Cell and Molecular Biology

Ninth Edition

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Chapter 1

Introduction to the Study of Cell and Molecular Biology

1.1 | The Discovery of Cells (1 of 3)

- Cells are the topic of intense study.
- The study of cells requires creative instruments and techniques.
- Cell biology is *reductionist*, based on the premise that studying the parts of the whole can explain the character of the whole.

1.1 | The Discovery of Cells (3 of 3)

Cell Theory

- The **cell theory** was articulated in the mid-1800s by Matthias Schleiden, Theodor Schwann and Rudolf Virchow.
  - All organisms are composed or one or more cells.
  - The cell is the structural unit of life.
  - Cells arise only by division from a pre-existing cell.
- Added since:
  - Cells contain genetic information (DNA) passed to next cell generation

1.2 | Basic Properties of Cells (1 of 11)

Cells are Highly Complex and Organized

- Life is the most basic property of cells.
- Cells can grow and reproduce in culture for extended periods.
- HeLa cells are cultured tumor cells isolated from a cancer patient (Henrietta Lacks)
- Cultured cells are an essential tool for cell biologists.

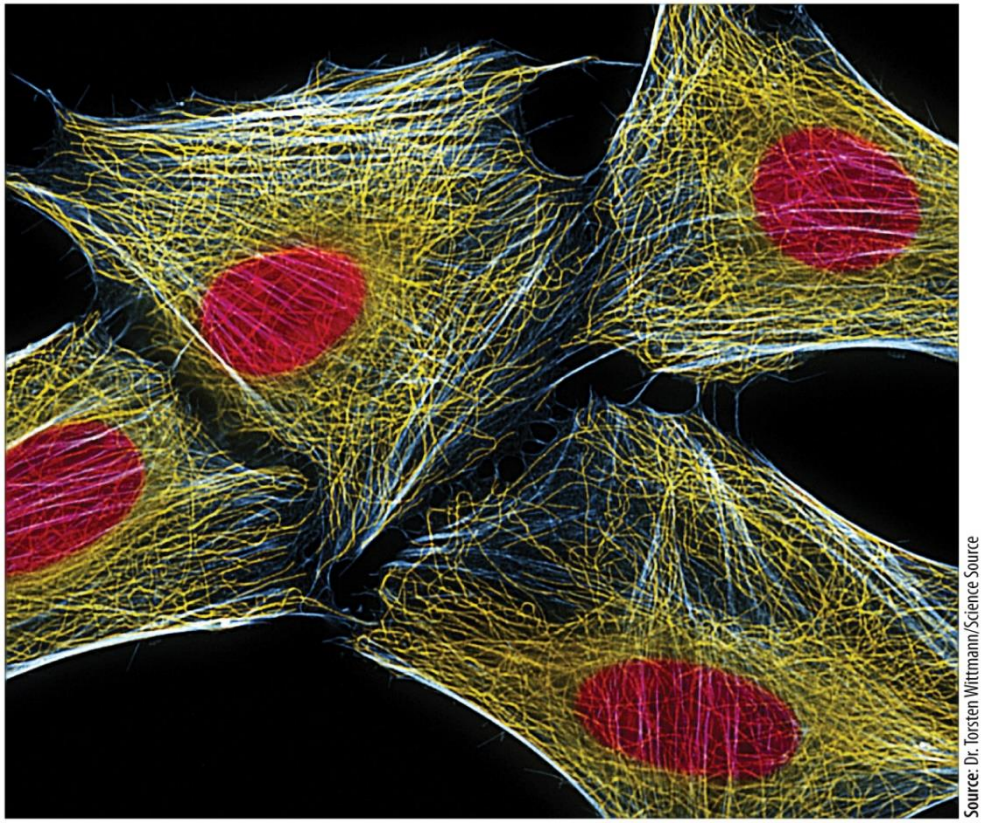

Fig. 1.2 HeLa cells

1.2 | Basic Properties of Cells (2 of 11)

Cells are Highly Complex and Organized

- Cellular processes are highly regulated.
- Cells from different species share similar structure, composition, and metabolic features.

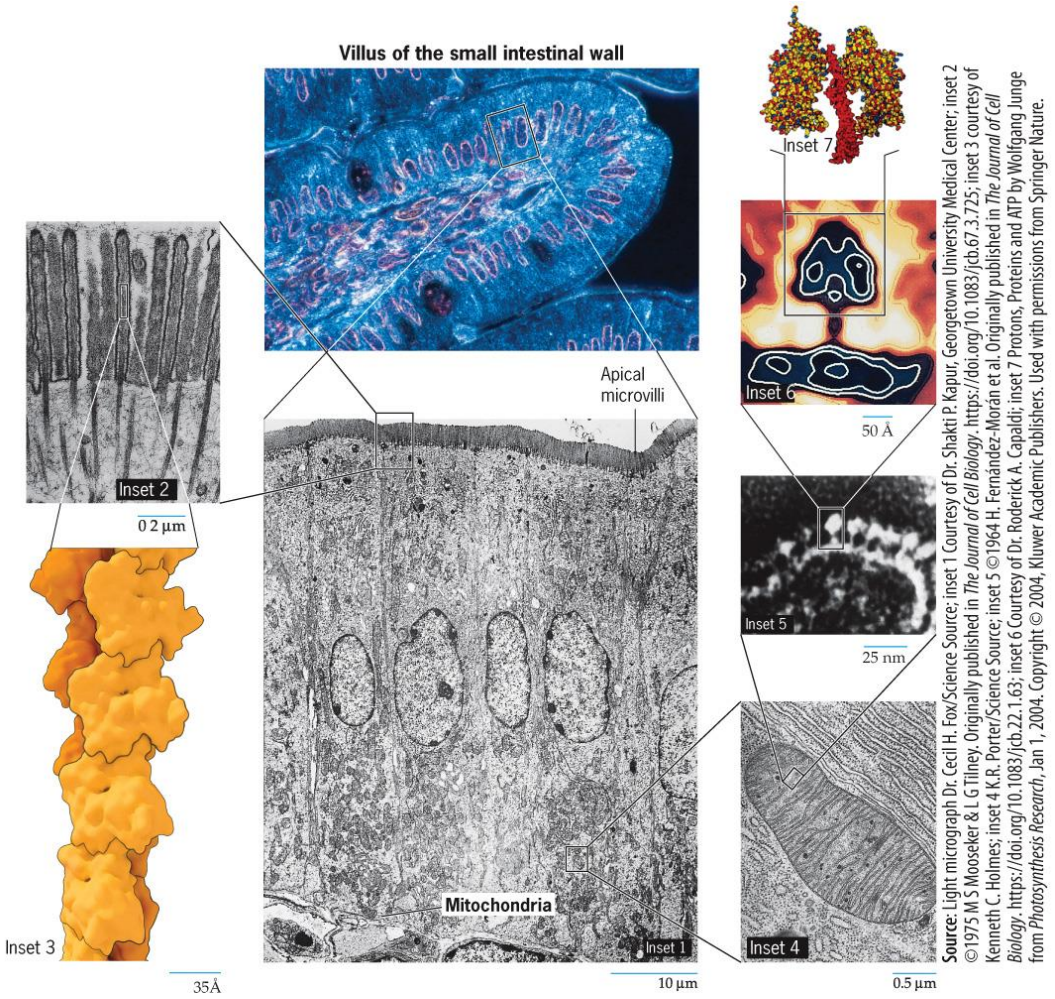

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Fig. 1.3 Levels of cellular and molecular organization

1.2 | Basic Properties of Cells (3 of 11)

Cells Possess a Genetic Program and the Means to Use It

- Information for building an organism is encoded in genes (constructed from DNA) and packaged into a set of chromosomes within the cell nucleus.
- Genes store information and instructions for:
- Constructing cellular structures, the directions for
- Running cellular activities, and the program for
- Making more of themselves.
- Genetic information can be haploid or diploid in cells

1.2 | Basic Properties of Cells (4 of 11)

Cells Are Capable of Producing More of Themselves

- Cells reproduce by division, a process in which the contents of a “mother” cell are distributed into two “daughter” cells.

