

Cambridge International AS & A Level

Chemistry

Practical Teacher's Guide

Roger Norris and Mike Wooster

Completely **Cambridge**
Cambridge resources
for
Cambridge qualifications

Roger Norris and Mike Wooster

Cambridge International
AS & A Level

Chemistry

Practical Teacher's Guide



CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom
One Liberty Plaza, 20th Floor, New York, NY 10006, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
4843/24, 2nd Floor, Ansari Road, Daryaganj, Delhi – 110002, India
79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.
It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

Information on this title: www.cambridge.org/9781108539098

© Cambridge University Press 2018

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2018

20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Printed in UK by CPI

A catalogue record for this publication is available from the British Library

ISBN 978-1-108-53909-8

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate. Information regarding prices, travel timetables, and other factual information given in this work is correct at the time of first printing but Cambridge University Press does not guarantee the accuracy of such information thereafter.

IGCSE® is the registered trademark.

All examination-style questions, sample mark schemes, solutions and/or comments that appear in this book were written by the author. In examination, the way marks would be awarded to answers like these may be different.

.....
NOTICE TO TEACHERS IN THE UK

It is illegal to reproduce any part of this work in material form (including photocopying and electronic storage) except under the following circumstances:

- (i) where you are abiding by a licence granted to your school or institution by the Copyright Licensing Agency;
- (ii) where no such licence exists, or where you wish to exceed the terms of a licence, and you have gained the written permission of Cambridge University Press;
- (iii) where you are allowed to reproduce without permission under the provisions of Chapter 3 of the Copyright, Designs and Patents Act 1988, which covers, for example, the reproduction of short passages within certain types of educational anthology and reproduction for the purposes of setting examination questions.

Contents

Introduction		v
Safety		vi
AS Practical Skills		vii
A Level Practical Skills		x
1 Masses, moles and atoms		
1.1	Empirical formula of hydrated copper(II) sulfate crystals	2
1.2	Relative atomic mass of magnesium using molar volumes	4
1.3	Percentage composition of a mixture of sodium hydrogen carbonate and sodium chloride	7
1.4	Relative atomic mass of calcium by two different methods: molar volume and titration	9
2 Structure and bonding		
2.1	Physical properties of three different types of chemical structure	13
2.2	Effect of temperature on the volume of a fixed mass of gas	15
2.3	Effect of pressure on the volume of a fixed mass of gas	17
3 Enthalpy changes		
3.1	Enthalpy change for the reaction between zinc and aqueous copper(II) sulfate solution	19
3.2	Enthalpy change of combustion of alcohols	22
3.3	Enthalpy change of thermal decomposition	25
3.4	Change in enthalpy of hydration of copper (II) sulfate	27
4 Redox reactions		
4.1	Understanding redox (I): investigating a reactivity series and displacement reactions	30
4.2	Understanding redox (II): investigating further reactions	32
5 Chemical equilibrium		
5.1	Applying Le Chatelier's principle to a gaseous equilibrium	35
5.2	Applying Le Chatelier's principle to an aqueous equilibrium	37
5.3	The equilibrium constant for the hydrolysis of ethyl ethanoate	39
6 Rates of reaction		
6.1	Effects of concentration on rate of chemical reaction	43
6.2	Effects of temperature and a homogeneous catalyst on the rate of chemical reaction	46
6.3	Observing a catalysed reaction	47
7 The properties of metals		
7.1	Properties of metal oxides and metal chlorides across Period 3	49
7.2	Relative atomic mass of magnesium using a back-titration method	51
7.3	Separation of two metal ions in solution	52
7.4	Identification of three metal compounds using qualitative analysis	54

8 The properties of non-metals	8.1	Formula of hydrated sodium thiosulfate crystals	56
	8.2	Preparation and properties of the hydrogen halides	58
	8.3	Reaction of bromine with sulfite ions (sulfate (IV))	60
	8.4	Identification of unknowns containing halide ions	62
9 Hydrocarbons and halogenoalkanes	9.1	Cracking of hydrocarbons	64
	9.2	How halogenoalkane structure affects the rate of hydrolysis	66
10 Organic compounds containing oxygen	10.1	Identifying four unknown organic compounds	68
11 More about enthalpy changes	11.1	Enthalpy change of vaporisation of water	72
	11.2	Enthalpy change of solution of chlorides	74
	11.3	Thermal decomposition of iron(II) ethanedioate	77
	11.4	Thermal decomposition of metal carbonates	80
	11.5	Enthalpy change of mixing	82
12 Electrochemistry	12.1	Determining the Faraday constant	86
	12.2	Comparing the voltage of electrochemical cells	88
	12.3	Half-cells containing only ions as reactants	90
	12.4	Changing the concentration of ions in an electrochemical cell	91
	12.5	Electrical conductivity of ethanoic acid	93
13 Further aspects of equilibria	13.1	Change in pH during an acid–base titration	95
	13.2	Partition of ammonia between water and trichloromethane	97
	13.3	An esterification reaction at equilibrium	99
	13.4	The effect of temperature on the $\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2$ equilibrium	101
	13.5	Equilibrium, entropy and enthalpy change	104
14 Reaction kinetics	14.1	Kinetics of the reaction between propanone and iodine	107
	14.2	Rate of decomposition of an organic compound	109
	14.3	Determination of the order of a reaction	111
	14.4	Effect of temperature on rate of reaction	114
15 Transition elements	15.1	Copper content of copper ore	118
	15.2	Analysis of iron tablets	120
	15.3	Formula of a complex ion	122
	15.4	Reaction of copper with potassium dichromate(VI)	124
16 More about organic chemistry	16.1	Making an azo dye	127
	16.2	Acylation of a nucleic acid	129
	16.3	Nitration of benzene	131
17 Identifying organic compounds	17.1	Extracting an amino acid from hair	133
	17.2	Identification of a white crystalline solid	134
	17.3	Preparation and identification of a colourless liquid	136

Introduction


Practical work is an essential part of any advanced Chemistry course. For Cambridge International AS & A Level Chemistry, Paper 3 and Paper 5 focus on the assessment of practical skills.

The practical investigations in the workbook have been carefully chosen to:

- meet the requirements of all the learning objectives for specific practical activities
- provide progressive guidance and practice of Assessment Objective 3 (AO3) skills.


The skills grids at the front of this guide summarise the practical skills that are assessed in Paper 3 (AS) and Paper 5 (A level). You can use these grids to search for practical investigations that involve a particular skill or skills. At the beginning of each practical investigation, the learning objectives and skills that are supported are also listed.

The order of the investigations presented follows the order of the topics in the Cambridge International AS & A Level Chemistry coursebook, but please note that this does not mean that they must be completed in that order. Some coursebook chapters involve the use of quantitative techniques. All techniques listed in the practical guidance are covered in the workbook.

 These points have been provided to give extra support to students who may be struggling with the investigation.

Each chapter of the workbook has more than one investigation so do choose those that you feel suits the equipment and time that you have available. Chemicals required by the investigations in the workbook have been chosen to be as commonly available as possible and virtually all the equipment required is that listed in the practical guidance. We have, however, provided a set of sample results for each Practical Investigation, which you can give to learners who have not managed to obtain a complete set of results themselves, so that they can continue to answer all of the Data analysis and Evaluation questions.

Although practical work requires time, it is time well spent. Practical work enables learners to acquire transferrable skills and gives them the confidence that the theory they have learned works in practice. Because of this, the details of the theory are more easily retained. The important learning experiences, when carrying out practical work, are the range of skills that are being used and developed – the *processes* of planning, carrying out, observing, recording, and analysing. The workbook gives the learners experience in developing these skills. It is not a series of mock practical exam papers! But, in carrying out the investigations, the learners will practise and acquire the skills that will enable them to be more confident when tackling their practical exam.

 These points provide additional tasks to extend more able learners.

Safety

Working safely in a science laboratory is an essential aspect of learning which characterises practical work. It is the duty of the school to make it clear to learners just what is expected of them when they are working in a laboratory.

In every investigation, every learner is expected to wear eye protection and long hair should be tied back. Safety goggles generally give more protection than safety spectacles. It is also advisable for them to wear a laboratory coat to protect their clothing from chemical splashes.

All chemicals should be treated as hazardous and whenever they are spilt on the skin they should be

washed off immediately using water. The apparent dangers of a chemical may not have been realised and therefore using them without safety precautions can lead to unforeseen problems.

Learners should also take responsibility for working safely. It is advisable that learners are made aware of the hazard signs on reagent bottles and in the laboratory. Table S1. shows some of the most common hazard symbols. This is not an exhaustive list, but it does list the most common hazard symbols encountered in school science laboratories. An up-to-date list of CLEAPPS hazards is available for students to download.





Hazard symbol	What does it mean?	Special points
	The substance is corrosive . It will damage your skin and tissues if it comes into contact with them.	Always wear safety goggles and if possible gloves when using corrosive substances.
	The substance is an irritant . If it comes into contact with your skin it can cause blisters and redness.	Always wear safety spectacles when using irritants.
	The substance is toxic and can cause death if swallowed, breathed in or absorbed by skin.	Wear gloves and eye protection.
	The substance is flammable and catches fire easily.	Keep the substance away from naked flames and when heating reaction mixtures use the hot water from a kettle rather than using Bunsen burners.
	The material is a biohazard . Examples are bacteria and fungi.	Seek advice about specific biohazards.
	The substance is an oxidising agent . It will liberate oxygen when heated or in the presence of a suitable catalyst.	Keep oxidising agents well away from flammable materials.

Table S1

AS Practical Skills

The following grids map the practical investigations from the workbook to the mark categories for Papers 3 and 5, as listed in the Cambridge International AS & A Level Chemistry syllabus.

The grids are designed to aid you when planning practical and theory lessons, to ensure learners develop the practical skills required as part of this course.

Manipulation, measurement and observation (MMO)

SKILL	CHAPTER									
	1	2	3	4	5	6	7	8	9	10
Collection of data and observations										
(a) set up apparatus correctly	1.1; 1.2; 1.3; 1.4	2.1; 2.2; 2.3	3.1; 3.2; 3.3; 3.4		5.1; 5.2; 5.3	6.1;	7.2; 7.3; 7.4	8.1; 8.2	9.1; 9.2	10.1
(b) follow instructions in written form or from diagrams	1.1; 1.2; 1.3; 1.4	2.1; 2.2; 2.3	3.1; 3.2; 3.3; 3.4	4.1; 4.2	5.1; 5.2; 5.3	6.1; 6.2	7.1; 7.2; 7.3; 7.4	8.1; 8.3; 8.4	9.1; 9.2	10.1
(c) use apparatus to collect an appropriate quantity and quality of data and observations	1.1; 1.2; 1.3; 1.4	2.1; 2.2; 2.3	3.1; 3.2; 3.3; 3.4	4.1; 4.2	5.1; 5.2; 5.3	6.1; 6.2	7.1; 7.2; 7.3; 7.4	8.1; 8.2; 8.3; 8.4	9.1; 9.2	10.1
(d) make measurements using pipettes, burettes, and other common laboratory apparatus	1.1; 1.2; 1.3; 1.4	2.1; 2.2; 2.3	3.1; 3.2; 3.3; 3.4		5.3	6.1	7.2	8.1		
(e) make accurate and consistent measurements and observations	1.1; 1.2; 1.3; 1.4	2.1; 2.2; 2.3	3.1; 3.2; 3.3; 3.4	4.1; 4.2	5.2; 5.3	6.1; 6.2; 6.3	7.1; 7.2; 7.3; 7.4	8.1; 8.2; 8.3; 8.4	9.1; 9.2	10.1
Decisions relating to measurements or observations										
(a) decide how many tests or observations to perform	1.1; 1.3; 1.4	2.2		4.1; 4.2	5.1; 5.3		7.2;	8.1; 8.2; 8.3	9.1	10.1
(b) make a suitable range and number of measurements suitable for the experiment	1.1; 1.3; 1.4	2.2	3.2; 3.4	4.2	5.3		7.2;	8.1; 8.3	9.1	
(c) decide how long to leave experiments running before making readings	1.1; 1.2; 1.4	2.1; 2.2	3.4	4.2	5.1; 5.2; 5.3	6.1	7.2; 7.3; 7.4	8.2; 8.3; 8.4	9.1; 9.2	10.1
(d) make as many repeated readings or observations as appropriate	1.1; 1.2; 1.3; 1.4	2.1; 2.2	3.3	4.1	5.1; 5.2		7.1; 7.2	8.1; 8.2	9.1	10.1
(e) identify where confirmatory tests are needed and the nature of these tests	1.3			4.1; 4.2						10.1
(f) choose reagents to distinguish between given ions				4.1; 4.2			7.3; 7.4	8.3	9.2	

vii

Presentation of data and observations (PDO)

SKILL	CHAPTER									
	1	2	3	4	5	6	7	8	9	10
Recording data and observations										
(a) present data, values or observations in a single table of results	1.2; 1.3	2.1; 2.2	3.1; 3.2; 3.3; 3.4	4.2	5.1; 5.2 5.3	6.1;	7.2;	8.1	9.1; 9.2	10.1

