# R1.1 Measuring enthalpy changes

■ Paper 1

1 Which of the following must have a negative value for a reaction to be exothermic?

  A enthalpy change

  B entropy change

  C equilibrium constant

  D standard cell potential

2 Which of the following reactions would you expect to have the most exothermic enthalpy change?

  A CH_4 (l) + $2O_2$ (l) → CO_2 (g) + $2H_2O$ (g)

  B CH_4 (l) + $2O_2$ (g) → CO_2 (g) + $2H_2O$ (g)

  C CH_4 (g) + $2O_2$ (g) → CO_2 (g) + $2H_2O$ (g)

  D CH_4 (g) + $2O_2$ (g) → CO_2 (g) + $2H_2O$ (l)

3 A temperature change of 6.4 °C is measured when adding 5.0 cm³ of 1.0 mol dm⁻³ hydrochloric acid to 5.0 cm³ of 1.0 mol dm⁻³ potassium hydroxide. Both solutions had the same initial temperature. For the resulting mixture assume the density is 1.0 g cm⁻³ and the specific heat capacity is 4.18 J g⁻¹ K⁻¹.

What is the change in enthalpy of the reaction in kJ mol⁻¹?

  A $\Delta H^{\ominus} = -\dfrac{10 \times 4.18 \times 6.4}{1.0 \times 0.005}$

  B $\Delta H^{\ominus} = -\dfrac{10 \times 4.18 \times 6.4}{1.0 \times 0.005 \times 2}$

  C $\Delta H^{\ominus} = -\dfrac{10 \times 4.18 \times 6.4}{1.0 \times 0.005 \times 1000}$

  D $\Delta H^{\ominus} = -\dfrac{10 \times 4.18 \times 6.4}{1.0 \times 0.005 \times 2 \times 1000}$

4 When equal masses of X and Y absorb the same amount of heat energy, their temperatures rise by 5 °C and 10 °C respectively. Which is correct?

  A The specific heat capacity of X is twice that of Y.

  B The specific heat capacity of X is half that of Y.

  C The specific heat capacity of X is one fifth that of Y.

  D The specific heat capacity of X is the same as Y.

5 The potential energy profile of a reaction is shown.
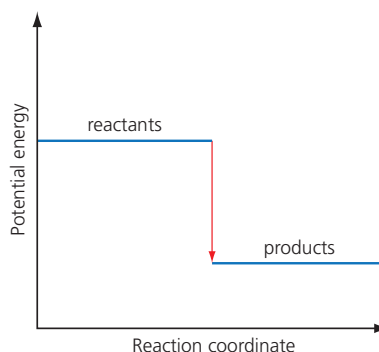
What can be determined about stability and energy change from the potential energy profile shown?

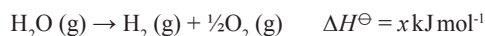|	More stable	Reaction
A	reactants	exothermic
B	reactants	endothermic
C	products	exothermic
D	products	endothermic

6 A sample of an ideal gas is cooled by 20 K. Which of the following is always true?

  A The gas has increased its volume at constant pressure.

  B The particles have less average kinetic energy.

  C The gas has condensed into a liquid.

  D The pressure of the gas has increased at constant volume.

7 The table shows the specific heat capacities of four metals.

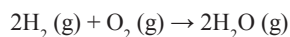| Metal	Specific heat capacity (J g⁻¹ K⁻¹)
copper	0.385
magnesium	1.02
mercury	0.138
lead	0.129

If 100 kJ of heat energy is absorbed by 10.0 g samples of each of the metals above, which are all at 25 °C, which metal will have the lowest temperature?

  A copper

  B magnesium

  C mercury

  D lead

8 Consider the following reaction.

$$H_2O\,(g) \rightarrow H_2\,(g) + \tfrac{1}{2}O_2\,(g) \qquad \Delta H^{\ominus} = x\,kJ\,mol^{-1}$$

What is the enthalpy change of:

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

A $\Delta H^{\ominus} = -x\,kJ\,mol^{-1}$

B $\Delta H^{\ominus} = 2x\,kJ\,mol^{-1}$

C $\Delta H^{\ominus} = -\tfrac{1}{2}x\,kJ\,mol^{-1}$

D $\Delta H^{\ominus} = -2x\,kJ\,mol^{-1}$

9 Which change of state is exothermic?

A $CO_2(s) \rightarrow CO_2(g)$

B $H_2O(l) \rightarrow H_2O(g)$

C $NH_3(g) \rightarrow NH_3(l)$

D $Fe(s) \rightarrow Fe(l)$

10 When $25.0\,cm^3$ $0.100\,mol\,dm^{-3}$ NaOH (aq) is mixed with $25.0\,cm^3$ $0.100\,mol\,dm^{-3}$ HCl (aq) at the same temperature, a temperature rise, ΔT, is recorded. What is the expression, in $kJ\,mol^{-1}$, for the enthalpy of neutralization? (Assume the density of the mixture $= 1.00\,g\,cm^{-3}$ and its specific heat capacity $= 4.18\,kJ\,kg^{-1}K^{-1}$.)

A $-\dfrac{25.0 \times 4.18 \times \Delta T}{50.0 \times 0.100}$

B $-\dfrac{25.0 \times 4.18 \times \Delta T}{25.0 \times 0.100}$

C $-\dfrac{50.0 \times 4.18 \times \Delta T}{50.0 \times 0.100}$

D $-\dfrac{50.0 \times 4.18 \times \Delta T}{25.0 \times 0.100}$

11 Which statement is correct for this reaction?

$$Fe_2O_3\,(s) + 3CO\,(g) \rightarrow 2Fe\,(s) + 3CO_2\,(g) \quad \Delta H^{\ominus} = -26.6\,kJ$$

A 13.3 kJ are released for every mole of Fe produced.

