OXFORD

CHEMISTRY FOR THE BIOSCIENCES

The essential concepts

THIRD EDITION

online resource centre

Jonathan Crowe & Tony Bradshaw

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The essential concepts

THIRD EDITION

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Periodic Table of the Elements

Key: atomic number / **Symbol** / name / relative atomic mass

Period \ Group →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** hydrogen 1.0079																	2 **He** helium 4.003
2	3 **Li** lithium 6.94	4 **Be** beryllium 9.012											5 **B** boron 10.81	6 **C** carbon 12.01	7 **N** nitrogen 14.01	8 **O** oxygen 16.00	9 **F** fluorine 19.00	10 **Ne** neon 20.18
3	11 **Na** sodium 22.99	12 **Mg** magnesium 24.32											13 **Al** aluminium 26.98	14 **Si** silicon 28.09	15 **P** phosphorus 30.97	16 **S** sulfur 32.06	17 **Cl** chlorine 35.45	18 **Ar** argon 39.95
4	19 **K** potassium 39.10	20 **Ca** calcium 40.08	21 **Sc** scandium 44.96	22 **Ti** titanium 47.87	23 **V** vanadium 50.94	24 **Cr** chromium 52.00	25 **Mn** manganese 54.94	26 **Fe** iron 55.85	27 **Co** cobalt 58.93	28 **Ni** nickel 58.69	29 **Cu** copper 63.55	30 **Zn** zinc 65.38(2)	31 **Ga** gallium 69.72	32 **Ge** germanium 72.63	33 **As** arsenic 74.92	34 **Se** selenium 78.96(3)	35 **Br** bromine 79.90	36 **Kr** krypton 83.80
5	37 **Rb** rubidium 85.4	38 **Sr** strontium 87.62	39 **Y** yttrium 88.91	40 **Zr** zirconium 91.22	41 **Nb** niobium 92.91	42 **Mo** molybdenum 95.96(2)	43 **Tc** technetium	44 **Ru** ruthenium 101.1	45 **Rh** rhodium 102.9	46 **Pd** palladium 106.4	47 **Ag** silver 107.9	48 **Cd** cadmium 112.4	49 **In** indium 114.8	50 **Sn** tin 118.7	51 **Sb** antimony 121.8	52 **Te** tellurium 127.6	53 **I** iodine 126.9	54 **Xe** xenon 131.3
6	55 **Cs** caesium 132.9	56 **Ba** barium 137.3	57-71 lanthanoids	72 **Hf** hafnium 178.5	73 **Ta** tantalum 180.9	74 **W** tungsten 183.8	75 **Re** rhenium 186.2	76 **Os** osmium 190.2	77 **Ir** iridium 192.2	78 **Pt** platinum 195.1	79 **Au** gold 197.0	80 **Hg** mercury 200.6	81 **Tl** thallium 204.38	82 **Pb** lead 207.2	83 **Bi** bismuth 209.0	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
7	87 **Fr** francium	88 **Ra** radium	89-103 actinoids	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadtium	111 **Rg** roentgenium	112 **Cn** copernicium		114 **Fl** flerovium		116 **Lv** livermorium		

57 **La** lanthanum 138.9	58 **Ce** cerium 140.1	59 **Pr** praseodymium 140.9	60 **Nd** neodymium 144.2	61 **Pm** promethium	62 **Sm** samarium 150.4	63 **Eu** europium 152.0	64 **Gd** gadolinium 157.3	65 **Tb** terbium 158.9	66 **Dy** dysprosium 162.5	67 **Ho** holmium 164.9	68 **Er** erbium 167.3	69 **Tm** thulium 168.9	70 **Yb** ytterbium 173.1	71 **Lu** lutetium 175.0
89 **Ac** actinium	90 **Th** thorium 232.0	91 **Pa** protactinium 231.0	92 **U** uranium 238.0	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fermium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

About the cover image: the chemical connection

The animal featured on the cover is commonly known as a koala bear (*Phascolarctos cinereus*) – but it's not really a bear at all! Rather it is an herbivorous marsupial – the last representative on Earth of the family Phascolarctidae.

Koalas are native to the east coast of Australia and achieve the astonishing feat of being able to extract all their nutritional requirements – food, water, and vitamins – from eucalyptus leaves alone. Indeed, koalas are rarely seen drinking water, except in times of drought. Eucalyptus leaves are very fibrous and are low in nutritional value; they also contain many poisonous chemicals. So, in order to exist solely on these leaves, koalas have acquired some unique adaptations to their physiology and biochemistry.

