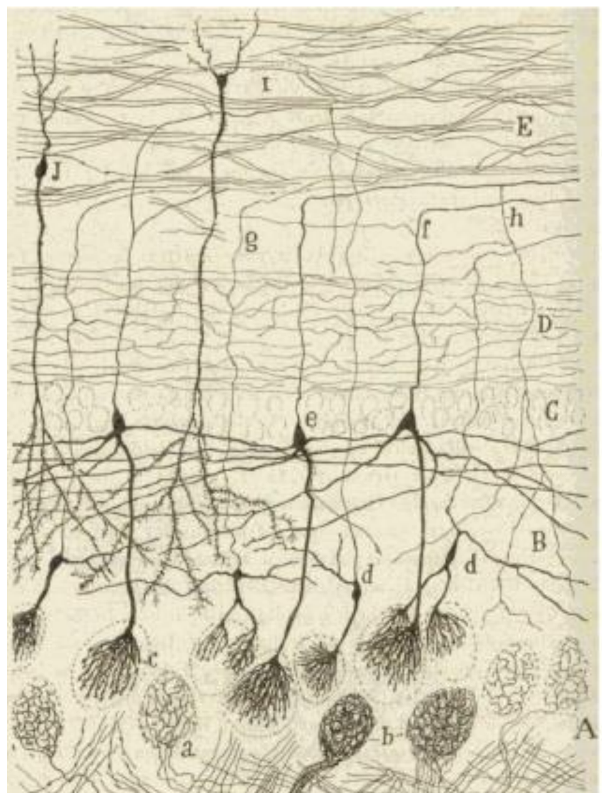
CHAPTER 1

Introduction to Cell Biology



Histology of the Nervous System of Man and Vertebrates by Cajal (1995) Fig. "Neurons in the cat brain." By permission of Oxford University Press.

1.0 | Introduction

We Are Cells

Cells make up our skin, our organs, and our muscles.

When we grow from **a tiny embryo into a large adult**, we do so by adding more and more cells.

Many medicines work by changing how cells behave, and in recent years **cells** themselves are being used as **medicines** to cure sick people.

Because all living things are made of one or more cells, the origin of life corresponds to the origin of cells.

1.1 | The Discovery of Cells

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

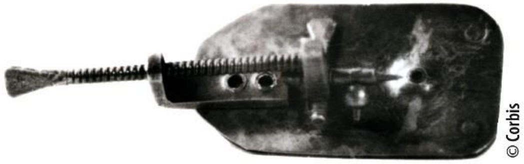
Microscopy

The discovery of cells followed from the invention of the **microscope** by Robert Hooke, and its refinement by Anton Leewenhoek.

Hooke termed the pores inside cork *cells* because they reminded him of the cells inhabited by monks living in a monastery.

Leeuwenhoek was the first to examine a drop of pond water under the microscope and observe the teeming microscopic "animalcules" that darted back and forth.

Leewenhoek: single lens microscope



Hooke: double lens microscope

1.1 | The Discovery of Cells

Cell Theory

The **cell theory** was articulated in the mid-1800s by Matthias Schleiden, Theodor Schwann and Rudolf Virchow.

1) All organisms are composed or one or more cells.
2) The cell is the structural unit of life.
3) Cells arise only by division from a pre-existing cell.

1.2 | Basic Properties of Cells

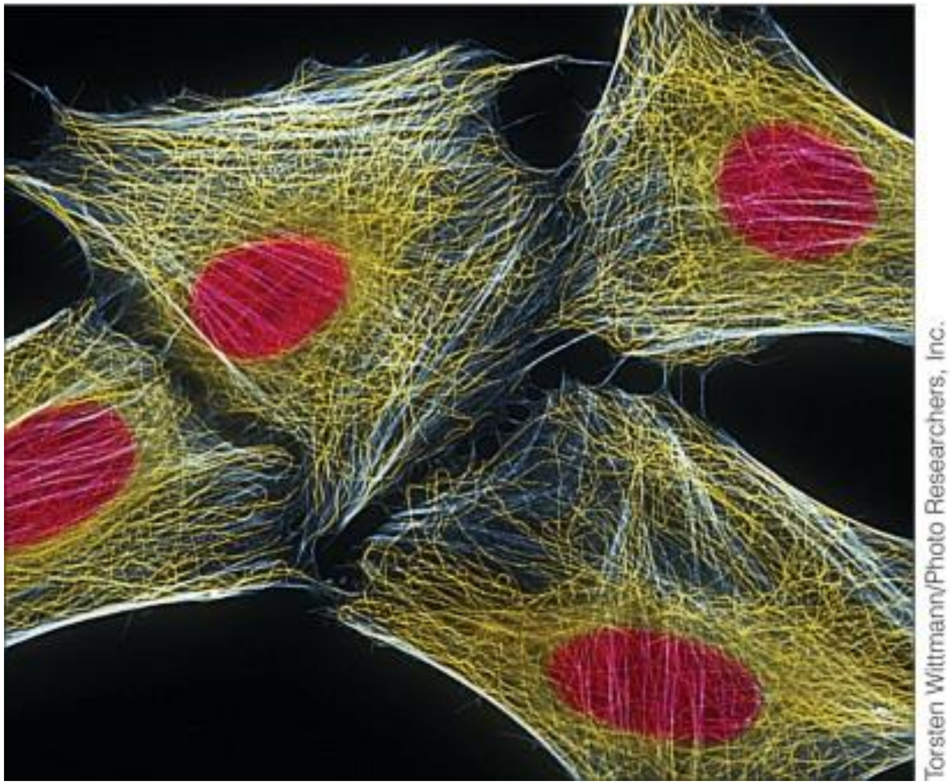
Cell Theory

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) by George and Martha Gey in 1951.

