Life exhibits varying degrees of organization. Atoms are organized into molecules, molecules into organelles, and organelles into cells, and so on. According to the Cell Theory, all living things are composed of one or more cells, and the functions of a multicellular organism are a consequence of the types of cells it has. Cells fall into two broad groups: prokaryotes and eukaryotes. Prokaryotic cells are smaller (as a general rule) and lack much of the internal compartmentalization and complexity of eukaryotic cells. No matter which type of cell we are considering, all cells have certain features in common, such as a cell membrane, DNA and RNA, cytoplasm, and ribosomes. Eukaryotic cells have a great variety of organelles and structures.

**Cell Size and Shape**

The shapes of cells are quite varied with some, such as neurons, being longer than they are wide and others, such as parenchyma (a common type of plant cell) and erythrocytes (red blood cells) being equidimensional. Some cells are encased in a rigid wall, which constrains their shape, while others have a flexible cell membrane (and no rigid cell wall).

The size of cells is also related to their functions. Eggs (or to use the Latin word, ova) are very large, often being the largest cells an organism produces. The large size of many eggs is related to the process of development that occurs after the egg is fertilized, when the contents of the egg (now termed a zygote) are used in a rapid series of cellular divisions, each requiring tremendous amounts of energy that is available in the zygote cells. Later in life the energy must be acquired, but at first a sort of inheritance/trust fund of energy is used.

Cells range in size from small bacteria to large, unfertilized eggs laid by birds and dinosaurs. The relative size ranges of biological things is shown in Figure 1. In science we use the metric system for measuring. Here are some measurements and conversions that will aid your understanding of biology.

1 meter = 100 cm = 1,000 mm = 1,000,000 µm = 1,000,000,000 nm

1 centimeter (cm) = 1/100 meter = 10 mm

1 millimeter (mm) = 1/1000 meter = 1/10 cm

1 micrometer (µm) = 1/1,000,000 meter = 1/10,000 cm

1 nanometer (nm) = 1/1,000,000,000 meter = 1/10,000,000 cm
The cell membrane functions as a semi-permeable barrier, allowing a very few molecules across it while fencing the majority of organically produced chemicals inside the cell. Electron microscopic examinations of cell membranes have led to the development of the lipid bilayer model (also referred to as the fluid-mosaic model). The most common molecule in the model is the phospholipid, which has a polar (hydrophilic) head and two nonpolar (hydrophobic) tails. These phospholipids are aligned tail to tail so the nonpolar areas form a hydrophobic region between the hydrophilic heads on the inner and outer surfaces of the membrane. This layering is termed a bilayer since an electron microscopic technique known as freeze-fracturing is able to split the bilayer, shown in Figure 2.

![Figure 2. Cell Membranes from Opposing Neurons (TEM x436,740). This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.](image)

Cholesterol is another important component of cell membranes embedded in the hydrophobic areas of the inner (tail-tail) region. Most bacterial cell membranes do not contain cholesterol. Cholesterol aids in the flexibility of a cell membrane.

Proteins, shown in Figure 2, are suspended in the inner layer, although the more hydrophilic areas of these proteins "stick out" into the cells interior as well as outside the cell. These proteins function as gateways that will allow certain molecules to cross into and out of the cell by moving through open areas of the protein channel. These integral proteins are sometimes known as gateway proteins. The outer surface of the membrane will tend to be rich in glycolipids, which have their hydrophobic tails embedded in the hydrophobic region of the membrane and their heads exposed outside the cell. These, along with carbohydrates attached to the integral proteins, are thought to function in the recognition of self, a sort of cellular identification system.

The contents (both chemical and organelles) of the cell are termed protoplasm, and are further subdivided into cytoplasm (all of the protoplasm except the contents of the nucleus) and
nucleoplasm (all of the material, plasma and DNA etc., within the **nucleus**).

