Exercises

74 What signs of $\Delta H^{\ominus}_{reaction}$ and $\Delta S^{\ominus}_{reaction}$ for a reaction result in a complete reaction at all temperatures?

	$\Delta H^{\ominus}_{reaction}$	$\Delta S^{\ominus}_{reaction}$
A	–	–
B	+	–
C	–	+
D	+	+

75 Which conditions correspond to a system of equilibrium?

I The entropy of the system is at a maximum.
II The free energy of a system is at a minimum.
III $\Delta G^{\ominus}_{reaction} = 0$

A I and II only **B** I and III only **C** II and III only **D** I, II, and III

76 Which values correspond to a reaction that can be reversed by changing the temperature.

	$\Delta H^{\ominus}_{reaction}$	$\Delta S^{\ominus}_{reaction}$
I	–	–
II	+	–
III	+	+

A I and II only **B** I and III only **C** II and III only **D** I, II, and III

77 Propene reacts with hydrogen in the presence of a nickel catalyst to form propane.

$$C_3H_6(g) + H_2(g) \rightarrow C_3H_8(g)$$

$\Delta H^{\ominus}_{reaction} = -123\ kJ\ mol^{-1}$; $\Delta S^{\ominus}_{reaction} = -128\ J\ K\ mol^{-1}$

Estimate the temperature range in which a mixture of all three gases will be present.

78 The Haber process is an important process in which ammonia is formed from nitrogen and hydrogen:

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

$\Delta S^{\ominus}_{reaction} = -198\ J\ K^{-1}\ mol^{-1}$; $\Delta H^{\ominus}_{reaction} = -93\ J\ K^{-1}\ mol^{-1}$

Estimate the temperature range in which a mixture of all three gases will be present.

Practice questions

1 A pure aluminium block with a mass of 10 g is heated so that its temperature increases from 20 °C to 50 °C. The specific heat capacity of aluminium is $8.99 \times 10^{-1}\ J\ g^{-1}\ K^{-1}$. Which expression gives the heat energy change in kJ?

A $10 \times 8.99 \times 10^{-1} \times 303$

B $10 \times 8.99 \times 10^{-1} \times 30$

C $\dfrac{10 \times 8.99 \times 10^{-1} \times 303}{1000}$

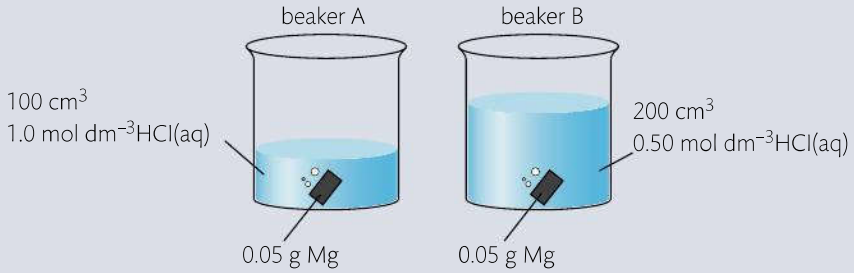
D $\dfrac{10 \times 8.99 \times 10^{-1} \times 30}{1000}$

2 Which processes have a negative enthalpy change?

I $2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(l)$
II $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
III $H_2O(g) \rightarrow H_2O(l)$

A I and II only **B** I and III only **C** II and III only **D** I, II, and III

3 Identical pieces of magnesium are added to two beakers, A and B, containing hydrochloric acid. Both acids have the same initial temperature but their volumes and concentrations differ.



Which statement is correct?

A The maximum temperature in A will be higher than in B.
B The maximum temperature in A and B will be equal.
C It is not possible to predict whether A or B will have the higher maximum temperature.
D The temperature in A and B will increase at the same rate.

