

# Chemistry

## for the IB Diploma

### Workbook

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# How to use this book

## Chapter outline

Each Chapter begins with a Chapter outline to briefly set out the learning aims and help with navigation through the topic.

### Chapter outline

- Recall that the periodic table is arranged into groups, periods and into four blocks associated with the four sub-levels: s, p, d and f.
- Recall that the period number is the outer energy level that is occupied by electrons.
- Recall that the number of the principal energy level and the number of the valence electrons in an atom can be deduced from its position on the periodic table.
- Explain the trends in atomic radius, ionic radius, ionisation energy, electron affinity and electronegativity across a period and down a group.
- Recall that the oxides change from basic through amphoteric to acidic across a period.
- Recall the equations for the reactions of  $\text{Na}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{P}_4\text{O}_{10}$  and the oxides of nitrogen and sulfur with water, and the pH of the solutions formed.
- Describe the reactions of the elements of group 1 and group 17.
- Recall the definition of a transition element and their characteristic properties. **HL**
- Explain the formation and shapes of complex ions. **HL**
- Explain why transition metal complex ions are coloured. **HL**

## Key terms and Key formulas

A list of Key terms and Key formulas at the start of each Chapter provide clear, straightforward definitions for the Key vocabulary. Key formulas can be referred to throughout the Chapter, to help with Exercises and Exam-style questions.

### KEY TERMS

**Acid deposition:** A more general term than acid rain; it refers to any process in which acidic substances leave the atmosphere and are deposited on the Earth's surface.

**Brønsted–Lowry acid:** A proton ( $\text{H}^+$ ) donor.

**Brønsted–Lowry base:** A proton ( $\text{H}^+$ ) acceptor.

**pH:** A measure of the concentration of hydrogen ions in an aqueous solution.  
 $\text{pH} = -\log_{10}[\text{H}^+]$

**Strong acid/base:** An acid/base that is completely dissociated into its ions in aqueous solution.

**Weak acid/base:** An acid/base that is only partially dissociated into its ions in aqueous solution.

## Exercises

Each Chapter contains a number of Exercises that relate to each chapter topic. Exercises can help to practice and consolidate learning.

### **HL** Exercise 8.2 – Lewis acids and bases

The idea of Lewis acids was developed at the same time as the Brønsted–Lowry theory. It has a broader scope than Brønsted–Lowry as it is not restricted to species that contain a hydrogen ion.

It should be remembered that all Brønsted–Lowry acids are Lewis acids but not all Lewis acids are Brønsted–Lowry ones; similarly, with bases.

In organic chemistry Lewis acids are termed electrophiles and Lewis bases are referred to as nucleophiles. This is covered in Topic 10.

- 1 a Define the terms 'Lewis acid' and 'Lewis base'.  
 b What type of bond is always formed in a Lewis acid–base reaction?

## Tips

Tip boxes feature on many pages and offer helpful hints to aid understanding of the topic, provide exam tips or offer prompts to help with a specific Exercise.

This question is very similar to Question 4 but with a different unknown. Imagine the amount of ester reacting is  $x$ , then the amount remaining at equilibrium =  $0.01 - x$ . Then follow a similar sequence of steps.

## Exam-style questions

Each chapter concludes with a list of Exam-style questions. These Exam-style questions provide an opportunity to practise what has been covered in each topic, and prepare for the types of question that will appear in the IB Chemistry Diploma exams.