**The Cell Wall | Back to Top**

Not all living things have **cell walls**, most notably animals and many of the more animal-like protistans. Bacteria have cell walls containing the chemical peptidoglycan. Plant cells, shown in Figures 3 and 4, have a variety of chemicals incorporated in their cell walls. **Cellulose**, a nondigestible (to humans anyway) polysaccharide is the most common chemical in the plant primary cell wall. Some plant cells also have **lignin** and other chemicals embedded in their secondary walls.

The cell wall is located outside the plasma membrane. **Plasmodesmata** are connections through which cells communicate chemically with each other through their thick walls. Fungi and many protists have cell walls although they do not contain cellulose, rather a variety of chemicals (**chitin** for fungi).

Animal cells, shown in Figure 5, lack a cell wall, and must instead rely on their cell membrane to maintain the integrity of the cell. Many protistans also lack cell walls, using variously modified cell membranes o act as a boundary to the inside of the cell.


![Diagram of a Plant Cell](https://www2.estrellamountain.edu/faculty/farabee/biobk/BioBookCELL2.html)
The nucleus | Back to Top

The nucleus, shown in Figures 6 and 7, occurs only in eukaryotic cells. It is the location for most of the nucleic acids a cell makes, such as DNA and RNA. Danish biologist Joachim Hammerling carried out an important experiment in 1943. His work (click here for a diagram) showed the role of...
the nucleus in controlling the shape and features of the cell. Deoxyribonucleic acid, DNA, is the physical carrier of inheritance and with the exception of plastid DNA (cpDNA and mDNA, found in the chloroplast and mitochondrion respectively) all DNA is restricted to the nucleus. Ribonucleic acid, RNA, is formed in the nucleus using the DNA base sequence as a template. RNA moves out into the cytoplasm where it functions in the assembly of proteins. The nucleolus is an area of the nucleus (usually two nucleoli per nucleus) where ribosomes are constructed.

Figure 6. Structure of the nucleus. Note the chromatin, uncoiled DNA that occupies the space within the nuclear envelope. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Figure 7. Liver cell nucleus and nucleolus (TEM x20,740). Cytoplasm, mitochondria, endoplasmic reticulum, and ribosomes also shown. This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.
The nuclear envelope, shown in Figure 8, is a double-membrane structure. Numerous pores occur in the envelope, allowing RNA and other chemicals to pass, but the DNA not to pass.


![Figure 8](image)

Figure 9. Nucleus with Nuclear Pores (TEM x73,200). The cytoplasm also contains numerous ribosomes. This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.

![Figure 9](image)
Cytoplasm | Back to Top

The cytoplasm was defined earlier as the material between the plasma membrane (cell membrane) and the nuclear envelope. Fibrous proteins that occur in the cytoplasm, referred to as the cytoskeleton maintain the shape of the cell as well as anchoring organelles, moving the cell and controlling internal movement of structures. Elements that comprise the cytoskeleton are shown in Figure 10. Microtubules function in cell division and serve as a "temporary scaffolding" for other organelles. Actin filaments are thin threads that function in cell division and cell motility. Intermediate filaments are between the size of the microtubules and the actin filaments.

Figure 10. Actin and tubulin components of the cytoskeleton. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.
Vacuoles and vesicles | Back to Top

**Vacuoles** are single-membrane organelles that are essentially part of the outside that is located within the cell. The single membrane is known in plant cells as a tonoplast. Many organisms will use vacuoles as storage areas. Vesicles are much smaller than vacuoles and function in transporting materials both within and to the outside of the cell.

Ribosomes | Back to Top

**Ribosomes** are the sites of protein synthesis. They are not membrane-bound and thus occur in both prokaryotes and eukaryotes. Eukaryotic ribosomes are slightly larger than prokaryotic ones. Structurally, the ribosome consists of a small and larger subunit, as shown in Figure 11. Biochemically, the ribosome consists of ribosomal RNA (rRNA) and some 50 structural proteins. Often ribosomes cluster on the endoplasmic reticulum, in which case they resemble a series of factories adjoining a railroad line. Figure 12 illustrates the many ribosomes attached to the endoplasmic reticulum. Click here for Ribosomes (More than you ever wanted to know about ribosomes!)

