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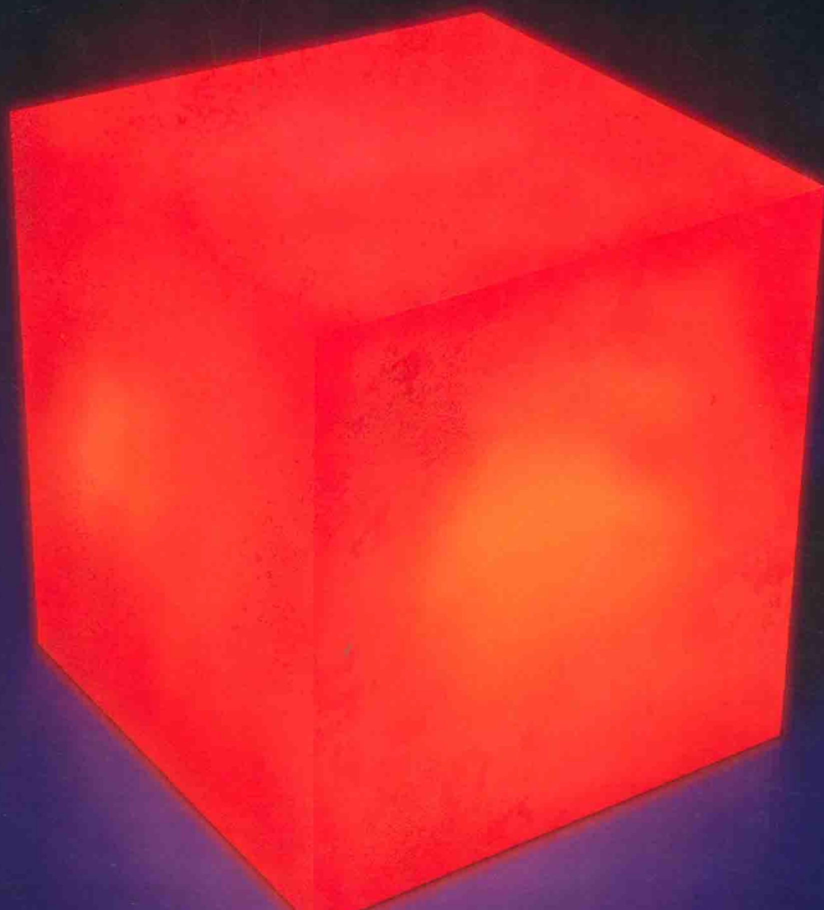
Atkins' PHYSICAL CHEMISTRY

10th Edition



Peter Atkins | Julio de Paula

Atkins'