B 26.6 kJ are absorbed for every mole of Fe produced.

C 53.2 kJ are released for every mole of Fe produced.

D 26.6 kJ are released for every mole of Fe produced.

12 Which expression gives the mass, in g, of ethanol required to produce 683.5 kJ of heat upon complete combustion? (molar mass for ethanol $= 46.0\,g\,mol^{-1}$)

$$C_2H_5OH\,(l) + 3O_2\,(g) \circledR 2CO_2\,(g) + 3H_2O\,(l)$$
$$\Delta H^{\ominus} = -1367\,kJ\,mol^{-1}$$
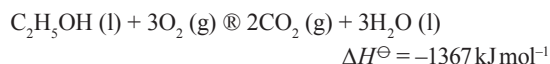
A $\dfrac{683.5}{1367 \times 46.0}$

B $\dfrac{1367}{683.5 \times 46.0}$

C $\dfrac{683.5 \times 46.0}{1367}$

D $\dfrac{1367 \times 46.0}{683.5}$

13 Which of the following is true for all endothermic reactions?

A The reaction has a negative enthalpy change.

B The reaction occurs slowly.

C There is a transfer of energy from the surroundings to the system.

D The surroundings will increase in temperature.

14 Which of the following is not implied by the $\ominus$ symbol?

A reacting 1 mole of a compound

B gas pressure of 1 bar or 10^5 pascal

C the most stable allotrope under standard conditions

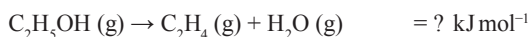D concentration of $1.0\,mol\,dm^{-3}$ (for solutions).

15 400 J of energy is transferred to two 1 kg blocks of different metals. One block of metal is made from copper and the other aluminium. The specific heat capacities of copper and aluminium are different. Which of the following statements is true?

A The blocks will increase in temperature by the same amount.

B The blocks will decrease in temperature by the same amount.

C The block with the highest specific heat capacity will have the largest temperature increase.

D The block with the lowest specific heat capacity will have the largest temperature increase.

16 Consider the following reaction.

$$2C_2H_4\,(g) + 2H_2O\,(g) \rightarrow 2C_2H_5OH\,(g) = y\,kJ\,mol^{-1}$$
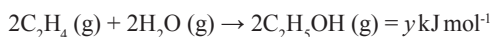
What will the enthalpy change of this reaction be?

$$C_2H_5OH\,(g) \rightarrow C_2H_4\,(g) + H_2O\,(g) \qquad = ?\ kJ\,mol^{-1}$$

A $+\tfrac{1}{2}y$ B $-\tfrac{1}{2}y$ C $-y$ D $+y$

■ Paper 2

1 a Explain what is meant by the term *standard enthalpy of reaction*. [3]

    b Describe an experiment to determine the enthalpy change of the reaction between dilute hydrochloric acid and aqueous sodium hydroxide. Show how the value of would be calculated from the data obtained. [9]

2 In aqueous solution, lithium hydroxide and hydrochloric acid react as follows.

$$LiOH\,(aq) + HCl\,(aq) \rightarrow LiCl\,(aq) + H_2O\,(l)$$
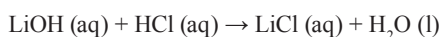
The data below is from an experiment to determine the standard enthalpy change of this reaction.

50.0 cm³ of a 0.500 mol dm⁻³ solution of LiOH was mixed rapidly in a glass beaker with 50.0 cm³ of a 0.500 mol dm⁻³ solution of HCl.

Initial temperature of each solution = 20.6 °C

Final temperature of the mixture = 24.1 °C

a   State, with a reason, whether the reaction is exothermic or endothermic.   [1]

b   Explain why the solutions were mixed rapidly.   [1]

c   Calculate the enthalpy change of this reaction in kJ mol⁻¹. Assume that the specific heat capacity of the solution is the same as that of water.   [4]

d   Identify the major source of error in the experimental procedure described above. Explain how it could be minimized.   [2]

e   The experiment was repeated but with an HCl concentration of 0.520 mol dm⁻³ instead of 0.500 mol dm⁻³. State and explain what the temperature change would be.   [2]

3   The data below is from an experiment used to measure the enthalpy change for the combustion of sucrose (common table sugar), $C_{12}H_{22}O_{11}$ (s). The time–temperature data was taken from a data-logging software program.

Plot of T versus t
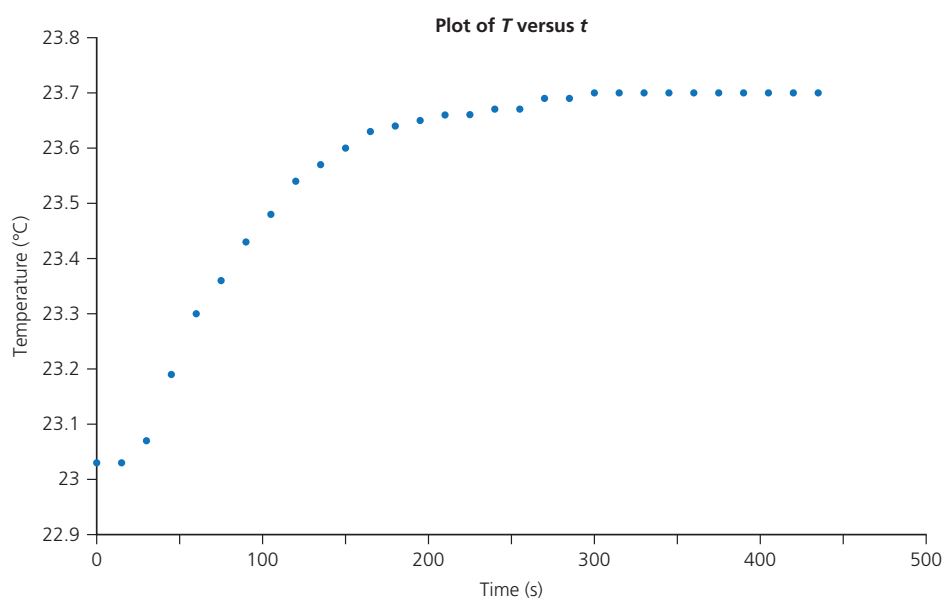
Mass of sample of sucrose, m = 0.4835 g

