Eukaryotic Cells

Eukaryotic cells contain membrane-enclosed organelles that play a pivotal role in their structure and function.

A pseudo-colored freeze-fracture transmission electron micrograph (TEM) of the nucleus of a pig kidney cell. Pores (yellow) in the nuclear membrane regulate the movement of molecules into and out of the nucleus of eukaryotic cells. Magnification = 25,000x. Biophoto Associates/Science Source.

Topics Covered in this Module

- Components of a Eukaryotic Cell
- Diverse Form and Function of Eukaryotic Cells

Major Objectives of this Module

- Identify cellular structures on a micrograph or diagram and name their functions.
- Relate the forms of different cell structures to their functions.
- Compare and contrast the structure and function of organelles found in animal and plant cells.
Components of a Eukaryotic Cell

As we learned in the last chapter, prokaryotic cells are enclosed in a singular cellular membrane, while eukaryotic cells have additional internal membrane-bound organelles. Organelles compartmentalize cellular activities, allowing the eukaryotic cell to be larger and more complex than prokaryotic cells. The first organisms on Earth were much like some of today's prokaryotes. How did eukaryotic cells evolve from prokaryotic ones? According to the endosymbiotic theory, which we discuss later in this module, eukaryotic mitochondria originated as free-living prokaryotes that were engulfed by an ancestral eukaryote and became symbiotic. A similar but independent event is believed to have given rise to plastids such as chloroplasts. How other cellular organelles, such as the endoplasmic reticulum, evolved is less clear. Scientists believe that these organelles may have developed from infolding of the plasma membrane of the proto-eukaryote.

The compartments in eukaryotic cells are called organelles: membrane-bound structures enclosed by a semi-permeable phospholipid membrane that is very similar in composition to the plasma membrane. Membrane-bound organelles are the primary feature that distinguishes eukaryotic cells from prokaryotic cells (Figures 1 and 2). Another major difference between prokaryotes and eukaryotes is the form and location of the chromosomes. In prokaryotic cells, a chromosome (typically a lone circular chromosome) is localized in the cytoplasm, in a region called the nucleoid. In eukaryotic cells, one or more linear chromosomes are contained within a double membrane-bound organelle called the nucleus.

Figure 1: A typical animal cell.
A view inside an animal cell. Notice the structures that are not present in plant cells: the centrosome, centrioles, and lysosomes (see Figure 2). Remember that cells are dynamic. The position and shape of many cell structures change from one moment to the next.
Figures 1 and 2 illustrate typical animal and plant cells and their common organelles. It is important to remember that eukaryotic cells come in all shapes and sizes. Eukaryotic cells are typically specialized in size and shape based on their function.

Figure 2: A typical plant cell.
Cross-section of a typical plant cell. Notice the structures that are not present in animal cells: chloroplasts, the central vacuole, the cell wall, and plasmodesmata. Remember that cells are dynamic. The positions and shapes of many cell structures change from one moment to the next.

© 2014 Nature Education All rights reserved. Transcript

Why is the nucleus important?
The nucleus is unique to eukaryotes. Bound by a double membrane, the nucleus functions much like the brain of the cell (Figure 3). A eukaryotic cell nucleus is often larger than an entire prokaryote. The nucleus processes inputs from the cytoplasm, storing and retrieving information and carrying out instructions contained within the genetic material in the nucleus. The nucleus contains the cell’s chromosomes, which consist of DNA and associated proteins. The DNA contains the genetically transmitted instructions for synthesizing RNA and proteins.

Figure 3: The nucleus.
Green fluorescent labeling highlights an entire mammalian cell, including its nucleus. At the center of the nucleus is the nucleolus (orange).
The nucleus is surrounded by a double membrane called the nuclear
envelope, which is made up of two phospholipid bilayers. The nuclear envelope also contains prominent nuclear pores. These protein-lined channels allow large molecular complexes to enter and leave the nucleus. In a non-dividing cell, the nucleus also contains one or more dark-staining areas called the nucleolus. Ribosomal RNA (rRNA) is synthesized in the nucleolus and combined with proteins to form the small and large subunits of the ribosomes, which are the protein-producing factories of the cell. These subunits move through nuclear pores to the cytoplasm, where a large and small subunit will assemble together to become a ribosome.