Firstly, koalas have a liver that is able to detoxify the poisons in eucalyptus leaves – poisons that would otherwise kill other animals. They also have an unusually large caecum – the blunt-ended pouch-like organ that forms part of the digestive tract and joins the small intestine to the large intestine. Despite being small in humans and other animals, the caecum of a koala stretches to a length of up to 2 m when unfolded – several times longer than the koala's body!

But it's really what we find *in* the caecum that gives the koala its eucalyptus-eating advantage: the caecum contains bacteria that are able to digest the fibre and extract the nutrients from the leaves. Given that the leaves have such low nutritional content, koalas must do their utmost to squeeze every last bit of nutritional value out of them. To that end, the digested leaves are retained in the caecum for a very long time to maximize the level of nutrient extraction that is achieved by the bacterial fermentation.

As fuel for survival is at such a premium, koalas have to minimize their energy expenditure. As such, they have a small brain (which needs relatively little energy) and a very low metabolic rate, and they sleep for up to 22 hours a day. (It's a tough life being a koala.)

This unique combination of biochemical and physiological peculiarities means the koala has adapted to a diet on which no other creature could survive. It's a remarkable feat of evolution.

We learn more about metabolism and energy in Chapters 13 and 14.

JWC: For Katy, with heartfelt thanks for her love and support.

TKB: For Caroline: friend and colleague whose support has been immeasurable. And to all the students who have had to sit through my lectures.

Table 1 Physical quantities commonly used in chemistry

Physical quantity	Symbol	SI unit
Amount of substance, chemical amount	n	mol
Atomic mass		amu (atomic mass unit)
Molar mass	M	kg mol^{-1}
Relative molecular mass	M_r	
Relative atomic mass	A_r	
Concentration of B	[B]	mol L^{-1}
Wavelength	l	metre, m

Table 2 Base SI units

Physical quantity	Symbol	SI unit
Length	l	metre, m
Mass	m	kilogram, kg
Time	t	seconds, s
Thermodynamic temperature	T	kelvin, K

Table 3 Other physical quantities

Physical quantity	SI unit
Area	m^2
Volume	m^3
Force	newton, N
Energy	joule, J
Pressure	pascal, Pa

Table 4 Prefixes to form the names and symbols of the decimal multiples and submultiples of SI units

	Multiple	Prefix	Symbol
	10^{-15}	femto	f
	10^{-12}	pico	p
	10^{-9}	nano	n
	10^{-6}	micro	µ
	10^{-3}	milli	m
	10^{-2}	centi	c
↑ Getting smaller	10^{-1}	deci	d
↓ Getting larger	10	deca	da
	10^{2}	hecto	h
	10^{3}	kilo	k
	10^{6}	mega	M
	10^{9}	giga	G

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Acknowledgements

We are grateful for the input from a number of colleagues during the preparation of this third edition, most notably colleagues at Oxford Brookes University, Dr Caroline Griffiths, Dr Peter Grebenik, Dr Alwyn Griffiths, and Professor David Fell, who all contributed with helpful discussion and scrutiny of parts of the text. We also thank those reviewers who provided critical feedback on the second edition, which shaped many of the changes we have made for this third edition:

Nick Brewer, University of Dundee
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James McEvoy, Royal Holloway, University of London
Nicola Slee, University of Essex
Renko de Vries, Wageningen University

It goes without saying that any mistakes or errors that remain are solely our responsibility.

We also received valuable help with the preparation of some artwork for the book. We thank Dr James Keeler, University of Cambridge, for preparing the orbital images that appear in Chapters 2, 3, and 8; and to Professor Peter Atkins, University of Oxford, for providing the electrostatic surface plots that appear in Chapters 3 and 4.

Chemical structures were prepared using a combination of ChemDraw Standard 12.0 and Chem3D Ultra 9.0. Biological structures were generated using the open-source software PyMOL (DeLano, W. L. *The PyMOL Molecular Graphics System* (2002) on the World Wide Web at **http://www.pymol.org/**), using data from the Protein Data Bank (**http://www.rcsb.org/pbd/**).

