Cambridge Assessment International Education

Practical Booklet 4
Enthalpy changes

Cambridge International AS & A Level
Chemistry 9701

Version 2.0

Cambridge Pathway

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Introduction

Practical work is an essential part of science. Scientists use evidence gained from prior observations and experiments to build models and theories. Their predictions are tested with practical work to check that they are consistent with the behaviour of the real world. Learners who are well trained and experienced in practical skills will be more confident in their own abilities. The skills developed through practical work provide a good foundation for those wishing to pursue science further, as well as for those entering employment or a non-science career.

The science syllabuses address practical skills that contribute to the overall understanding of scientific methodology. Learners should be able to:

- plan experiments and investigations
- collect, record and present observations, measurements and estimates
- analyse and interpret data to reach conclusions
- evaluate methods and quality of data, and suggest improvements.

The practical skills established at AS Level are extended further in the full A Level. Learners will need to have practised basic skills from the AS Level experiments before using these skills to tackle the more demanding A Level exercises. Although A Level practical skills are assessed by a timetabled written paper, the best preparation for this paper is through extensive hands-on experience in the laboratory.

The example experiments suggested here can form the basis of a well-structured scheme of practical work for the teaching of AS and A Level science. The experiments have been carefully selected to reinforce theory and to develop learners' practical skills. The syllabus, scheme of work and past papers also provide a useful guide to the type of practical skills that learners might be expected to develop further. About 20% of teaching time should be allocated to practical work (not including the time spent observing teacher demonstrations), so this set of experiments provides only the starting point for a much more extensive scheme of practical work.

Guidance for teachers

Aim

To determine the enthalpy change for a metal displacement reaction by adding a known mass of zinc powder to excess of aqueous copper (II) sulfate solution and recording the rise in temperature.

Outcomes

Syllabus section 5.1(a), 5.1(b)(i), 1.5(b)(i) and (iii), 5.1(c), 5.2(a) and 6.1(a)(ii) as well as experimental skills 2, 3 and 4

Further work: syllabus section 7.2(b) and experimental skill 1

Skills included in the practical

AS Level skills		How learners develop the skills
Manipulation, measurement and observation	*Successful collection of data and observations*	set up and use the apparatus to the level of precision indicated
	Quality of measurements or observations	obtain results that are close to those of an experienced chemist
Presentation of data and observations	*Recording data and observations*	record the times and temperatures with appropriate headings and units
	Display of calculation and reasoning	show the level of precision of their thermometer readings show working in the calculation and use significant figures appropriate to the precision of measurements
	Data layout	results clearly tabulated
Analysis, conclusions and evaluation	*Interpretation of data or observations and identifying sources of error*	calculate numbers of moles of reactants and the enthalpy change of the reaction
	Drawing conclusions	determine whether an exo- or endothermic reaction has taken place
	Suggesting improvements	suggest ways to improve the accuracy of the procedure suggest ways in which to extend the investigation to answer a new question

Method

Safety

- Learners must wear safety glasses for this investigation.

- This technique can be used to determine enthalpies of reaction for a variety of reactions involving solutions. The reaction must be fast enough to be complete within a few minutes (otherwise there is too much heat loss) and it is normal that one of the reactants is used in excess.

- Temperatures are always measured to half of the smallest graduation on the thermometer. In examinations, thermometers reading to 1 ºC are specified, so learners should be trained to read them to the nearest 0.5 ºC. Solutions must always be stirred thoroughly before any temperature is recorded and the bulb of the thermometer must be totally immersed in the solution.

- Learners should be taught how to carry out calculations of ΔH from the temperatures they measure. They should understand why it important to identify which reagent is in excess. They should remember that, for exothermic reactions, ΔH is negative and that ΔH is positive when the reaction proceeds with a decrease in temperature.

- Foamed plastic (polystyrene) cups provide a reasonable level of insulation against heat loss. Plotting a cooling curve provides a correction for heat that is inevitably lost while a reaction is taking place. Method B (see Worksheet) therefore provides more accurate values of ΔH.

- Learners should become familiar with using the apparatus provided so they can perform experiments accurately.

- **Extension involving Hess' Law**: learners could react magnesium turnings **[F]** with excess $CuSO_4$(aq), and determine the enthalpy change for this reaction. Using the ΔH value for the reaction of zinc with $CuSO_4$(aq), Hess' Law can be used to determine the ΔH value for the reaction of magnesium turnings with zinc sulfate solution.

