



Study Guide to accompany

CHEMICAL PRINCIPLES

THE QUEST FOR INSIGHT

Sixth Edition

JOHN KRENOS • JOSEPH POTENZA

Study Guide to Accompany

Atkins, Jones and Laverman's

CHEMICAL PRINCIPLES

The Quest for Insight

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PREFACE

This Study Guide accompanies the textbook *Chemical Principles: The Quest for Insight*, Sixth Edition, by Peter Atkins, Loretta Jones, and Leroy Laverman—an authoritative and thorough introduction to chemistry for students anticipating careers in science or engineering disciplines. We have followed the order of topics in the textbook chapter for chapter. The parallel between the symbols, concepts, and style of this supplement and the textbook enable the reader to move easily back and forth between the two.

Much of the Study Guide is presented in outline style with material highlighted by bullets, arrows, some tables, and figures. In general, bullets offset major items of importance for each section and arrows provide explanatory material, descriptive material, or some examples to reinforce a concept. This telegraphic style should help the student obtain a broad perspective of large blocks of material in a relatively short period of time, and may prove particularly useful in preparing for examinations. We believe that the Study Guide will be most useful following a careful reading of the text. Chapter **Sections** follow those in the text and contain descriptive material (bullets and arrows) as well as numerous examples. Many examples are worked out in detail. While we have covered most of the material in the text, we have not attempted to be encyclopedic. To help obtain a broad overview of the material, important equations are highlighted in boxes. Students may find this aspect of the guide particularly useful before exams. Where appropriate, we have introduced supplementary tables either to amplify material in the text, to clarify it further, or to summarize a body of material. Sprinkled throughout the guide are **Notes**; in the main, these are designed to point out common pitfalls. New in the sixth edition is a more readable, open format. The content is updated to closely follow changes and new approaches in the textbook.

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ACKNOWLEDGMENTS

The Study Guide authors, John Krenos and Joseph Potenza, are indebted to many individuals who have made significant contributions to it.

First and foremost, we wish to thank Beth Van Assen for a thorough and incisive reading of the drafts. Her critical suggestions led to improved readability and scientific accuracy of the Study Guide. Many examples and important sections of descriptive text were clarified and expanded with her help. Her encouragement, patience, and persistence were essential to the completion of this project.

We also thank two of our colleagues at Rutgers for critically reading three chapters. Harvey Schugar carefully reviewed Chapter 17. Our knowledge and appreciation of inorganic chemistry were broadened greatly by his comments and analysis. Spencer Knapp critiqued Chapters 19 and 20 and gave us a quick tutorial on modern organic chemistry. Many of the chemical structures were prepared with his help.

We also wish to gratefully acknowledge the help and encouragement of the staff at W. H. Freeman and Company. We especially thank Jessica Fiorillo (Associate Publisher) for asking us to author this guide, Jodi Isman (Project Editor) for guiding us through the laborious process of developing the original manuscript from scratch and also for helping with the editing of this edition, and Heidi Bamatter (Assistant Editor) for encouraging us to keep to a tight schedule.

Finally, we extol the efforts of the authors of the textbook, Peter Atkins, Loretta Jones, and Leroy Laverman in creating a new approach to teaching general chemistry. Beginning an introductory chemistry textbook with quantum theory is a logical, but challenging approach. The authors succeed by treating the fundamentals of chemistry (an “as needed” review) in a separate section and by minimizing the coverage of a great deal of material (mostly historical) presented in other books. In our opinion, this approach leads to the development of all the major topics in chemistry enlightened and enlivened in the first instance by the molecular viewpoint.

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Chapter 1 THE QUANTUM WORLD

INVESTIGATING ATOMS (Sections 1.1–1.3)