Cultured cells are an essential tool for cell biologists.



HeLa: first human cells for extended culturing

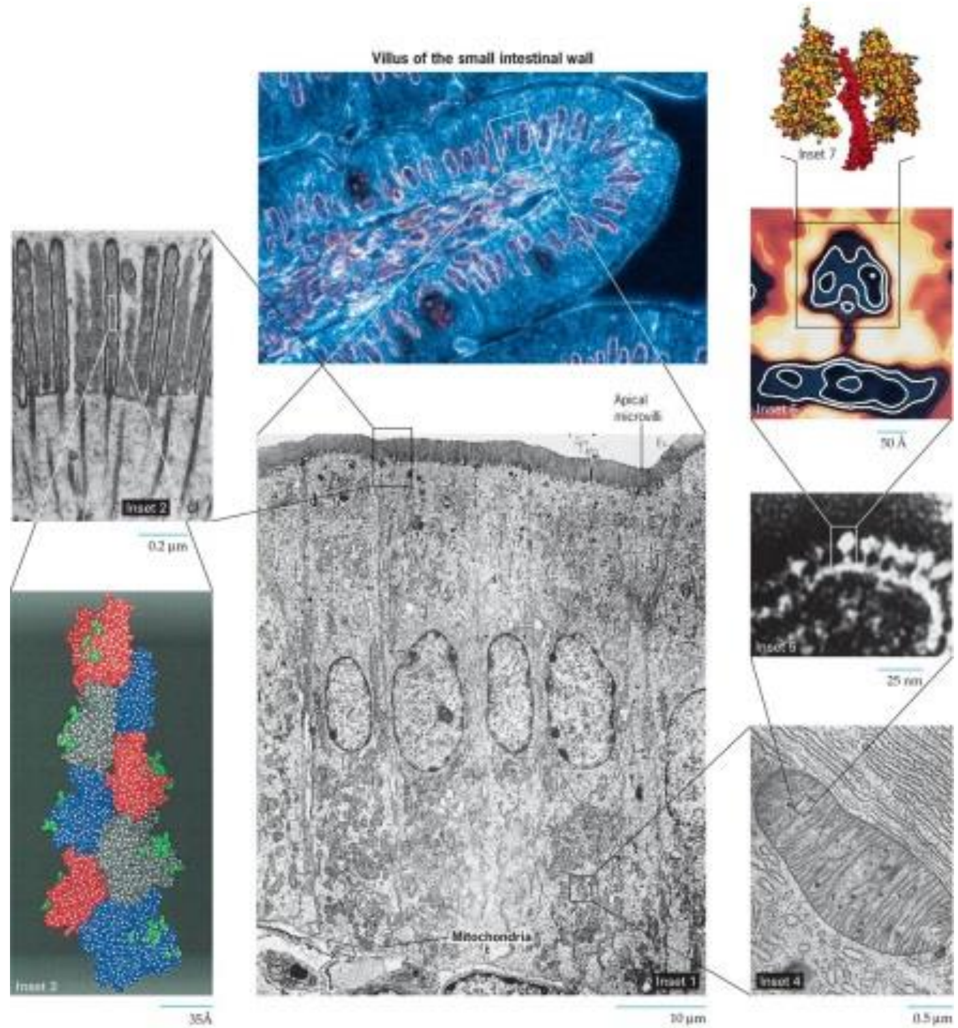
1.2 | Basic Properties of Cells

Cells are Highly Complex and Organized

Cellular processes are highly regulated.

Cells from different species share similar structure, composition and metabolic features that have been conserved throughout evolution.

Levels of cellular and molecular organization



Light micrograph Cecil Fox/photo Researchers; inset 1 courtesy of Shakti P. Kapur, Georgetown University Medical Center; inset 2 from Mark S. Mooseker and Lewis G. Tilney, J. Cell Biol. 67:729, 1975, reproduced with permission of the Rockefeller University Press; inset 3 courtesy of Kenneth C. Holmes; inset 4 Keith R. Porter/Photo Researchers; inset 5 courtesy of Humberto Fernandez-Moran; inset 6 courtesy of Roderick A. Capaldi; inset 7 courtesy of Wolfgang Junge, Holger Lill, and Siegfried Engelbrecht, University of Osnabrück, Germany.

1.2 | Basic Properties of Cells

Cells Possess a Genetic Program and the Means to Use It

Organisms are built according to information encoded in a collection of genes.

This information is packaged into a set of chromosomes that occupies the space of a cell nucleus.

Genes store information and constitute the blueprints for constructing cellular structures, the directions for running cellular activities, and the program for making more of themselves.

