Oxford Resources for IB

Chemistry – 2023 Edition

Answers

Tool 1 – Experimental techniques

Approaches to learning activity (page 310)

Answers will vary. Examples include:

Box 1: Waste reduction by reducing derivatives / using enzymes / reduction in the number of steps in a synthesis, maximising atom economy etc.

Box 2: Energy efficiency by conducting syntheses at lowest possible temperatures and pressures / use of catalysts, etc.

Box 3: Reduce waste and pollution by: employing real-time analysis for pollution prevention / design for degradation / use of green solvents, etc.

Practice questions (page 311)

1. **a.** Corrosive, toxic, oxidizing

  b. Irritant

  c. Corrosive, irritant, environmental hazard

  d. Corrosive, flammable

  e. Highly flammable, environmental hazard, health hazard, harmful

2. This will vary depending on your school's referencing system. In general, book references should contain:
  - Authors, ordered alphabetically according to surname
  - Publication year
  - Book title
  - Edition
  - Name of the publisher
  - Place of publication

3. Concentrated sulfuric acid: corrosive

  Concentrated hydrogen peroxide: harmful

Data-based question (page 312)
B

The results are precise: they are all close to each other (within the uncertainty).

The results are inaccurate: they are far (around 50%) from the theoretical value.

Practice questions (page 313)

4. The pH probe will report values to one or two decimal places and is not subject to the experimenter's visual interpretation of the colour of the pH paper.

5. Yes, an inappropriate method for addressing a research question will produce results that are low in validity. However the results can still be reliable if replicates and independent repetitions of the experiment produce the same results. For example, measuring the conductivity of water by using tap water instead of distilled water.

Data-based question (page 313)

The mass of the empty crucible cannot be higher than the mass of the crucible + hydrated copper(II) sulfate. Reasons for this mistake might have been:

- weighing the empty crucible along with its lid in the first measurement, and without the lid in subsequent measurements
- using a balance that had previously been tared by someone else.

Practice questions (page 313)

6. A

This measured quantity is given to 4 decimal places, indicating higher precision than the 1, 3 and 1 decimal place alternatives given in B, C and D, respectively.

7. No. The mass of the feather is just too low to be registered by this low-precision balance.

Practice questions (page 315)

8. Volumetric pipette, volumetric flask, burette

9. **a.** burette

b. volumetric flask

c. beaker or conical flask

d. measuring cylinder

10. 55.8 cm^3 ± 0.1 cm^3 (the last digit is uncertain and may be estimated differently by different people)

Practice questions (pages 317)

11. **a.** 75 s, 70 s and 73 s

b. An uncertainty of ± 1 or 2 seconds is probably suitable, depending on the delay caused by the experimenter's reaction time.

c. 73 s (nearest second)

12. **a.** The volume of water is very small. In most beakers this volume of water would not be sufficient to cover the thermometer bulb, reducing the validity of the temperature measurement. The bottom of the beaker is being heated, so the thermometer will be showing a higher temperature than that of the water.
When measuring the temperature of a liquid, the thermometer bulb should be submerged in the liquid without touching the bottom of the container.

b. The reagent's temperature will begin rising as soon as it is removed from the ice bath. In addition, the second reagent is presumably at room temperature. Due to these two reasons, the overall temperature of the reaction mixture will be higher than 2 °C.
Both reagents need to be cooled in the ice bath and the mixture needs to be kept in the ice bath.

c. The enzyme solution should be allowed to reach the desired temperature before starting the reaction.

13. The length is 19.50 – 11.85 = 7.65. The units are not specified.

The uncertainty of each measurement is ± 0.05 (half the smallest scale division). Since the values are subtracted the total uncertainty is added, giving ± 0.10.

14. The dimensions of a solid sample, such as a single calcium carbonate chip.

Practice questions (page 319)

15. Figure 17: The pH is approximately 2, but could be as low as 1 or as high as 3, depending on the viewer's visual perception. Depending on this range, a suitable uncertainty value would be ± 1 pH units.

Figure 18: The value shown by the pH probe is 6.5 ± 0.1. The universal indicator shows a pH of roughly 6 ± 1.

16. **a.** pH indicators are quick and convenient to use but they depend on human perception of colour (and some of them are toxic or harmful). They give a rough idea of pH rather than a quantitative reading.

b. pH probes give more precise pH values than indicators, but they require cleaning and calibration, can be temperature-sensitive and expensive. pH probes give quantitative results.

Practice questions (page 320)

17. In solids, current is carried by delocalized electrons.

18. In electrolytes (molten or aqueous ionic compounds), current is carried by mobile ions.

Practice questions (page 320)

19. a. The reactants, HCl and NaOH, are a strong acid and strong base, respectively. These substances are therefore completely ionized or dissociated. There is a lower total concentration of ions in the products, because while NaCl readily dissociates into ions, water does not. The decrease in concentration of ions leads to a decrease in electrical conductivity as the reaction proceeds.

b. The reactants, $AgNO_3$ and NaBr are soluble ionic compounds and therefore dissociated into ions. There is a lower total concentration of ions in the products because while $NaNO_3$ readily dissociates into ions, AgBr precipitates out of solution as a solid. The decrease in concentration of ions leads to a decrease in electrical conductivity as the reaction proceeds.

20. Answers will vary. Examples of typical answers include:

Variable	Experiment	Instrument
Mass	Determination of the empirical formula of a metal oxide	Top-pan balance
Volume	Redox titration	Burette
Time	Rate of the reaction between hydrochloric acid and calcium carbonate	Stopwatch
Temperature	Enthalpy of neutralization	Temperature probe, thermometer
pH	pH curve determination	pH probe
Current	Determination of the charge of an electron through electrolysis	Ammeter
Potential difference	Factors affecting cell potential	Voltmeter

Practice questions (page 322)

21. The correct order is E-B-D-F-A-G-C

22. The mistakes are:

The solution requires 0.050 mol of $CuSO_4$. Since copper(II) sulfate is hydrated, its formula when solid is $CuSO_4•5H_2O$ with molar mass 249.72 g mol^{-1}. The solution therefore requires 12.486 g. The student added less than this, presumably because they used the molar mass of anhydrous copper(II) sulfate, which does not take into account the water of crystallization.

The solid should not have been directly transferred into the volumetric flask as it could easily be spilled, could clog up the funnel or contaminate the joint of the flask. A solution should first be prepared in a beaker and then transferred to the flask when aqueous.

Tap water (which contains impurities) was used instead of deionized water.

The solution went above the mark on the flask. At this point the experimenter should have started over. Removing part of the solution would remove solute as well as solvent, affecting the concentration.

The flask should be inverted many more times than just twice.

Solutions should not be stored in volumetric flasks because volumetric flasks should be cleaned as soon as possible after being used. In addition, the stopper can jam if any of the solution dries inside the joint. The student should have transferred the solution into a suitably labelled storage flask.

