2

CELLS AND CELL DIVISION

CHAPTER OUTLINE

CELLULAR LINKS TO GENETIC DISEASES
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

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 through 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 be able to:

2-1 Cellular Links to Genetic Disease
2-1-1: Describe an example of how cell structure and function are influenced by genetic information.
2-2 The Chemistry of Cells
2-2-1: List the four classes of macromolecules that make up cells and explain how structure and function are interrelated in each.
2-3 Cell Structure Reflects Function
2-3-1: Label a generalized human cell.
2-3-2: List the two cellular domains and give the major characteristics of each.
2-3-3: Differentiate between the major cellular organelles and state their functions.
2-4 The Cell Cycle Describes the Life History of a Cell
2-4-1: Summarize the three phases of the cell cycle: interphase, mitosis, and cytokinesis.
2-4-2: List the three stages of interphase and explain what occurs at each stage.
2-4-3: Outline the four stages of mitosis and describe the characteristics of each stage.

2-5 Mitosis Is Essential for Growth and Cell Replacement

2-5-1: Discuss the importance of mitosis for growth and cell replacement and identify possible consequences when cell cycle regulation is interrupted.

2-6 Cell Division by Meiosis: The Basis of Sex

2-6-1: Compare and contrast mitosis and meiosis.

2-6-2: Illustrate the stages of meiosis I and meiosis II and describe what occurs at each stage.

2-6-3: Explain the two processes of meiosis that create new combinations of genes.

2-7 Formation of Gametes

2-7-1: Define the term gamete and outline the sequence of events leading to the formation of both male and female gametes.

2-7-2: Establish the significance of meiosis in the formation of gametes.

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.
- **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 (2*n*)**: 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.
- **Allele:** One of the possible alternative forms of a gene, usually distinguished from other alleles by its phenotypic effects.
- **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.
- **Primary oocyte:** The cell produced from oogonia that will begin meiosis during embryogenesis.
- **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_-mQS_FZ0

RESPONSES TO CASE STUDY QUESTIONS

1. There is a 25% chance that Sean and Michelle will have another child with CF. This is based on the 50% chance that Michelle will pass her mutation on to the oocyte and a 50% chance that Sean will have passed his mutation along to the sperm. Both parents are heterozygous carriers.

2. There is a 50% chance that another child will inherit the G551D mutation from Michelle.

3. Answers to this question may vary slightly, but should address the relative severity of CF connected with the G551D mutation, the combined impact of the G551D and the ΔF508 mutation, and the impacts of the ΔF508 mutation alone. Additional comments may involve the long-term impact and lifestyle associated with treatment of CF at these differing levels of severity.

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

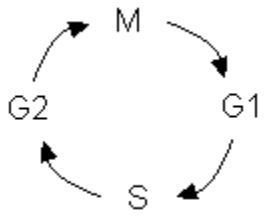
3. Humans contain 22 pairs of autosomes, or 44 total in body cells. Gametes contain 22 autosomes total.

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. No. 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. Instead, 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.

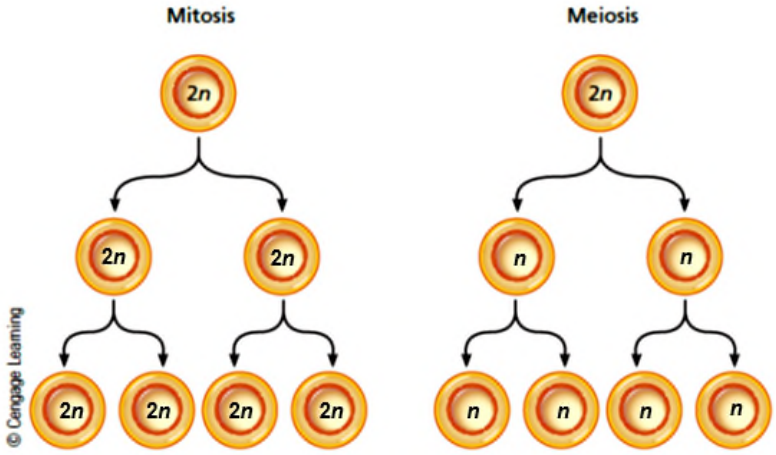
17. Cells undergo a finite number of divisions before they die; this is the Hayflick limit. If a mutation occurs in a gene or genes that control this limit, the Hayflick limit may be reduced so that cells age and die earlier than normal.

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.

Attribute	**Mitosis**	**Meiosis**
Number of daughter cells produced	2	4
Number of chromosomes per daughter cell	2*n*	*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

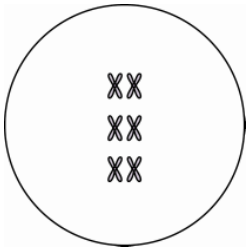
20.



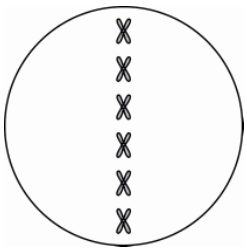
21. D

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

Chapter Two

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

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

Cells and Cell Division

Chapter 2

Michael R. Cummings
Illinois Institute of Technology

2.1 Case Study: Cellular Links to Genetic Disease

- Gaucher disease
  - Deficiency in fat metabolism leads to accumulation of fat in white blood cells in spleen, liver and bone marrow
  - Common (1 in 450) in individuals of Eastern European Jewish descent

Gaucher Disease (cont'd.)

- Treatment
  - Enzyme replacement therapy
    - 1-2 hour intravenous treatment, once every 2 weeks
    - $150,000 - $200,000 per year
  - Bone marrow transplant
    - Permanent cure
    - Shortage of bone marrow donors

Gaucher Disease (cont'd.)

- Questions to consider
  - Which treatment should be covered by insurance?
  - Should bone marrow transplants be reserved for life-threatening conditions, such as leukemia?

2.2 The Chemistry of Cells

- Cells are constructed from four classes of macromolecules:
  - Carbohydrates
    - Simple sugars and large polymers
  - Lipids
    - Fats and oils, phospholipids, and steroids
  - Proteins
    - Polymers of amino acids
  - Nucleic acids
    - Polymers of nucleotides

Table 2.1 The Main Macromolecules in Cells

TABLE 2.1 The Main Macromolecules in Cells

Class	Subclasses	Examples	Functions
CARBOHYDRATES	**Monosaccharides** (simple sugars)	Glucose	Energy source
	Oligosaccharides (short-chain carbohydrates)	Sucrose	A common sugar
	Polysaccharides (complex carbohydrates)	Starch, glycogen	Energy storage
LIPIDS	**Glycerides** Glycerol plus fatty acids	Fats	Energy storage
	Phospholipids Glycerol, fatty acids, phosphate group	Lecithin	Structure of cell membranes
	Sterols Carbon-ring structures	Cholesterol	Membrane structure, precursor to steroid hormones
PROTEINS	**Mostly fibrous** (sheets of polypeptide chains; mostly water insoluble)	Keratin Collagen	Structure of hair Structure of bones
	Mostly globular (protein chains folded into globular shapes; mostly water soluble)	Enzymes Hemoglobin Insulin Antibodies	Catalysts Oxygen transport Hormone Immune system
NUCLEIC ACIDS	**Adenosine phosphates** **Nucleic acids** (polymers of nucleotides)	ATP DNA, RNA	Energy carrier Storage, transmission of genetic information

