Oxford Resources for IB

Chemistry – 2023 Edition

Answers

Reactivity 1.1 – Measuring enthalpy changes

Activity (page 390)

- The glass of water is an open system.
- The system includes the water and ice in the glass. The surroundings are all matter that exists outside the glass of iced water. The glass can be considered the boundary between the system and the surroundings.
- Heat, Q, is a form of energy that is transferred from a warmer body to a cooler body, as a result of the temperature gradient. The water in the glass is warmer than the ice cubes ($H_2O(s)$). Energy will flow from the water into the ice cubes, warming them, so eventually they will melt. As the surroundings are warmer than the iced water, energy will flow from the surroundings into the system.
- Condensation occurs on the outside of the glass and you observe liquid water. The change of state is from a gas (water vapour) to a liquid (water). Energy is transferred into the surroundings when water vapour condenses into liquid water.

Practice question (page 393)

1. C

Practice questions (page 394)

2. **a.** $Q = mc\Delta T$

$= 1\ \text{kg} \times 4.18\ \text{kJ kg}^{-1}\ \text{K}^{-1} \times 1\ \text{K}$

$= 4.18\ \text{kJ}$

b. $Q = mc\Delta T$

$= 1000\ \text{kg} \times 0.385\ \text{kJ kg}^{-1}\ \text{K}^{-1} \times 1\ \text{K}$

$= 385\ \text{kJ}$

3. a

4. a

Practice questions (page 396)

5. $Q = mc\Delta T$

$= 30\ \text{g} \times 4.18\ \text{J g}^{-1}\ \text{K}^{-1} \times 30\ \text{K}$

$= 3762\ \text{J}$

6. First, convert kJ to J (× 1000)

Next, convert g to kg (÷ 1000)

$Q = mc\Delta T$

$$\Delta T = \frac{Q}{mc}$$

$$= \frac{675\ \text{J}}{0.125\ \text{kg} \times 385\ \text{J kg}^{-1}\ \text{K}^{-1}}$$

$= 14.0\ \text{K}$ (3 sf)

Skills questions (page 398)

Answers will vary depending on experimental data obtained.

The process shown in Worked example 3 (page 399) should be followed.

ATL questions (page 401)

1./2. Ignition device: source of ignition to combust the sample
Oxygen supply: ensures complete combustion
Temperature probe: measures temperature
Water bath: absorbs the heat released by combustion in the bomb
Calorimeter bomb: holds sample
Stirrer: even distribution of heat energy throughout the water bath
Jacket: thermal insulator to minimize heat loss to the surroundings.

3. Answers will vary e.g. good thermal insulation, complete combustion, closed environment minimizes loss of product, etc.

4. High specific heat capacity, readily available, liquid over a large temperature range, etc.

End of topic questions (pages 402–403)

1. Answers will depend on the student, but a possible answer might be: In a chemical reaction, total energy is conserved. All physical and chemical changes involve energy changes, regardless of their magnitude. When heat energy is released from a system into the surroundings, the chemical reaction is defined as an exothermic reaction. When heat energy is absorbed from the surroundings, the chemical reaction is defined as an endothermic reaction. Endothermic and exothermic reactions can be determined in a school laboratory using a simple calorimeter. The collection of experimental data in these reactions focuses on a change in temperature of the reaction solvent, normally water. When the change in the temperature is positive, an exothermic reaction has taken place. When the change in the temperature is negative, an endothermic reaction has taken place.

2. D

3. D

4. A

5. B

6. **a.** $\Delta H^{\ominus}$(rev) = 226 kJ mol^{-1}

b. $2NO_2(g) + H_2O(l) \rightarrow HNO_3(aq) + HNO_2(aq)$

or $4NO_2(g) + 2H_2O(l) + O_2(g) \rightarrow 4HNO_3(aq)$

Ionic equations would also be acceptable.

7. **a.** 3 minutes

b. The temperature is still rising while the reaction takes place

c. *Maximum temperature:* 54 °C

Assumption: that temperature would be reached if the reaction were instantaneous

OR that temperature would be reached if the reaction occurred without heat loss

Note:** Accept “rate of heat loss is constant”* ***OR *“rate of temperature decrease is constant”.*

d. *Any one of:*

excess copper(II) sulfate **AND** mass/amount of zinc is independent variable/being changed.

