

2

CELLS AND CELL DIVISION

CHAPTER OUTLINE

THE CHEMISTRY OF CELLS

CELL STRUCTURE REFLECTS FUNCTION

There are two cellular domains: the plasma membrane and the cytoplasm.

Organelles are specialized structures in the cytoplasm.

The endoplasmic reticulum folds, sorts, and ships proteins.

Molecular sorting takes place in the Golgi complex.

Lysosomes are cytoplasmic disposal sites.

Mitochondria are sites of energy conversion

Nucleus.

THE CELL CYCLE DESCRIBES THE LIFE

HISTORY OF A CELL

Interphase has three stages.

Cell division by mitosis occurs in four stages.

Cytokinesis divides the cytoplasm

MITOSIS IS ESSENTIAL FOR GROWTH

AND CELL REPLACEMENT

CELL DIVISION BY MEIOSIS: THE BASIS OF SEX

Meiosis I reduces the chromosome number.

Meiosis II begins with haploid cells.

Meiosis produces new combinations of genes in two ways.

FORMATION OF GAMETES

SPOTLIGHT ON . . . A Fatal Membrane Flaw

SPOTLIGHT ON . . . Cell Division and Spinal Cord Injuries

CHAPTER SUMMARY

The basic information contained in this chapter is normally covered in an introductory biology course, and is included here to serve as a review and a foundation for later chapters. However, the opening vignette establishes a direct link between cell structure/function and genetic disease, a theme maintained throughout the chapter. The major types of biochemicals are described, followed by a summary of cell organelles that ends with a description of the nucleus and its chromosome content.

This is followed by a section on the cell cycle, which outlines the three parts of the cycle and the three stages of interphase. It emphasizes the differences between cell cycles of different cell types. The information on cell division specifically underlies the account of Mendelian genetics that follows in chapter 3. Mitosis is introduced as a way of understanding the behavior of chromosomes in the cell cycle. A detailed presentation of mitosis is followed by a section on its significance, including an introduction to the interesting topic of the Hayflick limit on cell

division. This section includes evidence that mitosis and the cell cycle are under genetic control by introducing premature aging syndromes and cancer.

The key part of the chapter is concerned with the behavior of chromosomes in meiosis. Emphasis is placed on the specific purposes of meiosis I and meiosis II and the centrality of meiosis to sexual reproduction. To this end, details such as the stages of prophase I and tetrad terminology are omitted. This is followed by a section describing how meiosis produces novel gene combinations by random assortment of maternal and paternal chromosomes and by crossing over. These points are illustrated in two very helpful figures. The section on meiosis is accompanied by detailed illustrations emphasizing chromosome movements and how they differ from mitosis, and random chromosome assortment. It is difficult to overstate how important it is for the student to achieve a clear understanding of the events in meiosis to provide the foundation for an understanding of the physical basis of Mendelian genetics. The chapter ends with a description of gamete formation. Similarities and differences between oogenesis and spermatogenesis are presented in text and illustration and summarized in a table.

TEACHING/LEARNING OBJECTIVES

This chapter introduces the student to the concept that cells are the basic building blocks of all organisms, including humans, that they are all made of similar biochemicals and contain similar parts. Discrete structures within cells, known as chromosomes, are the cellular structures within which genes reside. The concepts of mitosis and meiosis as mechanisms of cell growth and organismic reproduction are detailed. An understanding of meiosis is essential for the student to comprehend the physical basis of genetic phenomena, such as segregation and independent assortment that will be covered in the next chapter. By the completion of this chapter, the student should have an understanding of:

- a. The chemical building blocks of all organisms
- b. The structure and organization of cells in higher organisms
- c. Chromosomes as cellular organelles that carry genetic information
- d. Mitosis and the cell cycle
- e. The significance of mitosis and the genetic control of the cell cycle
- f. The process of meiosis – generation of haploid cells and the production of genetic variety among gametes
- g. The similarities and differences between spermatogenesis and oogenesis

TERMS DEFINED IN THIS CHAPTER

- **Macromolecules:** Large cellular polymers assembled by chemically linking monomers together.
- **Carbohydrates:** Macromolecules including sugars, glycogen, and starches composed of sugar monomers linked and cross-linked together.