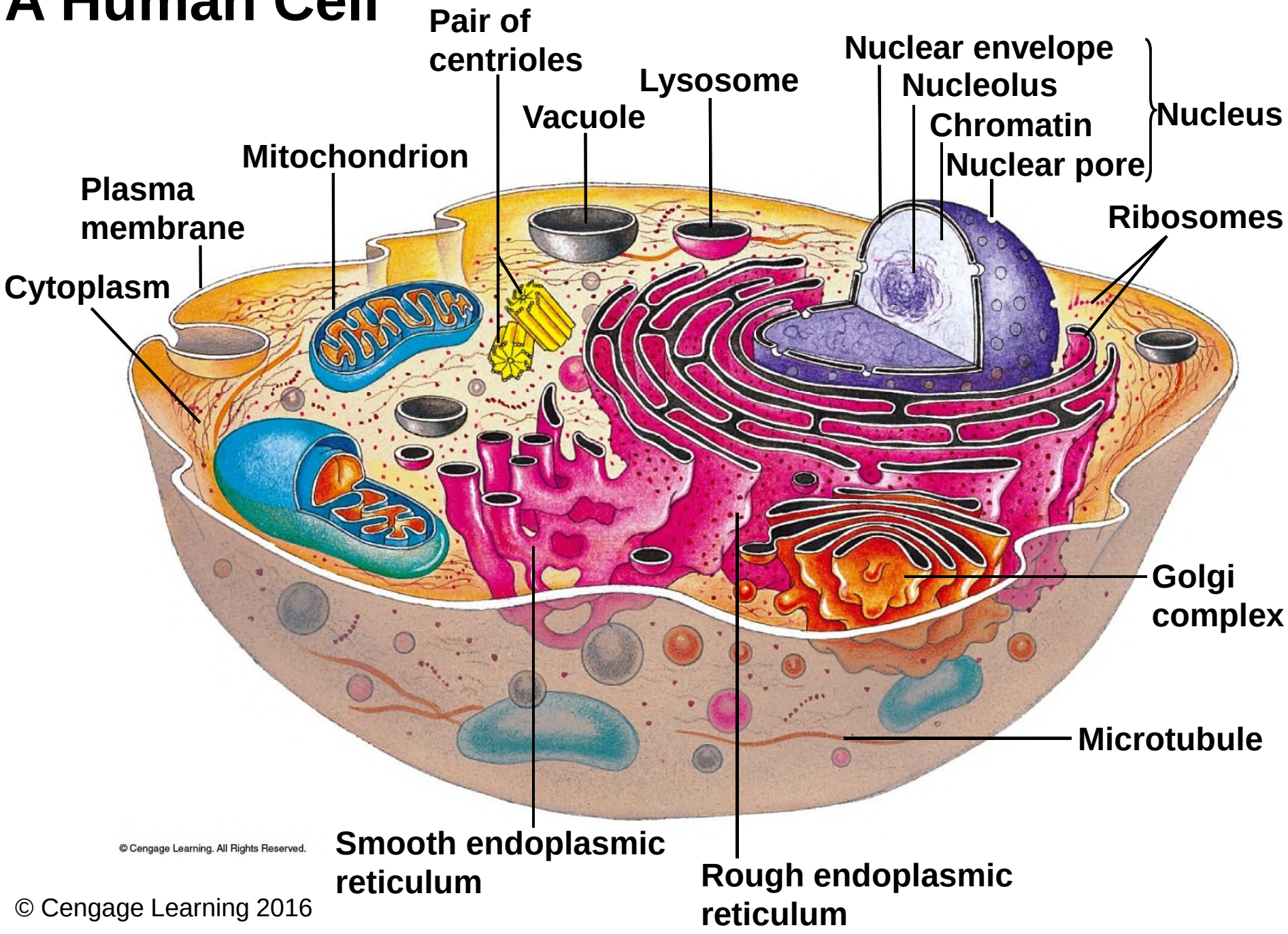
2.3 Cell Structure Reflects Function

- The basic structural and functional unit in all organisms, including humans, is the cell
- Cells may differ in size, shape, function and life cycle, but structurally they are all similar
- All eukaryotic cells have a plasma membrane, cytoplasm, membranous organelles, and a membrane-bound nucleus

2.3 Cell Structure Reflects Function (cont'd.)

- Cells have two cellular domains:
  - Plasma membrane
  - Cytoplasm
- Genetic disorders alter cellular structure or function