OR excess copper(II) sulfate **AND** with zinc in excess there is no independent variable [as amount of copper(II) sulfate is fixed]

Excess copper(II) sulfate **AND** having excess zinc will not yield different results in each trial

Excess zinc **AND** results can be used to see if amount of zinc affects temperature rise [so this can be allowed for]

Excess zinc **AND** reduces variables/keeps the amount reacting constant

e. For m:

Density of solution is 1.000 g cm^{-3} (same as water)

OR

25.00 cm^3 solution has a mass of 25.00 g

OR

Mass of zinc/reactant is negligible

OR

Mass of contents was 25.00 g

For c:

Specific heat capacity of solution is 4.18 J g^{-1} K^{-1} (same as water)

OR

Zinc/calorimeter/beaker/thermometer absorbs no heat

f. lower/less exothermic/less negative **AND** heat loss/some heat not accounted for

OR

lower/less exothermic/less negative **AND** mass of reaction mixture greater than 25.00 g

OR

greater/more exothermic/more negative **AND** specific heat of solution less than water

Note: *Accept "temperature is lower" instead of "heat loss".*

Accept "similar to theoretical value **AND** *heat losses have been compensated for".*

Accept "greater/more exothermic/more negative **AND** *linear extrapolation overestimates heat loss".*

8. a. heat = $mc\Delta T$

= 7.8 g × 4.18 J g^{-1} K^{-1} × (22.6 – 21.3)

= 42.4 J

b. $\text{enthalpy of combustion} = \frac{42.4\ \text{J}}{1.2\ \text{g}} = -35.33\ \text{J g}^{-1}$

$= -0.035\ \text{kJ g}^{-1}$

Reactivity 1.2 – Energy cycles in reactions

Practice questions (page 407)

1. bond enthalpy for H–Cl is 431.5 kJ mol^{-1}

2. amount of energy required to break bonds of reactants:

(4 × BE C–H) + (2 × BE O–H) = 4 × 414 + 2 × 463

= 2582 kJ mol^{-1}

amount of energy released during bond formation:

(3 × BE H–H) + (1 × BE C≡O)

= 3 × 436 + 1077

= 2385 kJ mol^{-1}

ΔH = 2582 – 2385 = +197 kJ mol^{-1}

3. a. $CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$

b. 1898 – 1997 = –99 kJ mol^{-1}

or 656 – 755 = –99 kJ mol^{-1} (if only use bonds that change)

c. exothermic, because the enthalpy change is negative

d. products

Practice questions (page 410)

4. $2CO_2(g) + 3H_2O(l) \rightarrow C_2H_5OH(l) + 3O_2(g)$ $\Delta H = +1367\ \text{kJ mol}^{-1}$ (reversed equation 1)

$2C(s) + 2O_2(g) \rightarrow 2CO_2(g)$ $\Delta H = 2 \times (-394)\ \text{kJ mol}^{-1}$ (doubled equation 2)

$3H_2(g) + 1\tfrac{1}{2}O_2(g) \rightarrow 3H_2O(l)$ $\Delta H = 3 \times (-286)\ \text{kJ mol}^{-1}$ (tripled equation 3)

These sum to the equation given in the question.

$\Delta H_f^{\ominus} = -279\ \text{kJ mol}^{-1}$

5. Create an enthalpy cycle diagram, with the required equation along the top and $2N_2$, $5O_2$ and $6H_2$ at the bottom.

Reverse and double equation 2:

$4NH_3(g) \rightarrow 2N_2(g) + 6H_2(g)$ $\Delta H = 2 \times (+92)\ \text{kJ mol}^{-1}$

Double equation 1:

$2N_2(g) + 2O_2(g) \rightarrow 4NO(g)$ $\Delta H = 2 \times (+66)\ \text{kJ mol}^{-1}$

Triple equation 3:

$6H_2(g) + 3O_2(g) \rightarrow 6H_2O(g)$ $\Delta H = 3 \times (-572)\ \text{kJ mol}^{-1}$

$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(l)$ $\Delta H = -1400\ \text{kJ mol}^{-1}$

Skills questions (page 411)

1. **a.** $2HCl(aq) + K_2CO_3(s) \rightarrow 2KCl(aq) + H_2O(l) + CO_2(g)$

b. $HCl(aq) + KHCO_3(s) \rightarrow KCl(aq) + H_2O(l) + CO_2(g)$

2. $n(HCl) = (0.030\ \text{cm}^3) \times (2\ \text{mol dm}^{-3}) = 0.06\ \text{mol}$

Mole ratio in first reaction $n(HCl) : n(K_2CO_3) = 2 : 1$

$$n(K_2CO_3) = \frac{3\ \text{g}}{138.21\ \text{g mol}^{-1}} = 0.02\ \text{mol}(1\ \text{sf})$$

$(2 \times 0.02) < 0.06$. Therefore, HCl is in excess.

Mole ratio in second reaction $n(HCl) : n(KHCO_3) = 1 : 1$

$$n(KHCO_3) = \frac{3\ \text{g}}{100.12\ \text{g mol}^{-1}} = 0.03\ \text{mol}(1\ \text{sf})$$

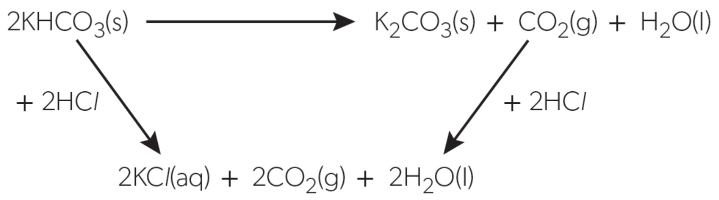
$0.03 < 0.06$. Therefore, HCl is in excess.