- **Lipids:** A class of cellular macromolecules including fats and oils that is insoluble in water.
- **Proteins:** A class of cellular macromolecules composed of amino acid monomers linked together.
- **Nucleic acids:** A class of cellular macromolecules composed of nucleotide monomers linked together. There are two types of nucleic acids, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), which differ in the structure of the monomers.
- **Molecules:** Structures composed of two or more atoms held together by chemical bonds.
- **Organelles:** Cytoplasmic structures that have specialized functions.
- **Endoplasmic reticulum (ER):** A system of cytoplasmic membranes arranged into sheets and channels whose function it is to synthesize and transport gene products.
- **Ribosomes:** Cytoplasmic particles that aid in the production of proteins.
- **Golgi complex:** Membranous organelles composed of a series of flattened sacs. They sort, modify, and package proteins synthesized in the ER.
- **Lysosomes:** Membrane-enclosed organelles that contain digestive enzymes.
- **Mitochondria (mitochondrion):** Membrane-bound organelles, present in the cytoplasm of all eukaryotic cells, which are the sites of energy production within the cells.
- **Nucleus:** The membrane-bound organelle in eukaryotic cells that contains the chromosomes.
- **Nucleolus (nucleoli):** A nuclear region that functions in the synthesis of ribosomes.
- **Chromatin:** The DNA and protein components of chromosomes, visible as clumps or threads in nuclei.
- **Chromosomes:** The thread-like structures in the nucleus that carry genetic information.
- **Sex chromosomes:** In humans, the X and Y chromosomes that are involved in sex determination.
- **Autosomes:** Chromosomes other than the sex chromosomes. In humans, chromosomes 1 to 22 are autosomes.
- **Genes:** The fundamental units of heredity.
- **Cell cycle:** The sequence of events that takes place between successive mitotic divisions.
- **Interphase:** The period of time in the cell cycle between mitotic divisions.
- **Mitosis:** Form of cell division that produces two cells, each of which has the same complement of chromosomes as the parent cell.
- **Cytokinesis:** The process of cytoplasmic division that accompanies cell division.

- **Prophase:** A stage in mitosis during which the chromosomes become visible and contain sister chromatids joined at the centromere.
- **Chromatid:** One of the strands of a duplicated chromosome joined by a single centromere to its sister chromatid.
- **Centromere:** A region of a chromosome to which microtubule fibers attach during cell division. The location of a centromere gives a chromosome its characteristic shape.
- **Sister chromatids:** Two chromatids joined by a common centromere. Each chromatid carries identical genetic information.
- **Metaphase:** A stage in mitosis during which the chromosomes move and become arranged near the middle of the cell.
- **Anaphase:** A stage in mitosis during which the centromeres split and the daughter chromosomes begin to separate.
- **Telophase:** The last stage of mitosis, during which the chromosomes of the daughter cells decondense and the nucleus re-forms.
- **Meiosis:** The process of cell division during which one cycle of chromosomal replication is followed by two successive cell divisions to produce four haploid cells.
- **Diploid ($2n$):** The condition in which each chromosome is represented twice as a member of a homologous pair.
- **Haploid (n):** The condition in which each chromosome is represented once in an unpaired condition.
- **Homologous chromosomes:** Chromosomes that physically associate (pair) during meiosis. Homologous chromosomes have identical gene loci.
- **Assortment:** The result of meiosis I that puts random combinations of maternal and paternal chromosomes into gametes.
- **Crossing over:** A process in which chromosomes physically exchange parts.
- **Spermatogonia:** Mitotically active cells in the gonads of males that give rise to primary spermatocytes.
- **Spermatids:** The four haploid cells produced by meiotic division of a primary spermatocyte.
- **Oogonia:** Mitotically active cells in the gonads of females that produce primary oocytes.
- **Secondary oocyte:** The large cell produced by the first meiotic division.
- **Ovum:** The haploid cell produced by meiosis that becomes the functional gamete.
- **Polar bodies:** Cells produced in the first or second meiotic division in female meiosis that contain little cytoplasm and will not function as gametes.

TEACHING HINTS

Despite your best efforts, and that of Michael Cummings, many students will confuse chromosome pairs with sister chromatids, sister chromatids with arms, and the events of meiosis I, meiosis II, and mitosis. Mitosis and meiosis are physical processes that must be studied visually for best results. Of the questions at the end of this text chapter, we strongly recommend numbers 11 and 19 thru 24. In addition, it is very helpful to give students assignments such as “Draw the chromosome configuration in a cell in anaphase I of meiosis in an organism where $2n = 6$.” Chromosome models made of modeling clay, pipe cleaners, or the kits sold by scientific supply companies are even better than drawings. Have the students identify such features as a centromere, a short arm of a chromatid, a pair of chromosomes, two non-sister chromatids, etc. Students commonly report that such exercises help them greatly to visualize and understand meiosis, and also that these exercises reveal to them that their understanding was incomplete, when they had thought they were on top of this material.

VIDEOS, WEBSITES, AND ANIMATIONS

VIDEOS

YouTube — The Inner Life of the Cell from Harvard University

Video showing cell structure and function.