A Human Cell



2.3 The Plasma Membrane

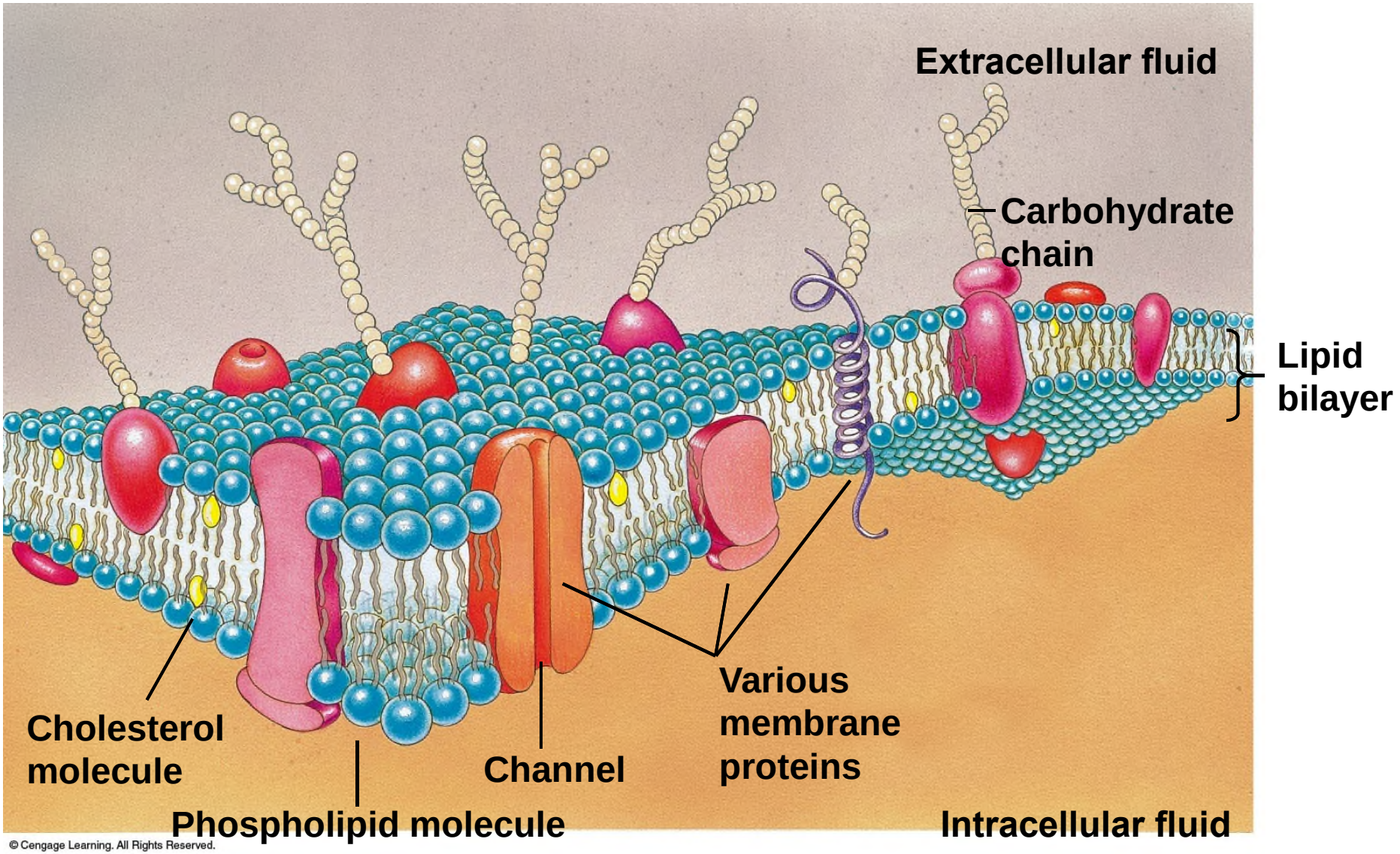


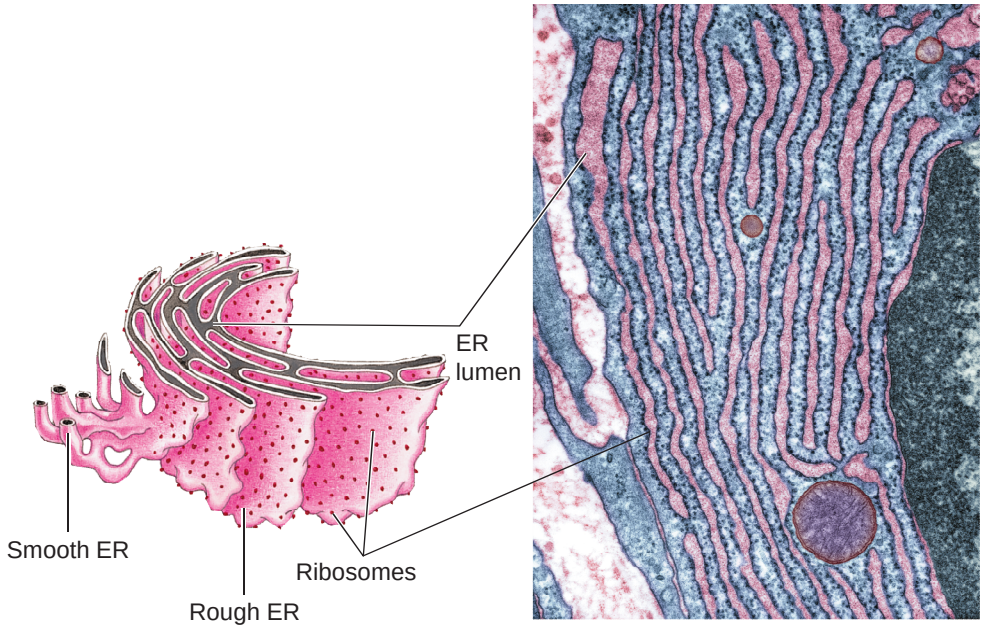
Table 2.2 Overview of Cell Organelles

TABLE 2.2 Overview of Cell Organelles

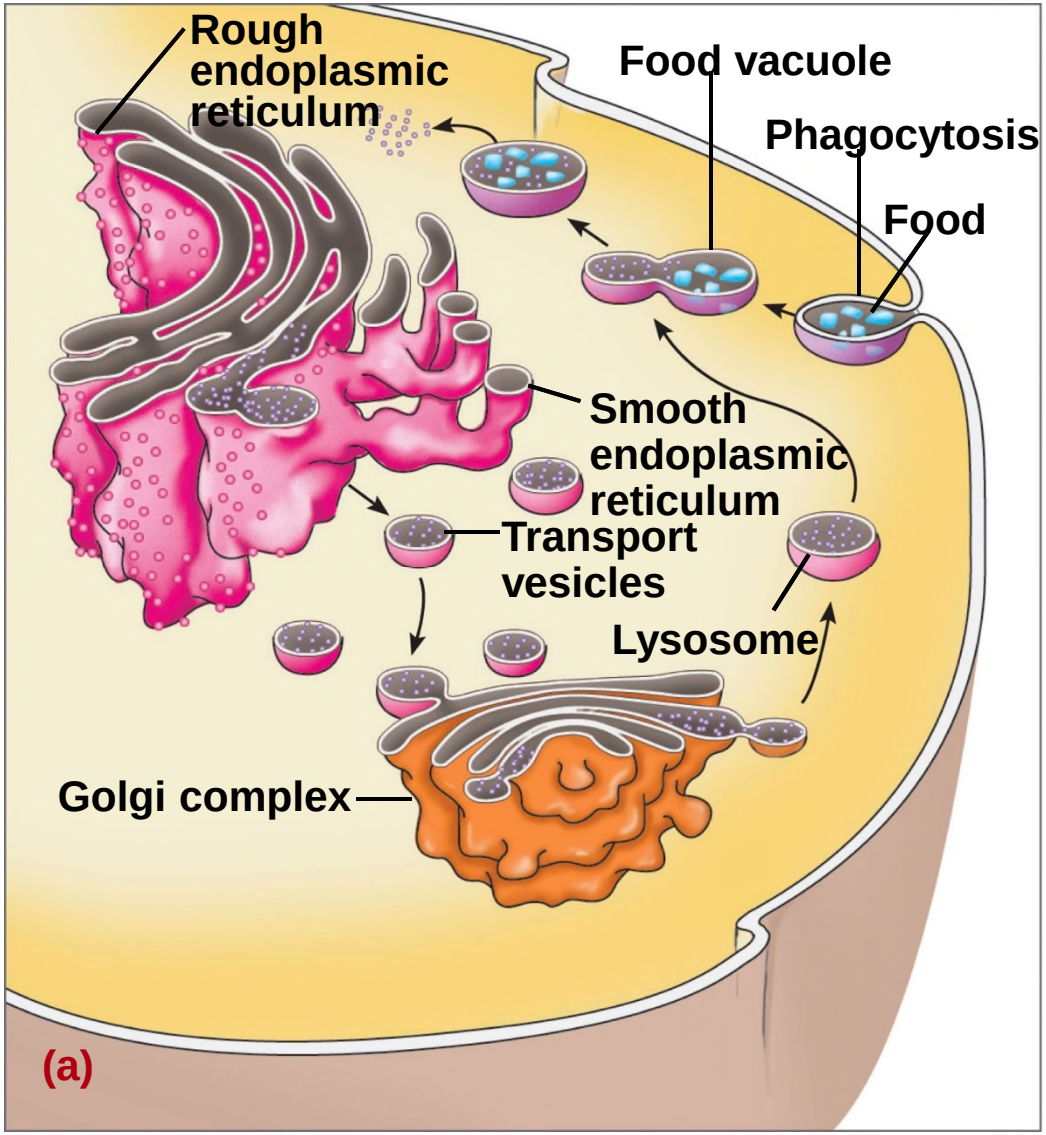
Organelle	Structure	Function
Nucleus	Round or oval body; surrounded by nuclear envelope.	Contains the genetic information necessary to control cell structure and function.
Nucleolus	Round or oval body in the nucleus containing DNA and RNA.	Produces ribosomes.
Endoplasmic reticulum	Network of membranous tubules in the cytoplasm of the cell. Smooth endoplasmic reticulum contains no ribosomes. Rough endoplasmic reticulum is studded with ribosomes.	Smooth endoplasmic reticulum (SER) is involved in producing phospholipids and has many different functions in different cells. Rough endoplasmic reticulum (RER) is the site of the synthesis of proteins for intracellular and extracellular use.
Ribosomes	Small particles found in the cytoplasm; made of RNA and protein.	Aids in the production of proteins on the RER and in ribosome complexes (polysomes).
Golgi complex	Series of flattened sacs and associated vesicles.	Sorts, chemically modifies, and packages proteins produced on the RER.
Secretory vesicles	Membrane-bound vesicles containing proteins produced by the RER and repackaged by the Golgi complex; contain protein hormones or enzymes.	Stores protein hormones or enzymes in the cytoplasm, awaiting a signal for release.
Lysosome	Membrane-bound structure containing digestive enzymes.	Combines with food vacuoles and digests materials engulfed by cells.
Mitochondria	Round, oval, or elongated structures with a double membrane. The inner membrane is extensively folded.	Completes the breakdown of glucose, producing ATP.

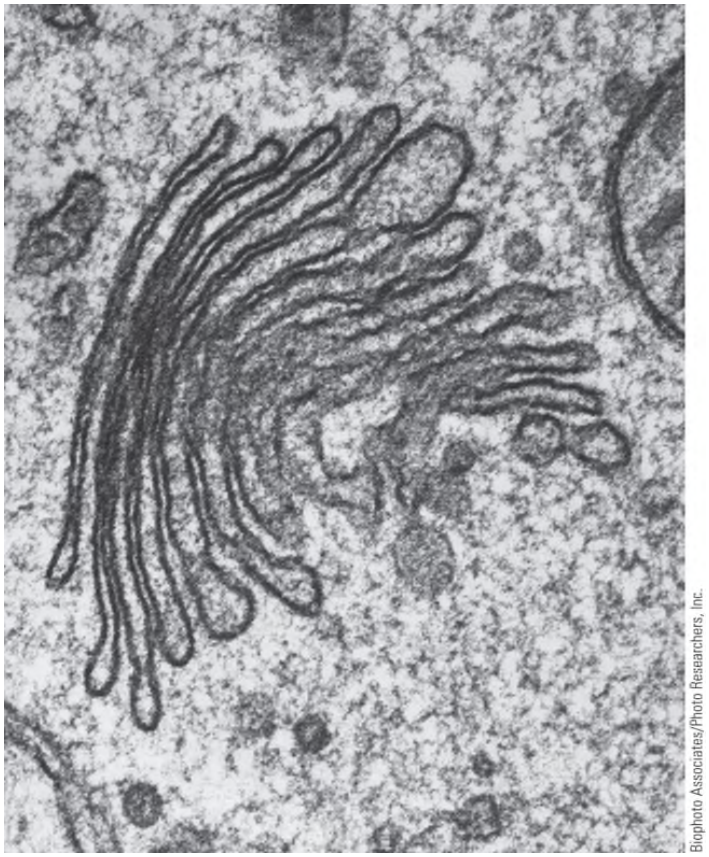
2.3 Endoplasmic Reticulum

- System of cytoplasmic membranes arranged into sheets and channels
- Found in the cytoplasm of eukaryotic cells
- Synthesizes and transports gene products



Golgi Complex and Lysosomes



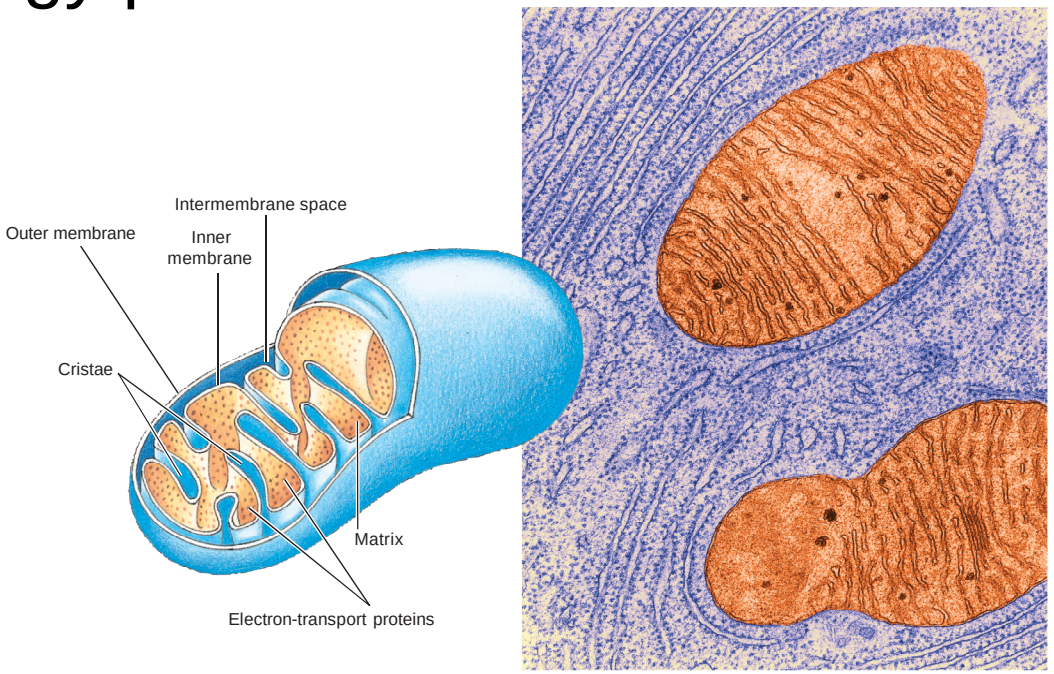


Biophoto Associates/Photo Researchers, Inc.