We'd also like to gratefully acknowledge those individuals at Oxford University Press who have steered the third edition through to completion. We thank Sarah Lodge for her valuable support, and our production editor, Suzy Armitage, for her careful attention throughout the production process. We also thank Julian Thomas and Heather Addison, our copy-editor and proofreader respectively, from whose eagle eyes the book has doubtless benefited greatly.

Finally, we give grateful thanks to our families, friends, and colleagues who have continued to offer encouragement and support, despite the neglect they have experienced in the face of the self-imposed solitary confinement with a laptop that book-writing demands.

JWC, Oxford
TKB, Oxford
June 2013

Welcome to *Chemistry for the Biosciences*

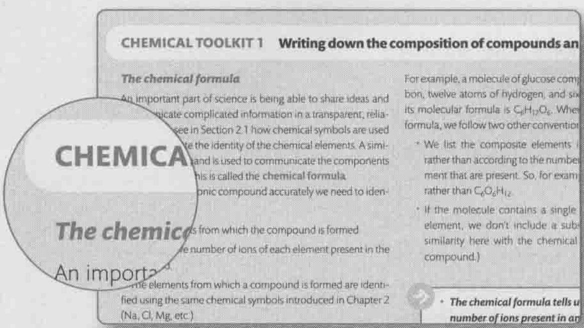
For students using this book

We've written this book to try to make learning the essentials of chemistry as easy and enjoyable as possible. You might be asking yourself 'Why should I bother with chemistry at all?' We've devoted Chapter 1 to answering this question; take a look at that chapter before you start reading the rest of the book.

Helping you to learn the essentials of chemistry

We've included a number of features to make this book as effective a learning tool as possible. These features include the following.

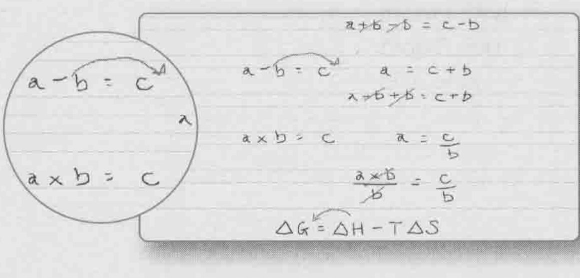
To help you master the essentials



Chemical toolkits

There are certain skills you need at your disposal to really be able to understand chemistry. These skills, which apply to topics covered throughout the book, are presented in the Chemical Toolkits. We include five Chemical Toolkits in this edition:

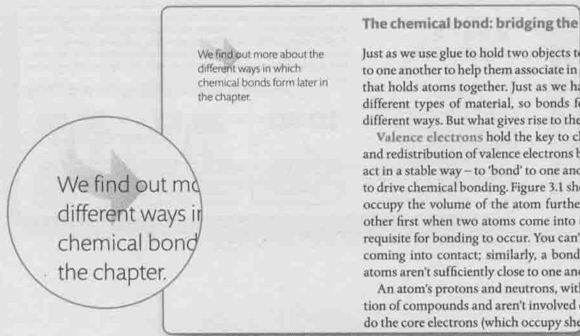
- Writing down the composition of compounds and molecules, p 85
- Using Lewis structures, p 86
- Using chemical notation: drawing chemical structures, p 189
- Using nomenclature to specify the structure of compounds, p 290
- Standard states: making sense of measurements, p 513



Mini tutorials

We have recorded a number of short videos to walk you through a selection of examples and calculations to help you master key numerical and data-handling skills. Look out for the QR code images in the text, scan the code with your smartphone, and go straight to the video that relates to the topic you're studying. Alternatively, you'll find our videos on YouTube; follow the link from our Online Resource Centre.

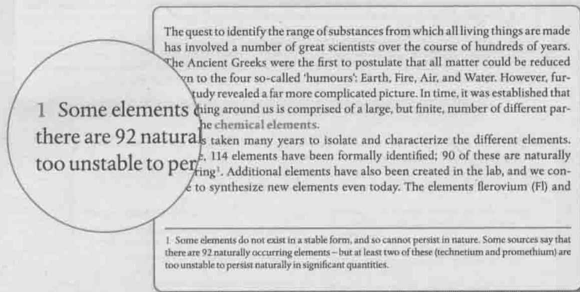
You can find the Online Resource Centre at **http://www.oxfordtextbooks.co.uk/orc/crowe3e/**