Figure 12. Ribosomes and Polyribosomes - liver cell (TEM x173,400). This image is copyright Dennis Kunkel at [www.DennisKunkel.com](http://www.DennisKunkel.com), used with permission.

**Endoplasmic reticulum** | **Back to Top**

*Endoplasmic reticulum*, shown in Figure 13 and 14, is a mesh of interconnected membranes that serve a function involving protein synthesis and transport. Rough endoplasmic reticulum (Rough ER) is so-named because of its rough appearance due to the numerous ribosomes that occur along the ER. Rough ER connects to the nuclear envelope through which the messenger RNA (mRNA) that is the blueprint for proteins travels to the ribosomes. Smooth ER; lacks the ribosomes characteristic of Rough ER and is thought to be involved in transport and a variety of other functions.
Figure 13. The endoplasmic reticulum. Rough endoplasmic reticulum is on the left, smooth endoplasmic reticulum is on the right. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Figure 14. Rough Endoplasmic Reticulum with Ribosomes (TEM x61,560). This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.

Golgi Apparatus and Dictyosomes | Back to Top
Golgi Complexes, shown in Figure 15 and 16, are flattened stacks of membrane-bound sacs. Italian biologist Camillo Golgi discovered these structures in the late 1890s, although their precise role in the cell was not deciphered until the mid-1900s. Golgi function as a packaging plant, modifying vesicles produced by the rough endoplasmic reticulum. New membrane material is assembled in various cisternae (layers) of the golgi.

Figure 16. Golgi Apparatus in a plant parenchyma cell from *Sauromatum guttatum* (TEM x145,700). Note the numerous vesicles near the Golgi. This image is copyright Dennis Kunkel at [www.DennisKunkel.com](http://www.DennisKunkel.com), used with permission.

Lysosomes, shown in Figure 17, are relatively large vesicles formed by the Golgi. They contain hydrolytic enzymes that could destroy the cell. Lysosome contents function in the extracellular breakdown of materials.

Mitochondria contain their own DNA (termed mDNA) and are thought to represent bacteria-like organisms incorporated into eukaryotic cells over 700 million years ago (perhaps even as far back as 1.5 billion years ago). They function as the sites of energy release (following glycolysis in the cytoplasm) and ATP formation (by chemiosmosis). The mitochondrion has been termed the powerhouse of the cell. Mitochondria are bounded by two membranes. The inner membrane folds into a series of cristae, which are the surfaces on which adenosine triphosphate (ATP) is generated. The matrix is the area of the mitochondrion surrounded by the inner mitochondrial membrane. Ribosomes and mitochondrial DNA are found in the matrix. The significance of these features will be discussed below. The structure of mitochondria is shown in Figure 18 and 19.

Figure 18. Structure of a mitochondrion. Note the various infoldings of the mitochondrial inner membrane that produce the cristae. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.
Mitochondria and endosymbiosis

During the 1980s, Lynn Margulis proposed the theory of endosymbiosis to explain the origin of mitochondria and chloroplasts from permanent resident prokaryotes. According to this idea, a larger prokaryote (or perhaps early eukaryote) engulfed or surrounded a smaller prokaryote some 1.5 billion to 700 million years ago. Steps in this sequence are illustrated in Figure 20.

Figure 20. The basic events in endosymbiosis. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Instead of digesting the smaller organisms the large one and the smaller one entered into a type of symbiosis known as mutualism, wherein both organisms benefit and neither is harmed. The larger organism gained excess ATP provided by the "protomitochondrion" and excess sugar provided by the "protochloroplast", while providing a stable environment and the raw materials the endosymbionts required. This is so strong that now eukaryotic cells cannot survive without
mitochondria (likewise photosynthetic eukaryotes cannot survive without chloroplasts), and the endosymbionts cannot survive outside their hosts. Nearly all eukaryotes have mitochondria. Mitochondrial division is remarkably similar to the prokaryotic methods that will be studied later in this course. A summary of the theory is available by clicking here.