<http://www.youtube.com/watch?v=GigxU1UXZxo&feature=related>

WEBSITES

Anti-Aging Today — Theories of Aging

Theories on the cellular basis of aging.

<http://www.anti-aging-today.org/research/aging/theory/dna-genetic.htm>

Cell

Journal of cell biology. Subscription required.

<http://www.cell.com/home>

The Biology Project – Cell Biology

Activities, problem sets and tutorials on many aspects of cell biology including the cell cycle, mitosis, and meiosis.

http://www.biology.arizona.edu/cell_bio/cell_bio.html

Genetics Home Reference

A guide to understanding genetic conditions and their cellular basis.

<http://ghr.nlm.nih.gov/>

Genetics Home Reference – Gaucher disease

Article on Gaucher disease with links for further information.

<http://ghr.nlm.nih.gov/condition/gaucher-disease>

Genetics Home Reference – Roberts syndrome

Article on Roberts syndrome with links for further information.

<http://ghr.nlm.nih.gov/condition/roberts-syndrome>

Genetics Home Reference – Werner syndrome

Article on Werner syndrome with links for further information.

<http://ghr.nlm.nih.gov/condition/werner-syndrome>

ANIMATIONS

Virtual Cell Animation Collection

Animations of various cell functions. Includes a guided flythrough tour of a virtual cell.

<http://vcell.ndsu.edu/animations/>

Cells Alive!

Interactive animations of plant, animal, and bacteria cells. Includes animations of mitosis, meiosis, and the cell cycle. Also includes puzzles and quizzes.

<http://www.cellsalive.com/>

YouTube – Mitosis

Narrated animation of mitosis.

http://www.youtube.com/watch?v=cvlpmmvB_m4

YouTube – Meiosis

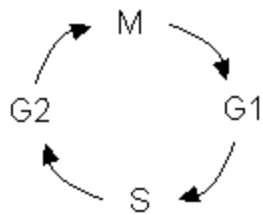
Narrated animation of meiosis.

http://www.youtube.com/watch?v=D1_-mOS_FZ0

ANSWERS TO TEXT QUESTIONS

1. With the division of the cytoplasm into compartments and organelles, each organelle can be specialized for its own specific functions, and therefore be more efficient in performing them.
2.
 - a. Chemical and physical cell barrier; controls flow of molecules; includes molecules that mark cell identity
 - b. Generation of metabolic energy
 - c. Maintenance and allocation of genetic material
 - d. Protein synthesis

3. Humans contain 22 pairs of autosomes, or 44 total in body cells. Gametes contain 22 autosomes total.
4.
 - a. A thread-like structure in the nucleus that carries genetic information
 - b. The component material of chromosomes
5. D
6. A sister chromatid is one of two exact copies of DNA synthesized from a “parent” DNA molecule. A sister chromatid gets replicated in the S phase of the cell cycle in preparation for cell division. Replication should occur in a very precise manner, ensuring that the sisters are both genetically identical to the original chromosome.
7. Cells undergo a cycle of events involving growth, DNA replication, and division. Daughter cells undergo the same series of events. During S phase, DNA synthesis and chromosome replication occur. During M, mitosis takes place.



8. A, E
9. Meiosis involves the production of haploid gametes. These gametes do not undergo further cell division and therefore do not “cycle.”
10. Meiosis II, the division responsible for the separation of sister chromatids, would no longer be necessary. Meiosis I, wherein homologs separate, would still be required.
11. Prophase: Chromosome condensation, spindle formation, centriole migration, nucleolar disintegration, nuclear membrane dissolution.
 Metaphase: Alignment of chromosomes in the middle of the cell. Attachment of centromeres to spindles.
 Anaphase: Centromere division, daughter chromosomes migrate to opposite cell poles.
 Telophase: Cytoplasmic division begins, reformation of nuclear membrane and nucleoli, disintegration of the spindle apparatus.
12. Cell furrowing involves constriction of the cell membrane that causes the cell to eventually divide. It is associated with the process of cytokinesis, cytoplasmic division of the cell. If

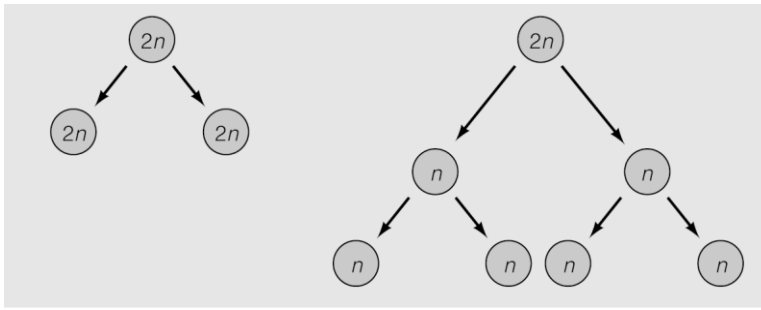
cytokinesis does not occur in mitosis, the cell will be left with a $2n + 2n$ ($4n$) number of chromosomes (tetraploid).