23. Solid sodium hydroxide is not a primary standard because part of its mass is made up of an unknown mass of water.

Practice questions (page 323)

24. $c_1 \times V_1 = c_2 \times V_2$

a. $5.00\ \text{mol dm}^{-3} \times V_1 = 1.00\ \text{mol dm}^{-3} \times 0.750\ \text{dm}^3$

$$V_1 = \frac{1.00\ \text{mol dm}^{-3} \times 0.750\ \text{dm}^3}{5.00\ \text{mol dm}^{-3}}$$

$V_1 = 0.150\ \text{dm}^3 = 150\ \text{cm}^3$

b. $5.00\ \text{mol dm}^{-3} \times V_1 = 0.150\ \text{mol dm}^{-3} \times 3.00\ \text{dm}^3$

$$V_1 = \frac{0.150\ \text{mol dm}^{-3} \times 3.00\ \text{dm}^3}{5.00\ \text{mol dm}^{-3}}$$

$V_1 = 0.0900\ \text{dm}^3 = 90.0\ \text{cm}^3$

25. First dilution: $0.50\ \text{mol dm}^{-3} \times \frac{1}{10} = 0.050\ \text{mol dm}^{-3} = 5.0 \times 10^{-2}\ \text{mol dm}^{-3}$

Second dilution: $0.50\ \text{mol dm}^{-3} \times \frac{1}{10} \times \frac{1}{10} = 0.0050\ \text{mol dm}^{-3} = 5.0 \times 10^{-3}\ \text{mol dm}^{-3}$

Third dilution: $0.50\ \text{mol dm}^{-3} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} = 0.00050\ \text{mol dm}^{-3} = 5.0 \times 10^{-4}\ \text{mol dm}^{-3}$

Fourth dilution: $0.50\ \text{mol dm}^{-3} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} = 0.000050\ \text{mol dm}^{-3} = 5.0 \times 10^{-5}\ \text{mol dm}^{-3}$

Practice questions (page 325)

26. Both require a heat source, condenser and anti-bumping granules.

Reflux is a heating technique used in the preparation of various compounds (particularly organic compounds). Distillation is a separation method.

27. Both are separation methods in which the most volatile component is separated first.

Fractional distillation requires a column packed with beads. It can be used to separate mixtures containing more than two volatile liquids.

Simple distillation is used to separate mixtures containing two components: one volatile and one non-volatile.

28. Aldehydes are generally more volatile than alcohols and carboxylic acids of similar molecular masses. The aldehyde in the oxidation of a primary alcohol can be obtained by heating the reaction mixture and distilling the aldehyde off as it forms.

Obtaining the carboxylic acid in the oxidation of an alcohol would require excess oxidizing agent and refluxing to oxidize any aldehydes into carboxylic acids. (Note: the resulting mixture would also contain the ester formed in the reaction between the alcohol and the carboxylic acid.)

Practice question (page 326)

29. Heating removes the water from the crystals. Heating to a constant mass ensures that there is no water remaining inside the crystals.

Practice questions (page 328)

30. a. The excess base is removed in the first filtration step.

b. Direct heating is faster, but it can lead to vigorous boiling and loss of solution through it spitting onto the lab bench and surroundings. Heating over a water bath is slower but it prevents loss of solution because the solvent (water) evaporates without boiling.

c. The crystals could decompose. Or, if they are hydrated, they would become anhydrous.

Practice questions (page 330)

31. a. Barium sulfate is insoluble and can be separated from the aqueous solution by filtration.

b. Ethanol and water have different boiling points, so they can be separated by fractional distillation.

c. Sodium chloride crystals can be obtained by crystallization. If the water is the desired component, it can be separated by simple distillation.

d. Water and cyclohexane are immiscible and can be separated with a separating funnel.

e. Aspirin is readily soluble in hot water but sparingly soluble in cold water. It can be separated from insoluble impurities by dissolving the mixture in hot water and performing a hot filtration. The soluble impurities can then be removed by recrystallization.

Data-based question (page 330)

The aspirin product contains impurities because its melting point is lower than the theoretical melting point, and it melts over a broad range of temperatures.

The melting point of the methyl 3-nitrobenzoate product is very close to the theoretical value, and the melting range is narrow. Therefore, the product is likely to be pure (Note: confirmation of the compound’s purity would require further analysis.)

Practice questions (pages 332–333)

32. a. A lid is placed on the container to ensure that the air inside is saturated with solvent vapour. This not only helps the chromatography, but it also reduces solvent loss by evaporation.

b. The yellow pigment has been carried furthest by the solvent and therefore it has the greatest affinity for the solvent.

33. First error: The start line is drawn in ink. The ink components will travel up the chromatogram along with the samples, interfering with the results.

Second error: The solvent is above the spots of food colourings being tested. The spots will dissolve in the solvent instead of travelling up the paper.

34. a. Leu (leucine)

b. Leucine has a non-polar hydrocarbon R group, so it has greater affinity for solvent 1. The R groups for aspartic acid and glutamic acid both contain a polar carboxyl (–COOH) group, giving these two amino acids greater affinity for the polar stationary phase. Their similar structures mean that their affinities for solvent 1 are also similar and hence the two separate only slightly in solvent 1.

Asp and Glu differ only by a CH_2. This difference becomes significant in the solvent 2 separation. Glu, being slightly less polar due to the additional CH_2 group it contains, travels a little farther than Asp. Leu is significantly less polar, so it is once again transported far up the plate.

It is worth pointing out that identifying suitable solvents is a trial-and-error process that can be very time consuming!

35. a. $R_F(\text{top}) = \dfrac{3.95\text{ cm}}{5.02\text{ cm}}$

$= 0.78685\ldots$

≈ 0.787 (3 sf)

b. R_F(middle) ≈ 0.5 because it is roughly halfway between the start line and solvent front.

R_F(bottom) ≈ 0.2 or 0.3 because it is roughly a quarter or a third of the way between the start line and solvent front.

Practice questions (page 333)

36. a. Insulated container and lid.

b. Nesting the insulated container in another.

37. a. $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

b. The reaction is exothermic because the temperature increased.

c. $Q = mc\Delta T$

$= 200\text{ g} \times 4.18\text{ J g}^{-1}\text{ K}^{-1} \times 11.0\text{ K}$

$= 9196\text{ J}$

$= 9.196\text{ kJ} \approx 9.20\text{ kJ}$ (3 sf)

d. Zinc is the limiting reactant.

$$n(\text{Zn}) = \frac{m}{M} = \frac{5.0\text{ g}}{65.38\text{ g mol}^{-1}}$$

$= 0.076476\ldots\text{ mol} \approx 0.076\text{ mol}$ (2 sf)

$$\Delta H = -\frac{Q}{n} = -\frac{9.196\text{ kJ}}{0.076476\ldots\text{ mol}}$$

$= -120.246\ldots\text{ kJ mol}^{-1} \approx -120\text{ kJ mol}^{-1}$ (2 sf)

e. It is assumed that

- The specific heat capacity of the solution is equal to that of water.
- All heat from the reaction is transferred to the solution.
- Heat is equally distributed throughout the solution.
- The mass of 1 cm^3 is 1 g.
- The specific heat capacity of the solid zinc is negligible.

Practice questions (page 334)

38. The mass of water should be measured instead of the volume.

The thermometer should not touch the bottom of the calorimeter, so a larger volume of water should be used.

The mass of water used should be sufficient to ensure it does not boil, and the student should ensure that the water does not boil in the minute of heating.

The heating time should be sufficient to ensure a measurable mass of fuel is consumed by combustion.

The spirit burner cap should be replaced immediately after each trial, to prevent solvent loss by evaporation.

The copper calorimeter should be placed at the same height above the spirit burner, and not too far up.

The heat gained by the calorimeter should be taken into account.

The apparatus should be set up in an area protected from draughts.

The student should also note the formation of any soot, which evidences incomplete combustion. Incomplete combustion is an example of a variable that cannot be controlled but should be monitored.