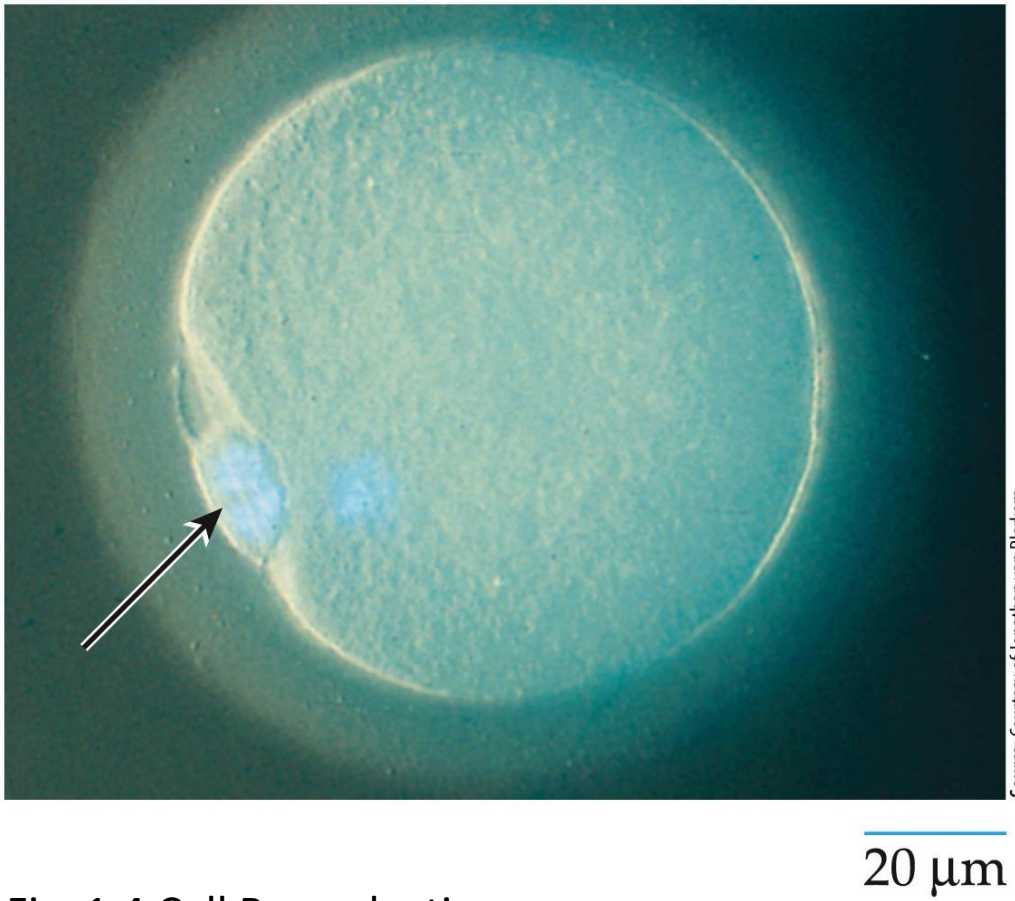
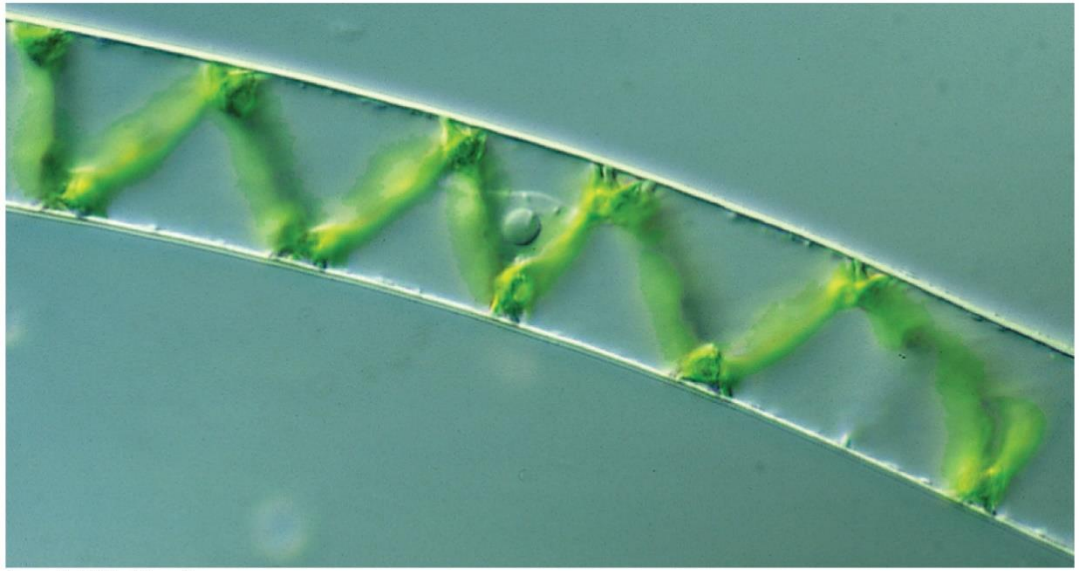


Fig. 1.4 Cell Reproduction

1.2 | Basic Properties of Cells (5 of 11)

Cells Acquire and Utilize Energy

- Photosynthesis provides fuel for all living organisms.
- Animal cells derive energy from the products of photosynthesis, mainly in the form of glucose.
- Cells can store glucose bond energy in ATP—a molecule with readily available energy.



Source: M. I. Walker/Science Source

Fig. 1.5 Acquiring energy

1.2 | Basic Properties of Cells (6 of 11)

Cells Carry Out a Variety of Chemical Reactions

- Cells function like miniaturized chemical plants.
- A bacterial cell is capable of hundreds of different chemical transformations.
- Virtually all chemical changes that take place in cells require enzymes to increase the rate at which a chemical reaction occurs.
- The sum total of the chemical reactions in a cell represents that cell's **metabolism**.

1.2 | Basic Properties of Cells (7 of 11)

Cells Engage in Mechanical Activities

- Cells are very active, they can: transport materials, assemble and disassemble structures, and sometimes move itself from one site to another.
- Activities are based on dynamic, mechanical changes within cells, many of which are initiated by changes in the shape of “motor” proteins.

