The Absolute, Ultimate Guide to

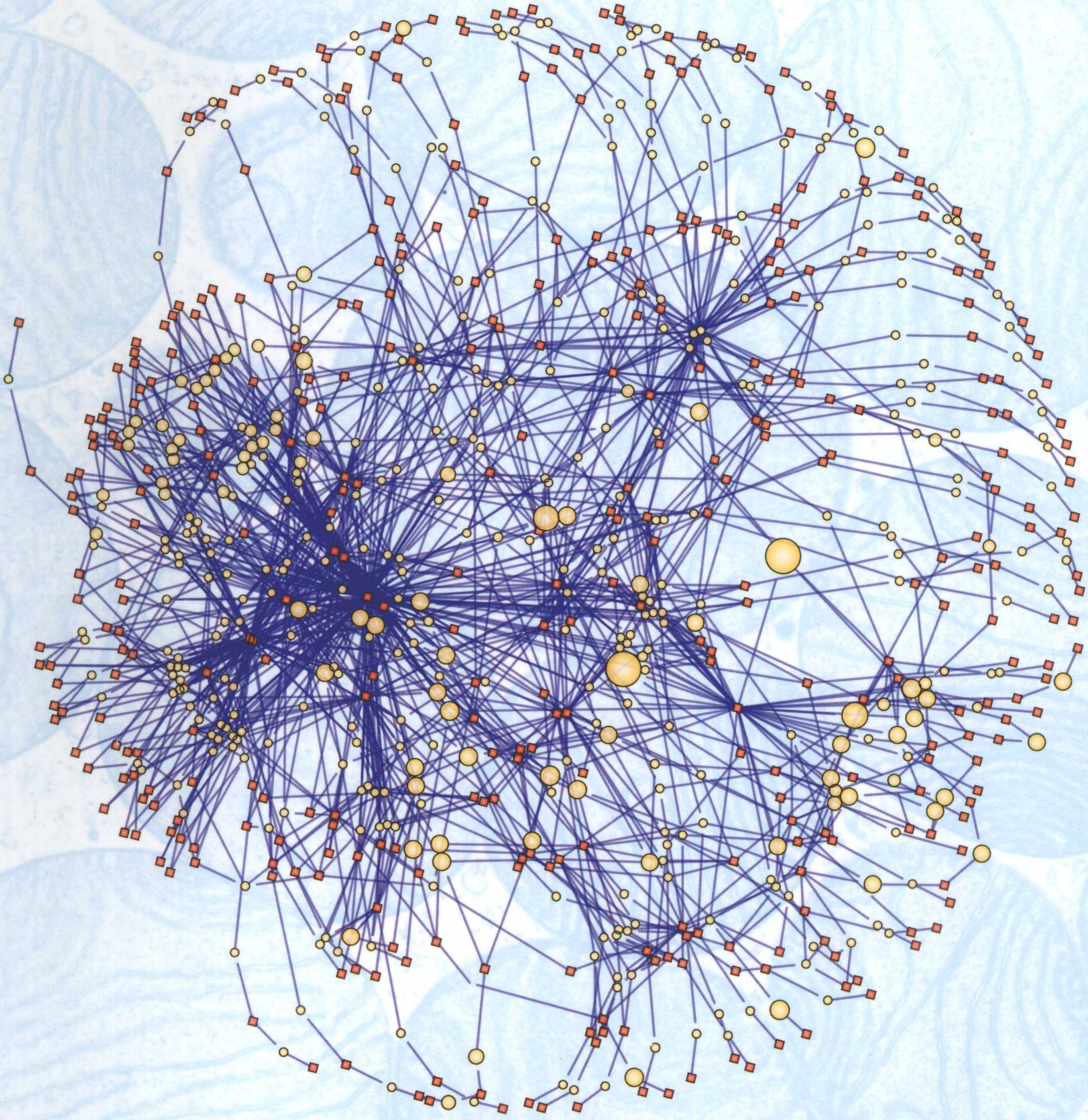
Lehninger

SIXTH EDITION

Principles of Biochemistry

Study Guide and Solutions Manual

Marcy Osgood | Karen Ocorr



The Absolute, Ultimate Guide to
Lehninger Principles of Biochemistry
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Study Guide and Solutions Manual

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Solutions Manual based on
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W. H. FREEMAN AND COMPANY
NEW YORK

ISBN-13: 978-1-4292-9476-8
ISBN-10: 1-4292-9476-0

Printed in the United States of America

Fourth printing

W. H. Freeman and Company
41 Madison Avenue
New York, NY 10010
Houndmills, Basingstoke RG21 6XS, England

www.whfreeman.com

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Preface

Learning a complex subject, such as biochemistry, is very much like learning a foreign language.