Data-based question (page 334)

m_{water} = 99.92 g – 24.03 g = 75.89 g

ΔT = 60.1 °C – 21.7 °C = 38.4 °C = 38.4 K

Q_{water} = 75.89 g × 4.18 J g^{-1} K^{-1} × 38.4 K = 12181… J = 12.181… kJ

$Q_{calorimeter}$ = 24.03 g × 0.385 J g^{-1} K^{-1} × 38.4 K = 355.3… J = 0.3553… kJ

Q_{total} = 12.181… kJ + 0.3553… kJ = 12.536… kJ

$\Delta m_{butan\text{-}1\text{-}ol}$ = 75.47 g – 74.38 g = 1.09 g

$$n_{butan-1-ol} = \frac{m_{butan-1-ol}}{M} = \frac{1.09\text{ g}}{74.14\text{ g mol}^{-1}} = 0.014702\ldots\text{ mol}$$

$$\Delta H = -\frac{Q}{n} = \frac{12.536\ldots\text{ kJ}}{0.014702\ldots\text{ mol}}$$

$$= -852.71\ldots\text{ kJ mol}^{-1} \approx -853\text{ kJ mol}^{-1}\text{ (3 sf)}$$

Practice questions (page 336)

39. a. To remove traces of previous reagents that may be in the burette and/or pipette. Traces of water in the burette or pipette could interfere with the titration because they would dilute the solution and thus affect the concentration.

b. To know roughly what volume of titrant must be added. This speeds up subsequent titrations.

c. Some water in the conical flask will not alter the number of moles of analyte in the flask, so the same volume of titrant will be needed for the titration. The results will not be affected (as long as this does not affect the visibility of the colour change at the endpoint).

d. Any three:

- Forgetting to rinse the volumetric glassware (burette or pipette) with their respective titration reagents.
- Forgetting to add the indicator to the analyte.
- Using a titrant that has an inexact concentration.
- Misjudging the colour change at the endpoint.
- Misreading the burette readings.
- Allowing air bubbles to form in the tip of the burette.

e. i. $2HCl(aq) + Na_2CO_3(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$

ii. $$n_{Na2CO3} = \frac{m}{M} = \frac{0.300\text{ g}}{105.99\text{ g mol}^{-1}} = 0.0028304\ldots\text{ mol}$$

n_{HCl} = 2 × n_{Na2CO3} = 2 × 0.00283 mol = 0.0056609… mol

$$V_{HCl} = \frac{23.83\text{ cm}^3}{1000} = 0.02383\text{ dm}^3$$

$$c_{HCl} = \frac{n_{HCl}}{V_{HCl}} = \frac{0.0056609\ldots\text{ mol}}{0.02383\text{ dm}^3} = 0.237554\ldots\text{ mol dm}^{-3} \approx 0.238\text{ mol dm}^{-3}\text{(3 sf)}$$

Practice question (page 338)

40. Both

- Contain two electrodes (cathode and anode) and at least one electrolyte
- Involve the interconversion between chemical and electrical energy
- Reduction occurs at the cathode and oxidation, at the anode

Voltaic cells

- Spontaneous transformation of chemical energy into electrical energy
- Usually separated into two half-cells
- Positive cathode and negative anode

Electrolytic cells

- Non-spontaneous transformation of electrical energy into chemical energy
- Use an external power source
- Usually not separated into two half-cells
- Positive anode and negative cathode

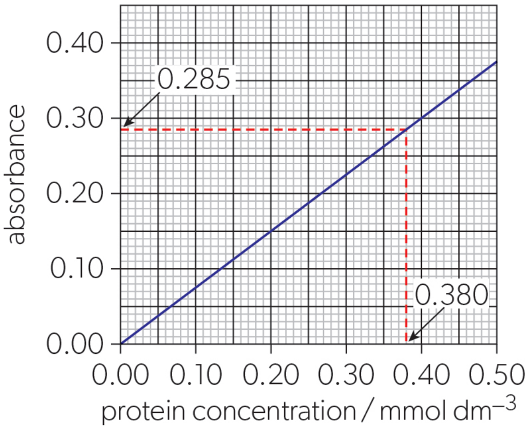
Practice questions (page 340)

41. a. 491 nm is at the boundary between blue and green in the colour wheel. The complementary colours are red and orange. The colour observed would be red-orange, which, in practice, is often referred to as ‘blood red’.

b. $c = \frac{A}{14000} = \frac{0.225}{14000} = 1.61 \times 10^{-5}\ \text{mol dm}^{-3}$

Data-based question (page 340)

The concentration is 0.380 mmol dm^{-3}.



Practice questions (page 341)

42. Answers may include:

Advantages of digital models

- Can be used to build very large molecules
- Files can be saved digitally and shared electronically
- Can be easily interconverted from one representation into another

Disadvantages

- Require availability of hardware and software
- Cannot be physically manipulated

So physical models are useful in school science labs for introducing concepts and digital models are useful for research, as they can be manipulated on screen.

Tool 2 – Technology

Activity (page 342)

1. Answers will vary.
2. Answers will vary.

Practice questions (page 345)

43. a. =0.4/(5*4.18)

b. =AVERAGE(42,32,45,46,48)

c. = -log(0.0034)

d. =10^(-12.5)

e. =MAX(A5:A8)-MIN(A5:A8)

44. a. Finds the maximum value in cells C6 to C10.

b. Adds up the contents of cells D5, E7 and G3.

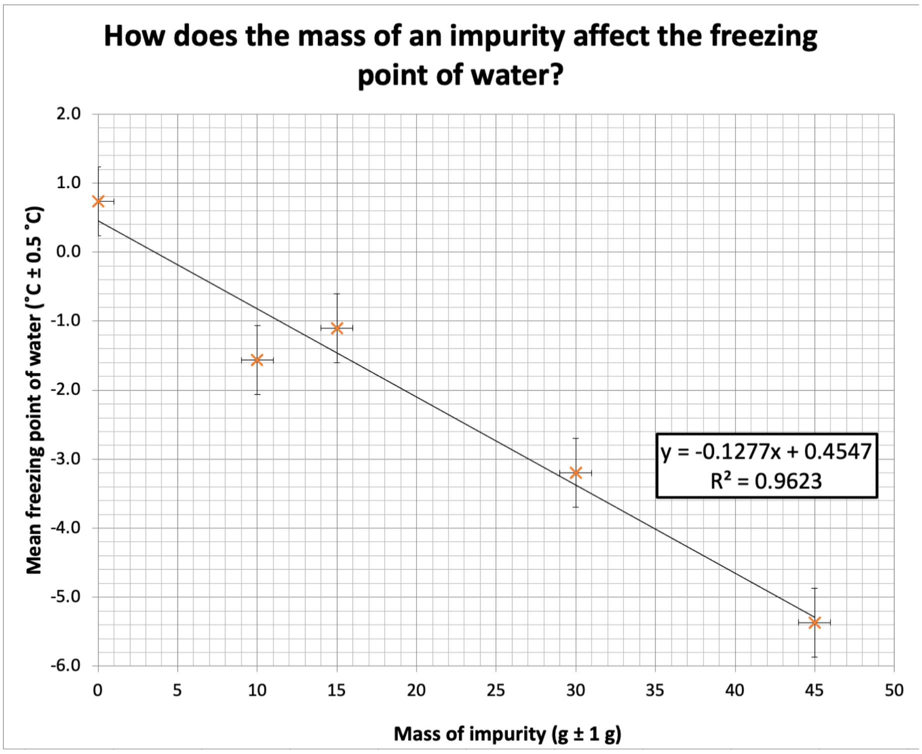
c. The formula computes the following from the values in cells A3, B3 and C4:

$$\frac{A3 \times B3 \times 4.18 \times 46.07}{C4}$$

45. a.

Mass of impurity / g ± 1 g	Freezing point / °C ± 0.5 °C			
	1	2	3	Mean
0	0.8	0.7	0.7	0.7
10	-1.6	-1.7	-1.4	-1.6
15	-1.0	-1.2	-1.1	-1.1
30	-3.2	-3.1	-3.3	-3.2
45	-5.3	-5.5	-5.3	-5.4

b.



Activity (page 346)

1. The purpose of this question is to prompt you to identify and extract data from a database. From this, you can analyse it, probably by plotting a graph, and then use your knowledge of bonding and intermolecular forces (*Structure 2*) to interpret and explain the observed trends.