1.2 | Basic Properties of Cells (8 of 11)

Cells Are Able to Respond to Stimuli

- A single-celled protest can move away from an object in its path or toward nutrients.
- Cells in plants or animals are covered with **receptors** that interact with substances in the environment.
- Hormones, growth factors, extracellular materials, and substances on the surfaces of other cells can interact with these receptors.
- Cells may respond to stimuli by altering their metabolism, moving from one place to another, or even committing suicide.

1.2 | Basic Properties of Cells (9 of 11)

Cells Are Capable of Self-Regulation

- Cells are robust and are protected from dangerous fluctuations in composition and behavior.
- Feedback circuits serve to return the cell to the appropriate state.
- Maintaining a complex, ordered state requires constant regulation.

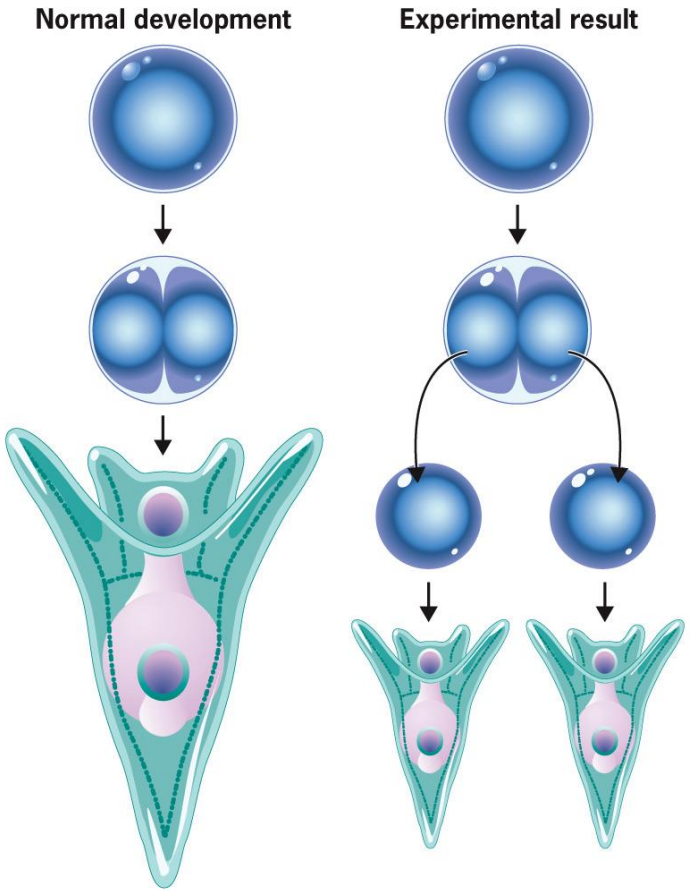


Fig. 1.6 Self-regulation

1.2 | Basic Properties of Cells (11 of 11)

Cells Evolve

- Whereas the origin of cells is shrouded in near-total mystery, the evolution of cells can be studied by examining organisms that are alive today.
- Cells share many features, including a common genetic code, a plasma membrane, and ribosomes.
- According to a tenet of modern biology, all living organisms evolved from a single, common ancestral cell that lived more than three billion years ago.
- This ancient cell is often referred to as the last universal common ancestor (or LUCA).

1.3 | Two Fundamentally Different Classes of Cells (1 of 19)

- Two basic classes of cells,
  - **Prokaryotic** – bacteria
  - **Eukaryotic** – plants, animals, protists, fungi
- These different classes are distinguished by their size and the types of organelles they contain.
- Both types of cells share an identical genetic language, a common set of metabolic pathways, and many common structural features.

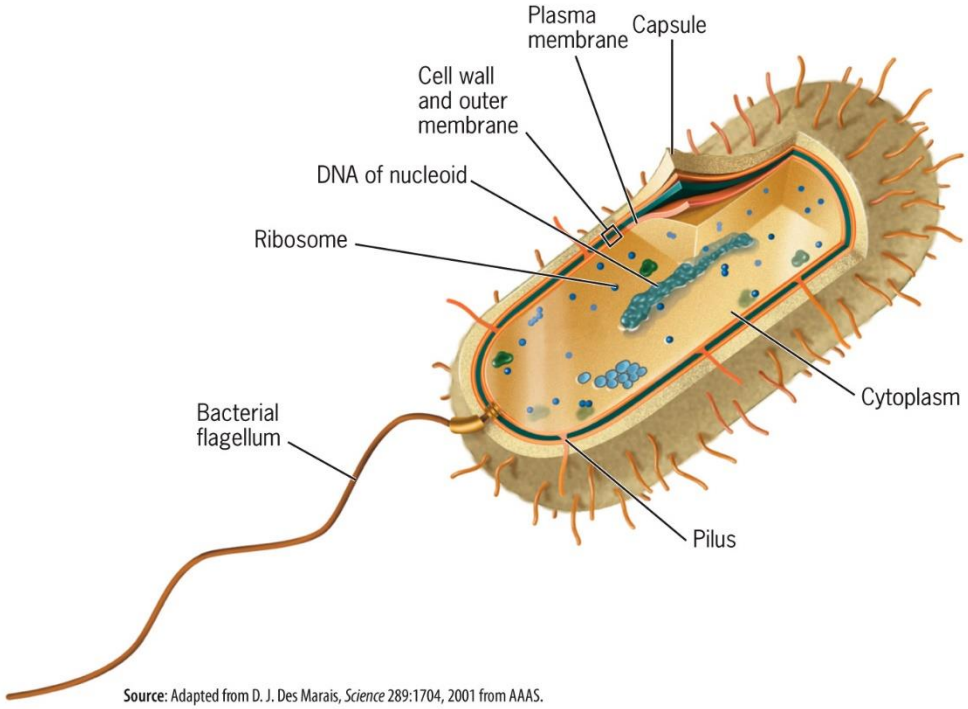
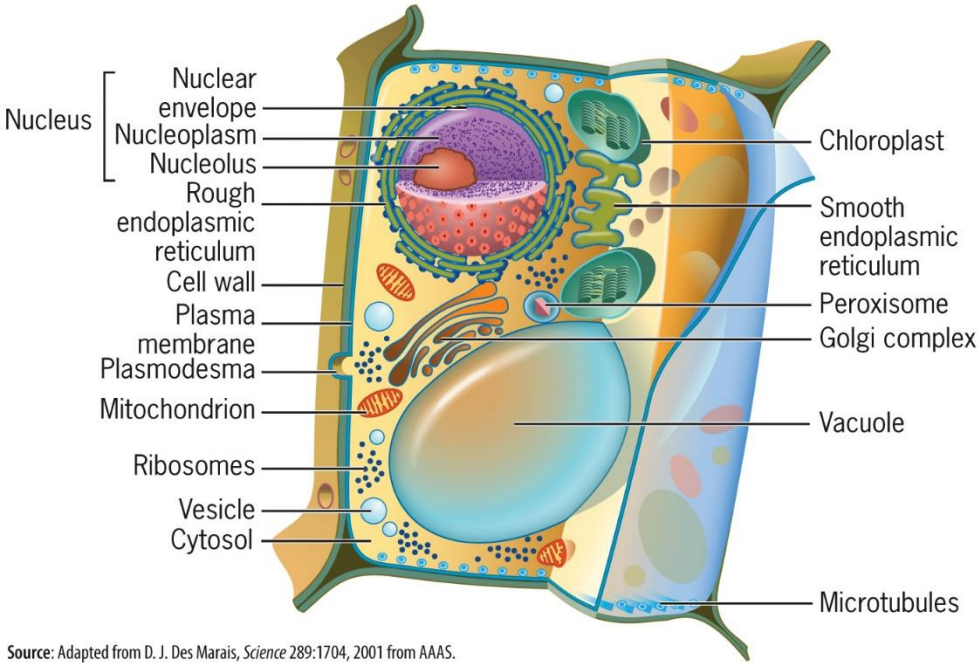


