the information given below. *[1]*

$O_3(g)$
$\Delta H_f^{\ominus} = +142.3\,kJ\,mol^{-1}$

. . . . . .

. . . . . .

. . . . . .

(iii) State why the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, for oxygen is not given. *[1]*

. . . . . .

. . . . . .

. . . . . .

(iv) Calculate the standard entropy change for the reaction, $\Delta S^{\ominus}$, in $JK^{-1}mol^{-1}$, using the thermodynamic data in section 12 of the data booklet and the information given below. *[1]*

$O_2(g)$	$O_3(g)$
$S^{\ominus} = +205.0\,JK^{-1}mol^{-1}$	$S^{\ominus} = +237.6\,JK^{-1}mol^{-1}$

. . . . . .

. . . . . .

. . . . . .

(v) Deduce the standard change in Gibbs Free Energy, $\Delta G^{\ominus}$, in $kJ\,mol^{-1}$, for this reaction at 298 K. *[1]*

. . . . . .

. . . . . .

. . . . . .

(vi) Deduce, giving a reason, whether the reaction is spontaneous or non-spontaneous at this temperature. *[1]*

. . . . . .

. . . . . .

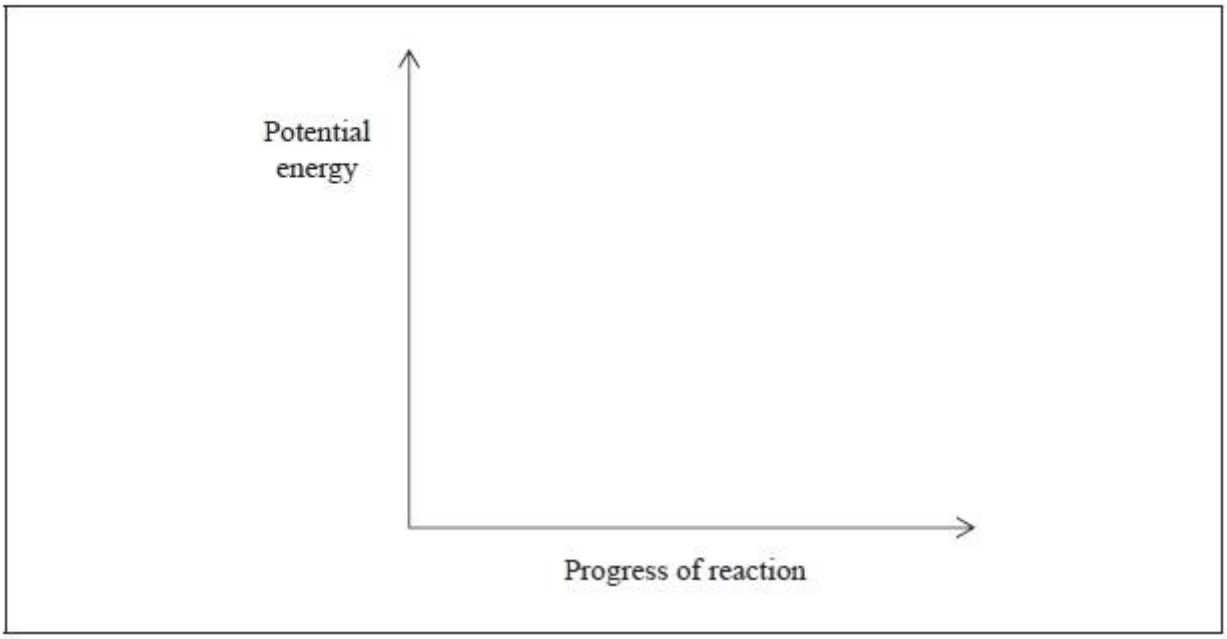
. . . . . .

2. One of the main constituents of acid deposition is sulfuric acid, H_2SO_4. This acid is formed from the sulfur dioxide pollutant, SO_2.

(b) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -198\,kJ$$

(c) Sketch the potential energy profile for the forward reaction in part (b) to show the effect of a catalyst on the activation energy, E_{act}. *[2]*



5. Many automobile manufacturers are developing vehicles that use hydrogen as a fuel.

(a) Suggest why such vehicles are considered to cause less harm to the environment than those with internal combustion engines. *[1]*

. . . . . .

. . . . . .

(b) Hydrogen can react with ethene to form ethane.

$$H_2(g) + C_2H_4(g) \rightarrow C_2H_6(g)$$

Using average bond enthalpies at 298 K from section 11 of the data booklet, calculate the change in enthalpy, ΔH, in $kJ\,mol^{-1}$, for this reaction. *[3]*

. . . . . .

. . . . . .

. . . . . .

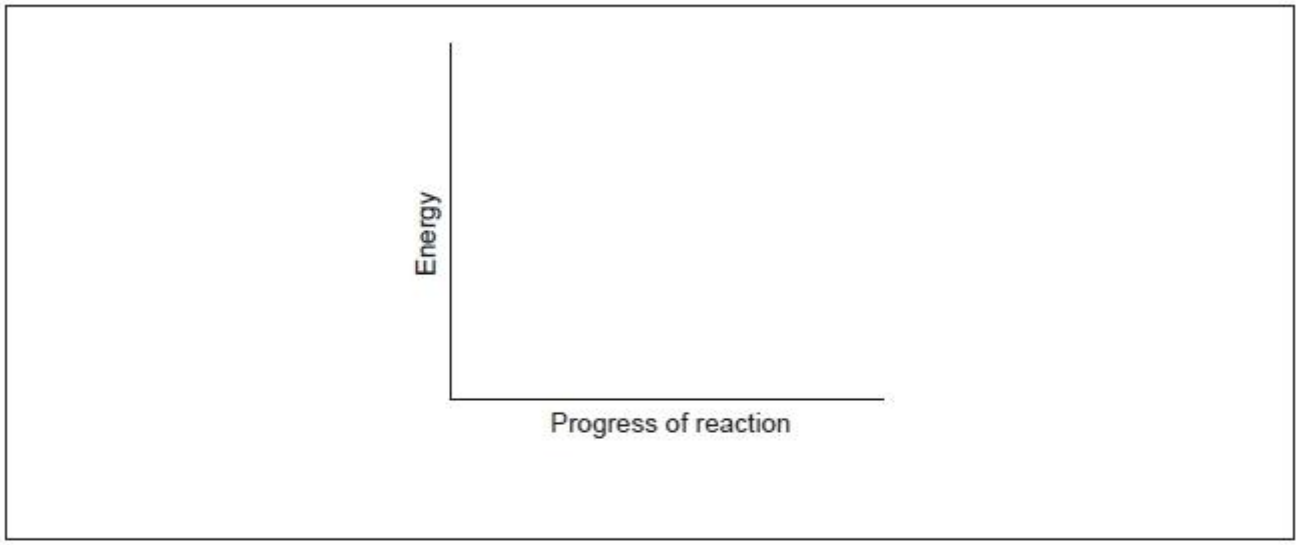
. . . . . .

. . . . . .

. . . . . .

Chem 5 3 **Q# 5/** IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q3

(b) The enthalpy change for the reaction between nitrogen monoxide and hydrogen is −664 kJ and its activation energy is 63 kJ.



(i) Sketch the potential energy profile for the overall reaction, using the axes given, indicating both the enthalpy of reaction and activation energy. [2]

(ii) This reaction is normally carried out using a catalyst. Draw a dotted line labelled "Catalysed" on the diagram above to indicate the effect of the catalyst. [1]

Chem 5 1 **Q# 6/** IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH_3.

(d) Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water.

(i) 200.0 g of air was heated by the energy from the complete combustion of 1.00 mol phosphine. Calculate the temperature rise using section 1 of the data booklet and the data below. [1]

Standard enthalpy of combustion of phosphine, $\Delta H_c^{\ominus} = -750\,\text{kJ mol}^{-1}$

Specific heat capacity of air = $1.00\,\text{J g}^{-1}\text{K}^{-1} = 1.00\,\text{kJ kg}^{-1}\text{K}^{-1}$

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Chem 5 3 **Q# 7/** IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

4. Tin(II) chloride is a white solid that is commonly used as a reducing agent.

(a) (i) State why you would expect tin(II) chloride to have a similar lattice enthalpy to strontium chloride, using section 9 of the data booklet. [1]

. . . . . .

. . . . . .

(ii) Calculate the molar enthalpy change when strontium chloride is dissolved in water, using sections 18 and 20 of the data booklet. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Chem 5 4 **Q# 8/** IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

2. Phosgene, $COCl_2$, is usually produced by the reaction between carbon monoxide and chlorine according to the equation:

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$$

(a)

(iii) The standard enthalpy change of formation of phosgene, $\Delta H_f^{\ominus}$, is $-220.1\,kJ\,mol^{-1}$. Determine the standard enthalpy change, $\Delta H^{\ominus}$, for the forward reaction of the equilibrium, in kJ, using section 12 of the data booklet. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iv) Calculate the standard entropy change, $\Delta S^{\ominus}$, in $J\,K^{-1}$, for the forward reaction at 25°C, using your answers to (a) (ii) and (a) (iii).
(If you did not obtain an answer to (a) (ii) and/or (a) (iii) use values of +20.0 kJ and −120.0 kJ respectively, although these are not the correct answers.) [2]

.....

.....

.....

.....

.....

6. Iron (III) oxide is the main source of iron but the decomposition of $Fe_2O_3(s)$ into its elements is extremely difficult due to a large positive value of $\Delta G^{\ominus}$.

(a) Consider the following reactions:

$$Fe_2O_3(s) \rightarrow 2Fe(s) + \frac{3}{2}O_2(g) \qquad \Delta G^{\ominus} = +742\,kJ\,mol^{-1}$$

$$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g) \qquad \Delta G^{\ominus} = -257\,kJ\,mol^{-1}$$

Suggest, with a reason, whether it is possible to produce iron by reacting Fe_2O_3 with CO. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) The thermite reaction is one of the most exothermic reactions.

$$Fe_2O_3(s) + 2Al(s) \rightarrow 2Fe(l) + Al_2O_3(s) \qquad \Delta H^{\ominus} = -825.2\,kJ$$

Species	$S^{\ominus}$ / $J\,K^{-1}\,mol^{-1}$	$\Delta G_f^{\ominus}$ / $kJ\,mol^{-1}$
Al (s)	+28.3	0
Al_2O_3 (s)	+50.9	–1582
Fe (l)	+34.8	+10.0
Fe_2O_3 (s)	+87.5	–742

(i) Calculate the standard free energy change, $\Delta G^{\ominus}$, in $kJ\,mol^{-1}$, by using values of the standard free energy change of formation, $\Delta G_f^{\ominus}$, from the table above. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Calculate the standard entropy change, $\Delta S^{\ominus}$, in $J K^{-1} mol^{-1}$, by using values of standard entropy, $S^{\ominus}$, from the table. [1]

. . . . . .

. . . . . .

. . . . . .

(iii) Calculate the standard free energy change, $\Delta G^{\ominus}$, for the reaction using $\Delta H^{\ominus}$ and $\Delta S^{\ominus}$ values at 25°C. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Chem 5 4 **Q# 10/** IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Table 11

3. Propane, $C_3H_8(g)$, undergoes complete combustion to form carbon dioxide, $CO_2(g)$, and water, $H_2O(g)$.

(a) State an equation for the complete combustion of propane, $C_3H_8(g)$. [1]

. . . . . .

. . . . . .

(b) Calculate the standard enthalpy change for the reaction in part (a) using bond enthalpy values given in table 10 of the data booklet. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

3. Carbon monoxide reacts with hydrogen to produce methanol.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$

Substance	$\Delta H_f^\ominus$ / kJ mol^{-1}	$\Delta G_f^\ominus$ / kJ mol^{-1}	$S^\ominus$ / J mol^{-1} K^{-1}
CO (g)	– 110.5	– 137.2	+ 197.6
CH_3OH (l)	– 239.0	– 166.0	+ 126.8

(a) Calculate the standard enthalpy change, $\Delta H^\ominus$, in kJ mol^{-1}, for the reaction. [1]

. . . . . .

. . . . . .

(b) Calculate the standard free energy change, $\Delta G^\ominus$, in kJ mol^{-1}, for the reaction ($\Delta G_f^\ominus(H_2) = 0$ kJ mol^{-1}). [1]

. . . . . .

. . . . . .

(c) Using the values obtained in parts (a) and (b), calculate the standard entropy change, $\Delta S^\ominus$, in J mol^{-1} K^{-1}, for the reaction at 298 K. [1]

. . . . . .

. . . . . .

. . . . . .

(d) Determine the absolute entropy, $S^\ominus$, in J mol^{-1} K^{-1}, for H_2(g) at 298 K. [2]

. . . . . .