Heat capacity of the system, C_{system} = 10.114 kJ K⁻¹

a   Calculate ΔT for the water surrounding the chamber in the calorimeter.   [1]

b   Determine the amount, in moles, of sucrose.   [1]

c   i)   Calculate the enthalpy change for the combustion of 1 mole of sucrose.   [2]

    ii)   The literature value for the combustion of sucrose is −5.6 × 10³ kJ mol⁻¹. Calculate the percentage error in your calculated value.   [1]

d   A hypothesis is suggested that TNT, 2-methyl-1,3,5-trinitrobenzene, is a powerful explosive because it has:

–   a large enthalpy of combustion

–   a high reaction rate

–   a large volume of gas generated upon combustion.

Use you answer in part (c)(i) and the following data to evaluate this hypothesis.   [3]

Equation for combustion	Relative rate of combustion	Enthalpy of combustion / kJ mol⁻¹
$C_{12}H_{22}O_{11}$ (s) + 12O₂ (g) → 12CO₂ (g) + 11H₂O (g)	low	−5600
2C₇H₅N₃O₆ (s) → 7CO₂(g) + 7C (s) + 5H₂O (g) + 3N₂ (g)	high	−3406

Higher Level Paper 2, IB Specimen Paper 2009, Section A, Q1

R1.2 Energy cycles in reactions

■ Paper 1

1 Which change of state is exothermic?

- **A** CO_2 (s) → CO_2 (g)
- **B** H_2O (l) → H_2O (g)
- **C** NH_3 (g) → NH_3 (l)
- **D** Fe(s) → Fe(l)

2 The C=C bond has a bond length of 134 pm and an average bond enthalpy of 614 kJ mol^{-1}. Which values would be most likely for the C–C bond?

	Bond length / pm	Average bond enthalpy / kJ mol^{-1}
A	154	346
B	154	780
C	116	346
D	116	780

3 Which equation represents the average bond enthalpy of the C−H bond in CH_4?

- **A** CH_4 (g) → CH_3 (g)+H (g)
- **B** $\frac{1}{4}CH_4$ (g) → $\frac{1}{4}C$ (g) + H (g)
- **C** CH_4 (g) → CH_3 (g) + $\frac{1}{2}H_2$ (g)
- **D** CH_4 (g) → C (g) + 4H (g)

4 Which statement is correct for this reaction

Fe_2O_3 (s) + 3CO (g) → 2Fe (s) + 3CO_2 (g) $\Delta H = -26.6$ kJ

- **A** 53.2 kJ are released for every mole of Fe produced.
- **B** 26.6 kJ are absorbed for every mole of Fe produced.
- **C** 13.3 kJ are released for every mole of Fe produced.
- **D** 26.6 kJ are released for every mole of Fe produced.

5 The enthalpy changes for two reactions are:

Br_2 (l) + F_2 (g) → 2BrF (g) $\Delta H = m$ kJ

Br_2 (l) + 3F_2 (g) → 2BrF_3 (g) $\Delta H = n$ kJ

What is the enthalpy change for the following reaction?

BrF_3 (g) → BrF (g) + F_2 (g)

- **A** $m - n$
- **B** $-m + n$
- **C** $\frac{1}{2}(-m + n)$
- **D** $\frac{1}{2}(m - n)$

6 What is the enthalpy change, in kJ mol^{-1}, of the following reaction?

$3H_2$ (g) + N_2 (g) ⇌ 2NH_3 (g)

Bond	Bond enthalpy / kJ mol^{-1}
N≡N	945
H–H	436
N–H	391

- **A** $(6 \times 391) - [(3 \times 436) + 945]$
- **B** $(3 \times 391) - (436 + 945)$
- **C** $-[(3 \times 436) + 945] + (3 \times 391)$
- **D** $-(6 \times 391) + [(3 \times 436) + 945]$

7 Which expression gives the enthalpy change, ΔH, for the thermal decomposition of calcium carbonate?

$CaCO_3$ (s) + 2HCl → $CaCl_2$ (aq) + H_2O (l) + CO_2 (g) ΔH_1

CaO (s) + 2HCl → $CaCl_2$ (aq) + H_2O (l) ΔH_2

- **A** $\Delta H = \Delta H_1 - \Delta H_2$
- **B** $\Delta H = 2\Delta H_1 - \Delta H_2$
- **C** $\Delta H = \Delta H_1 - 2\Delta H_2$
- **D** $\Delta H = \Delta H_1 + \Delta H_2$

8 In which order does the oxygen–oxygen bond enthalpy increase?

- **A** $H_2O_2 < O_2 < O_3$
- **B** $H_2O_2 < O_3 < O_2$
- **C** $O_2 < O_3 < H_2O_2$
- **D** $O_3 < H_2O_2 < O_2$

9 Which combination will give you the enthalpy change for the hydrogenation of ethene to ethane, ΔH_3?

2C (s) + 3H_2 (g) $\xrightarrow{\Delta H_2}$ C_2H_4 (g) + H_2 (g) $\xrightarrow{\Delta H_3}$ C_2H_6 (g)

ΔH_1 +2O_2 (g) ΔH_4 +2O_2 (g)