13. Both daughter cells have the normal diploid complement of all chromosomes except for 7. Therefore, one cell has three copies of chromosome 7 for a total chromosome number of 47. The other cell has only one copy of chromosome 7 for a total chromosome number of 45.
14. Anaphase, telophase of mitosis, and G1 of interphase. These are steps where one chromatid equals one chromosome. Sister chromatids have separated (in anaphase) and are then distributed into two daughter cells (in telophase). In the G1 phase, the two daughter cells are synthesizing cellular components and have not yet duplicated their DNA. During the S phase, chromosomes duplicate their genetic material creating sister chromatids. Starting with the S phase and ending with metaphase of mitosis, one chromosome equals two chromatids.
15. Faithful chromosome replication during S phase; independent alignment of chromosomes on the equatorial plate during metaphase; centromere division and chromosome migration during anaphase.
16. Epithelial cells, such as those on the skin and lining of the intestines, and cells in bone marrow that produce red blood cells.
17. Cells undergo a finite number of divisions before they die; this is the Hayflick limit. If a mutation occurs in a gene or genes that control this limit, the Hayflick limit may be reduced so that cells age and die earlier than normal.
18. Cell cycle genes can turn cell division on and off. If a gene normally promotes cell division, it can mutate to cause too much cell division. If a gene normally turns off cell division, it can mutate so that it can no longer repress cell division.

19.

	Mitosis	Meiosis
Number of daughter cells produced	2	4
Number of chromosomes per daughter cell	$2n$	n
Number of cell divisions	1	2
Do chromosomes pair? (Y/N)	N	Y
Does crossing over occur? (Y/N)	N	Y
Can the daughter cells divide again? (Y/N)	Y	N
Do the chromosomes replicate before division? (Y/N)	Y	Y
Type of cell produced	SOMATIC	GAMETE

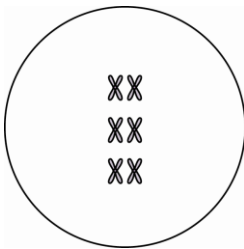
20.



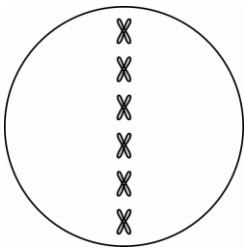
21. D

22. Left to right: E, C, B, D

23. a.



b.



c. 3

d. 3

e. 6

f. 6

24. a. Mitosis

b. Meiosis I

c. Meiosis II

25. 2 chromosomes, 4 chromatids, and 2 centromeres should be present.

26. Equal parts of a chromatid from each chromosome in the pair.

27. Meiotic anaphase I: No centromere division, chromosomes consisting of two sister chromatids are migrating.
Meiotic anaphase II: centromere division, the separating sister chromatids are migrating.
Meiotic anaphase II more closely resembles mitotic anaphase by the two criteria cited above.
28. During gamete formation, the 23 pairs of human chromosomes *independently assort*, creating gametes that are genetically different. For example, one gamete may have 10 paternally derived chromosomes and 13 maternally derived chromosomes. Another may have 8 paternally derived chromosomes and 15 maternally derived chromosomes. *Crossing over* also happens in meiosis where chromatids of paired chromosomes exchange chromosome parts (create new genetic combinations). This leads to even more genetic diversity.

DISCUSSION QUESTIONS

1. Since in most specialized cells of the body only a relatively small number of genes are active, why must mitosis involve the replication of a complete set of genes?
2. From an evolutionary standpoint, does it seem logical that mitosis evolved before meiosis, and that meiosis is really a specialized form of mitosis? Or should mitosis be regarded as a degenerate form of meiosis?
3. Would an understanding of the mechanism of the Hayflick limit lead to an increase in the human life span?
4. What is the difference between life span and life expectancy? Which genetic and non-genetic factors contribute to the gap between life span and life expectancy?
5. Compare and contrast the following:
 - a. prophase of mitosis and prophase I of meiosis
 - b. interphase preceding meiosis I and interphase preceding meiosis II
 - c. anaphase of mitosis and anaphase I of meiosis
6. What evidence exists that mitosis and the cell cycle are under genetic control?
7. Of what significance is crossing over? What other event in Meiosis I is of similar significance?
8. Describe the cell cycle. Do all cells go through this cycle at the same time?
9. Compare and contrast five items in mitosis and meiosis.
10. What is accomplished by the unequal cytokinesis of oogenesis?