In the study of a foreign language there are several distinct components that must be mastered: the vocabulary, the grammatical rules, and the integration of these words and rules so they can be used to communicate ideas. Similarly, in the study of biochemistry there is a very large (some would say vast) number of new terms and concepts, as well as a complex set of "rules" governing biochemical reactions that must all be memorized. All of this information must be integrated into an interrelated whole that describes biological systems.

Memorizing vocabulary and grammatical rules will not make you fluent in a foreign language; neither will such memorization make you fluent in biochemistry.

Similarly, listening to someone speak a foreign language will not, by itself, make you more capable of producing those same sounds, words, and sentences. The key to mastery of any new subject area, whether it is a foreign language or biochemistry, is the interaction of memorization, practice, and application until the information fits together into a coherent whole.

In this workbook we attempt to guide you through the material presented in Lehninger Principles of Biochemistry, Sixth Edition *by Nelson and Cox. The* **Step-by-Step Guide** *to each chapter includes three parts:*

- A one- to two-page summary of the **Major Concepts** helps you to see the "big picture" for each chapter.
- **What to Review** helps you make direct connections between the current material and related information presented elsewhere in the text.
- **Topics for Discussion** for each section and subsection in the chapter focus your attention on the main points being presented and help you internalize the information by *using* it.
- **Discussion Questions for Study Groups** are questions that are especially suited to Study Groups, either because they pull together several points made in the chapter or because they are more involved questions that would benefit from collaborative insight.

Each chapter also includes a **Self-Test** *for you to assess your progress in mastering biochemical terminology and facts, and learning to integrate and apply that information.*

- **Do You Know the Terms?** asks you to complete a crossword puzzle using the new vocabulary introduced in the chapter.
- **Do You Know the Facts?** tests how well you have learned the "rules" of biochemistry.
- **Applying What You Know** tests how well you "speak the language" of biochemistry, often in an experimental or metabolically relevant context.

Two especially popular features of the Absolute, Ultimate Guide *are:*

- The **Biochemistry on the Internet** problems will expose you to just a few of the analytical resources that are available to scientists on the Internet. The molecular models are fun to play with, and many of the questions provide you with an opportunity to analyze "data" as you might in an actual laboratory setting.
- The **Cell Map** is based on many semesters of use by our students. It is designed to help you place the biochemical pathways that you are learning about into their proper cellular perspective. The Cell Map questions tell you what to include in your Map, but you can be creative!

Students have told us it is a great study aid, that really helped them to make the connections between the various pathways.

In our experience, this material can best be assimilated when it is discussed in a study group.

A study group is nothing more than two to four people who get together on a regular basis (weekly) to "speak biochemistry." This type of interaction is critical to fluency in a foreign language and is no less critical in the successful assimilation of biochemistry. We designed our Step-by-Step Guide to each chapter with study groups in mind. The questions posed for each section can be used as springboards for study group discussions. We purposefully have *not* supplied answers to this section to force you to wrestle with the concepts. It is the struggle that will make you learn the material. In addition, because most of the answers can be readily worked out by a careful reading of the section of the text, the questions will focus your attention on the more important aspects of the material.

Detailed **Solutions** *to all the end-of-chapter textbook problems are included as a separate section in the* Absolute, Ultimate Guide.

We have taken great care to ensure that the solutions are correct, complete, and informative. The final answer to numerical problems has been rounded off to reflect the number of significant figures in the data.

We thank each and every one of our students for their invaluable feedback and input, which have helped to make this study guide its absolute and ultimate best.

About the Authors

Karen Ocorr received her Ph.D. from Wesleyan University, where she studied the physiology and neurochemistry of the lobster cardiac ganglion. She was an NIH postdoctoral research fellow at the University of Texas, examining the roles of enzymes and second messengers in neuronal plasticity in *Aplysia californica*. She continued these investigations at the California Institute of Technology and Stanford University, examining the role of intracellular signaling underlying long-term potentiation in the vertebrate hippocampus. She taught Introductory Biochemistry for 10 years at the University of Michigan, Ann Arbor, where she also taught Animal Physiology, Cell Biology, and Introductory Biology for Non-Majors. Currently she is an Assistant Research Professor at the Sanford-Burnham Medical Research Institute in La Jolla, California, where she is researching the roles of K^+ channels in heart function and disease, and is a visiting Lecture Professor at Hunan Normal University in Changsha, China, where she teaches biochemistry.