2CO_2 (g) + 3H_2 (g)

- **A** $\Delta H_2 + \Delta H_1 - \Delta H_4$
- **B** $\Delta H_2 - \Delta H_4 + \Delta H_1$
- **C** $-\Delta H_2 + \Delta H_1 - \Delta H_4$
- **D** $-\Delta H_2 - \Delta H_1 + \Delta H_4$

(Questions 10–17 HL only)

10 Hydrazine reacts with oxygen.

$$N_2H_4 \text{ (l)} + O_2 \text{ (g)} \rightarrow N_2 \text{ (g)} + 2H_2O \text{ (l)}$$
$$\Delta H^\ominus = -623 \text{ kJ mol}^{-1}$$
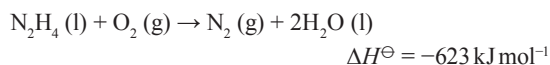
What is the standard enthalpy of formation of N_2H_4 (l) in kJ mol^{-1}? The standard enthalpy of formation of H_2O (l) is -286 kJ.

A $-623 - 286$

B $-623 + 572$

C $-572 + 623$

D $-286 + 623$

11 What is the enthalpy of combustion of urea, $(NH_2)_2CO$, in kJ mol^{-1}?

$$CO(NH_2)_2 \text{ (s)} + \frac{3}{2}O_2 \text{ (g)} \rightarrow CO_2 \text{ (g)} + N_2 \text{ (g)} + 2H_2O \text{ (l)}$$
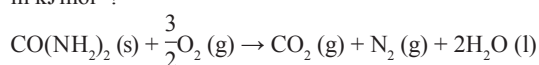
	$\Delta H_f^\ominus$ / kJ mol^{-1}
CO_2 (g)	-394
$CO(NH_2)_2$ (s)	-333
H_2O (l)	-286

A $(-333) - (-394) - 2 \times (-286)$

B $(-394) + 2 \times (-286) - \frac{3}{2} \times (-333)]$

C $(-394) + 2 \times (-286) + (-333)$
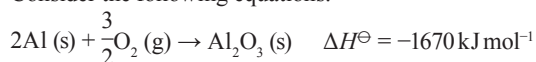
D $(-394) + 2 \times (-286) - (-333)$
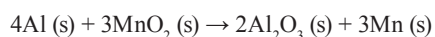
12 What is the enthalpy change of the reaction?

$$C_6H_{14} \text{ (l)} \rightarrow C_2H_4 \text{ (g)} + C_4H_{10} \text{ (g)}$$
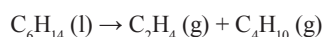
	$\Delta H_c^\ominus$ / kJ mol^{-1}
C_6H_{14} (l)	-4163
C_2H_4 (g)	-1411
C_4H_{10} (g)	-2878

A $+ 1411 + 2878 + 4163$

B $+ 1411 - 2878 - 4163$

C $+ 1411 + 2878 - 4163$

D $- 1411 - 2878 + 4163$

13 Consider the following equations:

$$2Al \text{ (s)} + \frac{3}{2}O_2 \text{ (g)} \rightarrow Al_2O_3 \text{ (s)} \quad \Delta H^\ominus = -1670 \text{ kJ mol}^{-1}$$

$$Mn \text{ (s)} + O_2 \text{ (g)} \rightarrow MnO_2 \text{ (s)} \quad \Delta H^\ominus = -520 \text{ kJ mol}^{-1}$$
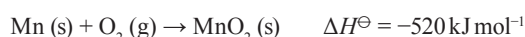
What is the standard enthalpy change, in kJ mol^{-1}, of the reaction below?

$$4Al \text{ (s)} + 3MnO_2 \text{ (s)} \rightarrow 2Al_2O_3 \text{ (s)} + 3Mn \text{ (s)}$$

A $-1670 + 520$

B $(\frac{3}{2} \times -1670) + (3 \times 520)$

C $(2 \times -1670) + (3 \times -520)$

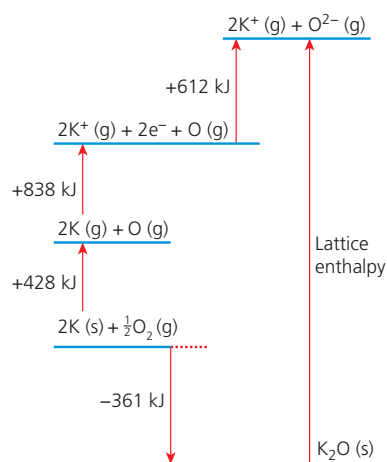**D** $(2 \times -1670) - (3 \times -520)$

14 Which equation shows the enthalpy of formation, $\Delta H_f^\ominus$, of ethanol?

A $2C \text{ (s)} + 3H_2 \text{ (g)} + \frac{1}{2}O_2 \text{ (g)} \rightarrow C_2H_5OH \text{ (g)}$

B $4C \text{ (s)} + 6H_2 \text{ (g)} + O_2 \text{ (g)} \rightarrow 2C_2H_5OH \text{ (g)}$

C $2C \text{ (s)} + 3H_2 \text{ (g)} + \frac{1}{2}O_2 \text{ (g)} \rightarrow C_2H_5OH \text{ (l)}$

D $4C \text{ (s)} + 6H_2 \text{ (g)} + O_2 \text{ (g)} \rightarrow 2C_2H_5OH \text{ (l)}$