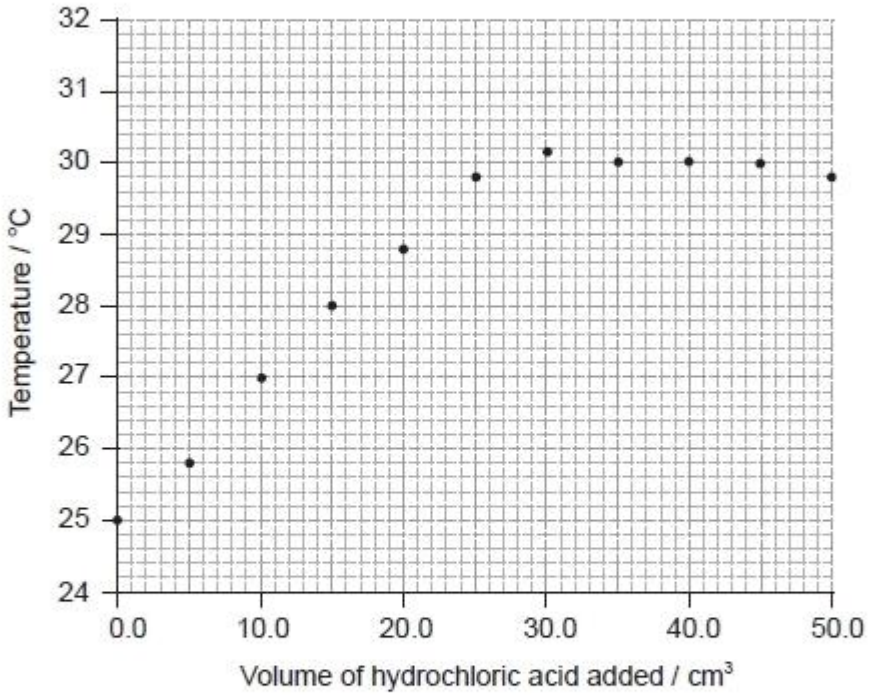
. . . . . .

. . . . . .

. . . . . .

1. A student carried out an experiment to determine the concentration of a hydrochloric acid solution and the enthalpy change of the reaction between aqueous sodium hydroxide and this acid by thermometric titration.

She added 5.0 cm^3 portions of hydrochloric acid to 25.0 cm^3 of 1.00 mol dm^{-3} sodium hydroxide solution in a glass beaker until the total volume of acid added was 50.0 cm^3, measuring the temperature of the mixture each time. Her results are plotted in the graph below.



The initial temperature of both solutions was the same.

(a) (i) By drawing appropriate lines, determine the volume of hydrochloric acid required to completely neutralize the 25.0 cm^3 of sodium hydroxide solution. [2]

. . . . . .

. . . . . .

(ii) Determine the concentration of the hydrochloric acid, including units. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) (i) Determine the change in temperature, ΔT. [1]

. . . . . .

. . . . . .

(ii) Calculate the enthalpy change, in $kJ\,mol^{-1}$, for the reaction of hydrochloric acid and sodium hydroxide solution. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iii) The accepted theoretical value from the literature of this enthalpy change is $-58\,kJ\,mol^{-1}$. Calculate the percentage error correct to **two** significant figures. [1]

. . . . . .

. . . . . .

(iv) Suggest the major source of error in the experimental procedure **and** an improvement that could be made to reduce it. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Chem 5 4 **Q# 13/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q6

(g) Determine the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of NaCl (s), in kJ mol^{-1}, using a Born-Haber cycle and tables 7, 10 and 13 of the data booklet. The standard enthalpy change of atomization (standard enthalpy change of sublimation), $\Delta H_{at}^{\ominus}$, of Na (s) is +108 kJ mol^{-1}. [4]

Chem 5 13 **Q# 14/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q5

(b) (i) Define the term *average bond enthalpy*. [2]

(ii) Ethanol can be used as a fuel. Determine the enthalpy of combustion of ethanol at 298 K, in kJ mol^{-1}, using the values in table 10 of the data booklet, assuming all reactants and products are gaseous. [4]

(c) Students can also measure the enthalpy of combustion of ethanol in the laboratory using calorimetry. Suggest the major source of systematic error in these procedures. [1]

.....

.....

(f) (i) The standard enthalpy change of combustion, $\Delta H_c^{\ominus}$, of propanoic acid is $-1527\,kJ\,mol^{-1}$. Determine the standard enthalpy change of formation of propanoic acid, in $kJ\,mol^{-1}$, using this information and data from table 12 of the data booklet. [4]

.....

.....

.....

.....

.....

.....

.....

.....

(ii) Deduce, giving a reason, the sign of the standard entropy change of the system for the formation of propanoic acid from its elements. [2]

.....

.....

.....

(e) Hydrochloric acid neutralizes sodium hydroxide, forming sodium chloride and water.

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) \qquad \Delta H^{\ominus} = -57.9\,kJ\,mol^{-1}$$

(i) Define *standard enthalpy change of reaction*, $\Delta H^{\ominus}$. *[2]*

. . . . . .

. . . . . .

. . . . . .

(ii) Determine the amount of energy released, in kJ, when $50.0\,cm^3$ of $1.00\,mol\,dm^{-3}$ sodium hydroxide solution reacts with $50.0\,cm^3$ of $1.00\,mol\,dm^{-3}$ hydrochloric acid solution. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iii) In an experiment, 2.50 g of solid sodium hydroxide was dissolved in 50.0 cm^3 of water. The temperature rose by 13.3 °C. Calculate the standard enthalpy change, in $kJ\,mol^{-1}$, for dissolving one mole of solid sodium hydroxide in water.

$$NaOH(s) \rightarrow NaOH(aq)$$ *[3]*

.....

.....

.....

.....

.....

.....

(iv) Using relevant data from previous question parts, determine $\Delta H^{\ominus}$, in $kJ\,mol^{-1}$, for the reaction of solid sodium hydroxide with hydrochloric acid.

$$NaOH(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$ *[2]*

.....

.....

2. The reaction between ethene and steam is used in the industrial production of ethanol.

$$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$$

The enthalpy change of the reaction can be calculated either by using average bond enthalpies or by using standard enthalpies of formation.

(a) Determine the enthalpy change of the reaction, in $kJ\,mol^{-1}$, using the average bond enthalpies in Table 10 of the Data Booklet. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) (i) Define the term *standard enthalpy change of formation*. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Determine the enthalpy change of the reaction, in $kJ\,mol^{-1}$, between ethene and steam using the enthalpy change of formation values given below.

Compound	$\Delta H_f^{\ominus}$ / $kJ\,mol^{-1}$
$C_2H_5OH(g)$	–235
$C_2H_4(g)$	+52
$H_2O(g)$	–242

[2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) Comment on which of the values obtained in (a) and (b)(ii) is more accurate, giving a reason. *[1]*

. . . . . .

. . . . . .

(d) Predict the sign of the entropy change of the reaction, ΔS, giving a reason. *[1]*

. . . . . .

. . . . . .

(c) Although magnesium is usually found as Mg^{2+} in its compounds, it is possible to use the Born–Haber cycle to investigate the possibility of Mg^{+} being able to form stable compounds.

Use the ionization energy data from part (b), along with the other data provided below, to determine the enthalpy change of formation of MgCl(s). Assume that, because Mg^{+} would be similar in size to Na^{+}, MgCl would have a similar lattice enthalpy to NaCl.

Enthalpy of atomization of Mg	+146 kJ mol^{-1}
Bond enthalpy in Cl_2	+243 kJ mol^{-1}
Electron affinity of Cl	–349 kJ mol^{-1}
Lattice enthalpy of NaCl	+790 kJ mol^{-1}

[3]

(d) Consider the lattice enthalpies of MgF_2, $MgCl_2$ and $CaCl_2$. List these from the most endothermic to the least endothermic and explain your order. *[3]*

Most endothermic ⟶ Least endothermic

(e) Magnesium hydroxide, $Mg(OH)_2$, is only sparingly soluble in water and the equilibrium below exists when excess solid is in contact with a saturated solution.

$$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$$

Outline how the solubility of magnesium hydroxide will vary with pH. *[2]*

Chem 5 10 **Q# 18/** IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/Table 12

4. Buta-1,3-diene can be hydrogenated to produce butane, according to the reaction below.

$$C_4H_6(g) + 2H_2(g) \rightarrow C_4H_{10}(g)$$

(b) Determine the standard enthalpy change of reaction, $\Delta H^{\ominus}$, in $kJ\,mol^{-1}$, at 298 K for the hydrogenation reaction, using Table 11 of the Data Booklet. *[1]*

(c) Calculate the standard free energy change, $\Delta G^{\ominus}$, in $kJ\,mol^{-1}$, at 298 K for the hydrogenation reaction, using Table 11 of the Data Booklet. *[1]*

(d) (i) Determine the standard entropy change of the reaction, $\Delta S^{\ominus}$, at 298 K, in $kJ\,K^{-1}\,mol^{-1}$, using your answers from (b) and (c). *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Explain why the standard entropy change for the hydrogenation of buta-1,3-diene has a negative sign. *[1]*

. . . . . .

. . . . . .

. . . . . .

(iii) Predict whether the hydrogenation reaction becomes more or less spontaneous as the temperature increases. *[1]*

. . . . . .

. . . . . .

(iv) Determine the temperature, in K, at which the spontaneity changes. *[2]*

. . . . . .

. . . . . .

. . . . . .

(v) Determine the standard entropy, $S^{\ominus}$, for hydrogen in $J K^{-1} mol^{-1}$, using Table 11 of the Data Booklet and your answer for (d)(i). *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Chem 5 7 **Q# 19/** IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/

1. (a) Two chemistry students wished to determine the enthalpy of hydration of anhydrous magnesium sulfate. They measured the initial and the highest temperature reached when anhydrous magnesium sulfate, $MgSO_4(s)$, was dissolved in water. They presented their results in the table below.

mass of anhydrous magnesium sulfate / g	3.01
volume of water / cm^3	50.0
initial temperature / °C	17.0
highest temperature / °C	26.7

(i) Calculate the amount, in mol, of anhydrous magnesium sulfate. *[1]*

. . . . . .

. . . . . .

(ii) Calculate the enthalpy change, ΔH_1, for anhydrous magnesium sulfate dissolving in water, in $kJ mol^{-1}$. State your answer to the correct number of significant figures. *[2]*

. . . . . .

. . . . . .

. . . . . .

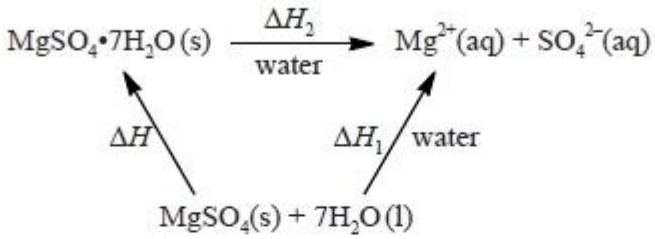
. . . . . .

. . . . . .

. . . . . .

(b) The students repeated the experiment using 6.16 g of solid hydrated magnesium sulfate, $MgSO_4 \cdot 7H_2O(s)$, and 50.0 cm^3 of water. They found the enthalpy change, ΔH_2, to be $+18\,kJ\,mol^{-1}$.

The enthalpy of hydration of solid anhydrous magnesium sulfate is difficult to determine experimentally, but can be determined using the diagram below.



(i) Determine the enthalpy change, ΔH, in $kJ\,mol^{-1}$, for the hydration of solid anhydrous magnesium sulfate, $MgSO_4$. *[1]*

. . . . . .

. . . . . .

(ii) The literature value for the enthalpy of hydration of anhydrous magnesium sulfate is $-103\,kJ\,mol^{-1}$. Calculate the percentage difference between the literature value and the value determined from experimental results, giving your answer to **one** decimal place. (If you did not obtain an answer for the experimental value in (b)(i) then use the value of $-100\,kJ\,mol^{-1}$, but this is **not** the correct value.) *[1]*

. . . . . .

. . . . . .

(c) Another group of students experimentally determined an enthalpy of hydration of $-95\,kJ\,mol^{-1}$. Outline two reasons which may explain the variation between the experimental and literature values. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

8. To determine the enthalpy change of combustion of methanol, CH_3OH, 0.230 g of methanol was combusted in a spirit burner. The heat released increased the temperature of 50.0 cm^3 of water from 24.5 °C to 45.8 °C.

(a) (i) Calculate the enthalpy change of combustion of methanol. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Using the theoretical value in Table 12 of the Data Booklet, discuss the experimental result, including **one** improvement that could be made. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Methanol can be produced according to the following equation.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$

(i) Calculate the standard enthalpy change of this reaction, using the values of enthalpy of combustion in Table 12 of the Data Booklet. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Calculate the standard entropy change for this reaction, $\Delta S^{\ominus}$, using Table 11 of the Data Booklet and given:
$S^{\ominus}(CO) = 198\,J\,K^{-1}\,mol^{-1}$ and $S^{\ominus}(H_2) = 131\,J\,K^{-1}\,mol^{-1}$. *[1]*

. . . . . .

. . . . . .

(iii) Calculate, stating units, the standard free energy change for this reaction, $\Delta G^{\ominus}$, at 298 K. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iv) Predict, with a reason, the effect of an increase in temperature on the spontaneity of this reaction. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Chem 5 8 **Q# 21/** IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/Table 11 of the DATA BOOKLET is needed/Q5

(c) Methanol reacts with carbon monoxide to form ethanoic acid, $CH_3COOH(l)$.

$$CH_3OH(l) + CO(g) \rightarrow CH_3COOH(l)$$

(i) Predict the sign of the entropy change, ΔS, of the system and explain your answer. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Define the term *standard enthalpy change of formation*, $\Delta H_f^{\ominus}$. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iii) The standard enthalpy change of formation of CO (g) is –111 kJ mol^{-1}. Using Table 11 of the Data Booklet, determine the enthalpy change of the reaction, in kJ mol^{-1}. *[1]*

. . . . . .