Fig. 1.8a The structure of cells

1.3 | Two Fundamentally Different Classes of Cells (2 of 19)

Characteristics That Distinguish Prokaryotic and Eukaryotic Cells

- Both bounded by plasma membranes of similar construction, serving as a selectively permeable barrier.
- Both may be surrounded by a rigid **cell wall** that protects the cell.
- Genetic material is membrane-bound in eukaryotes (**nucleus**), in **nuclear area** of cytosol in prokaryotes



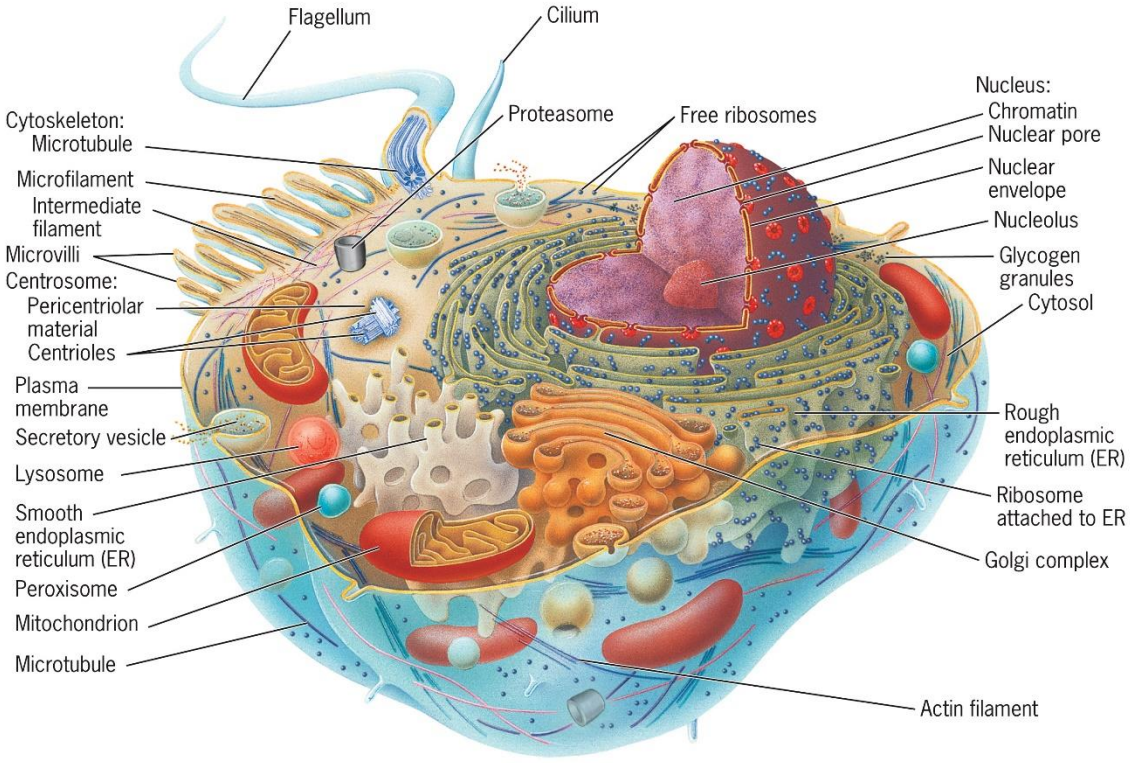
Source: Adapted from D. J. Des Marais, *Science* 289:1704, 2001 from AAAS.

Fig. 1.8b The structure of cells

1.3 | Two Fundamentally Different Classes of Cells (3 of 19)

Characteristics That Distinguish Prokaryotic and Eukaryotic Cells

- Eukaryotic cells are much more complex, both structurally and functionally, than prokaryotic cells.



Source: Adapted from D. J. Des Marais, *Science* 289:1704, 2001 from AAAS.

Fig. 1.8c The structure of cells

1.3 | Two Fundamentally Different Classes of Cells (4 of 19)

Characteristics That Distinguish Prokaryotic and Eukaryotic Cells

- Prokaryotes – relatively small amounts of DNA; 600-8,000 Mb
- Eukaryotes – simple yeast cells have 12 Mb DNA, most eukaryotic cells possess more
- Complex multicellular animals appear rather suddenly in the fossil record approximately 600 million years ago.

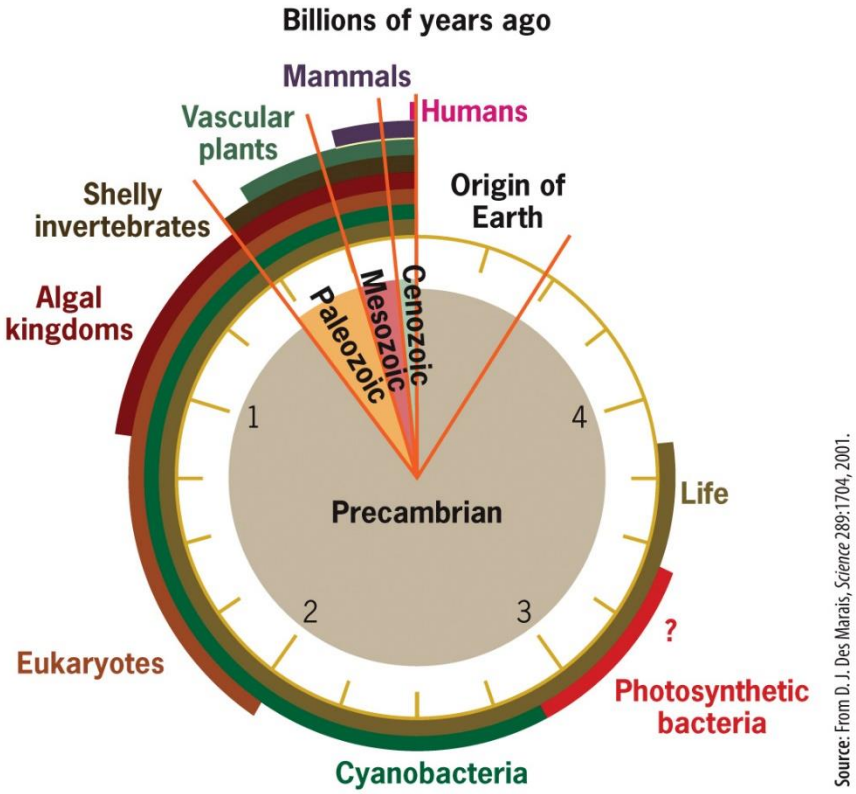


Fig. 1.9 Earth's biogeologic clock

1.3 | Two Fundamentally Different Classes of Cells (5 of 19)

Characteristics That Distinguish Prokaryotic and Eukaryotic Cells

- **Cytoplasm**: Eukaryotes have membrane-bound organelles and complex cytoskeletal proteins. Both have ribosomes but they differ in size.
- **Cellular reproduction**: Eukaryotes divide by mitosis; prokaryotes divide by simple fission.
- **Locomotion**: Eukaryotes use both cytoplasmic movement, and cilia and flagella; prokaryotes have flagella, but they differ in both form and mechanism.