- These techniques can be used for **further work** when studying strong and weak acids and alkalis. Learners can plan a suitable method and concentrations of reactants to use, in order to investigate whether the overall enthalpy change of reaction differs for strong and weak acids and alkalis when mixed in different combinations in neutralisation reactions.

Results

Learners should tabulate results showing a consistent number of decimal places in the balance readings and all thermometer readings recorded to either #.0 or #.5 °C. Headings should be unambiguous with units shown as / g or (g) and / °C or (°C), as specified in the syllabus.

Interpretation and evaluation

- The equations $n = m/A_r$ and $n = cV$ can be introduced or revised.

- The appropriate number of significant figures can be discussed. Answers to 2 – 4 sf are appropriate given the precision of the measuring instruments. The accuracy of the procedure is not as great as for a titration exercise, and in some experiments ΔT may be < 10.0 °C, so answers to 2 sf are acceptable, especially if a 1 dp balance is used.

- Errors in measurements made with balances, measuring cylinders and thermometers can be discussed. The difference between needing one reading (as in a measuring cylinder) and two readings (for the mass of zinc or the change in temperature) can be linked to maximum percentage errors. Heat energy losses can be discussed.

- Ways of reducing the inaccuracies can be discussed.

  (i) A lid with a hole for the thermometer can be used to reduce heat energy losses by convection. (The plastic cup should be of foamed plastic so would be a very poor conductor of heat. The supporting beaker further reduces heat losses by conduction.)

  (ii) A thermometer calibrated to 0.2 °C can be used so that the maximum error is ± 0.1 °C (max % error for ΔT = 37 ºC is 2.7% when using a thermometer accurate to ± 0.5 °C).

  (iii) The volume of $CuSO_4$(aq) can be measured with a burette (more precisely calibrated than a measuring cylinder) so that the volume of solution heated would be more accurate.

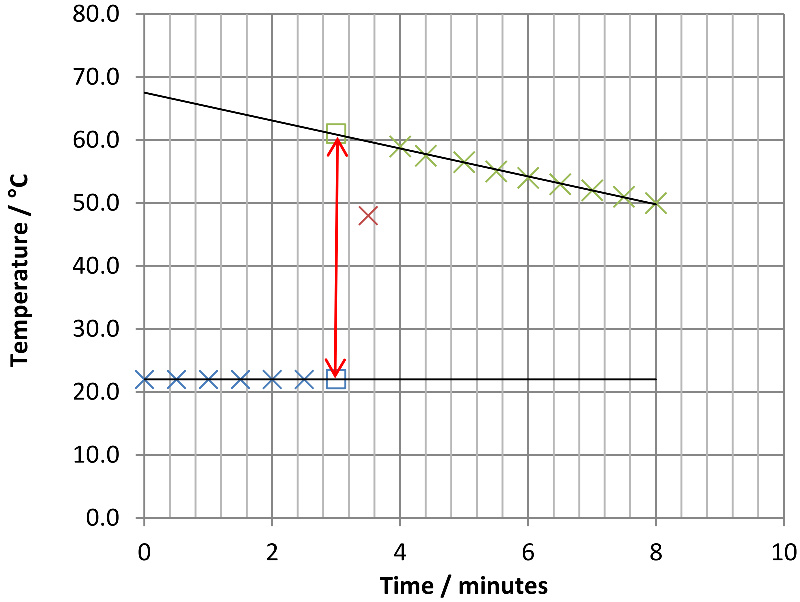
(iv) The amounts of reactants can be scaled up to decrease errors in volume and mass measurements. In any proposed scaling the $CuSO_4$ must remain in excess. (The use of a balance accurate to more dp is not significant unless the balance used in the experiment was to 1 dp.)