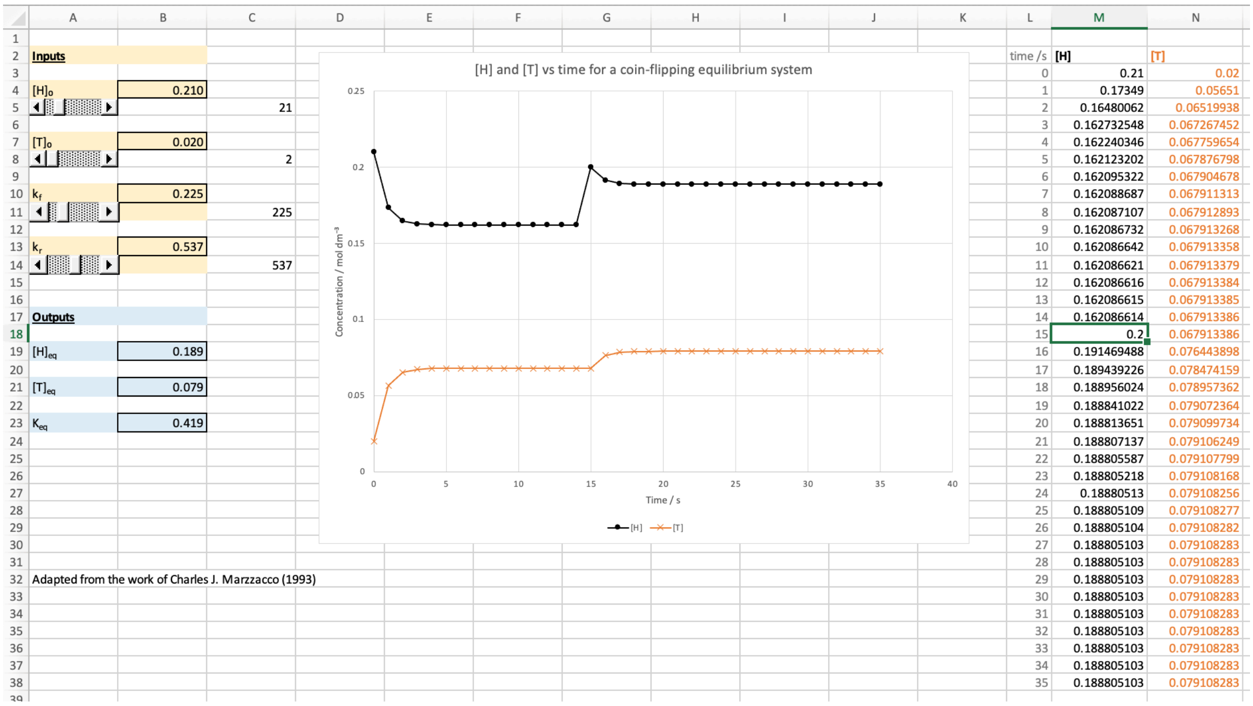
   Note that melting point data can also be found in the IB Chemistry data booklet.

2. Answers will vary.

Activity (page 348)

a. Answers will vary.

b. The graph shows an abrupt increase in the concentration that was manipulated directly (in this case H) and a gradual increase in the concentration of the other species (T) until equilibrium is re-established again. Example:

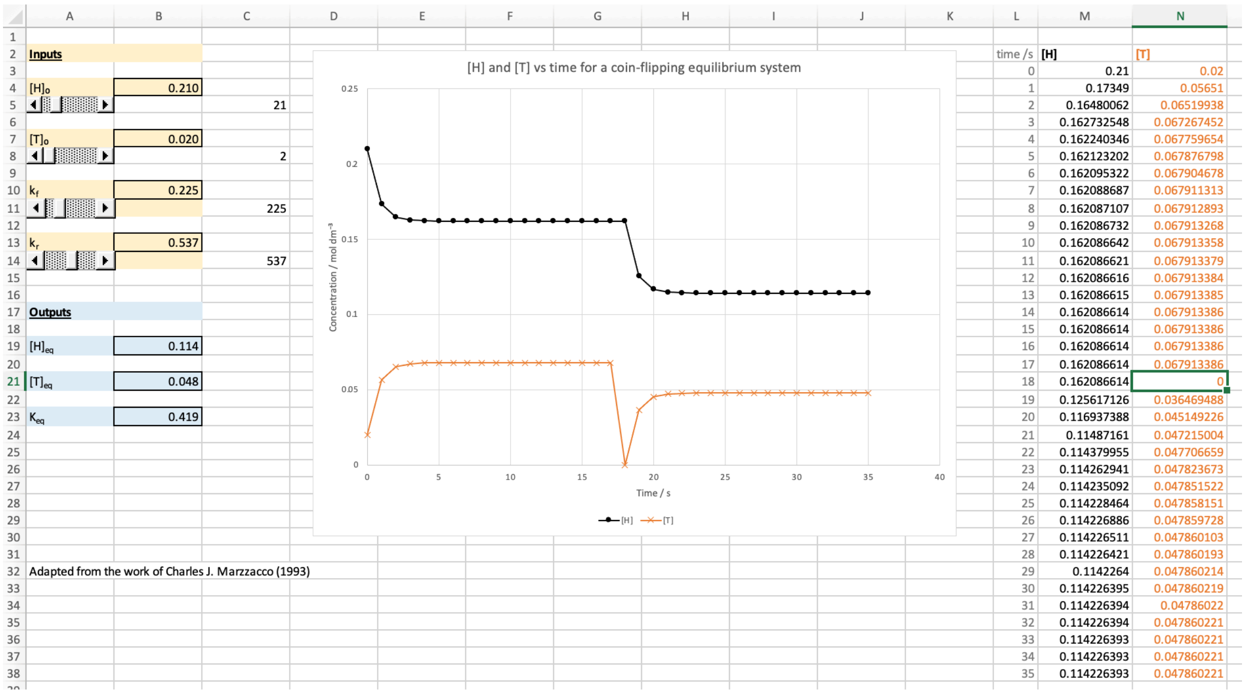


Inputs		
$[H]_o$	0.210	21
$[T]_o$	0.020	2
k_f	0.225	225
k_r	0.537	537
Outputs		
$[H]_{eq}$	0.189	
$[T]_{eq}$	0.079	
K_{eq}	0.419	

Adapted from the work of Charles J. Marzzacco (1993)

time /s	[H]	[T]
0	0.21	0.02
1	0.17349	0.05651
2	0.16480062	0.06519938
3	0.162732548	0.067267452
4	0.162240346	0.067759654
5	0.162123202	0.067876798
6	0.162095322	0.067904678
7	0.162088687	0.067911313
8	0.162087107	0.067912893
9	0.162086732	0.067913268
10	0.162086642	0.067913358
11	0.162086621	0.067913379
12	0.162086616	0.067913384
13	0.162086615	0.067913385
14	0.162086614	0.067913386
15	0.2	0.067913386
16	0.191469488	0.076443898
17	0.189439226	0.078474159
18	0.188956024	0.078957362
19	0.188841022	0.079072364
20	0.188813651	0.079099734
21	0.188807137	0.079106249
22	0.188805587	0.079107799
23	0.188805218	0.079108168
24	0.18880513	0.079108256
25	0.188805109	0.079108277
26	0.188805104	0.079108282
27	0.188805103	0.079108283
28	0.188805103	0.079108283
29	0.188805103	0.079108283
30	0.188805103	0.079108283
31	0.188805103	0.079108283
32	0.188805103	0.079108283
33	0.188805103	0.079108283
34	0.188805103	0.079108283
35	0.188805103	0.079108283

c. Manually enter a lower concentration value to one of the cells and observe the effect on the graph. The concentration of the manipulated species (in this case T) will decrease abruptly. The other species' concentration will gradually adjust until equilibrium is re-established.