4 Consider the following reactions.

$Cu_2O(s) + \frac{1}{2}O_2(g) \rightarrow 2CuO(s)$ $\Delta H^{\ominus} = -144$ kJ

$Cu_2O(s) \rightarrow Cu(s) + CuO(s)$ $\Delta H^{\ominus} = +11$ kJ

What is the value of $\Delta H^{\ominus}$, in kJ, for this reaction?

$$Cu(s) + \frac{1}{2}O_2(g) \rightarrow CuO(s)$$

A −144 + 11 **B** +144 − 11 **C** −144 − 11 **D** +144 + 11

5 Which equation best represents the bond enthalpy of HCl?

A $HCl(g) \rightarrow H^+(g) + Cl^-(g)$
B $HCl(g) \rightarrow H(g) + Cl(g)$
C $HCl(g) \rightarrow \frac{1}{2}H_2(g) + \frac{1}{2}Cl_2(g)$
D $2HCl(g) \rightarrow H_2(g) + Cl_2(g)$

6 Consider the equations below.

$CH_4(g) + O_2(g) \rightarrow HCHO(l) + H_2O(l)$ $\Delta H^{\ominus} = x$

$HCHO(l) + \frac{1}{2}O_2(g) \rightarrow HCOOH(l)$ $\Delta H^{\ominus} = y$

$2HCOOH(l) + \frac{1}{2}O_2(g) \rightarrow (COOH)_2(s) + H_2O(l)$ $\Delta H^{\ominus} = z$

What is the enthalpy change of the reaction below?

$$2CH_4(g) + 3\frac{1}{2}O_2(g) \rightarrow (COOH)_2(s) + 3H_2O(l)$$

A $x + y + z$ **B** $2x + y + z$ **C** $2x + 2y + z$ **D** $2x + 2y + 2z$

7 Which process represents the C–Cl bond enthalpy in tetrachloromethane?

A $CCl_4(g) \rightarrow C(g) + 4Cl(g)$
B $CCl_4(g) \rightarrow CCl_3(g) + Cl(g)$
C $CCl_4(l) \rightarrow C(g) + 4Cl(g)$
D $CCl_4(l) \rightarrow C(s) + 2Cl_2(g)$

8 What is the energy, in kJ, released when 1.00 mol of carbon monoxide is burned according to the following equation?

$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$ $\Delta H^{\ominus} = -564$ kJ

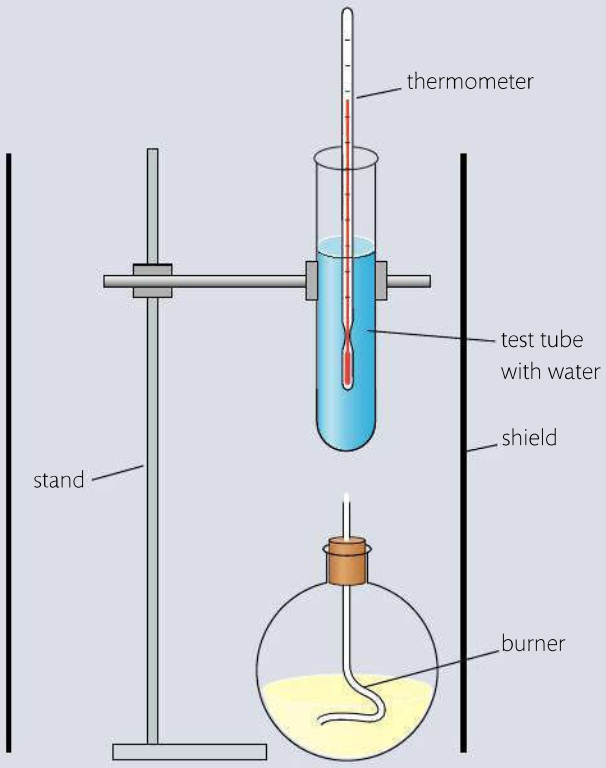
A 141 **B** 282 **C** 564 **D** 1128

9 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.