SKILL	CHAPTER									
	1	2	3	4	5	6	7	8	9	10
Recording data and observations (Continued)										
(b) draw up a table in advance of taking readings				4.2				8.1	9.1	10.1
(c) include in the results table: columns for raw data, calculated values and analyses	1.3; 1.4	2.1; 2.2	3.3; 3.4	4.2		6.1; 6.2	7.2	8.1		10.1
(d) use column headings containing both quantities and suitable scientific units	1.4		3.3; 3.4			6.2		8.1	9.1	
(e) record readings to the same degree of precision and observations to the same level of detail	1.1; 1.2; 1.3; 1.4	2.1; 2.2	3.1; 3.3; 3.4		5.1; 5.2; 5.3	6.1;	7.1; 7.2	8.1; 8.3; 8.4	9.1	
Display of calculations and reasoning										
(a) show all working in calculations and the key steps in your reasoning	1.1; 1.2; 1.3; 1.4	2.2; 2.3	3.1; 3.2; 3.3; 3.4		5.3	6.1	7.2	8.1		
(b) use the correct number of significant figures for calculated quantities	1.1; 1.2; 1.3; 1.4	2.2; 2.3	3.1; 3.2; 3.3; 3.4		5.3	6.1	7.2	8.1		
Data layout										
(a) choose a suitable, clear way of presenting data, for example, tables, graphs or a mixture			3.1; 3.4	4.2		6.1	7.1	8.1	9.1; 9.2	10.1
(b) decide how to plot the variables and whether a graph should be a straight line or a curve	1.1; 1.2	2.2	3.1; 3.4			6.1				
(c) plot appropriate variables on clearly labelled x- and y-axes	1.1; 1.2	2.2	3.1; 3.4			6.1				
(d) choose suitable scales for graph axes	1.1; 1.2	2.2	3.1; 3.4			6.1				
(e) plot all points or bars to an appropriate accuracy	1.1; 1.2	2.2	3.1; 3.4			6.1				
(f) draw best-fit lines taking into account the anomalous points	1.1; 1.2	2.2	3.1; 3.4			6.1;				

Analysis, conclusions and evaluation (ACE)

SKILL	CHAPTER									
	1	2	3	4	5	6	7	8	9	10
Data interpretation and sources of error										
(a) describe the patterns and trends shown by tables and graphs		2.2; 2.3	3.1; 3.4		5.1; 5.2	6.1; 6.2	7.1		9.2	
(b) describe and summarise the key points of a set of observations		2.1; 2.2; 2.3			5.1; 5.2	6.1	7.1		9.2	

SKILL	CHAPTER									
	1	2	3	4	5	6	7	8	9	10
Data interpretation and sources of error (Continued)										
(c) find an unknown value from a graph including the drawing of intersecting points	1.1; 1.2	2.2	3.1; 3.4							
(d) calculate other quantities from data or the mean from reproducible values	1.1; 1.2; 1.3;	2.2; 2.3	3.4		5.3	6.1	7.2	8.1	9.2	
(e) determine the gradient of a straight-line graph						6.1				
(f) evaluate the effectiveness of control variables										
(g) identify the most significant sources of error in an experiment	1.3; 1.4	2.2	3.1; 3.2 3.3		5.3		7.2			
(h) estimate in terms of number values the uncertainty in quantitative measurements	1.2; 1.3; 1.4		3.1; 3.2; 3.3		5.3					
(i) express these uncertainties as an actual or percentage error										
(j) show and understand the difference between systematic and random errors	1.2; 1.3; 1.4		3.1; 3.2							
Drawing conclusions										
(a) consider to what extent the experimental data support a given hypothesis	1.2; 1.3	2.3		4.2	5.1; 5.2; 5.3	6.1; 6.2; 6.3	7.1	8.3	9.2	10.1
(b) make further predictions arising from the experiment				4.2	5.1; 5.2	6.1; 6.3				
(c) draw conclusions from observations, data and calculated values	1.1; 1.2; 1.3; 1.4	2.1; 2.2; 2.3	3.1; 3.2; 3.3	4.1; 4.2	5.1; 5.3	6.1; 6.2; 6.3	7.1; 7.2	8.1; 8.2; 8.3; 8.4	9.1; 9.2	10.1
(d) make scientific explanations arising from the data, observations and conclusions	1.3; 1.4	2.1; 2.2		4.1; 4.2	5.1; 5.3	6.1; 6.2; 6.3	7.1	8.2; 8.3; 8.4	9.1; 9.2	10.1
Suggesting improvements										
(a) suggest modifications that improve the accuracy of the experiment/observations	1.1; 1.3; 1.4					6.1; 6.2				
(b) suggest how to extend the investigation to answer a new question						6.2	7.3			
(c) describe modifications to the experiment in words or diagrams	1.4					6.2				

A Level Practical Skills

Planning an investigation (PI)

SKILL	CHAPTER						
	11	12	13	14	15	16	17
Selecting information							
(a) locate, select, organise and present information from a variety of sources				14.3			17.1; 17.2; 17.3
(b) construct arguments to support hypotheses and justify a course of action	11.1; 11.3; 11.5			14.3; 14.4	15.2	16.1; 16.3	17.1; 17.2; 17.3
(c) apply knowledge, including principles, to new situations	11.1; 11.3; 11.5	12.3; 12.5	13.4; 13.5	14.1; 14.2; 14.4	15.1; 15.3; 15.4	16.1; 16.2; 16.3	17.1; 17.2; 17.3
Defining the problem under investigation							
(a) identify a safe, efficient procedure that leads to a reliable result	11.3; 11.4,	12.5	13.3; 13.4	14.3; 14.4	15.1; 15.4	16.1; 16.3	
(b) express the aim in terms of a prediction (in words or as a predicted graph)				14.3; 14.4			
(c) identify the steps needed to carry out the procedure	11.3; 11.4	12.4; 12.5	13.3; 13.4	14.3; 14.4	15.1; 15.4	16.1; 16.3	
(d) identify apparatus that is suitable for carrying out each step of the procedure	11.3; 11.4	12.3; 12.4; 12.5	13.3; 13.4	14.3; 14.4	15.1; 15.4	16.1; 16.3	17.1
(e) indicate how and why the procedure suggested will be effective			13.2; 13.4	14.4	15.3	16.1	
Control experiments and identification of variables							
(a) identify the independent variable and the dependent variable in an experiment or investigation	11.5	12.4		14.4; 14.4			
(b) explain how control experiments verify that no other factors influence the variables		12.5			15.3; 15.4	16.1; 16.2	
(c) identify any variables that are to be controlled	11.1; 11.3; 11.4	12.1; 12.5	13.2; 13.3	14.1; 14.3; 14.4	15.1; 15.3; 15.4	16.2	
Considering hazards							
(a) assess the risks of the proposed experiment	11.1; 11.3; 11.4; 11.5	12.1; 12.5	13.3; 13.4	14.3; 14.4	15.1; 15.4	16.1; 16.3	
(b) describe precautions that should be taken to keep risks to a minimum	11.4	12.5	13.2; 13.3; 13.4	14.3; 14.4	15.1; 15.4	16.1; 16.3	

Carrying out an investigation (COI)

SKILL	CHAPTER						
	11	12	13	14	15	16	17
Methods used							
(a) describe the method to be used when carrying out an investigation	11.1; 11.3; 11.4	12.3; 12.4; 12.5	13.3; 13.4	14.3; 14.4	15.1; 15.4	16.1	17.1
(b) describe the arrangement of the apparatus and the steps in the procedure to be followed	11.3; 11.4	12.4; 12.5	13.3; 13.4	14.3; 14.4	15.1; 15.4	16.1	17.1

SKILL	CHAPTER						
	11	12	13	14	15	16	17
Methods used (Continued)							
(c) arrange and use the apparatus provided correctly	11.1; 11.2; 11.4	12.1; 12.2; 12.3; 12.4	13.1	14.3; 14.4			
(d) suggest and use appropriate volumes and concentrations of reagents	11.3; 11.4	12.3; 12.4; 12.5	13.3; 13.4	14.3; 14.4	15.4	16.1; 16.3	
Carrying out the experiment							
(a) carry out the experiment by varying the independent variable and measuring the dependent variable	11.1; 11.2; 11.4	12.1; 12.2; 12.3; 12.4	13.1	14.3; 14.4			
(b) carry out the experiment so that key variables are controlled	11.1; 11.2; 11.4	12.1; 12.2; 12.3; 12.4	13.1	14.3; 14.4			
(c) carry out the experiment with the required degree of accuracy	11.1; 11.2; 11.4	12.1; 12.2; 12.3; 12.4	13.1	14.3; 14.4			
(d) carry out the experiment safely	11.1; 11.2; 11.4	12.1; 12.2; 12.3; 12.4	13.1	14.3; 14.4			

Handling information (HI)

SKILL	CHAPTER						
	11	12	13	14	15	16	17
Collecting and displaying data							
(a) describe the outcome of steps in the procedure relevant to the experiment	11.3; 11.4			14.3; 14.4			
(b) handle information, distinguishing the relevant from the irrelevant	11.1; 11.2; 11.3; 11.5	12.1; 12.3; 12.4; 12.5	13.1; 13.2; 13.3; 13.4	14.1; 14.2; 14.3; 14.4	15.2; 15.3		17.1; 17.2; 17.3
(c) draw up tables for data that need to be recorded	11.1; 11.2	12.4	13.1	14.3; 14.4			
Manipulating data							
(a) describe how the data might be used in order to reach a conclusion			13.1	14.1; 14.3; 14.4	15.2		17.2; 17.3
(b) manipulate numerical and other data	11.1; 11.2; 11.4; 11.5	12.1; 12.2, 12.4; 12.5	13.1; 13.2; 13.3; 13.5	14.1; 14.2; 14.3; 14.4	15.1; 15.2; 15.3; 15.4	16.2	17.2; 17.3
(c) translate information from one form to another including graphical information	11.1; 11.2; 11.5	12.4; 12.5	13.1; 13.2; 13.5	14.2; 14.3; 14.4	15.1; 15.3	16.2	

Data analysis (DA)

SKILL	CHAPTER						
	11	12	13	14	15	16	17
Identifying trends and patterns							
(a) analyse information so as to identify patterns and report trends	11.2;11.5	12.1; 12.2; 12.4; 12.5	13.1; 13.2; 13.3	14.1; 14.2; 14.3; 14.4	15.3; 15.4	16.2	17.1; 17.2; 17.3
(b) use tables and graphs of quantitative data to draw attention to key points	11.1			14.3; 14.4	15.4	16.2	17.2; 17.3
(c) comment, where necessary on the variability of the data	11.5	12.4	13.3	14.2; 14.3; 14.4	15.2; 15.3		
(d) analyse data from spectra or other published data to reach appropriate conclusions					15.3; 15.4		17.2; 17.3
Identifying and using calculations							
(a) identify calculations required and the means of presentation of data provided	11.3	12.1	13.1		15.1; 15.2		
(b) AL3.2.3 use calculations to enable simplification or explanation of data	11.1; 11.3	12.4	13.3; 13.5	14.1; 14.2	15.2; 15.3		

Conclusions and Predictions (CP)

SKILL	CHAPTER						
	11	12	13	14	15	16	17
Drawing conclusions							
(a) analyse qualitative data to draw appropriate conclusions	11.2; 11.4		13.1		15.1; 15.4		
(b) analyse quantitative data provided to draw conclusions	11.3; 11.4; 11.5	12.3; 12.4; 12.5	13.1; 13.2; 13.5	14.1; 14.3; 14.4	15.2; 15.3	16.2	17.1; 17.2; 17.3
(c) draw conclusions to describe the key features of the data and analyses			13.1	14.1; 14.3; 14.4			17.2; 17.3
(d) make detailed explanations of the data, analyses and conclusions				14.1; 14.3			17.2; 17.3
(e) consider whether the experimental data supports the conclusion reached	11.2; 11.3	12.2	13.3	14.3; 14.4	15.3		17.1; 17.2; 17.3
Making predictions							
(a) make further predictions, ask relevant questions and suggest improvements	11.2	12.1; 12.4	13.4	14.4			
(b) suggest improvements by asking relevant questions	11.2	12.1; 12.4	13.4	14.4			

Evaluating investigations (EI)

SKILL	CHAPTER						
	11	12	13	14	15	16	17
Identifying problems with the procedure							
(a) identify and explain the weaknesses of the experimental procedure used	11.1; 11.2; 11.4; 11.5	12.1; 12.2; 12.4	13.1; 13.3; 13.4	14.1,14.2; 14.3,14.4	15.1; 15.2		
(b) explain the effect of the incorrect use of apparatus on the results		12.4		14.1	15.3		
(c) use information provided to assess the effectiveness of the control of the variables				14.2; 14.3; 14.4		16.2	
(d) explain how changes in the conditions used may affect the results		12.1		14.3; 14.4			
(e) explain how changes in concentration of reagents may affect the results		12.2; 12.4		14.3			
Identifying problems with the data							
(a) identify anomalous values in data provided, give possible explanations and suggest how to deal with these.	11.5	12.5	13.1; 13.5		15.3		
(b) identify the extent to which readings provided have been reproduced	11.5		13.3		15.2		
(c) describe whether the range of data provided is sufficient	11.5		13.2; 13.5	14.2; 14.3; 14.4	15.2; 15.3		
Making a judgement on the conclusions							
(a) evaluate information and hypotheses	11.1; 11.2; 11.3; 11.4	12.1; 12.3; 12.4; 12.5	13.1; 13.2; 13.3; 13.4	14.1; 14.2; 14.3; 14.4	15.2; 15.3; 15.4		17.1
(b) evaluate information to make judgements on the confidence of the conclusions drawn	11.1; 11.2; 11.4; 11.5			14.1;14.2; 14.4	15.1; 15.3	16.2	17.1

Chapter 1:

Masses, moles and atoms

Chapter outline

This chapter relates to Chapter 1: Moles and equations, Chapter 2: Atomic structure and Chapter 3: Electrons in atoms in the coursebook.