Marcy Osgood received her Ph.D. from Rensselaer Polytechnic Institute. After two postdoctoral positions, she became an Assistant Professor in the Department of Physical Sciences at Albany College of Pharmacy, Union University. She was then a Lecturer in the Biology Department at the University of Michigan, Ann Arbor for nine years, where her research interests began to focus on educational issues. Her current position is as Associate Professor in the Department of Biochemistry and Molecular Biology and Assistant Dean of Undergraduate Medical Education at the University of New Mexico School of Medicine. Her current research efforts deal with assessment of problem-solving strategies.

Osgood and Ocorr have collaborated for 10 years to develop effective techniques for teaching biochemistry, all of which are based on educational research. This study guide is the result of these efforts and embodies much of what they have found to be effective over years of instruction at many levels and in many areas of the biological sciences. It includes thousands of discussion, quiz, and exam questions from their biochemistry courses. Osgood and Ocorr have been responsible for teaching biochemistry to more than 10,000 undergraduate students.

Study Guide

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chapter

1

The Foundations of Biochemistry

STEP-BY-STEP GUIDE

Major Concepts

All cells have common structural elements.

All cells are defined by a **plasma membrane,** which separates the contents of a cell from its surroundings and is a barrier to diffusion. All cells are divided into two major internal regions, the cytoplasm and a nuclear region. The **cytoplasm** contains soluble enzymes, metabolites, and cellular organelles. It is a very active and organized place, with constantly changing interactions occurring between its components. The contacts between biomolecules are primarily weak, noncovalent interactions, which collectively produce complex structure and functions. The **nuclear region** contains primarily DNA and associated proteins.

Cells can be classified according to the complement of cellular membranes and the complexity of the nuclear region.

There are two **domains** of single-celled microorganisms, **Bacteria** and **Archaea,** which differ in specific biochemical characteristics. **Eukaryotes** generally are larger than prokaryotes and include all protists, fungi, plants, and animals. The nuclear region of the single-celled organisms, the **nucleoid,** has no membrane to separate it from the rest of the cytoplasm. In addition, there are no other internal membranes and no internal **organelles.** Eukaryotic cells have plasma membranes as well as many membrane-bounded intracellular organelles and a membrane-bounded nucleus. Cells can be alternatively classified based upon their sources of energy and carbon.

Living matter is composed of low atomic weight elements.

Hydrogen, oxygen, nitrogen, and carbon are the most abundant elements in biomolecules. The bonding versatility of carbon makes it the most important and defining element in biochemical compounds. Most biomolecules are derivatives of hydrocarbons with a variety of attached functional groups. These functional groups determine the chemical behavior of biomolecules.

Biochemistry is three-dimensional.

In addition to the functional groups, the overall shape of a biomolecule greatly affects the types of interactions in which it can participate. Most biomolecules are asymmetric. Typically, only one of the possible (**chiral**) forms is found in living organisms. Interactions between many biomolecules (e.g., enzymes and their substrates) depend upon their ability to differentiate between **stereoisomers.**

Living organisms are interdependent; they exchange energy and matter with each other and the environment.

The sun is the ultimate source of (almost) all energy used by organisms. The **anabolic** reactions that use energy to form biological macromolecules and the **catabolic** reactions that liberate energy constitute the **metabolic pathways.** Most of these reactions require **enzymes** in order to proceed at useful rates; these biological catalysts lower the **activation energy.** Metabolic reactions can be linked through **ATP,** which can capture or release stored energy as needed by cells.

A thermodynamic system can be a single, simple chemical reaction or an entire organism.

The transfer of energy in a single reaction or in an organism can be described by three thermodynamic quantities: (Gibbs) **free energy, *G*; enthalpy, *H*; and entropy, *S*.** These quantities are related by the equation

$$\Delta G = \Delta H - (T\,\Delta S)$$

where T is the absolute temperature (in degrees Kelvin, or K). ΔG describes the change in free energy that occurs in a chemical reaction.

Reactions proceed spontaneously only if ΔG is negative, meaning energy is released by the reaction.
If ΔG is positive, the reaction requires an input of energy. Reactions are at equilibrium if $\Delta G = 0$.

The standard free-energy change, $\Delta G'^{\circ}$ is a physical constant and can be calculated from the equilibrium constant, K'_{eq}: $\Delta G'^{\circ} = -RT \ln K'_{eq}$.
For a system at equilibrium the rates of the forward and reverse reactions are equal; no further net change occurs in the system.

