Van De Graaff's

PHOTOGRAPHIC ATLAS for the Biology LABORATORY

EIGHTH EDITION

Byron J. Adams ■ John L. Crawley

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for the

Biology Laboratory

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Byron J. Adams
Brigham Young University

John L. Crawley

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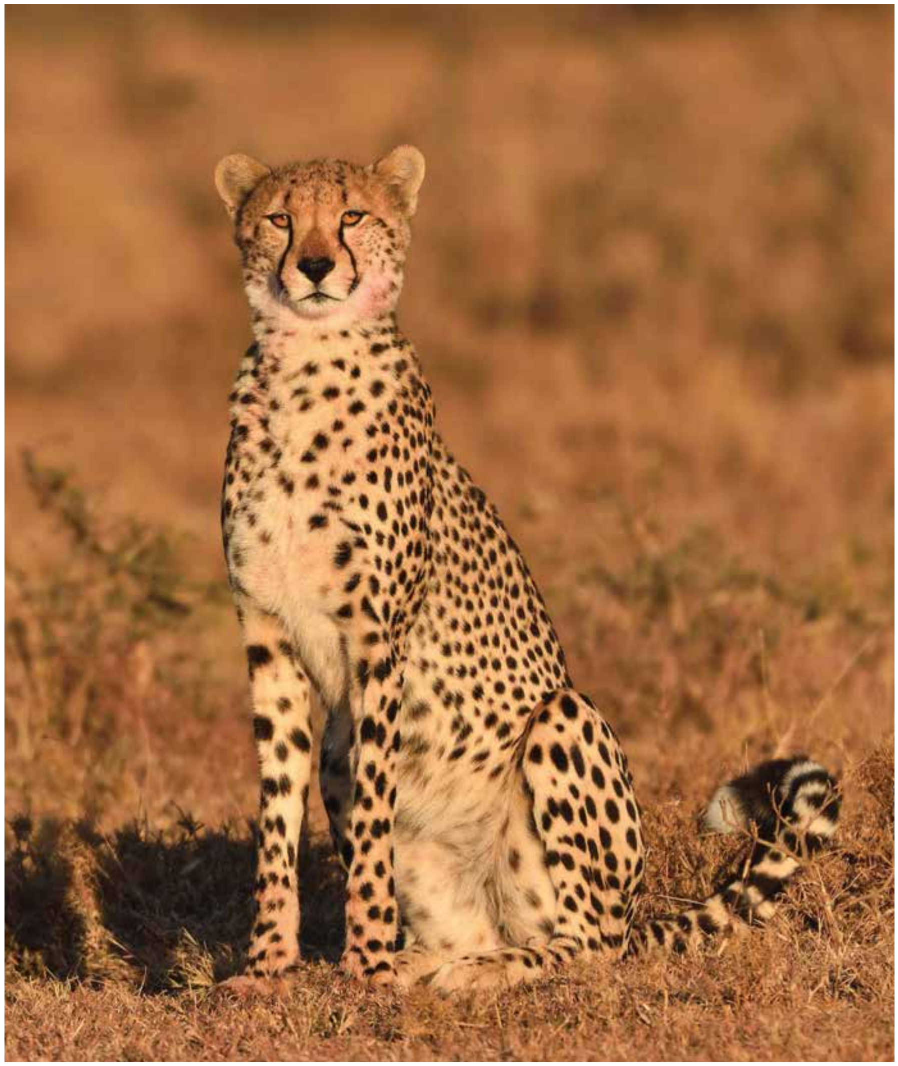
To our teachers, colleagues, friends, and students
who share with us a mutual love for biology.



A young cheetah, *Acinonyx jubatus*, in the morning light
on the Maasai Mara in Kenya, Africa.

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Cover: Horned puffin, *Fratercula corniculata*

Preface

Biology is an exciting, dynamic, and challenging science. It is the study of life. Students are fortunate to be living at a time when insights and discoveries in almost all aspects of biology are occurring at a very rapid pace. Much of the knowledge learned in a biology course has application in improving humanity and the quality of life. An understanding of biology is essential in establishing a secure foundation for more advanced courses in the biological sciences or health sciences.

Biology is a visually oriented science. *Van De Graaff's Photographic Atlas for the Biology Laboratory* is intended to provide you with quality photographs of animals similar to those you may have the opportunity to observe in a biology laboratory. It is designed to accompany any biology text or laboratory manual you may be using in the classroom. In certain courses *Van De Graaff's Photographic Atlas for the Biology Laboratory* could serve as the laboratory manual.

An objective of this atlas is to provide you with a balanced visual representation of the major kingdoms of biological organisms. Great care has been taken to construct completely labeled, informative figures that are depicted clearly and accurately. The micrographs are representative of what students will actually be looking at in their labs, not amazing one-of-a-kind photo contest winners. The terms used in this atlas are in agreement with those appearing in the more commonly used college biology texts.

Numerous dissections of plants and invertebrate and vertebrate animals were completed and photographed in the preparation of this atlas. These images are included for those students who have the opportunity to do similar dissections as part of their laboratory requirement.

Chapter 9 of this atlas is devoted to the biology of the human organism, which is emphasized in many biology textbooks and courses. In this chapter, you are provided with a complete set of photographs for each of the human body systems. Human cadavers have been carefully dissected and photographed to clearly depict each of the principal organs from each of the body systems. Selected radiographs (X-rays), CT scans, and MR images depict structures from living persons and thus provide an applied dimension to this portion of the atlas.

Preface to Eighth Edition

The success of the previous editions of *Van De Graaff's Photographic Atlas for the Biology Laboratory* provided opportunities to make changes to enhance the value of this new edition in aiding students in learning about living organisms. The revision of this atlas presented in its eighth edition required planning, organization, and significant work. As authors we have the opportunity and obligation to listen to the critiques and suggestions from students and faculty who have used this atlas. This constructive input is appreciated and has resulted in a greatly improved atlas.

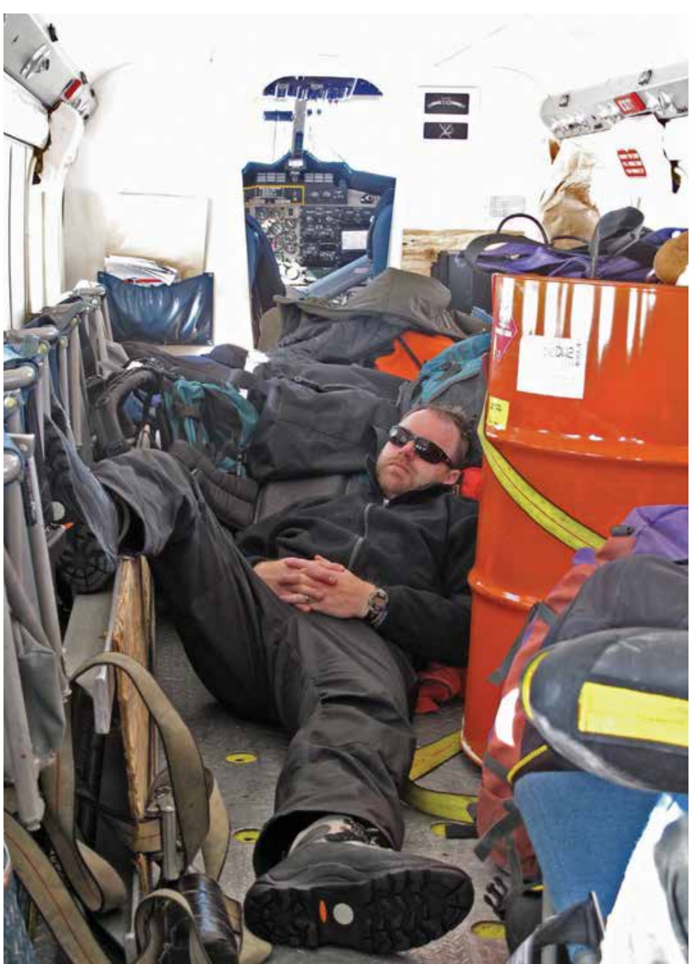
One objective in preparing this edition of the atlas was to create an inviting and updated pedagogy. The page layout was improved by careful selection of updated, new, and replacement photographs. Cladograms were updated, making the connections between taxonomy, morphology, and evolutionary history more intuitive. Images in this atlas were carefully evaluated for their quality, effectiveness, and accuracy. Enlarged images, in certain chapters, and additional photographs of representative organisms were added. Micrographs were chosen that would closely approximate what students would see in the lab.

About the Authors

Byron J. Adams

Byron grew up on a small farm in rural northeastern California, where his parents and schoolteachers nurtured his love of the natural world. He completed his undergraduate degree in Zoology in 1993 from Brigham Young University with an emphasis in marine biology and his Ph.D. in Biological Sciences from the University of Nebraska in 1998. Following a short stint as a postdoctoral fellow at the University of California-Davis, Byron took his first faculty position at the University of Florida prior to returning to Brigham Young University.

Byron's approach to understanding biology involves inferring evolutionary processes from patterns in nature. His research programs in biodiversity, evolution, and ecology have had the continuous support of the National Science Foundation as well as other agencies, including the United States Department of Agriculture and the National Human Genome Research Institute. His most recent projects involve fieldwork in Antarctica, where he and his colleagues are studying the relationship between biodiversity, ecosystem functioning, and climate change. When he's not freezing his butt off in the McMurdo Dry Valleys or southern Transantarctic Mountains, he makes his home in Woodland Hills, Utah.



Byron, on the plane, making his way back from the Transantarctic Mountains and heading for McMurdo Station.

John L. Crawley

John spent his early years growing up in Southern California, where he took every opportunity to explore nature and the outdoors. He currently resides in Provo, Utah, where he enjoys the proximity to the mountains, desert, and local rivers and lakes.

He received his degree in Zoology from Brigham Young University in 1988. While working as a researcher for the National Forest Service and Utah Division of Wildlife Resources in the early 1990s, John was invited to work on his first project for Morton Publishing, *A Photographic Atlas for the Anatomy and Physiology Laboratory.* After completion of that title, John has continued to work with Morton Publishing, and, to date, he has completed eight titles with them.

John has spent much of his life observing nature and taking pictures. His photography has provided the opportunity for him to travel widely, allowing him to observe and learn about other cultures and lands. His photos have appeared in national ads, magazines, and numerous publications. He has worked for groups such as Delta Airlines, *National Geographic*, Bureau of Land Management, U.S. Forest Service, and many others. His projects with Morton Publishing have been a great fit for his passion for photography and the biological sciences.

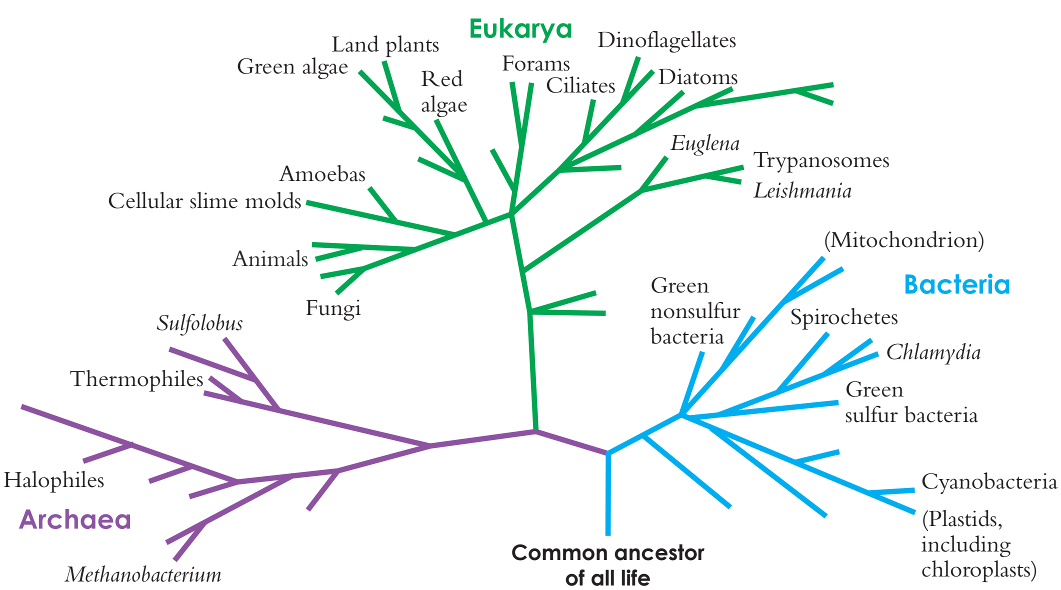
John snorkeling with green sea turtles in the Galapagos.

Prelude

Scientists work to determine accuracy in understanding the relationship of organisms even when it requires changing established concepts. DNA sequences, developmental pathways, and morphological structures, along with the fossil record and geological dating, are used to recover the evolutionary history of life (phylogeny) and represent this in a hierarchical classification (taxonomy). New methods for generating and analyzing evolutionary hypotheses continue to improve our understanding of phylogenetic relationships. Because classification schemes that reflect phylogenetic relationships have so much more explanatory power than simple lists of organisms, scientists are constantly updating their classification schemes to reflect these advances in knowledge.

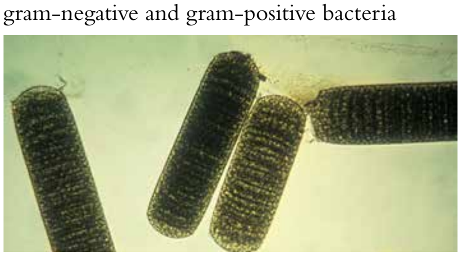
In 1758, Carolus Linnaeus, a Swedish naturalist, assigned all known kinds of organisms into two kingdoms—plants and animals. For over two centuries, this dichotomy of plants and animals served biologists well but has been replaced by the hypothesis of shared common ancestry by three major evolutionary lineages (see Exhibit 1). This hypothesis is based primarily on DNA sequence data but corroborates numerous other lines of evidence as well.

Exhibit 1 Domains, Kingdoms, and Representative Examples



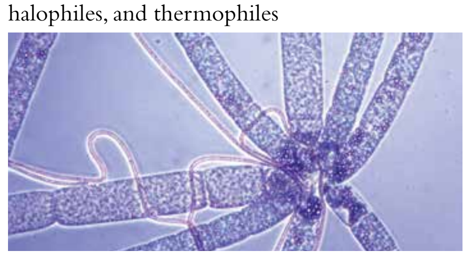
The Three Domains of Life
This phylogenetic tree summarizes the classification that depicts all of life divided into three domains—Bacteria, Archaea, and Eukarya. Note the diversity of the nonanimal lineages relative to the other organisms, their relatively recent emergence, and the bacterial origin of mitochondria and chloroplasts.

Domain Bacteria – Cyanobacteria, gram-negative and gram-positive bacteria



Oscillatoria sp., a cyanobacterium that reproduces through fragmentation.

Domain Archaea – Methanogens, halophiles, and thermophiles

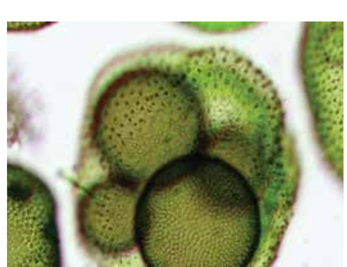


Thiothrix sp., a thermophile that oxidizes H_2S for an energy source.

Domain Eukaryota – Eukaryotes, single-celled, and multicelled organisms; fungi, "protists," plants, and animals

Kingdom Fungi | **Supergroup Archaeplastida** | **Kingdom Plantae** | **Kingdom Animalia**

Aspergillus sp. is a mold that reproduces asexually and sometimes sexually.



Volvox sp. is a motile green alga that reproduces asexually or sexually.

Musa sp., the banana, is high in nutritional value.

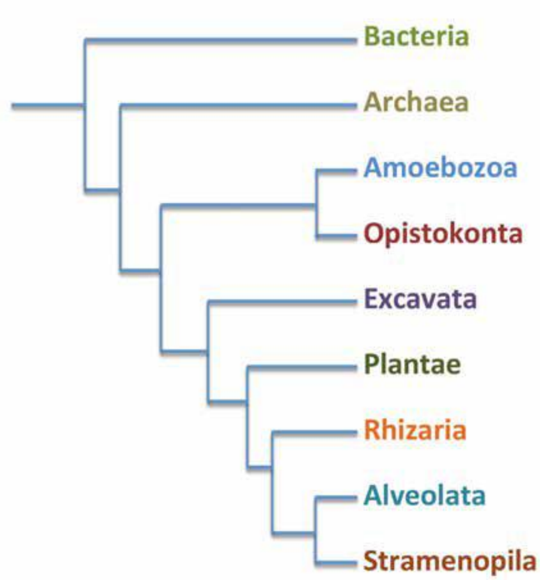
Chamaeleo calyptratus, the veiled chameleon, is known for its ability to change colors according to its mood.

Basic Characteristics of Domains

Characteristics	Domain Bacteria	Domain Archaea	Domain Eukarya
Nuclear envelope encloses genetic material (DNA)	No	No	Yes
Circular chromosomes	Yes (usually)	Yes	No
Membrane-enclosed organelles	No	No	Yes
Rotary flagella	Yes	Yes	No (cilia and flagella are undulatory)
Multicellular "species"*	No (although some cyanobacteria could be exceptions)	No	Yes (but there are also unicellular eukaryotes)
Cell walls (if present) composed of peptidoglycan	Yes	No	No
Plasma membrane lipids made of unbranched fatty acids bonded to glycerol by ester bonds	Yes	No (ether linkages)	Yes
RNA polymerase of more than 10 subunits	No (5 subunits)	Yes (13)	Yes (14+)
Number distinct types of RNA polymerase	1	1 (closely related to Pol II)	3 (Pol I, II, and III)
Initiation of translation	N-formylmethionine (fMet)	Methionine	Methionine

* Due primarily to their proclivity for horizontal gene transfer, Bacteria and Eukarya don't have species in the same sense that most Eukarya do (independently evolving evolutionary lineages with unique origins and fates).

Phylogenetic Relationships among the Major Groups of Eukaryotes



Common Classification System of Some Groups of Living Eukaryotes

- **Unikonta**
  - **Amoebozoa**
    - Phylum Amoebozoa
    - Phylum Myxomycota
  - **Opisthokonta**
    - **Kingdom Fungi**
      - Phylum Chytridiomycota
      - Phylum Zygomycota
      - Phylum Glomeromycota
      - Phylum Ascomycota
      - Phylum Basidiomycota
    - **Kingdom Animalia**
      - Phylum Porifera
      - Phylum Ctenophora
      - Phylum Cnidaria
      - **Protostomia**
        - **Lophotrochozoa**
          - Phylum Rotifera
          - Phylum Platyhelminthes
          - Phylum Gastrotricha
          - Phylum Brachiopoda
          - Phylum Phoronida
          - Phylum Nemertea
          - Phylum Entoprocta
          - Phylum Bryozoa
          - Phylum Annelida
          - Phylum Mollusca
        - **Ecdysozoa**
          - Phylum Kinorhyncha
          - Phylum Nematoda
          - Phylum Nematomorpha
          - Phylum Arthropoda
          - Phylum Tardigrada
      - **Deuterostomia**
        - Phylum Hemichordata
        - Phylum Echinodermata
        - Phylum Chordata
- **Bikonta**
  - **Excavata**
    - Phylum Euglenozoa
    - Phylum Metamonada
  - **Kingdom Plantae**
    - Phylum Rhodophyta
    - **Green Algae**
      - Phylum Chlorophyta
      - **Land Plants**
        - Phylum Hepatophyta
        - Phylum Bryophyta
        - Phylum Anthocerophyta
        - **Vascular Plants**
          - Phylum Lycophyta
          - Phylum Psilotophyta
          - Phylum Pteridophyta
          - Phylum Equisetophyta
          - **Seed Plants**
            - **Gymnosperms**
              - Phylum Ginkgophyta
              - Phylum Cycadophyta
              - Phylum Pinophyta
              - Phylum Gnetophyta
            - **Angiosperms**
              - Phylum Magnoliophyta (= Anthophyta)
- **Rhizaria**
  - Phylum Foraminifera
  - Phylum Cercozoa
- **Alveolata**
  - Phylum Ciliophora
- **Stramenopila**
  - Phylum Heterokontophyta
  - Phylum Oomycota
  - Phylum Phaeophyta

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Photo Credits

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Figure 1.2 Leica Microsystems

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Contents

1 Cells and Tissues

All organisms are composed of one or more cells. *Cells* are the basic structural and functional units of organisms. A cell is a minute, membrane-enclosed, protoplasmic mass consisting of chromosomes surrounded by cytoplasm. Specific organelles are contained in the cytoplasm that function independently but in coordination with one another. Prokaryotic cells (Fig. 1.1) and eukaryotic cells (Figs. 1.3 and 1.18) are the two basic types.

Prokaryotic cells lack a membrane-bound nucleus, instead containing a single strand of *nucleic acid*. These cells contain few organelles. A rigid or semirigid cell wall provides shape to the cell outside the *cell* (*plasma*) *membrane*. Bacteria are examples of prokaryotic, single-celled organisms.

Eukaryotic cells contain a true *nucleus* with multiple chromosomes, have several types of specialized organelles, and have a differentially permeable cell membrane. Organisms consisting of eukaryotic cells include protozoa, fungi, algae, plants, and invertebrate and vertebrate animals.

Plant cells differ in some ways from other eukaryotic cells in that their cell walls contain *cellulose* for stiffness (Fig. 1.3). Plant cells also contain vacuoles for water storage and membrane-bound *chloroplasts* with photosynthetic pigments for photosynthesis.

The *nucleus* is the large, spheroid body within the eukaryotic cell that contains the genetic material of the cell. The nucleus is enclosed by a double membrane called the *nuclear membrane*, or *nuclear envelope*. The *nucleolus* is a dense, nonmembranous body composed of protein and RNA molecules. The chromatin are fibers of protein and DNA molecules that make up a eukaryotic chromosome. Prior to cellular division, the chromatin shortens and coils into rod-shaped *chromosomes*. Chromosomes consist of DNA and structural proteins called *histones*.

The *cytoplasm* of the eukaryotic cell is the medium between the nuclear membrane and the cell membrane. *Organelles* are small membrane-bound structures within the cytoplasm. The cellular functions carried out by organelles are referred to as *metabolism*. The structure and function of the nucleus and principal organelles are listed in Table 1.1. In order for cells to remain alive, metabolize, and maintain homeostasis, they must have access to nutrients and respiratory gases, be able to eliminate wastes, and be in a constant, protective environment.

The *cell membrane* is composed of phospholipid, protein, and carbohydrate molecules. The cell membrane gives form to a cell and controls the passage of material into and out of a cell. More specifically, the proteins in the cell membrane provide:

1. structural support;
2. a mechanism of molecule transport across the membrane;
3. enzymatic control of chemical reactions;
4. receptors for hormones and other regulatory molecules; and
5. cellular markers (antigens), which identify the blood and tissue type.

The carbohydrate molecules:

1. repel negative objects due to their negative charge;
2. act as receptors for hormones and other regulatory molecules;
3. form specific cell markers that enable like cells to attach and aggregate into tissues; and
4. enter into immune reactions.

Tissues are groups of similar cells that perform specific functions (see Fig. 1.9). A flowering plant, for example, is composed of three tissue systems:

1. the *ground tissue system*, providing support, regeneration, respiration, photosynthesis, and storage;
2. the *vascular tissue system*, providing conduction passageways through the plant; and
3. the *dermal tissue system*, providing protection to the plant.

The tissues of the body of a multicellular animal are classified into four principal types (see Fig. 1.36):

1. *epithelial tissue* covers body and organ surfaces, lines body cavities and lumina (hollow portions of body tubes), and forms various glands;
2. *connective tissue* binds, supports, and protects body parts;
3. *muscle tissue* contracts to produce movements; and
4. *nervous tissue* initiates and transmits nerve impulses.

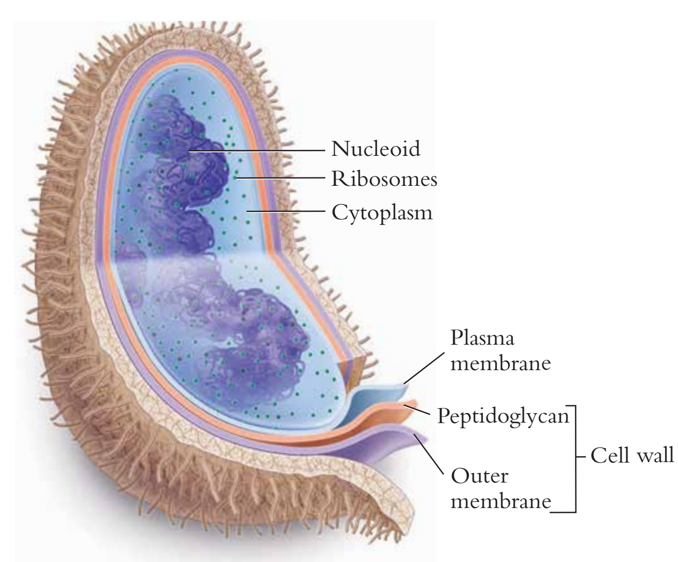


Figure 1.1 A generalized prokaryotic cell.

Table 1.1 Structure and Function of Eukaryotic Cellular Components

Component	Structure	Function
Cell (plasma) membrane	Composed of protein and phospholipid molecules	Provides form to cell; controls passage of materials into and out of cell
Cell wall	Cellulose fibrils	Provides structure and rigidity to plant cell
Cytoplasm	Fluid to jellylike substance	Serves as suspending medium for organelles and dissolved molecules
Endoplasmic reticulum	Interconnecting membrane-lined channels	Enables cell transport and processing of metabolic chemicals
Ribosome	Granules of nucleic acid (RNA) and protein	Synthesizes protein
Mitochondrion	Double-membraned sac with cristae (chambers)	Assembles ATP (cellular respiration)
Golgi complex	Flattened membrane-lined chambers	Synthesizes carbohydrates and packages molecules for secretion
Lysosome	Membrane-surrounded sac of enzymes	Digests foreign molecules and worn cells
Centrosome	Mass of protein that may contain rodlike centrioles	Organizes spindle fibers and assists mitosis and meiosis
Vacuole	Membranous sac	Stores and excretes substances within the cytoplasm; regulates cellular turgor pressure
Microfibril and microtubule	Protein strands and tubes	Forms cytoskeleton, supports cytoplasm, and transports materials
Cilium and flagellum	Cytoplasmic extensions from cell; containing microtubules	Movements of particles along cell surface, or cell movement
Nucleus	Nuclear envelope (membrane), nucleolus, and chromatin (DNA)	Contains genetic code that directs cell activity; forms ribosomes
Chloroplast	Inner (grana) membrane within outer membrane	Involved in photosynthesis

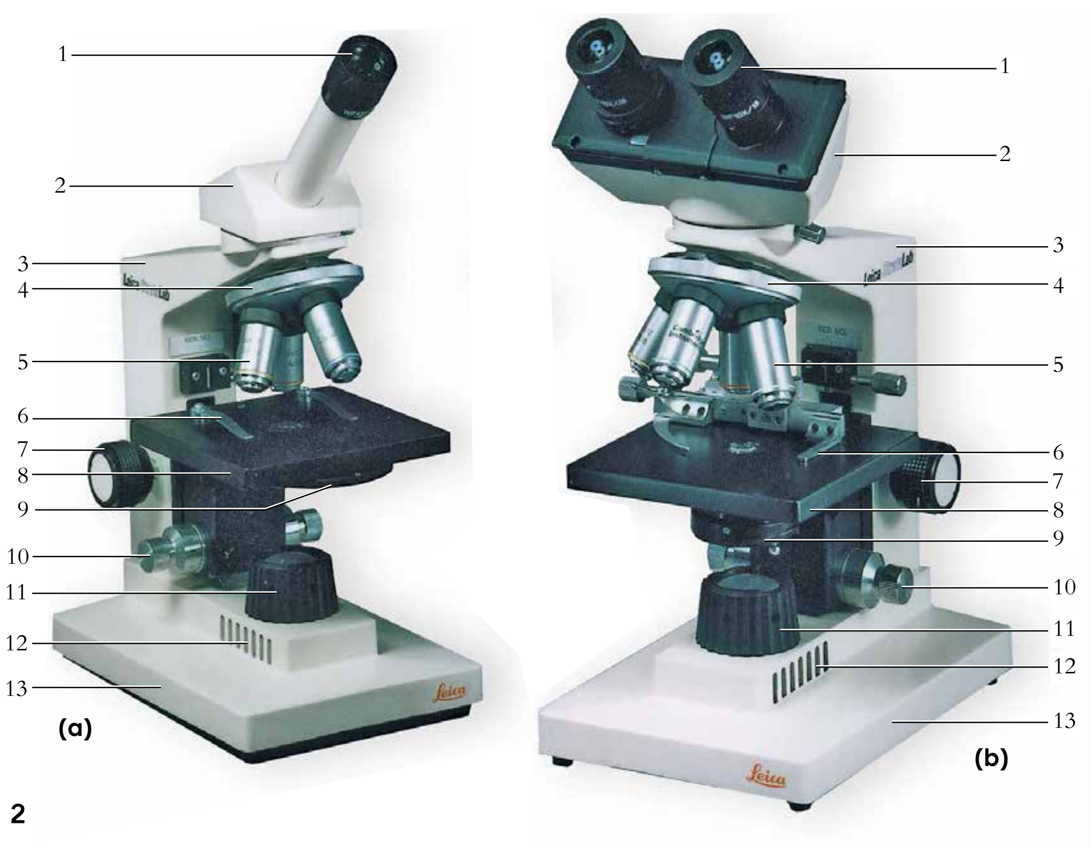


Figure 1.2 (a) A compound monocular microscope, and (b) a compound binocular microscope.
1. Eyepiece (ocular)
2. Head
3. Arm
4. Nosepiece
5. Objective
6. Stage clip
7. Coarse focus adjustment knob
8. Stage
9. Condenser
10. Fine focus adjustment knob
11. Collector lens with iris
12. Illuminator (inside)
13. Base

Plant Cells and Tissues

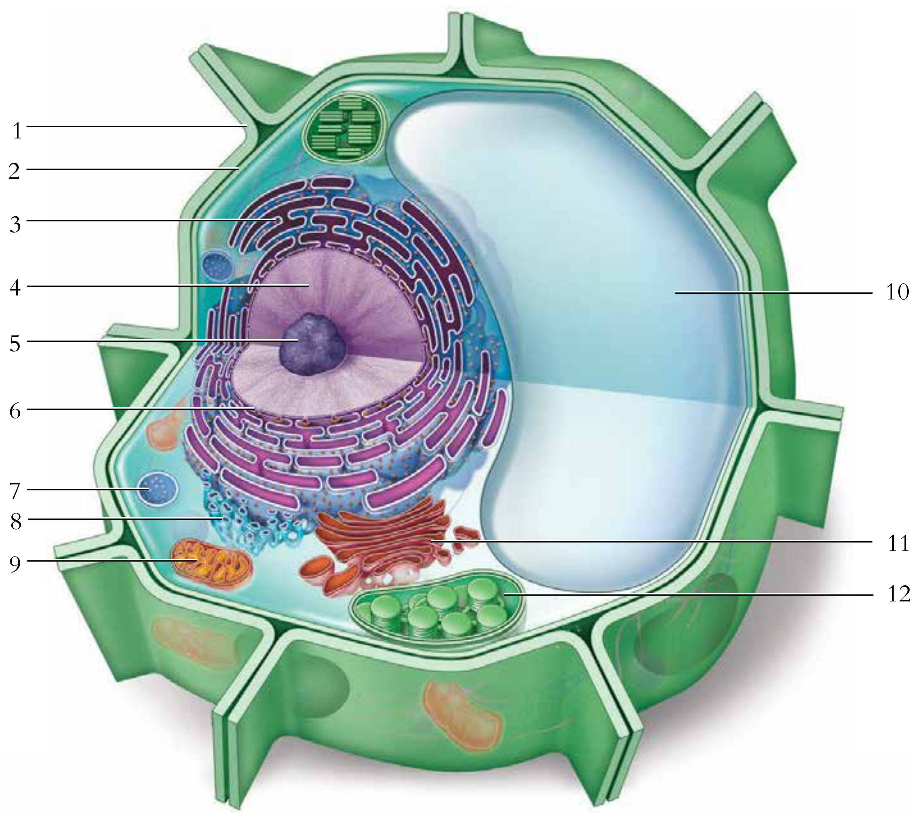


Figure 1.3 A typical eukaryotic plant cell.