3. Answers will vary depending on experimental data.

4. $2KHCO_3(s) \rightarrow K_2CO_3(s) + CO_2(g) + H_2O(g)$

Note that under standard conditions the correct state symbol for water is (l).

5.



6 and 7. Answers will depend on the experimental data obtained.

8. Answers will depend on the source of the theoretical value (which can be calculated using enthalpy of formation data).

9. The specific heat capacity of the solution is equal to that of water, no thermal energy is lost to the surroundings, thermal energy was evenly distributed in the solution, mass of water not measured and $1\ \text{g} = 1\ \text{cm}^3$ is assumed, etc.

Activity (page 412)

- **a.** $C_8H_{18}(l) + 12.5O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$ $\Delta H_c^\ominus = –5470\ \text{kJ mol}^{-1}$
- **b.** $C_6H_{12}O(s) + 8.5O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$ $\Delta H_c^\ominus = –3728\ \text{kJ mol}^{-1}$
- **c.** $CH_2O_2(l) + 0.5O_2(g) \rightarrow CO_2(g) + H_2O(l)$ $\Delta H_c^\ominus = –255\ \text{kJ mol}^{-1}$
- **d.** $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$ $\Delta H_c^\ominus = –2803\ \text{kJ mol}^{-1}$
- **e.** $C_2H_5Cl(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l) + HCl(g)$ $\Delta H_c^\ominus = –1413\ \text{kJ mol}^{-1}$

Activity (page 413)

- **a.** $3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$ $\Delta H_f^\ominus = –105\ \text{kJ mol}^{-1}$
- **b.** $C(s) + 1.5H_2(g) + 0.5Cl_2(g) \rightarrow CH_3Cl(g)$ $\Delta H_f^\ominus = –82.0\ \text{kJ mol}^{-1}$
- **c.** $2C(s) + 3H_2(g) + 0.5O_2(g) \rightarrow C_2H_6O(l)$ $\Delta H_f^\ominus = –278\ \text{kJ mol}^{-1}$
- **d.** $7C(s) + 3H_2(g) + O_2(g) \rightarrow C_6H_5COOH(s)$ $\Delta H_f^\ominus = –385\ \text{kJ mol}^{-1}$
- **e.** $C(s) + 0.5O_2(g) \rightarrow CO(g)$ $\Delta H_f^\ominus = –111\ \text{kJ mol}^{-1}$
- **f.** $C(s) + 2.5H_2(g) + 0.5N_2(g) \rightarrow CH_3NH_2(g)$ $\Delta H_f^\ominus = –23\ \text{kJ mol}^{-1}$

Practice question (page 415)

6. The standard enthalpy values given in the data booklet are rounded to the nearest whole numbers. If more precise values for the enthalpies of formation of carbon dioxide and water (–393.5 and –285.8 kJ mol^{-1}, respectively) were used in worked example 3, the final answer would be –173.3 kJ mol^{-1}. This case demonstrates the importance of precision in scientific measurements: imprecise (rounded) source data can affect both the precision and accuracy of the final result.

Practice questions (page 417)

7. 1: $C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H_f^\ominus = –394\ \text{kJ mol}^{-1}$

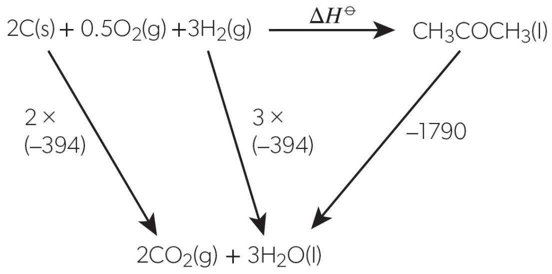
2: $H_2(g) + 0.5O_2(g) \rightarrow H_2O(l)$ $\Delta H_f^\ominus = –286\ \text{kJ mol}^{-1}$

3: $CH_3COCH_3(l) + 4O_2(g) \rightarrow 3CO_2(g) + 3H_2O(l)$ $\Delta H_f^\ominus = –1790\ \text{kJ mol}^{-1}$

Step 1: triple equation 1

Step 2: triple equation 2

Step 3: reverse equation 3



$\Delta H_f^\ominus = 3 \times (–394) + 3 \times (–286) + 1790$

$= –250\ \text{kJ mol}^{-1}$

8. a. the standard enthalpy of formation, $\Delta H_f^\ominus$, is the energy change upon the formation of 1 mol of a substance from its constituent elements in the standard state. Hydrogen, H_2, is the element in the standard state, so its standard enthalpy of formation is zero.