Typical results
Initial mass of weighing boat / g = 2.54
Mass of weighing boat and zinc / g = 4.57
Final mass of weighing boat / g = 2.55
Mass of zinc added / g = 2.02
Volume of aqueous $CuSO_4$ used = 40 cm^3
Initial temperature reading / ºC = 22.0
Final temperature reading / ºC = 59.0
Temperature change / ºC = 37.0

Calculation (unrounded values may be carried in the calculator)
Heat energy given out =$mc\Delta T$ = 40 x 4.18 x 37 = 6186 = 6.19 x 10^3 J

Moles of Zn = 2.02 / 65.4 = 3.09 x 10^{-2} mol
ΔH = – 6186 / (3.09 x 10^{-2} x 10^3) = – 200 kJ mol

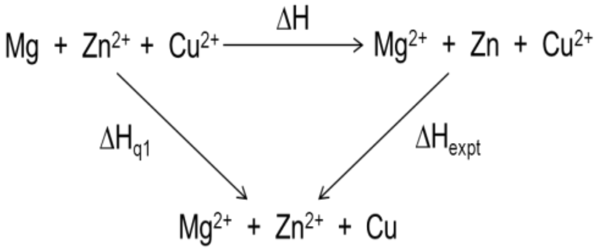
Graph of results for **Method B**



Temperature rise at 3 minutes = 61.0 – 22.0 = 39.0 °C; ΔH = – 211 kJ mol^{-1}

Questions

Discussion of which atoms / ions are taking part in the reactions leads to a suitable Hess' Law diagram.



(Using the results and data given in the learner section,
ΔH = –320 – (–200) = –120 kJ mol^{-1};
theoretical value = – (–153.89) + (–466.85) = –312.96 = –313 kJ mol^{-1}.)

Extension

If the extension practical exercise is carried out then possible reasons for the larger difference in ΔH for the experiment with magnesium turnings with copper sulfate solution from the theoretical value using $\Delta H_f^{\ominus}$ compared with that for zinc powder can be discussed. Learners may note some bubbling when magnesium is added to copper sulfate solution showing a competing reaction (releasing hydrogen) is occurring.

Further work

The students can plan an experiment to determine the enthalpy change of neutralisation reactions. This can be carried out in groups with each using a different combination of strong and weak acids and alkalis. This supports learning objective 5.1(b)(ii) and links up with learning objective 7.2(b) in addition to those listed above. Discussion can help learners decide what volumes and concentrations would give them a sensible temperature rise.

Information for technicians

Each learner will require:		
	(a)	Eye protection
	(b)	1 × 250 cm^3 beaker
	(c)	1 × foamed plastic (polystyrene) cup approximately 150 cm^3
	(d)	1 × thermometer (–10 ºC to +110 ºC at 1 ºC)
	(e)	1 × weighing boat or 100 cm^3 beaker
	(f)	1 × 50 cm^3 measuring cylinder
	(g)	access to a balance reading to **at least** 1 dp
[MH] [N]	(h)	50.0 cm^3 1.0 mol dm^{-3} copper(II) sulfate
[F] [N]	(i)	2.0 ± 0.1 g zinc powder (supplied in a stoppered container)

Extension:
Apparatus and 1.0 mol dm^{-3} copper(II) sulfate as above

[F]	(j)	0.8 ± 0.1 g magnesium turnings (supplied in a stoppered container)

Hazard symbols

GHS02 (flammable **F**)	GHS03 (oxidising **O**)
GHS05 (corrosive **C**)	GHS06 (acutely toxic **T**)
GHS07 (moderate hazard **MH**)	GHS08 (health hazard **HH**)
GHS09 (hazardous to the aquatic environment **N**)	

Worksheet

Aim

To determine the enthalpy change for a metal displacement reaction by adding a known mass of zinc powder to excess aqueous copper(II) sulfate solution and recording the rise in temperature.

Method A

Safety
• Wear eye protection. • 1.0 mol dm^{-3} copper(II) sulfate **[MH] [N]** • zinc powder **[F] [N]**

(1) Weigh the container with zinc.

(2) Support the plastic cup in a 250 cm^3 beaker.

(3) Using a 50 cm^3 measuring cylinder, pour 40 cm^3 of the copper(II) sulfate solution into the plastic cup.

(4) Measure the temperature of the copper(II) sulfate solution. Record your thermometer reading.

(5) Add all the zinc from the container to the copper(II) sulfate solution in the plastic cup.

(6) Use the thermometer to stir the mixture gently while the reaction takes place. (It is usually poor practice to stir a mixture with a thermometer. However, it is acceptable here because it is less likely that the thermometer will break with a plastic cup being used.)

(7) Measure and record the highest temperature reached.

(8) Reweigh the empty container (with any traces of zinc remaining). Record this mass. Calculate and record the mass of zinc used.

(9) Record the change in temperature and the mass of zinc powder added.

(10) If there is time, repeat the whole experiment.