**Plastids | Back to Top**

Plastids are also membrane-bound organelles that only occur in plants and photosynthetic eukaryotes. Leucoplasts, also known as amyloplasts (and shown in Figure 21) store starch, as well as sometimes protein or oils. Chromoplasts store pigments associated with the bright colors of flowers and/or fruits.

Figure 21. Starch grains in a fresh-cut potato tuber. Image from http://images.botany.org/set-13/13-008v.jpg.

Chloroplasts, illustrated in Figures 22 and 23, are the sites of photosynthesis in eukaryotes. They contain **chlorophyll**, the green pigment necessary for photosynthesis to occur, and associated accessory pigments (carotenes and xanthophylls) in **photosystems** embedded in membranous sacs, **thylakoids** (collectively a stack of thylakoids are a granum [plural = **grana**]) floating in a fluid termed the **stroma**. Chloroplasts contain many different types of accessory pigments, depending on the taxonomic group of the organism being observed.

Figure 22. Structure of the chloroplast. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used
Chloroplasts and endosymbiosis
Like mitochondria, chloroplasts have their own DNA, termed cpDNA. Chloroplasts of Green Algae (Protista) and Plants (descendants of some of the Green Algae) are thought to have originated by endosymbiosis of a prokaryotic alga similar to living Prochloron (the sole genus present in the Prochlorobacteria, shown in Figure 24). Chloroplasts of Red Algae (Protista) are very similar biochemically to cyanobacteria (also known as blue-green bacteria [algae to chronologically enhanced folks like myself :])). Endosymbiosis is also invoked for this similarity, perhaps indicating more than one endosymbiotic event occurred.

Figure 24. Prochloron, a photosynthetic bacteria, reveals the presence of numerous thylakoids in the transmission electron micrograph on the left. Prochloron occurs in long filaments, as shown by the light micrograph on the right below. Image from http://www.cas.muohio.edu/~wilsonkg/bot191/mouseth/m19p32.jpg.

Cell Movement | Back to Top

Cell movement; is both internal, referred to as cytoplasmic streaming, and external, referred to as motility. Internal movements of organelles are governed by actin filaments and other components of the cytoskeleton. These filaments make an area in which organelles such as chloroplasts can move. Internal movement is known as cytoplasmic streaming. External movement of cells is determined by special organelles for locomotion.

The cytoskeleton is a network of connected filaments and tubules. It extends from the nucleus to the plasma membrane. Electron microscopic studies showed the presence of an organized cytoplasm. Immunofluorescence microscopy identifies protein fibers as a major part of this cellular feature. The cytoskeleton components maintain cell shape and allow the cell and its organelles to move.

Actin filaments, shown in Figure 25, are long, thin fibers approximately seven nm in diameter. These filaments occur in bundles or meshlike networks. These filaments are polar, meaning there are differences between the ends of the strand. An actin filament consists of two chains of globular actin monomers twisted to form a helix. Actin filaments play a structural role, forming a dense complex web just under the plasma membrane. Actin filaments in microvilli of intestinal cells act to shorten the cell and thus to pull it out of the intestinal lumen. Likewise, the filaments can extend the cell into intestine when food is to be absorbed. In plant cells, actin filaments form tracts along which chloroplasts circulate.
Actin filaments move by interacting with myosin. The myosin combines with and splits ATP, thus binding to actin and changing the configuration to pull the actin filament forward. Similar action accounts for pinching off cells during cell division and for amoeboid movement.

Figure 25. Skeletal muscle fiber with exposed intracellular actin myosin filaments. The muscle fiber was cut perpendicular to its length to expose the intracellular actin myosin filaments. SEM X220. This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.