1. Cell wall
2. Cell (plasma) membrane
3. Rough endoplasmic reticulum
4. Nucleus
5. Nucleolus
6. Nuclear membrane (envelope)
7. Lysosome
8. Smooth endoplasmic reticulum
9. Mitochondrion
10. Vacuole
11. Golgi complex
12. Chloroplast

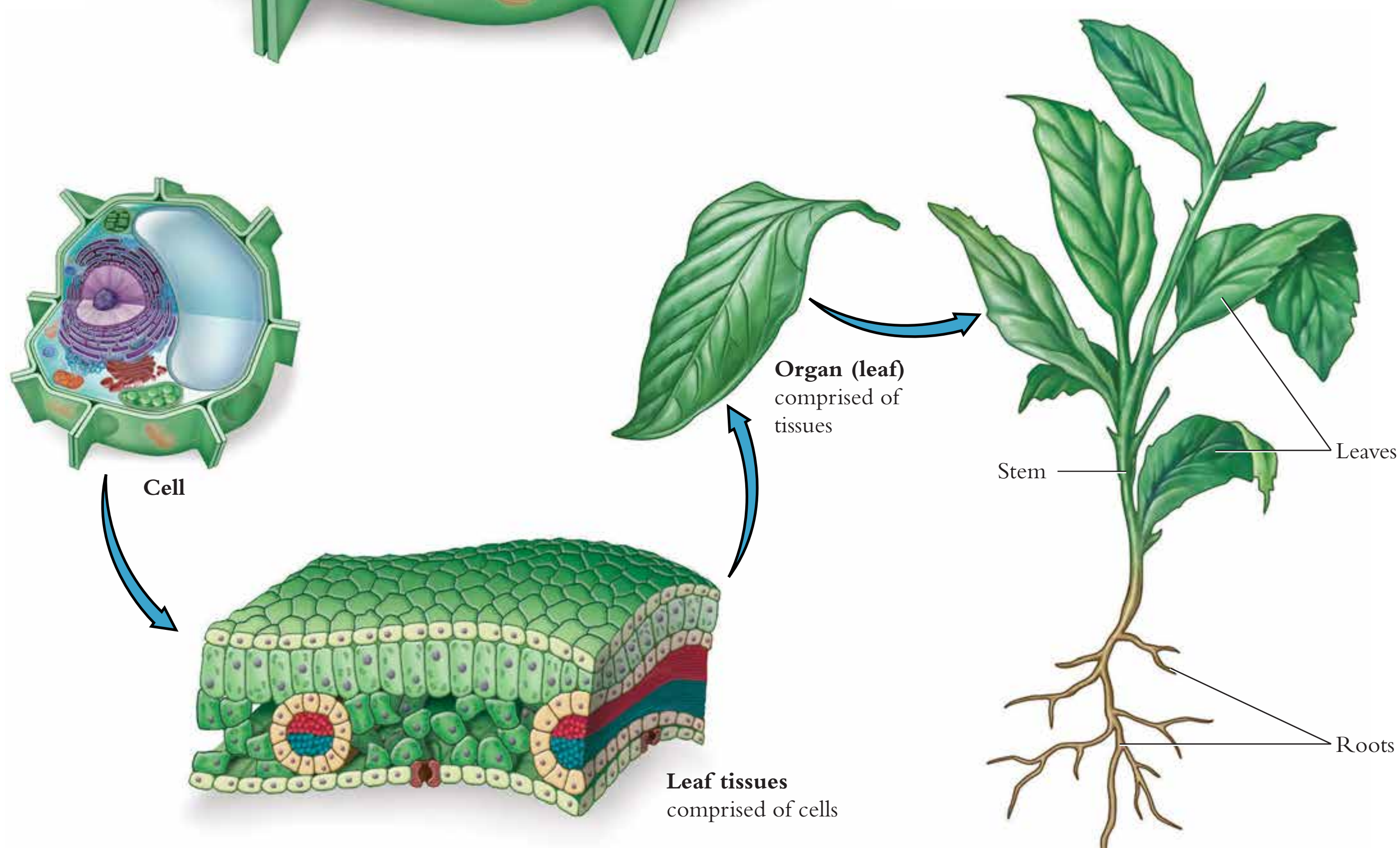
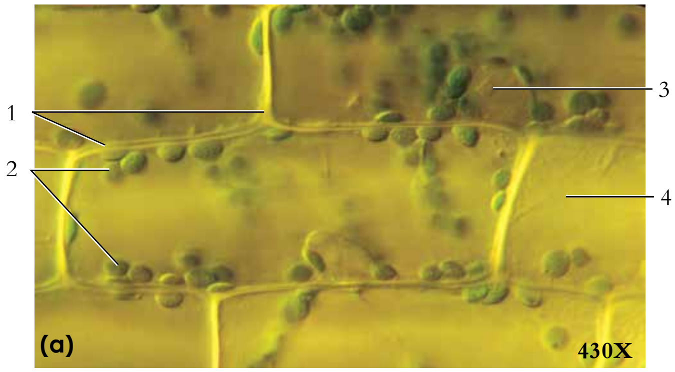


Figure 1.4 The structural levels of plant organization.



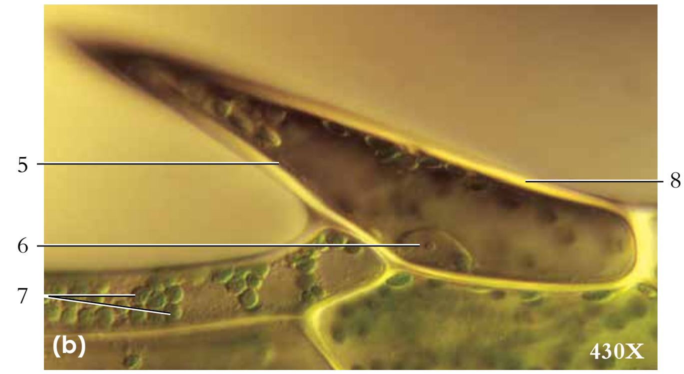
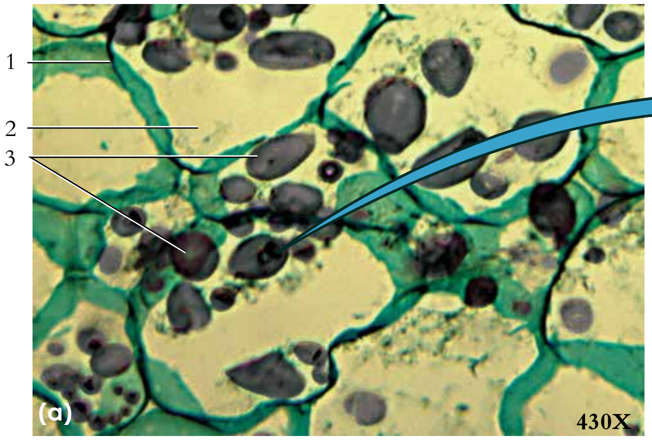


Figure 1.5 Live *Elodea* sp. leaf cells (a) photographed at the center of the leaf and (b) at the edge of the leaf.

1. Cell wall
2. Chloroplasts
3. Nucleus
4. Vacuole
5. Spine-shaped cell on exposed edge of leaf
6. Nucleus
7. Chloroplasts
8. Cell wall



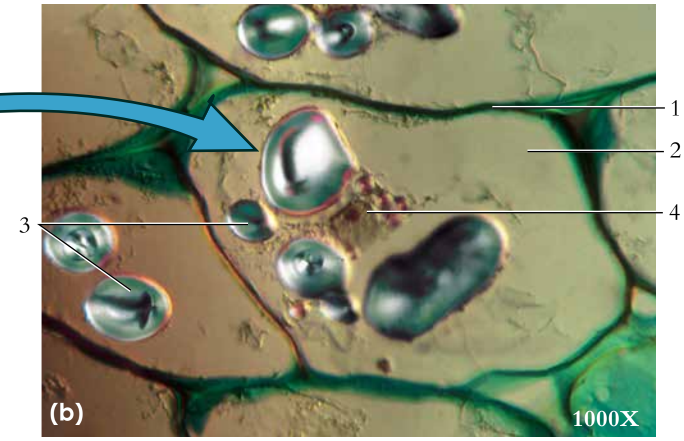


Figure 1.6 (a) Cells of a potato, *Solanum tuberosum*, showing starch grains at a low magnification, and (b) at a high magnification. Food is stored as starch in potato cells, which is deposited in organelles called amyloplasts.

1. Cell wall
2. Cytoplasm
3. Starch grains
4. Nucleus

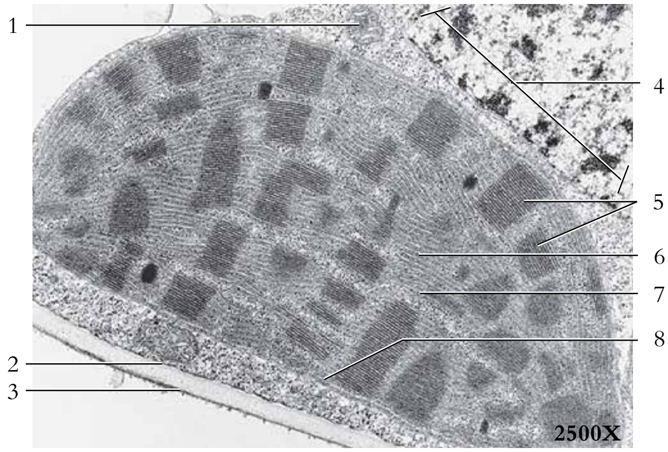


Figure 1.7 An electron micrograph of a portion of a sugarcane leaf cell.

1. Mitochondrion
2. Cell membrane
3. Cell wall
4. Nucleus
5. Grana
6. Stroma
7. Thylakoid membrane
8. Chloroplast envelope (outer membrane)

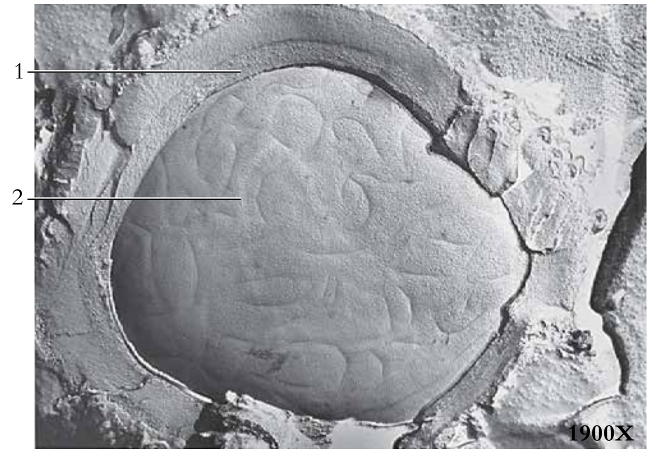


Figure 1.8 A fractured barley smut spore.

1. Cell wall
2. Cell membrane

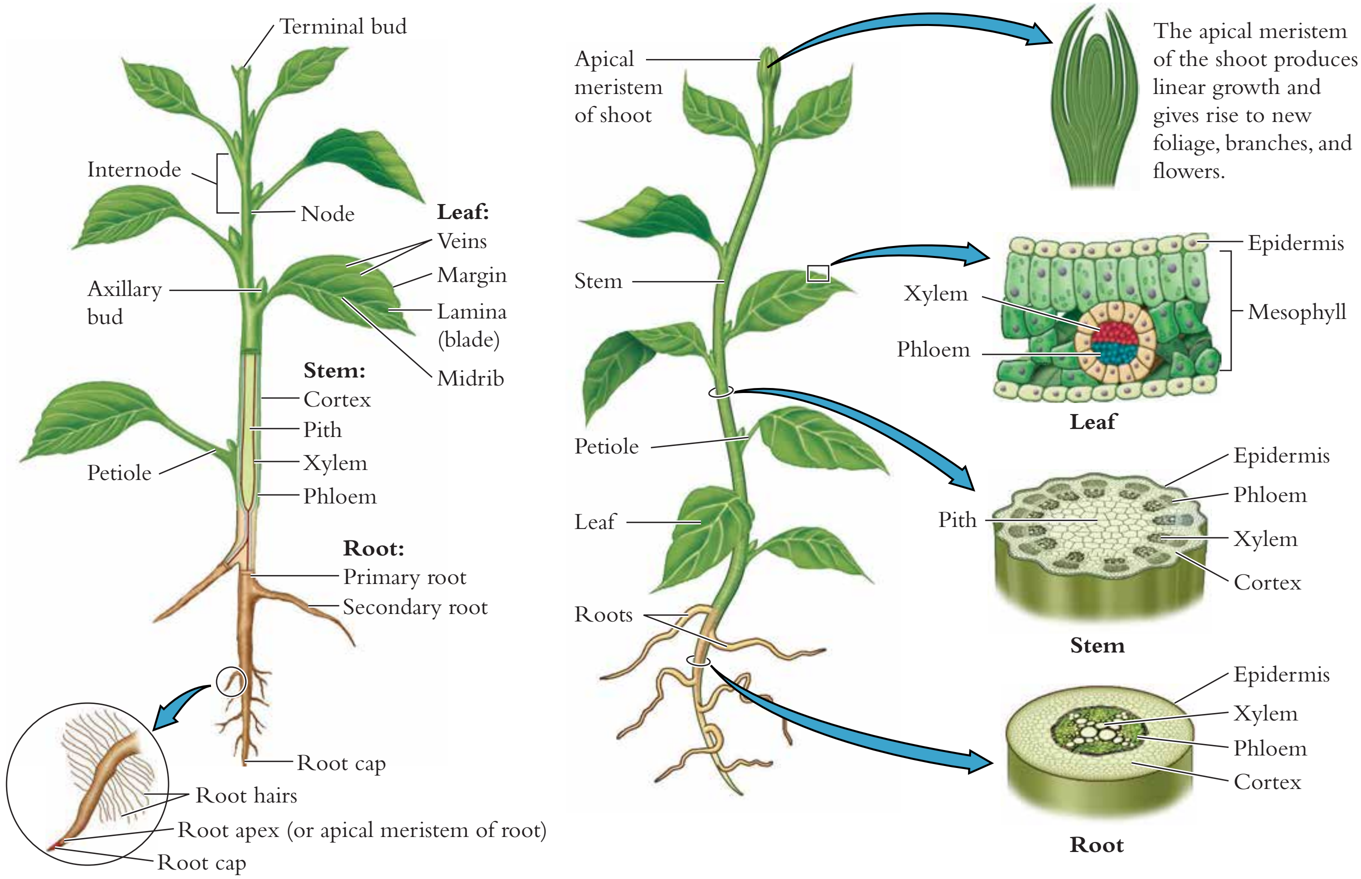


Figure 1.9 A diagram illustrating the anatomy and the principal organs and tissues of a typical dicot.

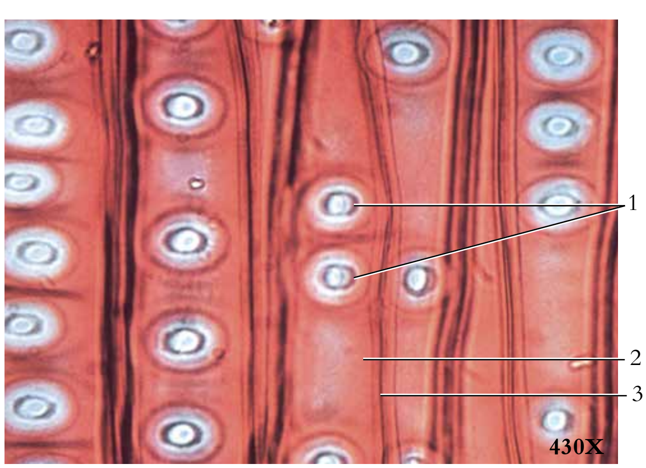


Figure 1.10 A longitudinal section through the xylem of a pine, *Pinus*, showing tracheid cells with prominent bordered pits.

1. Bordered pits
2. Tracheid cell
3. Cell wall

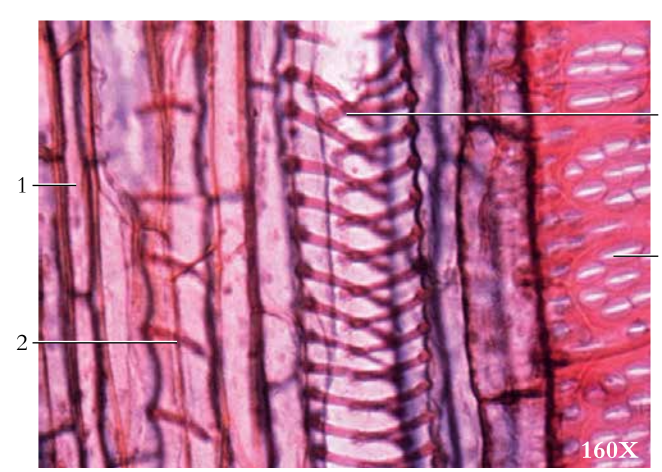


Figure 1.11 Longitudinal section through the xylem of a squash stem, *Cucurbita maxima.* The vessel elements shown here have several different patterns of wall thickenings.

1. Parenchyma
2. Annular vessel elements
3. Helical vessel elements
4. Pitted vessel elements

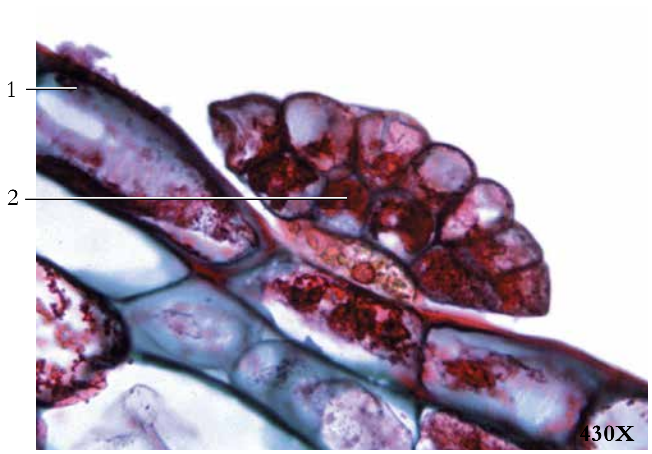


Figure 1.12 A section through a leaf of the venus flytrap, *Dionaea muscipula*, showing epidermal cells with a digestive gland. The gland is composed of secretory parenchyma cells.
1. Epidermis
2. Gland

Figure 1.13 An astrosclereid in the petiole of a pond lily, *Nuphar*.
1. Astrosclereid
2. Parenchyma cell
3. Crystals in cell wall

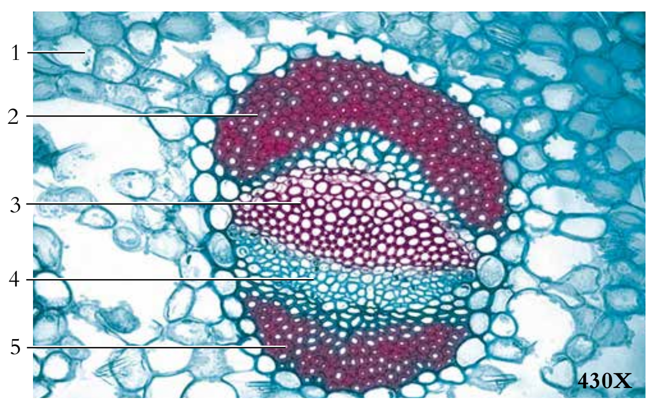


Figure 1.14 A transverse section through the leaf of a yucca, *Yucca brevifolia*, showing a vascular bundle (vein). Note the prominent sclerenchyma tissue forming caps on both sides of the bundle.
1. Leaf parenchyma
2. Leaf sclerenchyma (bundle cap)
3. Xylem
4. Phloem
5. Bundle cap

Figure 1.15 A section through the endosperm tissue of a persimmon, *Diospyros virginiana*. These thick-walled cells are actually parenchyma cells. Cytoplasmic connections, or plasmodesmata, are evident between cells.
1. Plasmodesmata
2. Cell lumen (interior space)

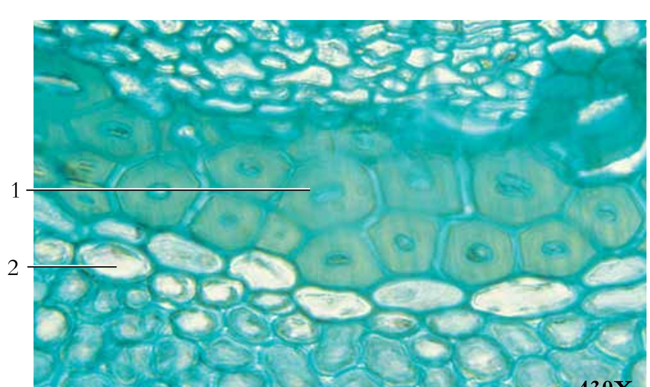


Figure 1.16 A transverse section through the stem of flax, *Linum*. Note the thick-walled fibers as compared to the thin-walled parenchyma cells.
1. Fibers
2. Parenchyma cell

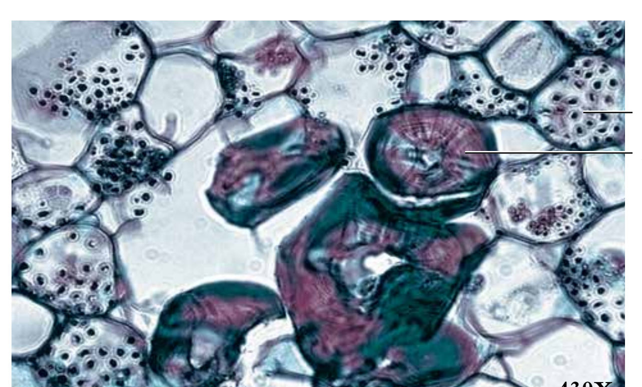


Figure 1.17 A section through the stem of a wax plant, *Hoya carnosa*. Thick-walled sclereids (stone cells) are evident.
1. Parenchyma cell containing starch grains
2. Sclereid (stone cell)

Animal Cells and Tissues

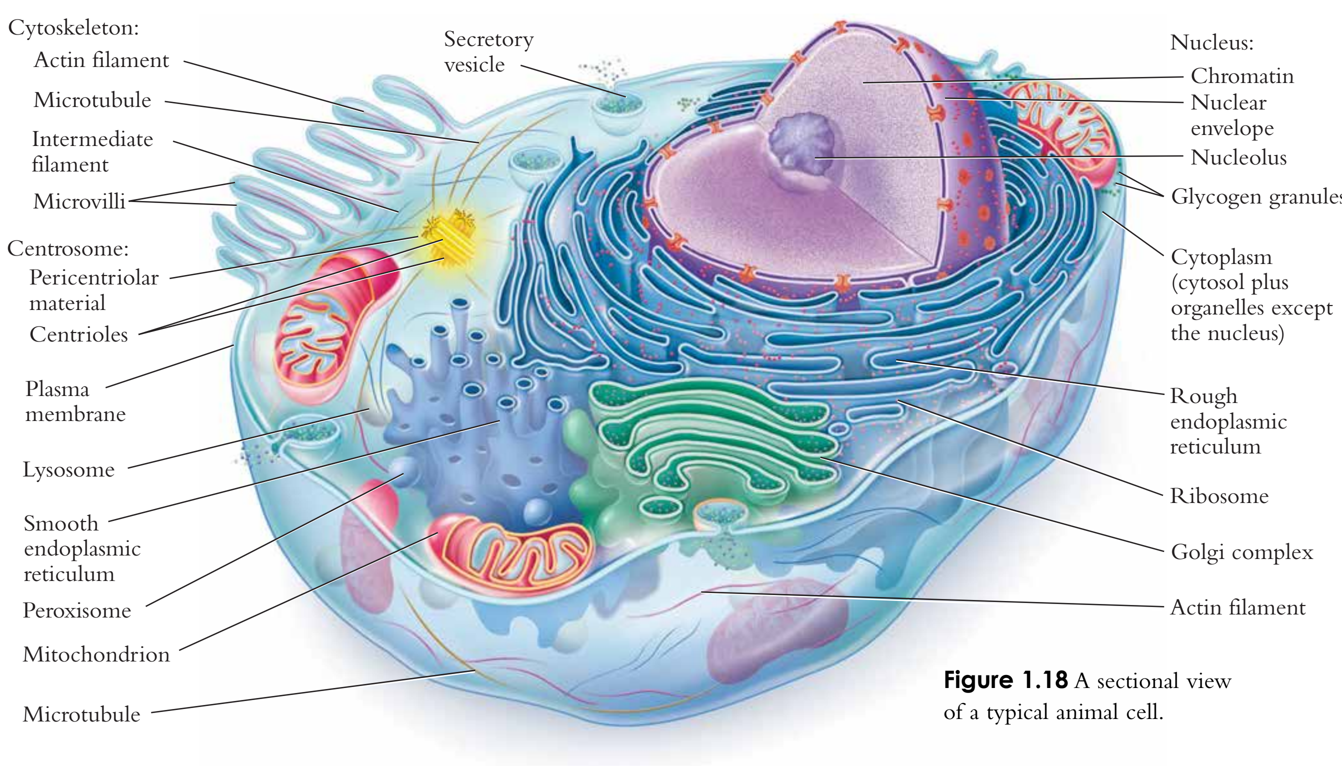


Figure 1.18 A sectional view of a typical animal cell.