1.1 The Nuclear Model of the Atom

• Background

- J. J. Thomson found that charged cathode-ray particles, which are now called **electrons**, were the same regardless of the metal used for the cathode. He concluded that they are part of the foundation of all atoms.
- Thomson measured a value of e/m_e , the ratio of the magnitude of the electron's charge e to its mass m_e . Values for e and m_e were not known until the physicist Robert Millikan carried out experiments that enabled the calculation of the value of e .
- Fundamental unit of charge: $e = 1.602 \times 10^{-19}$ C. Mass of the electron: 9.109×10^{-31} kg.
- The charge of $-e$ is “one unit” of negative charge, and the charge of e is “one unit” of positive charge.
- Based on the scattering of alpha particles on platinum foil, Ernest Rutherford proposed a nuclear model of the atom. Later work showed that the nucleus of an atom contains particles called **protons**, each of which has a charge of $+e$ (responsible for the positive charge), and **neutrons** (uncharged particles).
- The number of protons in the nucleus is different for each element and is called the **atomic number**, Z , of the element (*Fundamentals*, Section B). The total charge on an atomic nucleus of atomic number Z is $+Ze$ and, for the atoms to be electrically neutral, there must be Z electrons around it.

• Subatomic particles

- Electron: mass ($m = 9.109\,383 \times 10^{-31}$ kg) charge ($-e = -1.602\,177 \times 10^{-19}$ C)
- Proton: mass ($m = 1.672\,622 \times 10^{-27}$ kg) charge ($e = 1.602\,177 \times 10^{-19}$ C)
- Neutron: mass ($m = 1.674\,927 \times 10^{-27}$ kg) charge = 0

• Nucleus

- *Nucleons* (protons and neutrons) occupy a small volume at the center of the atom. The binding energy of the nucleus is attributed to a strong force (nuclear) acting over a very short distance.
- The radius of the nucleus (assumed to be spherical) is given roughly by $r_{\text{nuc}} = r_0 A^{1/3}$, where $r_0 \approx 1.3 \times 10^{-15}$ m = 1.3 fm.

• Atom

- Atomic number: $Z = N_p =$ number of protons in the nucleus
- Atomic mass number: $A = N_p + N_n =$ number of protons and neutrons in the nucleus
- Uncharged atom: $N_p = N_e$ (number of protons equals the number of electrons)
- *Electrons* occupy a much larger volume than the nucleus and define the “size” of the atom. The binding energy of the electrons is attributed to a weak force (coulomb) acting over a much longer distance than the strong force.

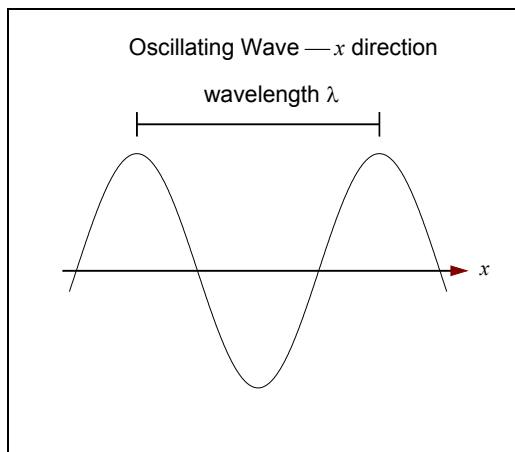
2 Chapter 1 The Quantum World

1.2 The Characteristics of Electromagnetic Radiation

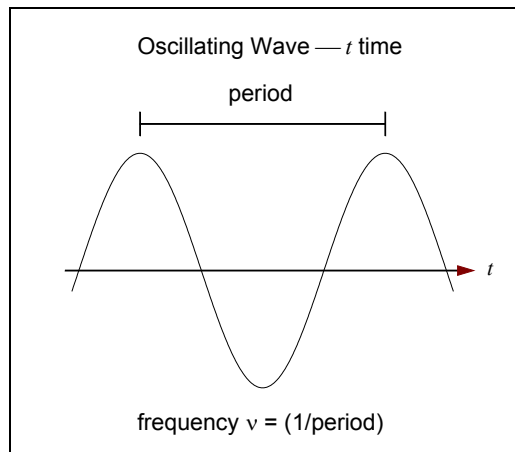
- **Oscillating amplitude of electric and magnetic field**

- Waves are characterized by *wavelength* λ (lambda) and *frequency* ν (nu).
- Waves always travel at the speed of light (constant for a given medium)
- No known upper or lower limit of frequency or wavelength

Distance Behavior (fixed time t)



Time Behavior (fixed position x)



Speed of light (distance/time) = wavelength / period = wavelength \times frequency

$$\boxed{c = \lambda \nu} \quad \text{speed of light} = \text{wavelength} \times \text{frequency}$$