Though ribosomes are made in the nucleolus, protein synthesis occurs in the cytoplasm or in another organelle called the rough endoplasmic reticulum (RER), which is suspended in the cytosol outside of the nucleus. If the DNA is inside the nucleus and the protein-synthesizing organelles are somewhere else in the cell, how do eukaryotic cells make proteins based on the blueprints contained within the DNA?

In the same way that we keep important documents in a safe place and make copies as needed, a eukaryote's DNA never leaves the protected confines of the nucleus. Instead, a transcript of one or more genes is made in the form of a messenger RNA (mRNA) molecule. True to its name, the mRNA carries the transcribed instructions out of the nucleus to the ribosomes. Ribosomes are able to use the genetic instructions encoded in mRNA molecules to make proteins.

During protein synthesis, mRNA binds to a small ribosomal subunit in the cytoplasm. The large ribosomal subunit then joins the complex to form a ribosome. If the mRNA encodes a soluble cytosolic protein, the ribosome remains free in the cytoplasm. If, however, the mRNA encodes a membrane-embedded or secretory protein, the ribosome attaches itself to the rough endoplasmic reticulum.

Test Yourself

What is the role of mRNA in protein synthesis?

Submit

The endomembrane system is a group of interrelated organelles. The endomembrane system is a set of organelles in a eukaryotic cell that are functionally interrelated. The endomembrane system includes the nuclear envelope, endoplasmic reticulum, Golgi apparatus, plasma membrane, and other organelles derived from these structures. The endoplasmic reticulum (ER) is an extensive network of membrane-enclosed compartments that connect directly to the nuclear envelope. Smooth endoplasmic reticulum (SER) does not contain attached ribosomes, and it is involved in lipid synthesis, metabolism of carbohydrates, calcium storage, and breaking down toxic substances in the cell. Rough endoplasmic reticulum (RER) appears rough because it is studded with ribosomes. What kind of proteins do the RER ribosomes produce? The ribosomes attached to rough endoplasmic reticulum are responsible for synthesizing membrane-embedded proteins and secretory proteins (that is, proteins excreted from the cell). Membrane-embedded proteins are incorporated into the rough endoplasmic reticulum membrane during protein synthesis. Secretory proteins are secreted into the lumen, which is the inside of the rough endoplasmic reticulum. Many secretory proteins are glycoproteins, or proteins with attached carbohydrates. Some carbohydrate modifications of proteins are made in the RER. The RER also makes phospholipids.

The Golgi apparatus is the "shipping and receiving" center of the cell's
endomembrane system (Figure 4). This organelle is composed of a stack of separate, flattened membrane sacs. The Golgi apparatus is asymmetrical and has two faces: a cis face and a trans face. The cis face is closest to the endoplasmic reticulum, and the trans face is closest to the plasma membrane. Vesicles that pinch off from the RER fuse with the cis face of the Golgi, bringing along with them newly synthesized membrane and secretory proteins. The newly synthesized proteins travel in vesicles from one Golgi membrane to the next until they reach the trans face. Vesicles leaving the trans face fuse with the plasma membrane or with the membrane of other cellular organelles. Membrane-embedded proteins stay in the membrane of final destination, and soluble proteins are released, either to the exterior of the cell or to the lumen of another organelle.

Sequential modifications to proteins and glycoproteins occur in successive Golgi compartments. The Golgi is also responsible for synthesis of other secreted molecules, such as pectins. Some modifications in the Golgi serve as tags. Like a postal address, a molecular tag tells cellular machinery to export the substance or where to send the substance in the cell.