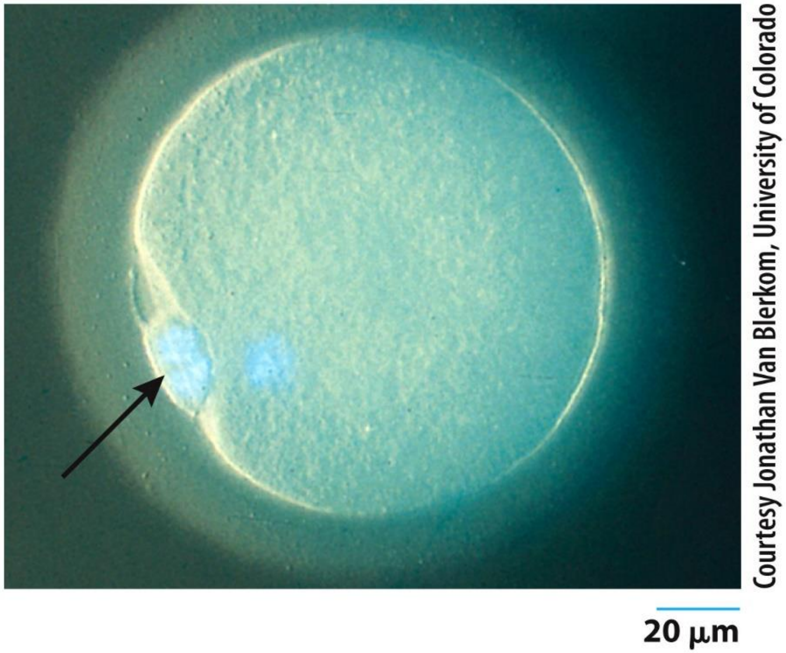
The molecular structure of genes allows for changes in genetic information (mutations) that lead to variation among individuals, which forms the basis of biological evolution.

1.2 | Basic Properties of Cells

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.

Prior to division, the genetic material is faithfully duplicated, and each daughter cell receives a complete and equal share of genetic information.



Mammalian oocyte after unequal cell division to produce polar body (arrow)

1.2 | Basic Properties of Cells

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 convert glucose into ATP—a substance with readily available energy.

Spirogyra: alga with ribbon-like chloroplast for photosynthesis

1.2 | Basic Properties of Cells

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

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.

Motor proteins are just one of many types of molecular "machines" used for mechanical activities.

1.2 | Basic Properties of Cells

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

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.

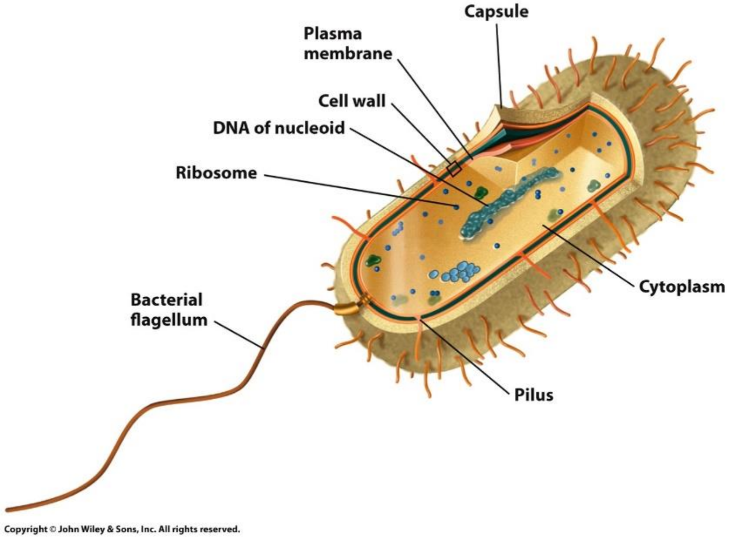
Maintaining a complex, ordered state requires constant regulation.

1.3 | Two Fundamentally Different Classes of Cells

Two basic classes of cells, prokaryotic and eukaryotic, are distinguished by their size and the types of organelles they contain.

Many basic differences as well as many similarities between the two types.

Because of their common ancestry, both types of cells share an identical genetic language, a common set of metabolic pathways, and many common structural features.



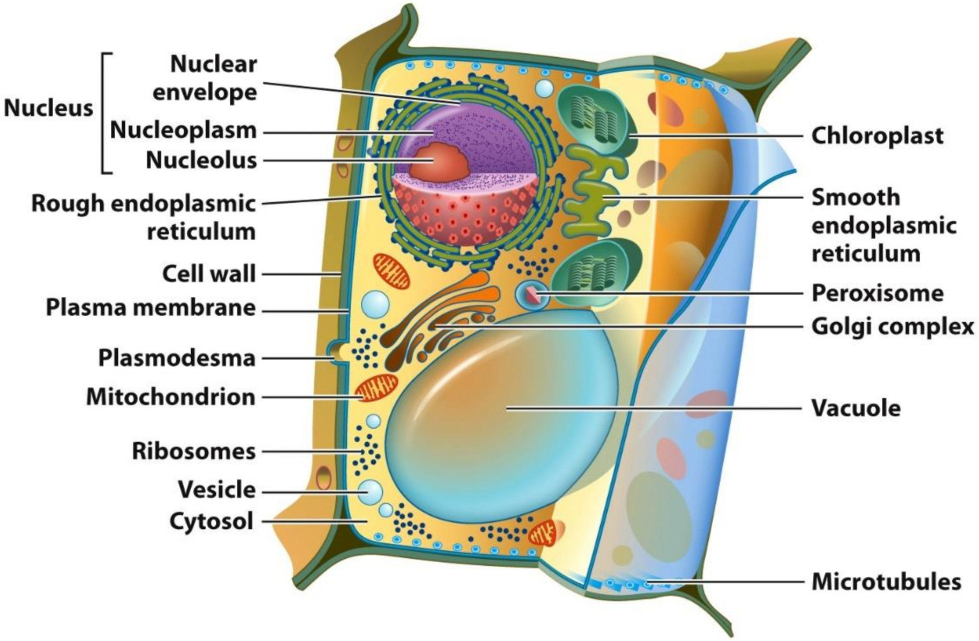
The structure of cells: Bacteria

1.3 | Two Fundamentally Different Classes of Cells

Both types of cells are bounded by plasma membranes of similar construction that serve as a selectively permeable barrier.