In this chapter learners will complete practical investigations on:

- 1.1 Empirical formula of hydrated copper(II) sulfate crystals
- 1.2 Relative atomic mass of magnesium using molar volumes
- 1.3 Percentage composition of a mixture of sodium hydrogen carbonate and sodium chloride
- 1.4 Relative atomic mass of calcium by two different methods: molar volume and titration

Practical investigation 1.1: Empirical formula of hydrated copper(II) sulfate crystals

Introduction

In this investigation learners determine the empirical formula (see Chapter 1 of the coursebook) of hydrated copper(II) sulfate by finding the value of x in $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$. They weigh out some hydrated copper(II) sulfate in an evaporating basin, heat it to constant mass, determine the mass of water present in their sample and then find the molar ratio: $\text{CuSO}_4 : \text{H}_2\text{O}$.

Skills focus

The following skill areas are developed and practised (see the skills grids at the front of this guide for codes):

MMO	Collection of data and observations: (a), (b), (c), (d) and (e) Decisions relating to measurements of observations: (a), (b) (c) and (d)
PDO	Recording data and observations: (e) Display of calculations and reasoning: (a) and (b) Data layout: (b), (c), (d), (e) and (f)
ACE	Data interpretation and sources of error: (c) and (d) Drawing conclusions: (c) Suggesting improvements: (a)

Duration

This investigation should take no more than 1 h to complete. However, as it is the first time learners will have completed error calculations you may need another hour to go through the errors involved.

Preparing for the investigation

- Learners should be made aware of the 'Skills Chapter' and how it informs them about the techniques they will be using.
- They will also need to have an awareness of the sources of errors.
- Learners will need to understand the concept of an empirical formula and be able to calculate the number of moles present.
- They should revise the concepts of moles and molar ratios.

Equipment

Each learner or group will need:

- a pipe-clay triangle
- an evaporating basin
- Bunsen burner and tripod
- tongs
- glass stirring rod
- two heat-resistant pads
- spatula

Access to:

- a supply of gas
- a top-pan balance that reads to at least two decimal places

Safety considerations

- Learners must wear eye protection at all times in this experiment and tie back long hair.
- When weighing the evaporating basin and copper sulfate the learners should place it on the extra heat-resistant mat and then carry it across to the top-pan balance.
- The copper(II) sulfate is an environmental hazard and should be recycled. It can be used as a test for water or dissolved in water and recrystallised. It could also be used in a Hess' Law determination.

Carrying out the investigation

- They may need help to understand what is meant by 'water of crystallisation' and how it is loosely bound to the copper(II) sulfate and that the number of water molecules per formula is a whole number.
- Assuming that the length of the practical time available is about 1 h then this is sufficient time for each group to do one determination.
- Allocate a given mass to each group. It is a good idea to give the larger masses of copper sulfate to the more able learners or more patient ones because they will obviously need more time in heating the copper(II) sulfate to give the anhydrous form.
- If they heat the copper sulfate properly there will be some at the beginning that will stick to the stirring rod and the basin and when this ceases to happen it shows that they are removing the water from the salt.
- The anhydrous salt should be as near white as possible but may have a greyish tinge after the heating is finished and constant mass is obtained.
- Ensure that if more than one balance is used, the learners should use the same balance throughout. By doing this any errors in the balances are reproducible.
- Some learners will need help on why some points on their graph lie above and below the line.
- Some will also need help on heating the copper(II) sulfate as gently as possible (see above) so will need to be trained on how to adjust the Bunsen flame to a very low level.
- Learners who struggle with the practical, especially the theoretical part, should be given the lowest value masses

so that their heating is over quickly and they can start processing their results.



More able learners should, if possible, be allowed to work on their own.

Common learner misconceptions

- When instructed to 'heat gently' some learners will still use a yellow flame.

Sample results

Mass of crystals/g	Mass of anhydrous copper(II) sulfate/g
0.20	0.12
0.50	0.32
0.80	0.51
2.50	1.60

Table 1.1

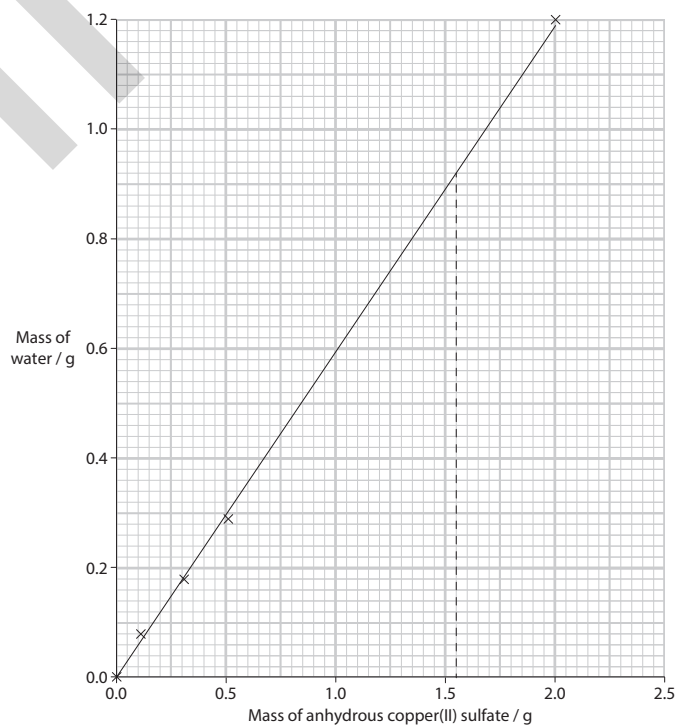


Figure 1.1

Answers to the workbook questions (using the sample results)

- a & b** It is quite easy to get a set of results that give the ideal answer for this practical (see Table 1.1 and Figure 1.1).
- c** As can be seen from the graph, the mass of water that combines with 1.60 g of copper(II) sulfate is 0.90 g
- d** Results shown in Table 1.2

	Copper(II) sulfate (CuSO ₄)	Water (H ₂ O)
Mass/g	1.60	0.90
Number of moles	$\frac{1.60}{159.6} = 0.0100$	$\frac{0.90}{18} = 0.0500$
Simplest ratio (divide by lowest number)	$\frac{0.0100}{0.0100} = 1$	$\frac{0.0500}{0.0100} = 5$

Table 1.2

- e** This means that the formula for the hydrated copper(II) sulfate is CuSO₄·5H₂O

- f** 0, 0 because if there is no copper(II) sulfate then there will be no water attached to it.
- g i** If a point lies **above the line** then it could have been heated too much and the copper (II) sulphate has decomposed to some extent.
- ii** If a point lies **below the line** there has been insufficient heating of the crystals and the water of crystallisation is still attached to them. However, it could be that the heated solid has been left to cool and absorbed water from the atmosphere.
- h** The best alternative is to use an oven. The temperature of the oven can be adjusted to one where the water of crystallisation will be removed but it will not be hot enough to decompose the copper(II) sulfate. Using a Bunsen burner cannot be sufficiently accurate. A possible way of determining the Bunsen burner temperature is to use a thermocouple to give a reading of the temperature. Even using this method is inaccurate because any slight change in the extent to which the air hole is opened will lead to a change in temperature.

Practical Investigation 1.2: Relative atomic mass of magnesium using molar volumes

Skills focus

The following skill areas are developed and practised (see the skills grids at the front of this guide for codes):

MMO	Collection of data and observations (a), (b), (c), (d) and (e) Decisions relating to measurements of observations (c) and (d)
PDO	Recording data and observations (a) and (e) Display of calculations and reasoning (a) and (b) Data layout (b), (c), (d), (e) and (f)
ACE	Data interpretation and sources of error (c), (d), (h), (i) and (j) Drawing conclusions (a) and (c)

Duration

This investigation should take approximately 1.5 h to complete.

Preparing for the investigation

- Learners should, ideally, have a good understanding of moles and molar volumes. The crucial relationships are:

$$A_r = \frac{\text{mass } (m)}{\text{number of moles } (n)} \text{ and } n = \frac{\text{Volume of gas in cm}^3}{24\,000}$$

Equipment

Each learner or group will need:

- either a trough;
a selection of measuring cylinders (10 cm³; 25 cm³ and 50 cm³); OR a 100 cm³ gas syringe
- 150 cm³ conical flask with retort stand, boss and clamp
- small piece of steel wool
- 25 cm³ measuring cylinder for acid
- one 10.0 cm length of magnesium ribbon
- 30 cm ruler
- plastic gloves (see safety considerations)

Access to:

- a top-pan balance reading to **at least** two decimal places
- 2 mol dm^{-3} hydrochloric acid

Alternative equipment

- Of the two sets of apparatus suggested, the easiest to set up is the one using the gas syringe. However, if gas syringes are not available, then the displacement of water in a measuring cylinder works very well.

Safety considerations

- Learners must wear eye protection at all times and tie hair back if it is long.
- Magnesium is highly flammable.
- Hydrogen is a flammable gas.
- 2 mol dm^{-3} hydrochloric acid is an irritant.
- Steel wool sometimes splinters and some learners could be quite sensitive to this. To lower the risk plastic gloves should be worn when using the steel wool to clean the magnesium.

Carrying out the investigation

- The point of weighing out 10 cm lengths of magnesium ribbon is that 10 cm will give a valid reading on the top-pan balance, especially if the balance reads to only two decimal places. The masses of the shorter lengths are then calculated using the relationship:

$$\text{mass} = \frac{\text{length}}{10} \times \text{mass of 10 cm length.}$$
- Please note that if learners are measuring the gas volume by displacement of water, the first problem to overcome is making sure that the measuring cylinder is full of water when it is put in the trough and that none or very little escapes. This can be done by either learners holding their hands over the end of the measuring cylinder or placing a piece of plastic wrap over the open end and then turn the measuring cylinder upside down when it is in the trough. Remember to remove the film before starting the actual measurement. A boiling tube will do as well as a conical flask for the reaction vessel.

- The main problem with the practical is the purity of the magnesium ribbon. If you have fresh ribbon then omit the cleaning. If it is visibly oxidised then it will need cleaning and that is done using the steel wool. This should be done by holding the ribbon using the wool and then drawing it through. Once should be enough. Any more than that will lead to irregularities in the thickness of the ribbon and inaccuracy when estimating the masses of the individual lengths.



Evaluation of a practical method always presents problems to learners and they will need help when estimating the percentage error due to using different apparatus.

- Before the practical, a short demonstration will give learners some idea of the volumes of gas that they will be dealing with. This can be their trial run but more able learners can be asked to do this for themselves. If the volume of gas for a 1 cm length of ribbon is found then they should be able to estimate the volumes for the other lengths and adjust their choice of measuring cylinder (if these are used) accordingly.



If learners are measuring the gas volume by displacement of water then they can be marked on which measuring cylinder they use for the most accurate measurements of gas volumes.

- Learners can be asked to analyse their results in Microsoft Excel or a similar data-handling application.