. . . . . .

(iv) The standard entropy of CO (g) is 198 J K^{-1} mol^{-1}. Using Table 11 of the Data Booklet, determine the standard entropy change of the reaction, in J K^{-1} mol^{-1}. *[1]*

. . . . . .

. . . . . .

(v) Determine the standard free energy change for the reaction at 298 K, in kJ mol^{-1}, using your answers from (iii) and (iv) and state whether the reaction is spontaneous or not. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

5. The strength of a covalent bond is measured in terms of its bond enthalpy.

(a) Define the term *average bond enthalpy*. *[2]*

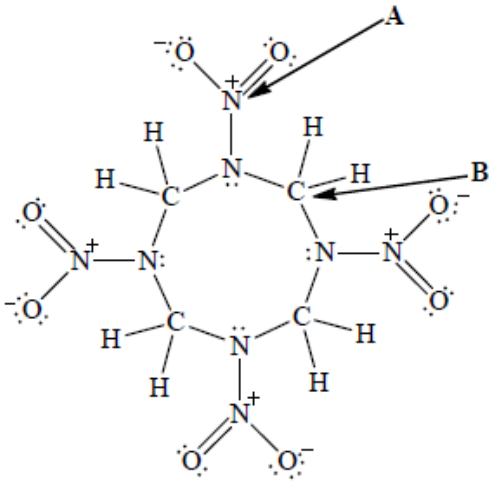
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) 1,3,5,7-tetranitro-1,3,5,7-tetrazocane, shown below, can be used as an explosive.



The following equation represents the thermal decomposition of the compound.

$$C_4H_8N_8O_8\,(s) \rightarrow 4N_2\,(g) + 4CO\,(g) + 4H_2O\,(g)$$

(i) Calculate the enthalpy change when 10.0 g of the compound decomposes, using average bond enthalpy data from Table 10 of the Data Booklet and the following additional average bond enthalpy data at 298 K. *[4]*

Bond	**ΔH / kJ mol^{-1}**
C≡O	1072
N–O	201
N=O	607

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

5. Ethane, C_2H_6, and disilane, Si_2H_6, are both hydrides of group 4 elements with similar structures but with different chemical properties.

(b) Disilane undergoes complete oxidation to form silicon dioxide and water.

$$2Si_2H_6(g) + 7O_2(g) \rightarrow 4SiO_2(s) + 6H_2O(l)$$

(i) The standard enthalpy of formation of the silicon compounds is given below.

	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$Si_2H_6(g)$	+80
$SiO_2(s)$	–911

Calculate the standard enthalpy change, in kJ, for this reaction using these data together with Table 12 of the Data Booklet. *[3]*

. . . . . .
. . . . . .
. . . . . .
. . . . . .
. . . . . .
. . . . . .

(ii) Calculate the standard enthalpy change, in kJ, for the corresponding combustion reaction of 2 moles of ethane, using Table 12 of the Data Booklet. *[1]*

. . . . . .
. . . . . .

(c) Disilane reacts with hydrogen to produce silane, SiH_4.

$$Si_2H_6(g) + H_2(g) \rightarrow 2SiH_4(g)$$

Use values from Table 10 of the Data Booklet to calculate the enthalpy change, $\Delta H^{\ominus}$, for this reaction. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

3. (a) Define the term *average bond enthalpy*. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Deduce the balanced chemical equation for the complete combustion of butan-1-ol. *[1]*

. . . . . .

. . . . . .

(c) Determine the standard enthalpy change, in $kJ\,mol^{-1}$, for the complete combustion of butan-1-ol, using the information from Table 10 of the Data Booklet. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

5. (a) Deduce and explain the sign of the entropy change for the following reaction.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$ *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Consider the reaction:

$$CuS(s) + H_2(g) \rightarrow Cu(s) + H_2S(g)$$

Given:

	$H_2S(g)$	$CuS(s)$
$\Delta G_f^{\ominus}$ / kJ mol^{-1}	–33.6	–53.6
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	–20.6	–53.1

(i) Suggest why the $\Delta H_f^{\ominus}$ values for $H_2(g)$ and $Cu(s)$ are not given in the table. *[1]*

. . . . . .

. . . . . .

(ii) Determine the standard enthalpy change at 298 K for the reaction. *[1]*

. . . . . .

. . . . . .

. . . . . .

(iii) Determine the standard free energy change at 298 K for the reaction. Deduce whether or not the reaction is spontaneous at this temperature. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iv) Determine the standard entropy change at 298 K for the reaction. *[1]*

. . . . . .

. . . . . .

. . . . . .

(v) Estimate the temperature, in K, at which the standard change in free energy equals zero. You should assume that the values of the standard enthalpy and entropy changes are not affected by the change in temperature. *[1]*

. . . . . .

. . . . . .

. . . . . .

1. Methanol is made in large quantities as it is used in the production of polymers and in fuels. The enthalpy of combustion of methanol can be determined theoretically or experimentally.

$$CH_3OH(l) + 1\tfrac{1}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

	$CH_3OH(l)$	$O_2(g)$	$CO_2(g)$	$H_2O(g)$
Standard enthalpy of formation, $\Delta H_f^{\ominus}$ / kJ mol^{-1}	–239	0	–394	–242
Entropy, $S^{\ominus}$ /J K^{-1} mol^{-1}	240	205	214	189

(a) Using the information from the table above, determine the theoretical enthalpy of combustion of methanol. *[2]*

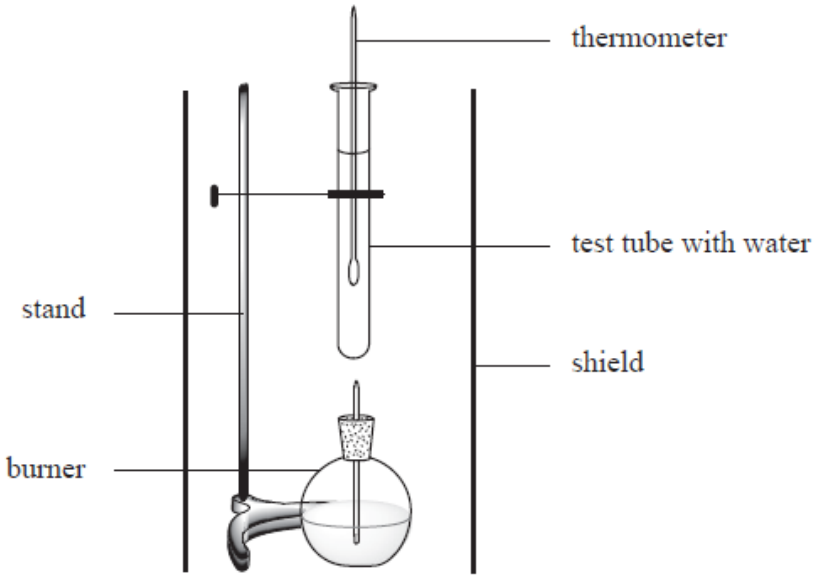
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) The enthalpy of combustion of methanol can also be determined experimentally in a school laboratory. A burner containing methanol was weighed and used to heat water in a test tube as illustrated below.



The following data were collected.

Initial mass of burner and methanol / g	80.557
Final mass of burner and methanol / g	80.034
Mass of water in test tube / g	20.000
Initial temperature of water / °C	21.5
Final temperature of water / °C	26.4

(i) Calculate the amount, in mol, of methanol burned. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Calculate the heat absorbed, in kJ, by the water. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iii) Determine the enthalpy change, in kJ mol^{-1}, for the combustion of methanol. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) The Data Booklet value for the enthalpy of combustion of methanol is –726 kJ mol^{-1}. Suggest why this value differs from the values calculated in parts (a) and (b).

(i) Part (a) *[1]*

. . . . . .

. . . . . .

(ii) Part (b) *[1]*

. . . . . .

. . . . . .

(d) Determine the $\Delta S^{\ominus}$ for the combustion of methanol. *[2]*

$$CH_3OH(l) + 1\tfrac{1}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(e) Using the enthalpy of combustion for methanol from Table 12 of the Data Booklet and the $\Delta S^{\ominus}$ determined in part (d), calculate the standard free energy change for the combustion of methanol. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

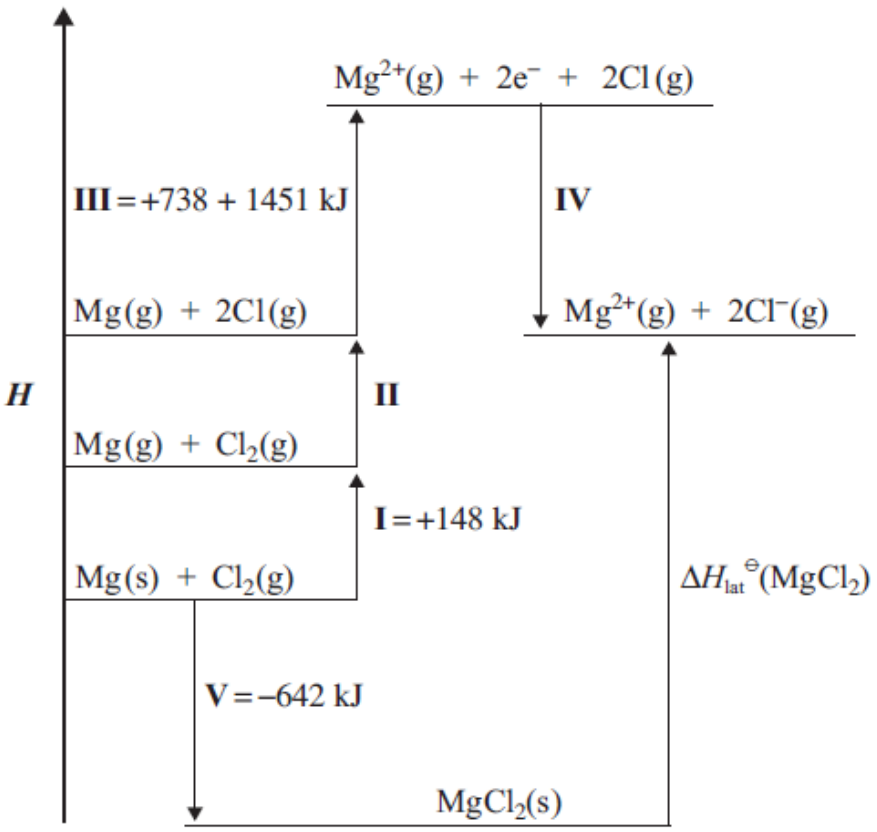
. . . . . .

(f) Explain whether changing the temperature will alter the spontaneity of the reaction. *[1]*

. . . . . .

. . . . . .

(c) The lattice enthalpy of magnesium chloride can be calculated from the Born-Haber cycle shown below.



(i) Identify the enthalpy changes labelled by **I** and **V** in the cycle. *[2]*

(ii) Use the ionization energies given in the cycle above and further data from the Data Booklet to calculate a value for the lattice enthalpy of magnesium chloride. *[4]*

(iv) The experimental lattice enthalpy of magnesium oxide is given in Table 13 of the Data Booklet. Explain why magnesium oxide has a higher lattice enthalpy than magnesium chloride. *[2]*

(c) The equation for the reaction between hydrazine and oxygen is given below.

$$N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(l)$$

(i) The enthalpy change of formation, $\Delta H_f^{\ominus}$, of liquid hydrazine is 50.6 kJ mol^{-1}. Use this value, together with data from Table 12 of the Data Booklet, to calculate the enthalpy change for this reaction. *[3]*

(ii) Use the bond enthalpy values from Table 10 of the Data Booklet to determine the enthalpy change for this reaction. *[3]*

(iii) Identify the calculation that produces the most accurate value for the enthalpy change for the reaction given and explain your choice. *[3]*

(iv) Calculate $\Delta S^{\ominus}$ for the reaction using the data below and comment on its magnitude. *[3]*

Substance	$S^{\ominus}$ / J K^{-1} mol^{-1}
$O_2(g)$	205
$N_2(g)$	191
$H_2O(l)$	69.9
$N_2H_4(l)$	121

(v) Calculate $\Delta G^{\ominus}$ for the reaction at 298 K. *[2]*

(vi) Predict, giving a reason, the spontaneity of the reaction above at both high and low temperatures. *[2]*

0

(a) The heat produced by the reaction can be calculated from the temperature change, ΔT, using the expression below.

$$\text{Heat change} = \text{Volume of } CuSO_4(aq) \times \text{Specific heat capacity of } H_2O \times \Delta T$$

Describe **two** assumptions made in using this expression to calculate heat changes. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) (i) Use the data presented by the data logging software to deduce the temperature change, ΔT, which would have occurred if the reaction had taken place instantaneously with no heat loss. *[2]*

. . . . . .

. . . . . .

(ii) Calculate the heat, in kJ, produced during the reaction using the expression given in part (a). *[1]*

. . . . . .

. . . . . .

(c) The colour of the solution changed from blue to colourless. Deduce the amount, in moles, of zinc which reacted in the polystyrene cup. *[1]*

. . . . . .