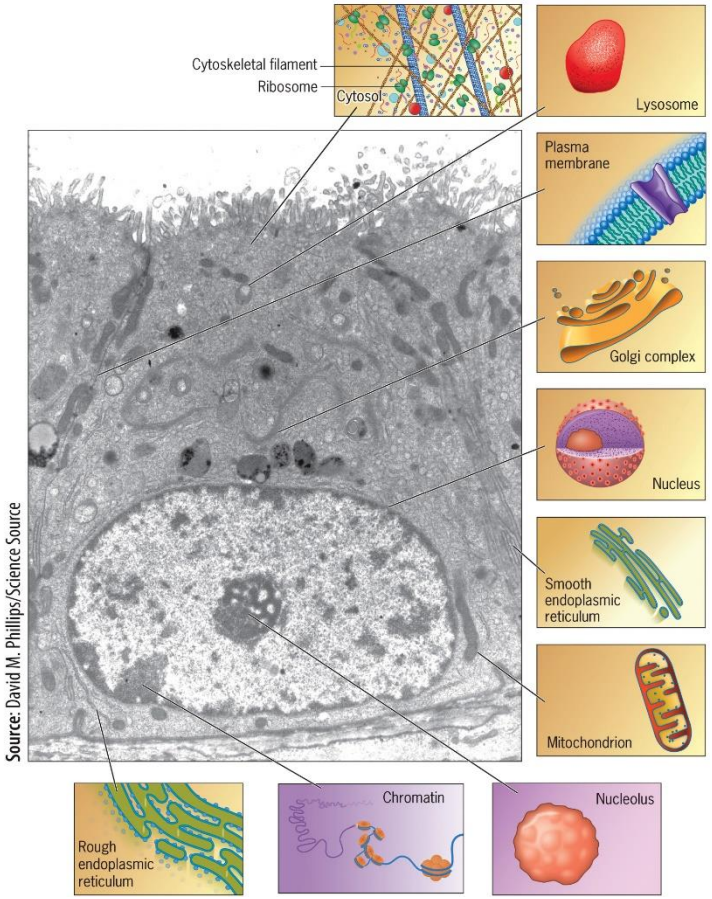
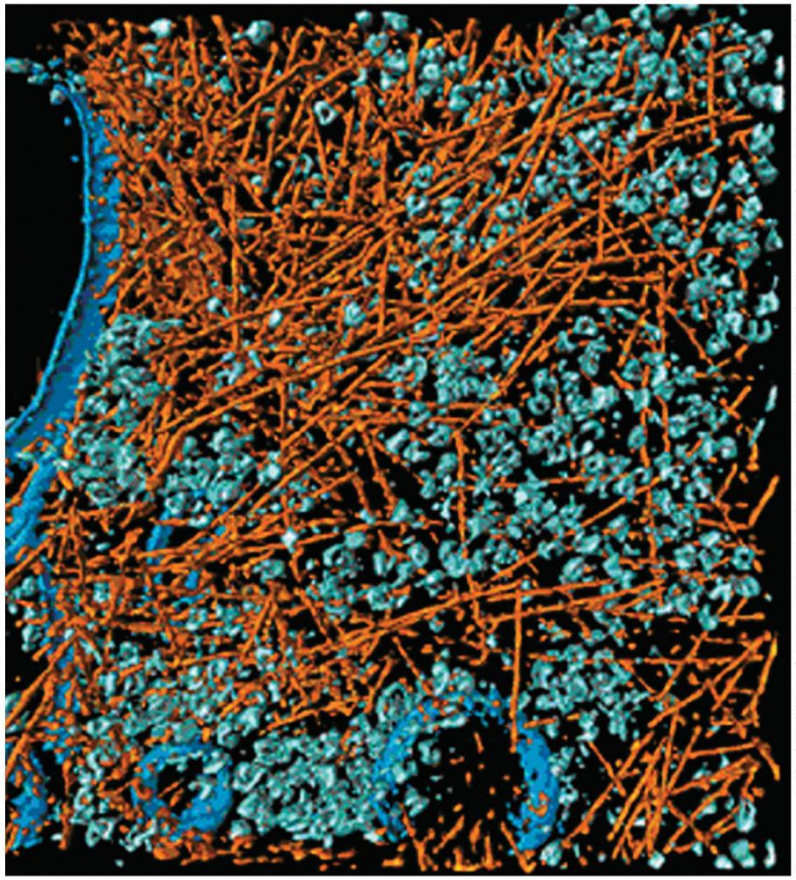


Fig. 1.10 The structure of a eukaryotic cell

1.3 | Two Fundamentally Different Classes of Cells (6 of 19)

Characteristics That Distinguish Prokaryotic and Eukaryotic Cells

- The cytoplasm of a eukaryotic cell is extremely crowded:
  - Near the cell membrane is a region where membrane-bound organelles tend to be absent.
  - The cytoskeleton and other large macromolecular complexes, mostly ribosomes, are found throughout the cytoplasm.



Source: From Ohad Medalia et al., *Science* 298:1211, 2002, Figure 3a. © 2002, reprinted with permission from AAAS. Photo provided courtesy of Wolfgang Baumeister.

Fig. 1.11 The cytoplasm of a eukaryotic cell is a crowded compartment

1.3 | Two Fundamentally Different Classes of Cells (7 of 19)

Characteristics That Distinguish Prokaryotic and Eukaryotic Cells

- Eukaryotic cells divide by a complex process of mitosis.
- Duplicated chromosomes condense into compact structures that are segregated by an elaborate microtubule-containing apparatus.
- This apparatus, the **mitotic spindle**, allows each daughter cell to receive an equivalent array of genetic material.