Margin comments

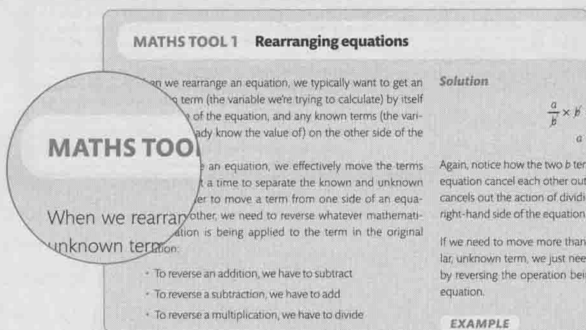
You'll see two types of comment in the margin as you read through the book.

- **Cross-references to other parts of the book**, so you can see how different topics fit together to give the overall 'big picture' of chemistry.
- **Additional guidance** – things to remember, common misconceptions, and other notes to help you grasp the key concepts as quickly and easily as possible.



Footnotes

Footnotes provide additional information to supplement what is being said in the text, without adding extra detail to the text itself.



Maths tools

Many students find the use of mathematics in biology to be hugely intimidating. However, mathematical and numerical tools are amongst some of the most useful tools at the biologist's disposal – helping us, for example, to analyse and make sense of data. In fact – and despite first impressions – maths can actually help to simplify the biological world, by helping us to model and describe processes and relationships in a way that would be impossible otherwise.

In recognition of the central role maths can play (alongside chemistry) in understanding biological systems, we have included a small number of Maths Tools, which give an overview of some of the mathematical tools that we use in the text. If you're confident in the use of maths then you won't need to look at these Tools; if you're less confident, however, you may want to take a look at them, just to refresh your memory, or develop your understanding. We include five Maths Tools in this edition:

- Rearranging equations, p 164
- Handling brackets, p 556
- The exponential and logarithmic functions, p 557
- Measuring the gradient of a curve, p 603
- Solving quadratic equations, p 659

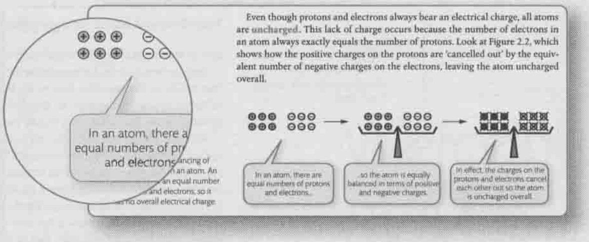
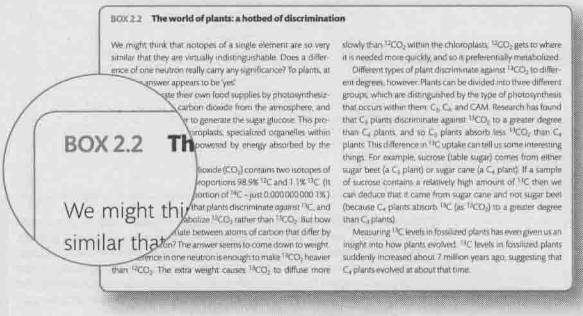


Figure annotations

Many of the figures include additional annotations to make it as clear as possible what the figure is showing. We also annotate many equations so you can see what they represent.

To make chemistry relevant to you

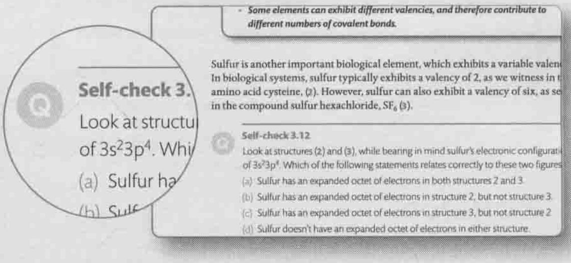
Boxes



Each chapter features a number of boxes that supplement the main text. In some cases, these boxes provide a little more detail about a concept being covered which isn't central to your grasping the subject matter, but which you might find interesting. Most often, however, they show how the chemical concepts being introduced apply to biological systems – examples of where chemistry quite literally comes to life. If you're reading the main text and find yourself thinking 'So what?', read some of the boxes to see how chemistry really is important in biological systems.

