CELL AND MOLECULAR BIOLOGY

CONCEPTS AND EXPERIMENTS

FOURTH EDITION

GERALD KARP

NANCY L. PRUITT

PROBLEMS BOOK AND STUDY GUIDE

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Colgate University

to accompany

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Concepts and Experiments

Fourth Edition

Gerald Karp

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To the Student

The astonishing pace at which new discoveries are being made in the fields of cell and molecular biology can be intimidating. You might ask yourself how the facts you learn in your cell biology course this year will look next year or a few years down the road. Will our understanding of cancer be the same? What new findings in cellular immunology will be made before I graduate from college? The best way to arm yourself against the obsolescence of facts is to construct your knowledge not around the details, but around concepts—the big ideas that form the scaffolding on which to hang the finer points. That way, when the facts grow or change, you will have the tools to integrate those changes into your understanding of the field. No doubt you will need to learn *some* facts, but to build lasting knowledge and become a life-long learner takes much more than memorization. You will need to develop your problem-solving skills using creating thinking; you will need to apply what you learn to novel situations; you will need to assess the value of various kinds of information, and the methods used to obtain it. That is what this workbook can help you to do. This kind of learning is more challenging than memorizing facts, but the extra effort is worth the trouble. The long term results are far more rewarding.

Here are some suggestions about how to get the most from and do well in your cell and molecular biology course: First, commit a certain number of hours each day to the study of cell and molecular biology. Do not let yourself get behind! Read each chapter of the text, then review the content using the outlines in this book 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 own understanding of a concept is to try explaining it to a friend. Practice explaining each of the **Learning Objectives**, anticipating questions. Can you answer them? If not, go back to the book or to the outline in **Reviewing the Chapter**.

Next, glance through the list of **Key Terms and Phrases**. They are arranged roughly in the order in which they appear 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 again, or **Reviewing the Chapter**.

Each chapter's **Key Figure** was selected to represent an important concept from the 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**. Try to answer the short answer questions in just a few carefully chosen words or phrases. If you consistently find that your answers take up more than the allotted space, perhaps you need to rethink your approach. Some of the multiple choice questions are simple recall, but others will ask you to take your knowledge one step further. Lastly, the **Problems and Essays** will require you to provide scientific explanations, interpret data, design experiments, or solve problems relating to the concepts in the chapter. Do your calculations right in the book, and don't cheat! Give yourself ample opportunity to work through to the answers on your own before looking in the **Appendix**.

Remember: The best professor, the best textbook, even the best study guide in the world cannot teach you unless you are committed to learning. Be an active participant in your own education.

Acknowledgments

I am privileged to teach cell and molecular biology to some of the finest students in the country, at Colgate University. Many of them have gone on to assume leadership roles in the field, and I hope I have played some small part in their success. I know my students play an important part in keeping me thinking about cell biology in new and productive ways, and I am grateful to them all—past and present.

I am also grateful to Project Editor Geraldine Osnato at John Wiley and Sons, who cheerfully answered my questions and ensured that I had the resources I needed.

A special thanks to my family, Jonathan, Nathan, and Danny, who made time for me when I needed time to work, made room for me to spread the chapters out all over the house, and made everything worthwhile for me in the end.

TABLE OF CONTENTS

1 Introduction to the Study of Cell and Molecular 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 domains 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. Describe some other noncellular pathogens, including virions and prions.
7. Become familiar with the theory and evidence that eukaryotic cells arose from an endosymbiotic relationship between prokaryotic ancestors.

Key Terms and Phrases

Robert Hooke
HeLa cells
metabolism
eukaryote
nucleus
mitochondria
cytoskeleton
Eucarya
methanogens
cyanobacteria
differentiation
virus
provirus
endosymbiont theory
lateral gene transfer
Anton van Leeuwenhoek
Schleiden, Schwann and Virchow
organelles
cell wall
nuclear envelope
endoplasmic reticulum
ribosome
Eubacteria
halophile
nitrogen fixation
micrometer
virion
viroid
Lynn Margulis
cell theory
ATP
prokaryote
cell surface receptors
nucleoid
chloroplast
bacterial conjugation
Archaea
thermoacidophile
Dictyostelium
nanometer
capsid
prion
Woese and Fox

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 cultured 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 species share similar structure, composition and metabolic features that have been conserved throughout evolution.
- D. Cells have a genetic program.
  1. Genes encode information to build each cell, and the organism.
  2. Genes encode information for cellular reproduction, activity, and structure.
- 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.
  4. Cells perform chemical reactions catalyzed by enzymes.
     (a) Chemical reactions occur in sequences.
     (b) Enzymes increase the rate of cellular chemical reactions.
  5. Metabolism is the sum of all cellular chemical reactions.
- G. Cells engage in numerous mechanical activities, including locomotion.
- H. Cells are able to respond to stimuli using 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 more than 3.7 billion years ago.
- B. Eukaryotes are protists, fungi, plants and animals. The first eukaryotes arose 1.6 billion years ago.
- C. Characteristics that distinguish prokaryotic and eukaryotic cells:
  1. Complexity: Prokaryotes are relatively simple; eukaryotes are more complex in structure and function.
  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, circular DNA chromosome.