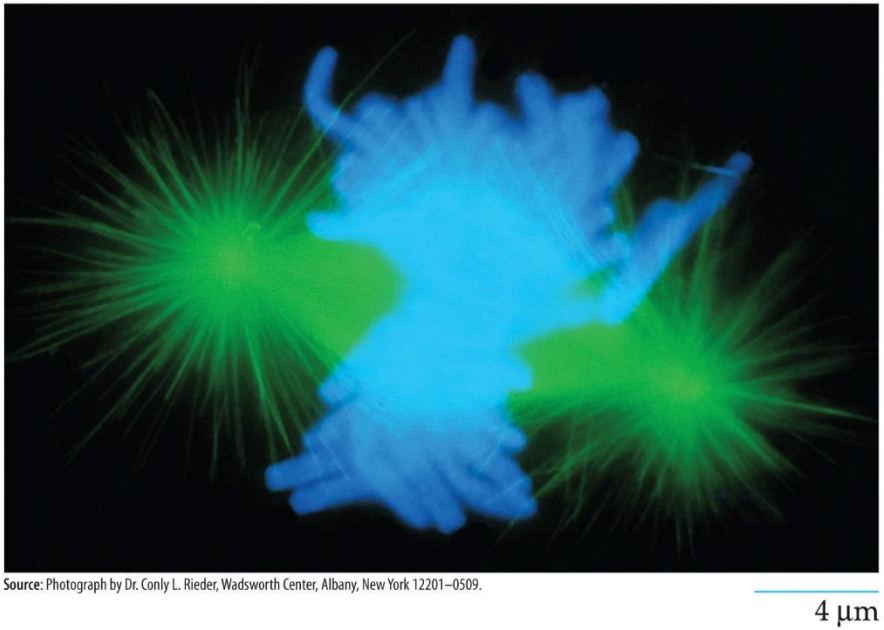


Fig. 1.12 Cell division in eukaryotes

1.3 | Two Fundamentally Different Classes of Cells (8 of 19)

Characteristics That Distinguish Prokaryotic and Eukaryotic Cells

- Prokaryotes contain one copy of their single chromosome and have no processes comparable to meiosis, gamete formation, or true fertilization.
- Some are capable of conjugation, in which a piece of DNA is passed to another cell.
- Prokaryotes are more adept at picking up and incorporating foreign DNA from their environment, which has had considerable impact on microbial evolution

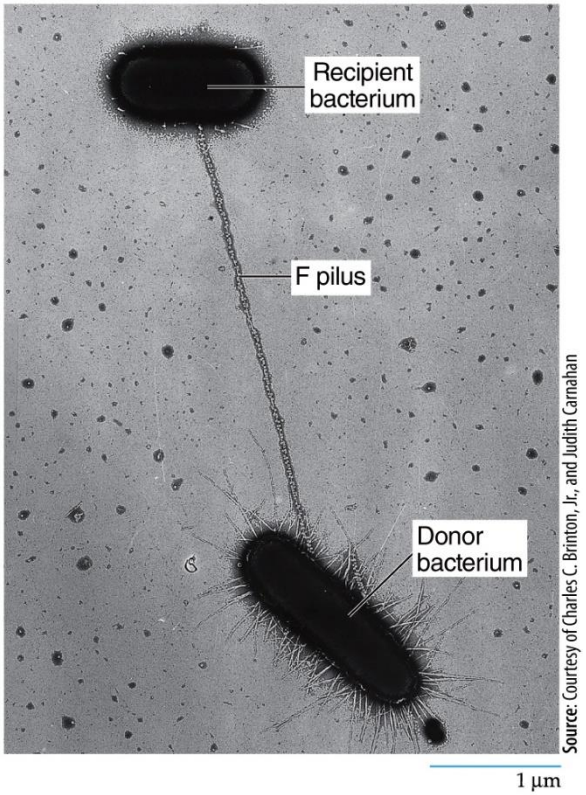


Fig. 1.13 Bacterial conjugation

1.3 | Two Fundamentally Different Classes of Cells (9 of 19)

Characteristics That Distinguish Prokaryotic and Eukaryotic Cells

- Locomotion in prokaryotes is relatively simple.
- Can be accomplished by a thin protein filament, called a flagellum, which protrudes from the cell and rotates.
- The rotations exert pressure against the surrounding fluid, propelling the cell through the medium.

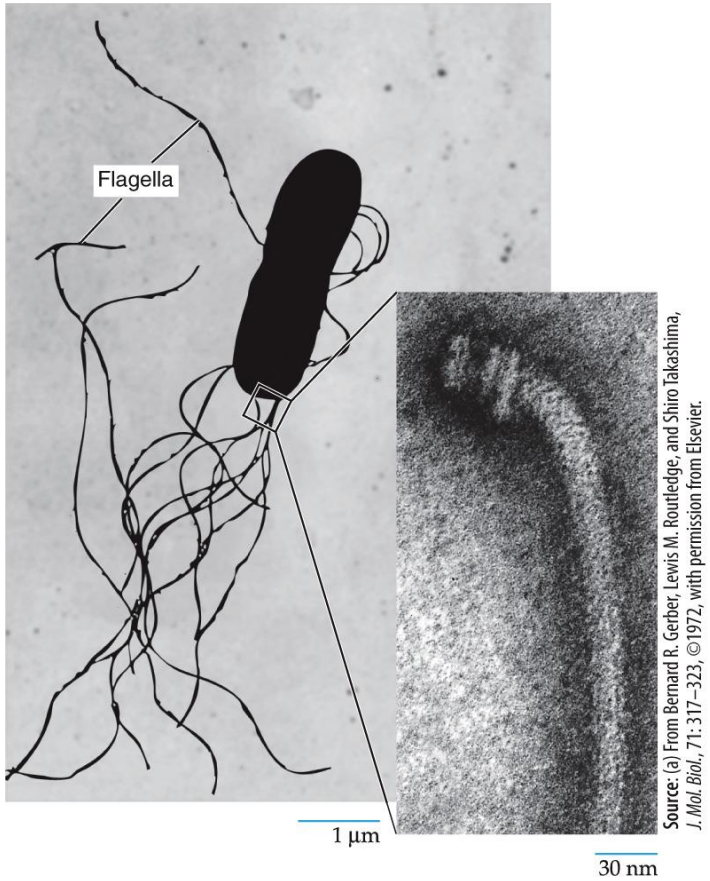
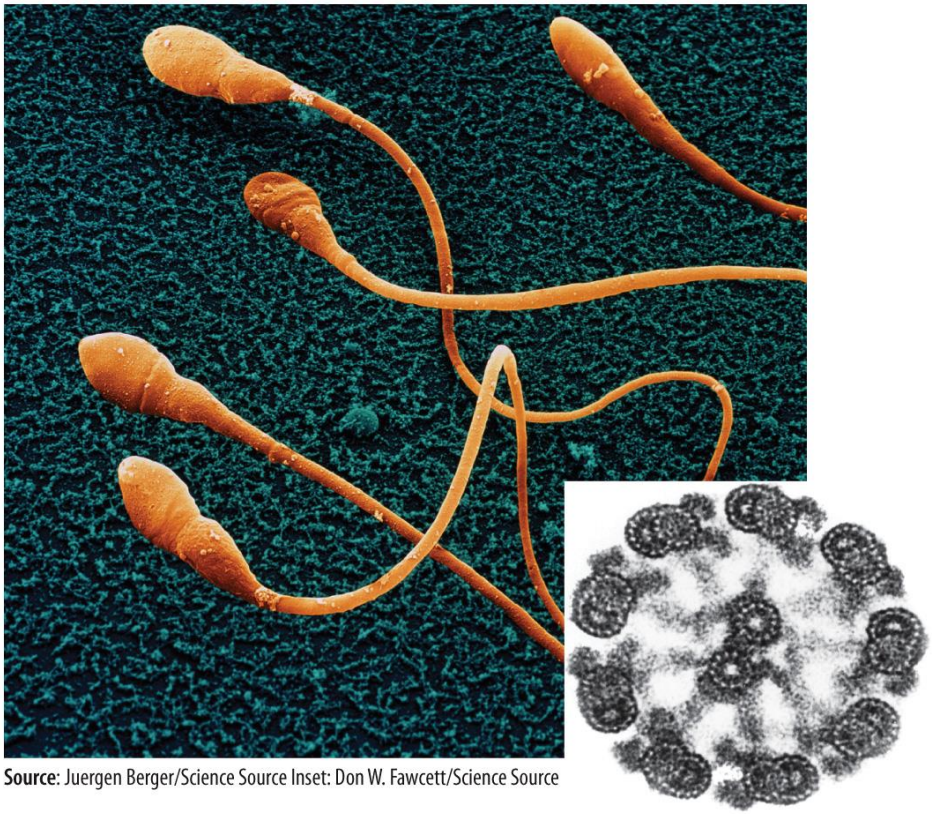