PHYSICAL CHEMISTRY

Tenth edition

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FUNDAMENTAL CONSTANTS

Constant	Symbol	Value		
			Power of 10	Units
Speed of light	c	2.997 924 58*	10^{8}	m s^{-1}
Elementary charge	e	1.602 176 565	10^{-19}	C
Planck's constant	h	6.626 069 57	10^{-34}	J s
	$\hbar = h/2\pi$	1.054 571 726	10^{-34}	J s
Boltzmann's constant	k	1.380 6488	10^{-23}	J K^{-1}
Avogadro's constant	N_A	6.022 141 29	10^{23}	mol^{-1}
Gas constant	$R = N_A k$	8.314 4621		J K^{-1} mol^{-1}
Faraday's constant	$F = N_A e$	9.648 533 65	10^{4}	C mol^{-1}
Mass				
Electron	m_e	9.109 382 91	10^{-31}	kg
Proton	m_p	1.672 621 777	10^{-27}	kg
Neutron	m_n	1.674 927 351	10^{-27}	kg
Atomic mass constant	m_u	1.660 538 921	10^{-27}	kg
Vacuum permeability	μ_0	4π*	10^{-7}	J s^2 C^{-2} m^{-1}
Vacuum permittivity	$\varepsilon_0 = 1/\mu_0 c^2$	8.854 187 817	10^{-12}	J^{-1} C^2 m^{-1}
	$4\pi\varepsilon_0$	1.112 650 056	10^{-10}	J^{-1} C^2 m^{-1}
Bohr magneton	$\mu_B = e\hbar/2m_e$	9.274 009 68	10^{-24}	J T^{-1}
Nuclear magneton	$\mu_N = e\hbar/2m_p$	5.050 783 53	10^{-27}	J T^{-1}
Proton magnetic moment	μ_p	1.410 606 743	10^{-26}	J T^{-1}
g-Value of electron	g_e	2.002 319 304		
Magnetogyric ratio				
Electron	$\gamma_e = -g_e e/2m_e$	−1.001 159 652	10^{10}	C kg^{-1}
Proton	$\gamma_p = 2\mu_p/\hbar$	2.675 222 004	10^{8}	C kg^{-1}
Bohr radius	$a_0 = 4\pi\varepsilon_0\hbar^2/e^2 m_e$	5.291 772 109	10^{-11}	m
Rydberg constant	$\tilde{R}_\infty = m_e e^4/8h^3 c\varepsilon_0^2$	1.097 373 157	10^{5}	cm^{-1}
	$hc\tilde{R}_\infty/e$	13.605 692 53		eV
Fine-structure constant	$\alpha = \mu_0 e^2 c/2h$	7.297 352 5698	10^{-3}	
	α^{-1}	1.370 359 990 74	10^{2}	
Second radiation constant	$c_2 = hc/k$	1.438 777 0	10^{-2}	m K
Stefan–Boltzmann constant	$\sigma = 2\pi^5 k^4/15h^3c^2$	5.670 373	10^{-8}	W m^{-2} K^{-4}
Standard acceleration of free fall	g	9.806 65*		m s^{-2}
Gravitational constant	G	6.673 84	10^{-11}	N m^2 kg^{-2}

* Exact value. For current values of the constants, see the National Institute of Standards and Technology (NIST) website.

Useful relations

At 298.15 K

RT	2.4790 kJ mol^{-1}	RT/F	25.693 mV
$RT \ln 10/F$	59.160 mV	kT/hc	207.225 cm^{-1}
kT/e	25.693 meV	$V_m^{\ominus}$	2.4790×10^{-2} m^3 mol^{-1} 24.790 dm^3 mol^{-1}

Selected units*

1 N	1 kg m s^{-2}	1 J	1 kg m^2 s^{-2}
1 Pa	1 kg m^{-1} s^{-2}	1 W	1 J s^{-1}
1 V	1 J C^{-1}	1 A	1 C s^{-1}
1 T	1 kg s^{-2} A^{-1}	1 P	10^{-1} kg m^{-1} s^{-1}
1 S	1 Ω^{-1} = 1 A V^{-1}		

* For multiples (milli, mega, etc.), see the *Resource section*

Conversion factors

$\theta/°C = T/K - 273.15$*

1 eV	$1.602\,177 \times 10^{-19}$ J 96.485 kJ mol^{-1} 8065.5 cm^{-1}	1 cal	4.184* J
1 atm	101.325* kPa 760* Torr	1 cm^{-1}	1.9864×10^{-23} J
1 D	$3.335\,64 \times 10^{-30}$ C m	1 Å	10^{-10} m*

* Exact value

Mathematical relations

$\pi = 3.141\,592\,653\,59\ \ldots$

$e = 2.718\,281\,828\,46\ \ldots$

Logarithms and exponentials

$\ln x + \ln y + \ldots = \ln xy \ldots$ $\quad$ $\ln x - \ln y = \ln(x/y)$

$a \ln x = \ln x^a$ $\quad$ $\ln x = (\ln 10) \log x = (2.302\,585\ \ldots) \log x$

$e^x e^y e^z \ldots = e^{x+y+z+\ldots}$ $\quad$ $e^x/e^y = e^{x-y}$

$(e^x)^a = e^{ax}$ $\quad$ $e^{\pm ix} = \cos x \pm i \sin x$

Series expansions

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$

$$\ln(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \cdots \qquad \ln x = (x-1) - \frac{(x-1)^2}{2} + \frac{(x-1)^3}{3} - \cdots$$

$$\frac{1}{1+x} = 1 - x + x^2 - \qquad \frac{1}{1-x} = 1 + x + x^2 + \cdots$$

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \cdots \qquad \cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \cdots$$