b. $\Delta H_f^\ominus = \sum(\Delta H_f^\ominus \text{ products}) – \sum(\Delta H_f^\ominus \text{ reactants})$

$= [3 \times (0) + (–111)] – [–74 + (–242)]$

$= 205\ \text{kJ mol}^{-1}$

c. bond enthalpy values are not specific to the compounds

values were experimentally determined/had uncertainties

different sources have slightly different values for bond enthalpies

9. a. $\Delta H^\ominus = (–286) + (–1411) = –1697\ \text{kJ mol}^{-1}$

b. step 1 = step 2 – step 3

$\Delta H^\ominus = (–1697) – (–1561) = –136\ \text{kJ mol}^{-1}$

c. Accurate:

no approximations were made in the cycle

OR values are specific to the compounds

OR Hess's law is a statement of conservation of energy

OR method is based on a law

OR data in table has small uncertainties

Approximate:

values were experimentally determined/had uncertainties

OR each value has been determined to only three/four significant figures

OR different sources have slightly different values for enthalpy of combustion

OR law is valid until disproved

OR law of conservation of energy is now conservation of mass–energy

OR small difference between two quite large terms leads to high percentage uncertainty

Practice question (page 421)

10. $\Delta H_f^{\ominus} = (+148) + (+738) + (+1451) + (+249) + (-141) + (+753) + (-3791) = -593 \text{ kJ mol}^{-1}$

End of topic questions (pages 422–423)

1. Answers will depend on the student, but a possible answer might be: The law of conservation of energy states that energy can neither be created or destroyed, it can only be interconverted between different forms. Hess's law states that regardless of the route by which a chemical reaction proceeds, the enthalpy change will always be the same, as long as the initial and final states of the system are the same. The application of Hess's Law and the Born-Haber cycle relies on the conservation of energy law. When we understand the value of the change in enthalpy for the overall chemical, for example the enthalpy of formation or the lattice enthalpy; we can calculate the value of a missing step in the energy cycle.

2. B

3. D

4. B

5. C

6. B

7. **a.** bonds broken = (N≡N) + 3 × (H–H)

= 945 + (3 × 436) = 2253

bonds made = 2 × 3(N–H)

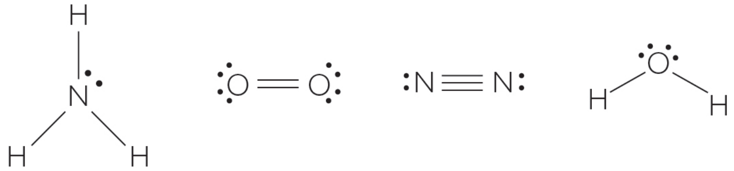
= 6 × 391 = 2346

$\Delta H = 2253 - 2346 = -93 \text{ kJ mol}^{-1}$

b. The reaction is exothermic, as the change in enthalpy is a negative value.

8. **a.** $4NH_3(g) + 3O_2(g) \rightarrow 2N_2(g) + 6H_2O(g)$

b.



c. bonds broken = 4 × 3(N–H) + 3(O=O)

= (4 × 3 × 391) + (3 × 498) = 6186

bonds made = 2(N≡N) + 6 × 2(O–H)

= (2 × 945) + (6 × 2 × 463) = 7446

$\Delta H = 6186 - 7446 = -1260 \text{ kJ mol}^{-1}$

9. **a.** bonds broken = 18(C–H) + 7(C–C)+ 12.5(O=O)

= (18 × 414) + (7 × 346) + (12.5 × 498) = 16099

bonds made = 8 × 2(C=O) + 9 × 2(O–H)

= (8 × 2 × 804) + (9 × 2 × 463) = 21198

ΔH = 16099 – 21198 = –5099 kJ mol^{-1}

b. The value of enthalpy of reaction calculated from bond enthalpies is less accurate as the values used in the calculation are average values and therefore only an approximation.

Bond enthalpy values are only valid for substances in the gaseous state; octane is a liquid.

Reactivity 1.3 – Energy from fuels

Activity (page 425)

Sulfur dioxide is widely used in the industrial production of sulfuric acid, paper manufacturing and the food industry as a preservative and antioxidant. The environmental impact of the release of sulfur dioxide into the atmosphere is increased acid deposition and the associated effects such as deforestation, increased acidity of lakes and rivers affecting the fish industry and the erosion of buildings and structures. Sulfur dioxide can also be harmful to the human respiratory system.