Sample results

Mass of 10 cm length of magnesium ribbon = 0.160 g

The results from one set of measurements are shown in Table 1.3

Length of Mg ribbon/cm	Mass of Mg/g	Expt. 1	Expt. 2	Average
0.00	0	0	0	0
0.50	0.008	8	8	8.0
1.00	0.016	16	17	16.5
1.50	0.024	23	25	24.0
2.00	0.032	30	31	30.5

Table 1.3

Answers to the workbook questions (using the sample results)

a Please see Figure 1.2

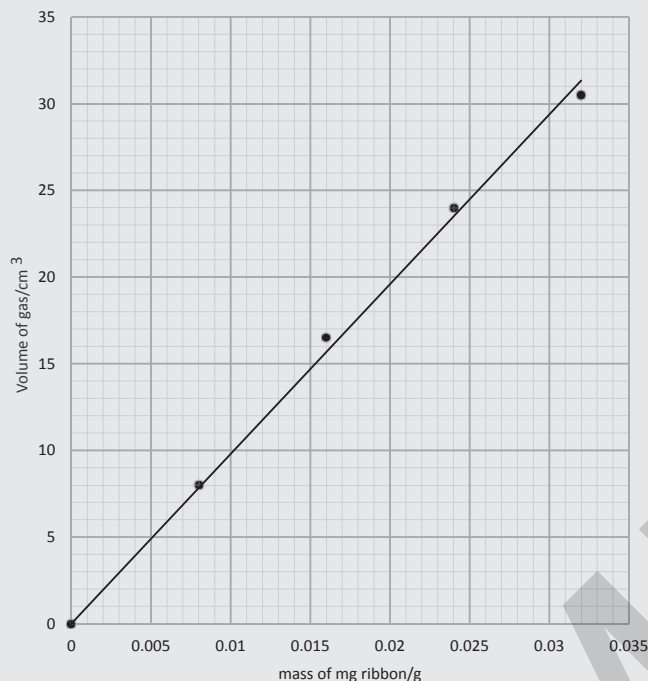


Figure 1.2

b Using Figure 1.2: 24.0 cm³ of H₂ is produced from 0.0245 g of magnesium

c $24.0 \text{ cm}^3 = \frac{24}{24,000} \text{ mol} = 0.001 \text{ mol of H}_2 = \text{number of mol of magnesium}$

Therefore, mass of 1 mol

$$= \frac{m}{n} = \frac{0.0245}{0.001} = 24.5 \text{ g mol}^{-1}$$

d Percentage error =

$$\frac{|\text{Actual value} - \text{experimental value}|}{\text{Actual value}} \times 100$$

$$= \frac{24.5 - 24.3}{24.3} \times 100\% = 0.823\%$$

The mass of 10 cm of magnesium ribbon is around 0.15–0.17 g.

In this experiment, the systematic errors come from the top-pan balance, the ruler and the measuring cylinder (or gas syringe).

e Maximum error from the top-pan balance

If the top-pan balance reads to 0.01 g then the maximum error can be estimated to be ± 0.005 g. If we think our 10 cm length of magnesium will weigh in the region of 0.15 g then the percentage

$$\text{error} = 2 \times \frac{0.005}{0.15} \times 100\% = 6.67\%$$

f Percentage error from measurements of lengths

For example, if the length is 1 cm then the maximum

$$\text{percentage error is equal to } \frac{0.05}{1.0} \times 100\% = 5\%$$

g Total error from length measurements

i The measurement of the lengths of magnesium ribbon. If we go by the rules that the maximum error or uncertainty is half the smallest possible measurement then the ruler reads to ± 0.5 mm. The length measurements will give the greatest error.

ii If they use measuring cylinders, learners should be marked on their choice. For example, if they estimate from their trial run that they will obtain around 20 cm³ from the reaction, then choosing a 50 cm³ measuring cylinder that is graduated in 2.0 cm³ divisions will give a maximum error of ± 1.0 cm³ (half the graduation's reading).

iii Total possible percentage error from apparatus readings. In this case, the maximum percentage error is $\frac{1}{20} \times 100\% = 5\%$. This error is halved if a 25 cm³ measuring cylinder is used.

h Other factors that limit accuracy and contribute to the error

- Because of the cleaning by the steel wool, the thickness of the magnesium ribbon is not the same along its whole length.
- There may still be some oxide present even after cleaning.

Practical Investigation 1.3: Percentage composition of a mixture of sodium hydrogen carbonate and sodium chloride

Introduction

In this investigation, learners will find the percentage composition of a mixture of sodium hydrogen carbonate and sodium chloride. They will do this by titrating the sodium hydrogen carbonate against standard hydrochloric acid.

Skills focus

The following skill areas are developed and practised (see the skills grids at the front of this guide for codes):

MMO	Collection of data and observations (a), (b), (c), (d) and (e) Decisions relating to measurements of observations: (a), (b) (d) and (e)
PDO	Recording data and observations (a), (c) and (e) Display of calculations and reasoning (a) and (b)
ACE	Data interpretation and sources of error (d) Drawing conclusions (a), (c) and (d) Suggesting improvements (a)

Duration

This investigation requires 1 h of preparation, including making up the solution of the mixture, then 1 h for the titrations and calculations.

Preparing for the investigation

- The volume of hydrochloric acid required can be calculated from the projected titre values. For example, if you calculate that the sodium hydrogen carbonate would require 17.00 cm^3 of acid for complete reaction, then if each learner or group does five titrations, 85 cm^3 is required and 100 cm^3 per learner/group would be an adequate allocation.

Equipment

Each learner or group will need:

- 150 cm^3 conical flask
- 250 cm^3 volumetric flask
- wash bottle of distilled water

- burette stand
- 25.0 cm^3 pipette
- white tile
- 250 cm^3 beaker and 100 cm^3 beaker
- stirring rod and small dropper
- small filter funnel for burette and larger one for volumetric flask
- weighing boat
- 50 cm^3 burette

Access to:

- a mixture of sodium hydrogen carbonate and sodium chloride. You can decide on the composition. If different classes are doing the same practical they can be given different mixtures to investigate.
- $0.100 \text{ mol dm}^{-3}$ hydrochloric acid
- The volume of hydrochloric acid required can be calculated from the projected titre values. For example, calculations might show that the sodium hydrogen carbonate would require 17.00 cm^3 of acid for a complete reaction. Therefore, if each student or group does five titrations, 85 cm^3 is required and 100 cm^3 per student/group would be an adequate allocation.
- methyl orange indicator and dropper
- either a two or three place top-pan balance
- distilled water

Safety considerations

- They must wear eye protection and tie hair back if it is long.
- The acid is an irritant at the concentration used in the experiment.
- Methyl orange is poisonous. Wash off skin immediately.

Carrying out the investigation

- As far as the mixture is concerned, a typical calculation is as follows:
 - Let us suppose we want the titre to be 17.20 cm^3 . Such a volume requires the learner to fill up their burette twice at most.
 - The number of moles of sodium hydrogen carbonate present in 25.00 cm^3 is: $17.20 \times 10^{-3} \times 0.1 = 1.72 \times 10^{-3} \text{ mol}$

- iii Therefore, in 250 cm^3 the learner has 1.72×10^{-2} mol or $1.72 \times 10^{-2} \times 84.1\text{ g} = 1.445\text{ g}$
 - iv If each learner requires 2.00 g of mixture, then the sodium chloride should contribute $2.00 - 1.45\text{ g} = 0.55\text{ g}$.
 - v The percentage composition of the mixture = 72.5% NaHCO_3 and 27.5% NaCl . If you have 20 learners then you will need $20 \times 2.00\text{ g}$ of mixture but allow for more because learners are still in the early stages of learning in detail about quantitative investigations and their technique may not yet be up to scratch.
 - vi Whatever is decided, there could be differences in the results obtained because the solid mixture may not be homogeneous. The only way to ensure complete homogeneity is to make up a solution of the mixture. This makes a very good discussion point at the end.
 - vii It is important that learners express the burette readings to $\pm 0.05\text{ cm}^3$. For example, if they get two readings such as 17.00 and 17.10 , then the average is 17.05 because burettes usually read to 0.05 cm^3 , which is one drop.
- Please be aware that learners tend to 'blow out' or expel the last drop of solution from their pipette. The pipette is calibrated so that this last remaining drop is not in the 25.00 cm^3 used.
 - The end-point of the methyl orange is in fact an orange colour. If a red colour is obtained, then they have overshot.
 - The biggest problem is how well you have mixed the sodium hydrogen carbonate and sodium chloride. It is not that big a problem because the apparatus used is overall very accurate and therefore the systematic errors are small. It is a random source of error and a source of an 'open question' at the end of the practical. A systematic error could be the learner who does the same thing wrong for every titration.



As already mentioned, making the whole mixture into a solution would remove the possibility of random distribution of the solids. Ask them to put forward one way to overcome the problem and see if they come up with a plausible method.

Common learner misconceptions

- The most common error is that learners forget that 25 cm^3 is only $\frac{1}{10}$ th of the total amount of solution they have prepared.

Sample results

	Rough titration/ cm^3	First accurate titration/ cm^3	Second accurate titration/ cm^3	Third accurate titration/ cm^3
Final burette reading/ cm^3	18.00	35.20	19.80	37.00
Starting burette reading/ cm^3	0.00	18.00	2.20	19.80
Titre/ cm^3	18.00	17.20	17.60	17.20

Table 1.4

Answers to workbook questions (using the sample results)

- a Change in enthalpy of hydration of copper (II) sulfate
 - b i Volume of 0.100 mol dm^{-3} hydrochloric acid needed to react completely with the sodium hydrogen carbonate present in 25 cm^3 of the mixture = 17.20 cm^3
 - ii Number of moles of hydrochloric acid reacting = number of moles of sodium hydrogen carbonate present in $25.00\text{ cm}^3 = 17.20 \times 10^{-3} \times 0.100 = 1.72 \times 10^{-3}$ = number of moles of sodium hydrogen carbonate present in 25.00 cm^3 of solution.
 - iii Mass of sodium hydrogen carbonate present ($m = n \times M_r$) = $1.72 \times 10^{-2} \times 84.1 = 1.45\text{ g}$
 - iv Total mass of mixture = 2.00 g
 - v Mass of sodium chloride present in mixture = $2.00 - 1.45 = 0.55\text{ g}$
 - vi Percentage of sodium hydrogen carbonate present mixture = $\frac{1.45}{2.00} \times 100\% = 72.5\%$
- Therefore, in 250 cm^3 of solution the number of moles of sodium hydrogen carbonate present = $1.72 \times 10^{-3} \times 10 = 1.72 \times 10^{-2}\text{ mol}$

- vii** What is the actual percentage composition of the mixture? = 72.5% NaHCO_3 and 27.5% NaCl

If you have 20 students then you will need $20 \times 2.00 \text{ g}$ of mixture but allow for more because students are still in the early stages of learning in detail about quantitative investigations and their technique may not yet be up to scratch.

- c** Percentage error =

$$\frac{|\text{Actual value} - \text{experimental value}|}{\text{Actual value}} \times 100$$

- d** The systematic errors:

- i** The top pan balance: if 2 readings are taken and the balance reads to 0.01 g then the percentage error for a mass of 2.00 g the percentage error = $2 \times \frac{0.005}{2.00} \times 100\% = 0.5\%$
- ii** The pipette: if this reads to $\pm 0.05 \text{ cm}^3$ then the percentage error = $\frac{0.05}{25.00} \times 100\% = 0.200\%$
- iii** The burette readings

It is important that the students express the burette readings to $\pm 0.05 \text{ cm}^3$. For example, if they get two readings such as 17.00 and 17.10 then the average is 17.05 because burettes usually read to 0.05 cm^3 , which is approximately one drop of solution.

The uncertainty for a burette is $\pm 0.05 \text{ cm}^3$ for each reading. Therefore, the uncertainty associated with the difference between two burette readings (a titre)

$$= 2 \times 0.05 = \pm 0.10 \text{ cm}^3$$

$$\text{Therefore, the error} = \frac{0.10}{17.20} \times 100\% = 0.58\%$$

- e** The main random error depends on the homogeneity of the mixture. Another possible error is in the purity of the sodium hydrogen carbonate. Over time it can decompose to give sodium carbonate.
- f** The main contribution to any percentage error is due to the solid mixture not being homogeneous.
- g** The only way to ensure complete homogeneity is to make up a solution of the mixture. This makes a very good discussion point at the end.

Practical investigation 1.4: Relative atomic mass of calcium by two different methods: molar volume and titration

Introduction

In this investigation, learners will react calcium with water to give hydrogen. The volume of hydrogen given by a known mass of calcium is measured and, using molar ratios, the number of moles of calcium is found and from this the relative atomic mass. The reaction of calcium with water also gives the alkali calcium hydroxide, which is titrated against standard hydrochloric acid. Again, the number of moles of calcium hydroxide (and therefore calcium) is determined and this will give another value for the relative atomic mass.

Skills focus

The following skill areas are developed and practised (see the skills grids at the front of this guide for codes):

- MMO Collection of data and observations: (a), (b), (c), (d) and (e)
Decisions relating to measurements of observations: (a), (b) (c) and (d)

- PDO Recording data and observations: (c) and (e)
Display of calculations and reasoning: (a) and (b)
- ACE Data interpretation and sources of error: (g) (h), (i) and (j)
Drawing conclusions: (c) and (d)
Suggesting improvements: (a) and (c)

Duration

This investigation is a summative exercise as it uses techniques from Investigations 1.2 and 1.3 and requires the learners to use several formulae and relationships.

Preparing for the investigation

- Of the two sets of apparatus suggested for collecting the gas, the easiest to set up is the one using the gas syringe. However, if gas syringes are not available, then the displacement of water in a measuring cylinder works very well.