Derivatives; for Integrals, see the Resource section

$$d(f+g) = df + dg \qquad d(fg) = f\,dg + g\,df$$

$$d\frac{f}{g} = \frac{1}{g}df - \frac{f}{g^2}dg \qquad \frac{df}{dt} = \frac{df}{dg}\frac{dg}{dt} \quad \text{for} \quad f = f(g(t))$$

$$\left(\frac{\partial y}{\partial x}\right)_z = 1/\left(\frac{\partial x}{\partial y}\right)_z \qquad \left(\frac{\partial y}{\partial x}\right)_z \left(\frac{\partial x}{\partial z}\right)_y \left(\frac{\partial z}{\partial y}\right)_x = -1$$

$$\frac{dx^n}{dx} = nx^{n-1} \qquad \frac{de^{ax}}{dx} = ae^{ax} \qquad \frac{d\ln(ax)}{dx} = \frac{1}{x}$$

$$df = g(x,y)dx + h(x,y)dy \text{ is exact if } \left(\frac{\partial g}{\partial y}\right)_x = \left(\frac{\partial h}{\partial x}\right)_y$$

Greek alphabet*

Α, α	alpha	Ι, ι	iota	Ρ, ρ	rho
Β, β	beta	Κ, κ	kappa	Σ, σ	sigma
Γ, γ	gamma	Λ, λ	lambda	Τ, τ	tau
Δ, δ	delta	Μ, μ	mu	Υ, υ	upsilon
Ε, ε	epsilon	Ν, ν	nu	Φ, φ	phi
Ζ, ζ	zeta	Ξ, ξ	xi	Χ, χ	chi
Η, η	eta	Ο, ο	omicron	Ψ, ψ	psi
Θ, θ	theta	Π, π	pi	Ω, ω	omega

* Oblique versions (α, β, …) are used to denote physical observables.

PREFACE

This new edition is the product of a thorough revision of content and its presentation. Our goal is to make the book even more accessible to students and useful to instructors by enhancing its flexibility. We hope that both categories of user will perceive and enjoy the renewed vitality of the text and the presentation of this demanding but engaging subject.

The text is still divided into three parts, but each chapter is now presented as a series of short and more readily mastered *Topics*. This new structure allows the instructor to tailor the text within the time constraints of the course as omissions will be easier to make, emphases satisfied more readily, and the trajectory through the subject modified more easily. For instance, it is now easier to approach the material either from a 'quantum first' or a 'thermodynamics first' perspective because it is no longer necessary to take a linear path through chapters. Instead, students and instructors can match the choice of Topics to their learning objectives. We have been very careful not to presuppose or impose a particular sequence, except where it is demanded by common sense.

We open with a *Foundations* chapter, which reviews basic concepts of chemistry and physics used through the text. Part 1 now carries the title *Thermodynamics*. New to this edition is coverage of ternary phase diagrams, which are important in applications of physical chemistry to engineering and materials science. Part 2 (*Structure*) continues to cover quantum theory, atomic and molecular structure, spectroscopy, molecular assemblies, and statistical thermodynamics. Part 3 (*Change*) has lost a chapter dedicated to catalysis, but not the material. Enzyme-catalysed reactions are now in Chapter 20, and heterogeneous catalysis is now part of a new Chapter 22 focused on surface structure and processes.

As always, we have paid special attention to helping students navigate and master this material. Each chapter opens with a brief summary of its Topics. Then each Topic begins with three questions: 'Why do you need to know this material?', 'What is the key idea?', and 'What do you need to know already?'. The answers to the third question point to other Topics that we consider appropriate to have studied or at least to refer to as background to the current Topic. The *Checklists* at the end of each Topic are useful distillations of the most important concepts and equations that appear in the exposition.

We continue to develop strategies to make mathematics, which is so central to the development of physical chemistry, accessible to students. In addition to associating *Mathematical background* sections with appropriate chapters, we give more help with the development of equations: we motivate them, justify them, and comment on the steps taken to derive them. We also added a new feature: *The chemist's toolkit*, which offers quick and immediate help on a concept from mathematics or physics.