### ? Exam-style questions

- 1 Deduce the heat energy supplied if 50 g of water with a specific heat capacity of  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$  increases in temperature by  $10^\circ\text{C}$ .  
A 210 J  
B 420 J  
C 2.1 kJ  
D 4200 J
- 2 In an experiment,  $50 \text{ cm}^3$  of a solution of HCl with a concentration of  $1 \text{ mol dm}^{-3}$  was reacted with  $50 \text{ cm}^3$  of a solution of NaOH with a concentration of  $1 \text{ mol dm}^{-3}$ . The temperature of the solution increased by  $12^\circ\text{C}$ . Calculate the temperature rise if  $50 \text{ cm}^3$  of the same HCl solution were reacted with  $50 \text{ cm}^3$  of a solution of NaOH with a concentration of  $0.5 \text{ mol dm}^{-3}$ .  
A  $6^\circ\text{C}$   
B  $12^\circ\text{C}$   
C  $24^\circ\text{C}$   
D  $3^\circ\text{C}$
- 3 Which of the following statements is not correct about endothermic reactions?  
A The surroundings lose energy.  
B The enthalpy change will be positive.  
C The enthalpy change will be negative.  
D The temperature of the surroundings decreases.

# Introduction

This workbook has been written to support students studying the IB Diploma Chemistry syllabus for examination up to 2022 at both Standard Level (SL) and Higher Level (HL). The aim is to support learning by providing questions that check both knowledge and understanding whilst progressing through the course.

The content is arranged in chapters that follow the syllabus and the HL material is clearly marked both in the chapter outline and at question level. Definitions and key formulas are included at the beginning of each chapter. The chapters can be approached in any order; however, it is recommended that the chapter on stoichiometric relationships is met sooner rather than later as a knowledge of moles and equations is fundamental to many of the other areas of chemistry.

Each chapter aims to develop both knowledge and understanding by including questions ranging from those that require simple recall to those needing a detailed explanation of an idea or concept. The skills grid maps the questions according to some of the command terms given in the subject guide; these are arranged by assessment objective. Each chapter is broken into sections which gradually work through the content, each focusing on a particular idea or concept. Support is provided throughout by the use of guidance boxes. These offer suggestions about how to tackle a question, hints and tips, and general exam advice. This support is gradually reduced throughout each section as understanding develops. Each chapter then ends with exam-style questions which draw together the ideas met throughout the whole chapter.

All four option topics have been included although questions from only one of these are selected in paper 3 of the final examinations. As some of the content of the option topics may be less familiar than that in the compulsory part of the course, the questions in these sections include more background to each concept.

The nature of science is an overarching theme of the chemistry course. It examines the processes and concepts that are central to scientific endeavour, and how science serves and connects with the wider community. As this is an overarching theme, ideas about the nature of science have been integrated into the questions within each topic where applicable; the ability to analyse data without bias and an appreciation of random and systematic errors is an example of where an understanding of the objectivity of science is developed in many different areas of the course.

Answers to all the questions are provided with working where appropriate. Much can be learnt from the answers and it is recommended that these are used, not just to check numerical answers, but to look closely at the longer answer questions too. Key points are indicated as well as general advice. The answers to the exam-style questions are generally more detailed than those that might be met in an official mark scheme. The aim is to develop an appreciation of the level of detail needed in examinations rather than simply provide the bare minimum required to score a mark. This should lead to better quality answers which clearly demonstrate understanding and leave the examiner no room for doubt.