(b)

2.3 Mitochondria

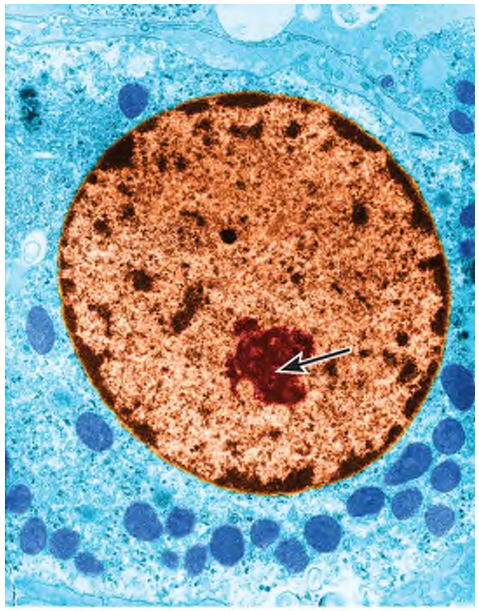
- Mitochondria (singular: mitochondrion)
- Membrane-bound organelles in the cytoplasm of eukaryotic cells
- Sites of energy production



Left: ©Cengage Learning; Right: Keith R. Porter/Science Source

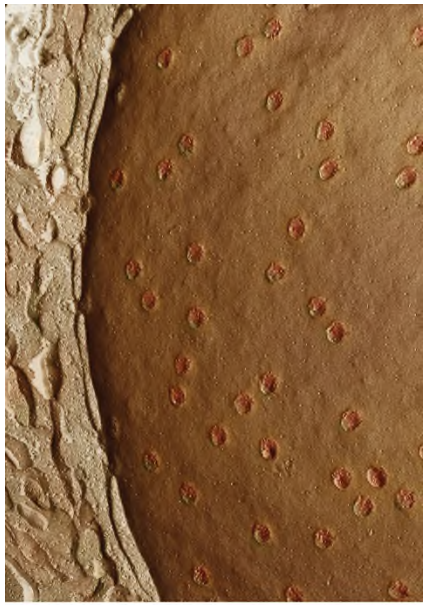
2.3 The Nucleus

- Membrane-bound organelle in eukaryotic cells
- Contains the chromosomes and nucleolus



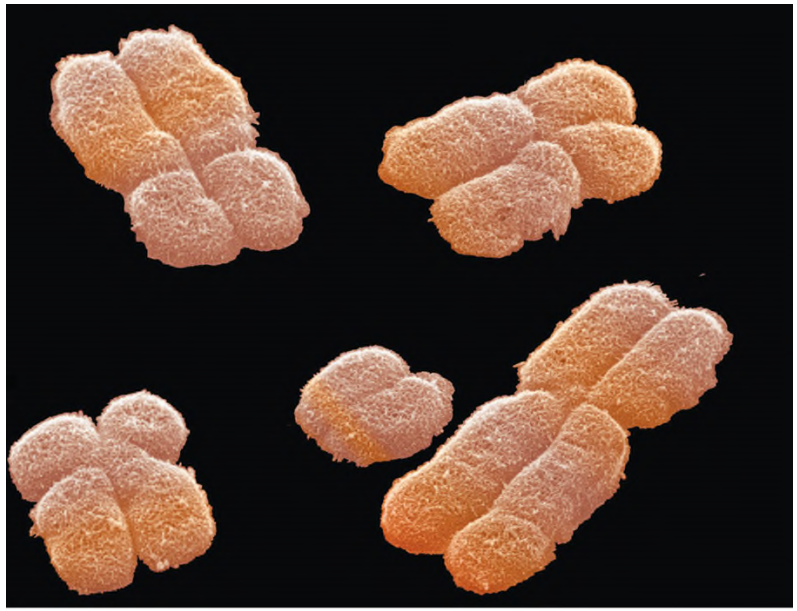
(a)

David M. Phillips/Science Source



(b)

Don W. Fawcett/Science Source



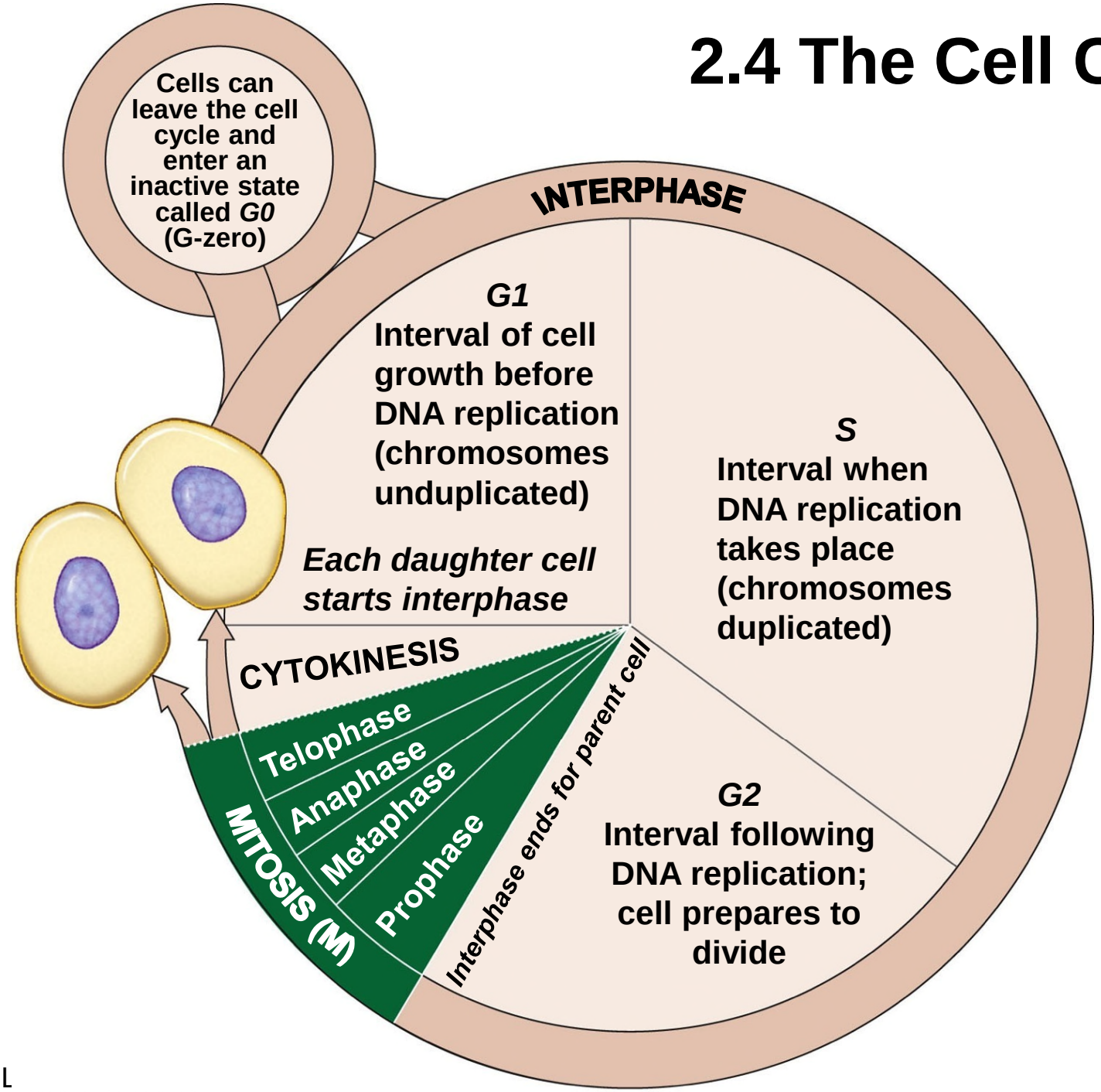
(c)

Andrew Syred/Science Source

2.4 The Cell Cycle Describes the Life History of a Cell

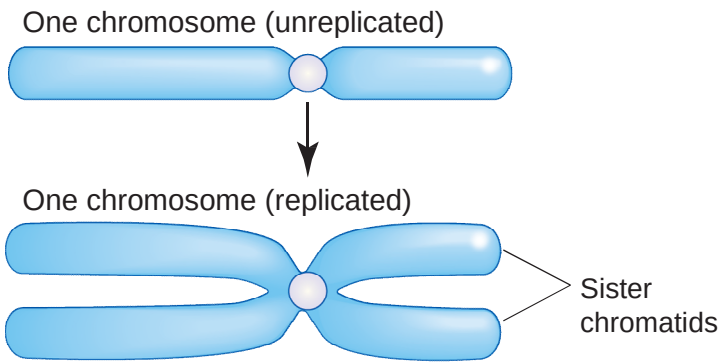
- The cell cycle is divided into three parts:
  - Interphase
    - Time between cell divisions
    - G1, S, and G2 phases
  - Mitosis
    - Division of the nucleus and segregation of the chromosomes into the future daughter cells
  - Cytokinesis
    - Division of the cytoplasm

2.4 The Cell Cycle



2.4 Chromosomes

- Chromatid
  - One strand of a duplicated chromosome
- Sister chromatids
  - Two chromatids joined by a common centromere
  - Each carries identical genetic information