This edition has more worked *Examples*, which require students to organize their thoughts about how to proceed with complex calculations, and more *Brief illustrations*, which show how to use an equation or deploy a concept in a straightforward way. Both have *Self-tests* to enable students to assess their grasp of the material. We have structured the end-of-chapter *Discussion questions*, *Exercises*, and *Problems* to match the grouping of the Topics, but have added Topic- and Chapter-crossing *Integrated activities* to show that several Topics are often necessary to solve a single problem. The *Resource section* has been restructured and augmented by the addition of a list of integrals that are used (and referred to) throughout the text.

We are, of course, alert to the development of electronic resources and have made a special effort in this edition to encourage the use of web-based tools, which are identified in the *Using the book* section that follows this preface. Important among these tools are *Impact* sections, which provide examples of how the material in the chapters is applied in such diverse areas as biochemistry, medicine, environmental science, and materials science.

Overall, we have taken this opportunity to refresh the text thoroughly, making it even more flexible, helpful, and up to date. As ever, we hope that you will contact us with your suggestions for its continued improvement.

PWA, Oxford
JdeP, Portland

USING THE BOOK

For the tenth edition of *Atkins' Physical Chemistry* we have tailored the text even more closely to the needs of students. First, the material within each chapter has been re-organized into discrete topics to improve accessibility, clarity, and flexibility. Second, in addition to the variety of learning features already present, we have significantly enhanced the mathematics support by adding new Chemist's toolkit boxes, and checklists of key concepts at the end of each topic.

Organizing the information

➤ Innovative new structure

Each chapter has been reorganized into short topics, making the text more readable for students and more flexible for instructors. Each topic opens with a comment on why it is important, a statement of the key idea, and a brief summary of the background needed to understand the topic.

> ➤ **Why do you need to know this material?**
>
> Because chemistry is about matter and the changes that it can undergo, both physically and chemically, the properties of matter underlie the entire discussion in this book.
>
> ➤ **What is the key idea?**
>
> The bulk properties of matter are related to the identities

➤ Notes on good practice

Our *Notes on good practice* will help you avoid making common mistakes. They encourage conformity to the international language of science by setting out the conventions and procedures adopted by the International Union of Pure and Applied Chemistry (IUPAC).

> applicable only to perfect gases (and other idealized systems) are labelled, as here, with a number in blue.
>
> *A note on good practice* Although the term 'ideal gas' is almost universally used in place of 'perfect gas', there are reasons for preferring the latter term. In an ideal system the interactions between molecules in a mixture are all the same. In a perfect gas not only are the interactions all the same but they are in fact zero. Few, though, make this useful distinction.
>
> Equation A.5, the **perfect gas equation**, is a summary of three empirical conclusions, namely Boyle's law ($p \propto 1/V$ at

➤ Resource section

The comprehensive *Resource section* at the end of the book contains a table of integrals, data tables, a summary of conventions about units, and character tables. Short extracts of these tables often appear in the topics themselves, principally to give an idea of the typical values of the physical quantities we are introducing.

> RESOURCE SECTION
>
> **Contents**

➤ Checklist of concepts

A *Checklist of key concepts* is provided at the end of each topic so that you can tick off those concepts which you feel you have mastered.

Checklist of concepts

- ☐ 1. The **entropy** acts as a signpost of spontaneous change.
- ☐ 2. Entropy change is defined in terms of heat transactions (the **Clausius definition**).
- ☐ 3. The **Boltzmann formula** defines absolute entropies in terms of the number of ways of achieving a configuration.

Presenting the mathematics

➤ Justifications

Mathematical development is an intrinsic part of physical chemistry, and to achieve full understanding you need to see how a particular expression is obtained and if any assumptions have been made. The *Justifications* are set off from the text to let you adjust the level of detail to meet your current needs and make it easier to review material.

Justification 3A.1 Heating accompanying reversible adiabatic expansion

This *Justification* is based on two features of the cycle. One feature is that the two temperatures T_h and T_c in eqn 3A.7 lie on the same adiabat in Fig. 3A.7. The second feature is that the energy transferred as heat during the two isothermal stages are

$$q_h = nRT_h \ln\frac{V_B}{V_A} \qquad q_c = nRT_c \ln\frac{V_D}{V_C}$$

We now show that the two volume ratios are related in a very simple way. From the relation between temperature and volume for reversible adiabatic processes (VT^c=constant, Topic 2D):

➤ Chemist's toolkits

New to the tenth edition, the *Chemist's toolkits* are succinct reminders of the mathematical concepts and techniques that you will need in order to understand a particular derivation being described in the main text.