Information needed for the formation and function of all living organisms is contained in their genetic material, which is usually DNA.
The linear sequence of nucleotides in a strand of DNA provides information specifying the linear sequence of amino acids in all the proteins made by an organism. In turn, the complement of proteins determines the repertoire of metabolic reactions and functions that an organism can perform. (In some viruses, the genetic material is RNA.)

Biological systems have a hierarchy of structure.
A relatively small number of **monomeric** subunits are the building blocks used to construct macromolecules. Macromolecules can then be arranged into supramolecular complexes. Different classes of macromolecules have different roles in cells. For example, membranes (supramolecular complexes of lipids, proteins, and carbohydrates) define and compartmentalize cells, whereas chromosomes (supramolecular complexes of DNA and proteins) encode and store genetic information.

Biomolecules first arose by chemical evolution.
The conditions under which life arose on Earth cannot be absolutely determined, but chemical evolution can be simulated in the laboratory. Considering the simplicity of the chemical reactions that probably led to the formation of small biomolecules, and eventually to macromolecules, the evolution of life seems to be possible on other planets.

What to Review

Part of this chapter is a review of organic and inorganic chemical principles. You may find it helpful to consult a good inorganic or organic chemistry text for additional background information. Using this and other texts as sources, make sure that you thoroughly understand the following definitions and concepts.

- Covalent bonds and their relationship to the number of unpaired electrons.
- The significance of the atomic numbers.
- Stereoisomerism; chirality.
- Electronegativity.
- Nucleophilic and electrophilic centers in reactions.

Topics for Discussion

Answering each of the following questions, especially in the context of study group discussions, should help you understand the important points of the chapter.

1.1 Cellular Foundations

1. What distinguishes living organisms from inanimate objects?

Cells Are the Structural and Functional Units of All Living Organisms

2. Cellular dimensions are difficult to imagine on a human scale. To put cells into perspective it is helpful to magnify them. The following table shows the relative sizes of cells and their components magnified 10,000-fold (from micrometer to millimeter scale). A typical eukaryotic cell, when magnified 10,000-fold, is about the size of a large platter. Complete the table below with familiar objects that are approximately the sizes indicated and assemble them on a large serving platter.

Cell or Cellular Component	Size at 10,000 x (mm)	Equivalent Size Object
Ribosome	0.3	
Lysosome	10	
Flagellum, diameter	0.15	
Nucleoid	10	
Mitochondrion	5 x 30	
Prokaryotic cell	10–100	
Chloroplast	20 x 80	
Nucleus	100	
Eukaryotic cell	500 (50 cm)	Large serving platter

Cellular Dimensions Are Limited by Diffusion

3. What sets the lower limit of cell size? The upper limit?

There Are Three Distinct Domains of Life

4. Why are eukaryotes considered to be more closely related to the archaea than to bacteria?

Organisms Differ Widely in Their Sources of Energy and Biosynthetic Precursors

5. Why are cyanobacteria considered among the most self-sufficient groups of organisms?

Bacterial and Archael Cells Contain Thousands of Different Biomolecules Enclosed within a Sturdy Cell Envelope

6. What are the structural features of prokaryotes that distinguish them from eukaryotes, which are discussed in the next section of the text?

Eukaryotic Cells Have a Variety of Membranous Organelles, Which Can Be Isolated for Study

7. What might be an advantage of compartmentalization of cells?

8. What are the differing characteristics of organelles that allow researchers to separate and isolate them from one another?

The Cytoplasm Is Organized by Cytoskeleton and Is Highly Dynamic

9. What are the three classes of cytoskeletal proteins? What are the functions of the cytoskeleton?

10. How do the organelles and cytoskeleton interact?

Cells Build Supramolecular Structures

11. What are the bonds and/or interactions that are important at each of the three levels of cell structure?

In Vitro Studies May Overlook Important Interactions among Molecules

12. What are the advantages, and the disadvantages, of the in vitro approach to studying biomolecules?

1.2 Chemical Foundations

13. What are the four most common elements in living organisms?

14. What is the importance of trace elements to animal life?

Biomolecules Are Compounds of Carbon with a Variety of Functional Groups

15. What is meant by the "bonding versatility" of carbon?

16. What factors influence the strength, length, and rotation of carbon bonds?

17. Review the common families of functional groups or organic compounds that are encountered in biomolecules.

Cells Contain a Universal Set of Small Molecules

18. What is the definition of *metabolome*?

Macromolecules Are the Major Constituents of Cells

19. What are macromolecules and how are they categorized?

20. Proteins and nucleic acids are always considered **informational macromolecules,** while polysaccharides are not always considered so; why is this the case?