# Skills grid

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AO	Skill	Stoichiometric relationships	Atomic structure	Periodicity	Chemical bonding and structure	Energetics	Chemical kinetics	Equilibrium	Acids and bases	Redox processes	Organic chemistry	Measurement, data processing and analysis	Materials (Option A)	Biochemistry (Option B)	Energy (Option C)	Medicinal chemistry (Option D)
1	define	1.3 Q1 1.4 Q1	2.2 Q1 2.2 Q2 2.4 Q1 2.6 Q5 2.7 Q1 2.7 Q3	3.6 Q1 14	4.2 Q1 4.2 Q3 4.3 Q1 4.6 Q4	5.3 Q1 5.4 Q1	6.1 Q1 13		8.2 Q1 8.4 Q1	9.8 Q1	10.1 Q1 10.1 Q2 10.2 Q3 10.4 Q1 10.5 Q1 11		12.5 Q1	13.2 Q4 13.3 Q3 13.4 Q1 13.5 Q1 13.6 Q2 13.8 Q3 13.9 Q1 3	14.1 Q1 14.3 Q4 1	15.1 Q1 15.1 Q2 15.3 Q1 15.4 Q3 15.5 Q1 15.8 Q1 15.8 Q2 15.9 Q2
1	draw		2.6 Q4	3.6 Q4 3.6 Q5 15	4.1 Q2 4.1 Q4 4.2 Q2 4.2 Q3 4.2 Q4 4.4 Q3 4.6 Q1 4.6 Q3 4.6 Q4 11 12 13	12 14	13			9.8 Q3 20	10.1 Q2 10.1 Q3 10.2 Q3 10.3 Q2 10.5 Q2 11 17	11.2 Q2 11.2 Q3	12.5 Q2 12.7 Q2 12.8 Q2 12.9 Q1 6	13.3 Q2 13.4 Q2 1 10		15.2 Q2
1	label	1.1 Q2				12 13		7.1 Q2 14		9.6 Q1				13.3 Q4 13.4 Q1 13.8 Q1 13.9 Q1 13.10 Q4 7	14.3 Q1 14.6 Q1	15.7 Q2
1	list		2.6 Q1		4.1 Q5		6.1 Q1						12.4 Q1	13.2 Q4	14.3 Q3	15.1 Q2
1	measure											11.1 Q2				
1	state	1.1 Q3 1.2 Q2 1.2 Q3 14	2.1 Q1 2.3 Q1 2.4 Q1 2.5 Q2 2.6 Q1 2.6 Q2 2.6 Q5 2.6 Q6 2.7 Q1 12	3.1 Q2 3.5 Q1 3.6 Q2 3.7 Q1 11 16	4.1 Q2 4.2 Q2 4.3 Q1 4.6 Q4 4.6 Q6 4.7 Q1 12 13	5.1 Q1 5.5 Q4 12	6.1 Q1 6.1 Q2 6.2 Q1 6.2 Q2 6.2 Q4 6.3 Q1	7.2 Q2 7.3 Q1 7.4 Q1 7.5 Q1	8.2 Q1 8.3 Q1 8.5 Q1 8.7 Q1 8.7 Q7 13 16 17	9.6 Q1 9.6 Q2 9.8 Q1 9.9 Q2 19	10.1 Q1 10.2 Q1 10.2 Q2 10.2 Q3 10.2 Q4 10.2 Q5 10.3 Q1 10.3 Q3 10.3 Q3 10.4 Q1 10.4 Q1 10.5 Q3 10.5 Q4 11 13	11.1 Q2 11.3 Q2 11.3 Q3 11.3 Q4 11.4 Q1 11.4 Q3	12.1 Q1 12.2 Q1 12.2 Q2 12.2 Q3 12.2 Q5 12.3 Q1 12.3 Q1 12.4 Q1 12.4 Q2 12.5 Q1 12.5 Q2 12.6 Q1 12.6 Q2 12.7 Q1 12.7 Q2 12.7 Q3 12.7 Q4	13.1 Q1 13.1 Q2 13.2 Q1 13.2 Q2 13.3 Q1 13.3 Q2 13.3 Q3 13.3 Q3 13.3 Q5 13.3 Q6 13.3 Q7 13.4 Q1 13.5 Q1 13.6 Q1 13.6 Q2 13.7 Q2 13.8 Q1 13.9 Q1 13.9 Q2 13.10 Q1	14.1 Q2 14.2 Q1 14.2 Q2 14.2 Q4 14.2 Q5 14.3 Q1 14.3 Q2 14.3 Q4 14.4 Q1 14.4 Q2 14.5 Q1 14.6 Q3 14.6 Q4 14.7 Q3 14.7 Q4 14.8 Q1 14.8 Q2 14.9 Q2 2 3	15.1 Q1 15.1 Q2 15.2 Q1 15.2 Q2 15.3 Q1 15.3 Q2 15.4 Q1 15.4 Q2 15.5 Q1 15.6 Q3 15.7 Q1 15.7 Q2 15.8 Q1 15.8 Q4 15.9 Q2 1 4 6 7