The chemist's toolkit A.1 Quantities and units

The result of a measurement is a **physical quantity** that is reported as a numerical multiple of a unit:

physical quantity = numerical value × unit

It follows that units may be treated like algebraic quantities and may be multiplied, divided, and cancelled. Thus, the expression (physical quantity)/unit is the numerical value (a dimensionless quantity) of the measurement in the specified

➤ Mathematical backgrounds

There are six *Mathematical background* sections dispersed throughout the text. They cover in detail the main mathematical concepts that you need to understand in order to be able to master physical chemistry. Each one is located at the end of the chapter to which it is most relevant.

Mathematical background 1 Differentiat

Two of the most important mathematical techniques in the physical sciences are differentiation and integration. They occur throughout the subject, and it is essential to be aware of the procedures involved.

MB1.1 Differentiation: definitions

Differentiation is concerned with the slopes of functions, such as the rate of change of a variable with time. The formal definition of the **derivative**, df/dx, of a function $f(x)$ is

➤ Annotated equations and equation labels

We have annotated many equations to help you follow how they are developed. An annotation can take you across the equals sign: it is a reminder of the substitution used, an approximation made, the terms that have been assumed constant, the integral used, and so on. An annotation can also be a reminder of the significance of an individual term in an expression. We sometimes colour a collection of numbers or symbols to show how they carry from one line to the next. Many of the equations are labelled to highlight their significance.

$$w=-nRT\int_{V_i}^{V_f}\frac{dV}{V} \overset{\text{Integral A.2}}{=} -nRT\ln\frac{V_f}{V_i}$$

Perfect gas, reversible, isothermal Work of expansion (2A.9)

➤ Checklists of equations

You don't have to memorize every equation in the text. A checklist at the end of each topic summarizes the most important equations and the conditions under which they apply.

Checklist of equations

Property	Equation
Compression factor	$Z=V_m/V_m^\circ$
Virial equation of state	$pV_m=RT(1+B/V_m+C/V_m^2+\cdots)$
van der Waals equation of state	$p=nRT/(V-nb)-a(n/V)^2$
Reduced variables	$X_r=X_m/X_c$

Setting up and solving problems

➤ Brief illustrations

A *Brief illustration* shows you how to use equations or concepts that have just been introduced in the text. They help you to learn how to use data, manipulate units correctly, and become familiar with the magnitudes of properties. They are all accompanied by a Self-test question which you can use to monitor your progress.

Brief illustration 1C.5 Corresponding states

The critical constants of argon and carbon dioxide are given in Table 1C.2. Suppose argon is at 23 atm and 200 K, its reduced pressure and temperature are then

$$p_r=\frac{23\,\text{atm}}{48.0\,\text{atm}}=0.48 \qquad T_r=\frac{200\,\text{K}}{150.7\,\text{K}}=1.33$$

For carbon dioxide to be in a corresponding state, its pressure and temperature would need to be

$$p=0.48\times(72.9\,\text{atm})=35\,\text{atm} \qquad T=1.33\times304.2\,\text{K}=405\,\text{K}$$

Self-test 1C.6 What would be the corresponding state of ammonia?

Answer: 53 atm, 539 K

➤ Worked examples

Worked *Examples* are more detailed illustrations of the application of the material, which require you to assemble and develop concepts and equations. We provide a suggested method for solving the problem and then implement it to reach the answer. Worked examples are also accompanied by *Self-test* questions.

Example 3A.2 Calculating the entropy change for a composite process

Calculate the entropy change when argon at 25 °C and 1.00 bar in a container of volume 0.500 dm^3 is allowed to expand to 1.000 dm^3 and is simultaneously heated to 100 °C.

Method As remarked in the text, use reversible isothermal expansion to the final volume, followed by reversible heating at constant volume to the final temperature. The entropy change in the first step is given by eqn 3A.16 and that of the second step, provided C_V is independent of temperature, by eqn 3A.20 (with C_V in place of C_p). In each case we need to

➤ Discussion questions

Discussion questions appear at the end of every chapter, where they are organized by topic. These questions are designed to encourage you to reflect on the material you have just read, and to view it conceptually.