Method B

Carry out steps (1)–(3) as in **Method A**

Draw a table for your results. You will be taking thermometer readings almost every ½ minute for 8 minutes.

Measure the temperature of the copper(II) sulfate solution. Record your thermometer reading. This is the temperature at time = 0.

Start the stop clock and take the temperature of the copper(II) sulfate solution every ½ minute for 2½ minutes. Record all your thermometer readings.

At 3 minutes add all the zinc to the copper(II) sulfate solution in the plastic cup.

Use the thermometer to stir the mixture gently while the reaction takes place.

Measure and record the temperature of the mixture every ½ minute from 3½ minutes to 8 minutes.

Reweigh the empty container (with any traces of zinc remaining). Record this mass. Calculate and record the mass of zinc used.

Plot a graph of temperature / °C (*y*-axis) against time / minutes (*x*-axis).

Worksheet, *continued*

(11) Read the new level of the alkali in the burette. (Remember, the meniscus should be at eye level.) Record this final burette reading in your result table.

(12) Discard the contents of the conical flask, wash it with water and discard the washings.

(13) Pipette 25.0 cm^3 of acid solution into the conical flask and add indicator.

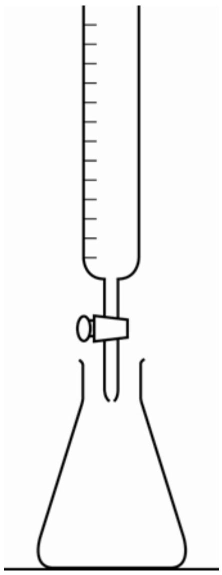
(14) If needed, top up the burette with the aqueous sodium hydroxide, take a reading of the level and record it. This is the initial burette reading

(15) Carry out an 'accurate' titration. Add aqueous sodium hydroxide from the burette to the aqueous amidosulfonic acid until the indicator just stays blue (or just stays yellow with methyl orange) when the solution is swirled. You should add the alkali a drop at a time, when close to the end point, until the colour of the indicator changes.

(16) Take the new reading of the alkali level and record it. This is the final burette reading.

(17) Repeat steps 15 – 19 until you have 2 concordant 'accurate' titres, that is, titres no more than 0.10 cm^3 apart.

Diagram of apparatus



Results

Record **all** your observations.

Tabulate the initial and final burette readings and titres (volume used) for the rough titration and as many accurate titres as deemed necessary with unambiguous headings and units shown as / cm^3 or (cm^3) (as specified in the syllabus).
Burette readings for the accurate titrations should always be recorded to the nearest 0.05 cm^3 and titres are considered to be concordant/consistent if they are within 0.10 cm^3.

Worksheet, *continued*

Interpretation and evaluation

Calculation

Use the Periodic Table for any data required.

(1) Calculate the number of moles of amidosulfonic acid, NH_2SO_3H, weighed out.
(2) Use your answer to (1) to calculate the number of moles of amidosulfonic acid present in the 25.0 cm^3 pipetted into your conical flask.
(3) Calculate the mean volume of sodium hydroxide that will be used in your calculations.
(4) Use your answer to (3) to calculate the number of moles of sodium hydroxide, 0.100 $mol\,dm^{-3}$ NaOH, required to neutralise the acid in the conical flask.
(5) Use your answers to (2) and (4) to calculate the mole ratio of alkali : acid.
(6) Write a balanced equation for the reaction between sodium hydroxide and amidosulfonic acid.

Extension

(7) Write an ionic equation, including state symbols, for the reaction.

Points to consider

(1) A pipette is marked as being accurate to ± 0.06 cm^3.
What is the maximum percentage error in the volume of amidosulfonic acid you pipetted into the conical flask?
(2) A single burette reading is accurate to ± 0.05 cm^3. What would be the maximum percentage error if your titre was 24.85 cm^3?
(3) The end point in a titration is when the indicator changes to the desired colour on adding one drop of reagent. One drop has a volume of approximately 0.05 cm^3. Calculate the number of moles of 0.100 $mol\,dm^{-3}$ of sodium hydroxide contained in this volume.
(4) The error in the balance reading is ± half the smallest division. For a 2 dp balance the error would be ± 0.005 g. Calculate the maximum percentage error for the mass of amidosulfonic acid you weighed out.
(5) Which piece of apparatus, the burette, pipette or the balance, caused the greatest percentage error in your experiment?

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