**Figure 4: Golgi apparatus.**
The Golgi apparatus is part of the endomembrane system of the cell. It is responsible for modifying, storing, and exporting substances from the cell. © 2011 Nature Education All rights reserved.

**Lysosomes are the cell’s digestive system and recycling center.**
The RER and Golgi apparatus produce another membrane-bound organelle — the lysosome. Lysosomes are vesicles containing powerful enzymes that digest food items engulfed by the cell. The vesicles of lysosomes have evolved to maintain a low pH environment within their lumen. This acidic environment provides the optimal conditions for the digestive enzymes to function.

Animals, fungi, and many protists are heterotrophs. A heterotroph is an organism that requires organic compounds, or food, for energy and for synthesis of new organic compounds. Heterotrophic cells possess various ways of taking in the food they need. Some cell types are able to take in nutrients by engulfing large substances through the process of phagocytosis (Figure 5). In phagocytosis, the cell first surrounds a nutrient with its plasma membrane. Once the plasma membrane completely surrounds the substance, the membrane pinches off to form a vesicle inside the cytoplasm of the cell. This vesicle, containing the engulfed food item, is called a food vacuole. Lysosomes fuse with these food vacuoles, and their
digestive enzymes break down the food items. Once the lysosomes have completely digested the food, the products of digestion (including simple sugars, amino acids, and other monomers) are transported out of the lysosome and into the cytoplasm to be used by the rest of the cell for energy and synthesis of other molecules. Another way that a cell uses phagocytosis is to defend itself against invading organisms like a bacterium. In this case, the physical processes of engulfing and digesting are very similar.

**Figure 5: Phagocytosis by an amoeba.**
This amoeba (pseudo-colored blue), a single-celled eukaryote, is engulfing an algal cell using phagocytosis. The amoeba is in the process of surrounding the algal cell with an extension of its cell membrane. Magnification = 9,750x

*Biophoto Associates/Science Source.*

In addition to their digestive functions, lysosomes can also use their digestive enzymes to recycle cellular components by autophagy. **Autophagy** is the process of breaking down and recycling malfunctioning or worn-out cell organelles. This process reclaims vital molecules from worn-out organelles — valuable materials that would otherwise be lost.

**Future perspectives.**
Imagine what it would be like to watch proteins and other molecules move around inside a living cell in real time. We would be able to see not only which molecules the cell produces but also watch where the molecules go after they are produced, either inside or outside the cell. Fortunately, thanks to a jellyfish and some new advances in microscopy, this ability is now possible.

The jellyfish in question is *Aequorea victoria*. It produces a protein called green fluorescent protein (GFP), which exhibits a green fluorescent color when exposed to ultraviolet or blue light. Cell and molecular biologists quickly recognized the value of GFP as a biomonitoring device. The gene encoding GFP can be joined to a gene of interest so that when the gene of interest is expressed as a protein, it will be tagged with GFP. Because GFP fluoresces, the expression of the tagged proteins can be visualized in a cell or organism.

Although tracking molecular movement within individual cells is useful in diagnosing some diseases, scientists ultimately aim to track molecules as they move throughout the body. Current whole-body imaging methods, such as magnetic resonance imaging (MRI), show detailed anatomy but cannot visualize or track molecules within the body. In contrast, proteins tagged with GFP and similar fluorescent molecules fluoresce and can be tracked throughout a cell or organism. Researchers can also map the tagged molecules’ distribution throughout tissues and organs. While the resolution of these images is not yet sharp enough for medical use, further research is underway. In the next decade, we may be able to watch molecules moving...
through our bodies just as easily as we watch television.

**The mitochondria and chloroplasts are energy-converting organelles.**

The power-generating organelles of eukaryotes are called **mitochondria** and **chloroplasts**. These power-generating organelles are quite different in structure and evolutionary history from other organelles. The mitochondria and chloroplasts have complex multi-layered membranes. They also contain their own DNA and ribosomes capable of synthesizing their own proteins, and they can divide and multiply largely free of the constraints of cell division. These features were clues to the origins of mitochondria and chloroplasts.