Both types of cells may be surrounded by a rigid *cell wall* that protects the cell.

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



The structure of cells: Plant cell

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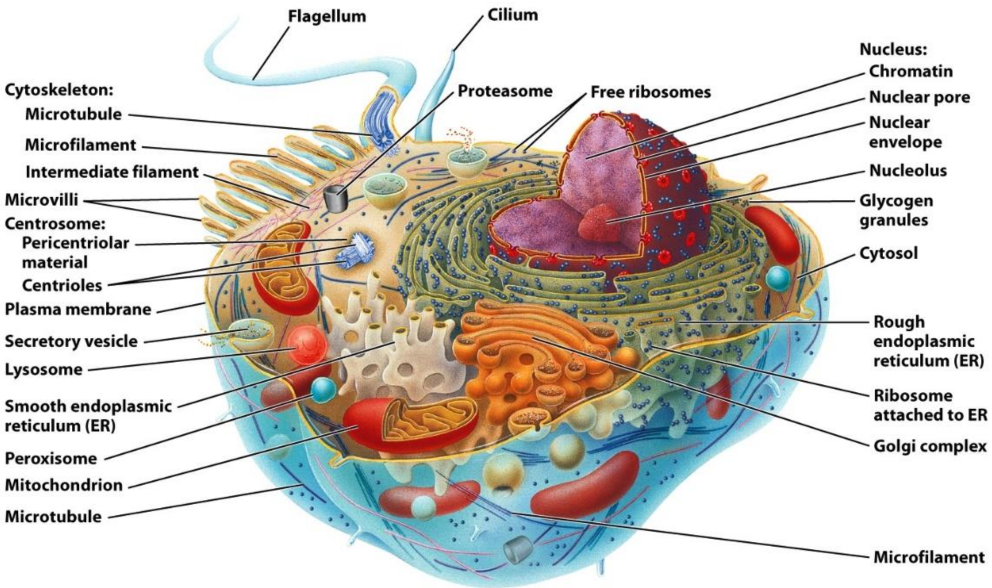


The structure of cells: Animal cell

1.3 | Two Fundamentally Different Classes of Cells

Prokaryotes are all bacteria, which arose ~3.7 billion years ago.

Eukaryotes include protists, animals, plants and fungi.

Complex multicellular animals appear rather suddenly in the fossil record approximately 600 million years ago.

1.3 | Two Fundamentally Different Classes of Cells

Complexity: Prokaryotes are relatively simple; eukaryotes are more complex in structure and function.

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.

Genetic material:

Packaging: Prokaryotes have a nucleoid region whereas eukaryotes have a membrane-bound nucleus.

Amount: Eukaryotes have much more genetic material than prokaryotes.

Form: Eukaryotes have many chromosomes made of both DNA and protein whereas prokaryotes have a single, circular DNA.

1.3 | Two Fundamentally Different Classes of Cells

Table 1.1 **A Comparison of Prokaryotic and eukaryotic Cells**

Features held in common by the two types of cells:
o Plasma membrane of similar construction
o Genetic information encoded in DNA using identical genetic code
o Similar mechanisms for transcription and translation of genetic information, including similar ribosomes
o Shared metabolic pathways (e.g., glycolysis and TCA cycle)
o Similar apparatus for conservation of chemical energy as ATP (located in the plasma membrane of prokaryotes and the mitochondrial membrane of eukaryotes)
o Similar mechanism of photosynthesis (between cyanobacteria and green plants)
o Similar mechanism for synthesizing and inserting membrane proteins
o Proteasomes (protein digesting structures) of similar construction (between archaebacteria and eukaryotes)
o Cytoskeletal filaments built of proteins similar to actin and tubulin

1.3 | Two Fundamentally Different Classes of Cells

Table 1.1 A Comparison of Prokaryotic and eukaryotic Cells

Features of eukaryotic cells not found in prokaryotes:

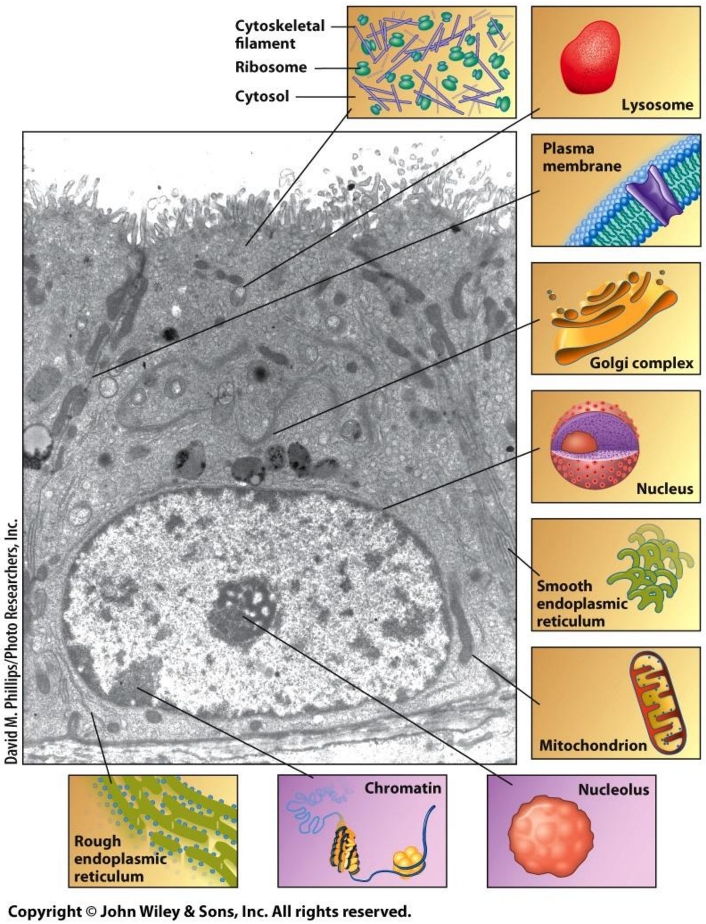
- Division of cells into nucleus and cytoplasm, separated by a nuclear envelope containing complex pore structures
- Complex chromosomes composed of DNA and associated proteins that are capable of compacting into mitotic structures
- Complex membranous cytoplasmic organelles (includes endoplasmic reticulum, Golgi complex, lysosomes, endosomes, peroxisomes, and glyoxisomes)
- Specialized cytoplasmic organelles for aerobic respiration (mitochondria) and photosynthesis (chloroplasts)
- Complex cytoskeletal system (including actinfilaments, intermediate filaments, and microtubules) and associated motor proteins
- Complex flagella and cilia
- Ability to ingest particulate material by enclosure within plasma membrane vesicles (phagocytosis)
- Cellulose-containing cell walls (in plants)
- Cell division using a microtubule-containing mitotic spindle that separates chromosomes
- Presence of two copies of genes per cell (diploidy), one from each parent
- Presence of three different RNA synthesizing enzymes (RNA polymerases)
- Sexual reproduction requiring meiosis and fertilization

1.3 | Two Fundamentally Different Classes of Cells

Eukaryotic cells possess a nucleus: a region bounded by a membranous structure called the nuclear envelope.

The cytoplasm of a eukaryotic cell is filled with a great diversity of structures.

The cytoplasmic membranes form a system of interconnecting channels and vesicles that function in the transport of substances from one part of a cell to another.



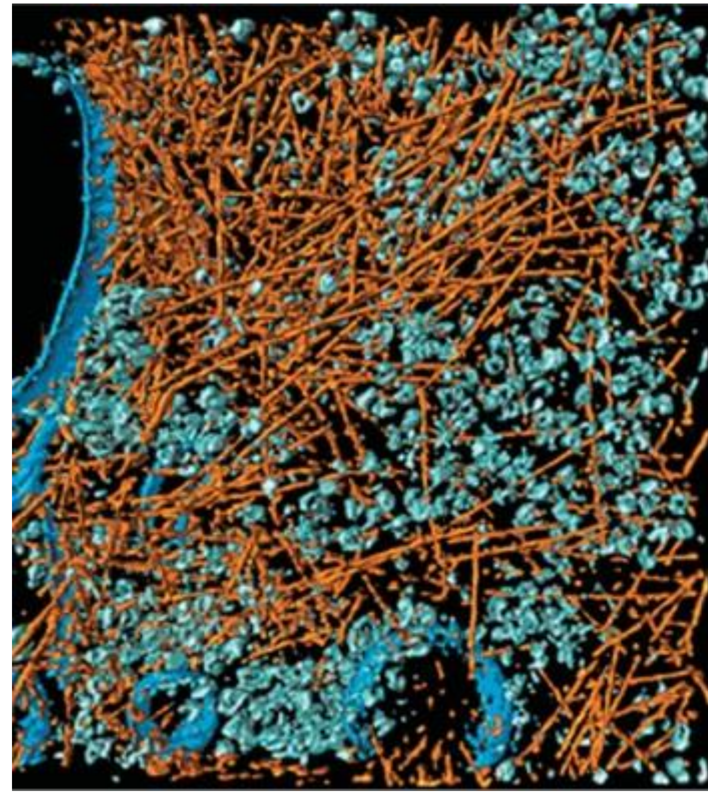
Eukaryotic cell structure: Epithelial cell from the male rat reproductive tract

1.3 | Two Fundamentally Different Classes of Cells

The cytoplasm of a eukaryotic cell is extremely crowded, leaving very little space for the soluble phase of the cytoplasm, the cytosol.

The cytoplasm 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.



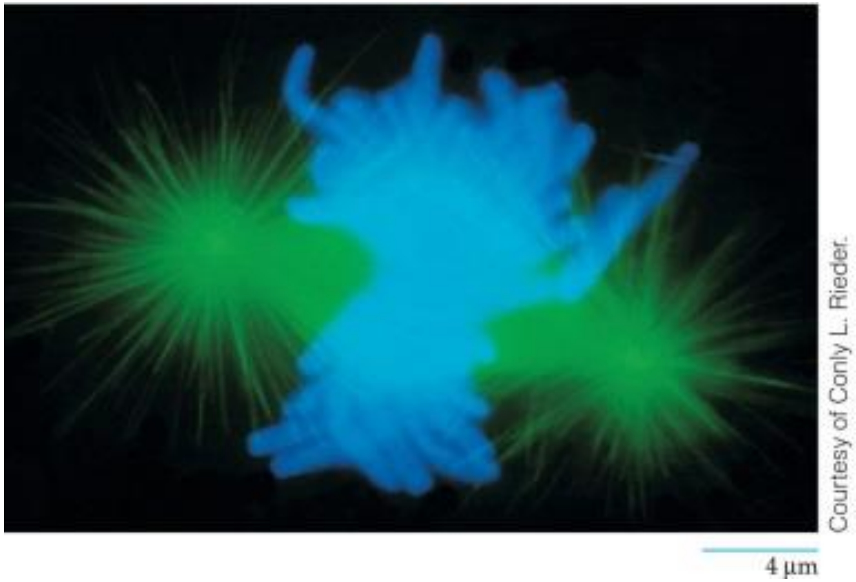
Colorized electron micrograph of a frozen single-celled eukaryote.
Cytoskeleton: Red
Ribosomes: Green
Cell membrane: Blue