Practice questions (page 427)

1. **a.** $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

b. $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$

c. $C_5H_{12}(l) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(l)$

d. $2C_6H_{14}(l) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(l)$

Practice questions (page 427)

2. **a.** $2C_3H_7OH(l) + 9O_2(g) \rightarrow 6CO_2(g) + 8H_2O(l)$

b. $2C_5H_{11}OH(l) + 15O_2(g) \rightarrow 10CO_2(g) + 12H_2O(l)$

c. $2C_7H_{15}OH(l) + 21O_2(g) \rightarrow 14CO_2(g) + 16H_2O(l)$

Practice questions (page 428)

3. **a.** $C_3H_7OH(l) + 3O_2(g) \rightarrow 3CO(g) + 4H_2O(l)$

b. $C_5H_{11}OH(l) + 5O_2(g) \rightarrow 5CO(g) + 6H_2O(l)$

c. $C_7H_{15}OH(l) + 7O_2(g) \rightarrow 7CO(g) + 8H_2O(l)$

Practice questions (page 432)

4. **a.** $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$

Carbon dioxide is the greenhouse gas.

b. 1 mol of C_3H_8 is 44.11 g mol^{-1}

$$\frac{2219 \text{ kJ mol}^{-1}}{44.11 \text{ g mol}^{-1}} = 50.31 \text{kJ g}^{-1}$$

50.31 kJ of energy is released when 1 g of propane is combusted.

c. 0.02267 × 3 = 0.0680 mol CO_2

0.0680 × 44.01 = 2.99 g CO_2

d. 2.99 tonnes of carbon dioxide. Increase in the average temperature throughput the World, which is known as global warming. Increase in extreme weather events. Thawing of glacial ice. Impact on food production (agriculture and livestock)

Skills questions (page 433)

Responses will vary greatly depending on the database used, and the research question. The guidance given in Tool 2, Tool 3 and Inquiry cycle chapters should be followed.

Practice questions (page 435)

5. **a.** $C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$

   b. Carbon dioxide, a greenhouse gas, is produced in both fermentation and combustion processes. However, ethanol-based fuels have a lower carbon footprint as the production of the carbon dioxide is offset by the absorption of carbon dioxide in the process of photosynthesis.

   c. Possible arguments are listed in table 1 on page 435.

Data-based questions (page 436)

1. The total biofuel production in terawatt-hours increased slowly for 15 years from 1990. Then production increased rapidly from 2005 onwards. In 2020, the production declined.
2. The contribution of the major geographical regions to the production of biofuels has become more evenly distributed over the past three decades.
3. Once the major supplier of biofuels when total production was small (1990s), South and Central America's market share has decreased from 80% from 20%.

Practice questions (page 440)

6. **a.** A primary electrochemical cell consumes materials and the reaction is non-reversible. Either the anode, electrolyte or both need to be replaced. Primary cells do not operate well under high current demand such as electric cars. In a secondary cell, chemical reactions that generate electricity can be reversed by applying an electric current. Secondary cells can deliver a stronger current flow than a primary cell.

   b. Lead–acid batteries convert chemical energy into electrical energy. The process is reversible and the batteries can be recharged. While this type of secondary cell has advantages over traditional primary cells, there are still problems associated with this type of battery, such as overheating, limited lifespan and environmental concerns in terms of their disposal.

   Hydrogen fuel cells are considered to be a clean energy source. Unlike lead-acid batteries, hydrogen cells have the ability to work continuously, generate less hazardous waste on disposal. They produce higher current per unit mass, have a higher specific energy, and they do not need to be recharged.

   c. The proton exchange membrane (PEM) selectively allows hydrogen ions to diffuse between the cathode and anode, prevents the passage of other ions, molecules and electrons between these electrodes. The protons formed at the anode move across the PEM to the cathode, where they combine with the oxygen gas and electrons. Oxygen gas is reduced to form water as a waste product.

   d. **i.** anode half-equation: $CH_3OH(aq) + H_2O(l) \rightarrow CO_2(g) + 6H^+(aq) + 6e^-$

   cathode half-equation: $1.5O_2(g) + 6H^+(aq) + 6e^- \rightarrow 3H_2O(l)$

   overall reaction: $CH_3OH(aq) + 1.5O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

   ii. *Advantage (any one of):*

   liquid methanol is easier to transport/store than gaseous hydrogen

   OR

   hydrogen is explosive

   longer membrane life (as it operates in aqueous environment)

   methanol has greater energy density than hydrogen

   Disadvantage (any one of):

   lower voltage

   lower power per unit mass «of the cell»

   lower efficiency

   toxic/can be mistaken for ethanol

   lower specific energy

   Ignore any cost references throughout.

   Accept "CO_2/greenhouse gas produced" ***OR*** *"requires a more highly efficient catalyst".*

   Do ***not*** *award marks for converse statements for the advantage and disadvantage.*

End of topic questions (page 441)

1. Answers will depend on the student, but a possible answer might be: The combustion of fossil fuels, typically coal, oil, natural gas, LPG and other hydrocarbons converts chemical energy into thermal energy. This thermal energy is then used to generate electrical energy to address our expanding energy needs. The challenges that face society are the significant environmental impact of increasing levels of carbon dioxide. Carbon dioxide is a greenhouse gas that traps heat energy inside the Earth's atmosphere, leading to global warming. Governments have the challenge of transitioning economies to clean energy alternatives which takes time, money, expertise and political willpower.