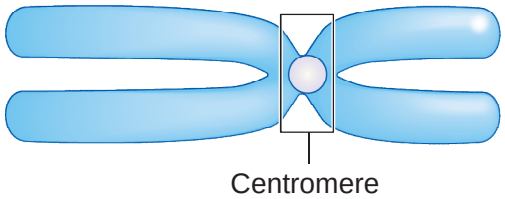


Table 2.3 Phases of the Cell Cycle

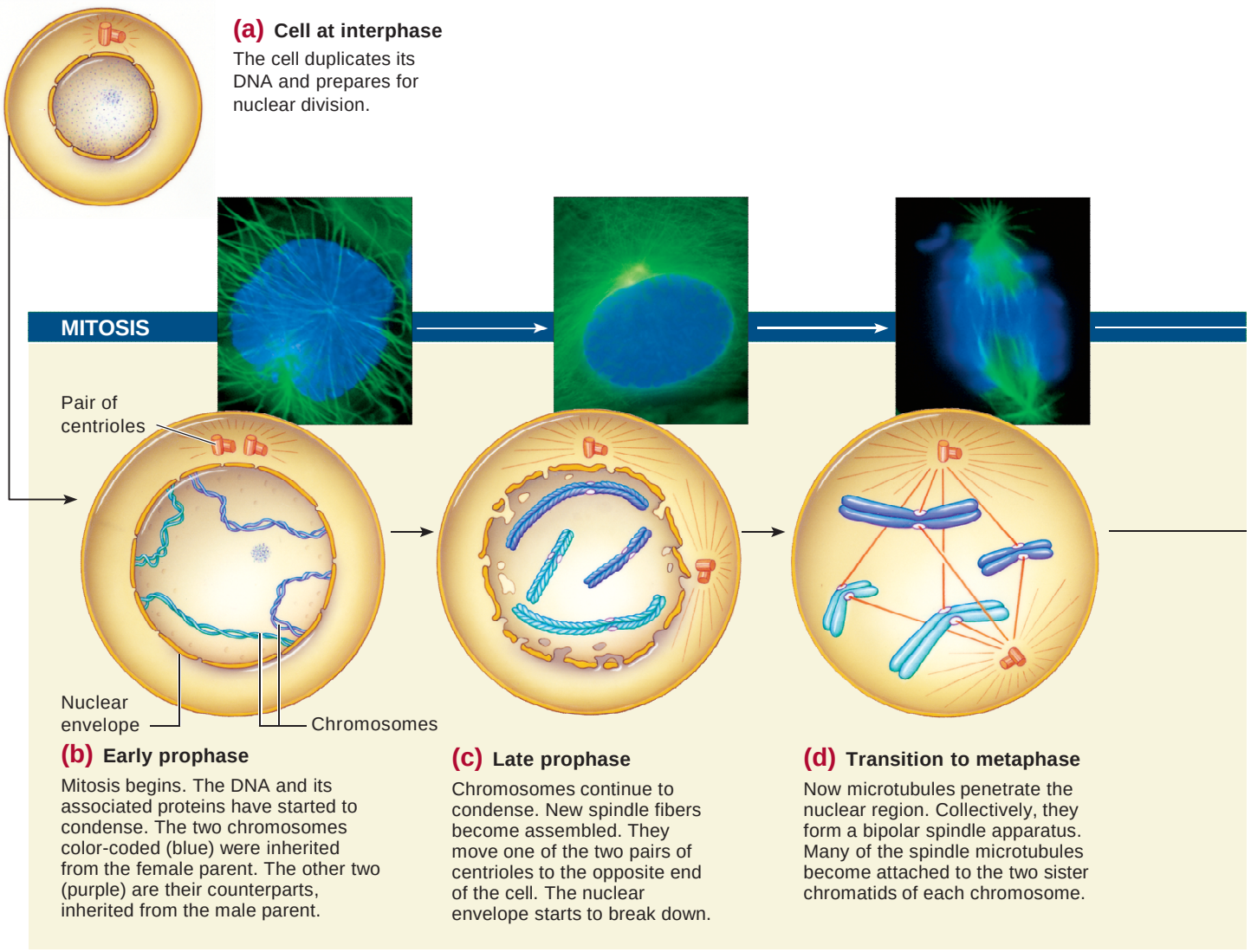
TABLE 2.3 Phases of the Cell Cycle

Phase	Characteristics
Interphase	
G1 (Gap 1)	Stage begins immediately after mitosis. RNA, proteins, and organelles are synthesized.
S (Synthesis)	DNA is replicated, and chromosomes form sister chromatids.
G2 (Gap 2)	Mitochondria divide. Precursors of spindle fibers are synthesized.
Mitosis	
Prophase	Chromosomes condense. Nuclear envelope disappears. Centrioles divide and migrate to opposite poles of the dividing cell. Spindle fibers form and attach to chromosomes.
Metaphase	Chromosomes line up on the midline of the dividing cell.
Anaphase	Chromosomes begin to separate.
Telophase	Chromosomes reach opposite poles. New nuclear envelope forms. Chromosomes decondense.
Cytokinesis	Cleavage furrow forms and deepens. Cytoplasm divides.

2.4 Stages of Mitosis

- Prophase
- Chromosomes visible
- Sister chromatids joined at the centromere
- Metaphase
- Chromosomes move to the middle of the cell
- Spindle microtubules attach to centromeres of the sister chromatids

2.4 Stages of Mitosis Continued

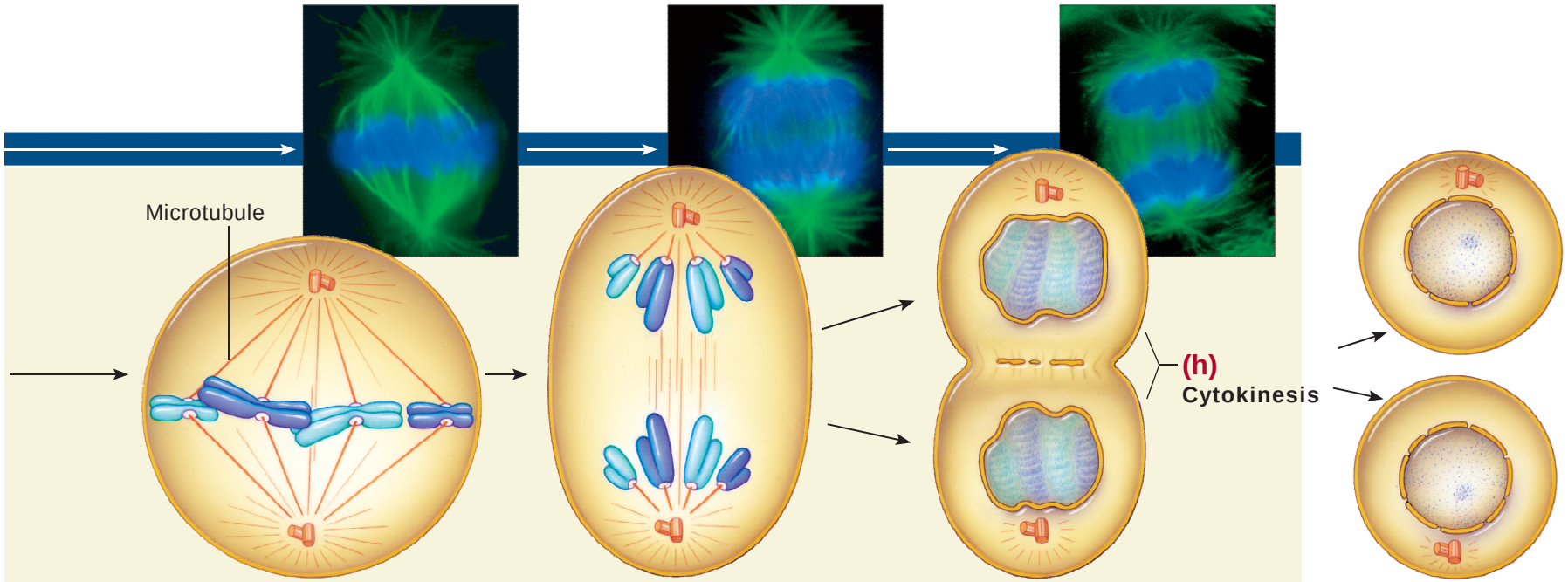


Jennifer C. Waters/Science Source

2.4 Stages of Mitosis Continued

- Anaphase
  - Centromeres split
  - Sister chromatids begin to separate
- Telophase
  - Chromosomes of the daughter cells decondense
  - Nuclei reform in daughter cells

2.4 Stages of Mitosis Continued



(e) Metaphase
All chromosomes have become lined up at the equator of the fully formed microtubular spindle. At this stage of mitosis and the cell cycle, chromosomes are in their most tightly condensed form.

(f) Anaphase
Attachments between the two sister chromatids of each chromosome break. The two are separate chromosomes, and microtubules move toward opposite spindle poles.

(g) Telophase
There are two clusters of chromosomes, which decondense. Patches of new membrane fuse to form a new nuclear envelope. Mitosis is completed.

(i) Interphase
Now there are two daughter cells. Each is diploid; its nucleus has two of each type of chromosome, just like the parent cell.

Jennifer C. Waters/Science Source

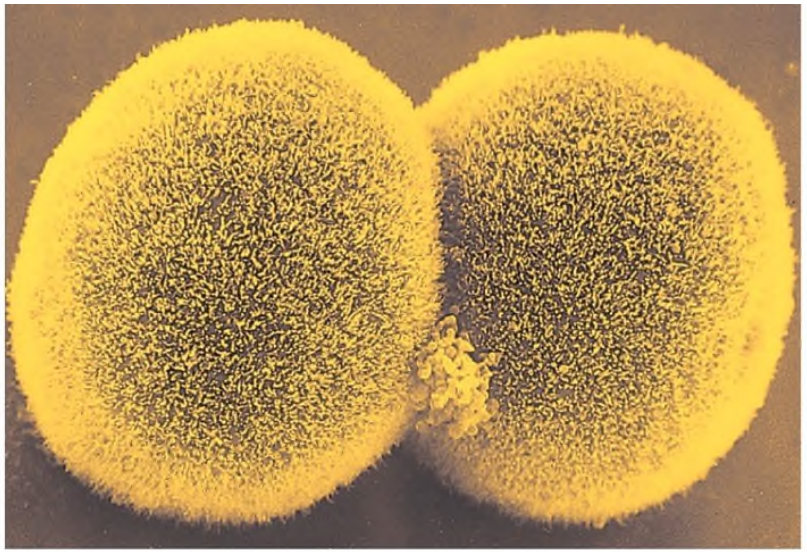
Table 2.4 Summary of Mitosis

TABLE 2.4 Summary of Mitosis

Stage	Characteristics
Prophase	Chromosomes become visible as threadlike structures. As they continue to condense, they are seen as double structures, with sister chromatids joined at a single centromere.
Metaphase	Chromosomes become aligned at equator of cell.
Anaphase	Centromeres divide, and chromosomes move toward opposite poles.
Telophase	Chromosomes decondense; nuclear membrane forms.