Inputs		
$[H]_o$	0.210	21
$[T]_o$	0.020	2
k_f	0.225	225
k_r	0.537	537
Outputs		
$[H]_{eq}$	0.114	
$[T]_{eq}$	0.048	
K_{eq}	0.419	

Adapted from the work of Charles J. Marzzacco (1993)

time /s	[H]	[T]
0	0.21	0.02
1	0.17349	0.05651
2	0.16480062	0.06519938
3	0.162732548	0.067267452
4	0.162240346	0.067759654
5	0.162123202	0.067876798
6	0.162095322	0.067904678
7	0.162088687	0.067911313
8	0.162087107	0.067912893
9	0.162086732	0.067913268
10	0.162086642	0.067913358
11	0.162086621	0.067913379
12	0.162086616	0.067913384
13	0.162086615	0.067913385
14	0.162086614	0.067913386
15	0.162086614	0.067913386
16	0.162086614	0.067913386
17	0.162086614	0.067913386
18	0.162086614	0
19	0.125617126	0.036469488
20	0.116937388	0.045149226
21	0.11487161	0.047215004
22	0.114379955	0.047706659
23	0.114262941	0.047823673
24	0.114235092	0.047851522
25	0.114228464	0.047858151
26	0.114226886	0.047859728
27	0.114226511	0.047860103
28	0.114226421	0.047860193
29	0.1142264	0.047860214
30	0.114226395	0.047860219
31	0.114226394	0.04786022
32	0.114226394	0.047860221
33	0.114226393	0.047860221
34	0.114226393	0.047860221
35	0.114226393	0.047860221

d. Answers will vary. For example:
- It assumes constant temperature.
- The calculation for K assumes that the reaction has reached equilibrium after 35 s. However, this is not the case at very low rate constant values.
- At high rate constant values, the concentration values fluctuate unrealistically at the start.

e. Answers will vary.

Activity (page 349)

a. Replacing the H atoms with methyl groups causes the bond angle to increase.

b. **i.** Answers will vary depending on the software used.

ii. Answers will vary. Possible extensions include:
- Investigating the effect of a halogen substituent on the bond angle and bond length in a different set of molecules, e.g. halogenoalkanes.
- Comparing modelled data to experimental data extracted from a molecular geometry database.
- Comparing the results of replicates and across different molecular editing software.

Tool 3 – Mathematics

Practice questions (page 350)

46. metre, cubic centimetre, pascal, kelvin, metre per second

47. **a.** second, s

b. joule, J

c. m^3

d. mol

e. pascal, Pa

48. **a.** time for reaction to happen = 16 s

The symbol for seconds is s, not sec.

b. temperature = 304 K

Temperature in kelvin is stated without the degree symbol.

c. enthalpy of reaction = -77.5 kJ mol^{-1}

There should be a space between different unit symbols, i.e. kJ and mol^{-1}.

d. mass = 0.33 g

There should be a space between the value and its unit.

e. melting point = 409 K

Fahrenheit is not an SI unit.

f. density = 0.78 g/dm^3 or 0.78 g dm^{-3}

g. volume = 500 cm^3

The symbol for cubic centimetres is cm^3.

h. amount = 0.5 mol

A decimal marker should be preceded by a number.

i. The SI unit for amount is mole. This mass should be converted to moles by dividing by the substance's molar mass.

j. R = 8.31 J K^{-1} mol^{-1}

There should be a space between different unit symbols.

Practice questions (page 352)

49. ± 0.5 cm^3

50. pH probe: 9.11 ± 0.01 (pH values have no units)

thermometer: 88.2 °C ± 0.5 °C

voltmeter: 1.20 V ± 0.05 V

Data-based questions (page 354)

a. Mean = 45.0667… cm^3 ≈ 45.1 cm^3 (1 dp)

b. Range = 47.7 cm^3 – 43.5 cm^3 = 4.2 cm^3

Half the range = 2.1 cm^3

Half-range uncertainty = ± 2 cm^3 (uncertainties are usually stated to 1 significant figure)

c. Difference between mean and maximum value = 47.7 cm^3 – 45.1 cm^3 = 2.6 cm^3

Difference between mean and minimum value = 45.1 cm^3 – 43.5 cm^3 = 1.6 cm^3

The furthest from the mean is 2.6 cm^3, which gives an uncertainty of ± 3 cm^3 if we round it to one significant figure, which is customary for uncertainties.

d. When different uncertainty estimates are possible, it is common practice to choose the largest. In this case, the largest of the three possible uncertainties is ± 3 cm^3 (± 0.5 cm^3 from the instrument, ± 2 cm^3 from the half-range method, ± 3 cm^3 from the furthest-from-the-mean method).

Activity (page 356)

Measured value	Absolute uncertainty	Percentage uncertainty	Relative uncertainty
19.96 cm^3	± 0.04 cm^3	± 0.2004% ≈ ± 0.2%	± 0.002004 ≈ ± 0.002
1.08 V	± 0.0216 V ≈ ± 0.02 V	± 2%	± 0.02
78.5 °C	± 0.785 °C ≈ ± 0.8 °C	± 1%	± 0.01

Data-based questions (page 362)

a. Mass of butanol = 49.38 g – 42.82 g = 6.56 g

b. Density of butanol = $\dfrac{6.56\ \text{g}}{8.1\ \text{cm}^3}$ = 0.80988… g cm^{-3} ≈ 0.81 g cm^{-3} (2 sf)

c. Mass uncertainty, $u(m)$ = ± 0.01 g + ± 0.01 g

= ± 0.02 g

$$\text{Density uncertainty}, u(D) = \left(\frac{\pm\ 0.02\ \text{g}}{6.56\ \text{g}} + \frac{\pm\ 0.5\ \text{cm}^3}{8.1\ \text{cm}^3}\right) \times 100\%$$

= ± 6.4777…% ≈ ± 6% (1 sf)

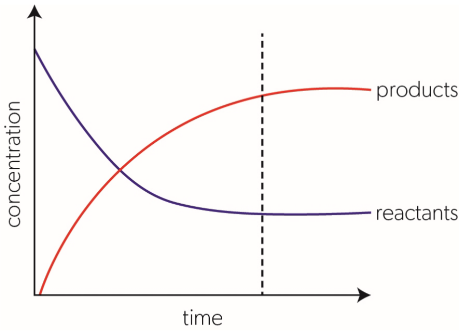
i. $\text{absolute uncertainty} = \dfrac{\pm\ 6}{100} \times 0.81\ \text{g cm}^{-3}$

= ± 0.0486 g cm^{-3} ≈ ± 0.05 g cm^{-3} (1sf)

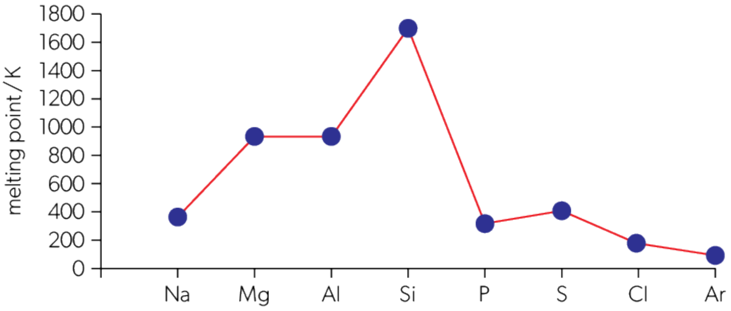
ii. $\text{relative uncertainty} = \dfrac{\pm\ 6}{100} = \pm\ 0.06$

Activity (page 363)

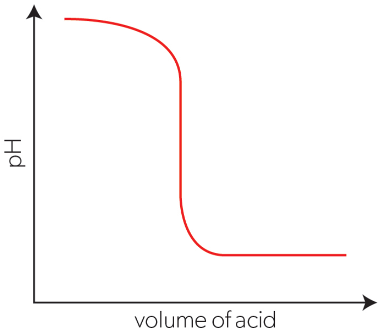
a.



b.



c.



