Problems Book and Study Guide

Cell and Molecular Biology

Concepts and Experiments

Gerald Karp

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PROBLEMS BOOK AND STUDY GUIDE

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JOHN WILEY & SONS, INC.
New York • Chichester • Brisbane • Toronto • Singapore

ISBN 0-471-14287-5

Printed in the United States of America

10 9 8 7 6 5 4 3

TO THE STUDENT

This companion to *Cell Biology: Concepts and Experiments* by Gerald Karp, like the textbook, is about learning by doing and learning by seeing what others have done. We want to challenge you to apply the concepts you read about in the text, and to stretch your imagination in ways that memorization cannot do. To do that, I have written a workbook that asks you to apply the principles presented in your text to novel situations, and even derive new concepts from those you've learned from your reading. You will find that this type of conceptual learning is more challenging than memorization– and more rewarding.

How to Use This Study Guide

After you've read each chapter of the text, remind yourself of the content using the outline called **Reviewing the Chapter**. You can glance only at the major headings in bold type, or allow your eye to take in more detail by reading subheadings. One of my favorite ways of testing my understanding of a concept is to try to explain it to a friend. Practice explaining each of the **Learning Objectives** to someone, anticipating their questions. Can you answer them? If not, go back to the book or to the outline in **Reviewing the Chapter**.

Next, glance down the list of **Key Terms and Phrases**. They are arranged roughly in the order in which they are presented in the chapters so related terms will be close together. Do the terms conjure up mental images or ideas? If not, better check the text or **Reviewing the Chapter**.

The **Key Figure** was chosen from the text to represent an important concept from each chapter. Use the **Questions for Thought** as a catalyst for discussion with a classmate, your professor, or teaching assistant, or just to ponder on your own.

Now get out your calculator and sharpen your pencils, you are ready to tackle the **Review Problems**. If you consistently find that your answers to the Short Answer section exceed the space that is allotted, perhaps you need to rethink your approach. Remember that a few carefully constructed, concise phrases are better than long-winded explanations in most cases. Some of the Multiple Choice questions are simple recall questions. Others will make you think. Lastly, the Problems and Essays will ask you to articulate clear, scientific explanations, interpret data, design experiments, or solve problems relating to each chapter. Do your calculations right in the book and don't cheat! Give yourself ample opportunity to find the answers on your own before looking in the **Appendix**.

Remember that your most important learning resource is not a study guide, a textbook, or even your professor. Your most important resource is YOU! Commit a certain number of hours every day to the study of cell biology; *don't* let yourself get behind. This study guide, the *Cell Biology* textbook, your professor, and all the resources at your university are there to help *you* to take charge of your education.

Acknowledgments

Many thanks to Olga Naidenko and Mark Baustian for their help in outlining the chapters. My friend Marilyn Graber did a superb job finding my errors. Any that remain are entirely my responsibility. Gerry Karp, whose earlier *Cell Biology* textbook sparked my interest as a student, provided a wonderful book from which to work and much encouragement while I prepared this study guide. Finally, Jonathan, Nathan, and Danny fended for themselves many evenings and weekends, allowing me the time to write this book. To them, I am most grateful of all.

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CHAPTER ONE

Introduction to the Study of Cell Biology

Learning Objectives

When you have finished this chapter, you should be able to:

1. Give a brief history of ideas about the cellular nature of life.
2. List the basic properties of cells.
3. Distinguish between prokaryotic and eukaryotic cells, and describe the characteristics of each, including:
   a. the major subkingdoms of prokaryotic cells.
   b. the process of differentiation and specialization in eukaryotes, including examples.
4. Appreciate the relative sizes of cells and their components, and the factors that limit the size of cells.
5. Understand the nature of viruses, their origins, and their mechanisms of infection.
6. Become familiar with other noncellular pathogens, including virions and prions.

Key Terms and Phrases

Robert Hooke	Anton van Leeuwenhoek	cell theory
George Gey	Schleiden, Schwann and Virchow	HeLa cells
ATP	metabolism	Hans Driesch
organelles	prokaryote	eukaryote
cell wall	cell surface receptors	nucleoid
nucleus	nuclear envelope	mesosomes
mitochondria	endoplasmic reticulum	Golgi complex
chloroplast	cytoskeleton	ribosome
bacterial conjugation	flagella	Archaebacteria
Eubacteria	methanogens	halophile
thermoacidophile	mycoplasma	cyanobacteria
nitrogen fixation	Dictyostelium	differentiation
micrometer	nanometer	virus
virion	Wendell Stanley	capsid
provirus	viroid	prion

Reviewing the Chapter

I. Introduction

A. Cells are the topic of intense study.
B. The study of cells requires creative instruments and techniques.
C. The study of cells lies on a spectrum of human endeavor, from subatomic physics to astronomy.