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AO	Skill	Stoichiometric relationships	Atomic structure	Periodicity	Chemical bonding and structure	Energetics	Chemical kinetics	Equilibrium	Acids and bases	Redox processes	Organic chemistry	Measurement, data processing and analysis	Materials (Option A)	Biochemistry (Option B)	Energy (Option C)	Medicinal chemistry (Option D)
1	state										15		12.8 Q2 12.8 Q3 12.10 Q2 2 3 5 7	13.10 Q4 1 4 5 8 10		
2	annotate								8.10 Q1							
2	calculate	1.3 Q1 1.3 Q2 1.4 Q3 1.4 Q4 1.4 Q5 1.5 Q1 1.5 Q2 1.5 Q3 1.6 Q1 1.6 Q2 1.6 Q3 2.1 Q1 1.7 Q1 2.2 Q2 1.7 Q2 2.3 Q1 1.7 Q3 1.7 Q4 2 3 4 5 6 10 11 12 13 15 16 17 18 19	2.1 Q1 2.1 Q2 2.2 Q2 2.3 Q1 2.7 Q2 8 11 13			5.1 Q2 5.1 Q3 5.2 Q1 5.2 Q2 5.3 Q1 5.3 Q2 5.4 Q2 5.4 Q3 5.5 Q3 5.5 Q5 1 2 10 11 12 14 15	6.3 Q1 12 14	7.6 Q1 7.6 Q2 7.6 Q3 7.6 Q4 7.7 Q1 7.7 Q2 7 8 9 15 16	8.4 Q2 8.4 Q3 8.4 Q4 8.7 Q3 8.7 Q4 8.7 Q5 8.7 Q6 8.9 Q1 2 13 14 15	9.5 Q1 9.5 Q2 9.5 Q3 9.7 Q3 9.7 Q5 9.9 Q5 9.9 Q6 9.9 Q7 8 11 12 14		11.1 Q2 11.1 Q3 2 3 11	12.2 Q2 12.5 Q3 12.8 Q3 12.10 Q5 2 7 8	13.3 Q3 13.6 Q5 13.7 Q3 13.7 Q4 3	14.1 Q1 14.2 Q5 14.3 Q4 14.6 Q3 14.6 Q5 14.7 Q1 14.7 Q2 1 3 4 5 6	15.4 Q3 15.6 Q3 15.8 Q2 15.9 Q2 1 3 6
2	describe	1.1 Q1 1.2 Q1 18	2.6 Q4 2.7 Q2	3.1 Q1 3.1 Q3 3.2 Q1 3.2 Q2 4.1 Q2 4.1 Q4 4.1 Q5 3.5 Q2 4.2 Q1 4.2 Q5 4.4 Q1 4.5 Q1 3.7 Q2 11 12 14 15 16	4.1 Q2 4.1 Q4 4.1 Q5 4.2 Q1 4.2 Q5 4.4 Q1 4.5 Q1 11 14	5.5 Q4 13 14		7.1 Q1 7.3 Q2 7.5 Q1 7.5 Q6 3	8.5 Q1 8.5 Q2 8.6 Q1 8.6 Q2 8.10 Q1 11 12	9.8 Q1 9.9 Q2 9.9 Q4 9.9 Q7 15 18 20	10.1 Q4 10.3 Q1 10.3 Q2 13 14 15 17	11.2 Q1 11.3 Q2	12.2 Q1 12.2 Q4 12.3 Q1 12.4 Q1 12.5 Q1 12.5 Q2 12.6 Q1 12.6 Q2 12.8 Q1 12.9 Q1 12.10 Q3 3 5	13.2 Q1 13.3 Q4 13.4 Q1 13.4 Q2 13.4 Q3 13.6 Q3 13.8 Q1 13.8 Q2 13.9 Q1 13.9 Q3 13.10 Q3 3 7	14.2 Q1 14.2 Q2 14.2 Q3 14.5 Q1 14.5 Q2 14.5 Q3 14.6 Q1 14.6 Q2 14.6 Q5 14.7 Q3 14.8 Q1 3 5	15.3 Q1 15.4 Q3 15.5 Q1 15.6 Q1 15.6 Q2 15.8 Q3 15.9 Q1 15.9 Q3 2 3 4 5
2	distinguish													13.2 Q5		