2. B

3. B

4. **a.** $2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(l)$

b. Carbon monoxide, CO, is a colourless and odourless poisonous gas that attaches irreversibly to the haemoglobin in the bloodstream. This reduces the oxygen-carrying capacity of the blood. This can lead to coma and eventually death.

c. $[(4 \times 414) + (1.5 \times 498)] - [(1 \times 1077) + (4 \times 463)] = -526\ \text{kJ mol}^{-1}$

5. **a.** $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

b. (showing strong) correlation between (atmospheric) CO_2 concentration/greenhouse gas concentration and average (global/surface/ocean) temperature

lab evidence that greenhouse gases/CO_2 absorb(s) infrared radiation

computer modelling

ice core data

tree-ring data

ocean sediments / coral reefs / sedimentary rocks data

*NOTE: Do **not** accept "global warming" for "average temperature".*

*Do **not** accept "traps/reflects heat" **OR** "thermal energy".*

Evidence must be outlined and connected to data.

Accept references to other valid greenhouse gases other than carbon dioxide/CO_2, such as methane/CH_4 or nitrous oxide/N_2O.

c. Biofuel raw material/sugar/glucose formed by photosynthesis

OR biofuel raw material/sugar/glucose uses up carbon dioxide during its formation

OR biofuel from capturing gases due to decaying organic matter formed from photosynthesis

Arguments based on materials coming from a plant source consuming carbon dioxide / carbon are acceptable.

$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$

Accept arguments based on material coming from plant sources consuming carbon dioxide/carbon for M1.

6. **a.** liquid in cell is less/not corrosive

OR

does not contain lead/toxic chemicals

OR

larger specific energy/charge capacity/current per unit mass

OR

does not have to be charged prior to use / is always ready for use as long as fuel is available

b. *Advantage (any one of):*

liquid methanol is easier to transport/store than gaseous hydrogen

hydrogen is explosive

longer membrane life (as it operates in aqueous environment)

methanol has greater energy density than hydrogen

Disadvantage (any one of):

lower voltage

lower power per unit mass of the cell

lower efficiency

toxic/can be mistaken for ethanol

lower specific energy

Ignore any cost references throughout.

Accept "CO_2/greenhouse gas produced" ***OR*** *"requires a more highly efficient catalyst".*

Do ***not*** *award marks for converse statements for the advantage and disadvantage.*

7. a. (portable) sources of electrical energy/electricity

OR

convert chemical «potential» energy to electrical energy/electricity

b. primary cells involve irreversible reactions **AND** rechargeable cells involve reversible reactions.

Accept "primary cells have a limited life before going 'flat' **AND** rechargeable cells can be recharged when 'flat'".

c. Voltage:

chemical nature of electrodes

OR

electrode reactions

Current:

diffusion rate

OR

internal resistance/resistance of the cell

Accept temperature for either but not both.

Accept concentration for either but not both.

Accept pH for either but not both.

Accept the current depends on the area/separation of the electrodes.

Reactivity 1.4 – Entropy and spontaneity

Practice questions (page 445)

1. a. positive, because number of moles of gaseous species increases

b. negative, because number of moles of gaseous species decreases

c. positive, because number of moles of gaseous species increases

d. positive, because number of moles of gaseous species increases

Practice questions (page 447)

2. B

3. D

4. $+74.5\ \text{J K}^{-1}\ \text{mol}^{-1}$

Practice questions (page 450)

5. a. $\Delta H^{\ominus} = [-165 + 2(-297) + 2(-92)] - [-453 + 2(-246)]$

$\Delta H^{\ominus} = +2\ \text{kJ mol}^{-1}$

b. $\Delta S^{\ominus} = [209 + 2(248) + 2(187)] - [167 + 2(279)]$

$\Delta S^{\ominus} = +354\ \text{J K}^{-1}\ \text{mol}^{-1}$

c. There is a large increase in entropy resulting in $T\Delta S > \Delta H$ at the reaction temperature.