15 Which ionic compound has the largest value of lattice enthalpy?
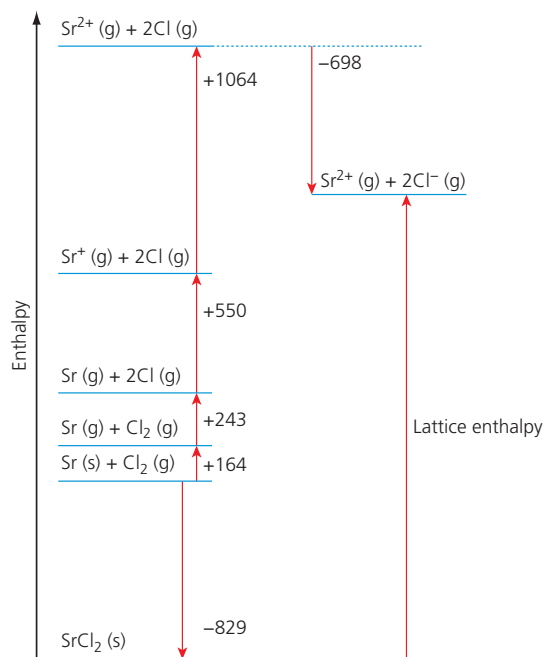
A MgS

B MgO

C $CaBr_2$

D NaF

16 The Born–Haber cycle for potassium oxide is shown below:

Which expression represents the lattice enthalpy in kJ mol^{-1}?

A $-361 + 428 + 838 + 612$

B $-(-361) + 428 + 838 + 612$

C $-361 + 428 + 838 - 612$

D $-(-361) + 428 + 838 - 612$

17 Which value represents the lattice enthalpy, in $kJ\,mol^{-1}$, of strontium chloride, $SrCl_2$?


A $-(-829) + 164 + 243 + 550 + 1064 - (-698)$

B $-829 + 164 + 243 + 550 + 1064 - 698$

C $-(-829) + 164 + 243 + 550 + 1064 - 698$

D $-829 + 164 + 243 + 550 + 1064 - (-698)$

■ Paper 2

1 In December 2010, researchers in Sweden announced the synthesis of N,N-dinitronitramide, $N(NO_2)_3$. They speculated that this compound, more commonly called trinitramide, may have significant potential as an environmentally friendly rocket fuel oxidant.

a Methanol reacts with trinitramide to form nitrogen, carbon dioxide and water. Deduce the coefficients required to balance the equation for this reaction.

$\_\_\ N(NO_2)_3\ (g) + \_\_\ CH_3OH\ (l) \rightarrow \_\_\ N_2\ (g) + \_\_\ CO_2\ (g) + \_\_\ H_2O\ (l)$ [1]
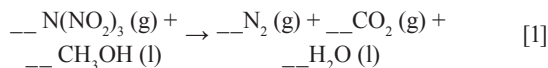
b Suggest **one** reason why trinitramide might be more environmentally friendly than other rocket fuel oxidants such as ammonium perchlorate (NH_4ClO_4). [1]

c Calculate the enthalpy change, in $kJ\,mol^{-1}$, when one mole of trinitramide decomposes to its elements, using bond enthalpies from section 12 of the data booklet. Assume that all the N–O bonds in this molecule have a bond enthalpy of $305\,kJ\,mol^{-1}$. [3]

Standard Level Paper 2, Time Zone 0, November 2013, Q4a–c

2 In the gas phase, A reacts with hydrogen to form D.
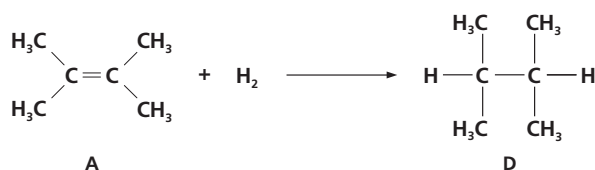
a Use bond enthalpies given in section 12 of the IB Chemistry data booklet to determine the enthalpy change, in $kJ\,mol^{-1}$, of the reaction. State whether the reaction is exothermic or endothermic. [4]

b The standard enthalpy change of combustion of A is $-4000\,kJ\,mol^{-1}$. Calculate the amount of A, in mol, that would have to be burned to raise the temperature of $1\,dm^3$ of water from $20\,°C$ to $100\,°C$. [2]

Standard Level Paper 2, Time Zone 2, May 2014, Q6g(iii–iv)

(Questions 3–4 HL only)

3 Ethanol, C_2H_5OH, has many industrial uses.

   a Define the term average bond enthalpy. [1]

   b Ethanol can be used as a fuel. Determine the enthalpy of combustion of ethanol at 298 K, in $kJ\,mol^{-1}$, using the values given in section 13 of the *IB Chemistry data booklet*, assuming all reactants and products are gaseous. [4]

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

   d 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 section 13 of the *IB Chemistry data booklet*. [4]

   Higher Level Paper 2, Time Zone 1, May 2015, Q5b(i–ii), c, f(i)

4 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 this table.
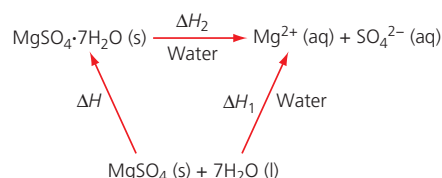
Mass of anhydrous magnesium sulfate / g	3.01
volume of water / cm³	50.0
initial temperature / °C	17.0
highest temperature / °C	26.7

   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, $MgSO_4\cdot7H_2O$ (s), and 50 cm³ of water. They found the enthalpy change, ΔH_2, to be $+18\,kJ\,mol^{-1}$.

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

$MgSO_4\cdot7H_2O$ (s) $\xrightarrow[\text{Water}]{\Delta H_2}$ Mg^{2+} (aq) + SO_4^{2-} (aq)

ΔH ΔH_1 / Water

$MgSO_4$ (s) + $7H_2O$ (l)

   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 result, giving your answer to **one** decimal place. (If you did not obtain an answer for the experimental value in (c) i), then use a 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]

   Higher Level Paper 2, Time Zone 1, May 2014, Q1a–c

R1.3 Energy from fuels

■ Paper 1

1 Which of the following is produced during the complete combustion of a hydrocarbon?

  A C

  B CO_2

  C CO

  D H_2

2 When 11 g of an organic compound is burnt in an excess of oxygen, 22 g of carbon dioxide and 9.0 g of water are produced as the only products of combustion. What is the empirical formula of the organic compound?