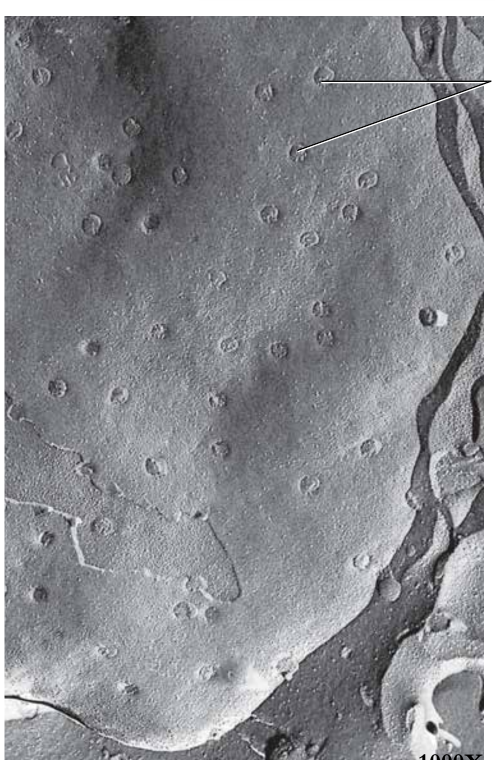


Figure 1.19 An electron micrograph of a freeze-fractured nuclear envelope showing the nuclear pores.
1. Nuclear pores

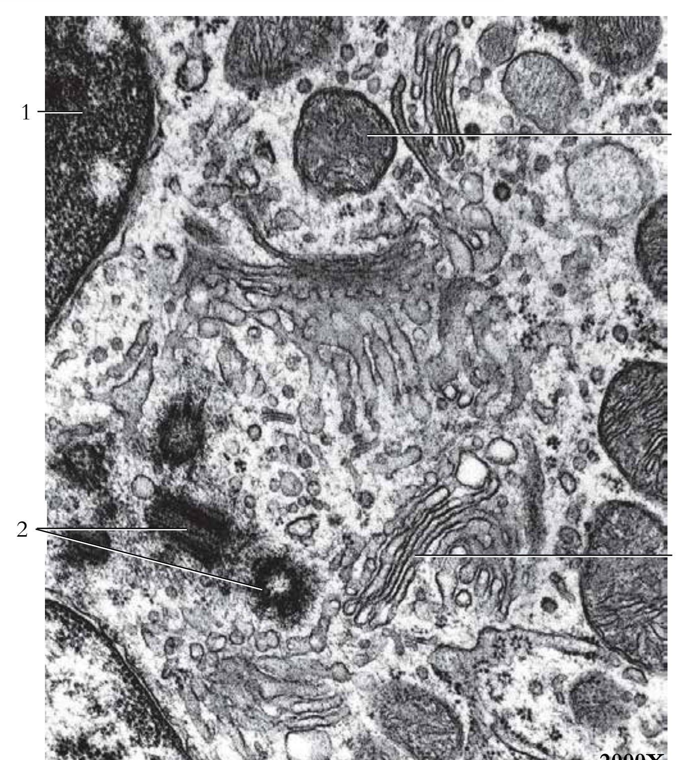


Figure 1.20 An electron micrograph of various organelles.

1. Nucleus
2. Centrioles
3. Mitochondrion
4. Golgi complex

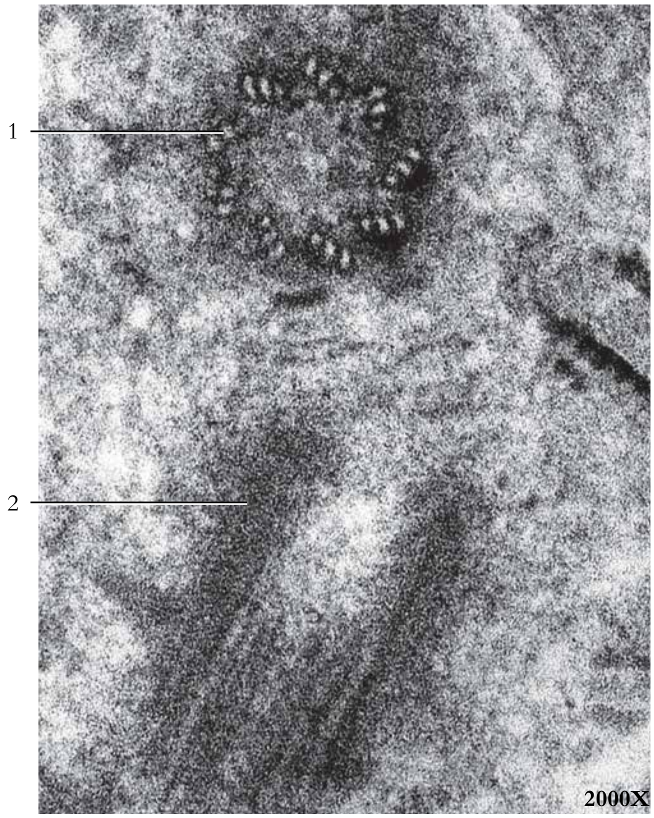


Figure 1.21 An electron micrograph of centrioles. The centrioles are positioned at right angles to one another.
1. Centriole (shown in transverse section)
2. Centriole (shown in longitudinal section)

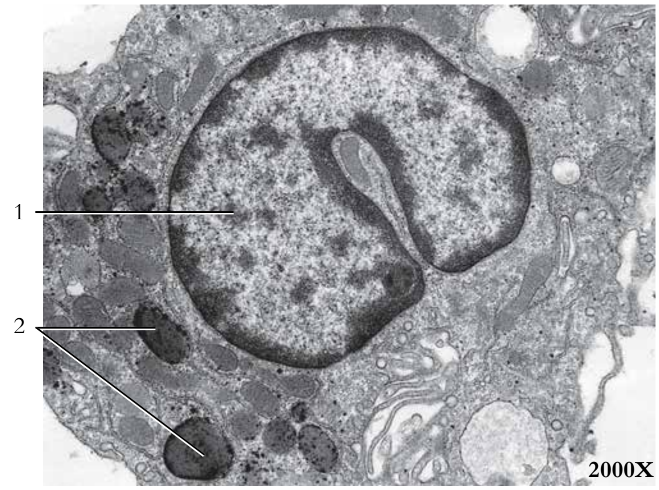


Figure 1.22 An electron micrograph of lysosomes.
1. Nucleus
2. Lysosomes

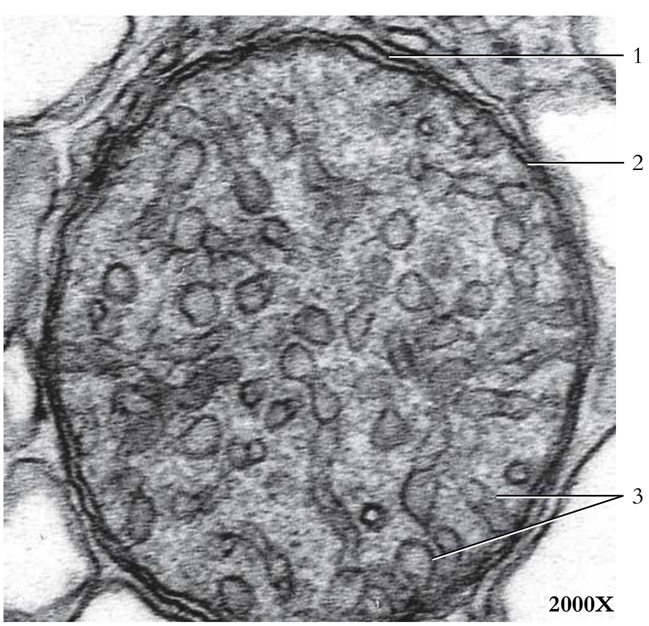


Figure 1.23 An electron micrograph of a mitochondrion.
1. Outer membrane
2. Inner membrane
3. Crista

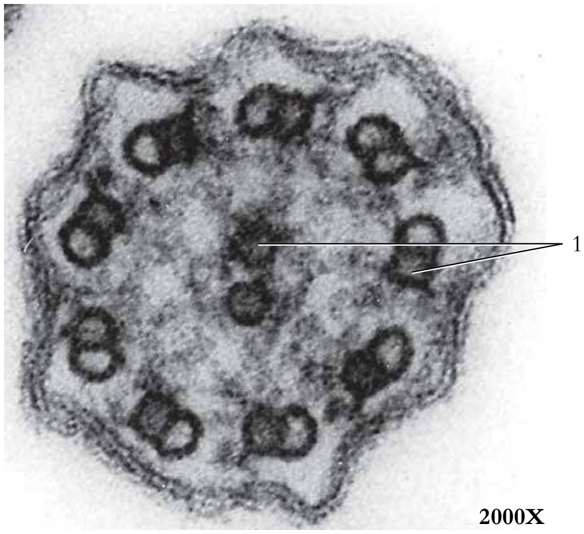


Figure 1.24 An electron micrograph of cilia (transverse section) showing the characteristic "9 + 2" arrangement of microtubules in the transverse sections.
1. Microtubules

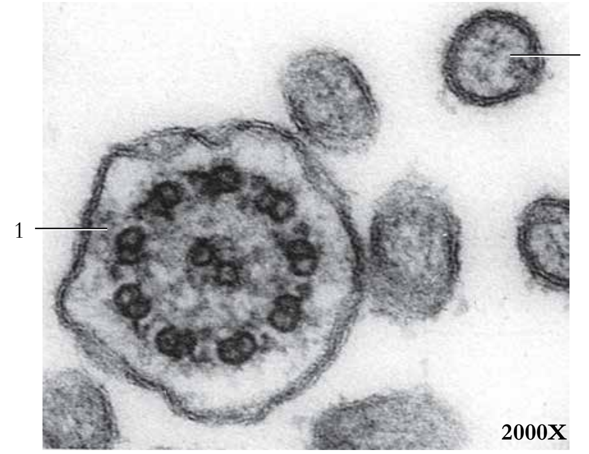


Figure 1.25 An electron micrograph showing the difference between a microvillus and a cilium.
1. Cilium
2. Microvillus

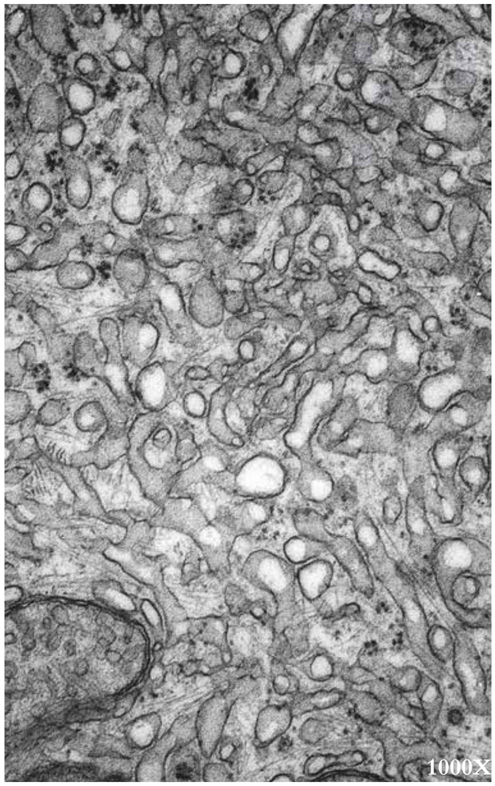


Figure 1.26 An electron micrograph of smooth endoplasmic reticulum from the testis.

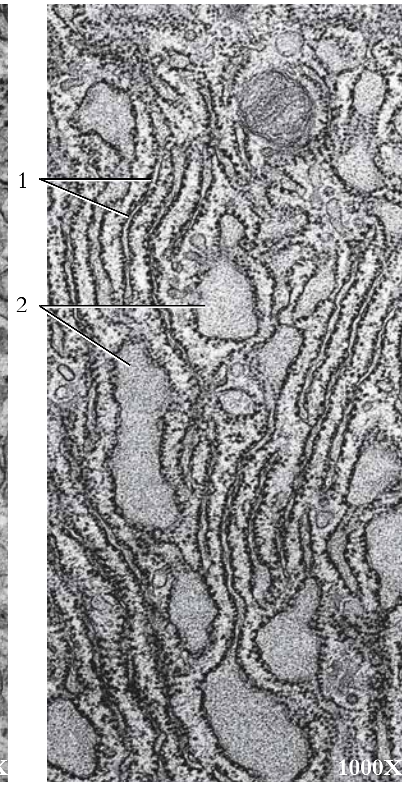


Figure 1.27 An electron micrograph of rough endoplasmic reticulum.

1. Ribosomes
2. Cisternae

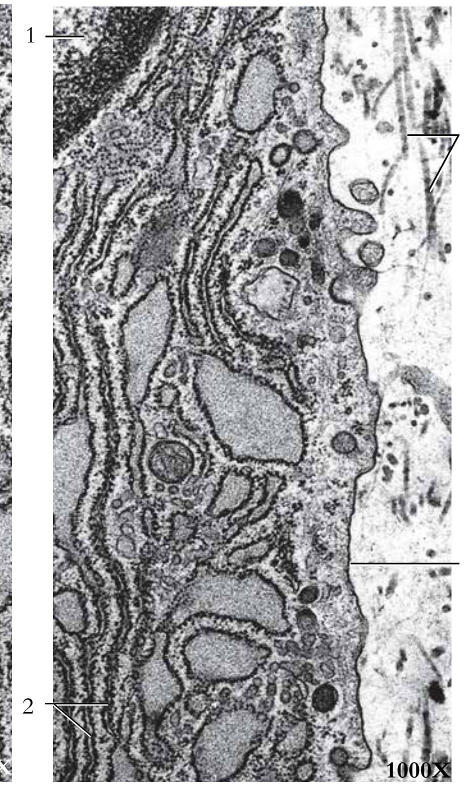


Figure 1.28 An electron micrograph of rough endoplasmic reticulum secreting collagenous filaments to the outside of the cell.

1. Nucleus
2. Rough endoplasmic reticulum
3. Collagenous filaments
4. Cell membrane

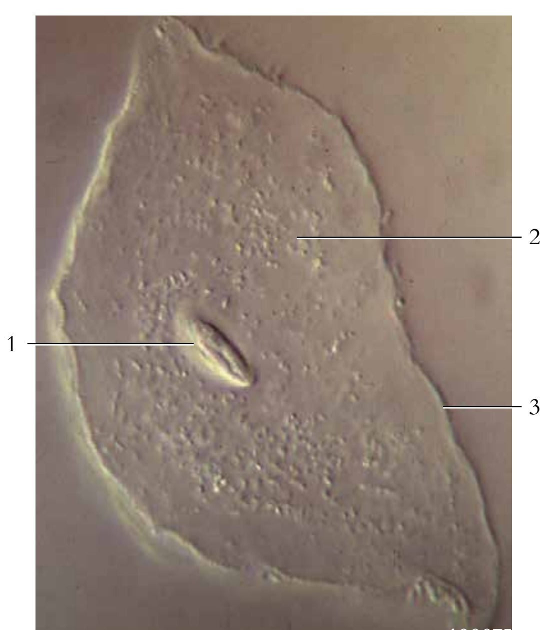


Figure 1.29 An epithelial cell from a cheek scraping.

1. Nucleus
2. Cytoplasm
3. Cell membrane

Figure 1.30 An electron micrograph of a human erythrocyte (red blood cell).

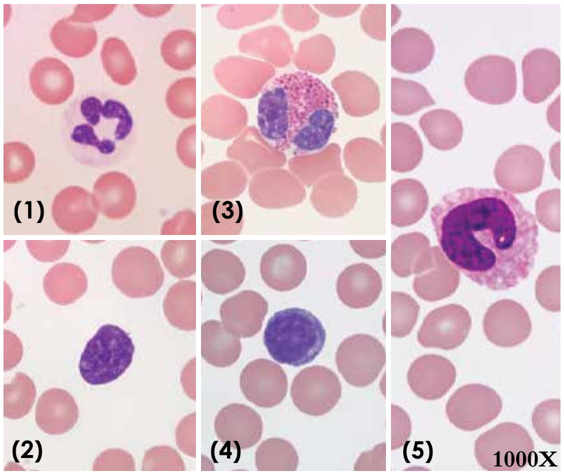


Figure 1.31 Types of leukocytes. Note that each photo contains several erythrocytes; these cells lack nuclei.

1. Neutrophil
2. Basophil
3. Eosinophil
4. Lymphocyte
5. Monocyte

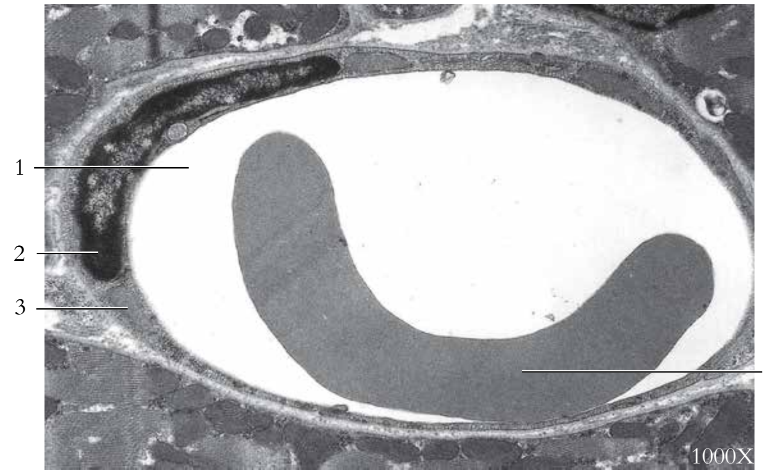


Figure 1.32 An electron micrograph of a capillary containing an erythrocyte.

1. Lumen of capillary
2. Nucleus of endothelial cell
3. Endothelial cell
4. Erythrocyte

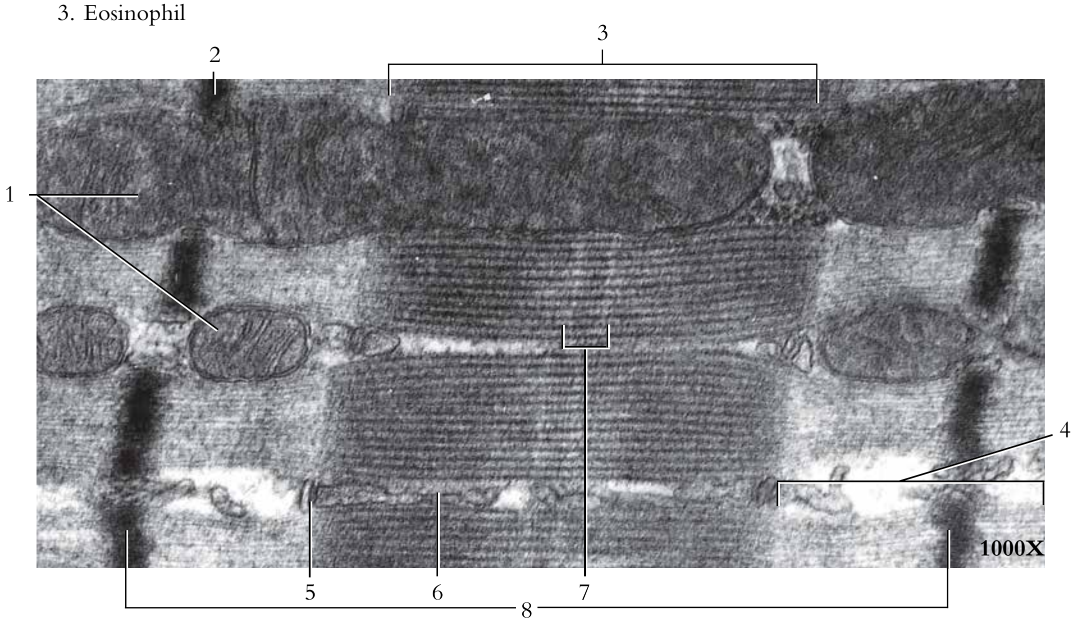


Figure 1.33 An electron micrograph of a skeletal muscle myofibril, showing the striations.

1. Mitochondria
2. Z line
3. A band
4. I band
5. T-tubule
6. Sarcoplasmic reticulum
7. M line
8. Sarcomere

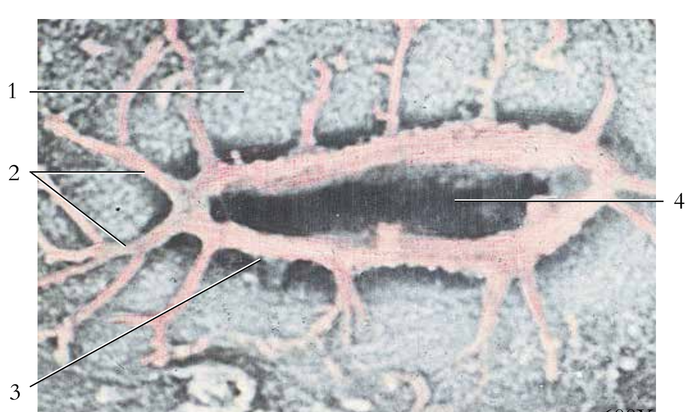


Figure 1.34 An electron micrograph of an osteocyte (bone cell) in cortical bone matrix.

1. Bone matrix
2. Canaliculi
3. Lacuna
4. Osteocyte

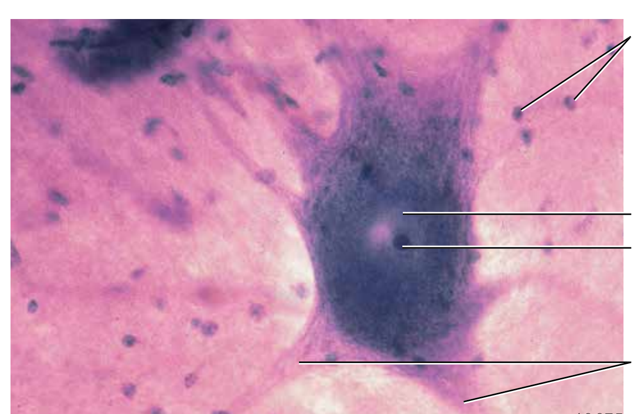
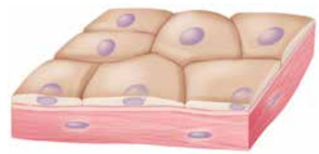


Figure 1.35 A neuron smear.

1. Nuclei of surrounding neuroglial cells
2. Nucleus of neuron
3. Nucleolus of neuron
4. Dendrites of neuron

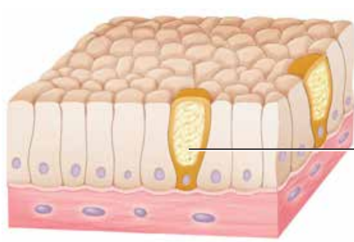
Epithelial Tissue

Epithelial tissue covers the outside of the body and lines all organs. Its primary function is to provide protection.



Simple squamous epithelium

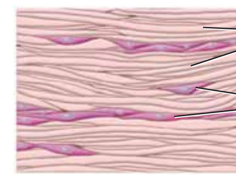
Simple cuboidal epithelium



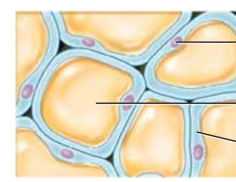
Simple columnar epithelium

Connective Tissue

Connective tissue functions as a binding and supportive tissue for all other tissues in the organism.



Dense regular connective tissue

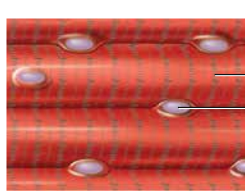


Adipose tissue

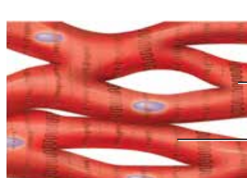
Bone tissue

Muscle Tissue

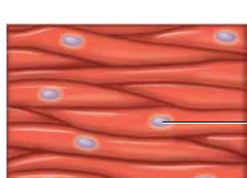
Muscle tissue is a tissue adapted to contract. Muscles provide movement and functionality to the organism.



Skeletal muscle



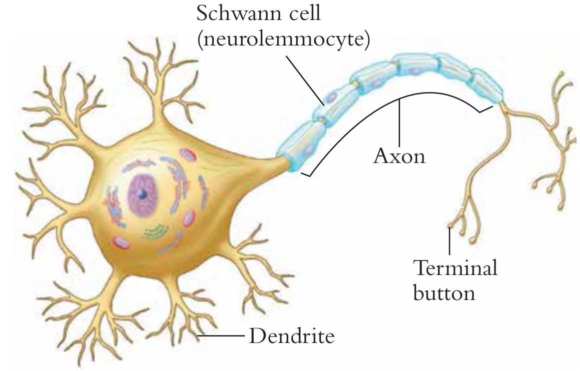
Cardiac muscle



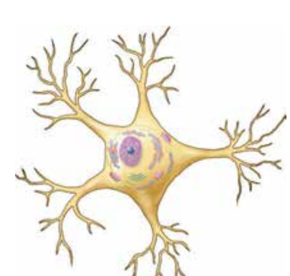
Smooth muscle

Nervous Tissue

Nervous tissue functions to receive stimuli and transmits signals from one part of the organism to another.



Neuron



Neurological cell

Figure 1.36 Some examples of animal tissues.

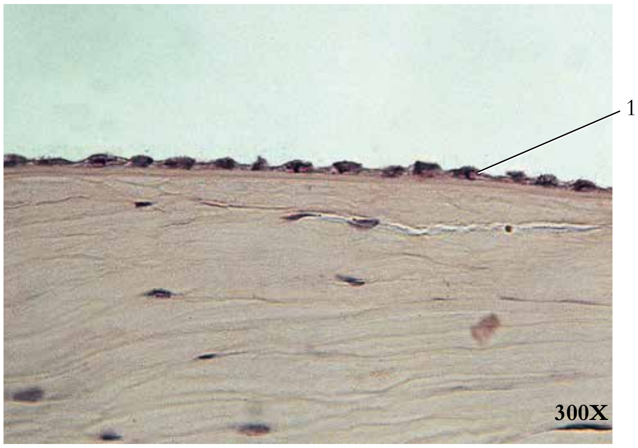


Figure 1.37 Simple squamous epithelium.
1. Single layer of flattened cells with elliptical nuclei

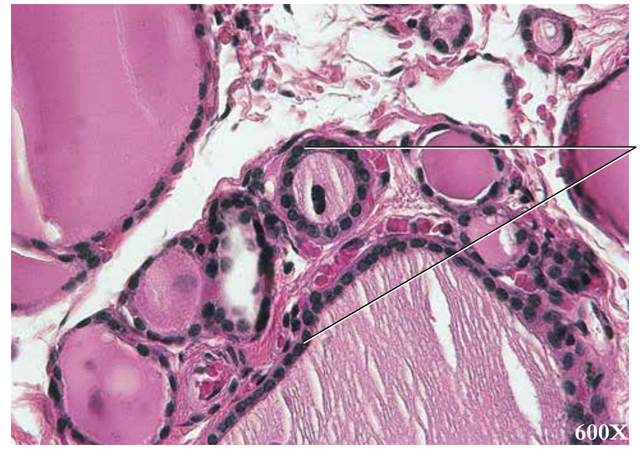


Figure 1.38 Simple cuboidal epithelium.
1. Single layer of cells with round nuclei

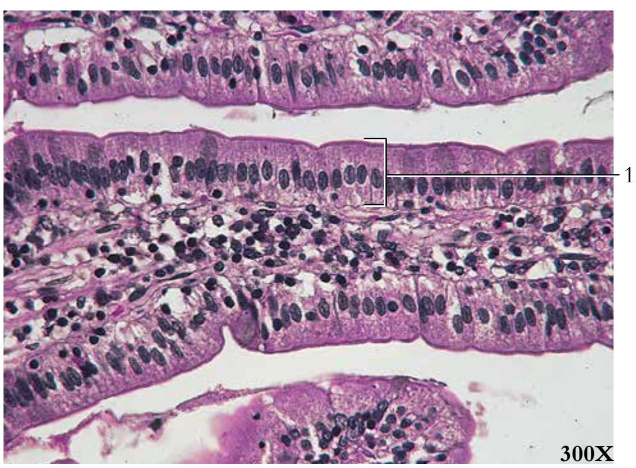


Figure 1.39 Simple columnar epithelium.
1. Single layer of cells with oval nuclei

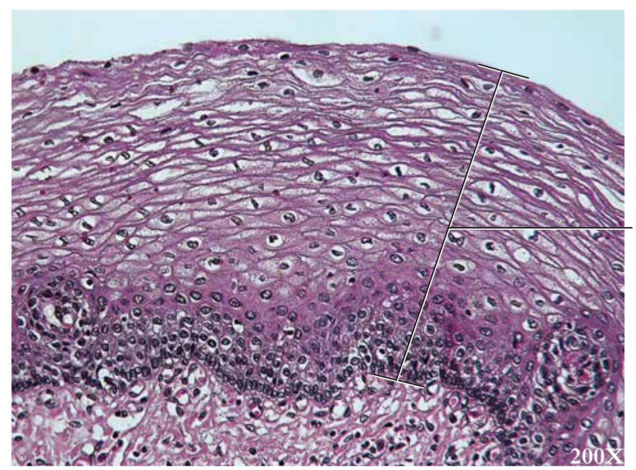


Figure 1.40 Stratified squamous epithelium.
1. Multiple layers of cells that are flattened at the upper layer

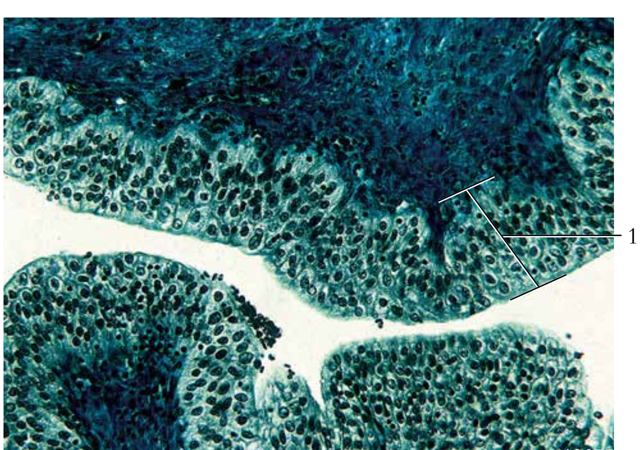


Figure 1.41 Stratified columnar epithelium.
1. Cells are balloon-like at surface

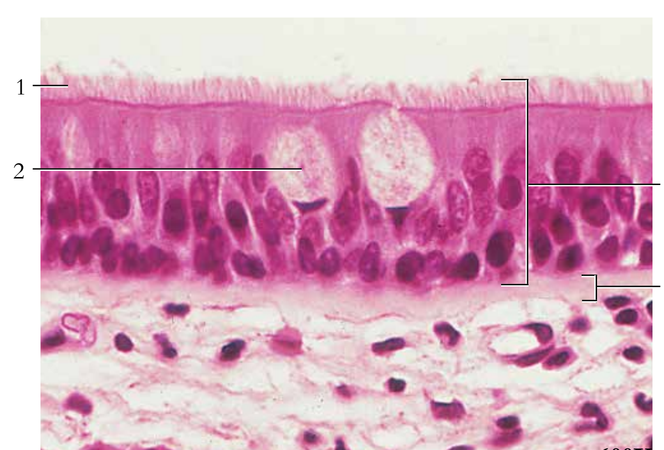


Figure 1.42 Pseudostratified columnar epithelium.
1. Cilia
2. Goblet cell
3. Pseudostratified columnar epithelium
4. Basement membrane