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

(a) Using the information from section 11 of the IB data booklet, determine the theoretical enthalpy of combustion of methanol. (3)

(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 1 mole 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)

(*Total 12 marks*)

10 The data below are from an experiment to measure the enthalpy change for the reaction of aqueous copper(II) sulfate, $CuSO_4(aq)$, and zinc, Zn(s).

$$Cu^{2+}(aq) + Zn(s) \rightarrow Cu(s) + Zn^{2+}(aq)$$

50.0 cm^3 of 1.00 mol dm^{-3} copper(II) sulfate solution was placed in a polystyrene cup and zinc powder was added after 100 seconds. The temperature–time data were taken from a data-logging software program. The table shows the initial 23 readings.

	A	B	C	D	E	F	G	H
1	time/s	temperature/°C						
2	0.0	24.8						
3	1.0	24.8						
4	2.0	24.8						
5	3.0	24.8						
6	4.0	24.8						
7	5.0	24.8						
8	6.0	24.8						
9	7.0	24.8						
10	8.0	24.8						
11	9.0	24.8						
12	10.0	24.8						
13	11.0	24.8						
14	12.0	24.8						
15	13.0	24.8						
16	14.0	24.8						
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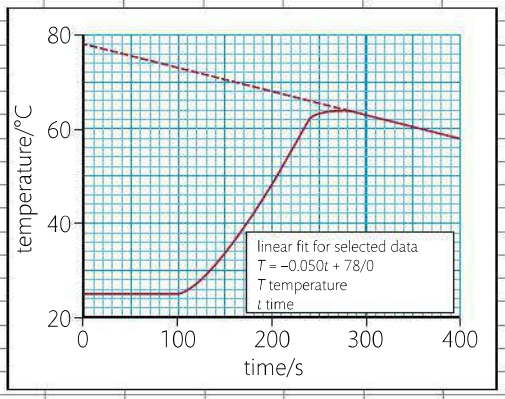


A straight line has been drawn through some of the data points. The equation for this line is given by the data-logging software as

$$T = -0.050t + 78.0$$

where T is the temperature at time t.

(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) State the assumption made in part (b)(i). (1)

(iii) 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)

(*Total 8 marks*)

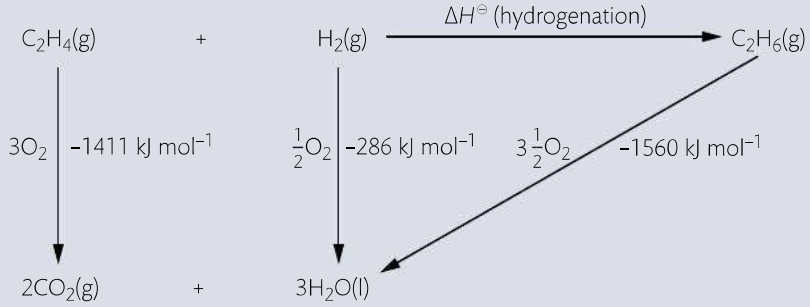
11 Two students were asked to use information from the data booklet to calculate a value for the enthalpy of hydrogenation of ethene to form ethane.

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

John used the average bond enthalpies from section 10. Marit used the values of enthalpies of combustion from section 13.

(a) Calculate the value for the enthalpy of hydrogenation of ethene obtained using the average bond enthalpies given in section 11. (2)

(b) Marit arranged the values she found in section 12 into an energy cycle.



Calculate the value for the enthalpy of hydrogenation of ethene from the energy cycle. (1)

(c) Suggest **one** reason why John's answer is slightly less accurate than Marit's answer. (1)

(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)

(*Total 7 marks*)

12 Hydrazine is a valuable rocket fuel. The equation for the reaction between hydrazine and oxygen is given below.

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

Use the bond enthalpy values from section 10 of the data booklet to determine the enthalpy change for this reaction. (3)

13 The following reactions take place in the ozone layer by the absorption of ultraviolet light.

I $O_3 \rightarrow O_2 + O\bullet$

II $O_2 \rightarrow O\bullet + O\bullet$

State and explain, by reference to the bonding, which of the reactions, I or II, requires a shorter wavelength. (2)