Activity (page 365)

Answers will vary. Example:

Anode	Cathode	Potential difference, *V* / ± 0.01 V			
		1	2	3	Mean
copper	silver	0.50	0.53	0.51	0.51
zinc	copper	0.80	0.78	0.74	0.77
zinc	silver	1.30	1.25	1.27	1.27
magnesium	zinc	1.54	1.43	*1.23	1.49
magnesium	copper	2.05	2.00	*1.34	2.03

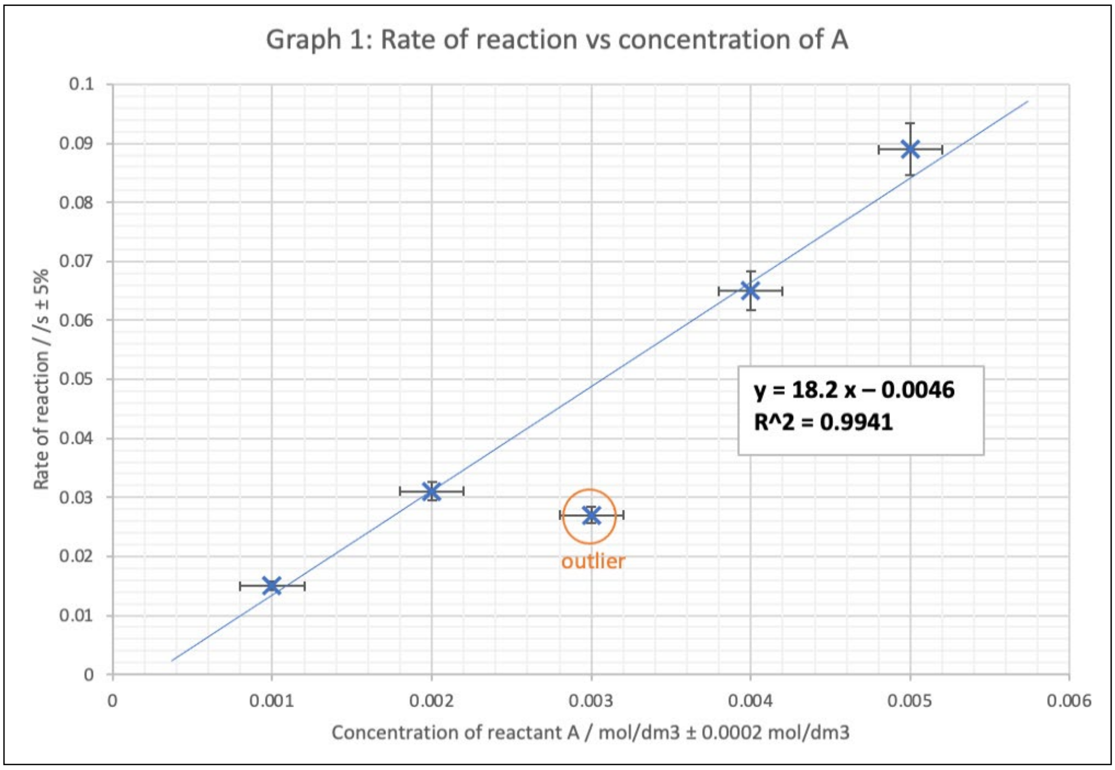
*These values are anomalies and have been excluded from the mean values.

Data-based questions (page 368)

1. The outlier is the temperature measurement taken at 1.5 minutes.
2. The log scale is useful because the ionization energy values cover a huge range. Plotting their logs allows us to condense the values into a smaller space, thus revealing trends that would otherwise be too difficult to identify.

Data-based questions (page 370)

Answers will vary. Example:



The third point is the outlier – the rate should not be lower than the preceding concentration. Note that the line of best fit goes through the error bars on all the points except this one. Whatever experimental error that caused this outlier, it led to a lower rate being measured. Possible errors include:

- stopping the timer too late
- starting the timer too early
- lower concentration of aqueous reagents
- lower temperature

Data-based questions (pages 377–378)

1. **a.** Positive

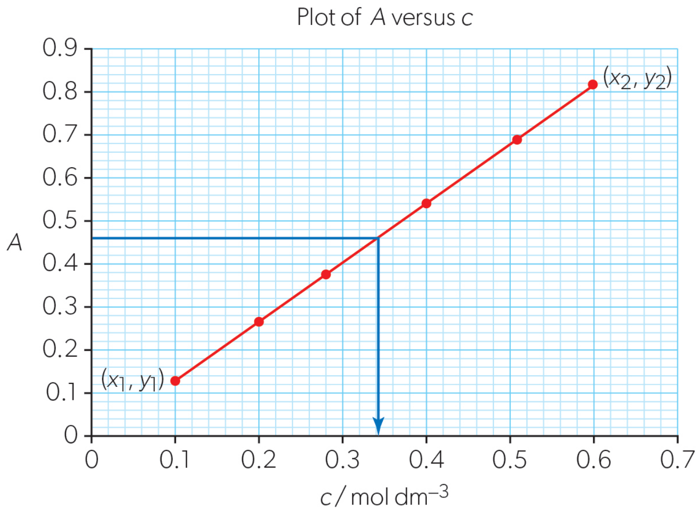
   b. No. The line does not go through (0,0), and the x and y values do not rise by the same ratio. Relationships are directly proportional when, for example, if you double the value of one variable, the other one doubles, too.

   c. $\frac{104 - 84}{24 - 7}$

   $= 1.1765\ldots\ \text{mm}^3\ {}^\circ\text{C}^{-1} = 1.2\ \text{mm}^3\ {}^\circ\text{C}^{-1}$ (2 sf)

   d. The volume of the sample of air rises by 1.2 mm^3 for every 1 °C temperature increase.

2. **a.**



b. See blue arrow above; unknown concentration is approx. 0.34 mol dm^{-3}

c. Using technology (a graphing software or a GDS) gives:

gradient = 1.357 mol^{-1} dm^3

≈ 1.4 mol^{-1} dm^3 (2 sf)

y-intercept = 0.0039

The equation is therefore A = (1.357 mol^{-1} dm^3) × c + 0.0039

d. The relationship is not quite directly proportional, because the line does not go through (0,0). However, since the y-intercept is close to zero, if measurement uncertainty data were available, we would be able to establish whether (0,0) is within the uncertainty.

3. **a.** $$\text{rate} = \frac{15\ \text{cm}^3}{25\ \text{s}}$$

= 0.60 cm^3 s^{-1}

b. The curve for experiment 2 at 25 s is not as steep as the curve for experiment 1. This suggests that the gradient is lower at this point, and therefore the rate is also lower. Experiment 2 has a higher overall rate. At t = 25 s, more of the reactants have reacted in experiment 2 than in experiment 1, hence the rate at this point is lower.

c. Experiment 2 has a higher overall rate because it is carried out at a higher temperature. The curve for experiment 2 rises steeply, indicating a high initial rate. It tapers off sooner than the experiment 1 curve, showing that experiment 2 reaction completes sooner than experiment 1. Reactions are faster at higher temperatures because the kinetic energy of the particles is greater, increasing the frequency of particle collisions. In addition, at higher temperatures, the proportion of particles with $E \geq E_A$ is greater, leading to a higher rate of successful collisions.