Practice questions (page 451)

6. a. bonds broken = 4(C–H) + C=C + H-H = (4 × 414) + 614 + 436 = 2706

bonds made = C–C + 6(C–H) = 346 + (6 × 414) = 2830

$\Delta H = 2706 - 2830 = -124 \text{ kJ mol}^{-1}$

b. $\Delta H^{\ominus} = \Sigma(\Delta H_f^{\ominus} \text{ products}) - \Sigma(\Delta H_f^{\ominus} \text{ reactants})$

$= [\Delta H_f^{\ominus}(C_2H_6)] - [\Delta H_f^{\ominus}(C_2H_4) + \Delta H_f^{\ominus}(H_2)]$

$= [-84] - [52 + 0] = -32 \text{ kJ mol}^{-1}$

c. The change in entropy value for this reaction should be negative ($\Delta S^{\ominus} < 0$) as there is a decrease in the number of moles of gaseous species from 2 mol to 1 mol.

d. $\Delta S^{\ominus} = \Sigma(\Delta S^{\ominus} \text{ products}) - \Sigma(\Delta S^{\ominus} \text{ reactants})$

$= [\Delta S^{\ominus}(C_2H_6(g)) + \Delta S^{\ominus}(H_2(g))] - [\Delta S^{\ominus}(C_2H_4(g))]$

$= [(+230)) +(131)] - [+220] = +141 \text{ kJ mol}^{-1}$

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

$= -32 \text{ kJ mol}^{-1} - (298 \text{ K} \times 0.141 \text{ kJ K}^{-1} \text{ mol}^{-1})$

$= -74 \text{ kJ mol}^{-1}$

$\Delta G^{\ominus}$ is always negative (< 0) as $\Delta H^{\ominus}$ is negative (< 0) and $\Delta S^{\ominus}$ is positive (> 0).

Skills questions (page 453)

1. ΔH for the dissolution process is negative because the process is exothermic. ΔS for the dissolution process is negative because of the regular arrangement of water molecules required to form hydrogen bonds with the amido groups along the polymer chain.

2. Answers will vary but should be consistent with the information given below figure 5.

3. Answers may include: concentration of PNIPAM, volume of either LiCl or LiBr, use of distilled water, gradual heating to allow for thermal equilibrium between the water bath and sample, etc.

4. *The effect of the presence or absence of an aqueous ionic compound:*

a. Results 5 should be compared to either 1 and 3 or 2 and 4.

b. In the presence of an aqueous ionic compound, the PNIPAM solution goes cloudy at a lower temperature. The effect is more pronounced when LiCl is used than LiBr.

The effect of concentration of aqueous ionic compound:

a. Results 1 and 2 should be compared (or alternatively, 3 and 4).

b. When the concentration of the ionic compound is higher , the PNIPAM solution goes cloudy at a lower temperature.

c. Answers will vary. For example, the ion-dipole interactions between water and the ions in the electrolyte reduce the solubility of the PNIPAM, causing the temperature at which the solution goes cloudy to decrease. Students may research and make reference to the Hofmeister effect.

d. Answers will vary, but students should identify that two points are insufficient for establishing a trend.

e. Answers will vary. Students could set out to obtain data across a greater range of concentrations, range of anions, range of cations, etc.

Practice questions (page 456)

7. a. $\Delta H^{\ominus} = (4 \times 33.2) - (2 \times 82) = -31.2 \text{ kJ mol}^{-1}$

b. $\Delta S^{\ominus} = (4 \times 240) - [(2 \times 220) + (3 \times 205)] = -95 \text{ J K}^{-1} \text{ mol}^{-1}$

c. $\Delta G^{\ominus} = -31.2 - 298 \times (-95 / 1000) = -2.89 \text{ kJ mol}^{-1}$

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

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

$$\ln K = -\frac{2.89 \times 10^3 \text{J mol}^{-1}}{8.31 \text{ J K}^{-1}\text{mol}^{-1} \times 298 \text{ K}}$$

$\ln K = 1.17$

$K = e^{1.17} = 3.22$

Skills questions (pages 457–458)

1. ΔS is positive due to the formation of a gas.

2. ΔH is positive because the process is endothermic. Thermal energy is absorbed to overcome the hydrogen bonds between water molecules.

3. At higher temperatures, the spontaneity increases because the magnitude of the $T\Delta S$ term increases, leading to a negative ΔG value.

4. $\Delta H = -242 - (-286) = +44\ \text{kJ mol}^{-1}$

$\Delta G = -229 - (-237) = +8\ \text{kJ mol}^{-1}$

$\Delta S = 189 - 70 = +119\ \text{J K}^{-1}\ \text{mol}^{-1}$

5. $\Delta G = 0$

$$T = -\frac{\Delta H}{\Delta S}$$

$T = -44 / 0.119 = 370$ K (3 sf)