➤ Exercises and Problems

Exercises and *Problems* are also provided at the end of every chapter, and organized by topic. They prompt you to test your understanding of the topics in that chapter. Exercises are designed as relatively straightforward numerical tests whereas the problems are more challenging. The Exercises come in related pairs, with final numerical answers available on the book's Online Resource Centre for the 'a' questions. Final numerical answers to the odd-numbered problems are also available on the Online Resource Centre.

TOPIC 3A Entropy

Discussion questions

3A.1 The evolution of life requires the organization of a very large number of molecules into biological cells. Does the formation of living organisms violate the Second Law of thermodynamics? State your conclusion clearly and present detailed arguments to support it.

3A.2 Discuss the significance of the terms 'dispersal' and 'disorder' in the context of the Second Law.

Exercises

3A.1(a) During a hypothetical process, the entropy of a system increases by 125 J K^{-1} while the entropy of the surroundings decreases by 125 J K^{-1}. Is the process spontaneous?
3A.1(b) During a hypothetical process, the entropy of a system increases by 105 J K^{-1} while the entropy of the surroundings decreases by 95 J K^{-1}. Is the process spontaneous?

3A.2(a) A certain ideal heat engine uses water at the triple point as the hot source and an organic liquid as the cold sink. It withdraws 10.00 kJ of heat from the hot source and generates 3.00 kJ of work. What is the temperature of the organic liquid?
3A.2(b) A certain ideal heat engine uses water at the triple point as the hot source and an organic liquid as the cold sink. It withdraws 2.71 kJ of heat from the hot source and generates 0.71 kJ of work. What is the temperature of the organic liquid?

➤ Integrated activities

At the end of most chapters, you will find questions that cross several topics and chapters, and are designed to help you use your knowledge creatively in a variety of ways. Some of the questions refer to the Living graphs in the Online Resource Centre, which you will find helpful for answering them.

➤ Solutions manuals

Two solutions manuals have been written by Charles Trapp, Marshall Cady, and Carmen Giunta to accompany this book.

The *Student's Solutions Manual* (ISBN 9780198708001) provides full solutions to the 'a' exercises and to the odd-numbered problems.

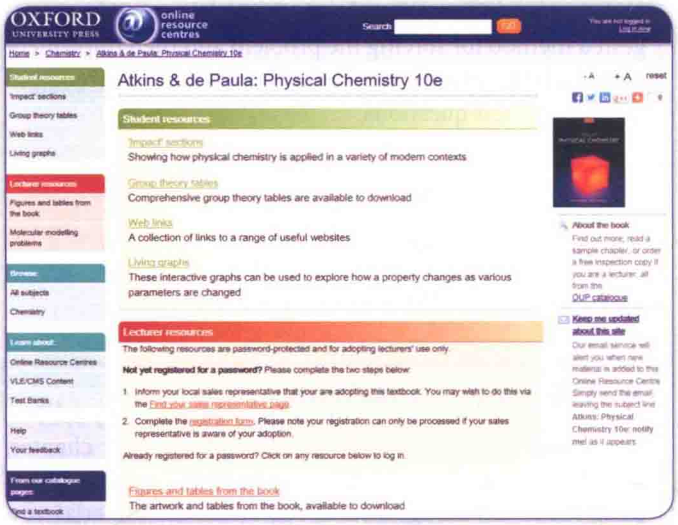
The *Instructor's Solutions Manual* provides full solutions to the 'b' exercises and to the even-numbered problems (available to download in the Online Resource Centre for registered adopters of the book only).

ONLINE RESOURCE CENTRE

The Online Resource Centre to accompany *Atkins' Physical Chemistry* provides a number of useful teaching and learning resources for students and lecturers.

The site can be accessed at:

www.oxfordtextbooks.co.uk/orc/pchem10e/



Lecturer resources are available only to registered adopters of the textbook. To register, simply visit the site and follow the link to the registration form.

Student resources are openly available to all, without registration.

Materials on the online resource centre include:

'Impact' sections

'Impact' sections show how physical chemistry is applied in a variety of modern contexts. New for this edition, the Impacts are linked from the text by QR code images. Alternatively, visit the URL displayed next to the QR code image.

Group theory tables

Comprehensive group theory tables are available to download.