. . . . . .

(d) Calculate the enthalpy change, in $kJ\,mol^{-1}$, for this reaction. *[1]*

. . . . . .

. . . . . .

Chem 5 10 **Q# 30/** IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/Table 10 of Data Booklet needed

5. (a) The production of ammonia is an important industrial process.

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

(i) Using the average bond enthalpy values in Table 10 of the Data Booklet, determine the standard enthalpy change for this reaction. *[3]*

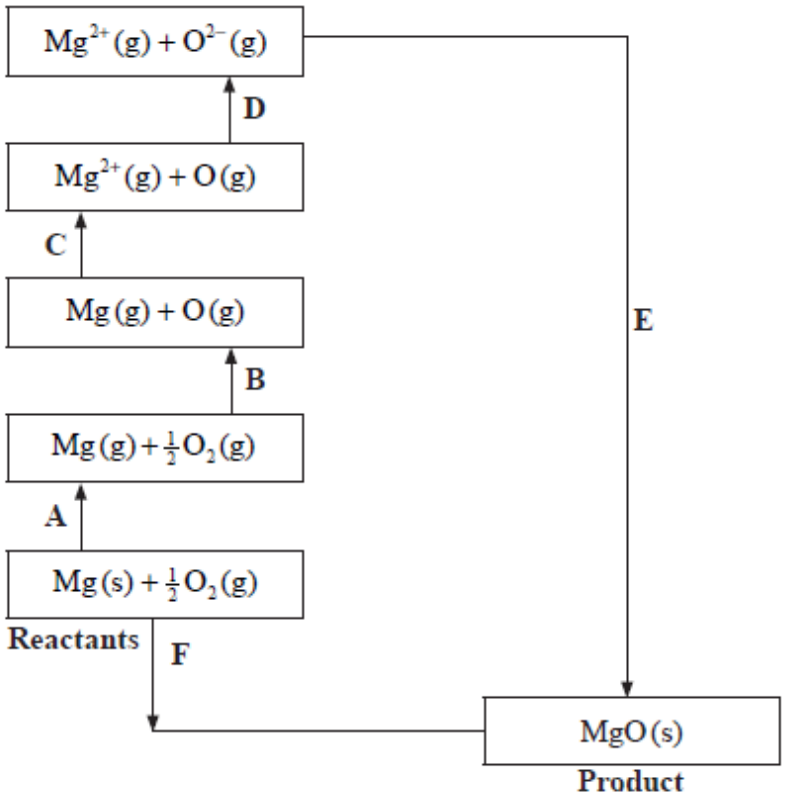
(ii) The standard entropy values, S, at 298 K for $N_2(g)$, $H_2(g)$ and $NH_3(g)$ are 193, 131 and 192 $JK^{-1}\ mol^{-1}$ respectively. Calculate $\Delta S^{\ominus}$ for the reaction and with reference to the equation above, explain the sign of $\Delta S^{\ominus}$. *[4]*

(iii) Calculate $\Delta G^{\ominus}$ for the reaction at 298 K. *[1]*

(iv) Describe and explain the effect of increasing temperature on the spontaneity of the reaction. *[2]*

Chem 5 25 **Q# 31/** IB Chem/2009/w/TZ0/Paper 2 Section B/Higher Level/

7. (a) The Born-Haber cycle for MgO under standard conditions is shown below.



The values are shown in the table below.

Process	Enthalpy change / kJ mol^{-1}
A	+150
B	+248
C	+736 + (+1450)
D	–142 + (+844)
E	
F	–602

(i) Identify the processes represented by **A**, **B** and **D** in the cycle. *[3]*

(ii) Define the enthalpy change, **F**. *[2]*

(iii) Determine the value of the enthalpy change, **E**. *[2]*

(iv) Define the enthalpy change **C** for the first value. Explain why the second value is significantly larger than the first. *[4]*

(v) The inter-ionic distance between the ions in NaF is very similar to that between the ions in MgO. Suggest with a reason, which compound has the higher lattice enthalpy value. *[2]*

(b) (i) The standard enthalpy change of three combustion reactions is given below in kJ.

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l) \qquad \Delta H^{\ominus} = -3120$$
$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) \qquad \Delta H^{\ominus} = -572$$
$$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l) \qquad \Delta H^{\ominus} = -1411$$

Based on the above information, calculate the standard change in enthalpy, $\Delta H^{\ominus}$, for the following reaction.

$$C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)$$ *[4]*

(ii) Predict, stating a reason, whether the sign of $\Delta S^{\ominus}$ for the above reaction would be positive or negative. *[2]*

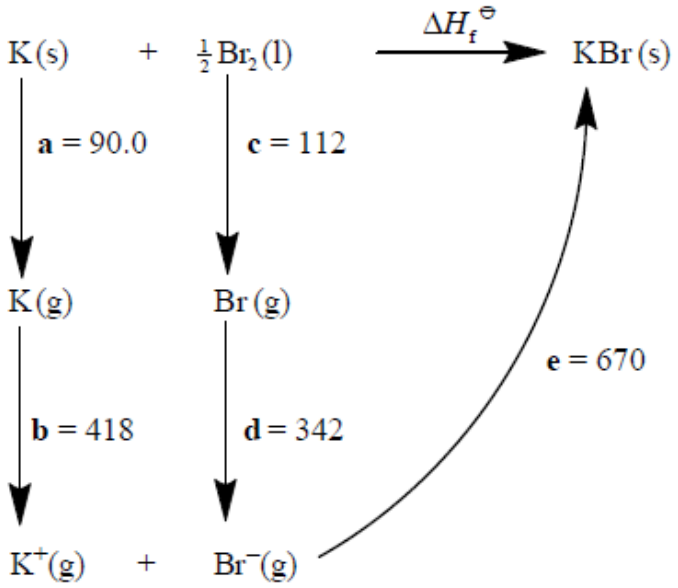
(iii) Discuss why the above reaction is non-spontaneous at low temperature but becomes spontaneous at high temperatures. *[2]*

(iv) Using bond enthalpy values, calculate $\Delta H^{\ominus}$ for the following reaction.

$$C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)$$ *[3]*

(v) Suggest with a reason, why the values obtained in parts (b) (i) and (b) (iv) are different. *[1]*

(b) Consider the following Born-Haber cycle:



The magnitudes for each of the enthalpy changes (**a** to **e**) are given in kJ mol^{-1} but their signs (+ or –) have been omitted.

(i) State the names for the enthalpy changes **c** and **d**. *[2]*

(ii) Deduce which **two** of the enthalpy changes **a** to **e** have negative signs. *[1]*

(iii) Determine the value for the enthalpy of formation of potassium bromide. *[2]*

(iv) Explain why the quantitative value for the lattice enthalpy of calcium bromide is larger than the value for the lattice enthalpy of potassium bromide. *[2]*

3. Two students were asked to use information from the Data Booklet to calculate a value for the enthalpy of hydrogenation of ethene to form ethane.

$$C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$$

John used the average bond enthalpies from Table 10. Marit used the values of enthalpies of combustion from Table 12.

(a) Calculate the value for the enthalpy of hydrogenation of ethene obtained using the average bond enthalpies given in Table 10. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Determine the value for the enthalpy of hydrogenation of ethene using the values for the enthalpies of combustion of ethene, hydrogen and ethane given in Table 12. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) Suggest **one** reason why John's answer is slightly less accurate than Marit's answer and calculate the percentage difference. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(d) John then decided to determine the enthalpy of hydrogenation of cyclohexene to produce cyclohexane.

$$C_6H_{10}(l) + H_2(g) \rightarrow C_6H_{12}(l)$$

(i) Use the average bond enthalpies to deduce a value for the enthalpy of hydrogenation of cyclohexene. *[1]*

. . . . . .

. . . . . .

(ii) The percentage difference between these two methods (average bond enthalpies and enthalpies of combustion) is greater for cyclohexene than it was for ethene. John's hypothesis was that it would be the same. Determine why the use of average bond enthalpies is less accurate for the cyclohexene equation shown above, than it was for ethene. Deduce what extra information is needed to provide a more accurate answer. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Chem 5 25 **Q# 34/** IB Chem/2008/w/TZ0/Paper 2 Section B/Higher Level/

5. (a) (i) Define the term *average bond enthalpy*. *[2]*

(ii) Explain why the H–H bond cannot be used as an example to illustrate average bond enthalpy. *[1]*

(b) The equation for the reaction between carbon dioxide and hydrogen is shown below.

$$CO_2(g) + 4H_2(g) \rightarrow CH_4(g) + 2H_2O(g)$$

(i) Use information from Table 10 in the Data Booklet to calculate the enthalpy change for this reaction. *[3]*

(ii) The following table shows the standard entropy values of the substances in the reaction above.

Substance	$CO_2(g)$	$H_2(g)$	$CH_4(g)$	$H_2O(g)$
$S^{\ominus}$ / $J\,K^{-1}\,mol^{-1}$	214	131	186	189

Calculate the standard entropy change for this reaction. *[3]*

(iii) Explain how the sign of $\Delta S^{\ominus}$ can be predicted from the equation for the reaction. *[2]*

(iv) Use your answers to parts (b) (i) and (b) (ii) to calculate the standard free energy change for the reaction, and so determine whether the above reaction is spontaneous at 298 K. (If you have not obtained answers to parts (b) (i) and (b) (ii), assume the following: $\Delta H^{\ominus} = -120\ \text{kJ mol}^{-1}$ and $\Delta S^{\ominus} = -80\ \text{J K}^{-1}\ \text{mol}^{-1}$, although these are not the correct values.) *[3]*

(c) The standard enthalpy changes for the following reactions can be found in Table 13 of the Data Booklet.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l)$$

$$C_8H_{18}(l) + 12\tfrac{1}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$$

Use this information to determine the standard enthalpy change for the formation of octane from its elements.

$$8C(s) + 9H_2(g) \rightarrow C_8H_{18}(l)$$ *[4]*

(d) A Born-Haber cycle can be used to calculate the lattice enthalpy of potassium fluoride, KF, from five known enthalpy changes. The equation for one of these enthalpy changes, the standard enthalpy change of formation, is shown below.

$$K(s) + \tfrac{1}{2}F_2(g) \rightarrow KF(s)$$

For each of the other **four** enthalpy changes, state the name of the enthalpy change and write an equation, including state symbols. *[4]*

(e) Lattice enthalpy values obtained from Born-Haber cycles are shown in Table 14 of the Data Booklet.

(i) Explain why sodium fluoride, NaF, has a greater lattice enthalpy value than potassium fluoride, KF. *[1]*

(ii) Explain why calcium fluoride, CaF_2, has a greater lattice enthalpy than potassium fluoride, KF. *[2]*

6. (a) The decomposition of solid barium carbonate is given by the following equation:

$$BaCO_3(s) \rightleftharpoons BaO(s) + CO_2(g)$$

Compound	$BaCO_3(s)$	$CO_2(g)$	$BaO(s)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	–1219	–394	–558
$S^{\ominus}$ / JK^{-1} mol^{-1}	+112	+214	+70

(i) Calculate the value of $\Delta G^{\ominus}$ in kJ mol^{-1} at 25°C. *[6]*

(ii) State with a reason whether the reaction is spontaneous at 25°C. *[1]*

(iii) Determine the minimum temperature above which this reaction is spontaneous. Explain your answer. *[4]*

Topic 5 Mark Scheme

Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

1.	a	iii	*Bonds broken*: 2C≡O + 3(H–H) / 2(1077 kJ mol^{-1}) + 3(436 kJ mol^{-1}) / 3462 «kJ» ✓ *Bonds formed*: 2(C–O) + 2(O–H) + 4(C–H) + (C–C) / 2(358 kJ mol^{-1}) + 2(463 kJ mol^{-1}) + 4(414 kJ mol^{-1}) + 346 kJ mol^{-1} / 3644 «kJ» ✓ «Enthalpy change = bonds broken – bonds formed = 3462 kJ – 3644 kJ =» –182 «kJ» ✓	*Award **[3]** for correct final answer.* *Award **[2 max]** for «+»182 «kJ».*	3
1.	b	i	«$\Delta H = \Sigma\ \Delta H_f$ products – $\Sigma\ \Delta H_f$ reactants = –454.8 kJ mol^{-1} – 2(–110.5 kJ mol^{-1}) =» –233.8 «kJ» ✓		1
1.	b	ii	in (a)(iii) gas is formed and in (b)(i) liquid is formed *OR* products are in different states *OR* conversion of gas to liquid is exothermic *OR* conversion of liquid to gas is endothermic *OR* enthalpy of vapourisation needs to be taken into account ✓	*Accept product is «now» a liquid.* *Accept answers referring to bond enthalpies being means/averages.*	1