Equipment

Each learner or group will need:

- apparatus for measuring gas volumes as used in Investigation 1.2

- small filter funnel for burette
- 50 cm³ burette
- weighing boat
- 150 cm³ conical flask
- wash bottle of distilled water
- burette stand
- 25 cm³ pipette
- white tile
- 250 cm³ beaker
- 25 cm³ measuring cylinder (for water)
- methyl orange indicator in dropper bottle

Access to:

- top-pan balance reading to **at least** two decimal places. A top-pan balance reading to three decimal places is preferable.
- 0.200 mol dm⁻³ hydrochloric acid
- access to **fresh** calcium granules
- distilled water

Safety considerations

- Learners must wear eye protection and tie their hair back if it is long.
- Calcium reacts vigorously with water. Emphasise that learners should not handle it with wet hands.
- Hydrogen is a flammable gas.
- 0.2 mol dm⁻³ hydrochloric acid is an irritant.
- It is important that if learners are using gas syringes they do not clamp the syringe too tightly. Firstly, they could crack the glass and it may also hinder the movement of the piston.
- The calcium hydroxide is an alkali and should be regarded as being corrosive. It should be washed off immediately if spilt on the skin.
- Methyl orange indicator is poisonous. If any is splashed onto skin it should be washed off immediately.

Carrying out the investigation

- One problem that needs to be overcome first is making sure that the measuring cylinder is full of water when it

is put in the trough and that none or very little escapes. This can be done by either learners holding their hands over the end of the measuring cylinder or placing a piece of plastic wrap over the open end and then turn the measuring cylinder upside down when it is in the trough. Remember to remove the film before starting the actual measurement.

- The main problem with the practical is the freshness of the calcium. If it is visibly oxidised, then the results will be inaccurate and this is one of the random errors encountered. If the top portion of your calcium looks to be oxidised then use the lower portions. An alternative is that if you know you are going to use calcium for Group II experiments, then as soon as it is bought, divide it up into smaller portions and store in small containers until ready to use. It is the constant exposure to air that leads in the end to its oxidation.



Make sure that learners have at least two sets of results to analyse. They may struggle on the first set but will get better the more practice they have.

- Once learners have started, then one of the group can do the determination of gas volumes while the other can do the titration. After they have done this once they can swap over.
- Before the practical, a short demonstration with an approximate mass of calcium will give learners some idea of the volumes of gas that they will be dealing with.
- Also, unless there is time for a trial run, learners could be given an idea of the volume of acid required for the titration.
- Evaluation of a practical method always presents problems to learners and they will need help when estimating the percentage error due to using different apparatus.



If you want to extend the more able learners, you can state that they know what the answer should be and they can work back to see what readings they should get. However, in this case it should be emphasised that the methods are not perfect and therefore cheating will give them fewer marks.

Common learner misconceptions

- Learners may need to be reminded that the calcium hydroxide is formed from the same mass of calcium as in the first method. This fact sometimes becomes lost when learners are doing their calculations.

Sample results

Part 1: Determination by molar volume

Example measurements shown in Table 1.5.

Learner	Mass of Ca/g	Volume of H ₂ /cm ³	At mass of Ca/g mol ⁻¹	Burette readings		Vol of HCl/cm ³	At mass of Ca/g mol ⁻¹
1	0.050	30.00	40.00	2nd	12.50	12.50	40.00
				1st	0.00		
	0.048	28.0	41.10	2nd	23.90	11.40	42.30
				1st	12.50		
2	0.040	24.0	40.0	2nd	10.00	10.00	40.00
				1st	0.00		
	0.055	31.0	42.5	2nd	24.50	14.50	37.70
				1st	10.00		
3	0.060	37.0	38.9	2nd	17.20	15.20	39.50
				1st	2.00		
	0.071	42.0	40.57	2nd	36.20	18.20	39.01
				1st	18.00		

Table 1.5

Answers to the workbook questions (using the sample results)

Weight of calcium = 0.048 g

- a i** Number of moles of hydrogen formed in first experiment:

$$n_{\text{hydrogen}} = \frac{28}{24000} = 1.17 \times 10^{-3} \text{ mol}$$

- ii** Number of moles of calcium:

$$n_{\text{calcium}} = n_{\text{hydrogen}} = 1.17 \times 10^{-3} \text{ mol}$$

- iii** Relative atomic mass of calcium:

$$A_r(\text{Ca}) = \frac{0.048}{1.17 \times 10^{-3}} = 41.0 \text{ g mol}^{-1}$$

- b** The percentage error in your result

Percentage error =

$$\frac{|\text{Actual value} - \text{experimental value}|}{\text{Actual value}} \times 100$$

The relative atomic mass result for this experiment is 41.0 which should be 40.1.

$$\text{This gives a percentage error of } \frac{41.0 - 40.1}{40.1} \times 100\% = 2.24\%$$

- c** Systematic errors in the apparatus:

- i** The weighing out of the calcium: If you use a top-pan balance reading to ± 0.001 g then the possible error is $\frac{1}{2} \times 0.001 = 0.0005$.

A mass of 0.048 g has a possible error of $\frac{0.0005}{0.048} \times 100\% = 1.04\%$. This will rise to 10.4% if you use a top-pan balance that measures to two decimal places.

- ii** The measurement of gas volume

A 100 cm³ measuring cylinder reads to ± 2.00 cm³ and therefore has a maximum error of ± 1.00 cm³. A volume of 28.0 cm³ has a possible error of $\frac{1}{28.0} \times 100\% = 3.60\%$.

- iii** Random errors in the method:

The calcium is possibly oxidised. In this case, the volume of hydrogen will be less than ideal and the value of n will be lower than expected. Therefore $\frac{m}{n}$ will give a value of the relative atomic mass higher than the published value. This method also assumes that the hydrogen is collected at R.T.P.

- iv** Improvements to Method 1:

If the calcium is oxidised then some of the mass weighed out is not calcium. The best way round this is to not use the calcium at the top of the container but use the calcium below it because it is less exposed to air.

Part 2: Determination by titration

Answers to the workbook questions (using 2nd set of sample results for learner 1 in Table 1.5)

Weight of calcium = 0.048 g

- d** The number of moles of hydrochloric acid reacting with the calcium hydroxide:

$$n_{\text{calcium}} = \frac{1}{2} n_{\text{HCl}} = \frac{1}{2} \times 11.40 \times 10^{-3} \times 0.200 = 1.14 \times 10^{-3}$$

- i** The number of moles of calcium hydroxide and therefore the number of moles of calcium:

$$n_{\text{calcium}} = \frac{1}{2} n_{\text{HCl}} = \frac{1}{2} \times 11.40 \times 10^{-3} \times 0.200 = 1.14 \times 10^{-3}$$

- ii** The relative atomic mass of calcium:

$$A_r(\text{Ca}) = \frac{0.048}{1.14 \times 10^{-3}} = 42.1 \text{ g mol}^{-1}$$

- e** The percentage errors:

- i** Weighing out of the calcium: $2 \times \left(\frac{0.0005}{0.048} \right) \times 100\% = 2.08\%$.

- ii** The titrations: The burettes read to $\pm 0.05 \text{ cm}^3$ and therefore in a titration where two readings are made, the error = $2 \times 0.05 = \pm 0.10 \text{ cm}^3$. This means that in the set of readings used, the error = $\frac{0.10}{11.40} \times 100\% = 0.88\%$

- iii** Total systematic error due to apparatus = $2.08 + 0.88 = 2.96\%$

- iv** If the value for the relative atomic mass is greater than it should be then $\frac{m}{n}$ is greater than it should be and we have overestimated the number of moles of calcium. This may be due to oxidation of the calcium so that n is smaller leading to a greater than expected value for A_r .

- f** Improvements to Method 2: If the concentration of the hydrochloric acid is reduced then more of it will be required in the titrations. This will reduce the percentage error in the results due to the titrations.

Chapter 2:

Structure and bonding

Chapter outline

This chapter refers to Chapters 4: Chemical bonding and Chapter 5: States of matter in the coursebook.

In this chapter learners will complete practical investigations on:

- 2.1 Physical properties of three different types of chemical structure
- 2.2 Effect of temperature on the volume of a fixed mass of gas
- 2.3 Effect of pressure on the volume of a fixed mass of gas

Preparing for the investigations

- Learners should be familiar with types of structure and how its structure affects the properties of a substance.
- Learners should be familiar with the behaviour of different types of structure when testing for electrical conductivity and melting point.
- The theory underlying the Gas Laws is fairly straightforward but the practical work will underpin what is learned in the theory lessons.
- If there are enough data loggers for a class practical then learners should be made familiar with how to use them, especially the single-step procedure which is required in this practical. If the Boyle's Law investigation is demonstrated then linking the data logger to a whiteboard would help learners follow the practical.

Practical investigation 2.1: Physical properties of three different types of chemical structure

Introduction

In this investigation, learners will carry out tests on three substances and make sense of their observations by using their knowledge of structures.

Skills focus

The following skill areas are developed and practised (see the skill grids at the front of this guide for codes):

- MMO Collection of data and observations (a, b, c, d and e)
 Decisions relating to measurements of
 observations (c) and (d)

PDO Recording data and observations (a), (c) and (e)

ACE Data interpretation and sources of error (b)
 Drawing conclusions (c) and (d)

Duration

- This investigation requires ½ hour for the practical work and the rest of the hour for discussion of results and a plenary.

Preparing for the investigation

- The silicon dioxide often contains impurities therefore it needs to be washed thoroughly with distilled water and dried in an oven before use.

Equipment

Each learner or group will need:

- Bunsen burner, tripod, gauze and heatproof mat
- 12 dry test tubes and a test-tube rack
- eight stoppers to fit test tubes
- two graphite rods in a holder
- three spatulas
- three leads and two crocodile clips
- 12V bulb
- power pack
- wash bottle filled with distilled water
- small evaporating basin
- tongs

Access to:

- cyclohexane
- wax
- white sand
- potassium iodide

Safety considerations

- The cyclohexane is flammable and harmful. It should not be disposed of by flushing down the sink. The best way to remove it is to place the reaction liquids in a large bottle which can then be disposed of safely, or it can be distilled and re-used.
- Cyclohexane must be kept away from naked flames.

- Learners should be told to obey safety instructions especially when heating some of the solids very strongly.

Carrying out the investigation

- The methods used are very simple but they need to be aware that apart from the investigation of electrical conductivity, they need to use small amounts of the three solids.



Ask learners to research the electrolysis of molten potassium iodide on the internet.

Common learner misconceptions

- Learners need to be aware of what constitutes a **soluble** solid. As stated above they need to use small amounts of solid.

Sample results

Please refer to Table 2.1

Substance	Type of structure	Summary of observations
Wax	Simple molecular	Melts easily therefore low melting point. Does not conduct electricity as a solid or in cyclohexane. Soluble in non-polar cyclohexane but not in water.
Silicon dioxide	Giant covalent	Does not melt therefore very high melting point. Does not conduct electricity as a solid or in water. Does not dissolve in water or cyclohexane.
Potassium iodide	Giant ionic	Melts if heated very strongly; high melting point. Does not conduct in solid state but does so in water. Soluble in water, insoluble in cyclohexane.

Table 2.1

Answers to the workbook questions (using the sample results)

Answers to the workbook questions

- a** Explain your observations for each of the **three** substances

i Wax

Wax has a simple molecular structure. It does not conduct electricity in a solid or in solution because there are no charge-carrying particles present. It is non-polar and therefore will dissolve in non-polar cyclohexane but not in polar water.

ii Potassium iodide

potassium iodide has a giant ionic structure. It does not conduct electricity as a solid because the ions

cannot move and carry the current, but they can do when they are dissolved in water and therefore potassium iodide solution is a conductor. High melting point because of the strong electrostatic attraction between the oppositely charged ions. It will dissolve in polar water but not in non-polar cyclohexane.

iii Silicon dioxide

Silicon dioxide has a giant covalent structure. It has a high melting point because all the strong covalent bonds have to be broken when it melts. Because all the bonds in the giant structure are covalent, it will not dissolve in polar water or in nonpolar cyclohexane.

Practical investigation 2.2: Effect of temperature on the volume of a fixed mass of gas

Introduction

In this investigation, learners will investigate how changing the temperature affects the volume of a gas. The gas used is air which is a mixture of gases but it is assumed that it will obey the ideal gas laws under these conditions. This is not a qualitative investigation; it is designed to show that extrapolation back to zero volume will give a temperature close to -273°C .

Skills focus

The following skill areas are developed and practised (see the skill grids at the front of this guide for codes):

MMO	Collection of data and observations: (a, b, c, d and e) Decisions relating to measurements of observations: (a, b, c and d)
PDO	Recording data and observations: (a), (c), (d) and (e) Display of calculations and reasoning: (a) and (b) Data layout: (b), (c), (d), (e) and (f)
ACE	Data interpretation and sources of error: (a), (c) and (e) Drawing conclusions: (c) and (d)

Duration

The practical aspects of this investigation require 1 h to complete. The follow-up lesson can be partly allocated to Practical investigation 2.3 because this will take a very short time. A quarter of an hour is easily enough time if learners are familiar with using the data logger.

Preparing for the investigation

- Learners need to know the volume of the flask and the tubing attaching it to the gas syringe. If the round bottom flasks are identical for all groups then one determination of the volume before the practical lesson will suffice. The method used is described in the practical method. The permanent marker pen can be used to show how far the stopper to the flask protrudes into the neck.
- The volume of the tubing can be found by filling it with water and measuring the water required to fill it. Another way of doing it is to measure the internal diameter of the tubing and its length and using the following formula:

Volume = $(\pi r^2 \times \text{length of tube})$ where r is the internal radius of the tube.