Intermediate filaments are between eight and eleven nm in diameter. They are between actin filaments and microtubules in size. The intermediate fibers are rope-like assemblies of fibrous polypeptides. Some of them support the nuclear envelope, while others support the plasma membrane, form cell-to-cell junctions.

Microtubules are small hollow cylinders (25 nm in diameter and from 200 nm-25 µm in length). These microtubules are composed of a globular protein tubulin. Assembly brings the two types of tubulin (alpha and beta) together as dimers, which arrange themselves in rows.

In animal cells and most protists, a structure known as a centrosome occurs. The centrosome contains two centrioles lying at right angles to each other. Centrioles are short cylinders with a 9 + 0 pattern of microtubule triplets. Centrioles serve as basal bodies for cilia and flagella. Plant and fungal cells have a structure equivalent to a centrosome, although it does not contain centrioles.
Cilia are short, usually numerous, hairlike projections that can move in an undulating fashion (e.g., the protzoan *Paramecium*, the cells lining the human upper respiratory tract). Flagella are longer, usually fewer in number, projections that move in whip-like fashion (e.g., sperm cells). Cilia and flagella are similar except for length, cilia being much shorter. They both have the characteristic 9 + 2 arrangement of microtubules shown in figures 26.

Figure 26. Cilia from an epithelial cell in cross section (TEM x199,500). Note the 9 + 2 arrangement of cilia. This image is copyright Dennis Kunkel at [www.DennisKunkel.com](http://www.DennisKunkel.com), used with permission.

Cilia and flagella move when the microtubules slide past one another. Both of these locomotion structures have a basal body at base with the same arrangement of microtubule triples as centrioles. Cilia and flagella grow by the addition of tubulin dimers to their tips.

Flagella work as whips pulling (as in *Chlamydomonas* or *Halosphaera*) or pushing (dinoflagellates, a group of single-celled Protista) the organism through the water. Cilia work like oars on a viking longship (*Paramecium* has 17,000 such oars covering its outer surface). The movement of these structures is shown in Figure 27.

Not all cells use cilia or flagella for movement. Some, such as *Amoeba*, *Chaos (Pelomyxa)* and human [leukocytes](https://www2.estrellamountain.edu/faculty/farabee/biobk/BioBookCELL2.html) (white blood cells), employ [pseudopodia](https://www2.estrellamountain.edu/faculty/farabee/biobk/BioBookCELL2.html) to move the cell. Unlike cilia and flagella, pseudopodia are not structures, but rather are associated with actin near the moving edge of the cell. The formation of a pseudopod is shown in Figure 28.


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**Learning Objectives** | [Back to Top](#)

- Give the function and cellular location of the following basic eukaryotic organelles and structures: cell membrane, nucleus, endoplasmic reticulum, Golgi bodies, lysosomes, mitochondria, ribosomes, chloroplasts, vacuoles, and cell walls.
- A micrometer is one-millionth of a meter long. A nanometer is one-billionth of a meter long. How many micrometers tall are you?
- Describe the function of the nuclear envelope and nucleolus.
- Describe the details of the structure of the chloroplast, the site of photosynthesis.
- Mature, living plant cells often have a large, fluid-filled central vacuole that can store amino acids, sugars, ions, and toxic wastes. Animal cells generally lack large vacuoles. How do animal cells perform these functions?
- Microtubules, microfilaments, and intermediate filaments are all main components of the cytoskeleton.
- Flagella and cilia propel eukaryotic cells through their environment; the microtubule organization in these organelles is a 9+2 array.