II. The Discovery of Cells

A. The discovery of cells followed from the invention of the microscope by Robert Hooke, and its refinement by Anton van Leeuwenhoek.
B. Cell theory was articulated in the mid-1800s by Schleiden, Schwann and Virchow.
    1. All organisms are composed of one or more cells.
    2. The cell is the structural unit of life.
    3. Cells arise from preexisting cells by division.

III. Basic Properties of Cells.

A. Life is the most basic property of cells.
B. Cells can grow and reproduce in culture for extended periods.
    1. HeLa cells are cultuired tumor cells isolated from a cancer patient named Henrietta Lacks by George Gey in 1951.
    2. Cultured cells, including HeLa cells, are an essential tool of cell biologists.
C. Cells are highly complex and organized.
    1. Cellular processes are highly regulated.
    2. Cells from different sources share similar structure, composition and metabolic features.
D. Cells have a genetic program.
    1. Genes encode information to build each cell, and the organism.
    2. Genes encode information for cellular reproduction.
E. Cells reproduce, and each daughter cell receives a complete set of genetic instructions.
F. Cells acquire and utilize energy.
    1. Photosynthesis provides fuel for all living organisms.
    2. Animal cells derive energy from the products of photosynthesis, often in the form of glucose.
    3. Cells can convert glucose into ATP— a substance with readily available energy.
G. Cells engage in numerous mechanical activities, including locomotion.
H. Cells are able to respond to stimuli via surface receptors that sense changes in the chemical environment.
I. Cells are capable of self-regulation.

IV. Two Fundamentally Different Classes of Cells

A. Prokaryotes are all bacteria. They arose 3.5 billion years ago.
B. Eukaryotes are protists, fungi, plants and animals. The first eukaryotes arose 1.5 billion years ago.
C. Characteristics that distinguish prokaryotic and eukaryotic cells:
    1. Complexity: Prokaryotes are relatively simple; eukaryotes are more complex.
    2. Genetic material:
        a. Packaging: Prokaryotes have a nucleoid region whereas eukaryotes have a true, membrane-bound nucleus.
        b. Amount: Eukaryotes have several orders of magnitude more genetic material than prokaryotes.
        c. Form: Eukaryotes have many chromosomes that are made of both DNA and protein whereas prokaryotes have a single DNA chromosome.
    3. Cytoplasm: Eukaryotes have membrane-bound organelles and cytoskeletal proteins; prokaryotes have neither. Both have ribosomes, although they differ in size.
    4. Cellular reproduction: Eukaryotes divide by mitosis; prokaryotes divide by simple fission.
    5. Locomotion: Eukaryotes use both cytoplasmic movement, and cilia and flagella; prokaryotes have flagella, but they differ in both form and mechanism from eukaryotic flagella.

V. Types of Prokaryotic Cells: Two Subkingdoms

A. Subkingdom Archaebacteria:
   1. Methanogens
   2. Halophiles
   3. Thermoacidophiles

B. Subkingdom Eubacteria:
   1. Includes the smallest known cells— the mycoplasma.
   2. Includes cyanobacteria— the photosynthetic bacteria that gave rise to green plants and an oxygen-rich atmosphere. Some cyanobacteria are nitrogen fixers, making nitrogen available for use by other organisms.

VI. Types of Eukaryotic Cells: Cell Specialization

A. Unicellular eukaryotes are complex single-celled organisms.

B. Multicellular eukaryotes have different cell types for different functions.
   1. The slime mold Dictyostelium is an example of unspecialized cells becoming specialized via differentiation during the life cycle.
   2. Differentiation occurs during embryonic development in other multicellular organisms.
   3. Numbers and arrangements of organelles relate to the function of the cell.
   4. Despite cellular differentiation, eukaryotic cells have many features in common.

VII. The Size of Cells and Their Components

A. Cells are commonly measured in units of micrometers (1 $\mu m = 10^{-6}$ meter) and nanometers (1 $nm = 10^{-9}$ meter).

B. Cells are typically small; cell size is limited:
   1. by the volume of cytoplasm that can be supported by the genes in the nucleus.
   2. by the volume of cytoplasm that can be supported by exchange of nutrients across a limited surface area, i.e., the surface area/volume ratio.
   3. by the distance over which substances can efficiently travel through the cytoplasm via diffusion.