SI units: $(\text{m} \cdot \text{s}^{-1})$ (m) (s^{-1}) [1 Hz (hertz) = 1 s^{-1}]

- The speed of light c (c_0 in vacuum $\approx 3.00 \times 10^8 \text{ m} \cdot \text{s}^{-1}$) depends on the medium it travels in. Medium effects on wavelength in the visible region are small (beyond three significant figures).
- Visible radiation or visible light: 700 nm to 400 nm.
- Ultraviolet radiation: $< 400 \text{ nm}$ ($< 200 \text{ nm}$ vacuum ultraviolet)
- Infrared radiation: $> 700 \text{ nm}$
- Visible spectrum colors (pneumonic): ROY G BIV (red, orange, yellow, green, blue, indigo, violet)
- See Table 1.1 in the text: Color, Frequency, and Wavelength of Electromagnetic Radiation

1.3 Atomic Spectra

- **Spectral lines**

- Discharge lamp of hydrogen



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→ Stefan–Boltzmann law:
$$\frac{\text{Power emitted (watts)}}{\text{Surface area (meter}^2)} = \text{constant} \times T^4$$

→ Wien's law:
$$T\lambda_{\text{max}} = \text{constant}$$
 where constant = 2.88 K·mm

Wavelength corresponding to maximum intensity = λ_{max}

At higher temperature, maximum intensity of radiation shifts to lower wavelength.

• Energy of a quantum (packet) of light (generally called a photon)

→ Postulated by Max Planck to explain black body radiation

→ Resolved the “ultraviolet catastrophe” of classical physics, which predicted intense ultraviolet radiation for all heated objects ($T > 0$)

→ Quantization of electromagnetic radiation

$$E = h\nu \quad \text{Photon energy} = \text{Planck constant} \times \text{photon frequency}$$

SI units: (J) ($h = 6.6261 \times 10^{-34}$ J·s) (s^{-1})

• Photoelectric effect

→ Ejection of electrons from a metal surface exposed to photons of sufficient energy

→ Indicates that light behaves as a particle

$$E_K = h\nu - \Phi$$

E_K = kinetic energy of the ejected electron, Φ = threshold energy (work function) required for electron ejection from the metal surface, and $h\nu$ = photon energy

→ $h\nu \geq \Phi$ required for electron ejection

• Bohr frequency condition

$$h\nu = E_{\text{upper}} - E_{\text{lower}}$$

Relates photon energy to energy difference between two energy levels in an atom

1.5 The Wave–Particle Duality of Matter

• Wave behavior of light

→ Diffraction and interference effects of superimposed waves (*constructive* and *destructive*)

• Matter has wave properties.

→ Proposed by Louis de Broglie

→ Consider matter with mass m and velocity v .

→ Such matter behaves as a wave with a characteristic wavelength.

$$\lambda = \frac{h}{mv}$$

de Broglie wavelength for a particle with linear momentum $p = mv$

→ Wave character of electrons is verified by electron diffraction.

1.6 The Uncertainty Principle

- **Complementarity of location (x) and momentum (p)**

→ Uncertainty in x is Δx ; uncertainty in p is Δp .

→ Limitation of knowledge (p and x cannot be determined simultaneously)

$$\Delta p \Delta x \geq \hbar/2 \quad \text{Heisenberg uncertainty principle, where } \hbar = h/2\pi$$

→ \hbar is called "h bar" $\hbar = 1.0546 \times 10^{-34}$ J·s

→ Refutes classical physics on the atomic scale

1.7 Wavefunctions and Energy Levels

- **Classical trajectories**

→ Precisely defined paths



- **Wavefunction Ψ**

→ Gives *probable* position of particle with mass m

- **Born interpretation**

→ Probability of finding particle in a region is proportional to ψ^2 .

- **Schrödinger equation**

→ Allows calculation of ψ by solving a differential equation

→ $H\Psi = E\Psi$; H is called the Hamiltonian

→ H represents the sum of kinetic energy and potential energy in a system

$$-\frac{\hbar^2}{2m} \nabla^2 \psi + V\psi = E\psi$$

- **Particle in a box**

→ Mass m confined between two rigid walls a distance L apart

→ $\psi = 0$ outside the box and at the walls (boundary condition)

→ The *operator* for a one-dimensional system is

$$\nabla^2 = \frac{d^2}{dx^2}$$