14 Which ionic compound has the greatest lattice enthalpy?

A MgO **B** CaO **C** NaF **D** KF

15 Which step(s) is/are endothermic in the Born–Haber cycle for the formation of LiCl?

A $\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$ and $Li(s) \rightarrow Li(g)$
B $Cl(g) + e^- \rightarrow Cl^-(g)$ and $Li(g) \rightarrow Li^+(g) + e^-$
C $Li^+(g) + Cl^-(g) \rightarrow LiCl(s)$
D $\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$ and $Cl(g) + e^- \rightarrow Cl^-(g)$

16 Which reaction has the greatest increase in entropy?

A $SO_2(g) + 2H_2S(g) \rightarrow 2H_2O(l) + 3S(s)$
B $CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$
C $CaC_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(s) + C_2H_2(g)$
D $N_2(g) + O_2(g) \rightarrow 2NO(g)$

17 Which change will **not** increase the entropy of a system?

A increasing the temperature
B changing the state from liquid to gas
C mixing different types of particles
D a reaction where four moles of gaseous reactants changes to two moles of gaseous products

18 What is the standard free energy change, $\Delta G^\ominus$, in kJ, for the following reaction?

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$

Compound	$\Delta G_f^\ominus$ / kJ mol^{-1}
$C_2H_5OH(l)$	–175
$CO_2(g)$	–394
$H_2O(g)$	–229
$O_2(g)$	0

A –1650 **B** –1300 **C** –448 **D** +1300

19 What is the standard entropy change, $\Delta S^\ominus$, for the following reaction?

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

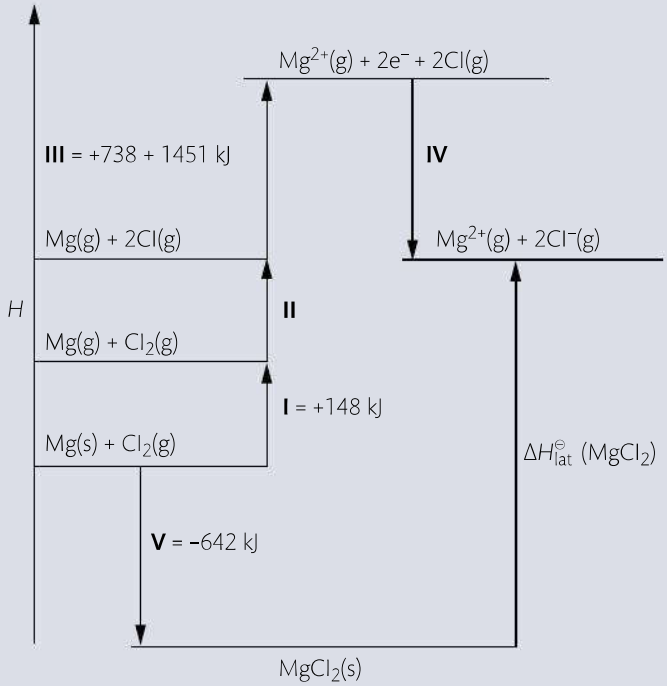
	$CO(g)$	$O_2(g)$	$CO_2(g)$
$S^\ominus$ / J K^{-1} mol^{-1}	198	205	214

A –189 **B** –173 **C** +173 **D** +189

20 A reaction has a standard enthalpy change, $\Delta H^\ominus$, of +10.00 kJ mol^{-1} at 298 K. The standard entropy change, $\Delta S^\ominus$, for the same reaction is +10.00 J K^{-1} mol^{-1}. What is the value of $\Delta G^\ominus$ for the reaction in kJ mol^{-1}?

A +9.75 **B** +7.02 **C** –240 **D** –2970

21 The lattice enthalpy of magnesium chloride can be calculated from the Born–Haber cycle shown below.



(a) Identify the enthalpy changes labelled **I** and **V** in the cycle. (2)

(b) 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)

(c) The theoretically calculated value for the lattice enthalpy of magnesium chloride is +2326 kJ. Explain the difference between the theoretically calculated value and the experimental value. (2)

(d) The experimental lattice enthalpy of magnesium oxide is given in section 18 of the data booklet. Explain why magnesium oxide has a higher lattice enthalpy than magnesium chloride. (2)

(Total 10 marks)