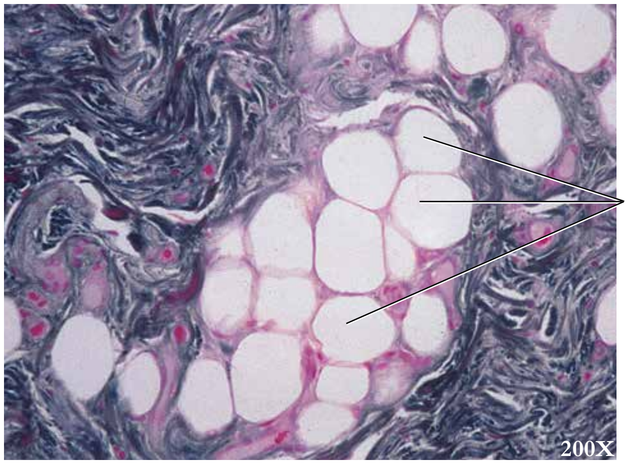


Figure 1.43 Adipose connective tissue.
1. Adipocytes (adipose cells)

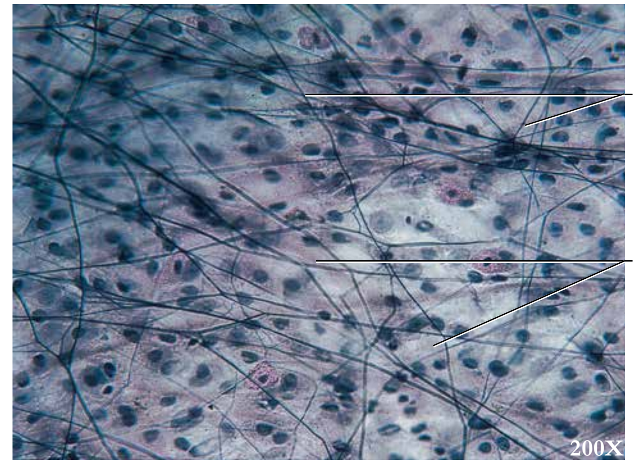


Figure 1.44 Loose connective tissue stained for fibers.
1. Elastic fibers (black)
2. Collagen fibers (pink)

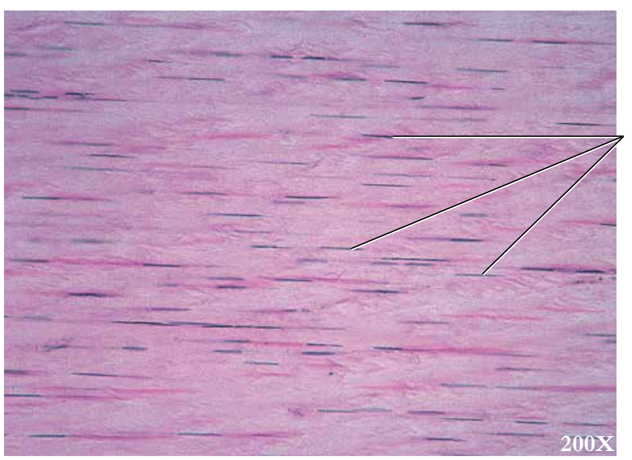


Figure 1.45 Dense regular connective tissue.
1. Nuclei of fibroblasts arranged in parallel rows between pink-stained collagen fibers

Figure 1.46 Dense irregular connective tissue.
1. Epidermis
2. Dense irregular connective tissue (reticular layer of dermis)

Figure 1.47 An electron micrograph of dense irregular connective tissue.
1. Collagenous fibers

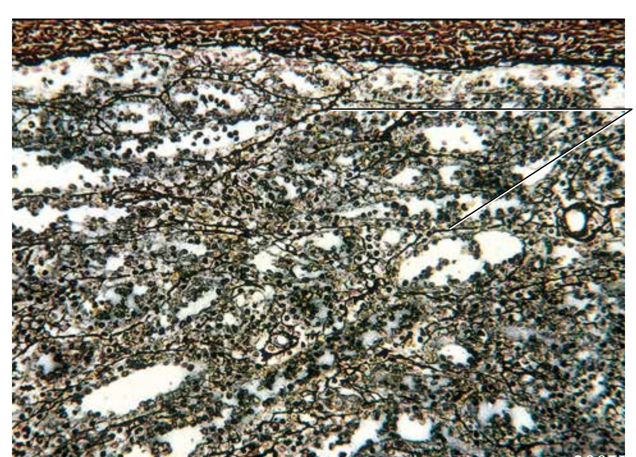


Figure 1.48 Reticular connective tissue.
1. Reticular fibers

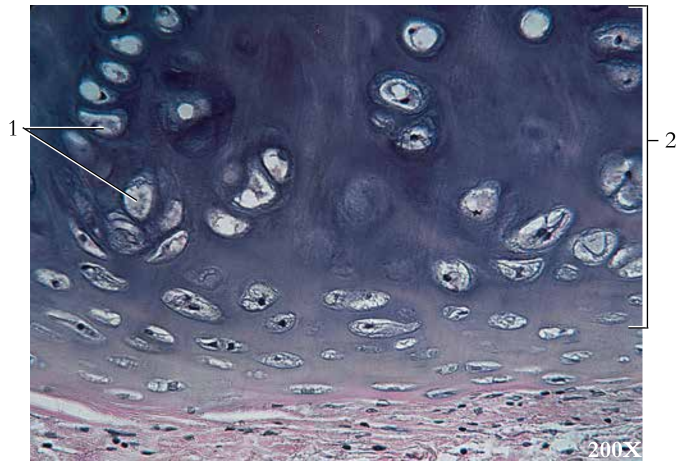


Figure 1.49 Hyaline cartilage.
1. Chondrocytes
2. Hyaline cartilage

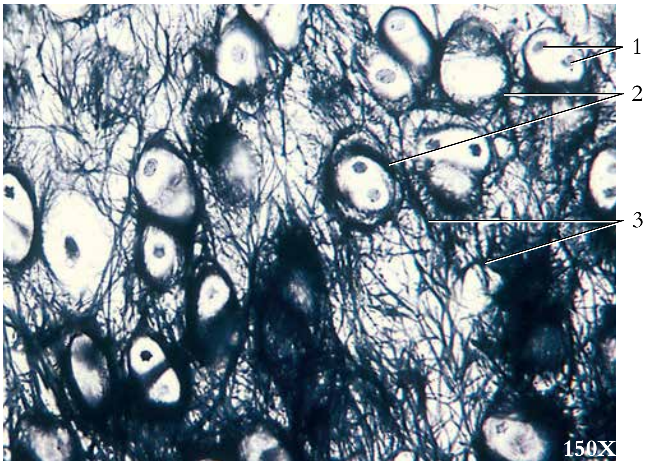


Figure 1.50 Elastic cartilage.
1. Chondrocytes
2. Lacunae
3. Elastic fibers

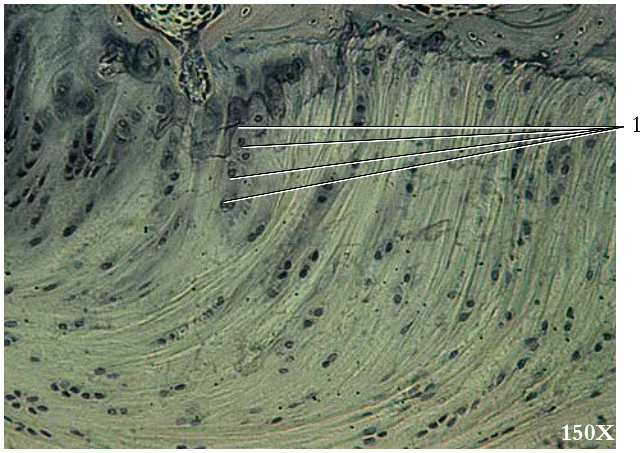


Figure 1.51 Fibrocartilage.
1. Chondrocytes arranged in a row

Figure 1.52 A transverse section of two osteons in compact bone tissue.
1. Lacunae containing osteocytes
2. Central (Haversian) canals
3. Lamellae

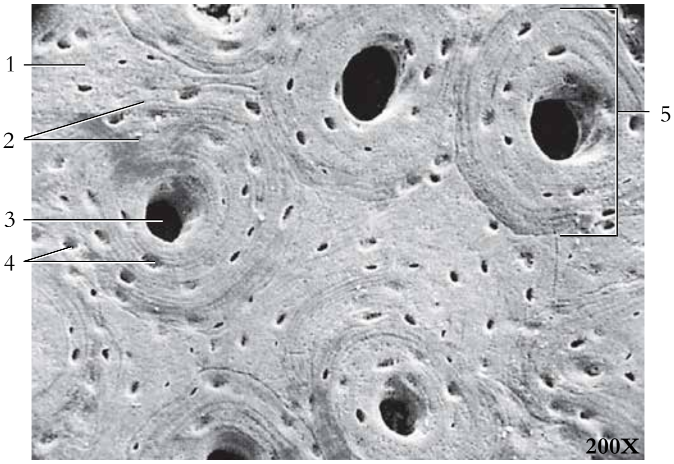


Figure 1.53 An electron micrograph of bone tissue.
1. Interstitial lamellae
2. Lamellae
3. Central canal (Haversian canal)
4. Lacunae
5. Osteon (Haversian system)

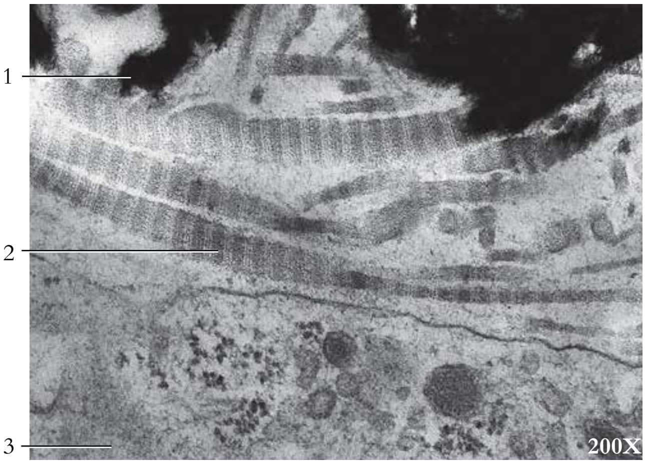


Figure 1.54 An electron micrograph of bone tissue formation.
1. Bone mineral (calcium salts stain black)
2. Collagenous filament (distinct banding pattern)
3. Collagen-secreting osteoblasts

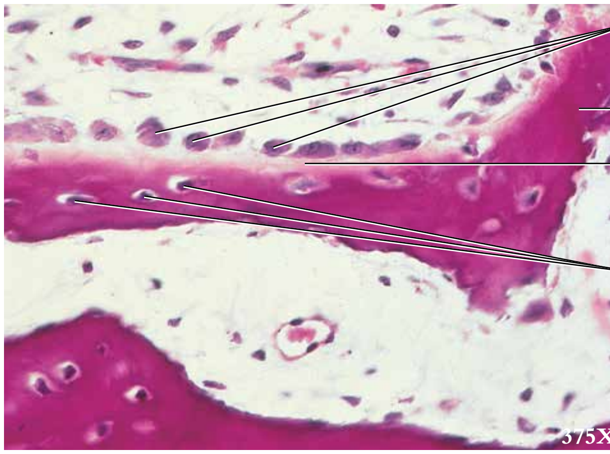


Figure 1.55 Osteoblasts.
1. Osteoblasts
2. Bone
3. Osteoid
4. Osteocytes

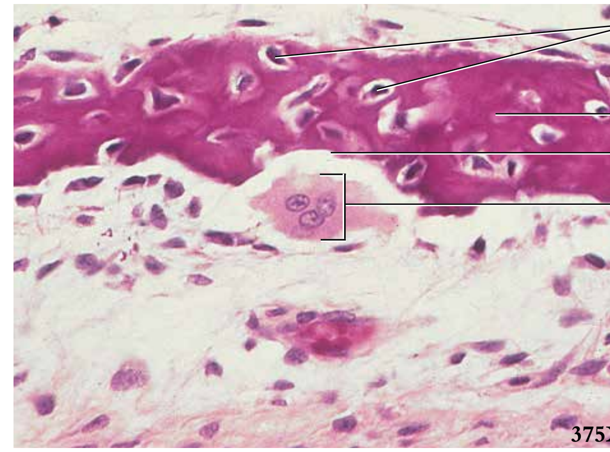


Figure 1.56 Osteoclast.
1. Osteocytes
2. Bone
3. Howship's lacuna
4. Osteoclast in Howship's lacuna

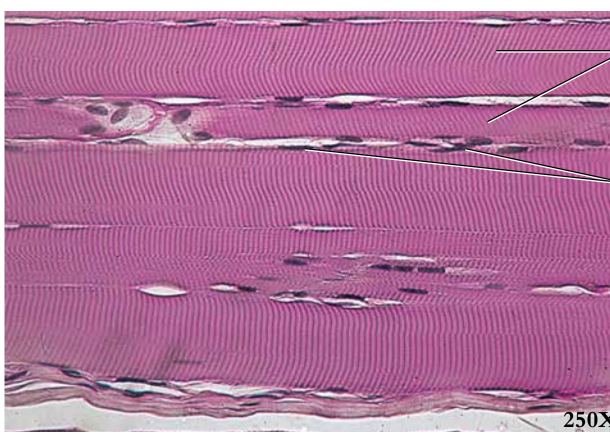


Figure 1.57 A longitudinal section of skeletal muscle tissue.
1. Skeletal muscle cells (note striations)
2. Multiple nuclei in periphery of cell

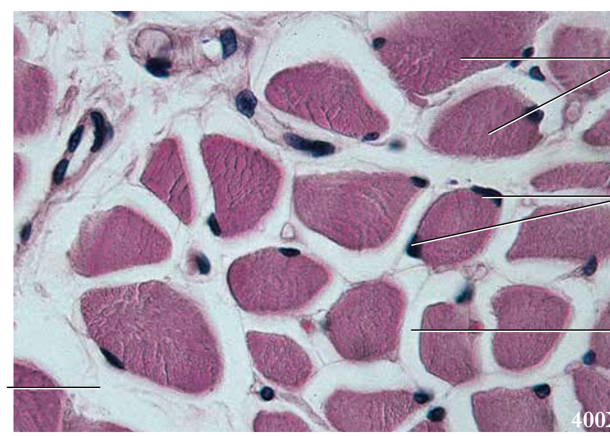


Figure 1.58 A transverse section of skeletal muscle tissue.
1. Perimysium (surrounds bundles of cells)
2. Skeletal muscle cells
3. Nuclei in periphery of cell
4. Endomysium (surrounds cells)

Figure 1.59 The attachment of skeletal muscle to tendon.
1. Skeletal muscle
2. Dense regular connective tissue (tendon)

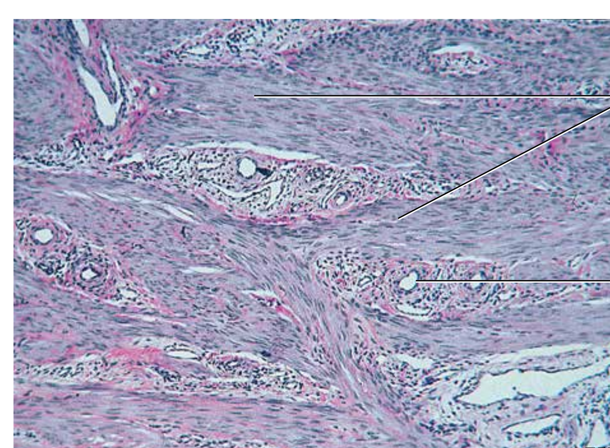


Figure 1.60 Smooth muscle tissue.
1. Smooth muscle
2. Blood vessel

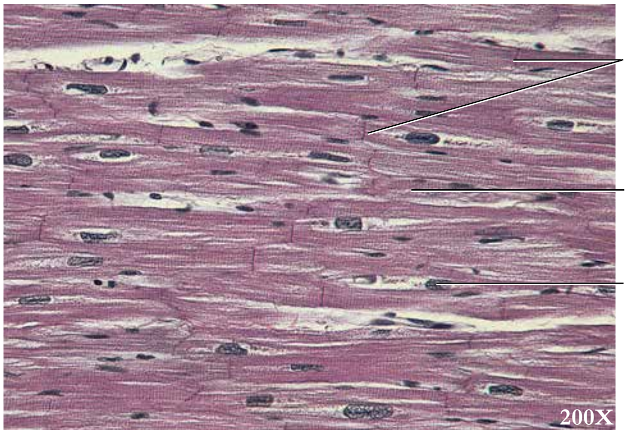


Figure 1.61 Cardiac muscle tissue.
1. Intercalated disks
2. Light-staining perinuclear sarcoplasm
3. Nucleus in center of cell

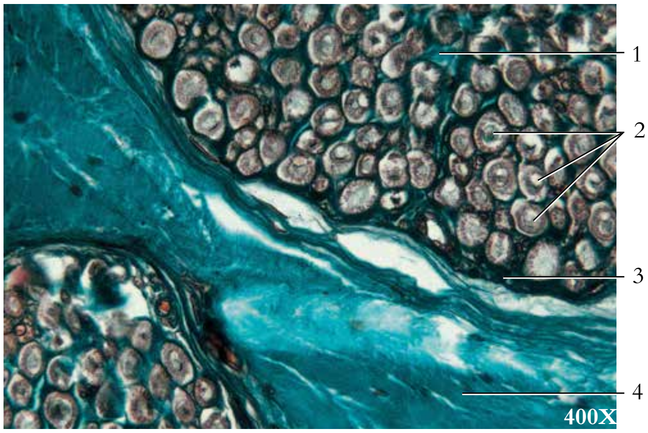


Figure 1.62 A transverse section of a nerve.
1. Endoneurium
2. Axons
3. Perineurium
4. Epineurium

Figure 1.63 A longitudinal section of axons.
1. Myelin sheath
2. Neurofibril nodes (nodes of Ranvier)

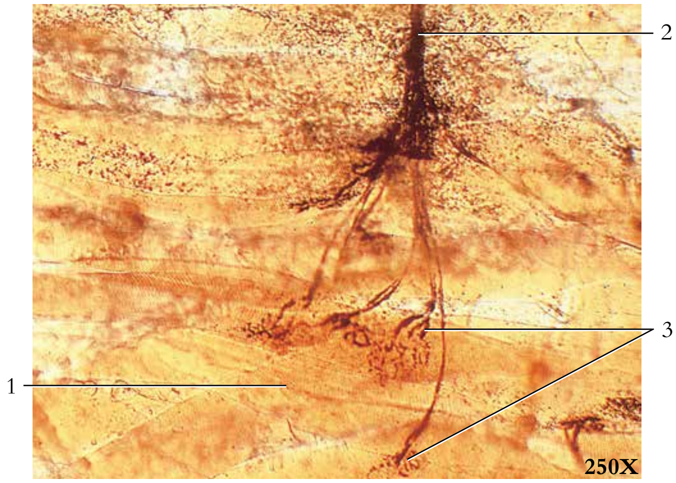


Figure 1.64 A neuromuscular junction.
1. Skeletal muscle fiber
2. Motor nerve
3. Motor end plates

Figure 1.65 Motor neurons from spinal cord.
1. Neuroglia cells
2. Dendrites
3. Nucleus

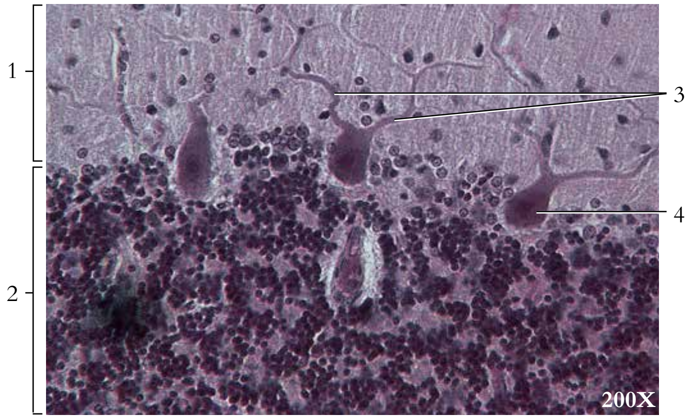


Figure 1.66 Purkinje neurons from the cerebellum.
1. Molecular layer of cerebellar cortex
2. Granular layer of cerebellar cortex
3. Dendrites of Purkinje cell
4. Purkinje cell body

2 Perpetuation of Life: Mitosis, Meiosis, and Development

The term *cell cycle* refers to how a multicellular organism develops, grows, and maintains and repairs body tissues. In the cell cycle, each new cell receives a complete copy of all genetic information in the parent cell and the cytoplasmic substances and organelles to carry out hereditary instructions.

The animal cell cycle (see Fig. 2.3) is divided into: 1) interphase, which includes Gap 1 (G1), Synthesis (S), and Gap 2 (G2) phases; and 2) mitosis, which includes prophase, metaphase, anaphase, and telophase. *Interphase* is the interval between successive cell divisions during which the cell is metabolizing and the chromosomes are directing RNA synthesis. The *G1 phase* is the first growth phase, the *S phase* is when DNA is replicated, and the *G2 phase* is the second growth phase. *Mitosis* (also known as karyokinesis) is the division of the nuclear parts of a cell to form two daughter nuclei with the same number of chromosomes as the original nucleus.

Like the animal cell cycle, the plant cell cycle consists of growth, synthesis, mitosis, and cytokinesis. *Growth* is the increase in cellular mass as the result of metabolism; *synthesis* is the production of DNA and RNA to regulate cellular activity; mitosis is the splitting of the nucleus and the equal separation of the chromatids; and cytokinesis is the division of the cytoplasm that accompanies mitosis.

Unlike animal cells, plant cells have a rigid cell wall that does not cleave during cytokinesis. Instead, a new cell wall is constructed between the daughter cells. Furthermore, many land plants do not have centrioles for the attachment of spindles. The microtubules in these plants form a barrel-shaped anastral spindle at each pole. Mitosis and cytokinesis in plants occur in basically the same sequence as these processes in animal cells.

Asexual reproduction is propagation without sex: that is, the production of new individuals by processes that do not involve *gametes* (sex cells). Asexual reproduction occurs in a variety of microorganisms, fungi, plants, and animals, wherein a single parent produces offspring with characteristics identical to itself. Asexual reproduction is not dependent on the presence of other individuals. No egg or sperm is required. In asexual reproduction, all the offspring are genetically identical (except for mutants). Types of asexual reproduction include:

1. *fission*—subdivision of a cell (or organism, population, species, etc.) into separate parts. Binary fission produces two separate parts; multiple fission produces more than two separate parts (cells, populations, species, etc.);
2. *sporulation*—multiple fission: many cells are formed and join together in a cyst-like structure (protozoans and fungi);
3. *budding*—buds develop organisms like the parent and then detach themselves (hydras, yeast, certain plants); and
4. *fragmentation*—organisms break into two or more parts, and each part is capable of becoming a complete organism (algae, flatworms, echinoderms).

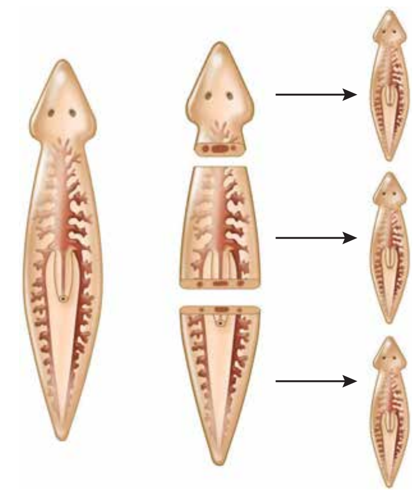
Sexual reproduction is propagation of new organisms through the union of genetic material from two parents. Sexual reproduction usually involves the fusion of haploid gametes (such as sperm and egg cells) during fertilization to form a zygote.

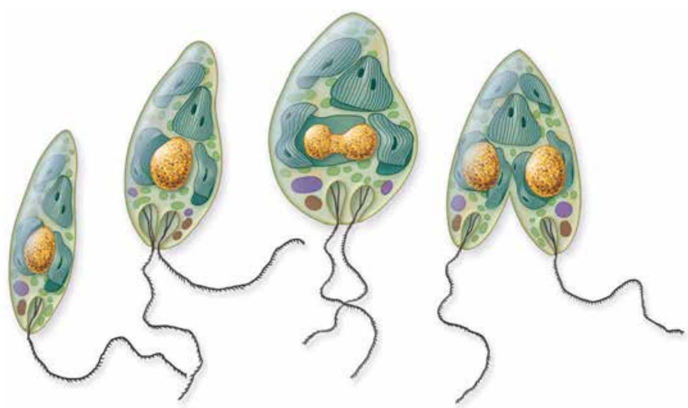
The major biological difference between sexual and asexual reproduction is that sexual reproduction produces genetic variation in the offspring. The combining of genetic material from the gametes produces offspring that are different from either parent and contain new combinations of characteristics. This may increase the ability of the species to survive environmental changes or to reproduce in new habitats. The only genetic variation that can arise in asexual reproduction comes from mutations.

Figure 2.1 Sexual reproduction. A pair of Hawaiian stilts, *Himantopus mexicanus knudseni*, in early spring.

Vegetative propagation

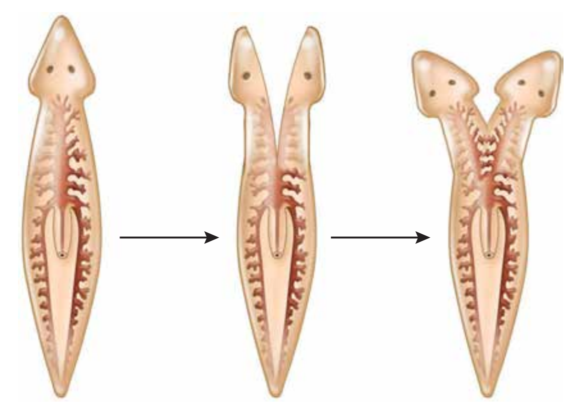
A plant produces external stems, or runners. Simple vegetative propagation occurs in a number of flowering plants, such as strawberries.





Binary fission

A single cell divides, forming two separate cells. Fission occurs in bacteria, protozoans, and other single-celled organisms.



Fragmentation

An multicellular organism breaks into two or more parts, each capable of becoming a complete organism. Fragmentation occurs in flatworms and echinoderms.

Figure 2.2 Types of asexual reproduction: vegetative propagation, binary fission, and fragmentation.

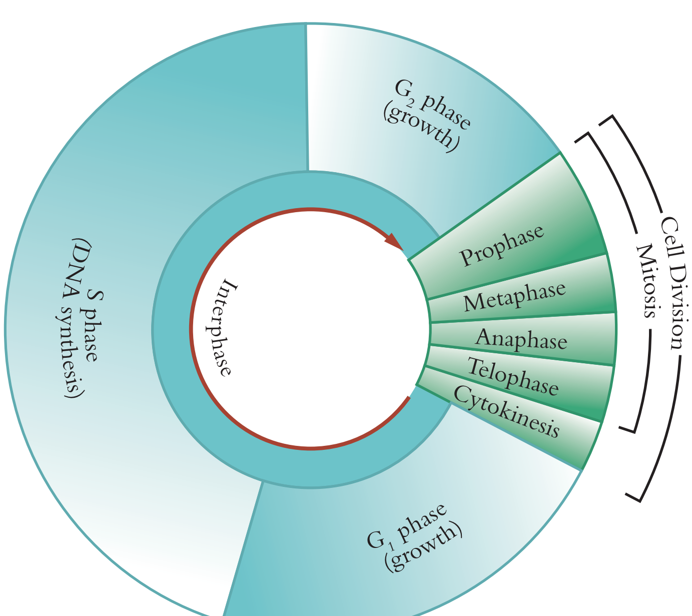


Figure 2.3 The animal cell cycle.

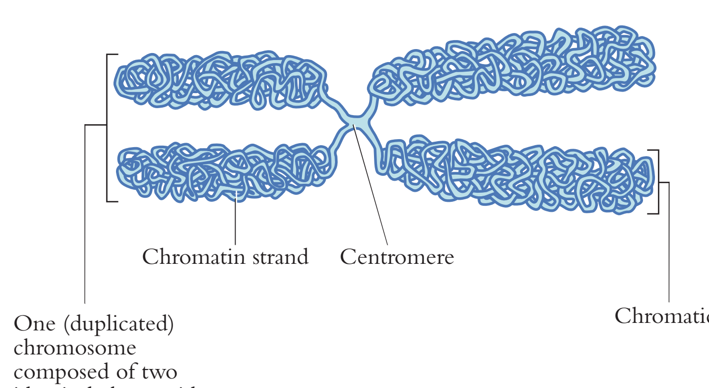
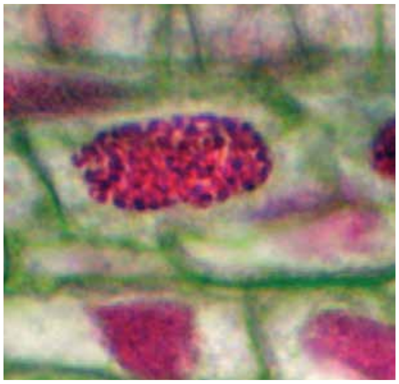
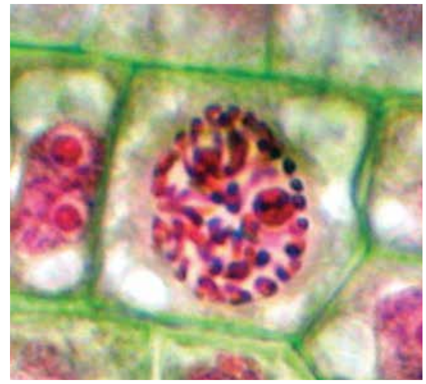


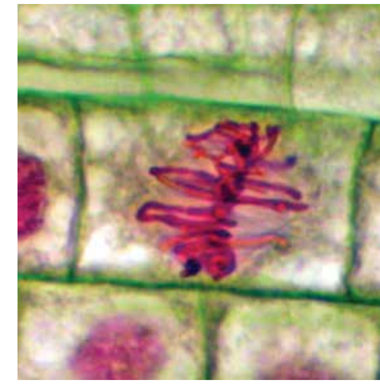
Figure 2.4 Each duplicated chromosome consists of two identical chromatids attached at the centrally located and constricted centromere.