- If the same length of tubing is used for each group then this value can be given to the whole class.

Equipment

Each learner or group will need:

- Bunsen burner, tripod, gauze and heatproof mat
- 100 cm³ round-bottomed flask
- stopper for flask attached to a short length of plastic or rubber tubing
- 100 cm³ measuring cylinder
- permanent marker pen
- dropper
- 100 cm³ gas syringe or apparatus to measure gas volume by displacement of water (see Skills chapter)
- metal container for heating water
- thermometer reading to 110 °C
- either a stirring rod or a small 'paddle' for stirring water in metal container
- water supply

Safety considerations

- Towards the end of the experiment there will be hot water which needs to be stirred on a tripod and gauze. Therefore, learners need to be very careful when they stir.

Carrying out the investigation

- It will take a little while for learners to understand how much heating is required to give a small temperature rise in the water and inevitably some of them will go past their desired temperature. Firstly, make sure they realise that it is not absolutely essential for them to get a temperature such as 30 °C or 40 °C. A temperature difference of 1 or 2° is not a disaster. If, however, they do go way past a desired temperature, then as described in the method they can add a small amount of cold water to get back near to the desired temperature.
- When analysing their results, learners may find that there is some flexibility when drawing their line. One way around this is to draw small circles round their points and sometimes this helps with ascertaining the best line to draw. The other way is to export their results into an Excel document and then draw a scatter chart to give them the desired line.
- The instructions in the method do help learners draw their line by stating the scales that need to be adhered to when drawing their graph.



Ask learners to write their own law using their results.

Common learner misconceptions

- Learners often still think in terms of $^{\circ}\text{C}$ when talking about temperature rather than in Kelvin. Therefore, learners often wonder why their line does not go through the origin.

Sample results

Please refer to Table 2.2

Temp/ $^{\circ}\text{C}$	18	32	39	45	54	60	65	72	80	85
Reading on syringe/ml	0	4	7	9	12	14	16	18	21	22
Total volume of gas/ cm^3	100	104	107	109	112	114	116	118	121	122

Table 2.2

Answers to the workbook questions (using the sample results)

- a** Figure 2.1 shows the sample results plotted.
- Check the best-fit line is correct
 - Temperature where volume is zero = $[-290^{\circ}\text{C}]$

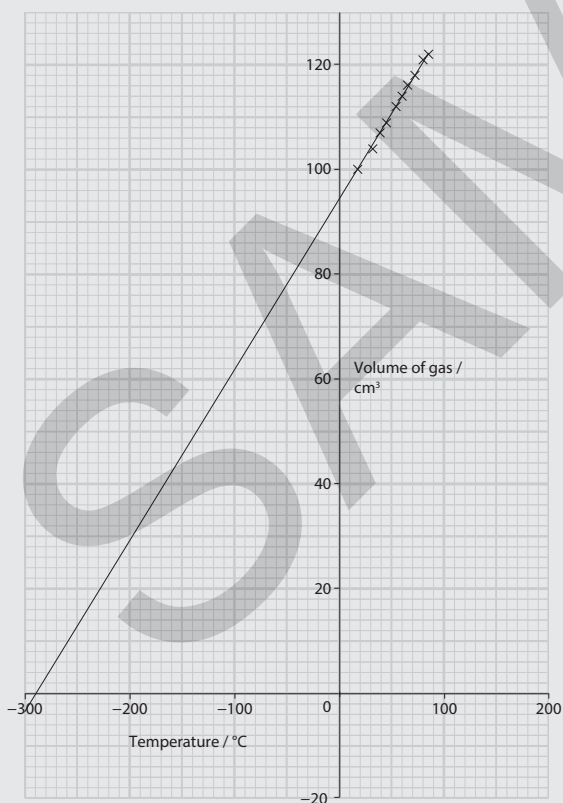


Figure 2.1

- The extrapolated value for the temperature when the volume of the gas is zero is approximately -290°C . This gives an experimental error of 6.22%.
- The main sources of error in the experiment are the stirring and the synchronisation between the temperature and the volume measurement.
- The name given to the temperature when the volume is zero is absolute zero.
- A reasonable law is that the volume of gas is directly proportional to the temperature of the gas if a scale reading from -290°C is used for the temperature scale.

Practical investigation 2.3: Effect of pressure on the volume of a fixed mass of gas

Introduction

In this investigation, learners or the teacher are asked to use a data logger. It is likely that there will be insufficient data loggers for a class practical and therefore it can be viewed as a demonstration. The practical requires the manipulation of data in order to establish a relationship between pressure and the volume of a fixed mass of gas. The gas used is air.

Skills focus

The following skill areas are developed and practised (see the skill grids at the front of this guide for codes):

MMO	Collection of data and observations: (b) and (c)
PDO	Recording data and observations: (a), (c) and (e) Display of calculations and reasoning: (a) and (b) Data layout: (b), (c), (d) (e) and (f)
ACE	Data interpretation and sources of error: (a) Drawing conclusions: (a) and (c)

Duration

- Although Practical 2.2 requires one hour for the practical work to be completed, the follow-up lesson can be partly allocated to this investigation because this will take a very short time. Fifteen minutes is easily enough if learners are familiar with using the data logger.

Equipment

Each learner or group will need:

- a laptop or other device that will interface with a data logger and run the software required
- a pressure data logger with any software required
- a 60 cm³ plastic syringe attached to a small length of plastic tubing which will fit the inlet to the pressure data logger.

Safety considerations

- The only thing that can possibly happen is that the tube might come off during the experiment but this is not likely to cause any great problems in terms of safety.

Carrying out the investigation

- When using the ideal gas equation, learners have to realise that the unit of volume is m³ and not cm³. The units on the data logger are probably given in kPa and they should also realise that this needs converting to Pa.



The more able learners will realise that $P \propto \frac{1}{V}$ and that $PV = \text{constant}$. Therefore, once the results are obtained they can be asked to plot the results in any way they wish. The correct way is to plot $\frac{1}{V}$ (horizontal axis) against P (vertical axis). The more able learners could also be asked to use an Excel spreadsheet to process the results.

Sample results

A sample set of results is shown in Table 2.3:

Volume of gas/cm ³	$\frac{1}{\text{volume}}$	Pressure of gas /kPa
60	0.0167	102.1
55	0.0182	108.6
50	0.0200	117.4
45	0.0222	127.2
40	0.0250	141.9
35	0.0286	155.2
30	0.0333	176.2
27	0.0370	190

Table 2.3

Answers to the workbook questions (using the sample results)

a $P \propto \frac{1}{V}$

b Refer to data in Table 2.3.

c Please refer to Figure 2.2, obtained from one set of results.

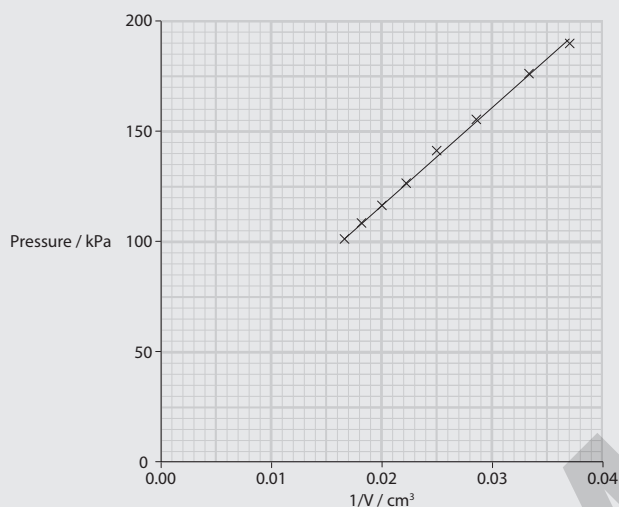


Figure 2.2

Note the R^2 value of 0.9983 is very close to 1 and therefore there is a great deal of certainty that it is a straight line.

d The results give a straight line and therefore the slope of the line is constant.

e The slope of the line = $\frac{P}{1/V} = PV = \text{constant}$

f If we take the first values from this set of results

$$P = 102.1 \text{ kPa} = 1.021 \times 10^5 \text{ Pa}$$

$$V = 60 \text{ cm}^3 = 60 \times 10^{-6} \text{ m}^3; n = \frac{60}{24000} = 0.0025 \text{ mol};$$

g The experiment was conducted at 20°C or 293 K

$$R = \frac{PV}{nT} = \frac{1.021 \times 10^5 \times 60 \times 10^{-6}}{0.0025 \times 293} = 8.36 \text{ J mol}^{-1} \text{ K}^{-1}$$

h The value of R given in the literature is $8.31 \text{ J mol}^{-1} \text{ K}^{-1}$

$$\text{The percentage error} = \frac{8.36 - 8.31}{8.31} \times 100\% = 0.60\%$$

i If we substitute these units into the equation for the units of R we have:

$$R = \frac{PV}{nT}; 1 \text{ Pa} = 1 \text{ N m}^{-2} \text{ (1 Newton per m}^2\text{)};$$

$$\text{Units of } R = \text{N m}^{-2} \times \text{m}^3 / \text{mol} \times \text{K} = \text{N m mol}^{-1} \text{ K}^{-1}$$

$$1 \text{ N m} = 1 \text{ J}$$

Therefore, units of $R = \text{J mol}^{-1} \text{ K}^{-1}$

Chapter 3:

Enthalpy changes

Chapter outline

This chapter relates to Chapter 6: Enthalpy changes in the coursebook

In this chapter, learners will complete practical investigations on:

- 3.1 Enthalpy change for the reaction between zinc and aqueous copper(II) sulfate solution
- 3.2 Enthalpy change of combustion of alcohols
- 3.3 Enthalpy change of a thermal decomposition
- 3.4 Change in enthalpy of hydration of copper (II) sulfate

Preparing for the investigations

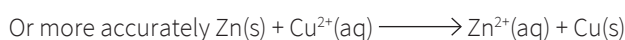
- Learners should be familiar with terms such as enthalpy and the various definitions associated with this topic. They need to understand these definitions and how they influence the handling of data. For example, standard enthalpy changes are always expressed in terms of kJ mol^{-1} .
- Learners can refer to the Skills chapter for the theory behind the temperature–time graph required for Practical Investigation 3.1.
- Learners should be confident in their conversion of J to kJ and realise that their initial heat calculations are expressed in J.
- Hess' Law investigations are straightforward to carry out but learners often do not understand the underlying theory behind what they are doing.

Practical investigation 3.1: Enthalpy change for the reaction between zinc and aqueous copper(II) sulfate

Introduction

This investigation requires learners to draw temperature–time graphs and use these to determine the temperature changes in the reaction. The two investigations are concerned with the same reaction but use different limiting reactants for each determination.

The reaction taking place is:



Skills focus

The following skill areas are developed and practised (refer the skills grids at the front of this guide for codes):

MMO	Collection of data and observations (a), (b), (c) (d) and (e)
PDO	Recording data and observations (a) and (e) Display of calculations and reasoning (a) and (b) Data layout (a) (b), (c), (d), (e) and (f)
ACE	Data interpretation and sources of error (a) and (c) Drawing conclusions (c)

Duration

- The practical work will take approximately half an hour to complete.
- The necessary introductions and plenaries will also take half an hour in total so one hour will probably be sufficient.

Preparing for the investigation

- This is probably the first time learners will have gathered data for a temperature–time graph and they may not get it right straightaway.

Equipment

Each learner or group will need:

- two small polystyrene beakers
- glass beaker large enough to hold the polystyrene beakers
- -10 to 110°C thermometer
- 25 cm^3 measuring cylinder


- plastic covers for polystyrene beakers
- a small spatula
- two weighing boats
- 1 mol dm⁻³ copper(II) sulfate solution
- zinc powder
- a top-pan balance that reads to at least two decimal places

Safety considerations


- The copper(II) sulfate is both an irritant and harmful and the zinc is flammable but there is no reason for using Bunsen burners.
- Be careful when disposing of any copper(II) sulfate because it is regarded as an environmental hazard.

Carrying out the investigation

- The reaction is quite a vigorous one and the lid of the polystyrene beaker does need to be stable and intact when the mixture is swirled.
- The second part of the investigation has the copper(II) sulfate as the limiting reactant and this necessitates the copper(II) sulfate being pure and the concentration of the solution being accurate.

 Initially, some learners do not understand the reasons for doing the experiment using a temperature-time graph; after they have actually done the experiment, however, and the results are explained they can usually understand the rationale.


 Some learners may need help with the calculation but it is probably more important that they complete both practical assignments before they start the calculations.

 The more able learners might find some value in working out the actual enthalpy change for the reaction.

The reaction may be summarised by the ionic equation:



The accepted value for $\Delta H_{\text{reaction}} = -219 \text{ kJ mol}^{-1}$

 The more able learners can calculate their values for the enthalpy change of reaction and work out their percentage accuracy using the theoretical results above and their experimental results.

Common learner misconceptions

- Learners must be able to convert heat/enthalpy changes from J to kJ. Occasionally they fail to do so.