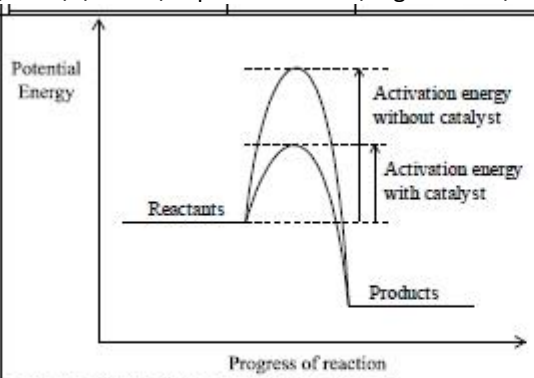
Question			Answers	Notes	Total
1.	b	iii	«ΔS is negative because five mols of» gases becomes «one mol of» liquid *OR* increase in complexity of product «compared to reactants» *OR* product more ordered «than reactants» ✓	*Accept "fewer moles of gas" but not "fewer molecules".*	1
1.	b	iv	$\Delta S = \left(\frac{-620.1}{1000}\right)$ «kJ K^{-1}» ✓ $\Delta G = -233.8\,\text{kJ} - (298\,\text{K}\left(\frac{-620.1}{1000}\right)\text{kJ K}^{-1}) = -49.0$ «kJ» ✓	*Award **[2]** for correct final answer.* *Award **[1 max]** for «+»185 × 10^3.* *If –244.0 kJ used, answer is:* $\Delta G = -244.0\,\text{kJ} - (298\,\text{K}\left(\frac{-620.1}{1000}\right)\text{kJ K}^{-1}) =$ –59.2 «kJ» *Award **[2]** for correct final answer.*	2
1.	b	v	increasing T makes ΔG larger/more positive/less negative *OR* $-T\Delta S$ will increase ✓		1

Q# 2/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

	c	i	$CH_4(g) + 5O_2(g) \rightarrow CO_2(g) + 2H_2O(g) + 2O_3(g)$ ✓		1
	c	ii	$\Delta H^\ominus = \langle[(-393.5) + (2)(-241.8) + (2)(+142.3)] - [(-74.0)] = \rangle - 660.8 \langle\text{kJ mol}^{-1}\rangle$ ✓		1
	c	iii	standard enthalpy change of formation/ $\Delta H_f^\ominus$ of an element ‹in most stable form› is always zero ✓		1
	c	iv	$\Delta S^\ominus = \langle[(+213.8) + (2)(+188.8) + (2)(+237.6)] - [(+186) + (5)(+205.0)] = \rangle$ $-144.4 \langle\text{J K}^{-1}\text{ mol}^{-1}\rangle$ ✓		1
	c	v	$\Delta G^\ominus = \left\langle \Delta H^\ominus - T\Delta S^\ominus = (-660.8) - (298)\left(\frac{-144.4}{1000}\right) = \right\rangle - 617.8 \langle\text{kJ mol}^{-1}\rangle$ ✓		1
	c	vi	spontaneous since negative $\Delta G^\ominus$ ✓		1

Question			Answers	Notes	Total
6.	d	i	O_2 has a double bond ✓ O_3 has intermediate bonds between double and single bonds ***OR*** O_3 has a bond order of 1½ ✓ bond in O_2 is stronger therefore I needs more energy ✓	*Do not award mark for I on its own with no justification.*	3
	d	ii	C–Cl ‹bond› breaks since weakest bond ✓ $CCl_2F_2 \xrightarrow{h\nu} \cdot CClF_2 + Cl\cdot$ ✓ $Cl\cdot + O_3 \rightarrow ClO\cdot + O_2$ ✓ $ClO\cdot + O\cdot \rightarrow O_2 + Cl\cdot$ ✓ $ClO\cdot + O_3 \rightarrow Cl\cdot + 2O_2$ ✓	*Allow representation of radicals without • as long as consistent throughout.*	5

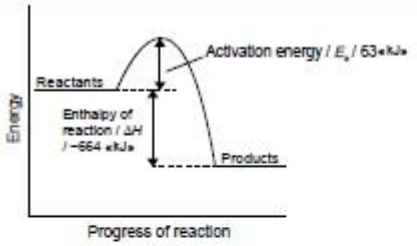
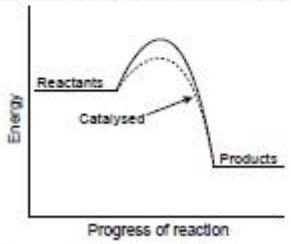
Q# 3/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q2

	c		 correct positions of reactants and products ✓ correct profile with labels showing activation energy with and without a catalyst ✓		2

Q# 4/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

Question			Answers	Notes	Total
5.	a		only water/H_2O produced ‹so non-polluting› ✓		1
	b		*Bond breaking*: (1)(H–H) + (4)(C–H) + (1)(C=C) ***OR*** (1)(436) + (4)(414) + (1)(614) = 2706 ‹kJ mol^{-1}› ✓ *Bond formation*: (6)(C–H) + (1)(C–C) ***OR*** (6)(414) + (1)(346) = 2830 ‹kJ mol^{-1}› ✓ ‹+2706 – 2830› = –124 ‹kJ mol^{-1}› ✓	*Award [2 max] for +124 ‹kJ mol^{-1}›.* *Award [3] for correct final answer.*	3

Q# 5/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

Question			Answers	Notes	Total
3.	b	i	 products lower than reactants ***AND*** enthalpy of reaction correctly marked and labelled with name or value ✓ activation energy correctly marked and labelled with name or value ✓	*Accept other clear ways of indicating energy/ enthalpy changes.*	2
3.	b	ii	 lower dotted curve, between same reactants and products levels, labelled "Catalysed" ✓		1

Q# 6/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

1.	d	i	temperature rise «= $\frac{750 \times 1.00}{0.2000 \times 1.00}$» = 3750 «°C/K» ✓	*Do not accept −3750.*	1

Q# 7/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

4.	a	i	same charge ***AND*** same/similar ionic radius ✓		1
4.	a	ii	enthalpy of hydration «= −1483 + 2 (−359)» = −2201 «kJ mol^{-1}» ✓ enthalpy of solution «= 2170 − 2201» = −31 «kJ mol^{-1}» ✓	*Award **[2]** for correct final answer.* *Award **[1 max]** for +31 «kJ mol^{-1}».* *Award **[1 max]** for ±4371.*	2

Q# 8/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

2.	a	iii	$\Delta H^{\ominus}$ = −220.1 − (−110.5) ✓ $\Delta H^{\ominus}$ = −109.6 «kJ» ✓	*Award **[2]** for correct final answer.* *Award **[1]** for −330.6, or +109.6 «kJ».*	2
2.	a	iv	$\Delta G^{\ominus}$ = −109.6 − (298 × $\Delta S^{\ominus}$) = + 11.7 «kJ» ✓ $\Delta S^{\ominus}$ «= − $\frac{(11.7 + 109.6) \times 10^3}{298}$» = −407 «J K^{-1}» ✓	*Award **[2]** for correct final answer.* *Award **[2]** for −470 «J K^{-1}» (result from given values).* *Do not penalize wrong value for T if already done in (a)(ii).* *Award **[1 max]** for −0.407 «kJ K^{-1}».* *Award **[1 max]** for −138.9 «J K^{-1}».*	2

Q# 9/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/

6. (a) possible to get iron **and** 3:1 ratio of the two equations;
The ratio may be shown in combining the equations/calculating overall ΔG/–29 (kJ).
possible to get iron **and** resultant ΔG is negative/–29 (kJ); ***[2]***
"Possible to get iron" needs only to be stated once.
Do not accept "possible to get iron" without any reason.
Do not accept "it is not possible to get iron because ΔG is positive".

(b) (i) $\Delta G^{\ominus} = [-1582 + 2 \times 10] - [-742]$;
$\Delta G^{\ominus} = -820\,(\text{kJ mol}^{-1})$; ***[2]***
*Award **[2]** for the correct final answer.*

(ii) $\left(\Delta S^{\ominus} = [50.9 + 2(34.8)] - [87.5 + 2(28.3)]\right) = -23.6\,(\text{JK}^{-1}\text{mol}^{-1})$; ***[1]***

(iii) $\Delta G^{\ominus} = [-825.2 - (298 \times (-0.0236))]$;
$\Delta G^{\ominus} = -818\,(\text{kJ mol}^{-1}) / -8.18 \times 10^5\,(\text{J mol}^{-1})$; ***[2]***
*Award **[2]** for the correct final answer.*
*Award **[0]** if b(i) is repeated here.*

Q# 10/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/

3. (a) $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$; ***[1]***
Ignore state symbols.

(b) *bonds broken:* 2(C–C)/694 + 8(C–H)/3304 + 5(O=O)/2490 / 6488 (kJ);
bonds made: 6(C=O)/4476 + 8(O–H)/3712 / 8188 (kJ);
(6488 – 8188 =) – 1700 (kJ mol^{-1}); ***[3]***
Ignore signs in M1 and M2.
*Award **[3]** for the correct final answer.*
*Award **[2]** for +1700 (kJ mol^{-1}).*
Accept values from 2016 data booklet to give 6494 (kJ) for M1, 8528 (kJ) for M2, and –2034 (kJ) for M3.

Q# 11/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/

3. (a) $(-239.0 - [-110.5] =) - 128.5\,(\text{kJmol}^{-1})$; **[1]**

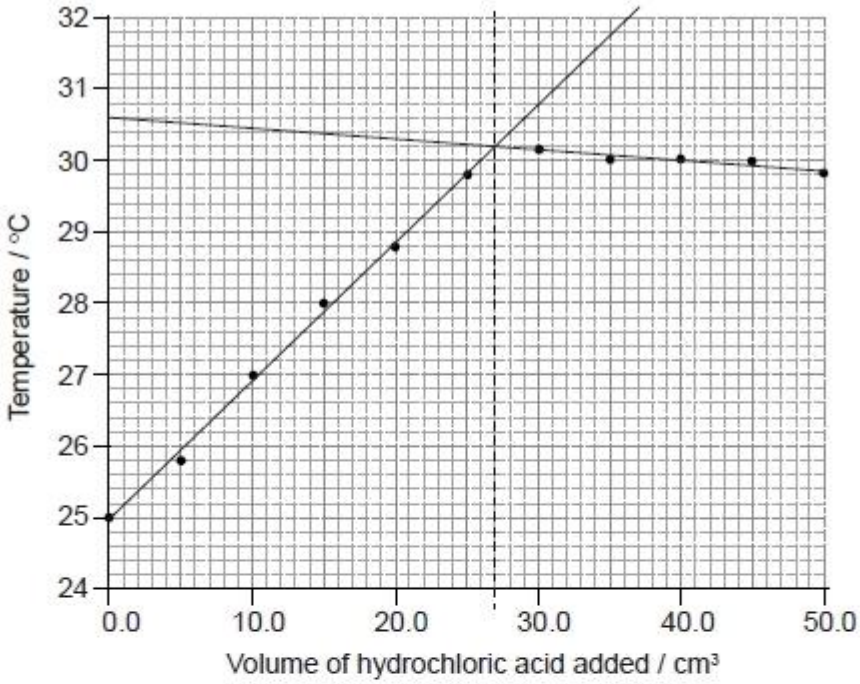
(b) $(-166.0 - [-137.2] =) - 28.8\,(\text{kJmol}^{-1})$; **[1]**

(c)
$$\left(\Delta G^{\ominus} = -28.8 = -128.5 - \left[\frac{298 \times \Delta S^{\ominus}}{1000}\right]\right)$$
$(\Delta S^{\ominus} =) - 335\,(\text{J mol}^{-1}\text{K}^{-1})$; **[1]**

(d) $\Delta S^{\ominus} = \sum S^{\ominus}_{products} - \sum S^{\ominus}_{reactants} / -335 = 126.8 - 197.6 - 2S^{\ominus}_{H_2}$;
$S^{\ominus}_{H_2} = (+)132\,(\text{Jmol}^{-1}\,\text{K}^{-1})$; **[2]**
*Award **[2]** for correct final answer.*
*Award **[1 max]** for $S^{\ominus}_{H_2} = (+)264\,(\text{Jmol}^{-1}\,\text{K}^{-1})$.*

Q# 12/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/

1. (a) (i)



drawing best-fit straight lines to show volume;
There should be approximately the same number of points above and below for both lines.

27.0 (cm^3); **[2]**
Accept any value in the range 26.0 to 28.0 (cm^3) if consistent with student's annotation on the graph.
Accept ECF for volumes in the range 27.0–30.0 cm^3 if it corresponds to maximum temperature of line drawn.
Volume should be given to one decimal place.

(ii) $([HCl]) = \frac{1.00 \times 0.0250}{0.0270}$;
$= 0.926\,mol\,dm^{-3}$; **[2]**
Volume of 26.0 gives [HCl] = 0.962 $moldm^{-3}$. Volume of 28.0 gives [HCl] = 0.893 $moldm^{-3}$.
*Award **[2]** for correct final answer with units.*
*Award **[1 max]** for correct concentration without units.*
Accept M, mol L^{-1}, mol/dm^3 as units.

(b) (i) $(30.2 - 25.0 =)(+)5.2(^{\circ}C/K)$; **[1]**

Any accepted value must be consistent with student's annotation on the graph but do not accept $\Delta T < 5.1$.
Accept (+)5.6(°C/K) (ie, taking into account heat loss and using T when volume = 0.0 cm^3).