1.3 | Two Fundamentally Different Classes of 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.



Cell division in eukaryotes
DNA (blue) and microtubules (green) of two daughter cells.

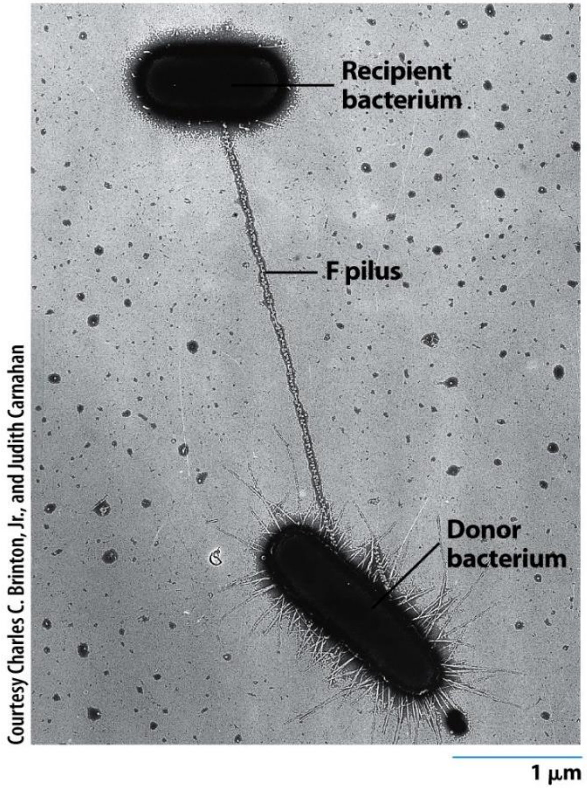
1.3 | Two Fundamentally Different Classes of Cells

Prokaryotes are mostly nonsexual organisms.

They 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



Bacterial conjugation
Sharing of DNA through the F pilus

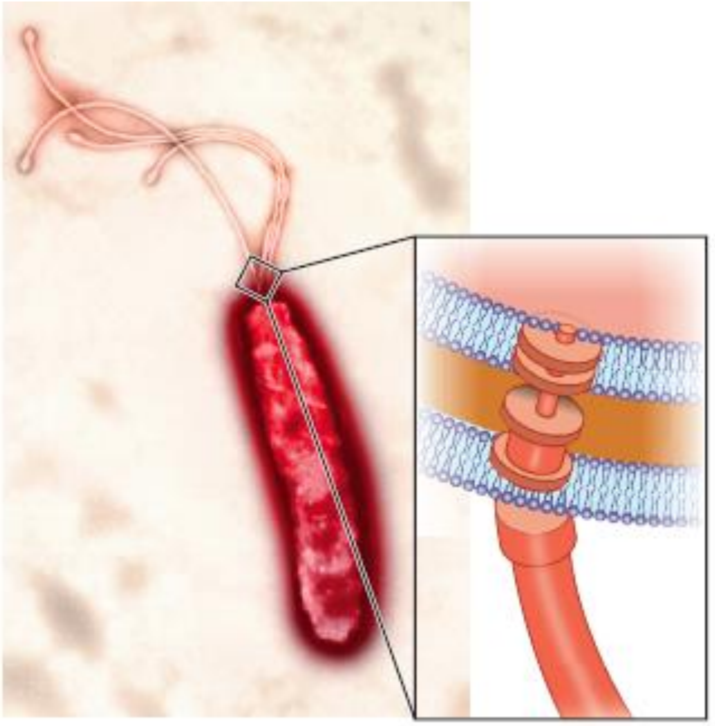
1.3 | Two Fundamentally Different Classes of Cells

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.