Sample results

Part 1

Table 3.1 gives an idea of the results learners should end the investigation with.

Copper(II) sulfate was in excess. The mass of the zinc was:

$$0.66 \text{ g} = \frac{0.66}{65.4} = 0.010 \text{ mol}$$

The number of moles of copper(II) sulfate = $C \times V = 1.00 \times 0.025 = 0.025 \text{ mol}$.

Therefore, the copper(II) sulfate is in excess and the limiting reactant is the zinc. This means that the number of moles reacting = 0.010 mol

Time /min	Temp. /°C
0	19
1	19
2	19
3	X
4	34.5
5	36
6	36
7	35
8	34.5
9	34
10	33.5

Table 3.1

Answers to the workbook questions (using the sample results)

Part 1

a See Figure 3.1

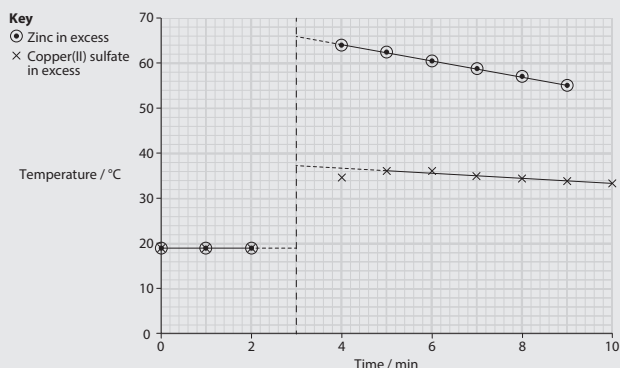


Figure 3.1

When the graph is plotted the initial temperature is 19°C and the maximum temperature measured by extrapolation is 37.6. The thermometer only reads to 1°C so this temperature is rounded up to 38°C.

The temperature change = 38 – 19 = 19°C.

b Enthalpy change: $q = m \times c \times \Delta T = 25 \times 4.18 \times 19 = 1985.5 \text{ J}$

c The number of moles of CuSO_4 present: $n = C \times V = 0.100 \times 0.025 = 0.0250 \text{ mol}$

d The number of moles of zinc present: $n = \frac{m}{A_r} = \frac{0.66}{65.4} = 0.0101$

e In this reaction the zinc reacts with an equal number of moles of copper(II) sulfate. In this experiment there are fewer moles of zinc than copper(II) sulfate so the zinc is the limiting reactant.

f The standard enthalpy change in kJ mol^{-1}

0.101 mol of reactants produce –1985.5 J of heat energy

Therefore, 1 mol of reactants produce $\frac{1985.5}{0.0101}$

$\Delta H = -197 \text{ kJ mol}^{-1}$. This is the standard enthalpy

change of reaction. The thermometer only reads to two significant figures and therefore this value can be rounded up to -200 kJ mol^{-1} .

Sample results

Part 2

Table 3.2 shows the results when zinc is in excess (6.50 g = 0.10 mol). This means that the number of moles reacting = 0.025 mol.

Time / min	0	1	2	3	4	5	6	7	8	9
Temp. / °C	19	19	19	X	64	62.5	60.5	59	57	55

Table 3.2

Answers to the workbook questions (using the sample results)

Part 2

a The number of moles of CuSO_4 present: $n = C \times V = 0.100 \times 0.025 = 0.0250 \text{ mol}$

b The number of moles of zinc present: $n = \frac{m}{A_r} = \frac{6.6}{65.4} = 0.101$

c See graph drawn in answer to Part 1.

d When the graph is drawn for these results, the initial temperature is 19°C and the maximum temperature is 66°C. This means that $\Delta T = 66 - 19^\circ\text{C} = 47^\circ\text{C}$

e The enthalpy change: $q = m \times c \times \Delta T = 25 \times 4.18 \times 47 = 4911.5 \text{ J}$

f The number of moles of CuSO_4 present: $n = C \times V = 1.00 \times 0.0250 \text{ mol} = 0.0250 \text{ mol}$

g The number of moles of zinc present

$$n = \frac{m}{A_r} = \frac{6.50}{65} = 0.0994$$

h In this experiment there is a greater number of moles of zinc and therefore the limiting reactant is the copper(II) sulfate solution.

i The standard enthalpy change in kJ mol^{-1}

\therefore The standard enthalpy change of reaction

$$\Delta H^\ominus_r = \frac{4911.5}{0.025} = -196460 \text{ J} = -196 \text{ kJ mol}^{-1} \text{ (3 s.f.)}$$

Note: the thermometer reads to just two significant figures so this can be rounded up to -200 kJ mol^{-1} .

j The reaction is the same both in both experiments and the values are expressed in terms of 1 mol.

k The accepted value for ΔH^\ominus_c is -219 kJ mol^{-1} .
Therefore, if we use -200 kJ mol^{-1} the percentage error for our results = $\frac{219 - 200}{219} \times 100\% = 8.7\%$

l The highest degree of error will be for Part 1 because the lower temperature rise is recorded and the smallest mass of zinc is weighed.

The balance weighs to 0.010 g and therefore its maximum error is $\pm 0.005 \text{ g}$.

Therefore, the maximum percentage error from weighing = $2 \times \frac{0.005}{0.66} \times 100\% = 1.52\%$

The thermometer can be read to 0.5°C , therefore the temperature change = $19 \pm 1^\circ\text{C}$.

Therefore, the maximum percentage error = $\frac{1}{19} \times 100\% = 5.3\%$

The volume can be read to 0.5 cm^3

Therefore percentage error from volume measurement = $\frac{0.5}{25} \times 100\% = 2\%$

The total percentage error from apparatus measurement = $1.52 + 5.30 + 2.00\% = 8.82\%$

m The main non-systematic error is obviously the heat loss through the apparatus.

Practical investigation 3.2: Enthalpy change of combustion of alcohols

Introduction

This practical is as much about what is wrong with it as what is good about it. Ideally, a bomb calorimeter would be used to find the enthalpy of combustion of alcohols. In this practical, however, spirit burners or micro burners are used.

For all four alcohols the temperature of water is raised by the same amount each time. This means that the heat /enthalpy change will be the same each time because the apparatus being used is identical. The apparatus set-up is a very simple one. Heat-resistant pads can be used to make the apparatus draught-free by placing them around the spirit burner and calorimeter. If glass calorimeters are used then the specific heat capacity should be changed but the calculation remains the same.

Skills focus

The following skill areas are developed and practised (refer the skills grids at the front of this guide for codes):

MMO	Collection of data and observations (a), (b), (c), (d) and (e) Decisions relating to measurements of observations (c)
PDO	Recording data and observations (a) Display of calculations and reasoning (a) and (b) Data layout (b), (c), (d), (e) and (f)
ACE	Data interpretation and sources of error (g) (h), (i) and (j) Drawing conclusions(c)

Duration

- The practical can be completed easily within one hour.
- Spirit burners can be allocated to specific alcohols and can be shared amongst the groups of learners. Groups of two are ideal.

Preparing for the investigation

- Learners need to know the definition of enthalpy of combustion

Equipment

Each learner or group will need:

- spirit burners containing the four alcohols
- copper wire stirrer
- clamp stand, boss and clamp
- at least two heat-resistant pads
- thermometer
- 100 cm^3 measuring cylinder
- lid/cover for spirit burner
- wooden splint

Access to:

- a top-pan balance reading to at least two decimal places – two balances strategically placed would be ideal
- a supply of water
- a Bunsen burner (for lighting splints)

Safety considerations

- They must wear eye protection at all times.
- All the alcohols are flammable.
- All the alcohols should be treated as harmful.
- When weighing the alcohols learners must transport them to the balance on a heat-resistant pad.

Carrying out the investigation

- Learners should realise that the heat required to heat up the calorimeter must be taken into consideration.
- Learners need to realise that as the spirit burners will almost certainly be shared amongst the group; they could well be holding up other groups if they do not complete their determination in a reasonable time.
- The biggest problem is getting the flame to the same height for each burner and adjusting the calorimeter position so that its bottom is the same distance from the flame each time.
- The temperature rise advocated in the workbook is 20 °C, which can be reached in a very short time – about 1 min. Extensive and vigorous stirring is required in each determination.



Learners have had about four or five investigations by now in which they have been shown how to calculate the errors due to their equipment. In this practical, they should at least be able to work out the percentage error of their results compared with the values available in scientific literature. After they have calculated the errors due to their apparatus, there should still be a certain percentage error which is not accounted for.

- The most obvious source of error is heat loss through the apparatus. Also, the combustions of the alcohols, especially those with a higher relative molecular mass, are not complete and the learner should be reminded of the definition of standard enthalpy of combustion.
- This incomplete combustion can be demonstrated by inspection of the underside of the calorimeter, where a carbon deposit is a good sign of incomplete combustion.



One way to extend the learner is to encourage them to use spreadsheets in order to automate their calculations and save themselves time. One could say that this is taking them away from carrying out the calculations. However, in constructing their spreadsheet and getting it working they are in fact doing the calculations and putting in formulae that they need to understand.

- To extend the more able learners, they can either take their values for the standard enthalpies of combustion or the values available in the literature and plot them against the relative molecular mass. From their graph they can find the enthalpy change when $\text{-CH}_2\text{-}$ is burned and from this calculate the bond enthalpy of the C–H bond.

Common learner misconceptions

- Learners sometimes fail to remember that they are heating up the calorimeter as well as the water. Because of this they must remember that the calorimeter has a different specific heat capacity to the water. The specific heat capacity of copper is $0.385 \text{ J g}^{-1} \text{ K}^{-1}$ and that of glass is $0.84 \text{ J g}^{-1} \text{ K}^{-1}$.

Answers to the workbook questions (using the sample results)

- a** The standard enthalpy changes of combustion for all four alcohols

Mass of copper calorimeter = 198.00 g

Enthalpy change for heating up 100 g of water by 20 °C in this copper calorimeter

$$= 0.385 \times 20 \times 198.00 + 4.18 \times 20 \times 100$$

$$= 1524.6 + 8360 = 9884.6 \text{ J}$$

This enthalpy change is the same for all four alcohols. In the results given below spirit burners were not available and microburners were used. The time taken for each determination was approximately 1–2 mins

Table 3.3 shows the results for all four alcohols taken from a spreadsheet.

Alcohol	Mass of burner + alcohol before burning	Mass of burner + alcohol after burning	Mass burned	RMM of alcohol	no. of moles burned	Enthalpy change/J	Standard enthalpy change in kJ mol^{-1}
methanol	5.41	4.79	0.62	32	0.019375	9884.6	-510.2
ethanol	6.05	5.57	0.48	46	0.010435	9884.6	-947.3
propan-1-ol	6.20	5.79	0.41	60	0.006833	9884.6	-1446.5
butan-1-ol	6.27	5.87	0.40	74	0.005405	9884.6	-1828.7

Table 3.3

b The percentage errors for each alcohol are shown in Table 3.4.

Alcohol	Standard enthalpy change in kJ mol^{-1}	Literature values for standard enthalpy of combustion in kJ mol^{-1}	percentage error
methanol	-510	-726	29.7
ethanol	-947	-1367	30.7
propan-1-ol	-1447	-2021	28.4
butan-1-ol	-1829	-2676	31.7

Table 3.4

c The maximum percentage error from apparatus shown in Table 3.5

Apparatus/reading	Reading error	Reading taken	Percentage error	Comments
Top-pan balance reads to 0.01 g error = 0.005	0.01	0.62	1.61	There are two mass readings with an error of ± 0.005 g each time
Measuring cylinder reading to $\pm 2 \text{ cm}^3$	1.00	100	1.00	The measuring cylinder measures to 2 cm^3 therefore uncertainty is $\pm 1 \text{ cm}^3$
Thermometer reading to ± 0.5	1.00	20.00	5.00	Two thermometer readings taken – both giving maximum error of $\pm 0.5^\circ\text{C}$ – therefore total error is 1.0°C
		Total %	7.61	

Table 3.5

d Measurement of uncertainty for the mass of alcohol burned for each alcohol.

$$\text{Methanol} \quad \text{Percentage error} = \frac{0.01}{0.62} \times 100\% = 1.61\%$$

$$\text{Ethanol} \quad \text{Percentage error} = \frac{0.01}{0.48} \times 100\% = 2.08\%$$

$$\text{Propan-1-ol} \quad \text{Percentage error} = \frac{0.01}{0.41} \times 100\% = 2.44\%$$

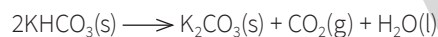
$$\text{Butan-1-ol} \quad \text{Percentage error} = \frac{0.01}{0.40} \times 100\% = 2.50\%$$

- e** Maximum percentage error for one alcohol
 Example = methanol
 Total error due to measuring apparatus = 7.61%
- f** For methanol, the difference between the total percentage error and the error due to the apparatus is $29.7 - 7.61 = 22.09\%$. This considerable difference is probably due to incomplete combustion of the alcohol and heat loss through conduction (through sides of calorimeter) and convection (hot waste gases not heating up calorimeter).