(ii) $Q = (m \times c \times \Delta T = (25.0 + 27.0) \times 4.18 \times 5.2 = 1130.272\,J =)1.13(kJ)$;
$n = (1.00 \times 0.0250 =)0.0250(mol)$;
$\Delta H = (-\frac{Q}{n} = -45210.88\,Jmol^{-1} =) - 45(kJmol^{-1})$; **[3]**

*Award **[3]** for correct final answer.*
*Award **[2]** for +45 (kJ mol^{-1}).*
Apply ECF for M3 even if both m and ΔT are incorrect in M1.
Accept use of c = 4.2 Jg^{-1}K^{-1}.

(iii) $\left(\left|\frac{-45 - (-58)}{(-58)}\right| \times 100 = \right)22\ (\%)$; **[1]**

Answer must be given to two significant figures.
Ignore sign.

(iv) heat losses;
better (thermal) insulation / using a polystyrene cup / putting a lid on the beaker; **[2]**
Accept other suitable methods for better thermal insulation but do not accept just "use a calorimeter" without reference to insulation.

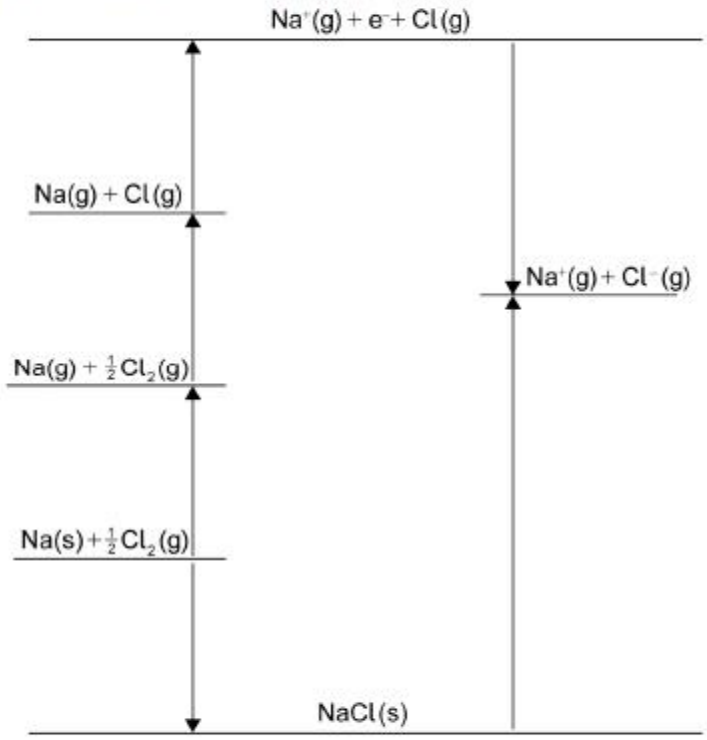
Q# 13/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q6

(g) atomization of chlorine $= \frac{1}{2}$ bond enthalpy / $\frac{1}{2}$ 243 / 121.5 (kJ mol^{-1});

correct values for *ionization* Na (+496 kJ mol^{-1}) **and** *electron affinity* Cl (–349 kJ mol^{-1}) **and** lattice enthalpy of NaCl (+790 kJ mol^{-1} / +769 kJ mol^{-1});

Born-Haber energy cycle;

Accept lines or arrows in energy cycle.



$\Delta H_f^{\ominus}(\text{NaCl(s)}) = -413.5 / -413 / -414\ (\text{kJ mol}^{-1})$; **[4]**

Accept –392.5 / –392 / –393 if +769 used for lattice enthalpy.

*Award **[4]** for correct final answer.*

Q# 14/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q5

(b) (i) energy needed to break (1 mol of) a bond in the gaseous state/phase; (averaged over) similar compounds; **[2]**

Do not accept "similar bonds" instead of "similar compounds".

Concept of "similar" is important for M2.

(ii) $CH_3CH_2OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$;

Bonds broken:

$347 + (5 \times 413) + 358 + 464 + (3 \times 498) / 4728\ (\text{kJ})$ /

C–C + 5C–H + C–O + O–H + 3O=O;

Bonds made:

$(4 \times 746) + (6 \times 464) = 5768\ (\text{kJ})$ / 4C=O + 6O–H;

$\Delta H = (4728 - 5768 =) - 1040\ (\text{kJmol}^{-1})$ / bonds broken – bonds formed; **[4]**

*Award **[4]** for correct final answer.*

*Award **[3]** for (+)1040 (kJ mol^{-1}).*

(c) heat loss (to the surroundings); **[1]**

(f) (i) $3C(s) + 3H_2(g) + O_2(g) \rightarrow CH_3CH_2COOH(l)$;

$\Delta H_f^\ominus = \sum \Delta H_c^\ominus (reactants) - \sum \Delta H_c^\ominus (products)$;

Accept any suitable energy cycle.

$\sum \Delta H_c^\ominus (reactants) = 3 \times (-394) + 3 \times (-286) / -2040\ (kJ\,mol^{-1})$;

$(\Delta H_f^\ominus = [3 \times (-394) + 3 \times (-286)] - (-1527) =) - 513\ (kJ\,mol^{-1})$;

OR

$CH_3CH_2COOH(l) + 3.5O_2(g) \rightarrow 3CO_2(g) + 3H_2O(g)$;

$\Delta H_c^\ominus = \sum \Delta H_f^\ominus (products) - \sum \Delta H_f^\ominus (reactants)$;

$\sum \Delta H_f^\ominus (products) = 3 \times (-394) + 3 \times (-286) / -2040\ (kJ\,mol^{-1})$;

$(\Delta H_f^\ominus = [3 \times (-394) + 3 \times (-286)] - (-1527) =) - 513\ (kJ\,mol^{-1})$; **[4]**

Ignore state symbols.
*Award **[4]** for correct final answer.*

(ii) negative;
reduction in the number of gaseous molecules; **[2]**

Q# 15/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q11

(e) (i) heat transferred/absorbed/released/enthalpy/potential energy change when 1 mol/molar amounts of reactant(s) react (to form products) / *OWTTE*;
under standard conditions / at a pressure 100 kPa/101.3 kPa/1 atm **and** temperature 298 K/25 °C; *[2]*

Award [2] for difference between standard enthalpies of products and standard enthalpies of reactants / $H^\ominus$ (products) – $H^\ominus$ (reactants).
Award [2] for difference between standard enthalpies of formation of products and standard enthalpies of formation of reactants / $\Sigma\Delta H_f^\circ$ (products) – $\Sigma\Delta H_f^\ominus$ (reactants).

(ii) $(1.00 \times 0.0500 =) 0.0500\,(mol)$;

$(0.0500 \times 57.9 =) 2.90\,(kJ)$; *[2]*

Ignore any negative sign.
Award [2] for correct final answer.
Award [1 max] for 2900 J.

(iii) $\left(\frac{2.50}{40.00} =\right) 0.0625\,(mol\ NaOH)$;

$0.0500 \times 4.18 \times 13.3 = 2.78\,(kJ) / 50.0 \times 4.18 \times 13.3 = 2780\,(J)$;

$\left(\frac{2.78}{0.0625}\right) = -44.5\,(kJ\,mol^{-1})$; *[3]*

Award [3] for correct final answer.
Negative sign is necessary for M3.
Award M2 and M3 if 52.5 g is used to obtain an enthalpy change of –46.7 (kJ mol-1).

(iv) $-44.5 - 57.9$ / correct Hess's Law cycle (as below) / correct manipulation of equations;

$$\begin{array}{ccc} NaOH(s) + HCl(aq) & \rightarrow & NaCl(aq) + H_2O(l) \\ \downarrow -44.5\,kJ & & \uparrow -57.9\,kJ \\ NaOH(aq) + HCl(aq) & & \end{array}$$

$-102.4\,kJ$; *[2]*

Award [2] for correct final answer.

(f) (i) zinc (only) forms the ion Zn^{2+} / has the oxidation state +2;
Allow forms only one ion / has only one oxidation state.
has full d-subshell/orbitals / does not have a partially filled d-subshell/orbitals (needed to exhibit transition metal properties); *[2]*

(ii) Fe^{2+}: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^6$ /[Ar] $3d^6$ **and** Fe^{3+}: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^5$ /[Ar] $3d^5$;
half-full sub-level/$3d^5$ has extra stability;
less repulsion between electrons / electrons singly occupy orbitals / electrons do not have to pair with other electrons; *[3]*
Accept converse points for Fe^{2+}.

Q# 16/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/

2. (a) (bonds broken) C=C and O–H / $612 + 464$ / 1076;
(bonds formed) C–C and C–H and C–O / $347 + 413 + 358$ / 1118;

OR

(bonds broken) C=C and two O–H and four C–H / $612 + 4(413) + 2(464)$ / 3192;
(bonds formed) C–C and five C–H and C–O and O–H / $347 + 5(413) + 358 + 464$ / 3234;

Ignore signs (+ and –) in M1 and M2. These two marks are awarded for recognizing the correct bonds.

enthalpy change $= -42\,(kJ)$; *[3]*
Correct sign is necessary for awarding M3.
Award [3] for the correct final answer.
Do not penalize candidates using the former Data Booklet bond energy values (348, 412 and 463) (final answer will then be -45(kJ)).

(b) (i) heat/enthalpy change when 1 mol of a compound/substance is formed;
from its elements in their standard states/at 100kPa/10^5Pa ; *[2]*

Allow 1.01×10^5 Pa/101kPa/1atm as an alternative to 100 kPa/10^5 Pa.
Allow under standard conditions or standard ambient temperature and pressure as an alternative to 100 kPa/10^5 Pa.
Allow "energy needed/absorbed" as an alternative to "heat/enthalpy change".
Temperature is not required in definition, allow if quoted (eg, 298K / 25 °C).

(ii) $(-235)-(52-242)$ / $\Delta H = \Sigma\Delta H_f^{\ominus}(\text{products}) - \Sigma\Delta H_f^{\ominus}(\text{reactants})$;
-45 (kJ) ; *[2]*
Award [2] for the correct final answer.
Award [1] for +45 or 45.

(c) value in (b)(ii) (is more accurate) as values used in (a) are average values / value in (b)(ii) (is more accurate) as exact bond enthalpy depends on the surroundings of the bond / *OWTTE*; *[1]*

(d) negative **and** fewer number of moles/molecules (of gas); *[1]*

Q# 17/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q8

(c) $\Delta H_{at}(\text{Cl}) = \frac{1}{2}\times 243\,(\text{kJ mol}^{-1})$;
Correct calculation of atomization enthalpy of Cl.

$\Delta H_f = +146 + \frac{1}{2}243 + 738 + (-349) + (-790)$;
Correct sign and magnitude of all terms.

$= -134\,(\text{kJ mol}^{-1})$; *[3]*
Award [3] for correct final answer.
Final mark involves correct computation of equation the student has produced.
Award [2] for –12 (bond enthalpy of Cl not halved) or +134 (signs wrong).
Award [1] for +12 (bond enthalpy of Cl not halved and signs wrong).

(d) $MgF_2 – MgCl_2 – CaCl_2$;
F^- smaller (ionic radius) than Cl^- / Cl^- larger (ionic radius) than F^-;
Mg^{2+} smaller (ionic radius) than Ca^{2+} / Ca^{2+} larger (ionic radius) than Mg^{2+}; *[3]*
Accept use of atomic radius rather than ionic radius.

(e) more soluble at low pH / less soluble at high pH;
higher pH / OH^- will shift the equilibrium to the left / lower pH / H^+ will (react with OH^- and) shift the equilibrium to the right; *[2]*

(b) $\Delta H^{\ominus} = \left(\Sigma\Delta H_f{}^{\ominus}(\text{products}) - \Sigma\Delta H_f{}^{\ominus}(\text{reactants}) = -127 - (110 + 0) = \right) - 237\,(\text{kJ mol}^{-1})$; *[1]*

(c) $\Delta G^{\ominus} = \left(\Sigma\Delta G_f{}^{\ominus}(\text{products}) - \Sigma\Delta G_f{}^{\ominus}(\text{reactants}) = -16 - (152 + 0) = \right) - 168\,(\text{kJ mol}^{-1})$; *[1]*

(d) (i) $\Delta S^{\ominus} = \left(\dfrac{\Delta H^{\ominus} - \Delta G^{\ominus}}{T} = \right)\dfrac{-237 - (-168)}{298}$;

$= -0.232\,(\text{kJ}\,K^{-1}\,\text{mol}^{-1})$; *[2]*

Award [2] for correct final answer.
Award [2] for –232 J K^{-1} mol^{-1} (units must be given).

(ii) 3 mol of gaseous reactants and 1 mol of gaseous products / fewer moles of gas in products; *[1]*

(iii) spontaneity decreases (as temperature increases because $T\Delta S^{\ominus}$ becomes a larger negative value/ $\Delta G^{\ominus}$ becomes positive at higher temperatures); *[1]*

(iv) $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus} = 0 / -237 - T(-0.232) = 0$;
$T = 1020\,(K)$;
Remember to allow ECF from 4(d)(i). *[2]*

(v) $\Delta S^{\ominus} = \Sigma S^{\ominus}(\text{products}) - \Sigma S^{\ominus}(\text{reactants})$ / $-232 = 310 - (279 + 2S^{\ominus}(\text{H}_2))$;
$S^{\ominus}(\text{H}_2) = \frac{1}{2}(310 - 279 + 232) = 132\,\text{J K}^{-1}\,\text{mol}^{-1}$; *[2]*

Award [2] for correct final answer.
Remember to allow ECF from 4(d)(i).