To reinforce your learning

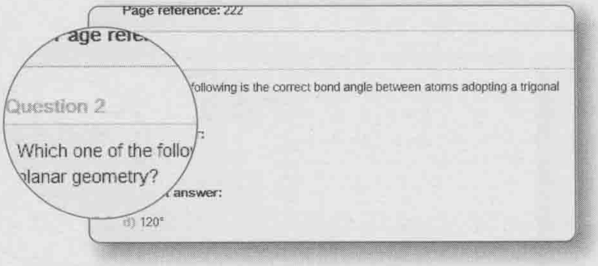
Self-check questions



We recommend that you attempt the self-check questions as you work through each chapter: they are an ideal way of checking whether you've properly got to grips with the concepts being introduced. Answers to self-check questions are given at the end of the book so you can quickly check whether you're on the right lines. Full solutions to numerical questions are provided in the book's Online Resource Centre. Take a look at these solutions if you're not sure of the strategy required to complete a particular calculation.

You can find the Online Resource Centre at **http://www.oxfordtextbooks.co.uk/orc/crowe3e/.**

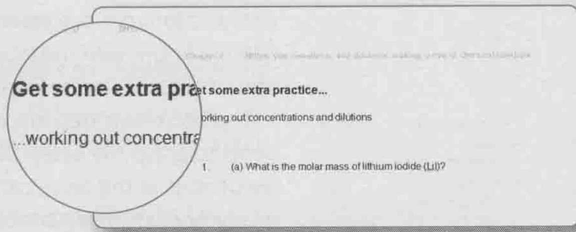
Online quizzing



To supplement the self-check questions provided throughout the text, the Online Resource Centre features a bank of over 150 additional questions in multiple-choice question format. Particularly useful as a way of checking what you do or don't understand prior to exams (to help focus your revision time), the multiple-choice questions are accompanied by feedback that refers back to the book so you can re-read topics that you're less confident about.

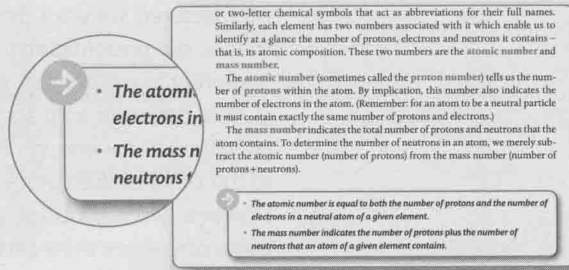
Problem-solving worksheets

Problem-solving worksheets, also available via the book's Online Resource Centre, have been written to give you some extra practice in developing your data-handling skills. Various topics in chemistry involve the handling of data – from the calculation of concentrations and dilutions, to the rate of enzyme-catalysed reactions. Complete the worksheets to banish any fear of data-handling that you might previously have had!



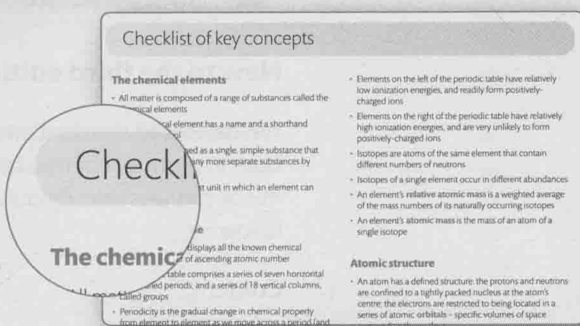
Key points

Key points appear throughout many chapters, and state the main take-home messages of the sections in which they appear. If you don't quite grasp the key points, then try re-reading the section.



Checklists of key concepts

Each chapter ends with a checklist of key concepts, which summarize the key learning points covered in the chapter. Use this checklist as a quick and easy way of revising the main points addressed, and as a prompt for going back to re-read any sections you're not sure about.



Any feedback?

If you have any feedback on the book – did you find any feature particularly helpful? Did you find anything difficult to follow? – do get in touch via the book's Online Resource Centre at **http://www.oxfordtextbooks.co.uk/orc/crowe3e/**.

For the lecturer: about this book

Chemical principles pervade much of the life sciences. Indeed, a biological scientist can only effectively probe the many questions surrounding biological systems that remain unanswered if they use **all** the tools at their disposal. Chemical tools are among the most powerful available to the biological scientist; it follows that chemical concepts should form a central part of any biosciences degree programme.