3. Cytoplasm: Eukaryotes have membrane-bound organelles and complex cytoskeletal proteins; prokaryotic cytoplasm is devoid of membranous structures and contains primitive cytoskeletal filaments. 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 Domains

A. Domain Archaea:
1. Methanogens
2. Halophiles
3. Acidophiles
4. Thermophiles

B. Domain Bacteria:
1. Includes the smallest known cells— the mycoplasma.
2. Includes cyanobacteria— some photosynthetic bacteria
a. Cyanobacteria gave rise to green plants and an oxygen-rich atmosphere.
b. Some cyanobacteria are nitrogen fixers.

C. Prokaryotic Diversity
1. Prokaryotes are identified and classified on the basis of specific DNA sequences.
2. Recent evidence indicates that prokaryotes are more diverse and numerous than previously imagined.

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.
5. Model Organisms:
a. Cell research focuses on five model organisms.
b. These are the yeast *Saccharomyces*, the mustard plant *Arabidopsis*, the nematode *Caenorhabditis elegans*, the fruit fly *Drosophila* and the mouse *Mus*.

VII. The Human Perspective: The Prospect for Cell Replacement Therapy

A. Stem cells are undifferentiated cells capable of self-renewal and differentiation.
1. Adult stem cells can be used to replace damaged or diseased adult tissue.
a. Hematopoietic stem cells can produce blood cells in bone marrow.
b. Neural stem cells may be used to treat neurodegenerative diseases.

2. Embryonic stem (ES) cells have even greater potential for differentiation than adult stem cells.
    a. ES cells must be differentiated in vitro, lest they cause cancer.
    b. The use of ES cells involves ethical considerations.

B. Organ replacement in the future may involve growing organs from stem cells.
1. Organs must be grown on inert scaffolding in the laboratory.
2. Stem cells used for organ regeneration must be compatible with the recipient's immune system.
3. Growing organs for transplant is still experimental.

VIII. The Size of Cells and Their Components

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

IX. 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.
J. The journey of viruses through living cells has recently been studied using fluoescent molecules.

X. Viroids

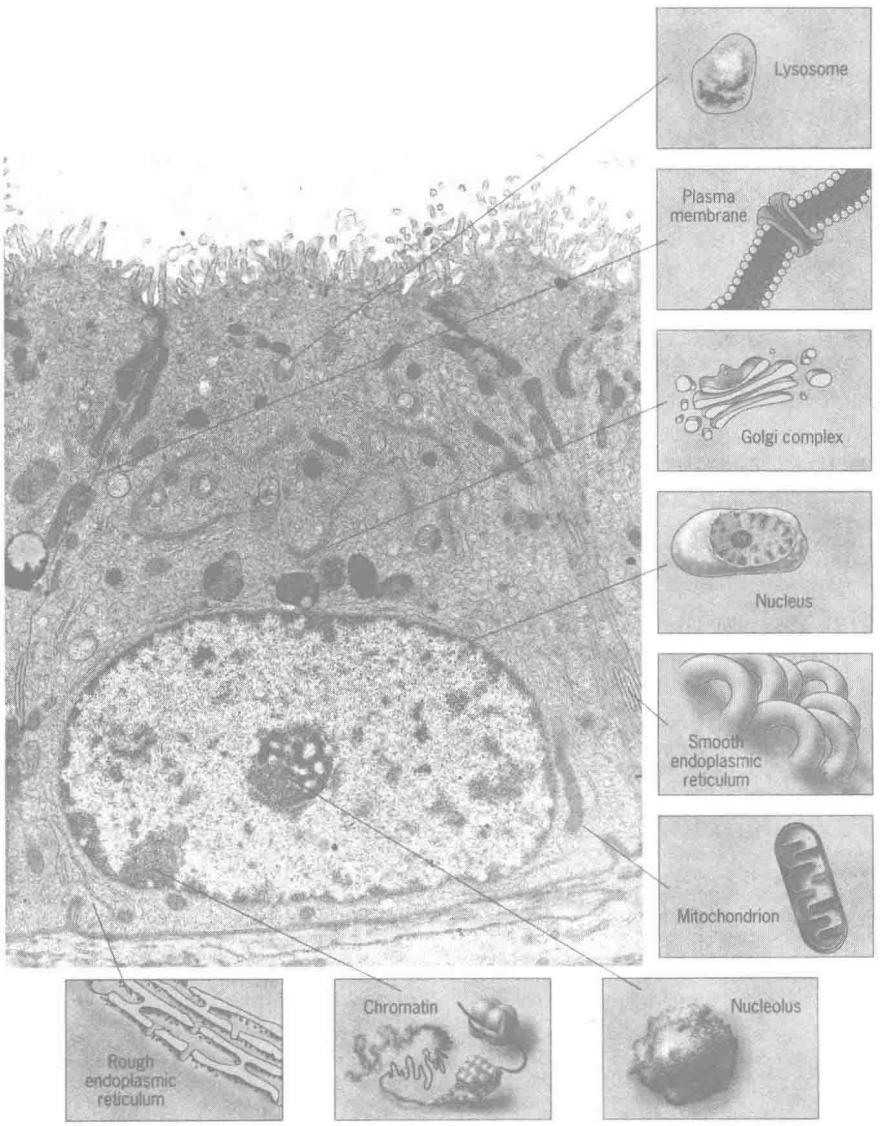
A. Viroids are pathogens, each consisting of a small, naked RNA molecule.
B. Viroids cause disease by interfering with gene expression in host cells.