Q# 19/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/

1. (a) (i) $n(MgSO_4) = \left(\frac{53.01}{120.37} = \right) 0.0250\,(mol)$; *[1]*

(ii) energy released $= 50.0 \times 4.18 \times 9.7 = 2027\,(J) / 2.027\,(kJ)$;

$\Delta H_1 = -81\,(kJ\,mol^{-1})$; *[2]*

Award [2] for correct answer.
Award [2] if 53.01 is used giving an answer of –86 (kJ mol^{-1}).
Award [1 max] for +81/81/+86/86 (kJ mol^{-1}).
Award [1 max] for –81000/–86000 if units are stated as J mol^{-1}.
Allow answers to 3 significant figures.

(b) (i) $\Delta H\,(= \Delta H_1 - \Delta H_2) = -99\,(kJ\,mol^{-1})$; *[1]*

Award [1] if –86 is used giving an answer of –104 (kJ mol^{-1}).

(ii) $\frac{(103-99)}{103} \times 100 = 3.9\%$; *[1]*

Accept answer of 2.9% if –100 used but only if a value for (b)(i) is not present.
Award [1] if –104 is used giving an answer of 1.0% .
Accept correct answers which are not to 1 decimal place.

(c) $MgSO_4$ not completely anhydrous / *OWTTE*;
$MgSO_4$ is impure;
heat loss to the atmosphere/surroundings;
specific heat capacity of solution is taken as that of pure water;
experiment was done once only so it is not scientific;
density of solution is taken to be 1 g cm^{-3};
mass of $7H_2O$ ignored in calculation;
uncertainty of thermometer is high so temperature change is unreliable;
literature values are carried out under standard conditions, but this experiment is not;
all solid not dissolved; *[2 max]*

8. (a) (i) $(q = mc\Delta T =)\ 0.0500 \times 4.18 \times 21.3 = 4.45$ (kJ);
Do not accept m = 0.05023 kg.

$(n\ methanol =)\ \dfrac{0.230}{32.05} = 7.18 \times 10^{-3}$ (mol) ;

$\Delta H = \dfrac{4.45}{7.18 \times 10^{-3}}$;

$\Delta H = -6.20 \times 10^{2}$ kJ mol^{-1}; *[4]*

Accept integer values of molar mass.
Final answer must have negative sign and correct units.
Award [4] for correct final answer with correct units.

(ii) less heat is liberated than theoretically/–726 kJ mol^{-1};
probably due to heat loss/incomplete combustion;
determine heat capacity of calorimeter and take heat absorbed by calorimeter into account / any suitable insulation method / measure temperature with time and extrapolation of graph to compensate heat loss / *OWTTE*; *[3]*
If the value calculated in (a) (i) is more exothermic than theoretically, allow ECF for M1 and for improvement if consistent.

(b) (i) $CH_3OH + \frac{3}{2}O_2 \rightarrow CO_2 + 2H_2O \quad \Delta H^{\ominus}_c = -726$ (kJ mol^{-1})
$CO + \frac{1}{2}O_2 \rightarrow CO_2 \quad \Delta H^{\ominus}_c = -283$ (kJ mol^{-1})
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad \Delta H^{\ominus}_c = -286$ (kJ mol^{-1})
*Award **[1 max]** for three correct values.*
Mark can be implicit in calculations.

$(\Delta H^{\ominus}_R =)\ 2(-286) + (-283) - (-726)$;
–129 (kJ mol^{-1}); *[3]*
Award [3] for correct final answer.
*Award **[2 max]** for +129 (kJ mol^{-1}).*

(ii) $(\Delta S^{\ominus} = 240 - 198 - 2 \times 131 =) - 220$ (J K^{-1} mol^{-1}) ; *[1]*

(iii) $(-129 - 298(-0.220) =) - 63.4$ kJ mol^{-1} ; *[2]*
*Award **[1]** for correct numerical answer and **[1]** for correct unit if the conversion has been made from J to kJ for $\Delta S^{\ominus}$.*

(iv) not spontaneous at high temperature;
$T\Delta S^{\ominus} < \Delta H^{\ominus}$ **and** $\Delta G^{\ominus}$ positive; *[2]*

(c) (i) (entropy decreases) negative/-/minus;
gaseous reactant more disordered / product more ordered than reactants / amount of gas decreases / *OWTTE*; ***[2]***
Allow number of moles of gas decreases.
M2 can only be scored if M1 is correct.

(ii) heat/enthalpy <u>change</u> when 1 mol of a compound is formed from its <u>elements</u>;
in their standard states / at 100 kPa/10^5 Pa/1 bar (pressure); ***[2]***
Allow 1.01×10^5 *Pa / 101 kPa / 1 atm.*
Allow under standard conditions or standard ambient temperature and pressure.
Temperatures not required in definition, allow if quoted (e.g. 298 K/25 °C – most common) but correct pressure value must be stated if given.
Only award M2 for a correct M1 or a near miss at M1.

(iii) $\Delta H^{\ominus} = (-485 + 111 + 239 =) -135\ (\text{kJ mol}^{-1})$; ***[1]***

(iv) $\Delta S^{\ominus} = (160 - 198 - 240) = -278\ (\text{J K}^{-1}\ \text{mol}^{-1})$; ***[1]***

(v) $\Delta G^{\ominus} = \left(\Delta H^{\ominus} - T\Delta S^{\ominus} = -135 + 298 \times \frac{278}{1000} =\right) - 52.2\ (\text{kJ mol}^{-1})$;
spontaneous (since negative $\Delta G^{\ominus}$); ***[2]***
Answer to M2 depends on sign given in M1.

Q# 22/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/

5. (a) energy needed to break (1 mol of) a bond in a gaseous molecule/state/phase; average calculated from a range of similar compounds / *OWTTE*; ***[2]***
Do not accept similar bonds instead of similar compounds.
M2 can be scored independently.

(b) (i) *Bonds breaking*:
$4 \times (N{=}O) + 4 \times (N{-}N) + 8 \times (C{-}H) + 4 \times (N{-}O) + 8 \times (C{-}N)$ /
$= (4)(607) + (4)(158) + (8)(413) + (4)(201) + (8)(286)$ /
$= 9456\ (\text{kJ mol}^{-1})$;

Bonds forming:
$4 \times (N{\equiv}N) + 4 \times (C{\equiv}O) + 8 \times (O{-}H)$ /
$= (4)(945) + (4)(1072) + (8)(464) / = 11780\ (\text{kJ mol}^{-1})$;

Enthalpy change:
$(9456 - 11780 =) -2324\ (\text{kJ mol}^{-1})$;
M3 is scored from M1-M2.
*Award **[2 max]** for (+)2324 (kJ mol^{-1}).*
*Award **[3]** for –2324 (kJ mol^{-1}) without working.*

$\left(10.0 \times \frac{-2324}{296.2} =\right) -78.5\ (\text{kJ})$; ***[4]***
M4 is scored from 10.0/296.2 × M3.
Allow answers of –78.2, –78 and –79 (kJ), but negative sign must be included.
*Award **[4]** for correct final answer.*

Q# 23/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/Q5

(b) (i) $(\sum \ddot{e} H_f^{\circ}$ (products) =) –5360 (kJ);
$(\sum \ddot{e} H_f^{\circ}$ (reactants) =) +160 (kJ);
= –5520 (kJ); ***[3]***

(ii) (–1560 × 2 =) –3120 (kJ); ***[1]***

(c) *Bonds broken:*
6Si–H, Si–Si, H–H / (+)2570 (kJ);
Bonds formed:
8Si–H / (–)2544 (kJ);
+26 (kJ);

OR

Bonds broken:
Si–Si, H–H / (+)662 (kJ);
Bonds formed:
2Si–H / (–)636 (kJ);
+26 (kJ); ***[3]***

Q# 24/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/

3. (a) energy required to break (1 mol of) a bond in a gaseous molecule/state;
Accept energy released when (1 mol of) a bond is formed in a gaseous molecule/ state / enthalpy change when (1 mol of) bonds are formed or broken in the gaseous molecule/state.

average values obtained from a number of similar bonds/compounds / *OWTTE*; ***[2]***

(b) $CH_3(CH_2)_3OH(l) + 6O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$; ***[1]***
Allow C_4H_9OH or $C_4H_{10}O$ for $CH_3(CH_2)_3OH$.
Ignore state symbols.

(c) *Bonds broken:*
$(6)(O{=}O) + (3)(C{-}C) + (1)(O{-}H) + (1)(C{-}O) + (9)(C{-}H)$ /
$\left((6)(498) + (3)(347) + (1)(464) + (1)(358) + (9)(413) =\right)8568\ (kJ\ mol^{-1})$;

Bonds formed:
$(8)(C{=}O) + (10)(O{-}H)$ / $\left((8)(746) + (10)(464) =\right)10608\ (kJ\ mol^{-1})$;
$\Delta H = (8568 - 10608 =) - 2040\ (kJ\ mol^{-1})$; ***[3]***
*Award **[3]** for correct final answer.*
*Award **[2]** for +2040 ($kJ\ mol^{-1}$).*

Q# 25/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/

5. (a) negative;
liquid more ordered than gaseous phase or *vice-versa* / *OWTTE*; ***[2]***

(b) (i) $\Delta H_f^{\ominus}$ of an element (in its most stable state) is zero (since formation of an element from itself is not a reaction) / *OWTTE*; ***[1]***
Do not allow an answer such as because they are elements.

(ii) $\Delta H^{\ominus} (= (1)(-20.6) - (1)(-53.1)) = 32.5\ (kJ\ mol^{-1})$ / $32500\ (J\ mol^{-1})$; ***[1]***
Allow 32.5 (kJ) or 3.25×10^4 (J).

(iii) $\Delta G^{\ominus} (= (1)(-33.6) - (1)(-53.6)) = 20.0\ (kJ\ mol^{-1})$ / $20000\ (J\ mol^{-1})$;
Allow 20.0 (kJ) or 2.00×10^4 (J).
non-spontaneous; ***[2]***

(iv) $\Delta S^{\ominus} (= (\Delta H^{\ominus} - \Delta G^{\ominus}) / T = (32.5 - 20.0)(1000) / 298) = 41.9\ (J\ K^{-1}\ mol^{-1})$ /
$4.19 \times 10^{-2}\ (kJ\ K^{-1}\ mol^{-1})$; ***[1]***
Allow 41.9 ($J\ K^{-1}$) or 4.19×10^{-2} ($kJ\ K^{-1}$).

(v) $T (= \Delta H / \Delta S = (32.5 \times 1000) / (41.9)) = 776\ (K)$; ***[1]***

Q# 26/ IB Chem/2011/s/TZ1/Paper 2 Section A/Higher Level/

1. (a) $(\Delta H^{\ominus} = \Sigma\Delta H_{f\,products}^{\ominus} - \Sigma\Delta H_{f\,reactants}^{\ominus})$

$\Delta H_c^{\ominus} = (2\times -242 + -394) - (-239)$ (kJ mol^{-1});

$\Delta H_c^{\ominus} = -639$ (kJ mol^{-1}); ***[2]***

*Award **[2]** for correct final answer.*
Do not award M2 if M1 incorrect.

(b) (i) m(methanol) = (80.557 – 80.034) = 0.523 (g);

$n(\text{methanol}) = \left(\frac{0.523\text{ g}}{32.05\text{ g mol}^{-1}}\right) = 0.0163$ (mol); ***[2]***

*Award **[2]** for correct final answer.*

(ii) ΔT = (26.4 – 21.5) = 4.9 (K);

$q = (mc\Delta T =)\ 20.000\times4.18\times4.9$ (J) / $20.000\times4.18\times4.9\times10^{-3}$ (kJ);

0.41 (kJ); ***[3]***

*Award **[3]** for correct final answer.*

(iii) $\Delta H_c^{\ominus} = -\frac{0.41\text{ (kJ)}}{0.0163\text{ (mol)}} / -25153$ (J mol^{-1});

= –25 (kJ mol^{-1}); ***[2]***

*Award **[2]** for correct final answer.*
*Award **[1]** for (+)25 (kJ mol^{-1}).*

(c) (i) not at standard conditions/1 atm **and** 298 K/25 °C / ΔH_{vap} for water; ***[1]***

(ii) not all heat produced transferred to water / heat lost to surroundings/environment / *OWTTE* / incomplete combustion (of methanol) / water forms as H_2O(l) instead of H_2O(g); ***[1]***

Do not allow just "heat lost".

(d) $\Delta S^{\ominus}\ (= \sum S^{\ominus}_{products} - \sum S^{\ominus}_{reactants}) = 2\times189 + 214 - (240 + 1.5\times205)$;

= 44.5 J K^{-1} mol^{-1} / 0.0445 kJ K^{-1} mol^{-1} ***[2]***

*Award **[2]** for correct final answer.*
Do not award M2 if M1 incorrect.