6. Actual boiling point of water = 373 K

$$\text{Percentage error} = \frac{|373 - 370|}{373} \times 100\%$$

$= 0.804\%$

8. Answers will vary but follow the guidance in Tool 3.

9. Gradient = $-\Delta S$

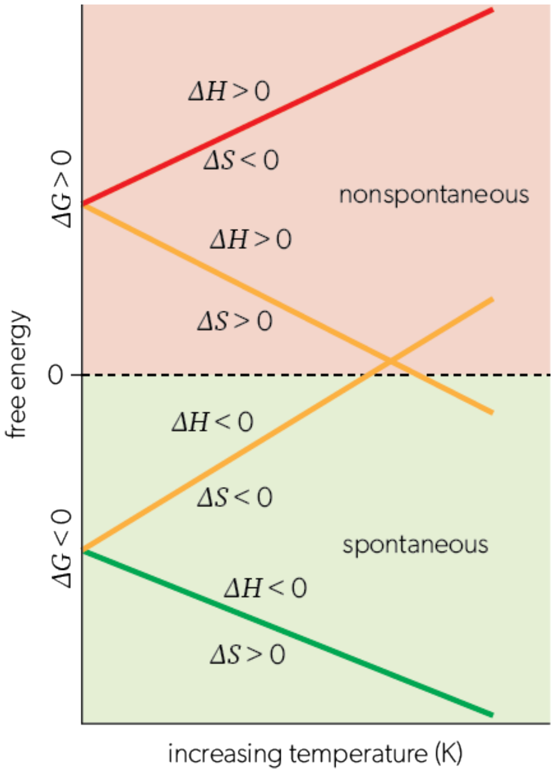
y-intercept = ΔH

x-intercept = temperature at which the change in spontaneity occurs.

10. The x-intercept must be determined. Use of the equation of the line will give the same answer as Q5 (around 370 K). If obtained visually, values for the x-intercept will vary.

11. The graph is linear because ΔS (i.e. the rate of change or gradient) is constant. The relationship is negative because ΔS for this process is positive.

13.



14.

ΔH (y-intercept)	ΔS (gradient)	Spontaneity
positive	negative	non-spontaneous at all temperatures
positive	positive	spontaneous at high temperatures
negative	negative	spontaneous at low temperatures
negative	positive	spontaneous at all temperatures

End of topic questions (page 459)

1. Answers will depend on the student, but a possible answer might be: Chemical systems can approach equilibrium from either the forward or reverse direction of a balanced chemical equation, e.g. $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$. The direction of change of a chemical reaction is determined by two key factors, the change in enthalpy and change in entropy (a measure of the disorder of the system). Exothermic reactions ($\Delta H^\ominus < 0$) are normally spontaneous for a given set of conditions. However, the entropy change and temperature of the system need to be considered to determine the direction of chemical change. The combinations for temperature, enthalpy and entropy change will determine if a reaction is spontaneous or non-spontaneous.

2. A

3. B

4. C

5. **a.** $\Delta S^\ominus = 270\ \text{J K}^{-1}\ \text{mol}^{-1} - 267\ \text{J K}^{-1}\ \text{mol}^{-1} - 131\ \text{J K}^{-1}\ \text{mol}^{-1}$

$\Delta S^\ominus = -128\ \text{J K}^{-1}\ \text{mol}^{-1}$

b. non spontaneous if $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus > 0$

OR

$\Delta H^\ominus > T\Delta S^\ominus$

$$T > \frac{-124.4}{-0.128} = 972\ \text{K}$$

6. **a.** $\Delta G^\ominus = -RT \ln K$

$= -8.31\ \text{J K}^{-1}\ \text{mol}^{-1} \times 298\ \text{K} \times \ln(5.01 \times 10^{-4}) \div 1000 = 18.8\ \text{kJ mol}^{-1}$

b. non-spontaneous, because $\Delta G^\ominus$ is positive

7. **a.** $\sum S(\text{RHS}) = 313\ \text{J K}^{-1}\ \text{mol}^{-1}$

$\sum S(\text{LHS}) = (4 \times 198) + 3$

$= 795\ \text{J K}^{-1}\ \text{mol}^{-1}$

$\Delta S^\ominus = \sum S(\text{RHS}) - \sum S(\text{LHS}) = 313 - 795 = -482\ \text{J K}^{-1}\ \text{mol}^{-1}$

b. $\Delta H^\ominus = -633 - 4 \times (-110.5) = -191\ \text{kJ mol}^{-1}$

c. When $\Delta G^\ominus = 0$, forward and reverse reaction are equally favourable.

$\Delta G^\ominus = 0$

$$T = \frac{\Delta H^\ominus}{\Delta S^\ominus} = \frac{191}{0.482} = 396\text{K} = 123\ °\text{C}$$

d. $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$

$= (-191) - 298 \times (-482 / 1000) = -47.36\ \text{kJ mol}^{-1}$

$\Delta G = \Delta G^\ominus + RT \ln Q$

$= -47364\ \text{J mol}^{-1} + (8.31\ \text{J K}^{-1}\ \text{mol}^{-1}) \times 298\ \text{K} \times \ln(0.5)$

$= -49080\ \text{J mol}^{-1} = -49.08\ \text{kJ mol}^{-1}$

ΔG is negative, so the reaction is spontaneous at this point in the reaction pathway.