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AO	Skill	Stoichiometric relationships	Atomic structure	Periodicity	Chemical bonding and structure	Energetics	Chemical kinetics	Equilibrium	Acids and bases	Redox processes	Organic chemistry	Measurement, data processing and analysis	Materials (Option A)	Biochemistry (Option B)	Energy (Option C)	Medicinal chemistry (Option D)
2	estimate				12 13	11			8.9 Q1							
2	identify	1.1 Q1 1.2 Q1 1.5 Q3 1 9	2.3 Q1 1 3 5 7 15	3.1 Q1 3.6 Q4 1 2 3 4 6 10	4.1 Q1 4.3 Q1 4.6 Q4 4.6 Q5 4.7 Q1 1 2 3 5	5.4 Q2 5.5 Q1 3 4 5 6 7 8 9	1 2 3 4 5 6 8 9 10	1 2 4 6	8.1 Q2 8.7 Q2 8.7 Q8 1 4 5 6 7 8 9 10 14	9.1 Q1 9.1 Q2 9.3 Q1 9.8 Q2 9.9 Q1 9.9 Q2 1 2 4 6 7 9 10	10.5 Q1 10.5 Q2 10.5 Q4 1 2 3 4 5 6 7 8 9 10	11.2 Q2 11.2 Q4 11.3 Q2 1 4 5 6 7 8 9 13	12.2 Q4 12.7 Q4 2 6c	13.2 Q3 13.9 Q3 13.10 Q1 2	14.2 Q3	
2	outline								12		16		12.7 Q4 12.9 Q3 12.10 Q2 2 3 6	13.2 Q4 13.2 Q5 13.6 Q4 13.7 Q2 13.7 Q4 13.9 Q3 13.9 Q4 3 4 8	14.2 Q2 14.4 Q2 14.5 Q2 14.5 Q3 14.7 Q3 2 4 5	15.1 Q1 15.2 Q1 15.2 Q2 15.2 Q3 15.5 Q2 15.6 Q1 15.8 Q3 3 4
3	analyse															
3	comment							7.7 Q1 7.7 Q2 16	13							
3	compare			3.2 Q1 11 13	11								12.9 Q1	2 9	1	1
3	compare and contrast									16 17				13.2 Q5 13.10 Q2		
3	construct					5.2 Q2 12				9.3 Q1 9.3 Q2			12.7 Q1 2 6			15.4 Q2 15.8 Q1
3	deduce	1.4 Q2 1.4 Q4 1.4 Q5 4 11 13 14 15	2.3 Q2 2 4 6 9	3.1 Q3 3.6 Q5 3.7 Q1 6 7 5 8 7 9 10 16	4.6 Q2 6 7 8 9 10 13	5.4 Q3 1	6.2 Q2 6.2 Q4 7 14 15	7.5 Q2 7.5 Q3 7.5 Q5 7.6 Q3 7.6 Q5 5 10 11 13 14	8.1 Q1 3 15	9.2 Q1 9.2 Q2 9.2 Q3 9.3 Q5 9.5 Q2 9.7 Q2 9.7 Q3 5 14	11	10 12 13 14	12.8 Q3 12.9 Q3 12.10 Q1 12.10 Q4 7	13.6 Q2 13.8 Q2 6	14.6 Q4 3 4	
3	design			3.4 Q2						9.4 Q2						