Web links

This collection of links to a range of useful websites is organized by chapter to aid navigation.

Figures and tables from the book

Lecturers can find the artwork and tables from the book in ready-to-download format. These may be used for lectures without charge (but not for commercial purposes without specific permission).

Molecular modelling problems

PDFs containing molecular modelling problems can be downloaded, designed for use with the Spartan Student™ software. However they can also be completed using any modelling software that allows Hartree-Fock, density functional, and MP2 calculations.

Living graphs

These interactive graphs can be used to explore how a property changes as various parameters are changed.

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A book as extensive as this could not have been written without significant input from many individuals. We would like to reiterate our thanks to the hundreds of people who contributed to the first nine editions. Many people gave their advice based on the ninth edition, and others, including students, reviewed the draft chapters for the tenth edition as they emerged. We wish to express our gratitude to the following colleagues:

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Because we prepared this edition at the same time as its sister volume, *Physical Chemistry: Quanta, matter, and change*, it goes without saying that our colleague on that book, Ron Friedman, has had an unconscious but considerable impact on this text too, and we cannot thank him enough for his contribution to this book. Our warm thanks also go to Charles Trapp, Carmen Giunta, and Marshall Cady who once again have produced the *Solutions manuals* that accompany this book and whose comments led us to make a number of improvements. Kerry Karukstis contributed helpfully to the Impacts that are now on the web.

Last, but by no means least, we would also like to thank our two commissioning editors, Jonathan Crowe of Oxford University Press and Jessica Fiorillo of W. H. Freeman & Co., and their teams for their encouragement, patience, advice, and assistance.

Periodic table of the elements

Period 1: 1 H hydrogen 1.0079 $1s^1$

Period	Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	I IA	II IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	III IIIA	IV IVA	V VA	VI VIA	VII VIIA	VIII VIIA
1																		2 He helium 4.00 $1s^2$
2	3 Li lithium 6.94 $2s^1$	4 Be beryllium 9.01 $2s^2$											5 B boron 10.81 $2s^22p^1$	6 C carbon 12.01 $2s^22p^2$	7 N nitrogen 14.01 $2s^22p^3$	8 O oxygen 16.00 $2s^22p^4$	9 F fluorine 19.00 $2s^22p^5$	10 Ne neon 20.18 $2s^22p^6$
3	11 Na sodium 22.99 $3s^1$	12 Mg magnesium 24.31 $3s^2$											13 Al aluminium 26.98 $3s^23p^1$	14 Si silicon 28.09 $3s^23p^2$	15 P phosphorus 30.97 $3s^23p^3$	16 S sulfur 32.06 $3s^23p^4$	17 Cl chlorine 35.45 $3s^23p^5$	18 Ar argon 39.95 $3s^23p^6$
4	19 K potassium 39.10 $4s^1$	20 Ca calcium 40.08 $4s^2$	21 Sc scandium 44.96 $3d^14s^2$	22 Ti titanium 47.87 $3d^24s^2$	23 V vanadium 50.94 $3d^34s^2$	24 Cr chromium 52.00 $3d^54s^1$	25 Mn manganese 54.94 $3d^54s^2$	26 Fe iron 55.84 $3d^64s^2$	27 Co cobalt 58.93 $3d^74s^2$	28 Ni nickel 58.69 $3d^84s^2$	29 Cu copper 63.55 $3d^{10}4s^1$	30 Zn zinc 65.41 $3d^{10}4s^2$	31 Ga gallium 69.72 $4s^24p^1$	32 Ge germanium 72.64 $4s^24p^2$	33 As arsenic 74.92 $4s^24p^3$	34 Se selenium 78.96 $4s^24p^4$	35 Br bromine 79.90 $4s^24p^5$	36 Kr krypton 83.80 $4s^24p^6$
5	37 Rb rubidium 85.47 $5s^1$	38 Sr strontium 87.62 $5s^2$	39 Y yttrium 88.91 $4d^15s^2$	40 Zr zirconium 91.22 $4d^25s^2$	41 Nb niobium 92.91 $4d^45s^1$	42 Mo molybdenum 95.94 $4d^55s^1$	43 Tc technetium (98) $4d^55s^2$	44 Ru ruthenium 101.07 $4d^75s^1$	45 Rh rhodium 102.90 $4d^85s^1$	46 Pd palladium 106.42 $4d^{10}$	47 Ag silver 107.87 $4d^{10}5s^1$	48 Cd cadmium 112.41 $4d^{10}5s^2$	49 In indium 114.82 $5s^25p^1$	50 Sn tin 118.71 $5s^25p^2$	51 Sb antimony 121.76 $5s^25p^3$	52 Te tellurium 127.60 $5s^25p^4$	53 I iodine 126.90 $5s^25p^5$	54 Xe xenon 131.29 $5s^25p^6$
6	55 Cs caesium 132.91 $6s^1$	56 Ba barium 137.33 $6s^2$	57 La lanthanum 138.91 $5d^16s^2$	72 Hf hafnium 178.49 $5d^26s^2$	73 Ta tantalum 180.95 $5d^36s^2$	74 W tungsten 183.84 $5d^46s^2$	75 Re rhenium 186.21 $5d^56s^2$	76 Os osmium 190.23 $5d^66s^2$	77 Ir iridium 192.22 $5d^76s^2$	78 Pt platinum 195.08 $5d^96s^1$	79 Au gold 196.97 $5d^{10}6s^1$	80 Hg mercury 200.59 $5d^{10}6s^2$	81 Tl thallium 204.38 $6s^26p^1$	82 Pb lead 207.2 $6s^26p^2$	83 Bi bismuth 208.98 $6s^26p^3$	84 Po polonium (209) $6s^26p^4$	85 At astatine (210) $6s^26p^5$	86 Rn radon (222) $6s^26p^6$
7	87 Fr francium (223) $7s^1$	88 Ra radium (226) $7s^2$	89 Ac actinium (227) $6d^17s^2$	104 Rf rutherfordium (261) $6d^27s^2$	105 Db dubnium (262) $6d^37s^2$	106 Sg seaborgium (263) $6d^47s^2$	107 Bh bohrium (262) $6d^57s^2$	108 Hs hassium (265) $6d^67s^2$	109 Mt meitnerium (266) $6d^77s^2$	110 Ds darmstadtium (271) $6d^87s^2$	111 Rg roentgenium (272) $6d^97s^2$	112 Cn copernicium ? $6d^{10}7s^2$	113	114 Fv flerovium ? $7s^27p^2$	115	116 Lv livermorium ? $7s^27p^4$	117	118