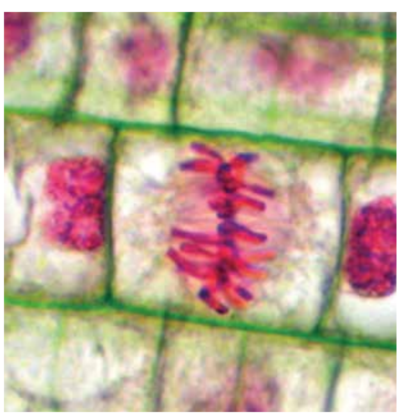
Early prophase — Chromatin begins to condense to form chromosomes.



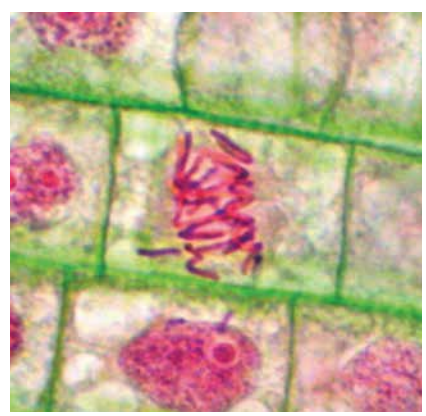
Late prophase — Nuclear envelope is intact, and chromatin condenses into chromosomes.



Early metaphase — Duplicated chromosomes are each made up of two chromatids, at equatorial plane.

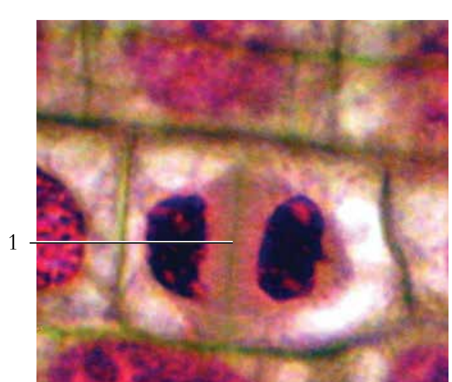


Late metaphase — Duplicated chromosomes are each made up of two chromatids, at equatorial plane.



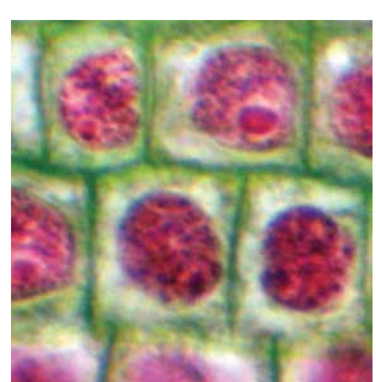
Early anaphase — Sister chromatids are beginning to separate into daughter chromosomes.

Late anaphase — Daughter chromosomes are nearing poles.



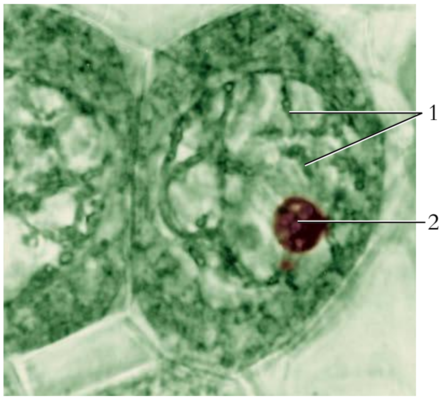
Telophase — Daughter chromosomes are at poles, and cell plate is forming.

1. Cell plate



Interphase — Two daughter cells result from cytokinesis.

Figure 2.5 The stages of mitosis in Hyacinth, *Hyacinthus*, root tip. (all 430X)

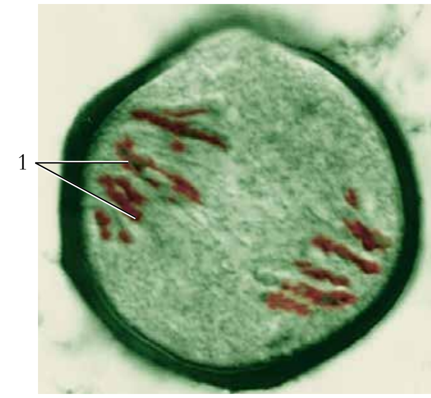


Prophase I — Each chromosome consists of two chromatids joined by a centromere.

1. Chromatids
2. Nucleolus

Metaphase I — Chromosome pairs align at the equator.

1. Chromosome pairs at equator
2. Spindle fibers

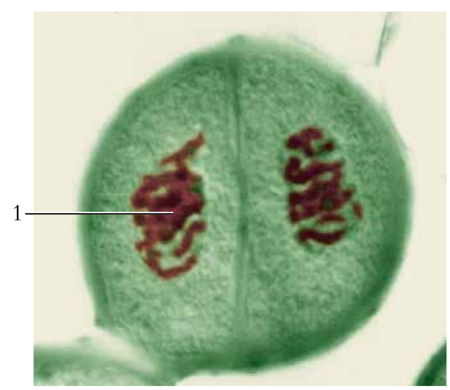


Anaphase I — No division at the centromeres occurs as the chromosomes separate, so one entire chromosome goes to each pole.

1. Chromosomes (two chromatids each)

Telophase I — Chromosomes lengthen and become less distinct. The cell plate (in some plants) forms between forming cells.

1. Cell plate (new cell wall)
2. Chromosome



Prophase II — Chromosomes condense as in prophase I.

1. Chromosomes

Metaphase II — Chromosomes align on the equator, and spindle fibers attach to the centromeres. This is similar to metaphase in mitosis.

1. Chromosomes

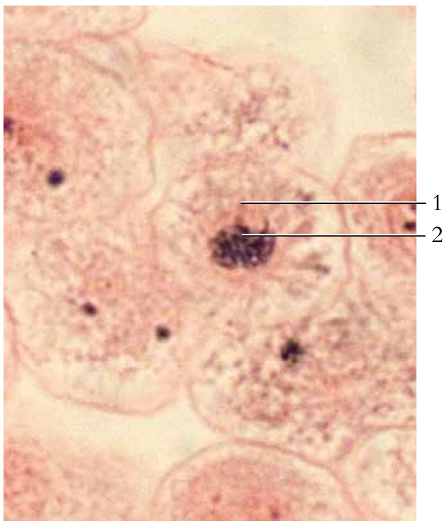
Anaphase II — Chromatids separate, and each is pulled to an opposite pole.

1. Chromatids

Telophase II — Cell division is complete, and cell walls of four haploid cells are formed.

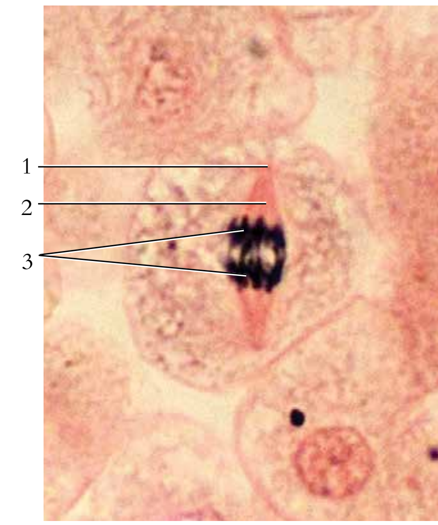
1. Chromatids
2. New cell walls (cell plates)

Figure 2.6 The stages of meiosis in lily microsporocytes to form microspores. 1000X.

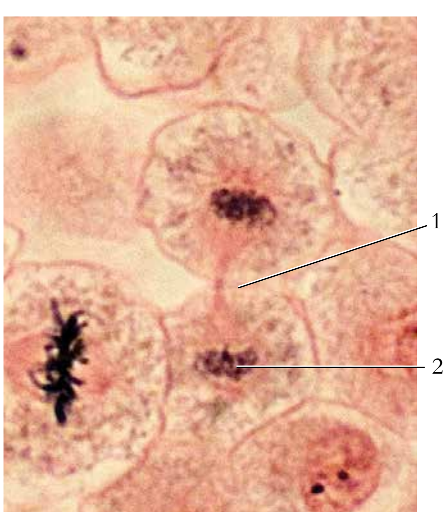


Prophase
Each chromosome consists of two chromatids joined by a centromere. Spindle fibers extend from each centriole.
1. Aster around centriole
2. Chromosomes

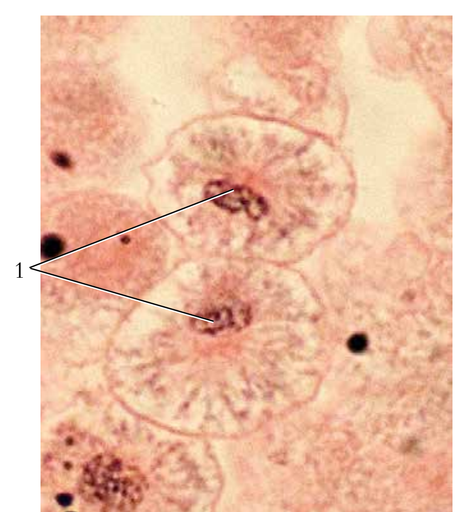
Metaphase
The chromosomes are positioned at the equator. The spindle fibers from each centriole attach to the centromeres.
1. Aster around centriole
2. Spindle fibers
3. Chromosomes at equator



Anaphase
The centromeres split, and the sister chromatids separate as each is pulled to an opposite pole.
1. Aster around centriole
2. Spindle fibers
3. Separating chromosomes



Telophase
The chromosomes lengthen (decondense) and become less distinct. The cell membrane forms between the forming daughter cells.
1. New cell membrane
2. Newly forming nucleus



Daughter cells
The single chromosomes (former chromatids—see anaphase) continue to lengthen (decondense) as the nuclear membrane reforms. Cell division is complete, and the newly formed cells grow and mature.
1. Daughter nuclei

Figure 2.7 The stages of animal cell mitosis followed by cytokinesis. Whitefish blastula. 500X.

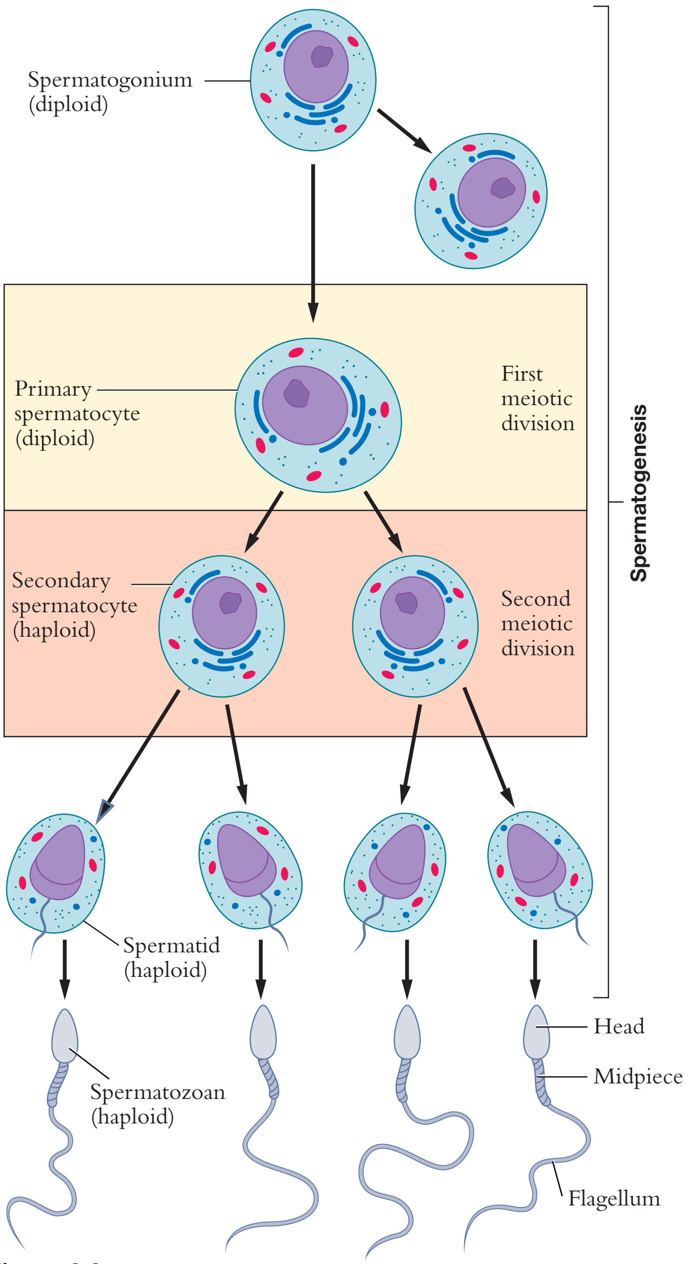


Figure 2.8 Spermatogenesis is the production of male gametes, or spermatozoa, through the process of meiosis.

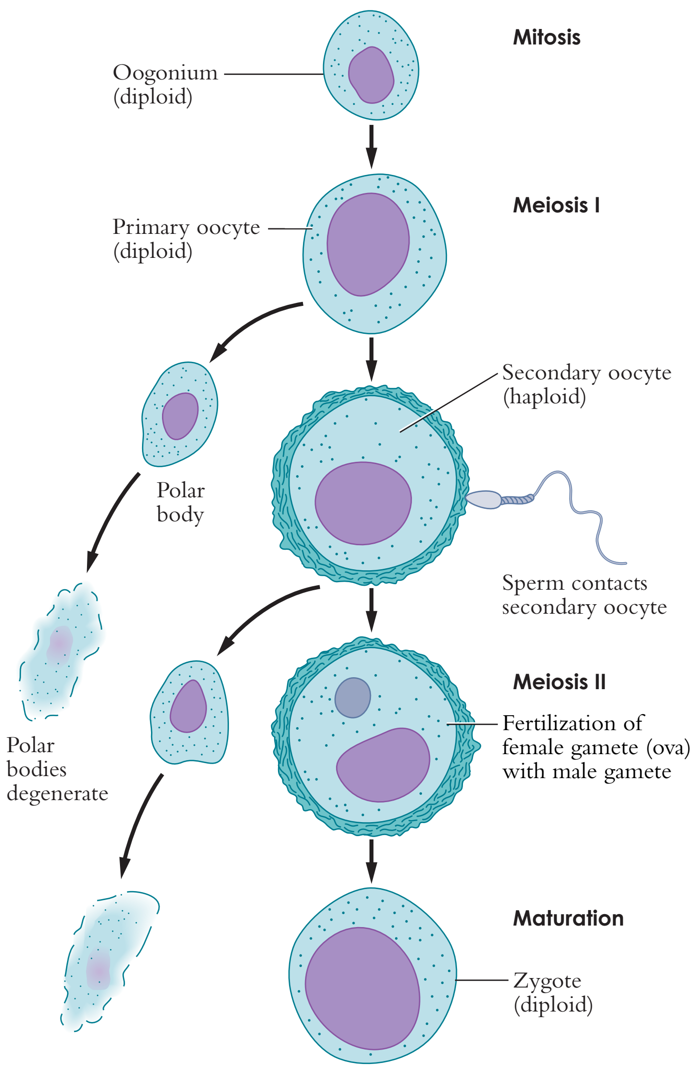


Figure 2.9 Oogenesis is the production of female gametes, or ova, through the process of meiosis.

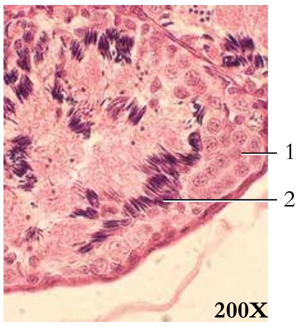


Figure 2.10 Frog testis.
1. Spermatocytes
2. Developing sperm

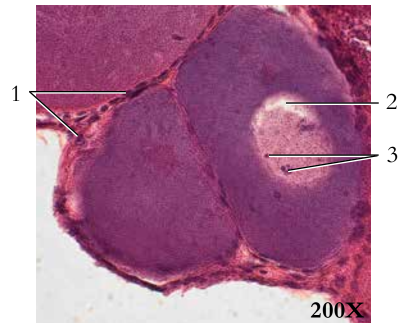


Figure 2.11 Frog ovary.
1. Follicle cells
2. Germinal vesicle
3. Nucleoli

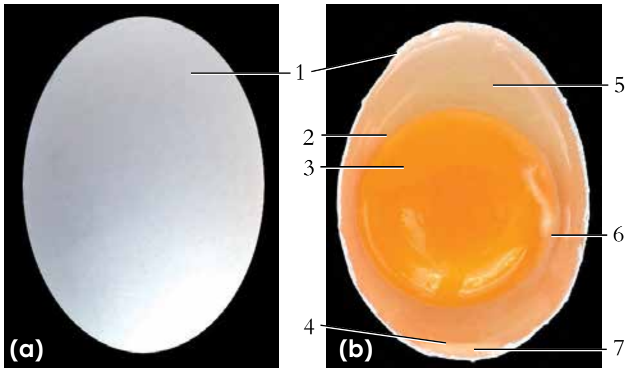
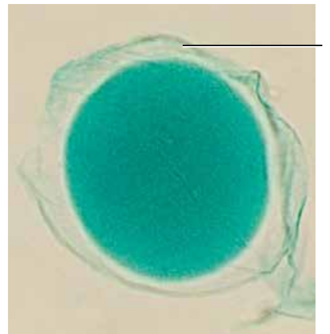


Figure 2.12 (a) An intact chicken egg and (b) a portion of the shell is removed exposing the internal structures.
1. Shell
2. Vitelline membrane
3. Yolk
4. Shell membrane
5. Albumen (egg white)
6. Chalaza (dense albumen)
7. Air space

Unfertilized egg
1. Nuclear membrane
2. Nucleus
3. Nucleolus
4. Cell membrane



Fertilized egg
1. Fertilization membrane

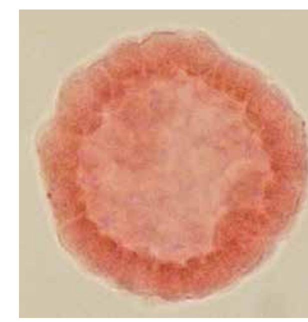
2-cell stage

4-cell stage

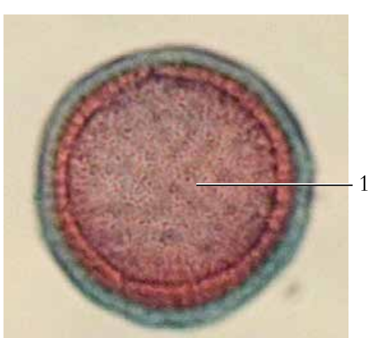
8-cell stage

16-cell stage

32-cell stage

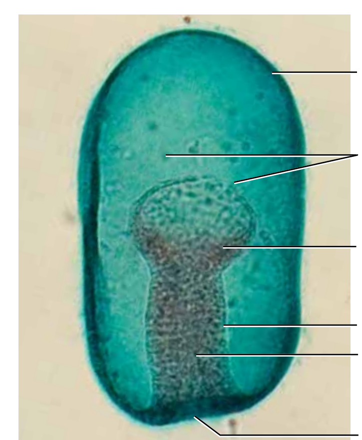


64-cell stage



Blastula
1. Blastocoel

Early gastrula
1. Blastocoel
2. Archenteron (gastrocoel)
3. Blastopore
4. Ectoderm
5. Endoderm



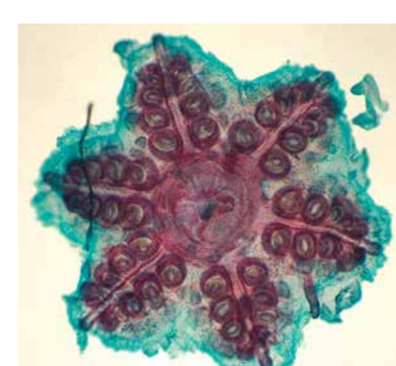
Late gastrula
1. Ectoderm
2. Mesenchyme cells
3. Coelomic sac
4. Endoderm
5. Archenteron (gastrocoel)
6. Blastopore

Bipinnaria larva

(lateral view)
1. Oral lobe
2. Mouth
3. Coelomic pouch
4. Stomach
5. Anus

Early brachiolaria larva

(anterior view)
1. Mouth
2. Stomach
3. Anus



Young sea star

Figure 2.13 The development of the sea star, *Asterias* sp. 100X.

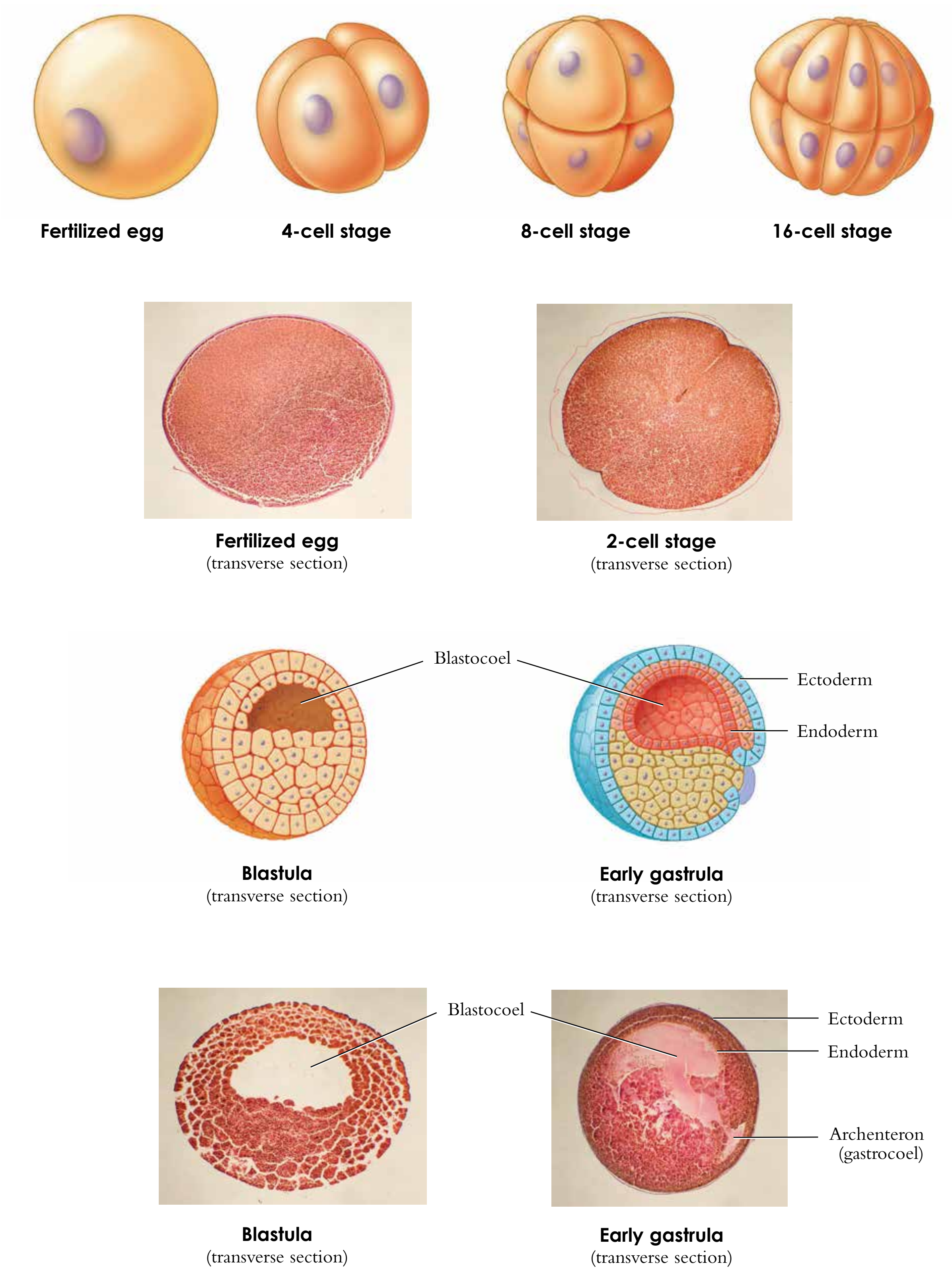
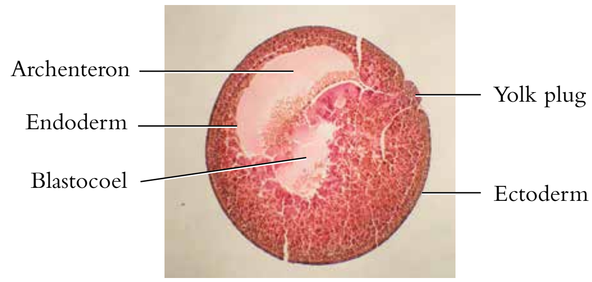
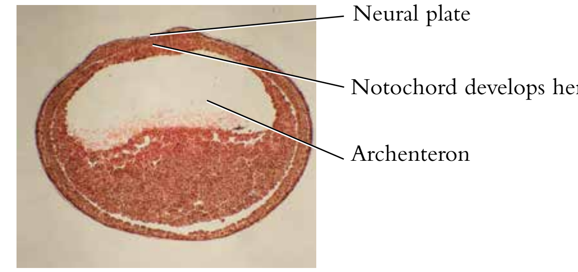


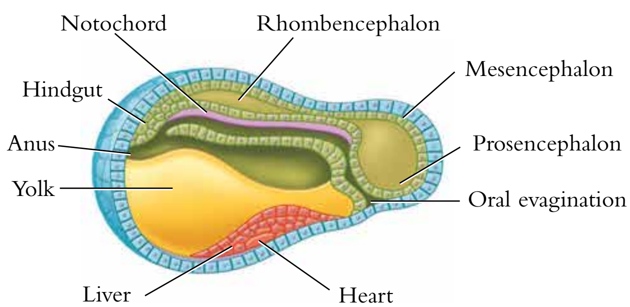
Figure 2.14 Frog development from fertilized egg to early gastrula, shown in diagram and photomicrographs. 100X.



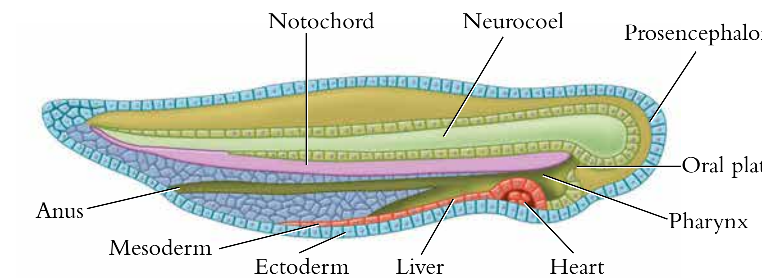
Gastrula
(transverse section)



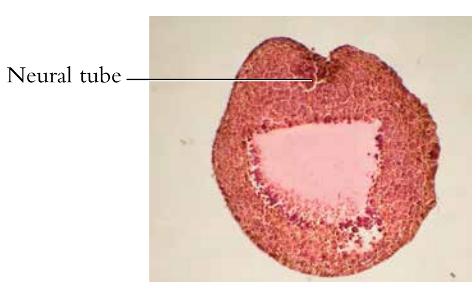
Early neural plate
(transverse section)



Neural tube stage
(longitudinal section)

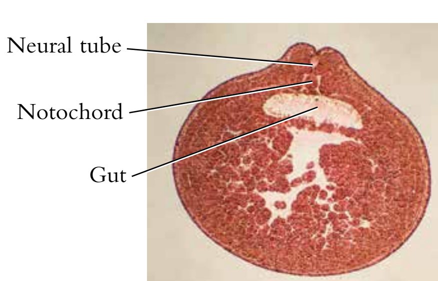


Late neural tube stage
(longitudinal section)

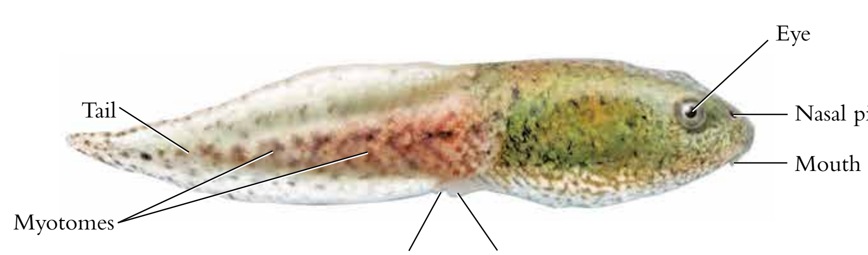


Neural tube stage
(transverse section)

Late neural tube stage
(longitudinal section)

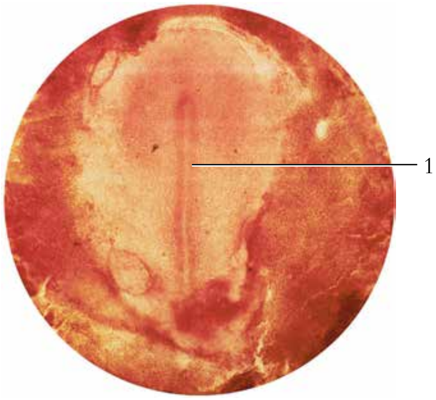


Late neural tube stage
(transverse section)

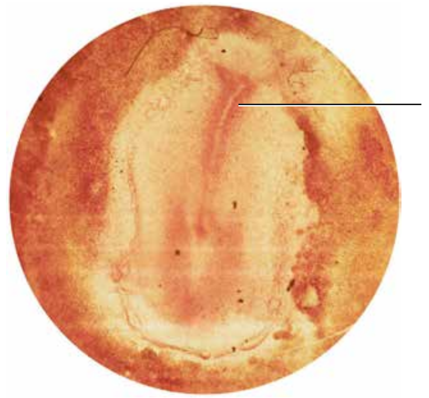


Tadpole stage

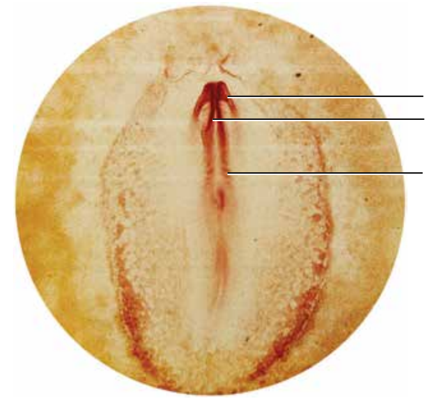
Figure 2.15 Frog development from gastrula to tadpole, shown in diagram and photomicrographs. 100X.