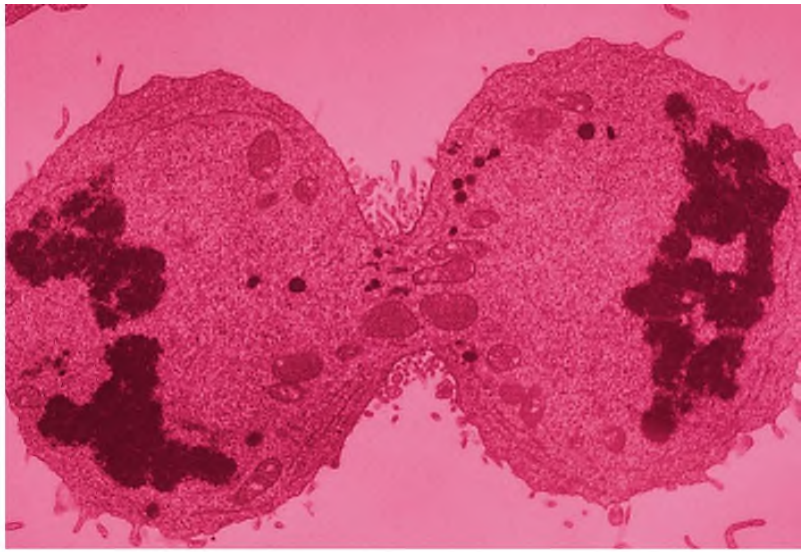
2.4 Cytokinesis Divides the Cytoplasm

- Cleavage furrow divides the cytoplasm equally into two daughter cells
- Organelles are distributed to the daughter cells



David M. Philips/Visuals Unlimited

(a)



(b)

2.5 Mitosis Is Essential for Growth and Cell Replacement

- Some cells continue to divide throughout the life cycle of the organism, while others do not divide during adulthood
- Hayflick limit
  - Cells can undergo only a certain (limited) number of cell divisions before they stop dividing; genetically controlled
  - Human embryonic cells divide about 50 times, while human adult cells divide 10-30 times
  - Allows growth to adulthood and cell replacement

2.5 Mitosis Is Essential for Growth and Cell Replacement (cont'd.)

- Alterations in the control of cell division can lead to genetic disorders, such as premature aging and cancer

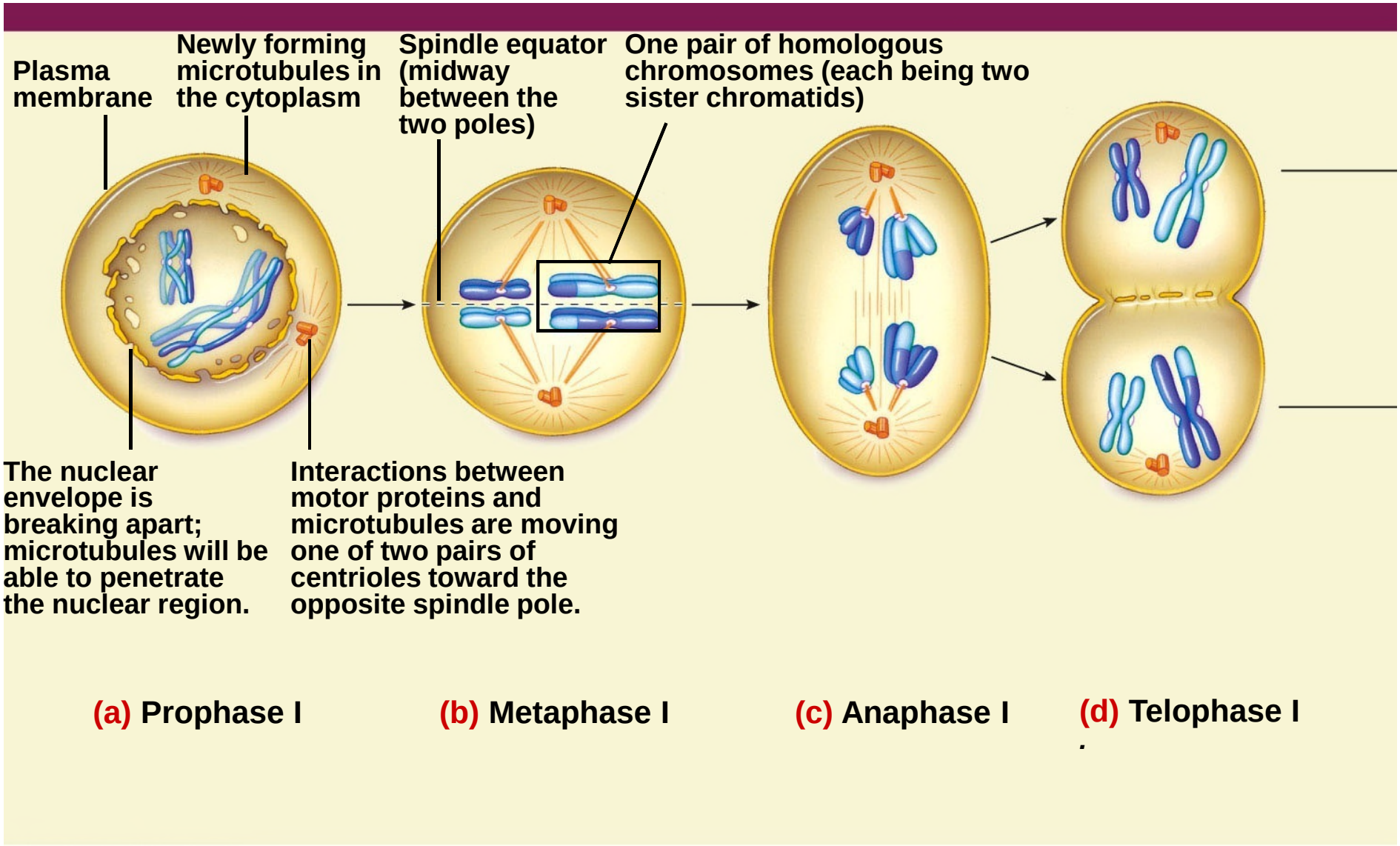
2.5 Progeria - Premature Aging

AP Photo/Gerald Herbert

2.6 Cell Division by Meiosis: The Basis of Sex

- Meiosis
  - Produces four haploid cells containing only one copy (paternal or maternal) of each chromosome
  - Two rounds of meiotic division
    - Meiosis I
      - Reduces the chromosome number from diploid to haploid
      - Crossing over results in genetic variation
    - Meiosis II
      - Separates the sister chromatids
      - Four haploid cells result