4. **a.** Using the points (0, 3.40 × 10^{-8}) and (15, 2.0 × 10^{-8}):

$$\text{rate} = \left|\frac{(2.0 \times 10^{-8}) - (3.40 \times 10^{-8})}{15 - 0}\right|$$

= 9.333…× 10^{-10} mol dm^{-3} s^{-1}

= 9.3 × 10^{-10} mol dm^{-3} s^{-1} (2 sf)

Answers will vary slightly depending on which points are selected for the gradient calculation.

b. $$\text{average rate} = \left|\frac{(1.50 \times 10^{-8}) - (3.40 \times 10^{-8})}{30 - 0}\right|$$

= 6.333… × 10^{-10} mol dm^{-3} s^{-1}

= 6.33 × 10^{-10} mol dm^{-3} s^{-1} (3 sf)

c. Part (a) gives a value for the initial rate, whereas part (b) gives the average rate over the first 30 seconds of the reaction. The initial rate of reaction is highest, after which the rate decreases. Compared to (a), the value for (b) is lower because (b) takes the average of the initial rate and the rates that follow it up until t = 30 s, which are all lower.

Data-based questions (page 382)

1. a. 19.5 °C

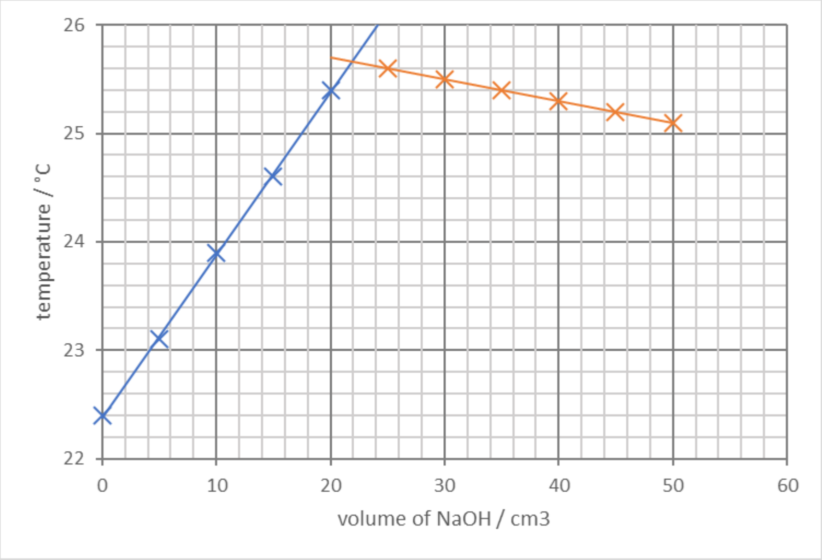
b. Exothermic; energy was released and the temperature increased.

c. To correct for heat loss to the surroundings.

d. Calculating Q: mass of copper(II) sulfate solution.

Calculating ΔH: volume and concentration of copper(II) sulfate, mass of zinc

2. a.



b. T_{max} = 25.7 °C

c. $$c(\text{HCl}) = \frac{V(\text{NaOH}) \times c(\text{NaOH})}{V(\text{HCl})}$$

$= 0.53\ \text{mol dm}^{-3}$

d. $Q = mc\Delta T$

$= 648.318\ \text{J}$

$$\Delta H = -\frac{Q}{n}$$

$$= -\frac{648.318}{0.02200\ \text{dm}^3 \times 0.600\ \text{mol dm}^{-3}}$$

$= -49115\ \text{J mol}^{-1} = -49\ \text{kJ mol}^{-1}$

Practice questions (page 384)

51. a. Systematic

b. Systematic

c. Systematic

d. Random

52. $$\text{percentage error} = \left|\frac{-1430-(-2676)}{-2676}\right|$$

$= 46.56203\ldots\% = 46.6\%$ (3 sf)

53. a. Student C: 39%

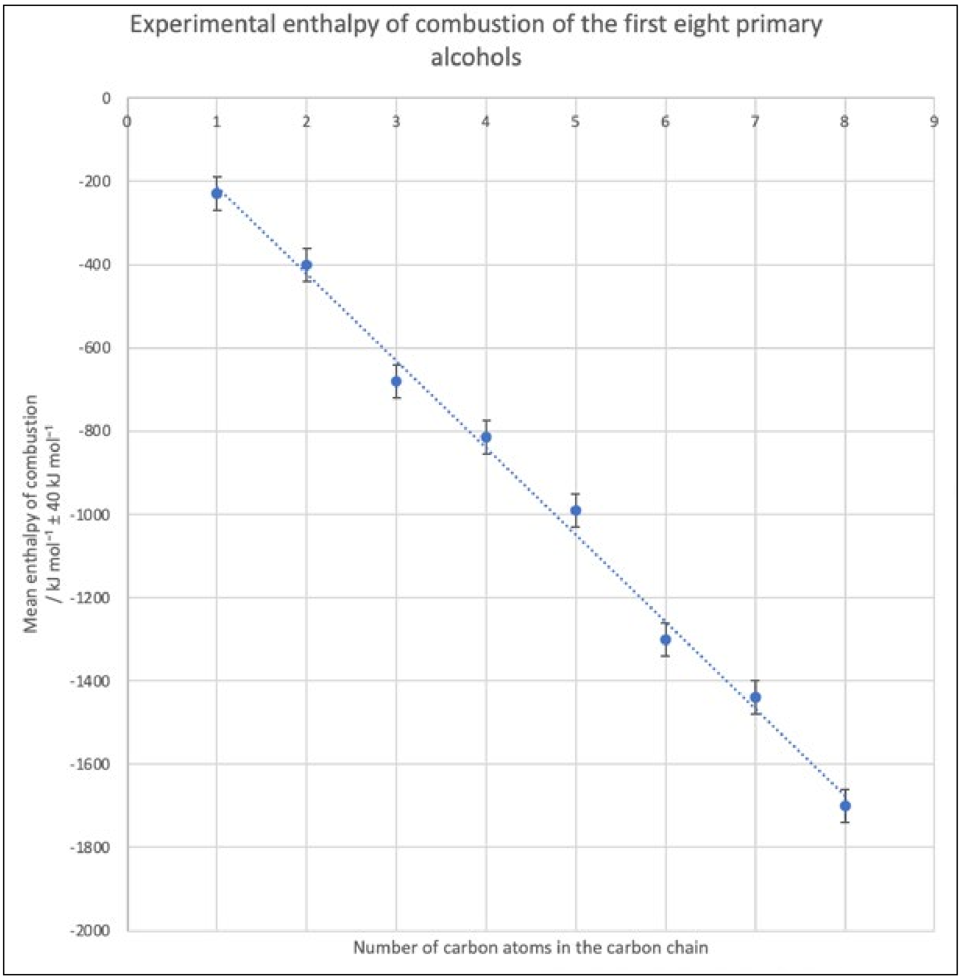
Student D: 12%

b. Student C: We can observe that the random error is relatively low because the result's uncertainty (± 4%) is relatively low, especially in comparison to the percentage error (39%: nearly ten times the random error!). The result and its uncertainty represent the range between –31 and –39 kJ mol^{-1}. The theoretical value does not lie within this range. This inaccuracy is probably due to the presence of significant systematic error.

Student D: We can observe significant impact of random error on the result. The uncertainty (± 10%) is high, and comparable to the percentage error (12%). The result and its uncertainty represent a range from –40 to –60 kJ mol^{-1}. The theoretical value falls within this range.

Practice questions (page 385)

54. a.