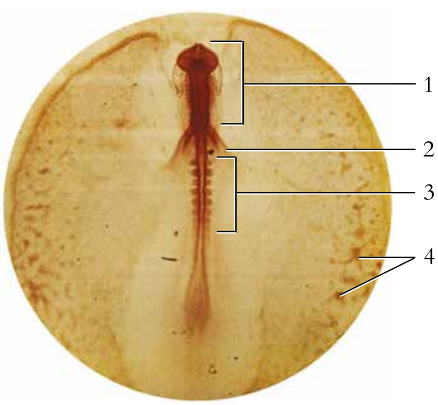
13-hour stage
1. Embryo main body formation



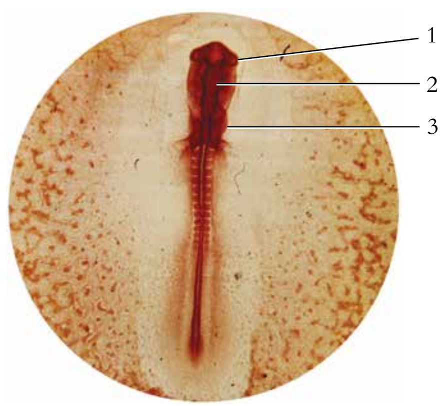
18-hour stage
1. Neurulation beginning



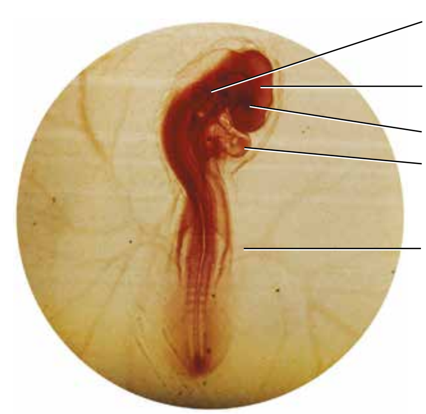
21-hour stage
1. Head fold
2. Neural fold
3. Muscle plate (somites)



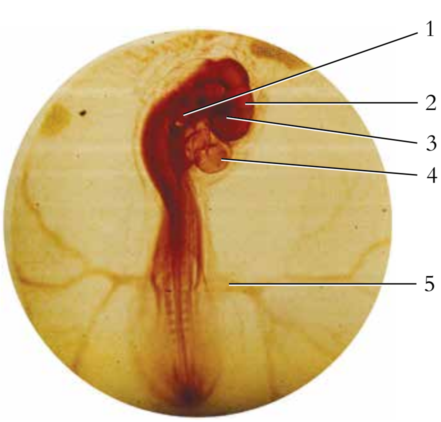
28-hour stage
1. Head fold and brain
2. Artery formation
3. Muscle plate (somites)
4. Blood vessel formation



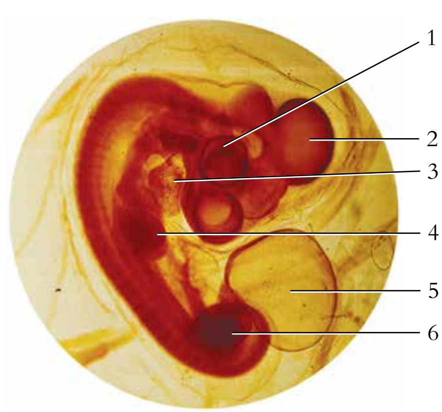
38-hour stage
1. Optic vesicle
2. Brain with five regions
3. Heart



48-hour stage
1. Ear
2. Brain
3. Eye
4. Heart
5. Artery



56-hour stage
1. Ear
2. Brain
3. Eye
4. Heart
5. Artery



96-hour stage
1. Eye
2. Mesencephalon
3. Heart
4. Wing formation
5. Fecal sac (allantois)
6. Leg formation

Figure 2.16 The stages of chick development. 20X.

3 Bacteria and Archaea

Bacteria range between 1 and 50 µm in width or diameter. The morphological appearance of bacteria may be spiral (spirillum), spherical (coccus), or rod-shaped (bacillus). Cocci and bacilli frequently form clusters or linear filaments and may have bacterial flagella. Relatively few species of bacteria cause infection. Hundreds of species of nonpathogenic bacteria live on the human body and within the gastrointestinal (GI) tract. Those in the GI tract constitute a person's gut fauna and are biologically critical to humans.

Photosynthetic bacteria contain chlorophyll and release oxygen during photosynthesis. Some bacteria are *obligate aerobes* (require O_2 for metabolism) and others are *facultative anaerobes* (indifferent to O_2 for metabolism). Some are *obligate anaerobes* (oxygen may poison them). Most bacteria are heterotrophic *saprophytes*, which secrete enzymes to break down surrounding organic molecules into absorbable compounds.

Most Archaea are thought to be adapted to a limited range of extreme conditions, although a few are more cosmopolitan and found in temperate environments. The cell walls of Archaea lack peptidoglycan (characteristic of bacteria). Archaea have distinctive RNAs and RNA polymerase enzymes. They include methanogens, typically found in swamps and marshes, and thermoacidophiles, found in acid hot springs, acidic soil, and deep oceanic volcanic vents.

Methanogens exist in oxygen-free environments and subsist on simple compounds such as CO_2, acetate, or methanol. As their name implies, Methanogens produce methane gas as a by-product of metabolism. These organisms are typically found in organic-rich mud and sludge that often contain fecal wastes.

Thermoacidophiles are resistant to hot temperatures and high acid concentrations. The cell membrane of these organisms contains high amounts of saturated fats, and their enzymes and other proteins are able to withstand extreme conditions without denaturation. These microscopic organisms thrive in most hot springs and hot, acid soils.

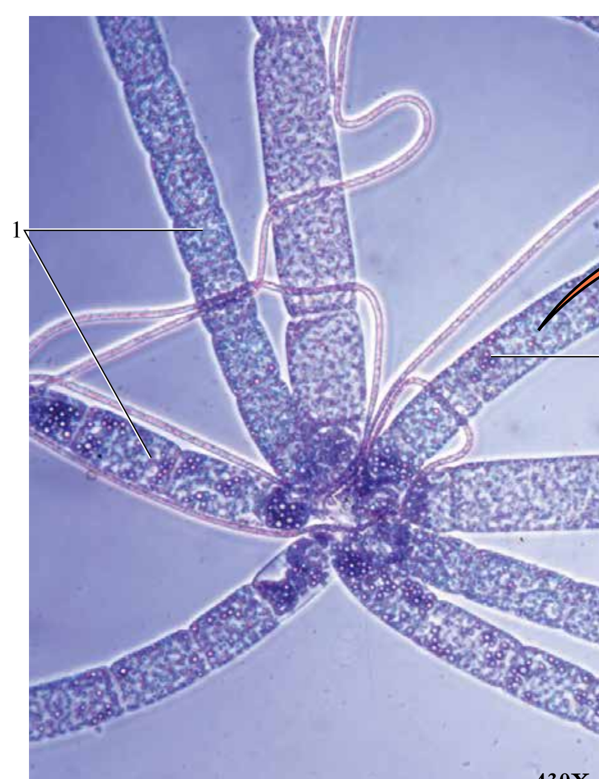


Figure 3.1 *Thiothrix* sp., a genus of bacteria that forms sulfur granules in its cytoplasm. These organisms obtain energy from oxidation of H_2S.
1. Filaments 2. Sulfur granules

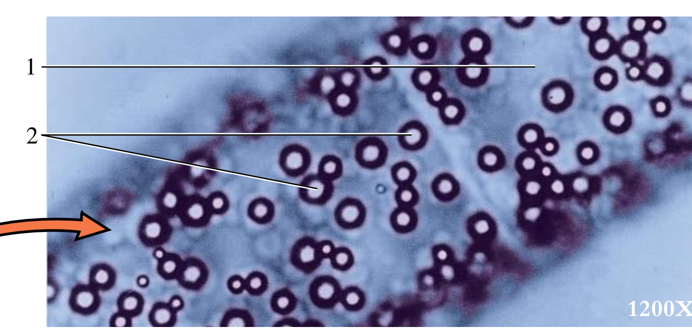


Figure 3.2 A magnified *Thiothrix* sp. filament with sulfur granules in its cytoplasm.
1. Cytoplasm 2. Sulfur granules

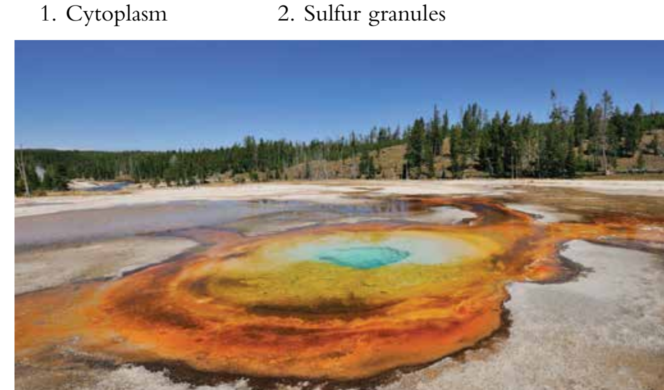


Figure 3.3 The first Archaea were discovered in extreme environments such as volcanic hot springs like those found in Yellowstone National Park.

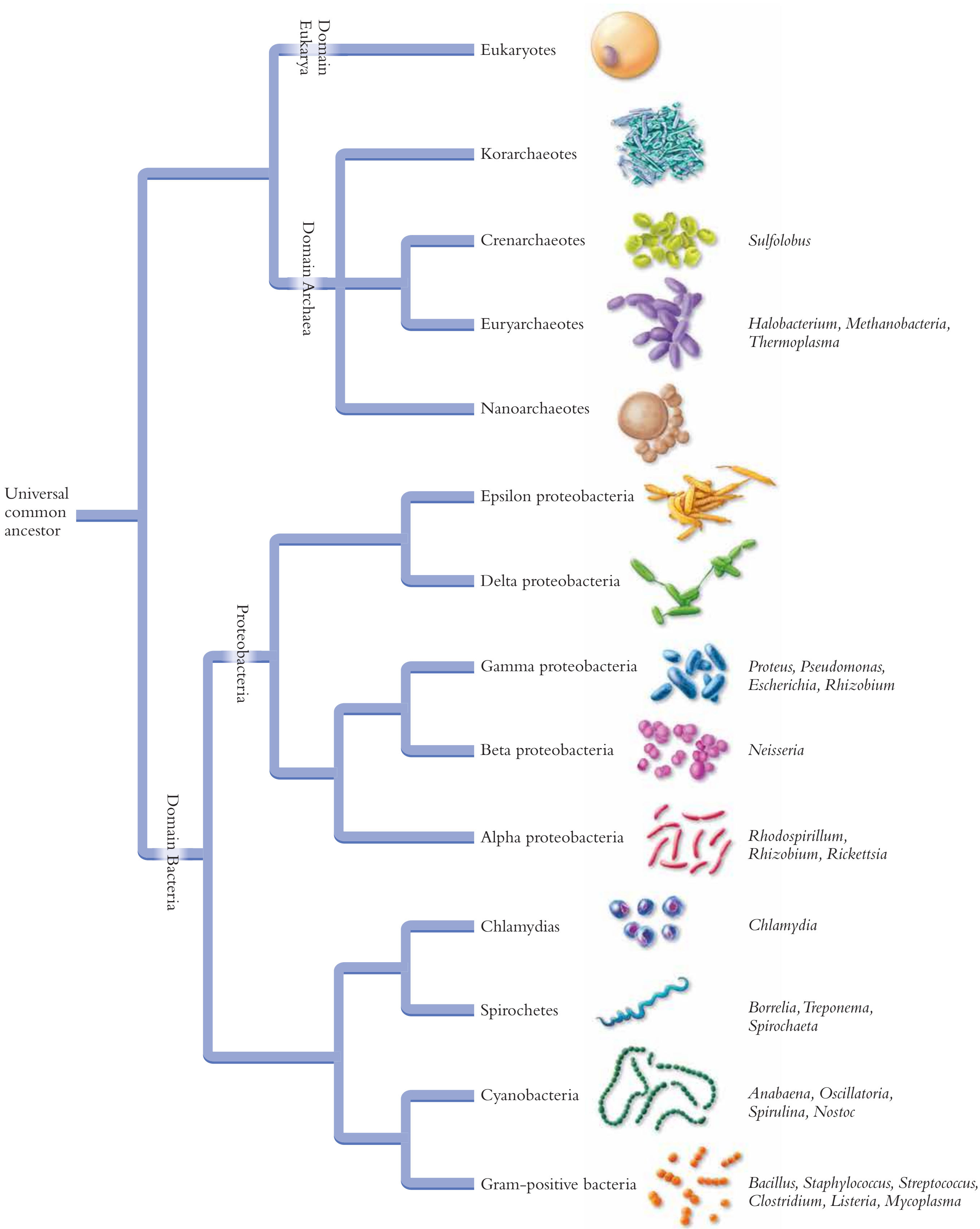


Figure 3.4 Phylogenetic relationships and classification of major bacteria and archaea lineages.

Figure 3.5 The bacterium *Bacillus megaterium*. *Bacillus* is capable of producing endospores. This species of *Bacillus* generally remains in chains after it divides.

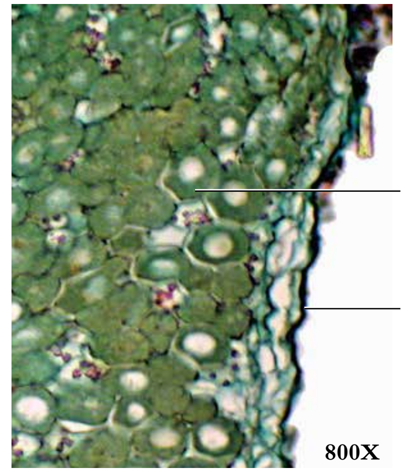


Figure 3.6 Transverse section through the root nodule of clover showing intracellular nitrogen-fixing bacteria.

1. Cell with bacteria
2. Epidermis

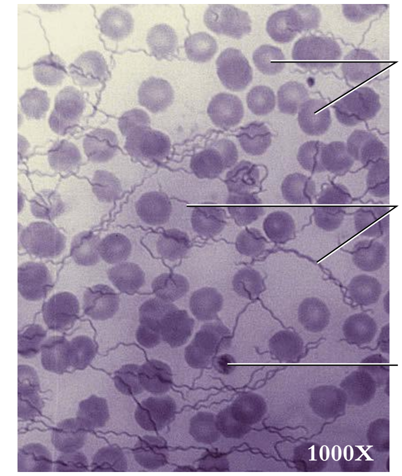


Figure 3.7 The spirochete, *Borella recurrentis*. Spirochetes are flexible rods twisted into helical shapes. This species causes relapsing fever.

1. Red blood cells
2. Spirochete
3. White blood cell

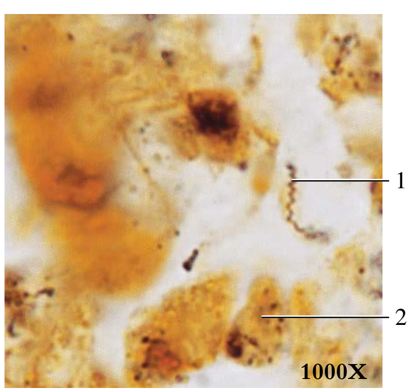


Figure 3.8 The spirochete *Treponema pallidum*. This species causes syphilis.

1. *Treponema pallidum*
2. White blood cell

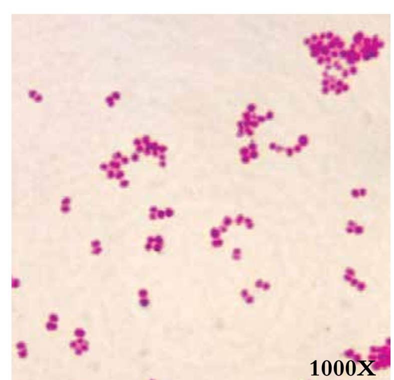


Figure 3.9 *Neisseria gonorrhoeae*. This is a diplococcus that causes gonorrhea.

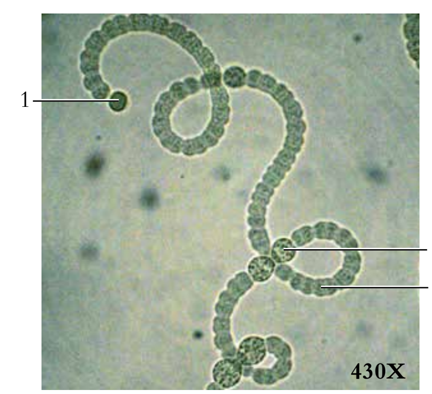


Figure 3.10 An *Anabaena* sp. filament. This organism is a nitrogen-fixing cyanobacterium. Nitrogen fixation takes place within the heterocyst cells.

1. Heterocyst
2. Spore (akinete)
3. Vegetative cell

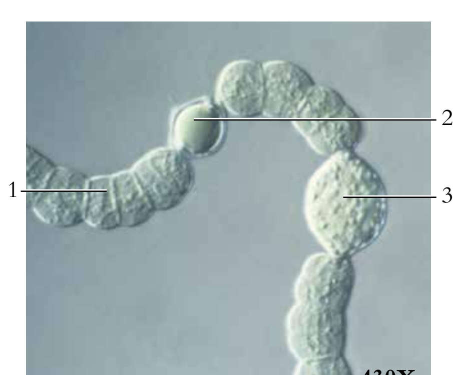


Figure 3.11 An *Anabaena* sp. filament. This is a nitrogen-fixing cyanobacterium. Nitrogen fixation takes place within the heterocyst cells.

1. Vegetative cell
2. Heterocyst
3. Spore

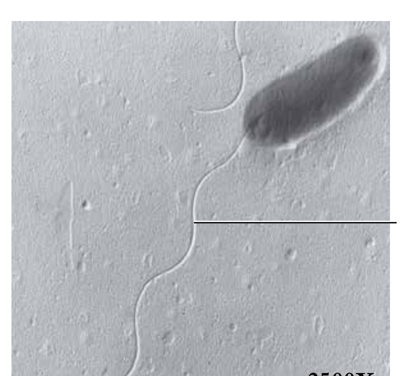


Figure 3.12 The flagellated bacterium, *Pseudomonas* sp.

1. Flagellum

Figure 3.13 The conjugation of the bacterium *Escherichia coli*. By this process of conjugation, genetic material is transferred through the conjugation tube from one cell to the other allowing genetic recombination.

1. Bacterium
2. Conjugation tube

Table 3.1 Some Representatives of Bacteria and Archaea

Categories	Representative Genera
Bacteria	
Photosynthetic bacteria	
Cyanobacteria	*Anabaena, Oscillatoria, Spirulina, Nostoc*
Green bacteria	*Chlorobium*
Purple bacteria	*Rhodospirillum*
Gram-negative bacteria	*Proteus, Pseudomonas, Escherichia, Rhizobium, Neisseria*
Gram-positive bacteria	*Bacillus, Staphylococcus, Streptococcus, Clostridium, Listeria*
Spirochetes	*Spirochaeta, Treponema*
Actinomycetes	*Streptomyces*
Rickettsias and Chlamydias	*Rickettsia, Chlamydia*
Mycoplasmas	*Mycoplasma*
Archaea	
Methanogens	*Halobacterium, Methanobacterium*
Thermoacidophiles	*Thermoplasma, Sulfolobus*
Halophiles	*Halobacterium*

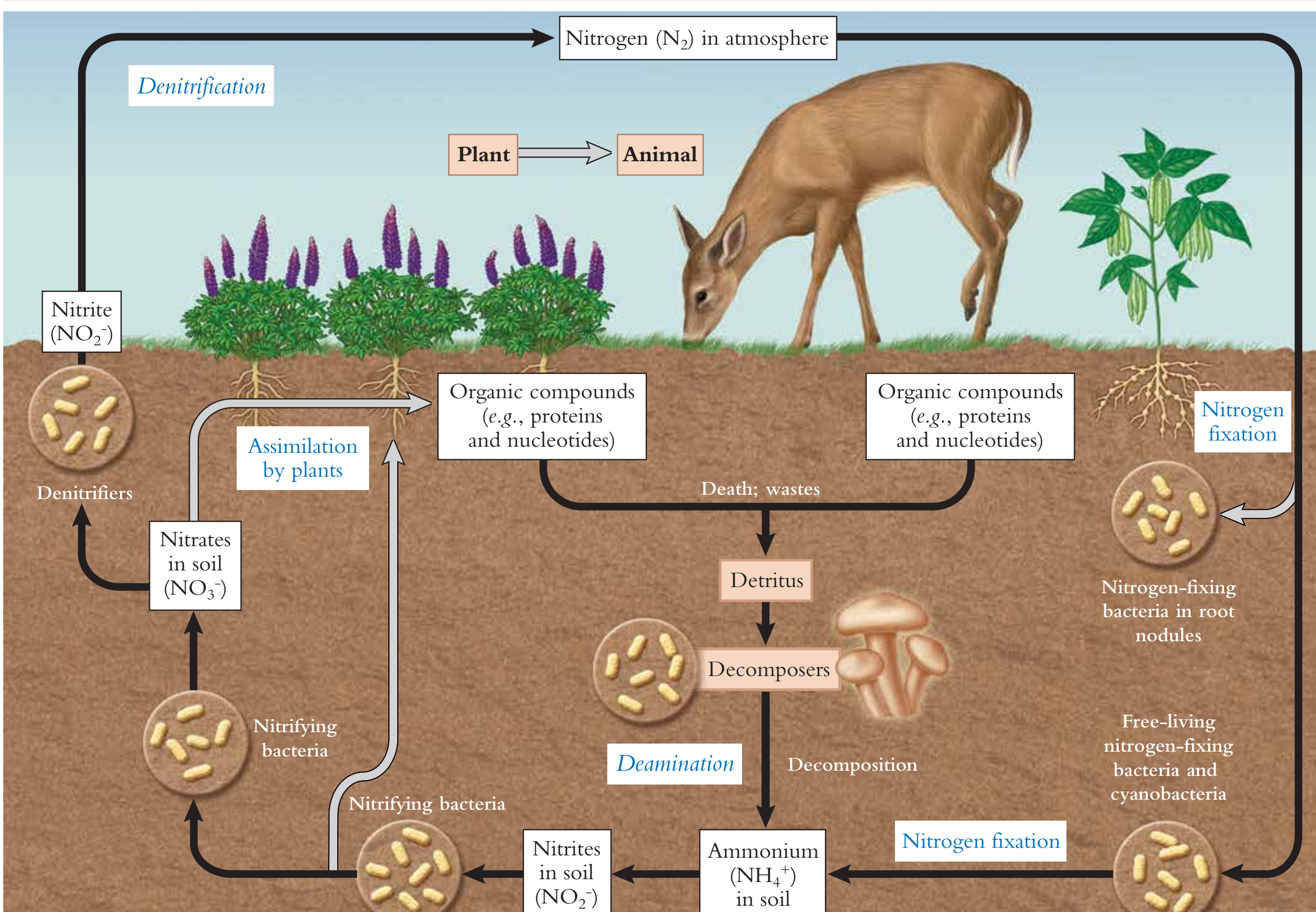


Figure 3.14 Few organisms have the ability to utilize atmospheric nitrogen. Nitrogen-fixing bacteria within the root nodules of legumes (and some free-living bacteria) provide a usable source of nitrogen to plants.

Figure 3.15 Colonies of *Streptococcus pyogenes* cultured on a sheep blood agar plate. *S. pyogenes* causes strep throat and rheumatic fever in humans. This agar plate is approximately 10 cm in diameter.

Figure 3.16 Cyanobacteria living in hot springs and hot streams, such as this 40 meter effluent from a geyser in Yellowstone National Park.

1. Mats of *Cyanophyta*

Figure 3.17 Cyanobacteria of several species growing in the effluent from a geyser. The different species are temperature-dependent and form the bands of color.

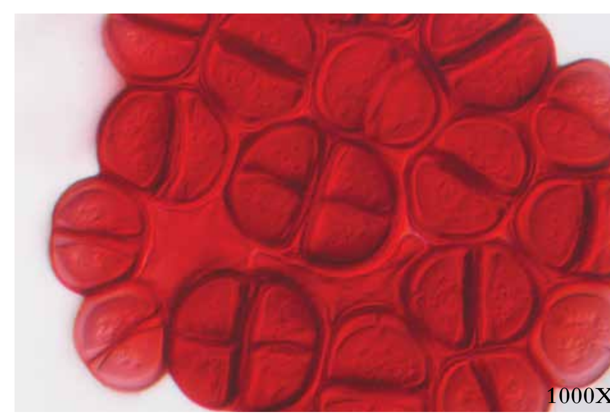


Figure 3.18 A magnified view of the cyanobacterium *Chroococcus* sp. shown with a red biological stain.

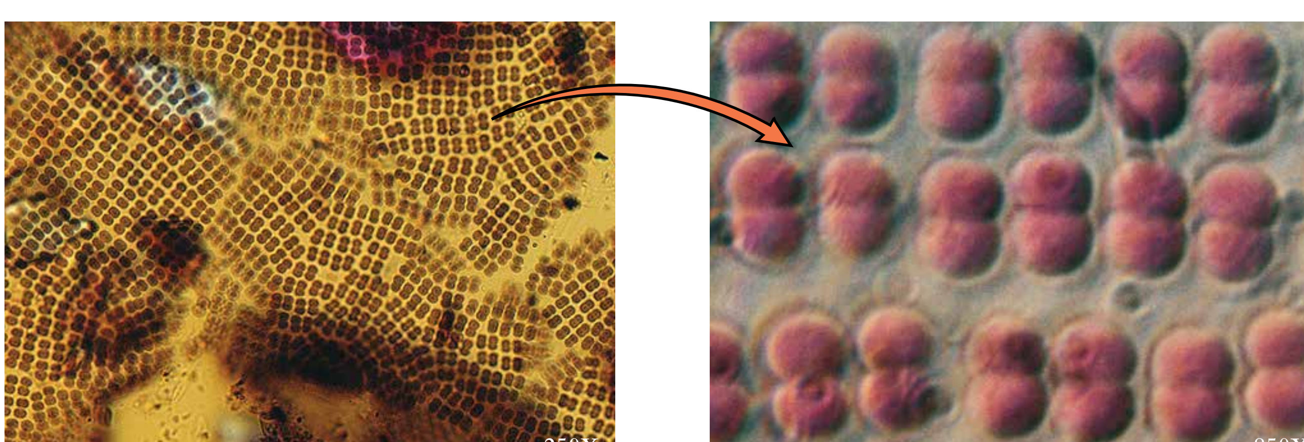


Figure 3.19 The cyanobacterium, *Merismopedia* sp., is characterized by flattened colonies of cells. The cells are in a single layer, usually aligned into groups of two or four.