This book fills the gap between texts for honours chemistry students (or 'chemistry majors') and the huge range of US-originated freshman 'general chemistry' texts. It is principally intended for those students with no more than a GCSE in science, and so assumes very little in the way of prior knowledge. For those students who have studied chemistry beyond GCSE, however, we hope that it will act as a good refresher, and will fulfil an important goal of showing how chemistry is an integral part of the study of biology – something perhaps not readily apparent from school-level studies.

It may be that your students need to know chemistry in somewhat more depth than that offered by this book. In essence, what we have written here is intended as a 'springboard' into the many excellent undergraduate chemistry texts that are already available. As such, it offers a bridge to undergraduate-level study, giving an introduction to those essential chemical concepts that life sciences students typically need to know, with the intention that it will give students the confidence and motivation to progress to the 'mainstream' chemistry texts if they need to know more.

The book is written in a deliberately conversational style. Its focus is on getting students to grasp the essential concepts, not on exhaustive coverage of the field (which we believe, at this level, can only really lead to rote learning of facts). We cover some relatively challenging concepts (for example, the notion of sigma and pi orbitals) but do so in a qualitative way – in the case of sigma and pi orbitals, merely using them to help provide a conceptual understanding of why molecules have the shape that they do. Throughout the book, we are writing for the biosciences student, not the chemistry lecturer: we want this book to be relevant to biosciences students, so we have shaped our presentation in a way that we hope will make them think 'Ah, so chemistry *is* relevant to me after all, and I *can* grasp what's going on'.

As is common with any book of this type, we faced a fine balance between simplifying material enough for students to grasp the concepts readily, and simplifying to the point of inaccuracy. We hope that, on the whole, we've got the balance right. However, writing a book is an ongoing process of refinement; we would be glad to know where you think we didn't get things right, so we can refine them in the future.

You can send us your feedback via the book's Online Resource Centre at **http://www.oxfordtextbooks.co.uk/orc/crowe3e/.**

New to the third edition

We have used the third edition to enhance the text's coverage in a number of ways, both in terms of content covered, and learning support offered. Alongside numerous minor changes throughout each chapter of the text, the primary revisions include the following.

Content

- A new chapter, Metals in Biology, reviews the importance of metal ions in biological systems, to complement the coverage of organic compounds in other chapters.
- Coverage of organic compounds in Chapters 6 and 7 has been streamlined, with more emphasis on common features and trends.
- An enhanced and extended discussion of chemical reactions includes substantially increased coverage of redox reactions and electrode potentials, to prepare students for the development of these concepts in biochemistry courses; and more emphasis on the carbonyl group and nucleophilic attack, and the reactions of carbonyl-containing compounds.
- The concept of ionization energy is now introduced in Chapter 2.
- The coverage of hydrogen bonding in Chapter 4 is strengthened, to include the concept of hydrogen bond donors and acceptors.
- Enhanced coverage of resonance theory stresses the impact of the phenomenon on molecular shape, structure, and reactivity.
- Coverage of enthalpy changes in Chapter 14 now includes more discussion of enthalpies of formation and Hess's Law.

Structure

- Coverage of the mole and concentrations is brought forward to Chapter 5, giving students earlier exposure to these central concepts.
- Coverage of the structure of biological molecules is now integrated into Chapter 10, Biological Macromolecules.
- Coverage of chemical reactions is brought forward to Chapters 12 and 13, putting this topic back at the heart of the book.
- The overview of hydrocarbons has been reorganized to make the discussion more comparative, and to highlight common features.

Learning features

- New Chemical Toolkits explore some of the key skills and tools essential to understanding chemistry, and complement the existing Maths Tools.
- New problem-solving questions, available via the book's Online Resource Centre, help students to develop their data-handling skills.
- A greater number of self-check questions provide students with more opportunities for active learning while reading each chapter.
- Video screencasts online walk readers through a selection of examples and calculations to help them master key numerical and data-handling skills.

Teaching support

This book is accompanied by an **Online Resource Centre** at **http://www.oxfordtextbooks.co.uk/orc/crowe3e/** which features:

Figures from the book, available to download

A time-saving resource to support your lecture preparation.

Test bank of multiple-choice questions

A bank of multiple-choice questions, with answers keyed to the book. The test bank features an average of ten questions per chapter, giving you a pool of questions from which to develop your own customized question bank to use for formative or summative assessment purposes.

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