Meiosis I



Meiosis II

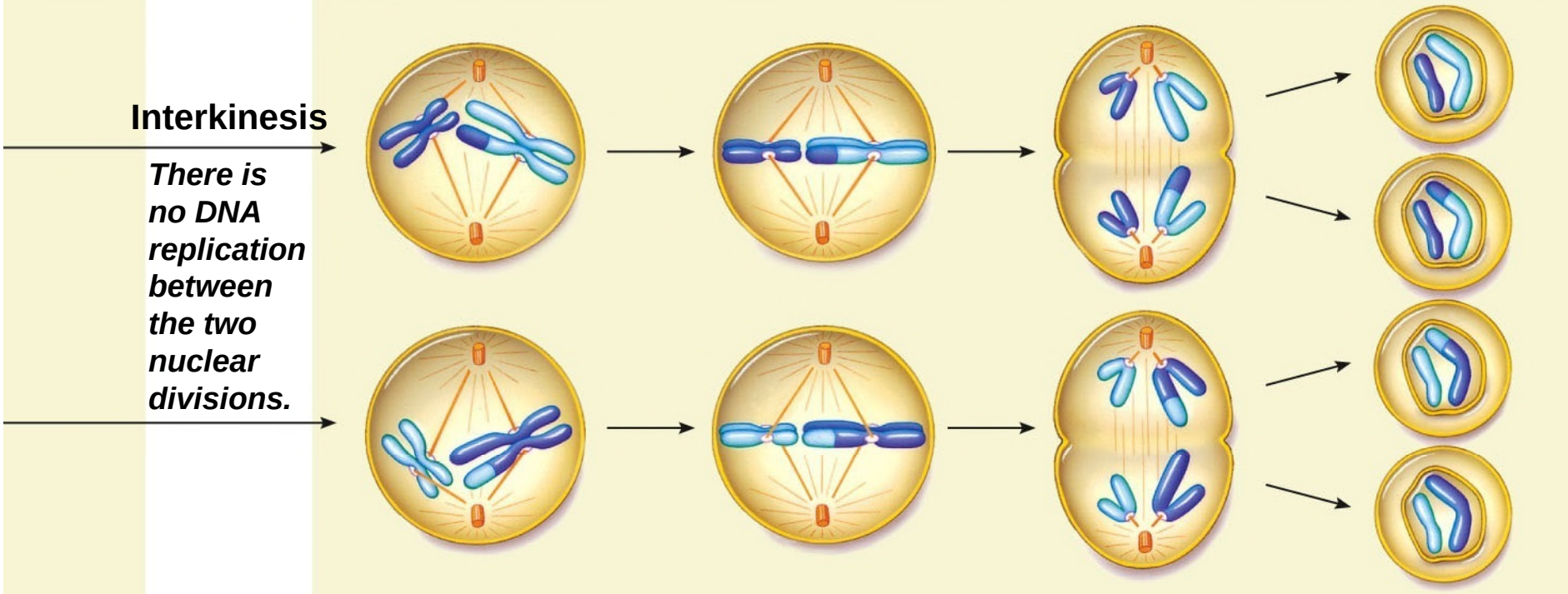
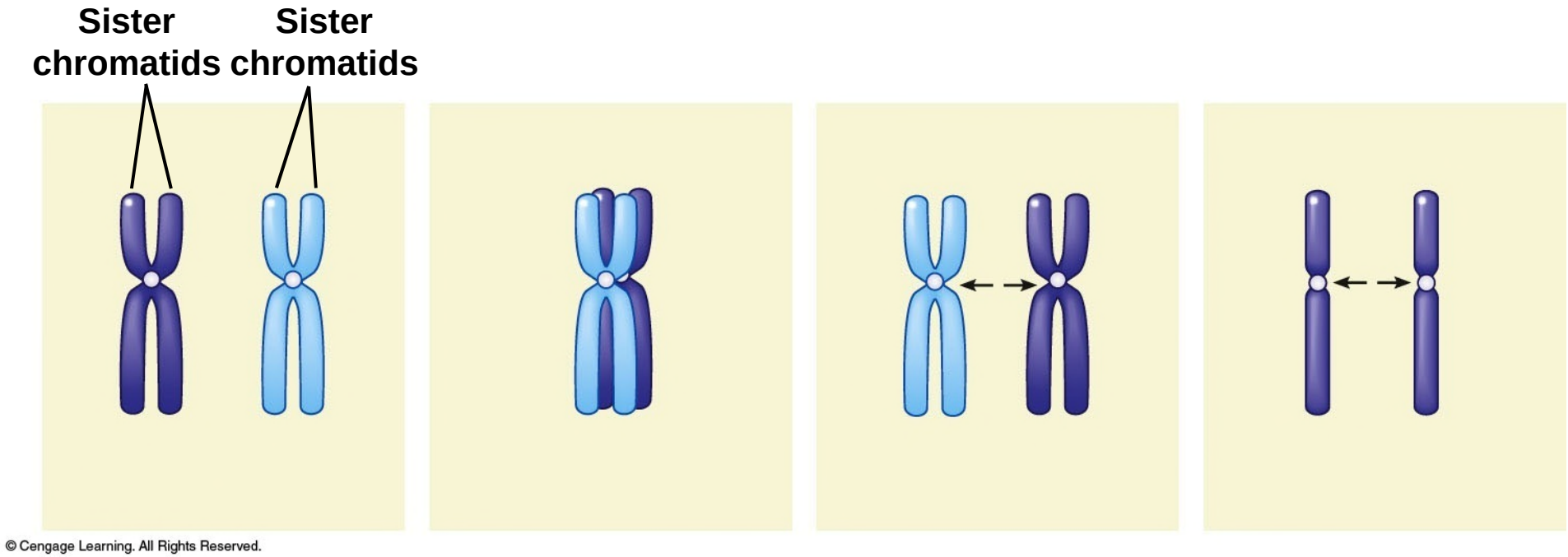


Table 2.5 Summary of Meiosis

TABLE 2.5 Summary of Meiosis

Stage	Characteristics
Prophase I	Chromosomes become visible, homologous chromosomes pair, and sister chromatids become apparent. Recombination takes place.
Metaphase I	Paired chromosomes align at equator of cell.
Anaphase I	Paired homologous chromosomes separate. Members of each chromosome pair move to opposite poles.
Telophase I	Chromosomes uncoil, become dispersed.
Cytokinesis	Cytoplasm divides, forming two cells.
Prophase II	Chromosomes re-coil, shorten.
Metaphase II	Unpaired chromosomes become aligned at equator of cell.
Anaphase II	Centromeres separate. Daughter chromosomes, which were sister chromatids, pull apart.
Telophase II	Chromosomes uncoil, nuclear envelope re-forms. Meiosis ends.
Cytokinesis	The cytoplasm divides, forming daughter cells.