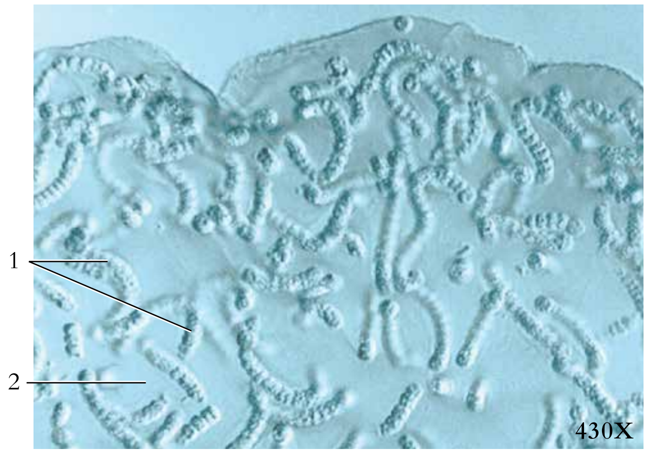


Figure 3.20 A colony of *Nostoc* sp. filaments. Individual filaments secrete mucilage, which forms a gelatinous matrix around all filaments.
1. Filaments 2. Gelatinous matrix

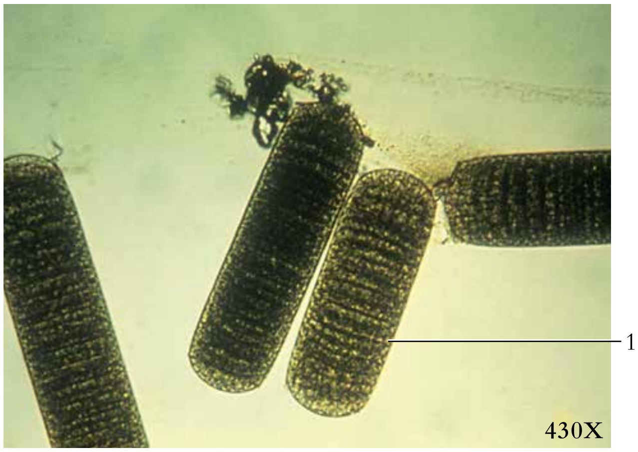


Figure 3.21 The filaments of *Oscillatoria* sp. The only way this cyanobacterium can reproduce is through fragmentation of a filament. Fragments are known as hormogonia.
1. Hormogonium

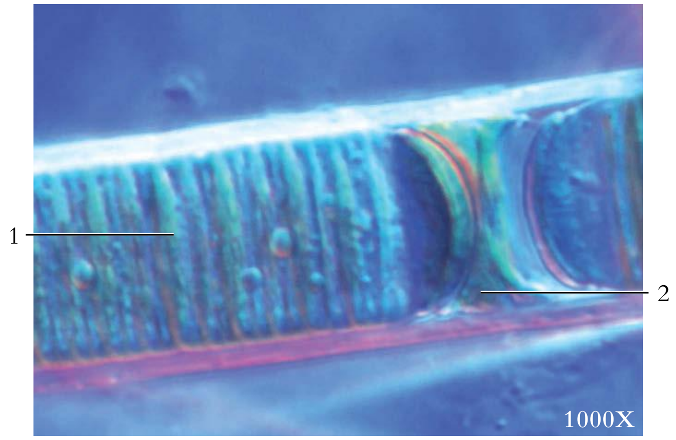


Figure 3.22 A portion of a cylindrical filament of *Oscillatoria* sp. This cyanobacterium is common in most aquatic habitats.
1. Filament segment (hormogonium) 2. Separation disk (necridium)

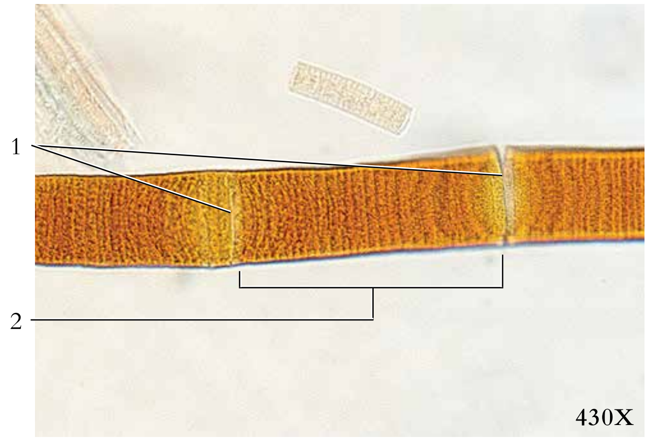


Figure 3.23 An *Oscillatoria* sp. filament showing necridia.
1. Necridia 2. Hormogonium

Figure 3.24 *Scytonema* sp., a cyanobacterium, common on moistened soil. Notice the falsely branched filament typical of this genus. This species also demonstrates "winged" sheaths.
1. False branching 2. "Winged" sheath

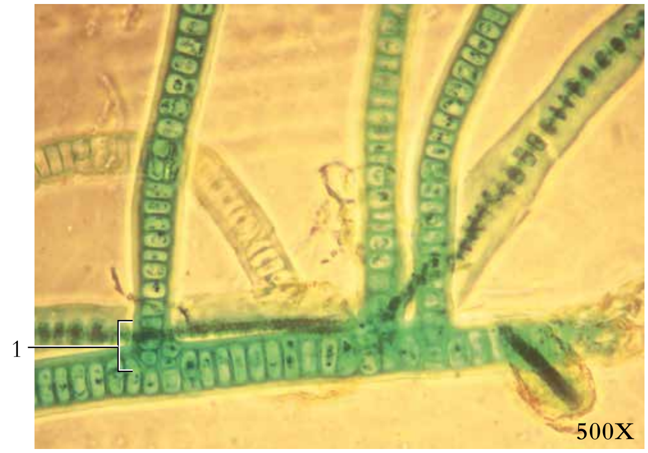


Figure 3.25 The cyanobacterium, *Stigonema* sp. This species has true-branched filaments caused from cell division in two separate planes.
1. True branching

Figure 3.26 *Tolypothrix* sp., a cyanobacterium with a single false-branched filament.
1. Heterocysts 2. False branching 3. Sheath

Figure 3.27 Longitudinal section of a fossilized stromatolite two billion years old. Layering indicates the communities of bacteria and cyanobacteria mixed with sediments. This specimen originates from Australia (scale in mm).

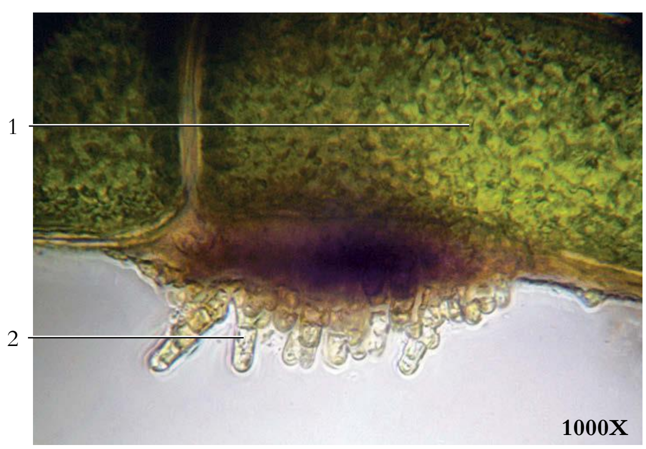


Figure 3.28 Cyanobacterium, *Chamaesiphon* sp., growing as an epiphyte on green algae, *Cladophora* sp.
1. *Cladophora* sp. 2. *Chamaesiphon* sp.

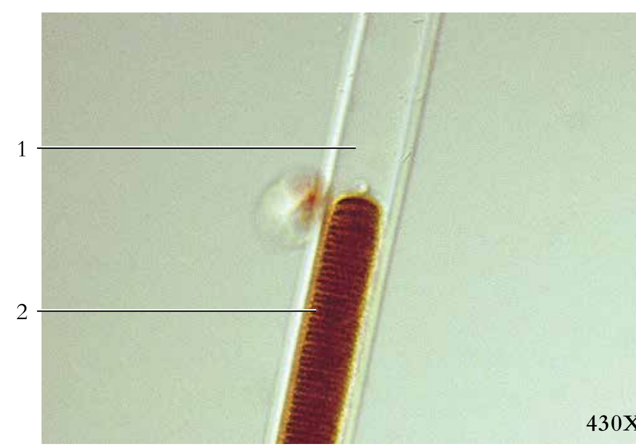


Figure 3.29 *Lyngbya birgei*, a cyanobacterium, is common in eutrophic water throughout North America.
1. Extended sheath 2. Filament of living cells

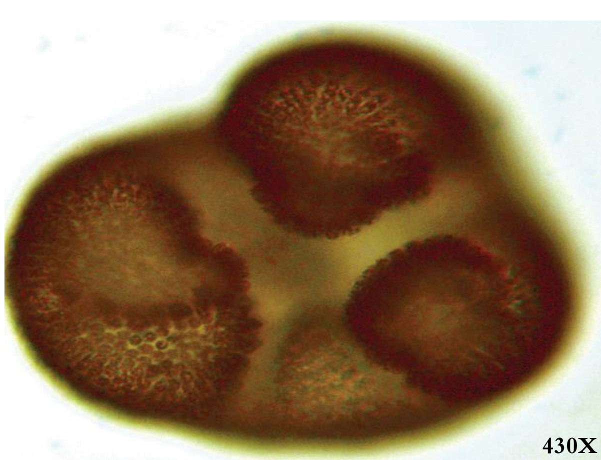


Figure 3.30 *Microcystis aeruginosa*, a cyanobacterium that can cause toxic water "blooms."

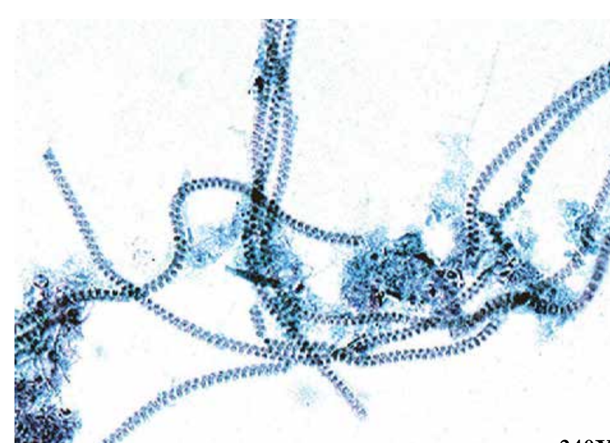


Figure 3.31 *Spirulina* sp., a cyanobacterium, showing characteristic spiral trichomes.

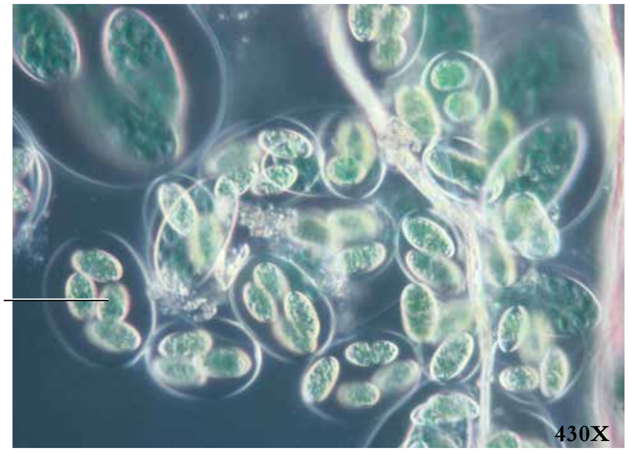


Figure 3.32 *Glaucocystis* sp., a green alga with cyanobacteria as endosymbionts.
1. Cyanobacteria endosymbiont

Figure 3.33 *Microcoleus* sp., one of the most common cyanobacteria in and on soils throughout the world. It is characterized by several filaments in a common sheath.

Figure 3.34 A satellite image of a large lake. The circular pattern in the water is composed of dense growths of cyanobacteria.

Figure 3.35 *Arthrospira* sp., a common cyanobacterium.

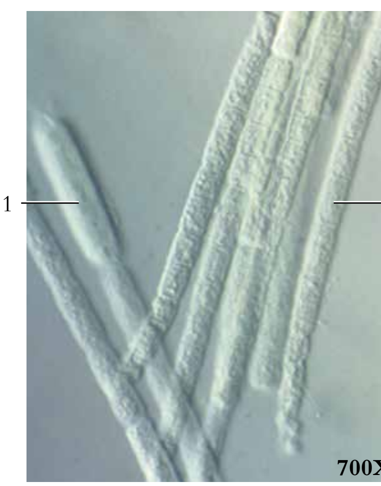


Figure 3.36 The cyanobacterium *Aphanizomenon* sp., common in nutrient-rich (often polluted) waters around the world.
1. Spore (akinete) 2. Filament

Figure 3.37 A spring seep in Zion National Park, Utah.
1. Mat of cyanobacteria.

Figure 3.38 A researcher examining cyanobacterial growths on soil in Canyonlands National Park, Utah.

Figure 3.39 A close-up photo of cryptobiotic soil crust. These crusts are composed of cyanobacteria, fungi, lichens, and other organisms.

4 Select Single-Celled Eukaryote Supergroup Phyla ("Protists")

All animals are eukaryotes—their cells contain a membrane-bound nucleus that contains their genetic material. Most eukaryotic cells also contain membrane-bound organelles, such as mitochondria, chloroplasts, and digestive vacuoles and are even capable of meiosis and sexual reproduction. Eukaryotes are most closely related to Archaea but acquired their organelles from Bacteria by way of endosymbiosis (see Exhibit 1 on page vi).

We easily recognize the majority of multicellular animals—the Metazoa—and distinguish these from plants and fungi. But there is a tremendous diversity of eukaryotes that aren't metazoans, fungi, or plants. Some contain chloroplasts, some don't. Most are single-celled, but some aren't. Most are microscopic, but some, like giant kelp, are very large. These organisms, which do not constitute a natural, or monophyletic group, are defined more by what they aren't than by what they are. But because they play an important role in understanding the evolutionary transitions that took place between prokaryotes and metazoans over a billion years ago, they are crucial components of any serious study of zoology.

Historically, the Linnean classification system ranked taxa according to morphological similarity. As phylogenetic analyses have become increasingly sophisticated and accurate, some of the well-known Linnean taxa have turned out to be evolutionary grades (as opposed to clades), united by primitive (plesiomorphic), as opposed to derived (apomorphic), characters. Such is the case for many independent evolutionary lineages of eukaryotes that are either unicellular or multicellular but without specialized tissues. Heretofore known as "protists," in this chapter we present them in a phylogenetic context that more accurately reflects their evolutionary history and current taxonomic status.

Most of the unicellular taxa in Table 4.1 are abundant in aquatic habitats, and many are important constituents of plankton. Plankton are communities of organisms that drift passively or swim slowly in ponds, lakes, and oceans. Plankton are a major source of food for other aquatic organisms. Phototrophic (plantlike) microeukaryotes are major food producers in aquatic ecosystems. Key members of this group are from the Phylum Heterokontophyta, which includes the diatoms and golden algae. The cell wall of a diatom is composed largely of silica rather than cellulose. Some diatoms move in a slow, gliding way as cytoplasm glides through slits in the cell wall.

The Phylum Dinoflagellata also constitutes a large component of the phototrophic plankton. In most species of dinoflagellates, the cell wall is formed of armor-like plates of cellulose. Dinoflagellates are motile, having two flagella. Generally, one encircles the organism in a transverse groove, and the other projects to the posterior.

Among the unicellular microeukaryotes, or "protozoan" (animallike) phyla are the Amoebozoa, Apicomplexa, Euglenozoa, Metamonada, and Ciliophora. Locomotion of these heterotrophs is by way of flagella, cilia, or pseudopodia of various sorts. In feeding upon other organisms or organic particles, they use simple diffusion, pinocytosis, active transport, or phagocytosis. Although most of these organisms reproduce asexually, some species may also reproduce sexually during a portion of their life cycle. Most protozoa are harmless, although some are parasitic and may cause human disease, including African sleeping sickness and malaria.

Figure 4.1 A *Paramecium caudatum*.

Table 4.1 Representative Single-Celled Eukaryote Phyla

Phyla and Representative Kinds	Characteristics
Heterokontophyta — diatoms and golden algae	Diatom cell walls composed of or impregnated with silica, often with two halves; plastids often golden in Chrysophyceae due to chlorophyll composition
Amoebozoa — amoebozoa	Cytoskeleton of microtubules and microfilaments; amoeboid locomotion
Euglenozoa — flagellated protozoa	Use flagella or pseudopodia for locomotion; mostly parasitic
Metamonada — trichomonads	Flagellate protozoan, *Trichomonas* sp.
Ciliophora — ciliates and *Paramecium*	Use cilia to move and feed
Dinoflagellata — dinoflagellates	Two flagella in grooves of wall; brownish-gold plastids
Apicomplexa — sporozoa and *Plasmodium*	Lack locomotor capabilities and contractile vacuoles; mostly parasitic

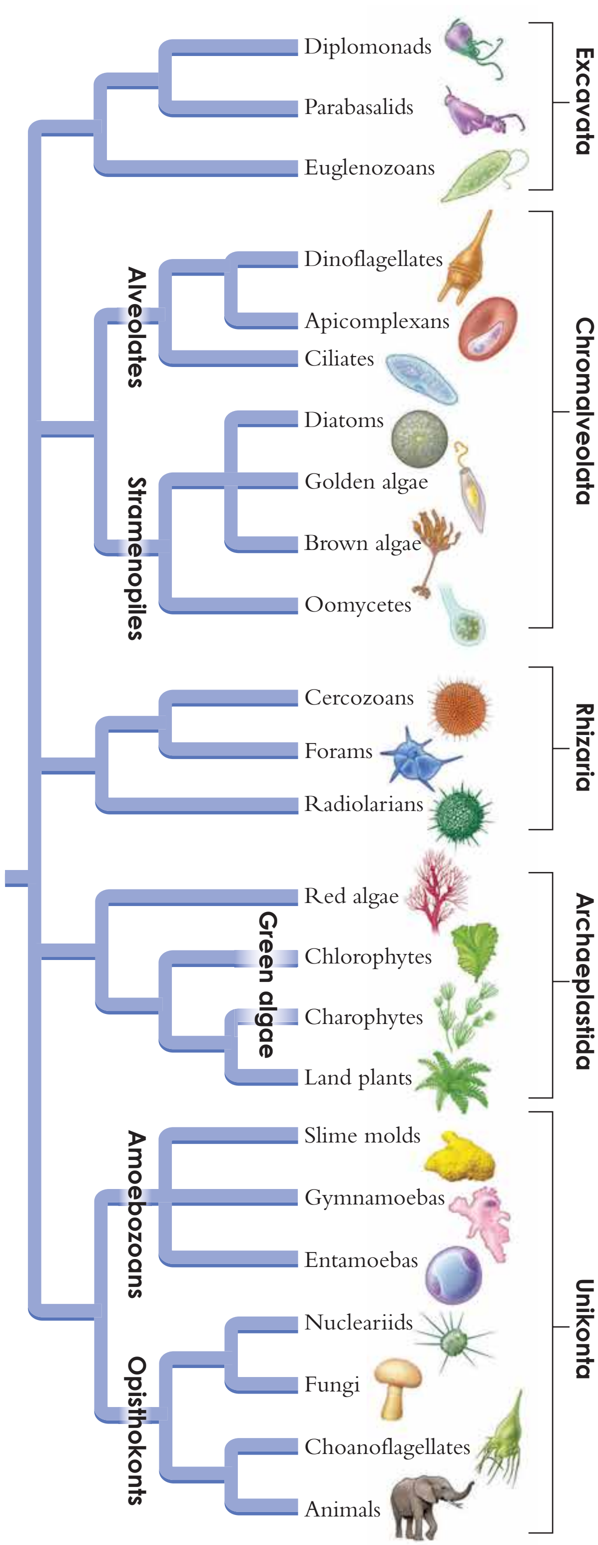


Figure 4.2 The phylogenetic relationships and classification of major eukaryote lineages.

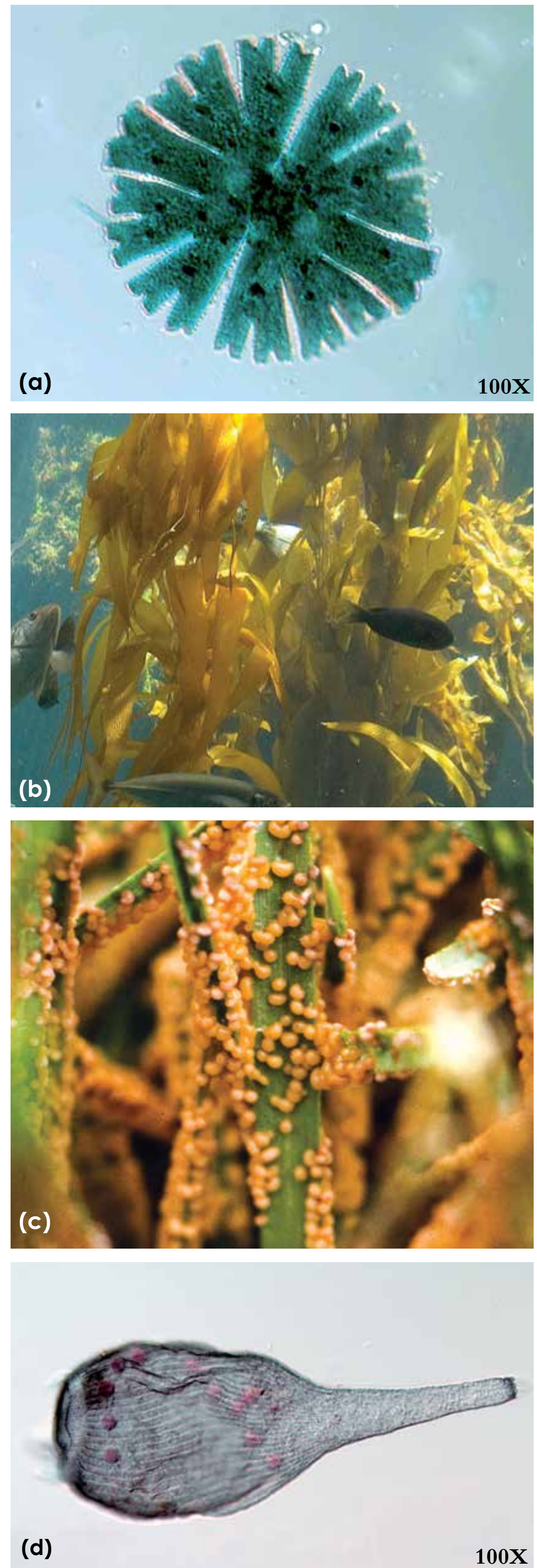


Figure 4.3 Example Protista include: (a) desmid, *Micrasterias* sp., (b) kelp, *Macrocystis* sp., (c) a slime mold, *Physarum cinerea*, and (d) a protozoa, *Stentor* sp.

Phylum Heterokontophyta – diatoms and golden algae

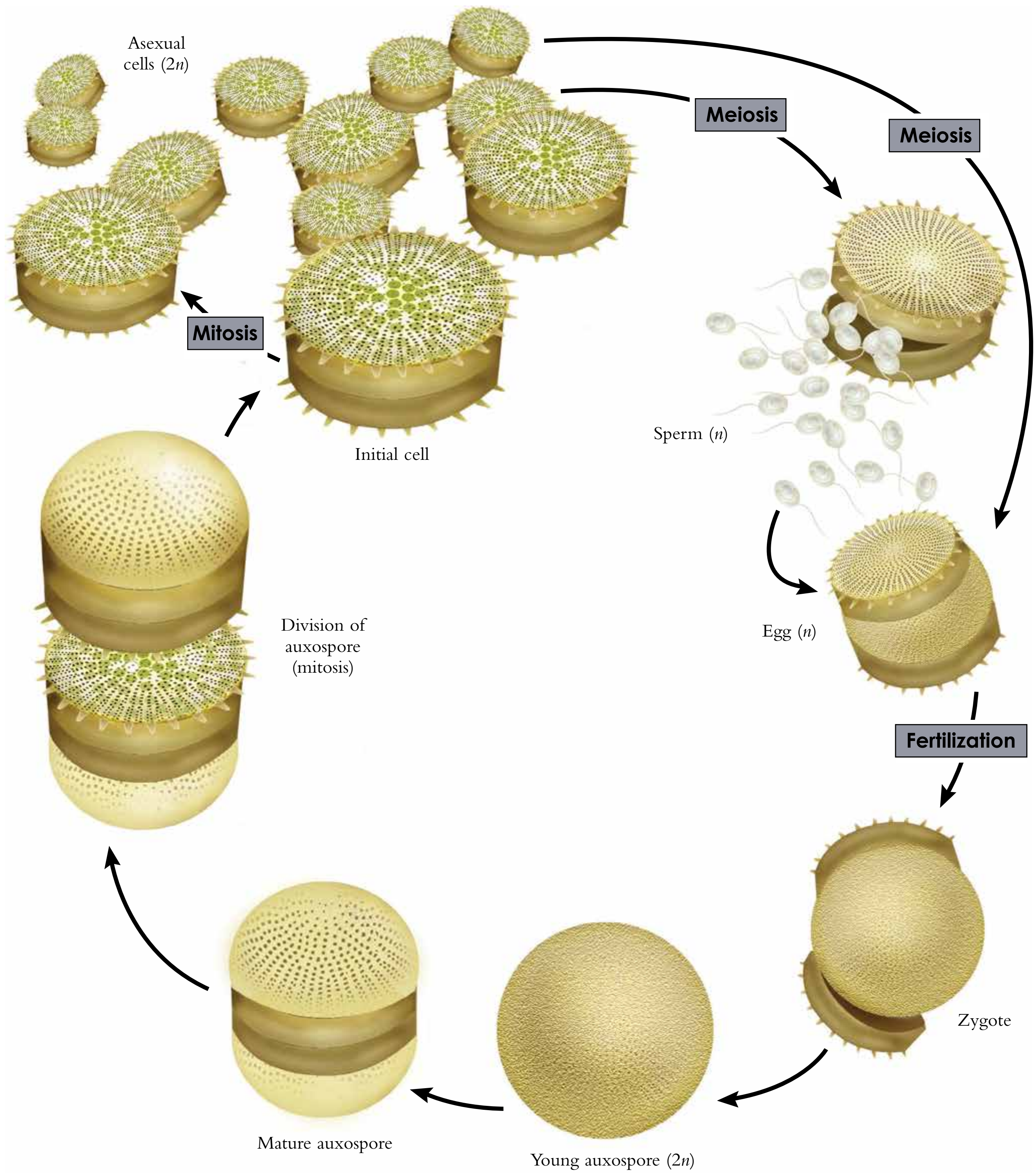


Figure 4.4 Life cycle of a centric diatom.

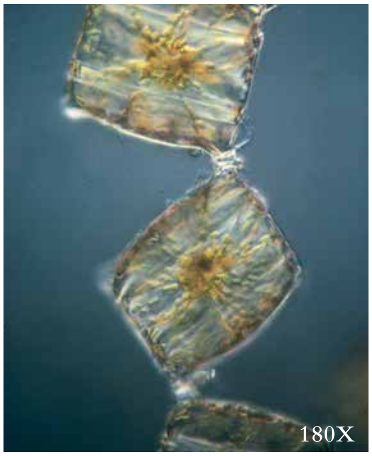


Figure 4.5 *Biddulphia* sp., a diatom forming colonies. These cells are beginning cell division.

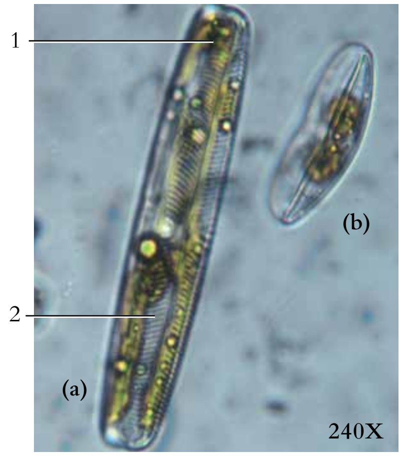


Figure 4.6 Live specimens of pennate (bilaterally symmetrical) diatoms. (a) *Navicula* sp., and (b) *Cymbella* sp.
1. Chloroplast 2. Striae

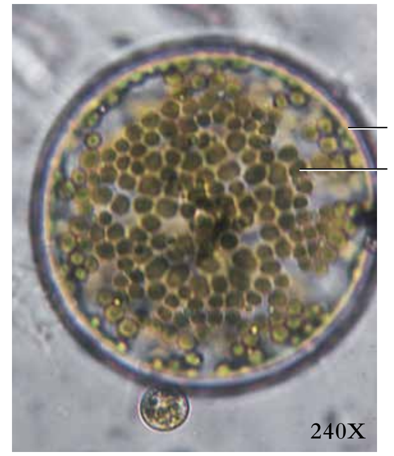


Figure 4.7 *Hyalodiscus* sp., a centric (radially symmetrical) diatom, from a freshwater spring in Nevada.
1. Silica cell wall 2. Chloroplasts

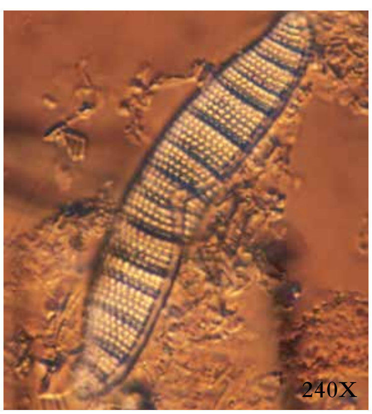


Figure 4.8 *Epithemia* sp., a distinctive pennate freshwater diatom.

Figure 4.9 *Stephanodiscus* sp., a centric diatom.

Figure 4.10 Two common freshwater diatoms.
1. *Cocconeis* 2. *Amphora*

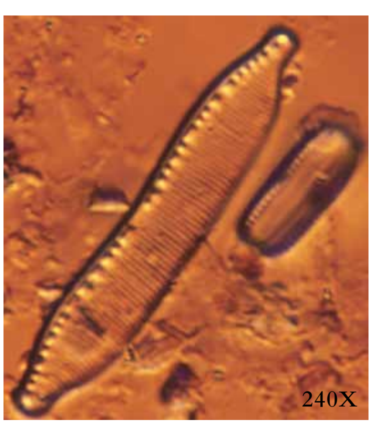


Figure 4.11 *Hantzschia* sp., one of the most common soil diatoms.