Fig. 1.14 The different between prokaryotic and eukaryotic flagella

1.3 | Two Fundamentally Different Classes of Cells (10 of 19)

Characteristics That Distinguish Prokaryotic and Eukaryotic Cells

- Certain eukaryotic cells, including many protists and sperm cells, also possess flagella.
- Eukaryotic versions are much more complex than the simple protein filaments of bacteria, and they generate movement by a different mechanism.



Source: Juergen Berger/Science Source Inset: Don W. Fawcett/Science Source

Fig. 1.14 The difference between prokaryotic and eukaryotic flagella

1.3 | Two Fundamentally Different Classes of Cells (11 of 19)

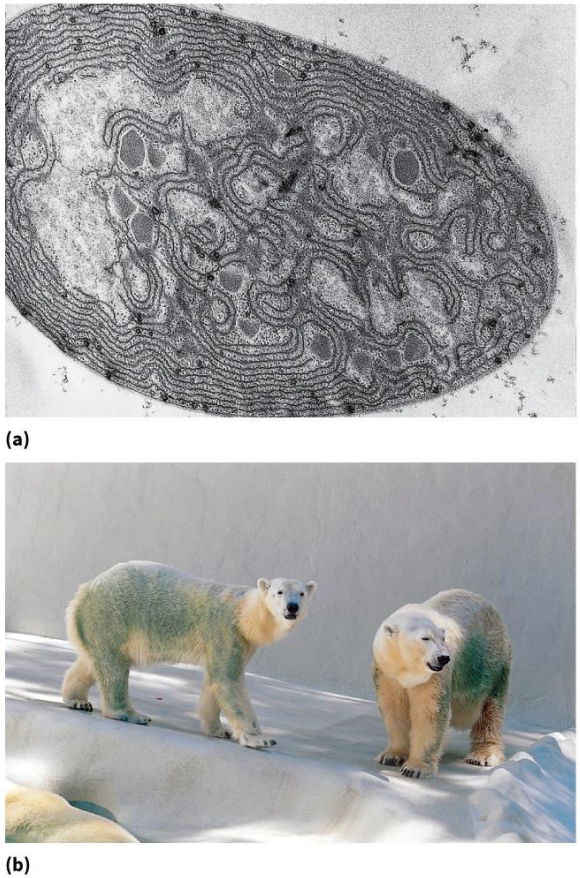
Types of Prokaryotic Cells: Domain Archaea and Domain Bacteria

- Archaea are evolutionarlity related species that live in extremely inhospitable environments, often referred to as “extremophiles.”
  - **Methanogens**: Convert CO_2 and H_2 gases into methane
  - **Halophiles**: Live in extremely salty environments, like the Dead Sea or deep sea brine pools with salinity equivalent to 5M $MgCl_2$.
  - **Acidophiles**: Acid-loving prokaryotes that thrive at a pH as low as 0.
  - **Thermophiles**: Live at very high temperatures.
  - **Hyperthermophiles**: Live in the hydrothermal vents of the ocean floor up to a temperature of 121˚C, the temperature used to sterilize surgical instruments in an autoclave.

1.3 | Two Fundamentally Different Classes of Cells (12 of 19)

Types of Prokaryotic Cells: Domain Archaea and Domain Bacteria

- Bacteria are present in every conceivable habitat on Earth, even found in rock layers kilometers beneath the Earth's surface.
- Cyanobacteria contain arrays of cytoplasmic membranes that serve as sites of photosynthesis.
- Cyanobacteria gave rise to green plants and an oxygen-rich atmosphere, and some are capable of **nitrogen fixation**.



Source: (a) Courtesy of Norma J. Lang. (b) Courtesy Zoological Society of San Diego

Fig. 1.15 Cyanobacteria

1.3 | Two Fundamentally Different Classes of Cells (13 of 19)

Types of Prokaryotic Cells: Prokaryotic Diversity

- 6000 species of prokaryotes have been identified, less than one-tenth of 1 percent of the millions of prokaryotic species thought to exist.
- DNA sequencing is so rapid and cost-efficient that virtually all of the genes present in the microbes of a given habitat can be sequenced, generating a collective genome, or **metagenome**.
- These same molecular strategies are being used to explore the collection of microbes living on us, known as the human **microbiome**.

1.3 | Two Fundamentally Different Classes of Cells (14 of 19)

Types of Prokaryotic Cells: Domain Archaea and Domain Bacteria

Environment	Environment No. of prokaryotic cells, x 10^{28}	Pg of C in prokaryotes*
Aquatic habitats	12	2.2
Oceanic subsurface	355	303
Soil	26	26
Terrestrial subsurface	25–250	22–215
Total	415–640	353–546

*1 petagram (Pg) = 1015g.

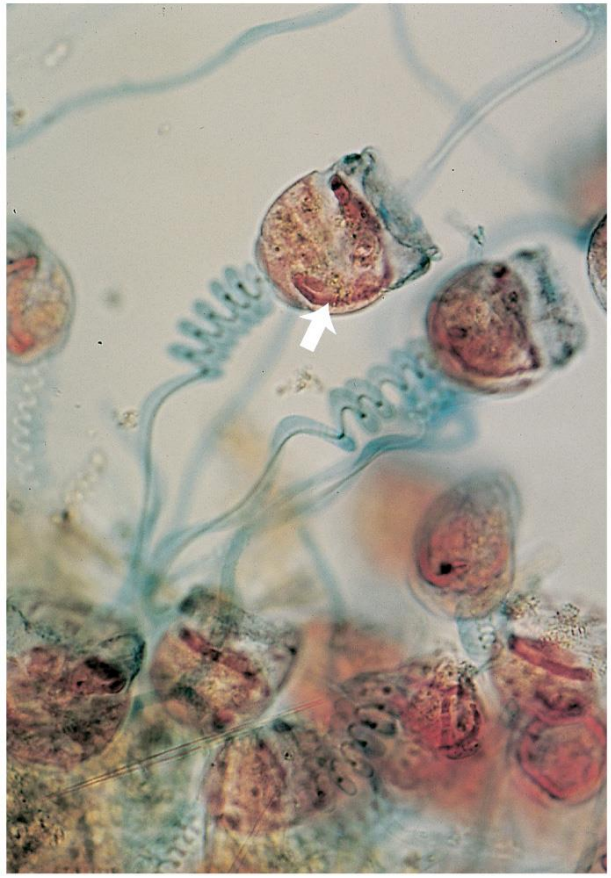
Source: W. B. Whitman et al., *Proc. Nat'l. Acad. Sci. U.S.A.* 95: 6578, 1998 Copyright (1998) National Academy of Sciences, U.S.A. Reproduced with permission of National Academy of Sciences.