VIII. Viruses

A. Viruses are pathogens first described in the late 1800s.

B. Viruses are obligatory intracellular parasites.

C. A virion is a virus particle outside the host cell.

D. Viral structure:
   1. The genetic material can be single- or double-stranded DNA or RNA.
   2. The protein capsid surrounds the genetic material in the virion.
   3. The capsid may be polyhedral in some viruses.
   4. A lipid envelope may surround the capsid in some viruses; the lipids may contain viral proteins.

E. Virus and host:
   1. Viruses have surface proteins that bind to the surface of the host cell.
   2. Viral specificity for a certain host is determined by the virus's surface proteins.

F. Viruses are not considered living.

G. Viral infection types:
   1. Lytic infection— the virus redirects the host into making more virus particles, the host cell ruptures and releases the viruses.
   2. Integrated infection— the virus integrates its DNA (called the provirus) into the host cell's chromosomes.
      a. The infected host may behave normally until an external stimulus activates the provirus, leading to lysis and release of viral progeny.
      b. The host may give rise to viral progeny by bidding, as in HIV.
      c. The host may become malignant.

H. Viral origins:
    1. Viruses had to arise after their hosts evolved— they cannot survive without their hosts.
    2. Viruses probably arose as fragments of host chromosomes that became somewhat autonomous.

I. Viruses are good models for studying mechanisms of genetic expression, and good vectors for introducing foreign genes into cells.

IX. Viroids

A. Viroids are pathogens, each consisting of a small, naked RNA molecule.

B. Viroids cause disease by interfering with gene expression in host cells.

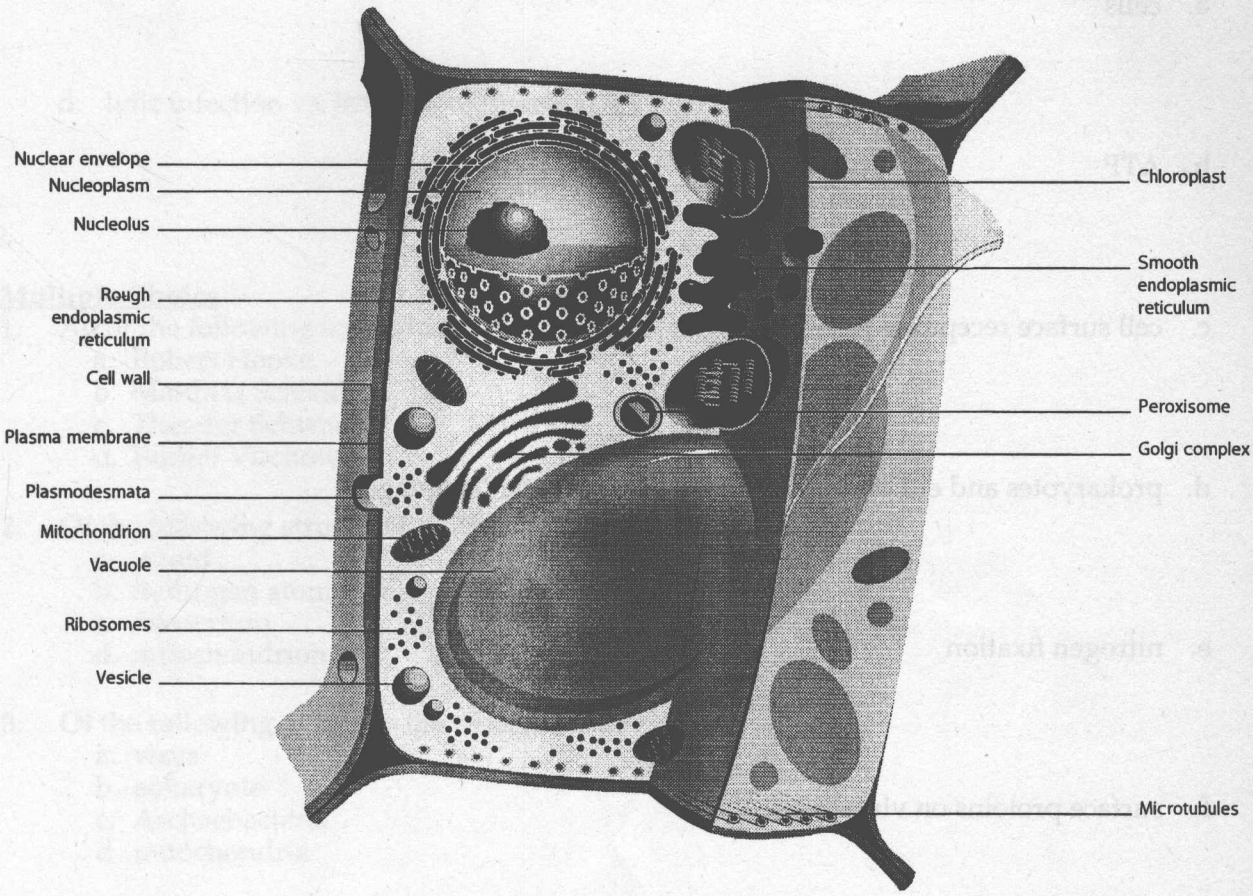
X. Prions (Experimental Pathways)