Period															
6	58 Ce cerium 140.12 $4f^15d^16s^2$	59 Pr praseodymium 140.91 $4f^36s^2$	60 Nd neodymium 144.24 $4f^46s^2$	61 Pm prometheum (145) $4f^56s^2$	62 Sm samarium 150.36 $4f^66s^2$	63 Eu europium 151.96 $4f^76s^2$	64 Gd gadolinium 157.25 $4f^75d^16s^2$	65 Tb terbium 158.93 $4f^96s^2$	66 Dy dysprosium 162.50 $4f^{10}6s^2$	67 Ho holmium 164.93 $4f^{11}6s^2$	68 Er erbium 167.26 $4f^{12}6s^2$	69 Tm thulium 168.93 $4f^{13}6s^2$	70 Yb ytterbium 173.04 $4f^{14}6s^2$	71 Lu lutetium 174.97 $5d^16s^2$	Lanthanoids (lanthanides)
7	90 Th thorium 232.04 $6d^27s^2$	91 Pa protactinium 231.04 $5f^26d^17s^2$	92 U uranium 238.03 $5f^36d^17s^2$	93 Np neptunium (237) $5f^46d^17s^2$	94 Pu plutonium (244) $5f^67s^2$	95 Am americium (243) $5f^77s^2$	96 Cm curium (247) $5f^76d^17s^2$	97 Bk berkelium (247) $5f^97s^2$	98 Cf californium (251) $5f^{10}7s^2$	99 Es einsteinium (252) $5f^{11}7s^2$	100 Fm fermium (257) $5f^{12}7s^2$	101 Md mendelevium (258) $5f^{13}7s^2$	102 No nobelium (259) $5f^{14}7s^2$	103 Lr lawrencium (262) $6d^17s^2$	Actinoids (actinides)

Molar masses (atomic weights) quoted to the number of significant figures given here can be regarded as typical of most naturally occurring samples

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