Number and Biomass of Prokaryotes in the World

1.3 | Two Fundamentally Different Classes of Cells (15 of 19)

Types of Eukaryotic Cells

- The most complex eukaryotic cells are found among the single-celled Protists.
- The machinery needed for sensing the environment, trapping food, expelling excess fluid, and evading predators is found in a single cell.
- *Vorticella* have a contractile ribbon in the stalk and a large macronucleus that contains multiple copies of its genes.



Source: Carolina Biological/Medical Images

Fig. 1.16 *Vorticella*, a complex ciliated protist

1.3 | Two Fundamentally Different Classes of Cells (16 of 19)

Types of Eukaryotic Cells: Cell Differentiation

- *Multicellular* eukaryotes have different cell types for different functions.
- **Differentiation** – the formation of specialized cells
- The numbers and arrangements of organelles relate to the function and activity of the cell.
- Despite differentiation, cells have many features in common most being composed of the same organelles.

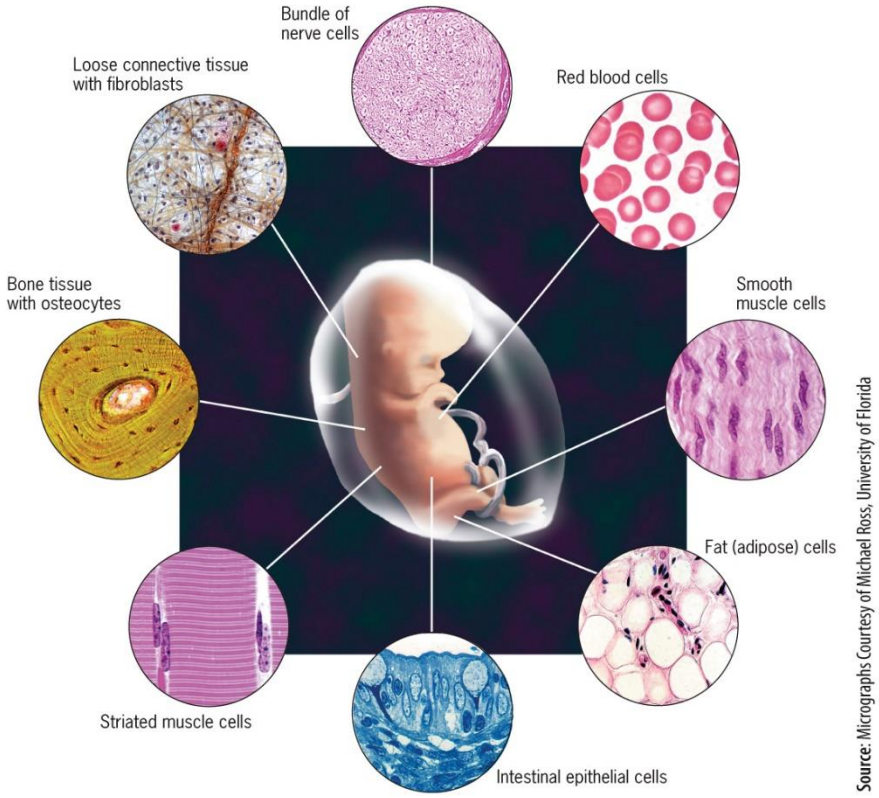


Fig. 1.17 Pathways of cell differentiation

1.3 | Two Fundamentally Different Classes of Cells (17 of 19)

Types of Eukaryotic Cells: Model Organisms

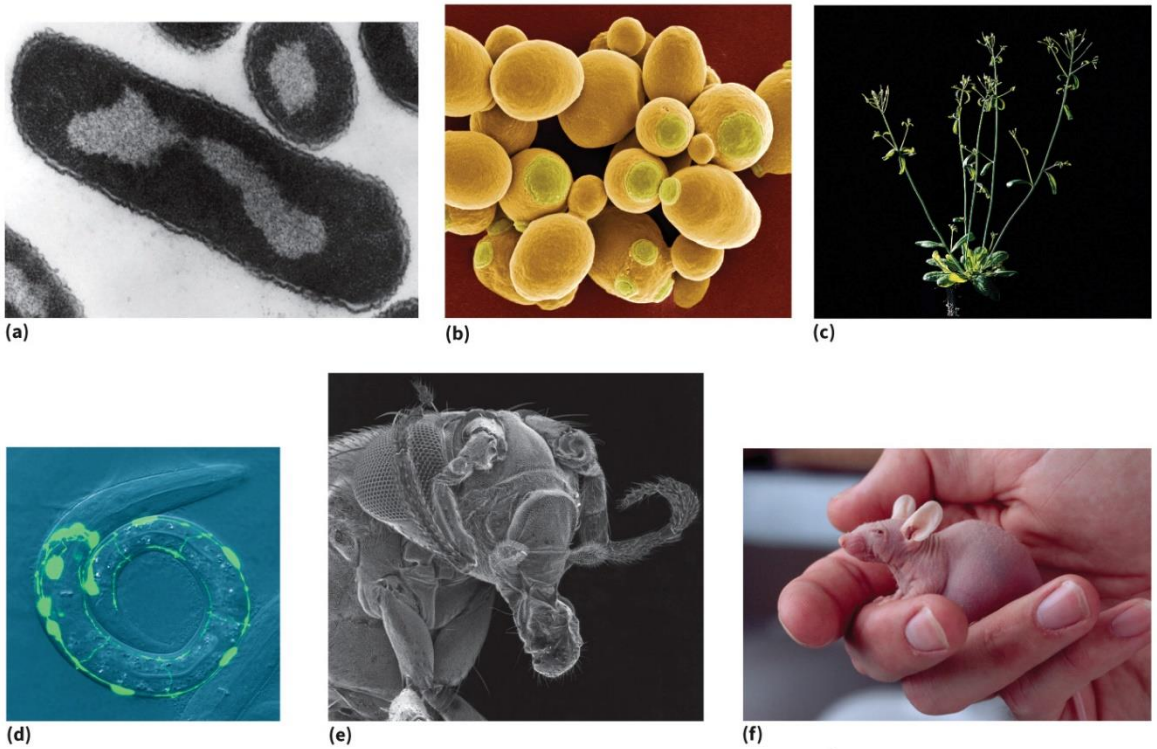


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Fig. 1.18 Six model organisms