XI. Experimental Pathways: The Origin of Eukaryotic Cells

A. Prokaryotic cells arose first and gave rise to eukaryotic cells.
B. Endosymbiont Theory: organelles in eukaryotic cells (mitochondria and chloroplasts) evolved from smaller prokaryotic cells.
C. Evidence to support the Endosymbiont theory
    1. Absence of eukaryote species with organelles in an intermediate stage of evolution.
    2. Many symbiotic relations are known among different organisms.
    3. Organelles of eukaryotic cells contain their own DNA and the machinery to synthesize proteins.
    4. The nucleotide sequences of rRNAs from eukaryotic organelles resembled that of prokaryotes.
    5. Organelles duplicate independently of the cell nucleus.
D. New ideas about the origin of eukaryotic cells have emerged from studies of genomes.
    1. Based on nucleotide sequences of single genes, Carl Woese proposed three major cell lineages.
        a. Bacteria include gram positive, gram negative and cyanobacteria.
        b. Archaea include halophiles, thermophiles, methangens and acidophiles.
        c. Eucarya include plants, animals, fungi and protists.
    2. Based on whole genomes, many organisms appear to be genetic mosaics.
        a. Lateral gene transfer results in organisms with both parental DNA and DNA from other organisms in the environment.
        b. Bacteria and Eucarya show evidence of lateral gene transfer in their genomes.

Key Figure

Figure 1.11. The structure of a eukaryotic cell.



Questions for Thought:

1. Is this a plant cell or an animal cell? What structures identify it as such?
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 an epithelial 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. model organisms

   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*

   i. bacterial conjugation

2. Compare and contrast the following:

   a. prokaryote vs. eukaryote

   b. virus vs. virion

   c. lytic infection vs. integrative infection

   d. Bacteria vs. Archaea

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. Archaeon
   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 Archaea 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.

12. Bone marrow transplants are to blood transfusions as organ engineering is to _?_ .
    a. organ transplant.
    b. organ transfusion.
    c. bone marrow transfusions.
    d. stem cell growth.

13. The *most* powerful tool for determining evolutionary relationships among cell types is
    a. the study of cell shape.
    b. the study of organelle shape.
    c. the study of amino acid sequences in proteins.
    d. the study of nucleic acid sequences in genomes.

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

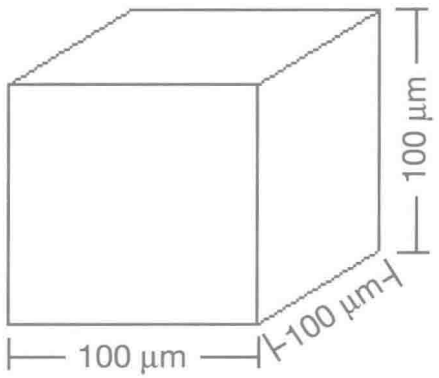
   b. cells that synthesize and secrete protein, such as an insulin-producing cell from the pancreas or an antibody-producing lymphocyte

   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?