  A CH_2O

  B CH_2

  C C_4H_7O

  D C_2H_4O

3 Which of the following compounds is most likely to have some incomplete combustion when burnt in oxygen?

  A C_2H_5OH

  B CH_3OH

  C $C_6H_5CH_3$

  D C_3H_8

4 What is the reducing agent in the combustion of glucose $(C_6H_{12}O_6)$?

  A O_2

  B CO_2

  C $C_6H_{12}O_6$

  D H_2

5 Which of the following is not a greenhouse gas?

  A CH_4

  B N_2

  C CO_2

  D H_2O

6 Which of the following is correct?

	CO$_2$ absorbs radiation in the	CO$_2$ contributes to	CO$_2$ is a product of
A	UV region	the greenhouse effect	fermentation
B	IR region	acid rain	photosynthesis
C	IR region	the greenhouse effect	photosynthesis
D	IR region	the greenhouse effect	fermentation

7 A balloon is filled with 200 cm³ of a hydrocarbon mixture. The hydrocarbon mixture consists of 25% ethane and 75% propane. What is the minimum volume of pure oxygen needed for complete combustion?

  A 925 cm³

  B 1000 cm³

  C 650 cm³

  D 700 cm³

8 This question is about two fossil fuels, natural gas and coal. Select the row which shows the correct answers.

	Produces the most CO$_2$ per gram of fuel burnt	Releases the most energy per gram of fuel burnt
A	natural gas	coal
B	natural gas	natural gas
C	coal	natural gas
D	coal	coal

9 Which statement is false?

  A Ethanol has a lower specific energy (energy content per gram) than gasoline.

  B Ethanol is a biofuel that reduces the demand for gasoline.

  C Biofuels are renewable energy sources.

  D Biofuels are carbon neutral.

10 The hydrocarbon C_4H_8 was burnt in air. Incomplete combustion occurred. Which equation, A, B, C or D, correctly represents an incomplete combustion reaction?

  A $C_4H_8 + 4O \rightarrow 4CO + 4H_2$

  B $C_4H_8 + 4O_2 \rightarrow 4CO + 4H_2O$

  C $C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$

  D $C_4H_8 + 8O \rightarrow 4CO_2 + 4H_2$

11 Which statement about diesel and biodiesel is correct?

  A Diesel consists of long-chain hydrocarbons; biodiesel contains benzene and its derivatives.

  B Diesel has greater viscosity and hence flows more slowly along fuel lines than biodiesel.

  C Diesel emits soot (small carbon particles) when burning is incomplete; biodiesel does not produce any harmful emissions when burnt.

  D Diesel is produced by distilling crude oil; biodiesel is produced by transesterification of oils in plants.

12 Which of these is not a disadvantage of using a hydrogen–oxygen fuel cell?

A very low efficiency

B fuel storage can be problematic

C needs constant supply of fuel

D expensive metals are needed on the electrodes

■ Paper 2

1 In recent years, there has been worldwide interest in the extraction of 'shale gas' (mainly methane) as an important energy source.

The table shows the percentage composition of shale gas from one source.

Percentage composition				
CH_4	C_2H_x	C_3H_y	CO_2	N_2
88.0	0.8	0.7	10.4	0.1

In the general chemical formulas above, x and y are variables.

a Draw the structures (cyclic and/or non-cyclic) of four possible compounds with the formula C_3H_y. [2]

b Suggest a chemical method by which carbon dioxide could be removed from shale gas. [1]

The table shows a comparison of the specific energy content of shale gas, fuel oil (burnt in ships and furnaces) and coal.

	Shale gas	Fuel oil	Coal
Specific energy / $kJ\,g^{-1}$		42	33
Relative volume of CO_2 formed per kJ released	117	164	208

c i The enthalpy change of combustion of methane is $\Delta_cH^\ominus = -891\,kJ\,mol^{-1}$. Calculate the specific energy of methane. [1]

ii State and explain whether the specific energy of untreated shale gas will be lower or higher than that of methane. [1]

d Suggest why shale gas produces the smallest amount of carbon dioxide for ever kiloJoule (kJ) of energy released [1]

2 Ethanol is an example of a biofuel used in place of gasoline.

a State two advantages and two disadvantages associated with the use of ethanol as a biofuel. [4]

The table shows some information about some alcohols and the amount of heat energy released when one mole of each alcohol is completely burnt in oxygen.

Alcohols	Molecular formula	Energy released / $kJ\,mol^{-1}$	Density $g\,cm^{-3}$
methanol	CH_3OH	726	0.793
ethanol	C_2H_5OH	1367	0.789
propan-1-ol	C_3H_7OH	2021	0.804
butan-1-ol	C_4H_9OH	2676	0.810

b Write a chemical equation for the complete combustion of butan-1-ol. [1]

c Sandro suggests that filling a car's fuel tank with butan-1-ol instead of methanol would mean there is more than 3 times the chemical energy in the tank. Explain why his statement is incorrect. [1]

d Ethanol and gasoline have different physical and chemical properties. When $1.00\,dm^3$ of petrol is burnt completely in air, $38\,000\,kJ$ of energy is released. Using the data from the table, calculate the amount of energy released when $1.00\,dm^3$ of ethanol is burnt completely in air given that the density of ethanol is $0.780\,g\,cm^{-3}$. [3]