Three-Dimensional Structure Is Described by Configuration and Conformation

21. What are the three types of models that are used to represent the three-dimensional structure of molecules? What different kinds of information are provided by each type of model?

22. What is the difference between a diastereomer and an enantiomer?

Box 1–2 Louis Pasteur and Optical Activity: In Vino, Veritas

23. Use the structural formulas of Pasteur's two forms of tartaric acid to follow the description of RS nomenclature in the text.

24. How does the high potential energy of the eclipsed conformation affect the dynamics of ethane?

25. What are the advantages and disadvantages of the techniques of x-ray crystallography and NMR spectroscopy?

Interactions between Biomolecules Are Stereospecific

26. Why do cells produce only one form of a chiral compound rather than a racemic mixture?

1.3 Physical Foundations

Living Organisms Exist in a Dynamic Steady State, Never at Equilibrium with Their Surroundings

27. What is the difference between **dynamic steady state** and **equilibrium?** Make sure you understand these terms; the concepts will recur constantly throughout the text.

Organisms Transform Energy and Matter from Their Surroundings

28. Is it possible to design a closed system that incorporates living organisms? Why or why not?

The Flow of Electrons Provides Energy for Organisms

29. What happens (in terms of electron flow) to the reactant that is oxidized?

Creating and Maintaining Order Requires Work and Energy

30. What are the qualities that determine the free energy (G) in a system?

31. How are cells able to synthesize polymers if such reactions are thermodynamically unfavorable?

Energy Coupling Links Reactions in Biology

32. In terms of potential energy, energy transductions, and entropy, explain the following normal human daily activities: eating, moving, excreting. Where do the sun and ATP fit into this scheme?

Box 1–3 Entropy: Things Fall Apart

33. Does the oxidation of glucose represent an increase or decrease in entropy? Does it have a positive or negative ΔG?

K_{eq} *and* $\Delta G°$ *Quantify a Reaction's Tendency to Proceed Spontaneously*

34. What are the two ways of expressing a driving force on a reaction?

Enzymes Promote Sequences of Chemical Reactions

35. Why are enzymes essential in biochemical reactions?

36. How do enzymes overcome activation barriers?

37. Why is the option of increasing temperature to overcome these barriers *not* possible in living cells?

Metabolism Is Regulated to Achieve Balance and Economy

38. What would be the negative consequences to the cell of making too much of one metabolite?

1.4 Genetic Foundations

Genetic Continuity Is Vested in Single DNA Molecules

39. Why can we not describe the "average" behavior of a DNA molecule?

The Structure of DNA Allows for Its Replication and Repair with Near-Perfect Fidelity

40. How do complementary strands assure continuity of information?

The Linear Sequence in DNA Encodes Proteins with Three-Dimensional Structures

41. How are the instructions contained in the linear sequence of DNA translated into a three-dimensional enzyme or structural protein?

42. What forces contribute to the three-dimensional structure?

1.5 Evolutionary Foundations

Changes in the Hereditary Instructions Allow Evolution

43. How can a change in the DNA instructions affect the final form of a protein?

Biomolecules First Arose by Chemical Evolution

44. Under what environmental conditions are the first biomolecules thought to have been formed?

45. What energy sources may have been available to drive prebiotic evolution?

RNA or Related Precursors May Have Been the First Genes and Catalysts

46. What are the lines of evidence suggesting that RNA or a similar molecule was both the first gene and the first catalyst?

Biological Evolution Began More Than Three and a Half Billion Years Ago

47. How might it be possible to determine if a fossil carbon compound were of biological origin?

The First Cell Probably Used Inorganic Fuels

48. Why is it likely that autotrophs evolved only after the appearance of heterotrophs?

Eukaryotic Cells Evolved from Simple Precursors in Several Stages

49. How are nuclei thought to have evolved?

Molecular Anatomy Reveals Evolutionary Relationships

50. Compare the definitions of *homologs, paralogs,* and *orthologs.*

Functional Genomics Shows the Allocations of Genes to Specific Cellular Processes

51. What is the difference between *E. coli* and *H. sapiens* in terms of percentage of genes devoted to membrane transporters?

Genomic Comparisons Have Increasing Importance in Human Biology and Medicine

52. What would you predict would be the difference between a chimpanzee and *H. sapiens* in terms of percentage of genes devoted to membrane transporters?