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AO	Skill	Stoichiometric relationships	Atomic structure	Periodicity	Chemical bonding and structure	Energetics	Chemical kinetics	Equilibrium	Acids and bases	Redox processes	Organic chemistry	Measurement, data processing and analysis	Materials (Option A)	Biochemistry (Option B)	Energy (Option C)	Medicinal chemistry (Option D)
3	determine	1.2 Q2 7 8 18			4.1 Q3 4.2 Q4	5.5 Q5		7.5 Q3 11	8.4 Q1	9.2 Q4 9.3 Q3 9.3 Q4 9.5 Q3 9.6 Q3 9.7 Q1 9.9 Q3 3 13	10.5 Q3	11.2 Q1 11.3 Q1 14				
3	discuss													13.6 Q5	14.4 Q2 14.5 Q3	
3	evaluate											11.1 Q1				
3	explain	1.1 Q2 1.2 Q1	2.2 Q2 2.5 Q1 2.5 Q2 2.7 Q3 3.6 Q1 2.7 Q4 11 12 14	3.2 Q1 3.2 Q2 3.2 Q3 3.3 Q1 3.4 Q1 3.6 Q1 3.6 Q3 3.7 Q1 11 14 15	4.1 Q4 4.2 Q2 4.2 Q5 4.3 Q1 4.4 Q1 4.4 Q3 4.4 Q4 4.5 Q1 4.6 Q6 11 11 12 14	5.1 Q1 5.1 Q3 5.3 Q1 5.4 Q2 14	6.1 Q1 6.1 Q3 6.2 Q3 6.3 Q1 11 12 13 14	7.1 Q2 7.2 Q1 7.4 Q1 7.4 Q2 7.4 Q3 11 11 12 13	8.3 Q1 8.5 Q2 8.6 Q1 8.7 Q6 8.8 Q2 8.9 Q2 8.10 Q2 11 12 13 15	9.5 Q3	10.2 Q1 10.3 Q1 10.5 Q1 10.5 Q3 11 12 13 15	11.1 Q2 11	12.2 Q3 12.3 Q1 12.5 Q2 12.6 Q2 12.8 Q1 12.9 Q2 12.9 Q3 12.10 Q1 12.10 Q3 12.10 Q5 1 2 4	13.2 Q1 13.2 Q5 13.3 Q1 13.3 Q2 13.3 Q3 13.6 Q4 13.7 Q1 13.7 Q2 13.7 Q3 13.9 Q2 13.10 Q1 2 6 7	14.3 Q2 14.3 Q3 14.4 Q2 14.8 Q1 1 2 4 6	15.1 Q1 15.2 Q3 15.4 Q3 15.7 Q2 1 2 3 4 5
3	predict					5.5 Q2 13	12	7.5 Q4		9.4 Q1 9.7 Q4				13.5 Q1 13.9 Q2		
3	sketch		2.6 Q4 2.7 Q4 13	15	4.6 Q3	5.1 Q1	6.1 Q2 6.1 Q3 6.2 Q3	13 14	8.8 Q1 14					13.7 Q2 6 9		
3	suggest		11	3.5 Q1 13 15	4.4 Q2 4.4 Q4 4.6 Q1 4.6 Q2 4.6 Q6 12	5.1 Q1 5.1 Q3 5.3 Q1 5.4 Q2 5.4 Q3 11 12	6.1 Q3 11 12 15		8.3 Q3 8.6 Q2 8.8 Q3 8.10 Q1 13		10.3 Q2 10.3 Q4 10.4 Q1	11.1 Q3 11.3 Q3 11.3 Q4 11.4 Q1 11.4. Q2 11 13 14	12.7 Q1 12.7 Q2 6	13.3 Q7 13.5 Q1 13.7 Q3	14.5 Q2	15.2 Q2 15.2 Q3 15.5 Q2 15.6 Q2 15.6 Q3 15.9 Q1 15.9 Q4 2 7