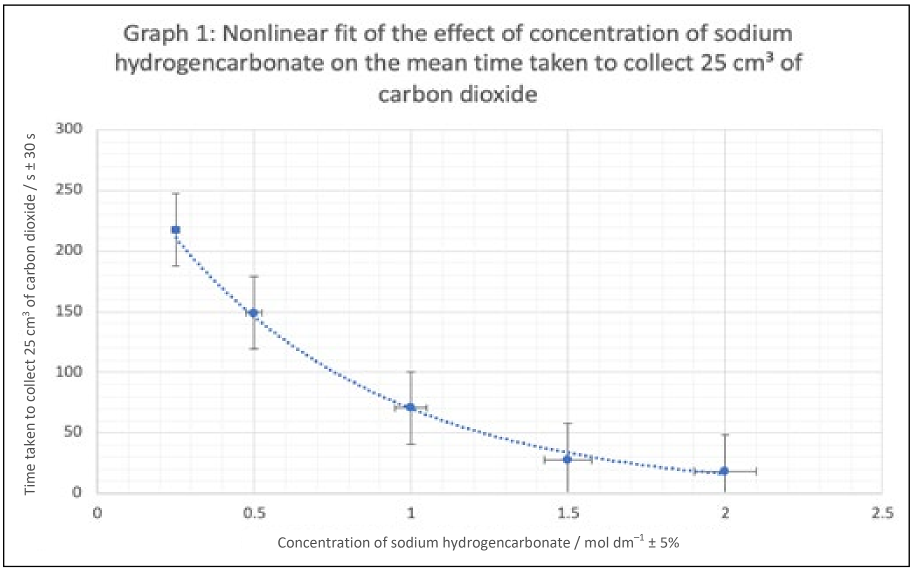
b. The magnitudes of the experimental values are all significantly smaller than the published ΔH values, indicating that the impact of systematic error was significant.

c. The points do not all fall on the line of best fit but the line of best does go through most of the error bars and there are no obvious outliers. This suggests that some random error was present. However, in spite of the presence of random error, it can be observed that the relationship between combustion enthalpy and carbon chain length is negative and linear.

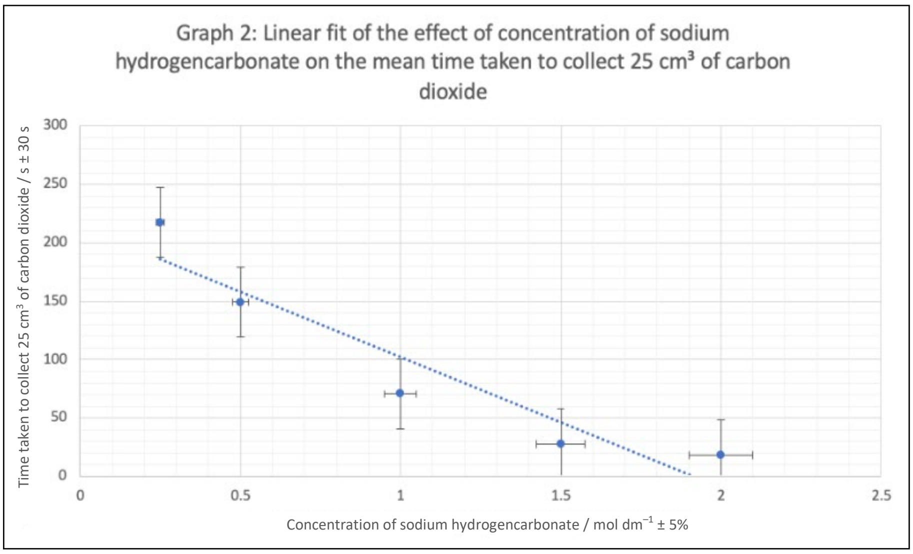
55. a, b.

Concentration of sodium hydrogencarbonate / mol dm^{-3} ± 5%	Time taken to produce 25 cm^3 of carbon dioxide / s ± 1 s						
	1	2	3	Mean	½ range	Percentage uncertainty	Percentage uncertainty (1 sf)
0.25	210	277	166	218	56	25	30
0.50	195	135	118	149	39	26	30
1.00	66	93	53	71	20	28	30
1.50	21	27	35	28	7	25	30
2.00	15	25	15	18	5	27	30

c.



Graph 1: Nonlinear fit of the effect of concentration of sodium hydrogencarbonate on the mean time taken to collect 25 cm³ of carbon dioxide



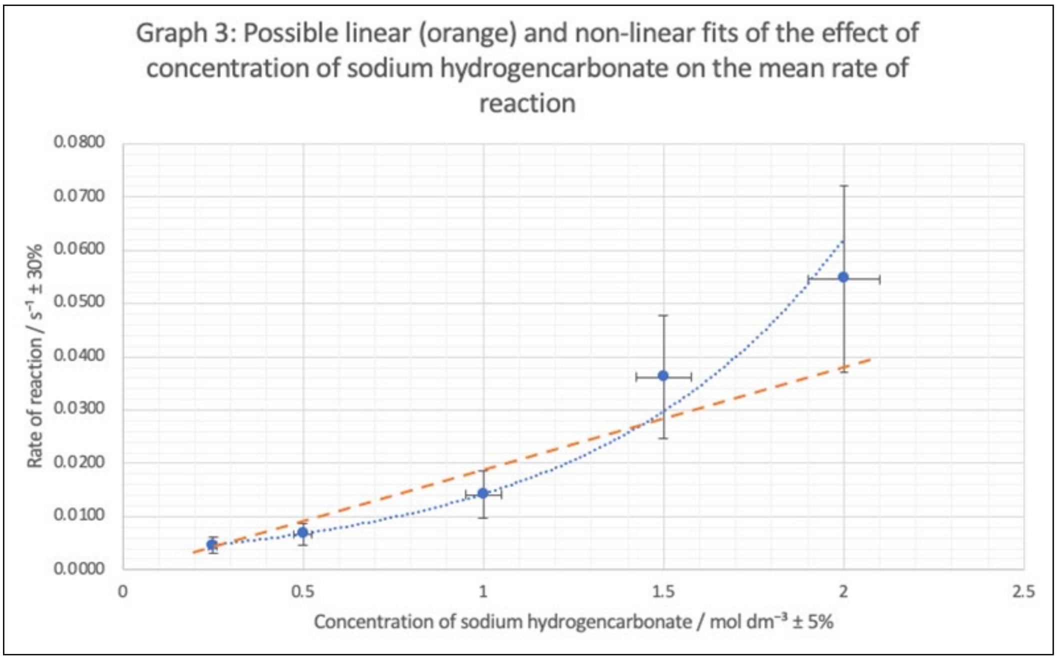
Graph 2: Linear fit of the effect of concentration of sodium hydrogencarbonate on the mean time taken to collect 25 cm³ of carbon dioxide

d. The error bars are large, indicating significant random error. Graph 1 and graph 2 show non-linear and linear fits, respectively. Due to the large random error, there is no clear evidence in these graphs that favours one fit over the other.

e.

Concentration of sodium hydrogencarbonate / mol dm^{-3} ± 5%	Time taken to produce 25 cm^3 of carbon dioxide / s ± 1 s				Rate of reaction / s^{-1} ± 30%
	1	2	3	Mean	
0.25	210	277	166	218	0.0046
0.50	195	135	118	149	0.0067
1.00	66	93	53	71	0.014
1.50	21	27	35	28	0.036
2.00	15	25	15	18	0.055

f.



Graph 3: Possible linear (orange) and non-linear fits of the effect of concentration of sodium hydrogencarbonate on the mean rate of reaction

g. Two possible fits, one linear, one non-linear, are shown in graph 3. Neither one goes through the origin, which we would expect given that at a concentration of zero the rate is also zero. The non-zero intercepts suggest the presence of systematic errors. The impact of random error is significant. Due to the large error bars, a variety of fits would suit the data. The relationship between sodium hydrogencarbonate and rate is positive, but we are unable to conclude whether the relationship is linear or not.