Practical investigation 3.3: Enthalpy change of thermal decomposition

Introduction

The enthalpy change for some reactions is impossible to measure. Because thermal decomposition is an endothermic reaction, it is impossible to find the heat change directly. The only way to find these changes is to use Hess' Law. In this investigation we look at the thermal decomposition of potassium hydrogen carbonate.



Skills focus

The following skill areas are developed and practised (see the skill grids at the front of this guide for codes):

MMO	Collection of data and observations (a), (b), (c), (d) and (e) Decisions relating to measurements of observations (d)
PDO	Recording data and observations (a) and (c) Display of calculations and reasoning (a) and (b)
ACE	Data interpretation and sources of error (a), (c) (d) and (e) Drawing conclusions (c) and (d)

Duration

- The practical can be completed easily within half an hour.
- Learners can work individually.
- If a lesson lasts for one hour then the majority of the time can be spent explaining the theory behind the method used and, in the plenary, how they are going to calculate the changes.

Preparing for the investigation

- Learners need to know the theory behind Hess' Law and how it can be used to determine enthalpy changes that otherwise would be impossible to determine.
- Learners need to revise reactions between acids and carbonates or hydrogen carbonates.

Equipment

Each learner or group will need:

- polystyrene beaker and lid with hole for thermometer
- glass beaker to hold the polystyrene beaker
- thermometer – one reading from -10 to 50°C with 0.2°C divisions is preferable
- spatula
- weighing boats
- 50 cm^3 measuring cylinder
- cotton wool to act as extra insulation

Access to:

- a top-pan balance reading to at least two decimal places – two balances strategically placed would be ideal.
- a supply of water
- 2.00 mol dm^{-3} hydrochloric acid
- potassium hydrogen carbonate and potassium carbonate

Safety considerations

- Learners must wear eye protection at all times
- The acid is an irritant
- In the reactions there is quite a lot of effervescence and therefore care must be taken in replacing the lid as soon as the solids are added to the acid to minimise exposure to acid spray.

Carrying out the investigation

- Many learners do not use twice the enthalpy change ΔH_1 in their calculations. They should also realise that the sign given to the enthalpy change (plus or minus) is vitally important to the final result.



A number of learners struggle with Hess' law and therefore practice in these calculations will obviously help them overcome these difficulties

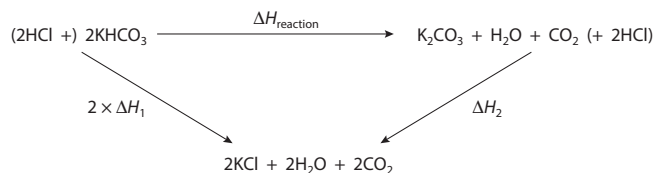


Figure 3.2



Encourage learners to use spreadsheets in order to automate their calculations and save themselves time. If you are worried that this will take them away from carrying out the calculations themselves, remember that in constructing their spreadsheet and getting it to work they are in fact doing the calculations and putting in formulae that they need to understand.

Common learner misconceptions

- The Hess cycle used for this practical investigation is shown in Figure 3.2.

Answers to the workbook questions (using the sample results)

a–f The results shown in Table 3.6 are from a typical laboratory investigation of this topic.

Mass of $\text{KHCO}_3 = 2.55 \text{ g}$

Mass of $\text{K}_2\text{CO}_3 = 3.46 \text{ g}$

	Initial temp. °C	Final temp. °C	Change in temp. °C	Enthalpy change (q)/J	Mass of KHCO_3/g	Relative formula mass/ g mol^{-1}	Number of moles	Standard enthalpy change
Reaction 1	18	14.4	-3.6	+752.4	2.55	100.1	0.025475	+29.5 kJ mol^{-1}
Reaction 2	17.9	22.2	+4.3	-898.7	3.46	138.2	0.025036	-35.9 kJ mol^{-1}

Table 3.6

g The standard enthalpy change for the reaction:

Using Hess' Law $\Delta H_r + \Delta H_2 = 2 \Delta H_1$;

$\Delta H_r = 2 \Delta H_1 - \Delta H_2 = 2 \times 29.5 - (-35.9) = +94.9 \text{ kJ mol}^{-1}$

The accepted values using the standard enthalpies of formation = +93.4 kJ mol^{-1}

h The percentage error = $\left[\frac{94.9 - 93.4}{93.4} \right] \times 100\% = 1.6\%$

i Maximum percentage error

Reaction 1

The thermometer reads to $\pm 0.2^\circ\text{C}$ and therefore the uncertainty is $\pm 0.1^\circ\text{C}$. There are two temperature readings and therefore the total uncertainty is 0.2°C

The percentage error = $\left(\frac{0.2}{3.6} \right) \times 100\% = 5.56\%$

For the weighing, there are two readings being made and for each one the uncertainty is ± 0.005 g.

Therefore the percentage error = $2 \times \frac{0.005}{2.55} \times 100\% = 0.39\%$

For measurement of acid using measuring cylinder the measuring cylinder measures to 1 cm^3 and therefore uncertainty = $\pm 0.5 \text{ cm}^3$

Percentage error = $(\frac{0.5}{50}) \times 100\% = 1\%$

Therefore, the total percentage error for reaction 1 = $5.56 + 0.39 + 1 = 6.95\%$

Reaction 2

Percentage error from temperature measurement = $(\frac{0.2}{4.3}) \times 100\% = 4.65\%$

Percentage error from weighing = $2 \times \frac{0.005}{3.46} \times 100\% = 0.29\%$

Percentage error due to measurement of acid = 1%

Therefore, total percentage error = $4.65 + 0.29 + 1.0 = 5.94\%$

The total possible error due to measuring apparatus = $5.94 + 6.95 = 12.89\%$

This means that the actual error for the experiment (1.6%) is well within the error due to the measuring apparatus.

Practical investigation 3.4: Change in enthalpy of hydration of copper (II) sulfate

Introduction

This practical will complete this series of experiments because it allows learners to both use techniques they have already encountered and enables them to make calculations based on Hess's law.

The reaction studied is the hydration of copper(II) sulfate:



The Hess cycle used is shown in Figure 3.3.

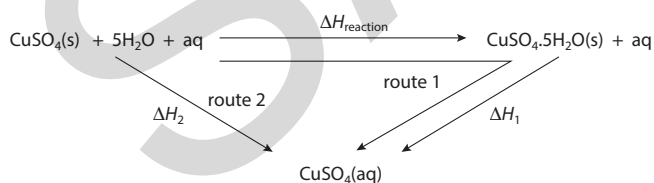


Figure 3.3

Skills focus

The following skill areas are developed and practised (refer the skills grids at the front of this guide for codes):

MMO Collection of data and observations (a), (b), (c), and (d)

Decisions relating to measurements of observations (b)

PDO Recording data and observations (a), (c), (d) and (e)
Display of calculations and reasoning (a) and (b)
Data layout (a), (b), (c), (d), (e) and (f)

ACE Data interpretation and sources of error (a), (c), (d) and (e)
Drawing conclusions (c) and (d)

Duration

This practical takes one hour to complete.

Preparing for the investigation

- Preparation of anhydrous copper(II) sulfate. To save time and reduce inaccuracies, it is best to take some copper sulfate crystals and heat them in an oven which is set at about 200°C . It is advisable to check the oven beforehand by heating a small quantity of crystals to check the accuracy of the oven's temperature.
- Each learner or group of learners will need something in excess of 4 g to weigh out for their 0.025 mol of the anhydrous salt. Therefore, this must be taken into account when deciding how much needs to be roasted in the oven. The solid will need to be stirred at various times to make sure that the loss of water is uniform throughout the solid.

Equipment

Each learner or group will need access to:


- two polystyrene beakers plus lids
- thermometer which reads from -10°C to 50°C in 0.2°C divisions
- spatula
- wash bottle containing distilled water
- glass beaker large enough to hold the polystyrene beakers
- cotton wool to improve the insulation of the polystyrene beakers
- a 50 cm^3 measuring cylinder
- weighing boat x 2
- Top-pan balance which reads at least to two decimal places
- anhydrous copper(II) sulfate
- hydrated copper(II) sulfate crystals
- distilled water
- paper towels


Safety considerations

- Eye protection must be worn at all times during this experiment.
- The copper(II) sulfate solution is an irritant and copper(II) sulfate is an environmental poison; any solution formed should be poured into a bottle. This copper sulfate solution can be used to crystallise out pure copper sulfate which can be used for other experiments.

Carrying out the investigation

- The temperature change for the dissolving of the hydrated copper(II) sulfate crystals is small and therefore if at all possible a thermometer (or temperature data logger) reading to 0.2°C should be used.
- Some learners will still have problems with understanding the Hess cycle. The cycle, however, is quite easy to understand. They will need help with the amount of water present in the hydrated crystals.

 Learners have had a reasonable amount of experience now using the techniques and theory utilised in this practical. Therefore, it may be a good idea to use this practical investigation to gauge their progress.

 Ask learners to explain how the apparatus could be improved (e.g. Dewar flasks could be used). A joulemeter and immersion heater can be used to measure the actual amount of energy required to heat up the flask by the temperature measured in the reaction. This then accounts for the energy needed to heat up the flask as well as the water. Ask them to write an explanation of how that set-up works and how it is an improvement on their own set-up.

Common learner misconceptions

- It is difficult for some learners to understand why it is impossible to determine the enthalpy change for the hydration of anhydrous copper(II) sulfate.

Sample results

The following results shown in Table 3.7 were obtained for this experiment for ΔH_2

$$\text{Mass of anhydrous copper(II) sulfate} = 3.99\text{ g} = \frac{3.99}{159.6} = 0.025\text{ mol}$$

Time /min	Temperature/ $^{\circ}\text{C}$
0	17.5
1	17.6
2	17.8
3	18.1
4	X
5	25.4
6	25.8
7	25.7
8	25.5
9	25.3
10	25.1

Table 3.7

Answers to the workbook questions (using the sample results)

Part 1: For the determination of ΔH_2 .

- a See Figure 3.4
- b Using the graph the initial temperature = 18.2 °C and the final temperature = 26.4 °C
- c Temperature change = 8.2 °C
- d \therefore Enthalpy change = $50 \times 4.18 \times (26.2 - 18.2) = -1672 \text{ J}$
- e Standard enthalpy change for $\Delta H_2 = \left(\frac{-1672}{0.025} \right) \div 1000 = -66.9 \text{ kJ mol}^{-1}$

For ΔH_1 ; Mass of copper(II) sulfate crystals = 6.24 g

$$= \frac{6.24}{249.6} = 0.025 \text{ mol}$$

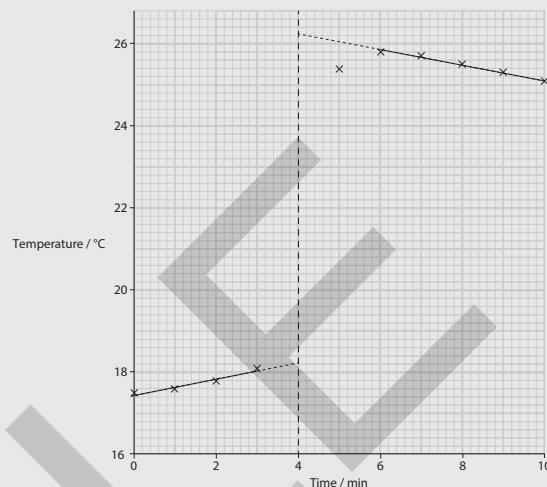


Figure 3.4

Part 2: For the determination of ΔH_1 .

- a The initial temperature = 18.0 °C and the final temperature = 17.0 °C
- b \therefore Enthalpy change = $50 \times 4.18 \times (18.0 - 17.0) = +209 \text{ J}$
- c Standard enthalpy change for $\Delta H_2 = (+209/0.025) \div 1000 = +8.36 \text{ kJ mol}^{-1}$
- d $\therefore \Delta H_{\text{reaction}} = \Delta H_2 - \Delta H_1 = -66.9 - (+8.36) = -75.3$ (three significant figures)
- e The accepted value is $-78.2 \therefore$ percentage error = $\frac{78.2 - 75.3}{78.2} \times 100\% = 3.71\%$
- f The errors due to the apparatus are shown in Table 3.8.

Apparatus/reading	Reading to	Reading taken	Percentage error	Comments
Top-pan balance reads to 0.01 g error = 0.005	0.01	3.99	0.25	There are two mass readings with an error of $\pm 0.005 \text{ g}$ each time
	0.01	6.24	0.16	
Measuring cylinder reading to $\pm 1 \text{ cm}^3$	1.0	50.0	1.00	The uncertainty is $\pm 0.5 \text{ cm}^3$
	1.0	50.0	1.00	
Thermometer reading to ± 0.2	0.2	8.2	2.44	Two thermometer readings taken for each experiment – both giving maximum error of $\pm 0.1 \text{ }^\circ\text{C}$ therefore total error is $0.2 \text{ }^\circ\text{C}$
	0.2	1.0	20.00	
		Total %	24.85	

Table 3.8

The potential errors due to the measuring apparatus can explain the percentage error in the experiment.