A. New evidence links two degenerative brain diseases to single proteins called prions (proteinaceous infectious particles).

B. The mechanism of infection by a protein is not well understood, and somewhat controversial.

Key Figure

Figure 1.9. The structure of cells.



Questions for Thought:

1. What structures immediately identify this as a plant cell?

2. What structures shown here do plant cells, animal cells and prokaryotic cells have in common?

3. What is the largest intracellular structure in the plant cell? The animal cell? The bacterial cell?

4. This is a "generalized" cell, shown to give you an overview of what kinds of structures occur in this cell type. How might the numbers of the different organelles differ in cells with specific functions?

Review Problems

Short Answer

1. Give the significance (not the definition) of the following terms or phrases. Say what they do or why they are important. For example:
   photosynthesis: *ultimate source of energy supporting all life on Earth.*

   a. cells

   b. ATP

   c. cell surface receptors

   d. prokaryotes and eukaryotes share the same genetic "language"

   e. nitrogen fixation

   f. surface proteins on viruses

   g. genetic similarity between genes of viruses and their hosts

   h. life cycle of Dictyostelium

2. Compare and contrast the following:
   a. prokaryote vs. eukaryote

b. endoplasmic reticulum vs. mesosomes

c. virus vs. virion

d. lytic infection vs. integrative infection

Multiple Choice

1. All of the following individuals contributed to cell theory except:
   a. Robert Hooke.
   b. Matthias Schleiden.
   c. Theodor Schwann.
   d. Rudolf Virchow.

2. Of the following structures, which is the smallest?
   a. viroid
   b. hydrogen atom
   c. bacterium
   d. mitochondrion

3. Of the following, which is the most primitive?
   a. virus
   b. eukaryote
   c. Archaebacteria
   d. mitochondria

4. Cell theory includes all of the following except:
   a. All organisms are composed of one or more cells.
   b. The cell is the most primitive form of life.
   c. The cell is the structural unit of life.
   d. Cells arise by division of preexisting cells.

5. All of the following are basic properties of cells except:
   a. Cells have nuclei and mitochondria.
   b. Cells have a genetic program and the means to use it.
   c. Cells are capable of producing more of themselves.
   d. Cells are able to respond to stimuli.

6. The Archaebacteria include all of the following except:
   a. methanogens.
   b. halophiles.
   c. thermoacidophiles.
   d. cyanobacteria.

7. Evolutionary relationships between groups of organisms are determined using which of the following types of information?
   a. comparisons of nucleotide sequences
   b. comparisons of biochemical pathways
   c. comparisons of structural features
   d. all of the above

8. All of the following are features of prokaryotes except:
   a. nitrogen fixation.
   b. photosynthesis.
   c. sexual reproduction.
   d. locomotion.

9. Which of the following may account for the small size of cells?
   a. the rate of diffusion
   b. the surface area/volume ratio
   c. the number of mRNAs that can be produced by the nucleus
   d. all of the above

10. Which of the following statements is not true of viruses:
    a. Viruses have been successfully grown in pure cultures in test tubes.
    b. All viruses are obligatory intracellular parasites.
    c. All viruses have either DNA or RNA as their genetic material.
    d. Viruses probably arose from small fragments of cellular chromosomes.

11. If you were to study the sequences of nucleic acids in a variety of viruses and viral hosts, you would probably find more similarities:
    a. among different viruses than between viruses and their hosts.
    b. among different viral hosts than among different viruses.
    c. among different viral hosts than between viruses and their hosts.
    d. between viruses and their hosts than among different viruses.

Problems and Essays

1. Mitochondria and chloroplasts can be isolated from broken cells and, given the proper nutrients, can undergo respiration and photosynthesis in a test tube for several hours. Why, then, are these organelles not considered the basic unit of life?

2. Given that all the cells of the slime mold Dictyostelium have identical genetic information, why do some develop into stalk cells and others into spore cells?