(e) temperature of 298 K;

$\Delta G_c^{\ominus} = (\Delta H_c^{\ominus} - T\Delta S_c^{\ominus} =) -726 - 298\times44.5\times10^{-3}$ (kJ mol^{-1}) /

$-726\,000 - 298\times44.5$ (J mol^{-1});

= –739 kJ mol^{-1} / -7.39×10^5 J mol^{-1}; ***[3]***

*Award **[3]** for correct final answer.*

(f) $\Delta G_c^{\ominus}$ is always negative **and** temperature won't alter spontaneity of reaction; ***[1]***

Q# 27/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/4

(c) (i) *I*:
atomization/sublimation (of Mg) / $\Delta H^{\ominus}_{atomization}(Mg)$ / $\Delta H^{\ominus}_{sublimation}(Mg)$;

V:
enthalpy change of formation of $(MgCl_2)$ / $\Delta H^{\ominus}_{formation}(MgCl_2)$; *[2]*

(ii) *Energy value for II*:
+243;

Energy value for III:
$738 + 1451 = 2189$;

Energy value for IV:
$2(-349)$;
$\Delta H^{\ominus}_{lat}(MgCl_2) = 642 + 148 + 243 + 2189 = (+)2252(KJ)$; *[4]*

(iv) oxide greater charge;
oxide smaller radius; *[2]*
Accept opposite arguments.

Q# 28/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/Q7

(c) (i) $\Delta H_r^{\ominus} = \Sigma\Delta H_f^{\ominus}$ products $- \Sigma\Delta H_f^{\ominus}$ reactants;
Can be implied by working.

$\Delta H_f^{\ominus}(H_2O(l)) = -286(kJ)$;
$\Delta H_r^{\ominus} = 2(-286) - 50.6 = -622.6(kJ)$;
Award [3] for correct final answer.

[3]

(ii) bonds broken: 4 N–H, N–N, O=O / $+2220(kJ\,mol^{-1})$;
bonds formed: N≡N, 4 O–H / $-2801(kJ\,mol^{-1})$;
$-581(kJ\,mol^{-1})$; *[3]*
Award [3] for correct final answer.

(iii) value based on ΔH_f more accurate;
ΔH_f accurate for compounds in reaction;
bond energy calculation assumes average bond energies;
(bond energy calculation) only applies to gaseous states / ignores intermolecular bonds; *[3 max]*

(iv) $\Delta S^{\ominus} = \Sigma S^{\ominus}$ (products) $- \Sigma S^{\ominus}$ (reactants);
Can be implied by working.

$= 191 + (2 \times 69.9) - 205 - 121 = +4.8(J\,K^{-1}mol^{-1})$;
Award [2] for correct final answer.

small value since number of mol of g on both sides the same; *[3]*

(v) $\Delta G^{\ominus} = -622.6 - 298(0.0048)$;
$= -624.0\,(\text{kJ mol}^{-1})$;

Award [2] for correct final answer.
Allow 623.9 to 624.1. *[2]*

(vi) all reactions are spontaneous;
ΔG is negative (at high temperatures and low temperatures); *[2]*

Q# 29/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/

1. (a) all heat is transferred to water/copper sulfate solution / no heat loss;
specific heat capacity of zinc is zero/negligible / no heat is absorbed by the zinc;
density of water/solution = 1.0 / density of solution = density of water;
heat capacity of cup is zero / no heat is absorbed by the cup;
specific heat capacity of solution = specific heat capacity of water;
temperature uniform throughout solution; *[2 max]*
Award [1] each for any two.
Accept energy instead of heat.

(b) (i) $T_{\text{final}} = 73.0\,(^{\circ}\text{C})$;
Allow in the range 72 to 74 (°C).

$\Delta T = 48.2\,(^{\circ}\text{C})$; *[2]*
Allow in the range 47 to 49 (°C).
Award [2] for correct final answer
Allow ECF if T_{final} or $T_{initial}$ correct.

(ii) 10.1 (kJ); *[1]*
Allow in the range 9.9 to 10.2 (kJ).

(c) $\left(n_{\text{Zn}} = n_{\text{CuSO}_4} = \frac{1.00 \times 50.0}{1000}\right) = 0.0500\,(\text{mol})$; *[1]*

(d) $-201\,(\text{kJ mol}^{-1})$; *[1]*
Allow in the range −197 to − 206 ($kJ\,mol^{-1}$).
Value must be negative to award mark.

Q# 30/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/

5. (a) (i) correct substitution of values and numbers of bonds broken / $(1\times945)+(3\times436)/2253$;
correct substitution of values and numbers of bonds made / $(6\times391)/2346$;
$\Delta H =$ (sum of energies of bonds broken) – (sum of energies of bonds formed)
$= (2253–2346) -93$ (kJ); *[3]*
Ignore units.
*Award **[3]** for correct final answer.*
*Award **[2 max]** for +93 or 93.*

(ii) entropy of products = $2 \times 192 = 384$;
entropy of reactants = $193+(3\times131) = 586$;
$\Delta S^{\ominus}$ (= sum of entropies of products) – (sum of entropies of reactants) / $(384–586) = –202$ ($J\ K^{-1}\ mol^{-1}$);
*Award **[3]** for correct final answer.*
*Award **[2 max]** for +202 or 202.*
Ignore units.

negative as more ordered/less disordered / four moles become two moles / fewer molecules of gas; *[4]*

(iii) $(\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus} = -93-298(-0.202)) = -32.8$ ($kJ\ mol^{-1}$); *[1]*

(iv) reaction becomes less spontaneous;
ΔG becomes more positive/less negative / $T\Delta S$ becomes larger; *[2]*

Q# 31/ IB Chem/2009/w/TZ0/Paper 2 Section B/Higher Level/

7. (a) (i) **A:** sublimation/atomization;
B: atomization/half dissociation enthalpy;
D: (sum of 1st and 2nd) electron affinity; *[3]*
Do not accept vaporization for A and B.
Accept ΔH_{AT}. or ΔH_{EA}.

(ii) enthalpy change when one mole of the compound is formed from its elements (in their standard states);
under standard conditions / 25 °C/298 K **and** 1 atm/101.3 kPa/1.01 × 105 Pa; *[2]*

(iii) $-602 = 150 + 248 + 2186 + 702 + E$;
-3888 ($kJ\ mol^{-1}$); *[2]*
Do not allow 3889 (given in data booklet).
Allow 3888 (i.e no minus sign).
Award [2] for the correct final answer.

(iv) energy required to remove one electron;
from an atom in its gaseous state;
electron removed from a positive ion;
decrease in electron-electron repulsion / increase in nucleus-electron attraction; *[4]*

(v) MgO;
double ionic charge / both ions carry +2 and –2 charge/greater charge compared to +1 and –1; *[2]*

(b) (i) $(C_2H_6(g) + 3\frac{1}{2}O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l))$ $\Delta H^{\ominus} = -1560$;

$(H_2O(l) \rightarrow H_2(g) + \frac{1}{2}O_2(g))$ $\Delta H^{\ominus} = +286$;

$(2CO_2(g) + 2H_2O(l) \rightarrow C_2H_4(g) + 3O_2(g))$ $\Delta H^{\ominus} = +1411$;

$(C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g))$ $\Delta H^{\ominus} = +137\,(kJ)$; *[4]*

Allow other correct methods.
Award [2] for –137.
Allow ECF for the final marking point.

(ii) positive;
increase in number of moles of gas; *[2]*

(iii) at low temperature, $\Delta H^{\ominus}$ is positive **and** ΔG is positive;
at high temperature, factor $T\Delta S^{\ominus}$ predominates **and** ΔG is negative; *[2]*

(iv) Bonds broken (1C–C, 6C–H, or 1C–C, 2C–H) = 2825/1173;
Bonds made (1C=C, 1H–H, 4C–H) = 2700/1048;
+125 (kJ); *[3]*
Allow 125 but not –125 (kJ) for the final mark.
Award [3] for the correct final answer.

(v) bond enthalpy values are average values; *[1]*

Q# 32/ IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/Q6

(b) (i) **c**: atomization (enthalpy);
d: electron affinity; ***[2]***

(ii) **d** and **e**; ***[1]***

(iii) $\Delta H_f = 90.0 + 418 + 112 + (-342) + (-670)$;
$= -392\ kJ\ mol^{-1}$; ***[2]***

(iv) Ca^{2+} is smaller than K^+ **and** Ca^{2+} has more charge than K^+ / Ca^{2+} has a greater charge density;
so the attractive forces between the ions are stronger; ***[2]***
Do not accept 'stronger ionic bonds'
*Award **[1 max]** if reference is made to atoms or molecules instead of ions.*

Q# 33/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

3. (a) energy required = C=C + H–H/612 + 436 and
energy released = C–C + 2 (C–H)/347 + 2 (413) /
energy required = C=C + H–H + 4 (C–H)/612 + 436 + 4(413) and
energy released = C–C + 6 (C–H)/347 + 6(413) ;

ΔH = (1048 – 1173)/(2700 – 2825) = –125 kJ mol^{-1} ; ***[2]***

(b) ΔH = –1411 + (–286) – (–1560) /correct energy cycle drawn;
= –137 kJ mol^{-1} ; ***[2]***
*Award **[1 max]** for incorrect or missing sign.*

(c) the actual values for the specific bonds may be different to the average values / the combustion values referred to the specific compounds / *OWTTE*;
(percentage difference) = $\frac{(137-125)}{137} \times 100 = 8.76\%$; ***[2]***
Accept $\frac{(137-125)}{125} \times 100 = 9.60\%$.

(d) (i) –125 kJ mol^{-1}; ***[1]***

(ii) average bond enthalpies do not apply to the liquid state / *OWTTE*;
the enthalpy of vaporization/condensation of cyclohexene and cyclohexane / *OWTTE*; ***[2]***

5. (a) (i) energy change to break/make (one mole) of bonds (in molecule) in gaseous state; averaged over similar compounds; *[2]*

(ii) H–H bond is only present in one molecule/*OWTTE*; *[1]*

(b) (i) bonds broken: 2 C=O and 4 H–H / 1486 + 1744 / 3230;
bonds formed: 4 C–H and 4 O–H / 1648 + 1852 / 3500;
$\Delta H\ (= 3230 - 3500) = -270\ (\text{kJ/kJ mol}^{-1})$; *[3]*
ECF from bonds broken and formed.
Correct final answer scores [3] marks.
270 kJ/kJ mol^{-1} or +270 kJ/kJ mol^{-1} scores [2] marks.

(ii) reactants entropy $= 214 + (4 \times 131) = 738$;
products entropy $= 186 + (2 \times 189) = 564$;
$\Delta S^{\ominus}\ (= 564 - 738) = -174\ (\text{J K}^{-1}\ \text{mol}^{-1})$; *[3]*
ECF from reactants and products entropy.
Correct final answer scores [3] marks.
174 J K^{-1} mol^{-1} or +174 J K^{-1} mol^{-1} scores [2] marks.

(iii) sign should be negative because of increase in order/decrease in disorder; fewer moles of gas on right; *[2]*

(iv) $\Delta G^{\ominus} = -270 - (298 \times -0.174)$;
Mark is for correct use of $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ and unit conversion.

$= -218\ \text{kJ mol}^{-1}$ / kJ;

spontaneous because $\Delta G^{\ominus}$ negative; *[3]*

(c) *for first equation* $8 \times -394 / -3152$;
for second equation $9 \times -286 / -2574$;
for third equation $+5512$;
$\Delta H^{\ominus} = -214\ (\text{kJ or kJ mol}^{-1})$; *[4]*
No penalty for missing units, but penalize wrong units by –1(U).
Correct final answer award [4] marks.
All marks can be scored from enthalpy cycle.
Consider ECF for final mark.

(d) atomization / sublimation / vaporization **and** $K(s) \rightarrow K(g)$;
ionization / first ionization energy **and** $K(g) \rightarrow K^{+}(g) + e^{-}$;
atomization / $\frac{1}{2}$ bond enthalpy **and** $\frac{1}{2} F_2(g) \rightarrow F(g)$;
electron affinity **and** $F(g) + e^{-} \rightarrow F^{-}(g)$; *[4]*
No penalty for using e instead of e^{-}.
Penalize missing state symbols every time.

(e) (i) Na^{+} smaller (ion/radius) / greater charge density than K^{+}; *[1]*

(ii) Ca^{2+} larger ionic charge / greater charge density (compared to K^{+});
stronger electrostatic attraction / stronger attraction between ions; *[2]*
Allow second marking point in (e)(i) if not given in (e)(ii).

Q# 35/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/

6. (a) (i) $\Delta H^{\ominus} = [-394 + (-558)] - [-1219]$;
$= +267 (\text{kJ mol}^{-1})$;
$\Delta S^{\ominus} = [214 + 70] - [112]$;
$= +172\ (\text{JK}^{-1}\ \text{mol}^{-1})$;
$\Delta G^{\ominus} = 267 - (298)(0.172)$;
$= +216 (\text{kJ mol}^{-1})$; *[6]*

(ii) non-spontaneous as $\Delta G^{\ominus}$ is positive; *[1]*

(iii) $\Delta G = \text{O / T} = \dfrac{\Delta H^{\ominus}}{\Delta S^{\ominus}}$;
267/0.172;
1550 K/1552 K/1277 ° C/1279 ° C ;
the factor $\text{T}\Delta S^{\ominus}$ predominates and $\Delta G^{\ominus}$ becomes negative / $\text{T}\Delta S^{\ominus}$ must be greater than ΔH for $\Delta G^{\ominus}$ to be negative; *[4]*