Low magnification

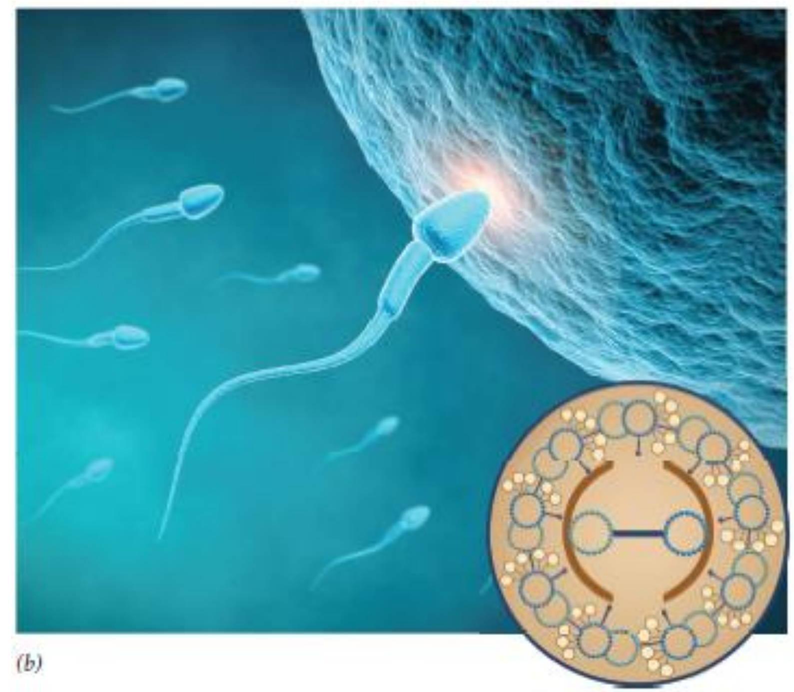


Helicobacter bacterium
Multiple flagella for locomotion

1.3 | Two Fundamentally Different Classes of 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.



Human sperm cells
Single flagella

1.4 | Types of Prokaryotic Cells

Domain Archaea and Domain Bacteria

The best known Archaea are 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^{o}C, the temperature used to sterilize surgical instruments in an autoclave.

1.4 | Types of Prokaryotic Cells

Domain Archaea and Domain Bacteria

Domain Bacteria includes the smallest known cells, the mycoplasma, which lack a cell wall.

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.

Cyanobacteria: electron micrograph

Cyanobacteria in polar bear coats

1.4 | Types of Prokaryotic Cells

Prokaryotic Diversity

Roughly 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.*

Functions of proteins encoded by these microbial genomes include the synthesis of vitamins, the breakdown of complex plant sugars, and the prevention of growth of pathogenic organisms.

1.5 | Types of Eukaryotic Cells

The most complex eukaryotic cells may not found inside of plants or animals, but rather 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.

Vorticella, a complex ciliated protist

1.5 | Types of Eukaryotic Cells

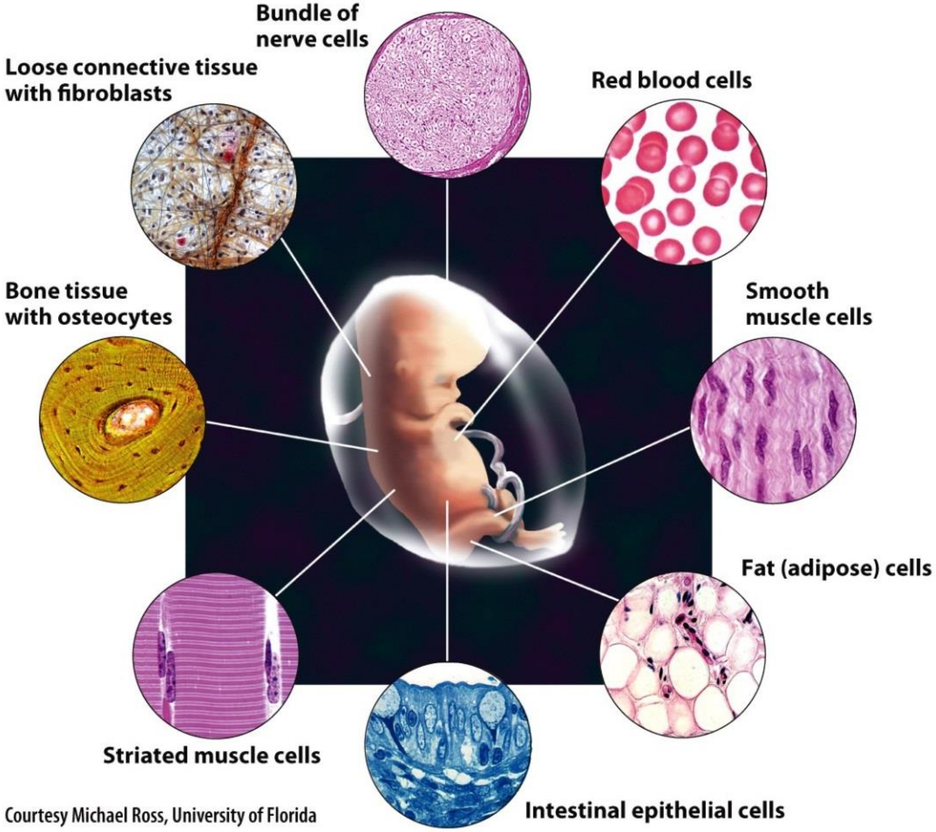
Cell Differentiation

Multicellular eukaryotes have different cell types for different functions.

Cell differentiation occurs during embryonic development in multicellular organisms.

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.



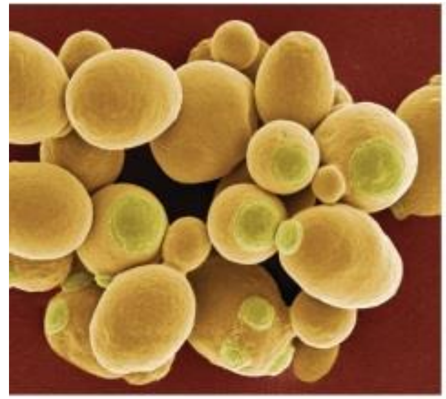
Pathways of cell differentiation

1.5 | Types of Eukaryotic Cells

Model Organisms

(a)

Escherichia coli (bacterium)