3. Given that cell structure reflects cell function, what structural features would you predict in the following?
   a. cells that line the digestive tract and take up nutrients across the wall of the intestine into the blood

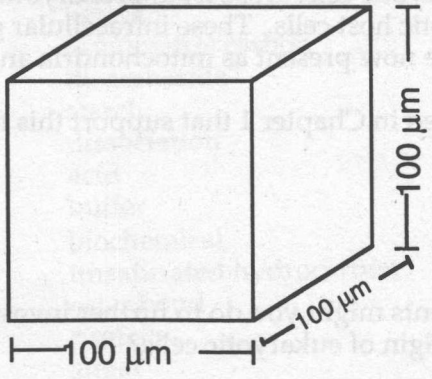
   b. cells that synthesize and secrete protein, such as an insulin-producing cell from the pancreas or an antibody-producing lymphocyte

   c. a leaf cell

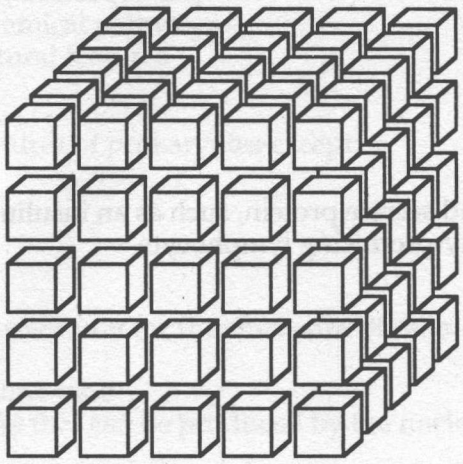
   d. a contractile cell, such as a muscle cell

4. Of viruses that infect bacteria or viruses that infect humans, which type is older and why?

5. Consider a large, roughly cuboidal cell that measures 100 μm on a side.
   a. What is its surface area/volume ratio?



b. Assume that a cell requires a surface area/volume ratio of at least 3 to survive. Would dividing this cell into 125 cells which together had a volume of 1,000,000 μm3 ensure survival?



6. Given that some antibiotic drugs kill pathogens by interfering with replication of bacterial chromosomes, why can't we use these drugs to cure the common cold?

7. Why does the HIV virus lack genes for synthesizing its own lipid envelope?

8. What biochemical evidence could be used to show that modern green plants evolved from cyanobacterial ancestors and not from other photosynthetic prokaryotes?

9. Biologists believe that eukaryotic cells arose from prokaryotic ancestors that took up residence in other prokaryotic host cells. These intracellular guests eventually lost the ability to live on their own, and are now present as mitochondria and chloroplasts in modern eukaryotes.
   a. Find three facts presented in Chapter 1 that support this theory of eukaryotic origins.

   b. What kinds of experiments might you do to further investigate whether this explanation could account for the origin of eukaryotic cells?

CHAPTER TWO

The Chemical Basis of Life

Learning Objectives

When you have finished this chapter, you should be able to:

1. Explain why an understanding of chemistry is essential to the study of cell biology.
2. Describe the nature of covalent bonds, and why some bonds have unequal distributions of electrical charge.
3. Identify polar and nonpolar molecules, and understand the consequences of polarity in cellular molecules.
4. List the types of weak bonds and explain why they are important in cells.
5. Explain why water is ideally suited to life.
6. Define and understand the importance of pH in cells.
7. List the four cellular macromolecules and their building blocks. Describe how the building blocks are assembled into macromolecules.
8. Describe the levels of protein structure, and the factors that determine the structure of proteins in cells.
9. Give examples of some important cellular proteins.
10. Recognize some of the potential of biotechnology– and some of the dangers.

Key Terms and Phrases

molecule
electronegativity
ionization
free radical
hydrogen bond (H-bond)
van der Waals forces
carbonyl group
stereoisomer (enantiomer)
glycosidic bond
glycogen
amylopectin
amphoteric
K_W
inorganic molecule
saturated hydrocarbon
functional group
macromolecule
polysaccharide
monomer
cellulose
cellulase
compound
polar
anion
weak bond
hydrophilic
metabolic intermediate
ketose
asymmetric carbon
disaccharide
starch
dissociation
acid
buffer
biochemical
unsaturated hydrocarbon
ester bond
protein
sugar
nucleic acid
chitin
lipid
covalent bond
nonpolar
cation
ionic bond
hydrophobic
carbohydrate
aldose
pyranose
oligosaccharide
amylose
pH
base
organic molecule
hydrocarbon
structural isomer
amide bond
amino acid
polymer
nucleotide
glycosaminoglycan
fatty acid