3 a Methanol can be used directly as a fuel in fuel cells. State the half equations for the redox reactions occurring at the anode and cathode in a methanol–oxygen fuel cell. [2]

Propan-2-ol is another alcohol which can act as a fuel in a fuel cell. In an analogous process to methanol, propan-2-ol is oxidized to carbon dioxide and hydrogen ions, and the hydrogen ions move through the electrolyte to react with oxygen to produce water.

b Suggest half equations for the reactions occurring at the electrodes in a propan-2-ol fuel cell, and hence deduce the equation for the overall reaction. [3]

c State one advantage a propan-2-ol fuel cell will have over a hydrogen fuel cell. [1]

4 Intercontinental jet airlines use kerosene as fuel. The formula of kerosene may be taken as $C_{14}H_{30}$.

a State the homologous series kerosene belongs to. [1]

The flight path from Singapore to London is approximately $10\,700\,km$. a typical intercontinental jet airliner burns $10.8\,kg$ of kerosene for each kilometre covered.

b i Calculate the mass, in tonnes, of $C_{14}H_{30}$ burnt on a flight from Singapore to London. [1 tonne = 1000 kg] [1]

ii Calculate the mass of carbon dioxide, CO_2, produced during this flight. [2]
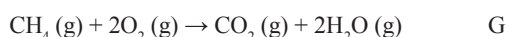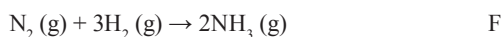
R1.4 Entropy and spontaneity (HL)

Paper 1

1 When barium hydroxide and ammonium thiocyanate powders are stirred together with a thermometer, the chemical reaction between them causes the temperature to drop from room temperature to below the freezing point of water.

Which row of the table describes the entropy changes involved?

	ΔS_{system}	$\Delta S_{surroundings}$	ΔS_{total}
A	increase	increase	decrease
B	increase	decrease	increase
C	decrease	increase	increase
D	decrease	decrease	decrease

2 Consider the following reactions in the gas phase:

N_2 (g) + $3H_2$ (g) → $2NH_3$ (g)   F

CH_4 (g) + $2O_2$ (g) → CO_2 (g) + $2H_2O$ (g)   G

C_2H_6 (g) + $3\frac{1}{2}O_2$ (g) → $2CO_2$ (g) + $3H_2O$ (g)   H

What is the order of increasing standard entropy change, ΔS, for these reactions, with the most negative first?

A F,G,H

B F,H,G

C G,H,F

D H,G,F

3 The overall chemical equation for the electrolysis of dilute sulfuric acid using inert electrodes is shown below.

$2H_2O$ (l) → $2H_2$ (g) + O_2 (g)

Which row of the table gives the correct sign for each property of the reaction?

	$\Delta H^{\ominus}$	$\Delta S^{\ominus}$	$\Delta G^{\ominus}$
A	−	+	+
B	+	−	−
C	−	−	−
D	+	+	+

4 Which reaction has the greatest increase in entropy?

A $Pb(NO_3)_2$ (aq) + 2KCl (aq) → $PbCl_2$ (s) + $2KNO_3$ (aq)

B $SrCO_3$ (s) → SrO (s) + CO_2 (g)

C $3H_2$ (g) + N_2 (g) → $2NH_3$ (g)

D H_2 (g) + I_2 (g) → 2HI (g)

5 Which row of the table corresponds to a system at equilibrium?

	Entropy	Gibbs energy
A	maximum	maximum
B	maximum	minimum
C	minimum	maximum
D	minimum	minimum

6 Which reaction has the greatest increase in the entropy of the system?

A HI (g) + NH_3 (g) → NH_4I (s)

B $(NH_4)_2Cr_2O_7$ (s) → Cr_2O_3 (s) + N_2 (g) + $4H_2O$ (g)

C H_2O (g) → H_2O (s)

D $ZnCO_3$ (s) → ZnO (s) + CO_2 (g)

7 What are the signs for the entropy changes associated with vaporization of water?

H_2O (l) → H_2O (g)
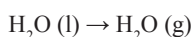
	ΔSsystem	ΔSsurroundings
A	+	+
B	+	−
C	−	+
D	−	−

8 The complete combustion of propanone, $(CH_3)_2CO$ (l), in oxygen is exothermic. Which row of the table correctly describes the reaction?

	ΔH	ΔS	Spontaneous/non-spontaneous
A	negative	positive	spontaneous
B	negative	positive	non-spontaneous
C	positive	negative	spontaneous
D	positive	positive	non-spontaneous

9 What are the signs of $\Delta H^{\ominus}$ and $\Delta S^{\ominus}$ for a reaction which is spontaneous at low temperatures and non-spontaneous at very high temperature?

	$\Delta H^{\ominus}$	$\Delta S^{\ominus}$
A	+	+
B	+	−
C	−	−
D	−	+

10 Which of the following terms is equivalent to the entropy change of the surroundings?

A $\Delta G^{\ominus}$

B $T\Delta S^{\ominus}$

C $-\dfrac{\Delta H^{\ominus}}{T}$

D $-T\Delta S^{\ominus}$

11 Given that the enthalpy change of vaporisation of water is $+40.8\,\text{kJ}\,\text{mol}^{-1}$, what term gives the entropy change when $36.04\,\text{g}$ of water boil to form water vapour?