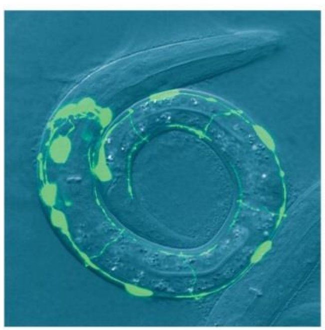


(b)

Saccharomyces (yeast)

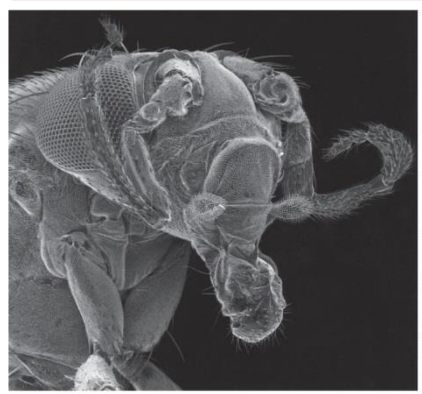
(c)

Arabidopsis (mustard plant)



(d)

Caenorhabditis elegans (nematode)



(e)

Drosophila (fruit fly)

(f)

Mus musculus (mouse)

1.6 | The Sizes of Cells and Their Components

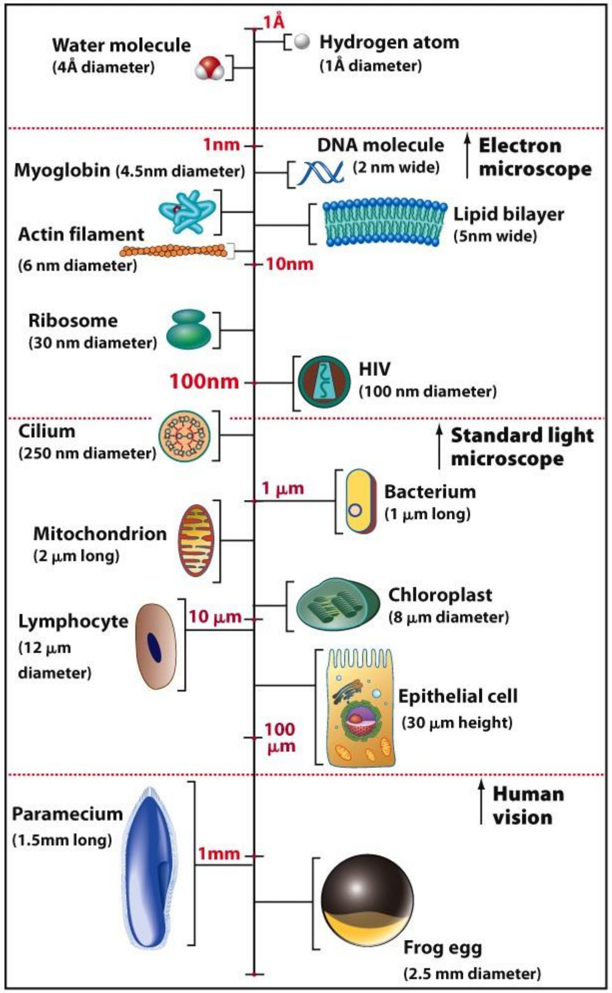
Cells are commonly measured in units of **micrometers** (1 μm = 10^{-6} meter) and **nanometers** (1 nm = 10^{-9} meter).

The cell size is limited:
1) By the volume of cytoplasm that can be supported by the genes in the nucleus.

2) By the volume of cytoplasm that can be supported by exchange of nutrients.

3) By the distance over which substances can efficiently travel through the cytoplasm via *diffusion*.

However, some eukaryotic cells can be extremely large, as the green alga *Acetabularia* is more than 10 cm long.



Relative sizes of cells and cell components

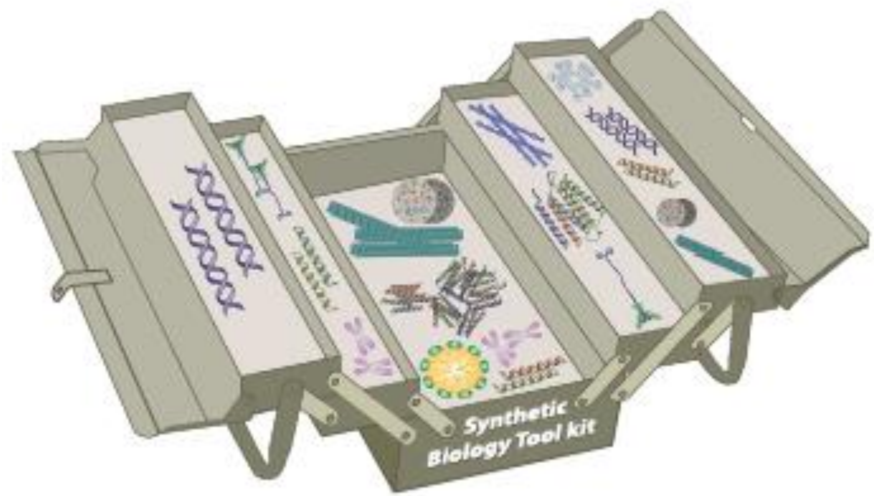
1.6 | The Sizes of Cells and Their Components

Synthetic Biology is a field oriented to create a living cell in the laboratory.

A more modest goal is to develop novel life forms, beginning with existing organisms.

Possible applications to medicine, industry, or the environment.

Prospect is good after replacing the genome of one bacterium with that of a closely related species.



Synthetic biology toolbox:
Nucleic acids, proteins, and lipids