2.6 Summary of Chromosome Movement during Meiosis



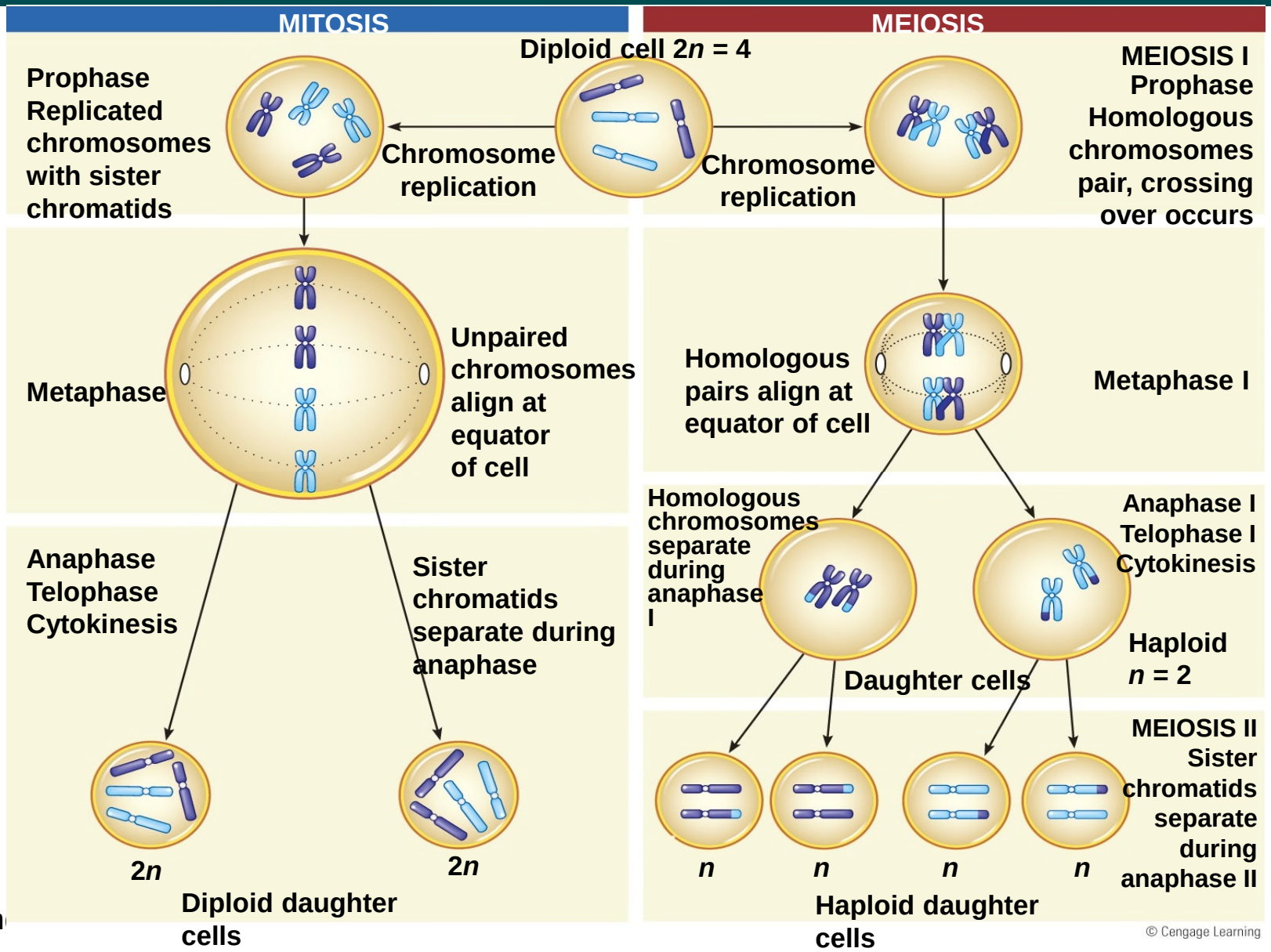
Members of chromosome pair

Each chromosome pairs with its homologue

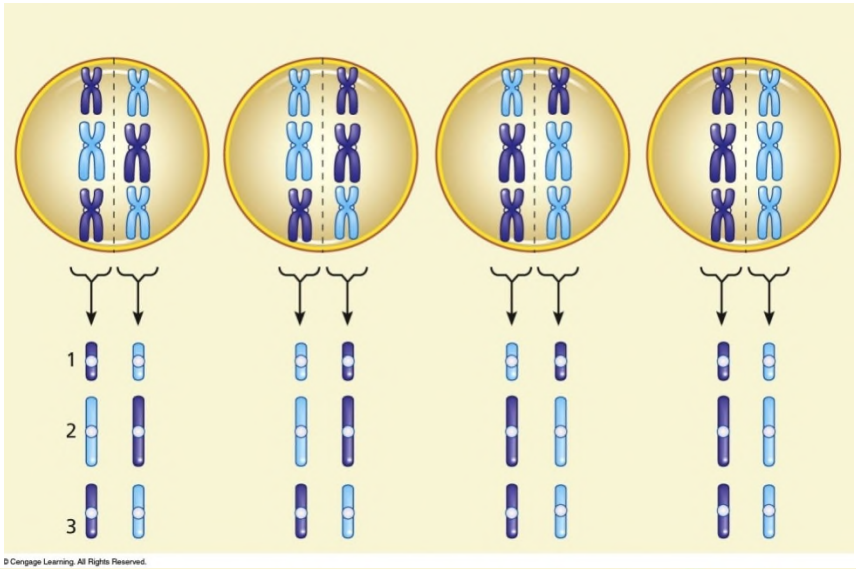
Paired homologues separate in meiosis I

Sister chromatids separate and become individual chromosomes in meiosis II

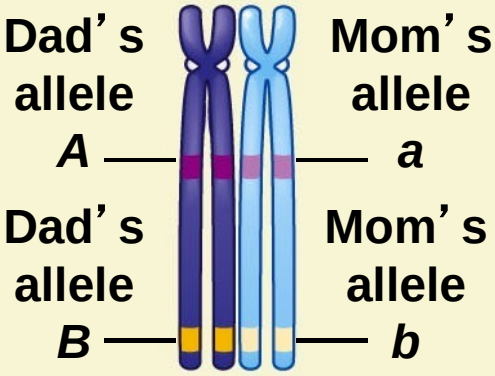
2.6 Comparing Mitosis and Meiosis



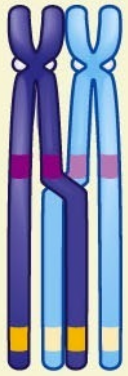
2.6 Random Assortment and Crossing Over



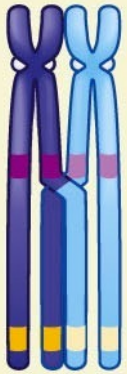
(a) Random assortment of chromosomes in meiosis



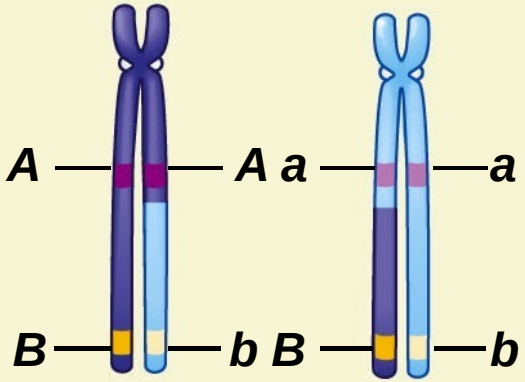
In Prophase I, homologous chromosomes physically pair with one another.



Crossing over takes place between non-sister chromatids.



There is a physical exchange of chromosome segments and the genes they carry.



Crossing over generates new combinations of Mom's and Dad's alleles.

(b)

2.7 Formation of Gametes

- Meiosis results in two kinds of haploid, sexual gametes
- Sperm
  - Produced by males through spermatogenesis in the testes
  - Mitotic spermatogonia produce spermatocytes
  - Meiosis in spermatocytes produce haploid spermatids that mature into sperm cells

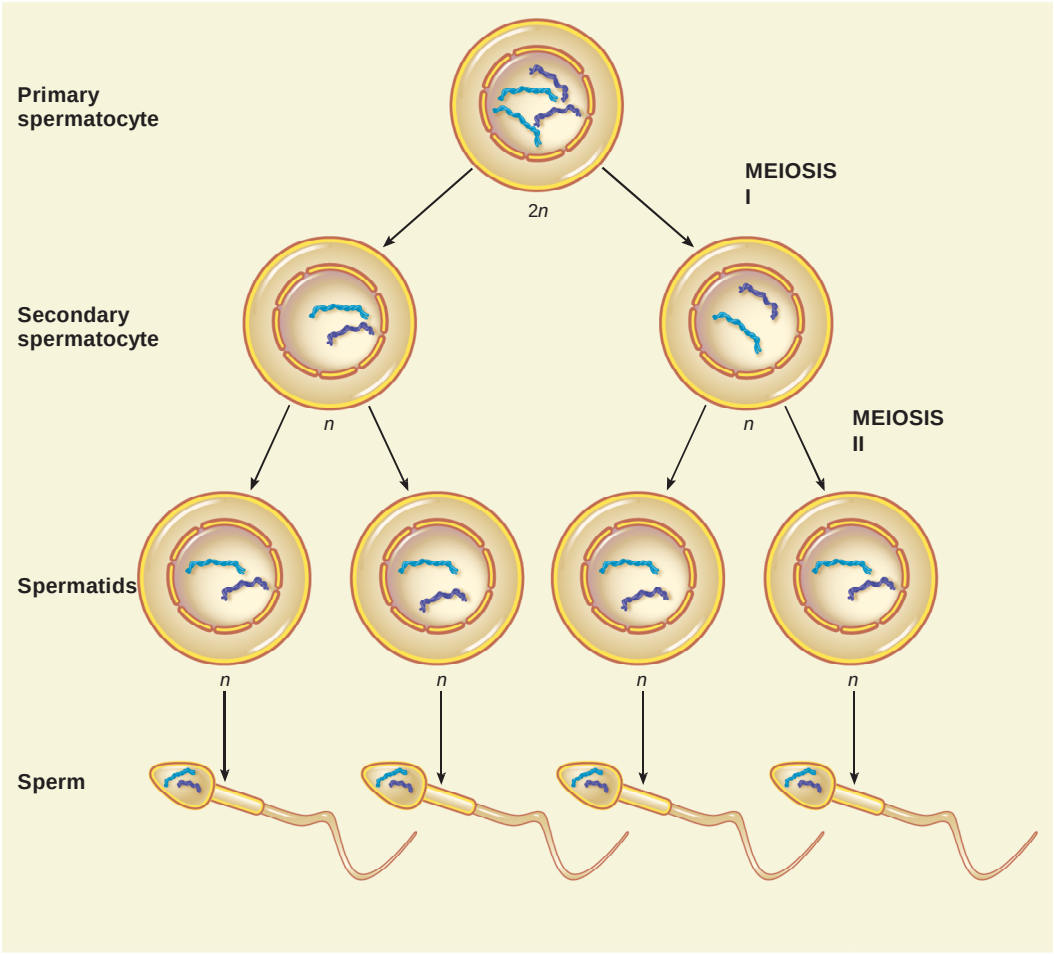
2.7 Formation of Gametes (cont'd.)

- Oocytes
  - Produced by females through oogenesis in the ovary
  - Mitotic oogonia produce primary oocytes
  - Meiosis in primary oocytes produce ova (ovum = singular)

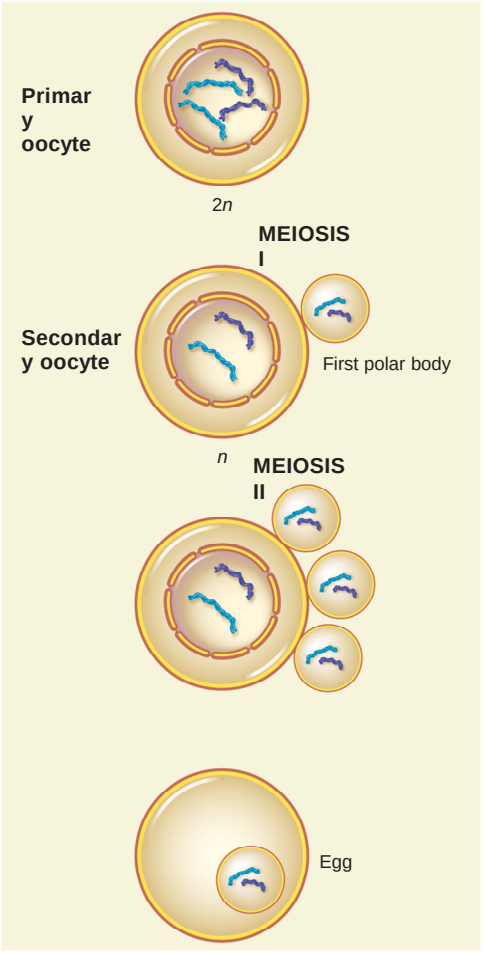
2.7 Comparison of Sperm and Egg Production in Humans

- Sperm and egg development differ in timing and functionality of haploid daughter cells
  - Sperm
    - Continually produced from puberty until death
    - Four mature sperm from one spermatocyte
  - Oocytes
    - Finite number of primary oocytes arrested in meiosis I produced during embryonic development
    - Meiosis II completed upon fertilization
    - Only one mature ovum results from one primary oocyte

2.7 Sperm and Egg Development in Humans



(a)



(b)

Table 2.6 Comparing Spermatogenesis and Oogenesis

TABLE 2.6 A Comparison of the Duration of Meiosis in Males and Females

Spermatogenesis		Oogenesis	
Begins at Puberty		**Begins During Embryogenesis**	
Spermatogonium	16 days	Oogonium	Forms at 2–3 months after conception
↓		↓	
Primary spermatocyte	16 days	Primary oocyte	Forms at 2–3 months of gestation. Remains in meiosis I until ovulation, 12–50 years after formation.
↓		↓	
Secondary spermatocyte	16 days	Secondary oocyte	
↓		↓	
Spermatid	16 days	Ootid	Less than 1 day, when fertilization occurs
↓			
Mature sperm		Mature egg-zygote	
Total time	64 days	Total time	12–50 years