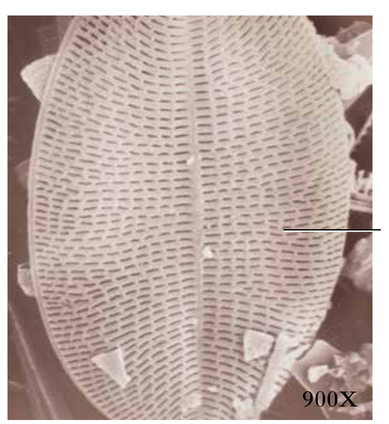


Figure 4.12 A scanning electron micrograph of *Cocconeis* sp., a common freshwater diatom.
1. Striae containing pores, or punctae, in the frustule (silicon cell wall).

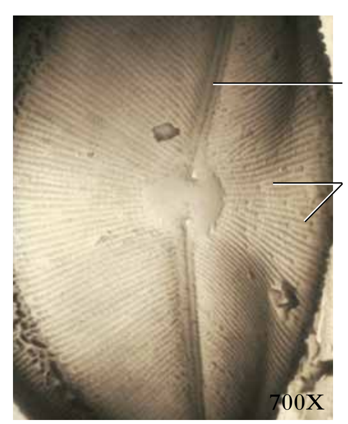


Figure 4.13 A scanning electron micrograph of the diatom *Achnanthes flexella.*
1. Raphe 2. Striae

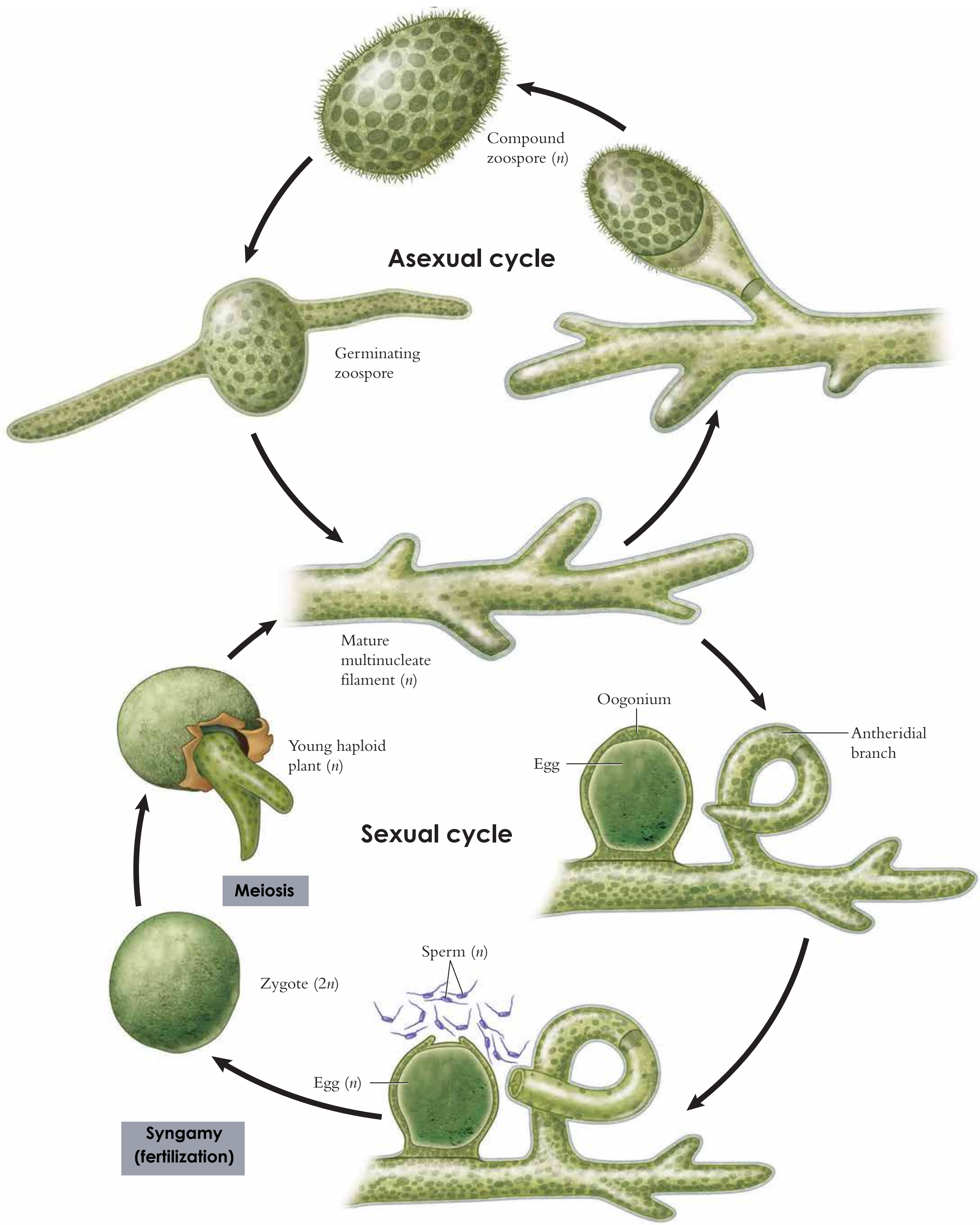


Figure 4.14 The life cycle of the "water felt alga," *Vaucheria* sp.

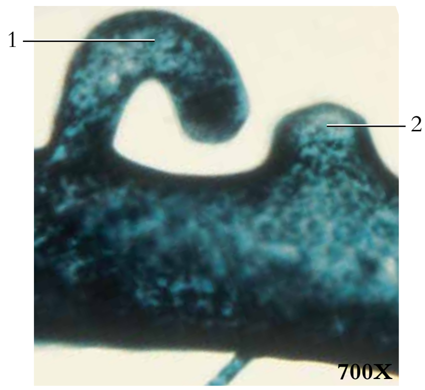


Figure 4.15 A filament with immature gametangia of the "water felt" alga, *Vaucheria* sp. *Vaucheria* is a chrysophyte that is widespread in freshwater and marine habitats. It is also found in the mud of brackish areas that periodically become submerged and then exposed to air.

1. Antheridium
2. Developing oogonium

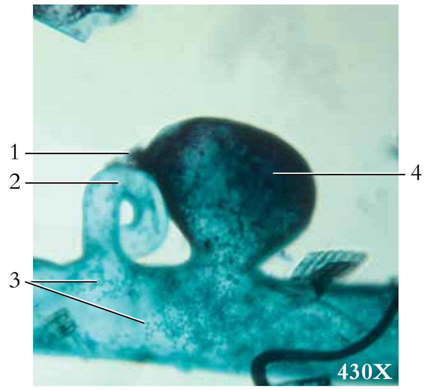


Figure 4.16 A *Vaucheria* sp., with mature gametangia.

1. Fertilization pore
2. Antheridium
3. Chloroplasts
4. Developing oogonium

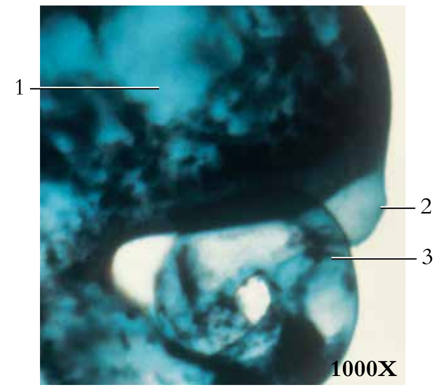


Figure 4.17 A *Vaucheria* sp., with mature gametangia.

1. Oogonium
2. Fertilization pore
3. Antheridium

Phylum Dinoflagellata – dinoflagellates

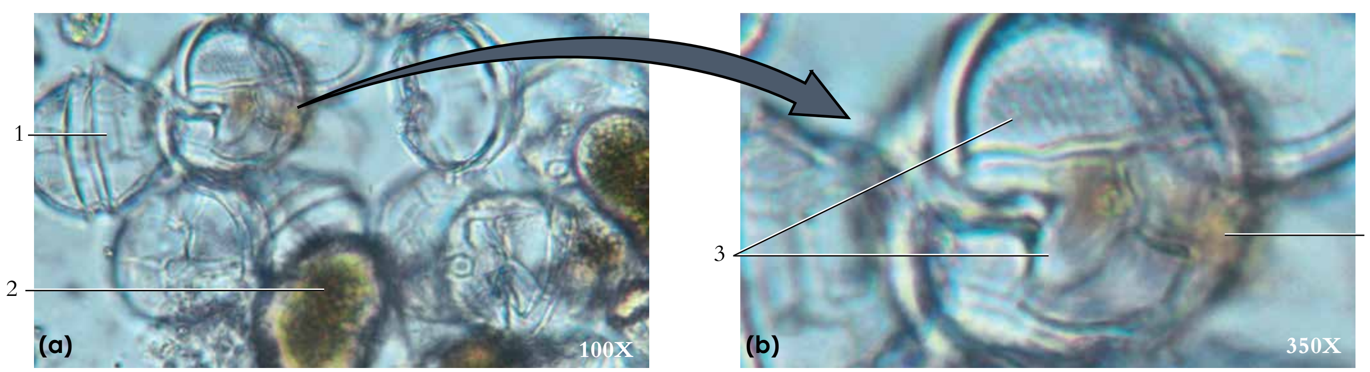


Figure 4.18 The dinoflagellates, *Peridinium* sp. (a) Some organisms are living; (b) others are dead and have lost their cytoplasm and consist of resistant cell walls.

1. Dead dinoflagellate
2. Living dinoflagellate
3. Cellulose plates
4. Remnant of cytoplasm

Figure 4.19 A giant clam with bluish coloration due to endosymbiont dinoflagellates.

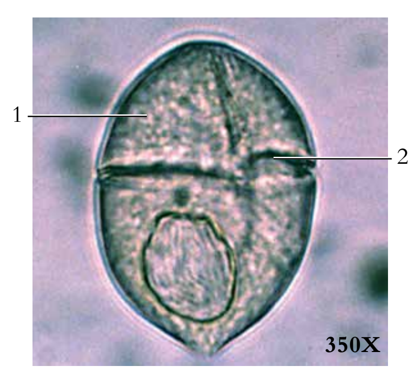


Figure 4.20 A photomicrograph of *Peridinium* sp. The cell wall of many dinoflagellates is composed of overlapping plates of cellulose.

1. Wall of cellulose plates
2. Transverse groove

Figure 4.21 *Ceratium* sp. is a common freshwater dinoflagellate.

1. Transverse groove
2. Trailing flagellum

Phylum Amoebozoa – amoebas

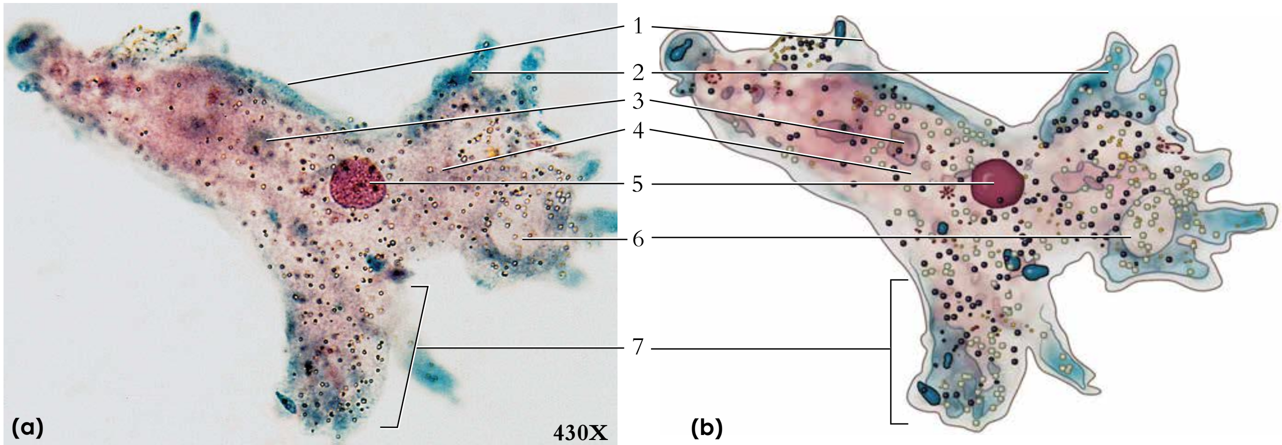


Figure 4.22 The *Amoeba proteus* is a freshwater protozoan that moves by forming cytoplasmic extensions called pseudopodia. (a) Stained cell, and (b) diagram.

1. Cell membrane
2. Ectoplasm
3. Food vacuole
4. Endoplasm
5. Nucleus
6. Contractile vacuole
7. Pseudopodia

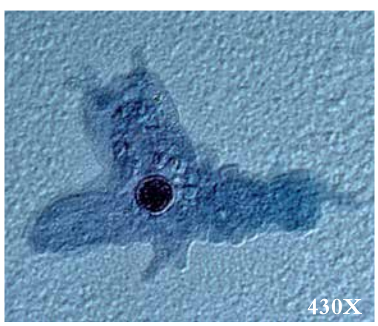


Figure 4.23 *Amoeba proteus* (stained blue).

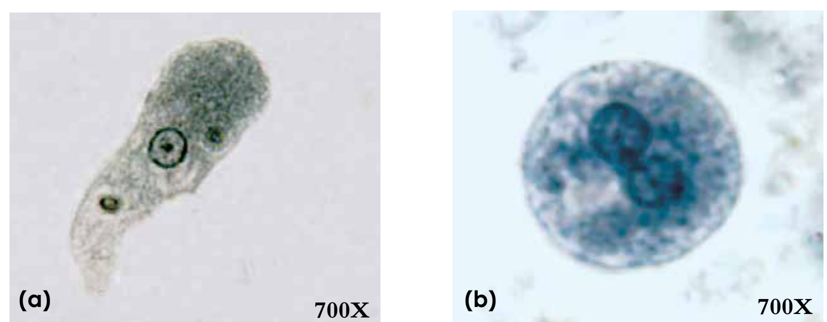


Figure 4.24 Protozoan *Entamoeba histolytica* is the causative agent of amoebic dysentery, a disease most common in areas with poor sanitation. (a) A trophozoite, and (b) a cyst.

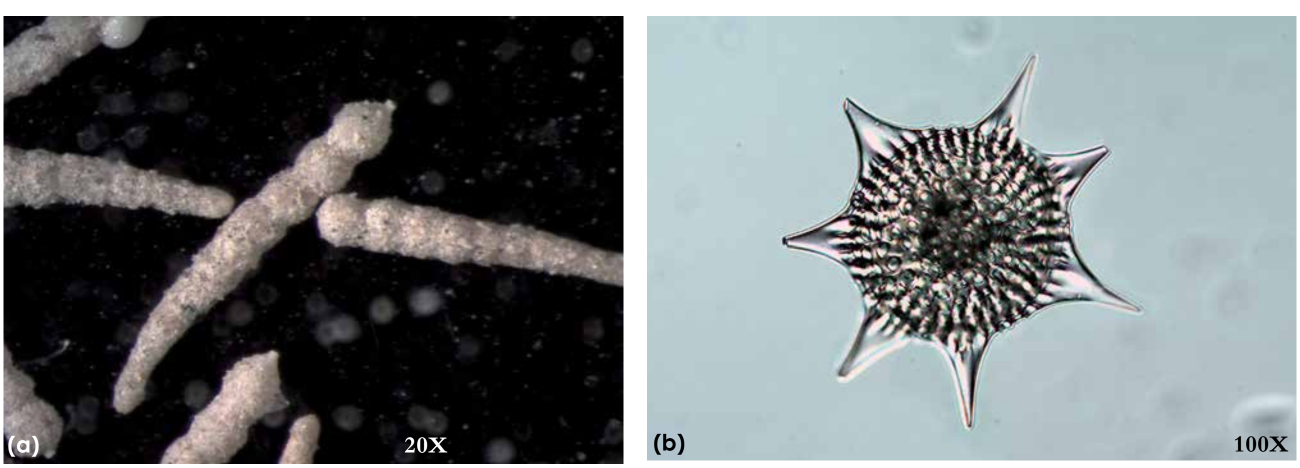


Figure 4.25 Examples of some common amoeba-like organisms, (a) foraminiferan, *Arenaceous* sp., and (b) radiolarian.

Phylum Apicomplexa – *Plasmodium*

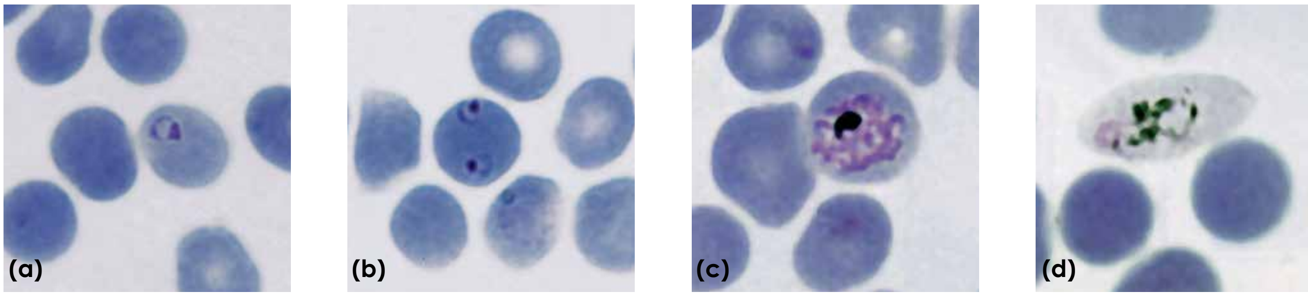


Figure 4.26 The protozoan *Plasmodium falciparum* causes malaria, which is transmitted by the female *Anopheles* mosquito. (a) The ring stage in a red blood cell, (b) a double infection, (c) a developing schizont, and (d) a gametocyte.

Phylum Metamonada and Phylum Euglenozoa – flagellated protozoans

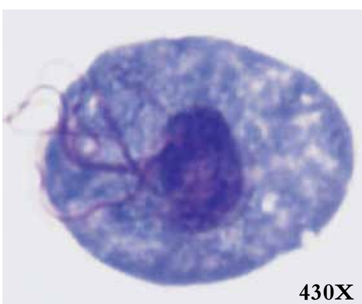


Figure 4.27 The protozoan *Trichomonas vaginalis* is the causative agent of trichomoniasis. Trichomoniasis is an inflammation of the genitourinary mucosal surfaces—the urethra, vulva, vagina, and cervix in females and the urethra, prostate, and seminal vesicles in males.

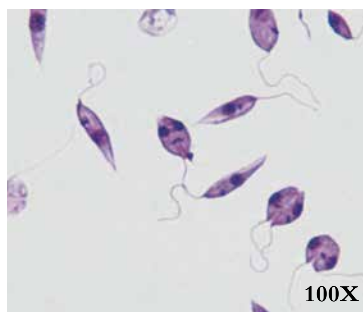


Figure 4.28 The protozoan *Leishmania donovani* is the causative agent of leishmaniasis, or kala-azar disease, in humans. The sandfly is the infectious host of this disease.

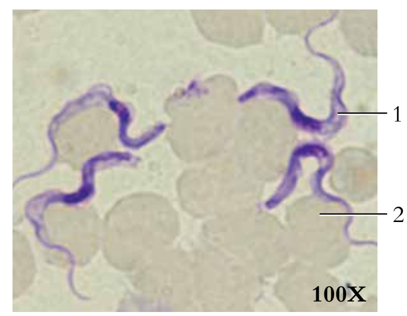


Figure 4.29 A flagellated protozoan, *Trypanosoma brucei*, is the causative agent of trypanosomiasis, or African sleeping sickness. The tsetse fly is the infectious host of this disease in humans.

1. *Trypanosoma brucei*
2. Red blood cell

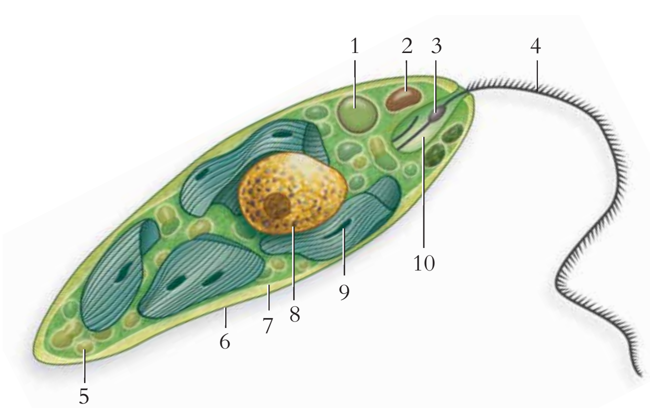


Figure 4.30 A diagram of *Euglena,* a genus of flagellates that contains chloroplasts. They are freshwater organisms that have a flexible pellicle rather than a rigid cell wall.

1. Long flagellum
2. Photoreceptor
3. Eyespot
4. Contractile vacuole
5. Reservoir
6. Chloroplast
7. Nucleus
8. Pellicle
9. Cell membrane
10. Paramylon granule

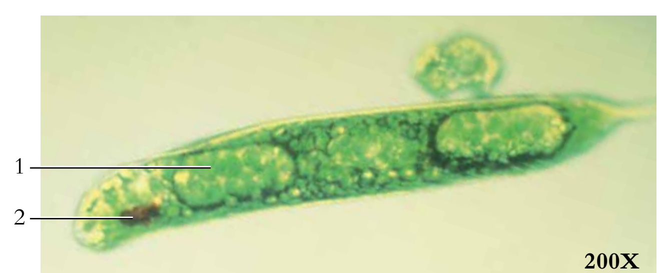


Figure 4.31 A species of *Euglena*.

1. Paramylon body
2. Photoreceptor

Figure 4.32 A species of *Euglena* from a brackish lake.

1. Pellicle
2. Photoreceptor

Phylum Ciliophora – ciliates and paramecia

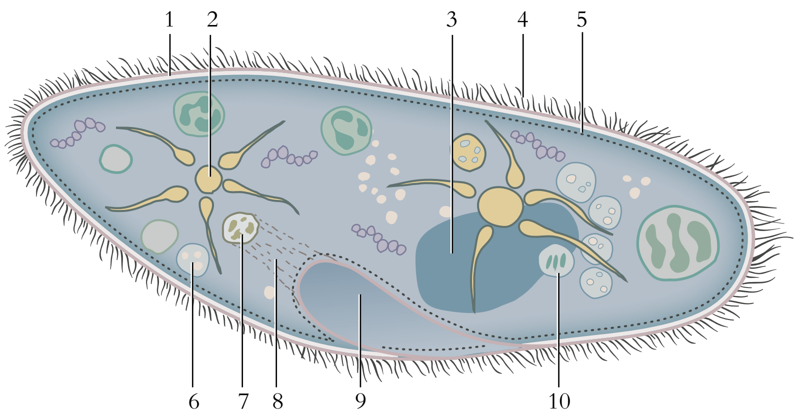


Figure 4.33 *Paramecium caudatum* is a ciliated protozoan. The poisonous trichocysts of these unicellular organisms are used for defense and capturing prey.

1. Pellicle
2. Contractile vacuole
3. Macronucleus
4. Cilia
5. Trichocyst
6. Food vacuole
7. Forming food vacuole
8. Gullet
9. Oral groove
10. Micronucleus

Figure 4.34 *Paramecium caudatum* is a ciliated protozoan. Paramecia are usually common in ponds containing decaying organic matter.

1. Macronucleus
2. Contractile vacuole
3. Micronucleus
4. Pellicle
5. Cilia

Figure 4.35 *Paramecium bursaria* is a unicellular, slipper-shaped organism. When disturbed or threatened, they release spear-like trichocysts as a defense.

1. Trichocysts
2. Macronucleus
3. Micronucleus
4. Pellicle

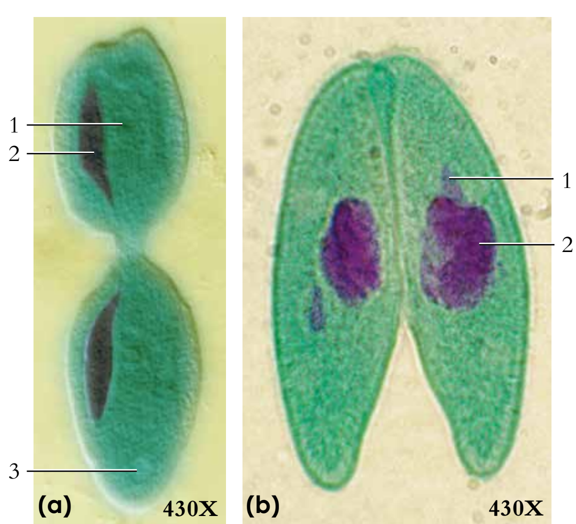


Figure 4.36 (a) A *Paramecium* sp. in fission, and (b) a *Paramecium* in conjugation.

1. Micronucleus
2. Macronucleus
3. Contractile vacuole

Figure 4.37 A prepared slide showing a group of *Paramecium* sp.

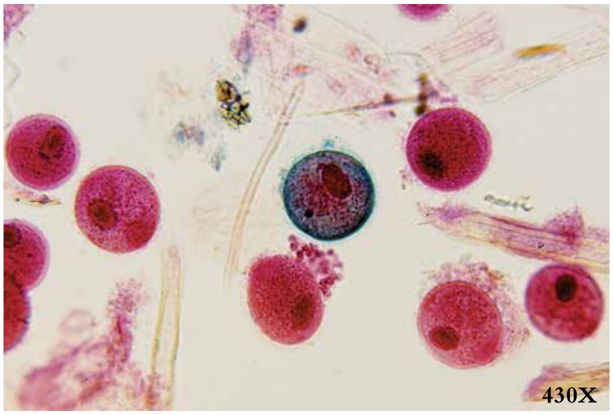


Figure 4.38 *Balantidium coli*, the causative agent of balantidiasis. Cysts in sewage-contaminated water are the infective form.

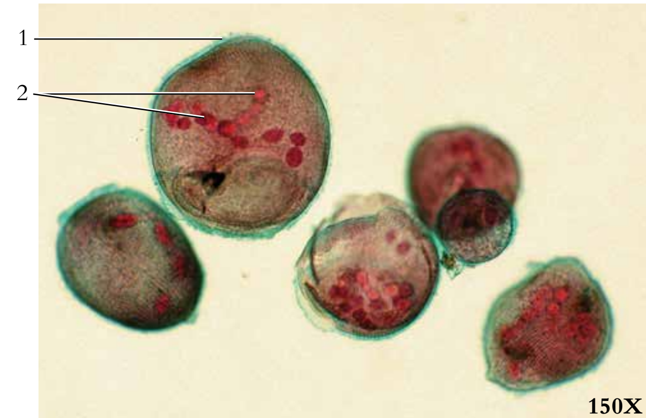


Figure 4.39 *Stentor* sp., a free-swimming form that has adopted an oval shape.
1. Cilia 2. Macronucleus (moniliform)

Table 4.2 Some Representatives of Protista: Primarily Multicellular Organisms

Phylum and Representative Kinds	Characteristics
Algae	
Phylum Chlorophyta—green algae	Unicellular, colonial, filamentous, and multicellular platelike forms; mostly freshwater; reproduce asexually and sexually; undergo alternation of generations
Phylum Phaeophyta—brown algae, giant kelp	Multicellular, mostly marine often in the intertidal zone; most with alternation of generations
Phylum Rhodophyta—red algae	Multicellular, mostly marine; sexual reproduction but with no flagellated cells; alternation of generations common
Protists Resembling Fungi	
Phylum Myxomycota—plasmodial slime molds	Multinucleated continuum of cytoplasm without cell membranes; amoeboid plasmodium during feeding stage; produce asexual fruiting bodies; gametes produced by meiosis
Phylum Dictyosteliomycota—cellular slime molds	Solitary cells during feeding stage; cells aggregate when food is scarce; produce asexual fruiting bodies
Phylum Oomycota—water molds, white rusts, and downy mildews	Decomposers or parasitic forms; walls of cellulose, dispersal by nonmotile spores or flagellated zoospores, gametes produced by meiosis

Phylum Chlorophyta – green algae

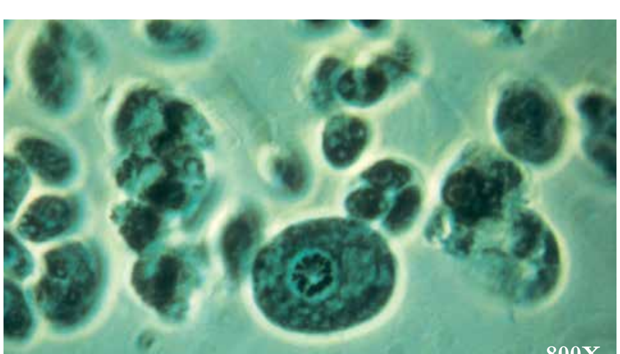


Figure 4.40 *Chlamydomonas* sp., a common unicellular green alga.

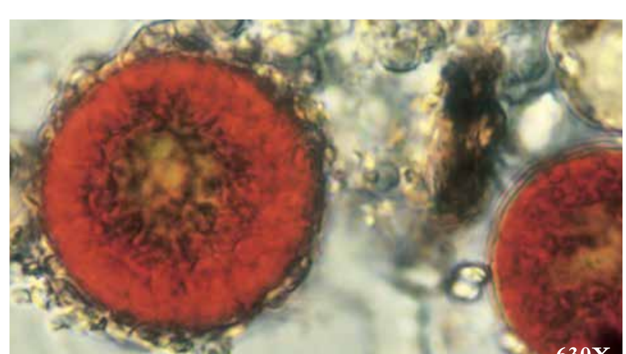


Figure 4.41 *Chlamydomonas nivalis*, the common snow alga.