Terms | Back to Top

actin | carotenes | cellulose | cell walls | chemiosmosis | chitin
chlorophyll | cristae | cyanobacteria | cytoplasm | cytoskeleton | dinoflagellates
endoplasmic | erythrocyes | eukaryotic | fluid-mosaic | Golgi | complexes
reticulum | Green Algae | hydrophilic | hydrophobic | leukocytes | lysosomes | microtubules
mitochondria | mutualism | neurons | nucleus | nucleolus | ova
parenchyma | phospholipid | photosystems | plasmodesmata | plastid | pseudopodia
Red Algae | ribosomal RNA | ribosomes | stroma | symbiosis | thylakoids
vacuoles | zygote

Review Questions | Back to Top

1. There are ____ micrometers (µm) in one millimeter (mm). a) 1; b) 10; c) 100; d) 1000; e) 1/1000
2. Human cells have a size range between ____ and ____ micrometers (µm). a) 10-100; b) 1-10; c) 100-1000; d) 1/10-1/1000
3. Chloroplasts and bacteria are ___ in size. a) similar; b) at different ends of the size range; c) exactly the same; d) none of these.
4. The plasma membrane does all of these except _______. a) contains the hereditary material; b) acts as a boundary or border for the cytoplasm; c) regulates passage of material in and out of the cell; d) functions in the recognition of self
5. Which of these materials is not a major component of the plasma membrane? a) phospholipids; b) glycoproteins; c) proteins; d) DNA
6. Cells walls are found in members of these kingdoms, except for ____, which all lack cell walls. a) plants; b) animals; c) bacteria; d) fungi
7. The polysaccharide ____ is a major component of plant cell walls. a) chitin; b) peptidoglycan; c) cellulose; d) mannitol; e) cholesterol
8. Plant cells have ____ and ____, which are not present in animal cells. a) mitochondria, chloroplasts; b) cell membranes, cell walls; c) chloroplasts, nucleus; d) chloroplasts, cell wall
9. The ____ is the membrane enclosed structure in eukaryotic cells that contains the DNA of the cell. a) mitochondrion; b) chloroplast; c) nucleolus; d) nucleus
10. Ribosomes are constructed in the ____. a) endoplasmic reticulum; b) nucleoid; c) nucleolus; d) nuclear pore
11. Rough endoplasmic reticulum is the area in a cell where ____ are synthesized. a) polysaccharides; b) proteins; c) lipids; d) DNA
12. The smooth endoplasmic reticulum is the area in a cell where ____ are synthesized. a) polysaccharides; b) proteins; c) lipids; d) DNA
13. The mitochondrion functions in ____. a) lipid storage; b) protein synthesis; c) photosynthesis; d) DNA replication; e) ATP synthesis

14. The thin extensions of the inner mitochondrial membrane are known as ____. a) cristae; b) matrix; c) thylakoids; d) stroma

15. The chloroplast functions in ____. a) lipid storage; b) protein synthesis; c) photosynthesis; d) DNA replication; e) ATP synthesis

16. Which of these cellular organelles have their own DNA? a) chloroplast; b) nucleus; c) mitochondrion; d) all of these

17. The theory of ___ was proposed to explain the possible origin of chloroplasts and mitochondria. a) evolution; b) endosymbiosis; c) endocytosis; d) cells

18. Long, whiplike microfibrils that facilitate movement by cells are known as ____. a) cilia; b) flagella; c) leather; d) pseudopodia

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* Protist Image Data: Pictures and resources about Protista.
* Cell Biology Lab Manual: Lab protocols and links pertaining to cell biology. A nice place to look for new things to do in labs.
* MIT Hypertextbook Chapter on Cell Biology: Excellent site with illustrations and additional details to complement the above material.
* WWW Cell Biology Course: An excellent site employing image maps and details about cell biology.
* Dictionary of Cell Biology: A searchable dictionary pertinent to this topic.
* Cells Alive! Very interesting site with new features each month.
* Ribosomes A text with links to illustrations. More than you ever wanted to know about ribosomes!
* Charlie and Bobby Jo's Excellent Adventure Look out, honey, I shrunk the lab! Humorous journey through a cell. (Dr. Sata, University of Texas).
* The Cell Nucleus This easily navigated series of well illustrated pages presents an impressive amount of information about the various functions carried out by the nucleus.
* The Cytoskeleton This site provides additional details about the components of the cytoskeleton.

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Email: mj.farabee@emcmail.maricopa.edu

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