A $\dfrac{40.8 \times 10^3 \times 36.04}{18.02 \times 398}\,\text{J}\,\text{K}^{-1}$

B $-\dfrac{40.8 \times 36.04}{18.02 \times 373}\,\text{J}\,\text{K}^{-1}$

C $\dfrac{40.8 \times 10^3 \times 36.04}{18.02 \times 373}\,\text{J}\,\text{K}^{-1}$

D $-\dfrac{40.8 \times 10^3 \times 36.04}{18.02 \times 373}\,\text{J}\,\text{K}^{-1}$

12 In a sealed vessel, ammonium chloride forms an equilibrium with ammonia and hydrogen chloride:

$$NH_4Cl\ (s) \rightleftharpoons NH_3\ (g) + HCl\ (g)\quad \Delta G^{\ominus} = +91\,\text{kJ}\,\text{mol}^{-1}$$

$$\Delta G^{\ominus} = -RT\ \ln K$$

Which of the following statements is correct?

A The equilibrium mixture will contain mainly reactants and the value of $K \ll 1$.

B The equilibrium mixture will contain mainly reactants and the value of $K \gg 1$.

C The equilibrium mixture will contain mainly products and the value of $K \ll 1$.

D The equilibrium mixture will contain mainly products and the value of $K \gg 1$.

13 What is the correct order of decreasing entropy for a pure substance?

A liquid > solid > gas

B solid > gas > liquid

C solid > liquid > gas

D gas > liquid > solid

14 The expression for the standard free energy change of a reaction is given by the Gibbs equation:

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

What are the signs for $\Delta H^{\ominus}$ and $\Delta S^{\ominus}$ for a reaction that is spontaneous at all temperatures?

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

15 Which of the following combination of thermodynamic changes for a forward reaction would result in the most products?

	Entropy	Enthalpy
A	decreasing	decreasing
B	increasing	decreasing
C	increasing	increasing
D	decreasing	increasing

16 Which of the following has the highest entropy?

A $H_2O\ (g)$ at $150\,°C$

B $H_2O\ (g)$ at $100\,°C$

C $H_2O\ (l)$ at $100\,°C$

D $H_2O\ (l)$ at $4\,°C$ (the temperature of maximum density)

17 For systems at equilibrium, which of the following must always be true?

A $\Delta S = 0$

B $q = 0$

C $\Delta H = 0$

D $\Delta G = 0$

■ Paper 2

1 Magnesium carbonate decomposes on heating according to the equation shown below. The values of the standard enthalpy change and standard entropy change of the decomposition are provided.

$$MgCO_3\ (s) \rightarrow MgO(s) + CO_2\ (g)\quad \Delta H^{\ominus} = +117\,\text{kJ}\,\text{mol}^{-1}$$
$$\text{and}$$
$$\Delta S^{\ominus} = +175\,\text{J}\,\text{mol}^{-1}\,\text{K}^{-1}$$
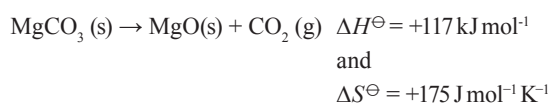
a Explain why the entropy increases when magnesium carbonate decomposes. [1]

b Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, for the decomposition of magnesium carbonate. Hence, comment on the spontaneity of the decomposition of magnesium carbonate under standard conditions. [2]

2 The table lists the standard enthalpy change of formation of four compounds.

Compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
H_2O (l)	−286
HCl (g)	−92
SiO_2 (s)	−910
$SiCl_4$ (l)	−640

a State the meaning of standard enthalpy change of formation of a compound. [2]

b i State the balanced equation, with state symbols, for the reaction between silicon tetrachloride and water to form silicon dioxide and hydrogen chloride gas. [2]

ii Using the data in the table, calculate the standard enthalpy change for the reaction in part b) i). [2]

c State and explain whether the hydrolysis has a positive, negative or zero change in entropy. [2]

d Use the Gibbs equation to explain why the hydrolysis of liquid silicon tetrachloride is always a spontaneous process. [2]

3 Solid mercury(II) sulfide, HgS, can exist in either the red or black form. The $\Delta H^{\ominus}$ for the conversion from the red to black form is +4.2 kJ mol^{-1}.

HgS (red) → HgS (black); $\Delta H^{\ominus}$ = +4.2 kJ mol^{-1}

The standard entropy values, $S^{\ominus}$, for HgS (red) and HgS (black) are +77.8 J K^{-1} mol^{-1} and +88.3 J K^{-1} mol^{-1}, respectively.

a Determine the minimum temperature HgS (red) must be heated to in order to change it to HgS (black). [3]

b Given that the equilibrium constant, K, of the reaction at 298 K is 2.97 × 10^{-13}, calculate the value of $\Delta G^{\ominus}$ of the reaction under standard conditions. [1]

c Comment on the sign of $\Delta G^{\ominus}$ with reference to the position of equilibrium of the reaction under standard conditions. [1]

4 Hydrogen can be made from steam according to the following equation:

H_2O (g) + C (s) → H_2 (g) + CO (g)
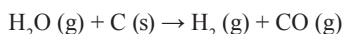
The Gibbs free energy change of the reaction at two different temperatures are shown:

ΔG_1 = +78 kJ mol^{-1} at 378 K ΔG_2 = −58 kJ mol^{-1} at 1300 K.

a Deduce the correct signs of ΔH and ΔS for this reaction. [2]

b Calculate the values of ΔH and ΔS. You can assume they are independent of temperature. [4]

5 At a pressure of 1.01 × 10^5 Pa and a temperature of 188 K, the liquid and gaseous states of HCl will be in equilibrium:

HCl (l) ⇌ HCl (g); ΔG = 0.0 kJ mol^{-1} and ΔH = +16.8 kJ mol^{-1}
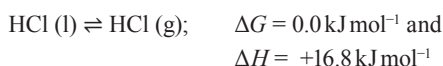
The enthalpy change for the vaporization process, the forward reaction as written, is shown.

a Calculate the entropy change, ΔS, for the vaporization, and explain the significance of its sign. [2]

b Calculate ΔG for this process at a temperature of 298 K, and explain the significance of its sign. [2]