The **endosymbiotic theory** suggests that ancient free-living host prokaryotes obtained mitochondria and chloroplasts by first engulfing other energy-processing prokaryotes but not killing them. The engulfed prokaryotes became symbiotic, benefitting from living safely within the host cell's cytoplasm and gaining nutrients. In exchange, the engulfed prokaryotes provided their host cells with energy. The symbiotic relationship between the engulfed cell and the host cell ultimately evolved to a point where the two cells were no longer independent. Much of the prokaryotic DNA was transferred to the nucleus of the host cell, and the engulfed cell became an integrated organelle, either a mitochondrion or a chloroplast. Nearly all eukaryotic cells have mitochondria, while photosynthetic eukaryotes such as plants and most algae also contain chloroplasts. Photosynthetic lineages arose well after the heterotrophic lineages that must obtain their organic molecules by consuming other organisms, but they evolved in a similar way. Existing mitochondria-containing cells engulfed and became symbiotic with photosynthetic prokaryotes with the ability to process energy from sunlight.

Many scientists suspect that eukaryotes could have gained other organelles through endosymbiosis. Recent genetic studies have found that eukaryotic DNA contains genes not only from bacteria but also from archaea. Could the ancestor of all eukaryotes actually have been an archaean that engulfed its membrane-bound organelles, including the double-membrane nucleus? The debate rages on today, more than 40 years after Lynn Margulis first published her endosymbiotic theory of the evolution of eukaryotes.

Mitochondria transform chemical energy via cellular respiration. They do so by using the energy derived from the breakdown of carbohydrates and lipids to make ATP. Mitochondria are an essential component in almost all eukaryotic cells. Each mitochondrion can divide to form two mitochondria (Figure 6). Defects impairing mitochondrial fusion occur in a number of human genetic disorders, indicating that these networks are essential for the normal function of many cells types. Scientists speculate that mitochondrial networks allow ATP synthesis to occur in oxygen-poor parts of the cell.
Mitochondria possess an inner and an outer membrane (Figure 7). To maximize the surface area on which chemical reactions occur, the inner membrane is folded, forming pockets called **cristae**. The inner membrane surrounds the interior of the mitochondrion, called the **matrix**. Mitochondrial DNA, ribosomes, and enzymes performing a variety of functions are present in the mitochondria. The area between the inner and outer membranes is called the intermembrane space. An electrochemical gradient formed across the inner membrane provides energy for ATP synthesis.
A view inside a mitochondrion. Notice that the cristae are folds of the inner mitochondrial membrane.

Chloroplasts (Figure 8) perform photosynthesis, a process in which energy from sunlight is used to fix carbon dioxide (CO$_2$) into organic compounds. The chloroplast is bound by two membranes called the outer and inner membranes. Within the inner membrane are thylakoids, which form a third membrane layer. Thylakoids, which are flat and round, form stacks called grana (singular: granum). A granum resembles a stack of pancakes. The fluid surrounding the thylakoids is called the stroma.

Appropriate to their function, chloroplasts house photosynthetic pigments, such as chlorophyll molecules that absorb light energy. These pigments are contained within the membranes of the thylakoids (Figure 9). Within the
thylakoid, light energy is used to make ATP. Energy from ATP is then used by enzymes in the stroma to synthesize sugars from CO₂.

**Figure 9: Chloroplast micrograph.**
This transmission electron microscope image shows a cross-section of a chloroplast from a tobacco leaf (*Nicotiana tabacum*). Notice the darkly stained stacks and runs of thylakoid membranes. The stacked regions of thylakoid membrane are the grana. The white areas are sites of chloroplast DNA. Magnification = 44,000x

**Dr. Jeremy Burgess/Science Source.**

**Test Yourself**

In what way do chloroplasts and mitochondria perform opposite functions?

Submit

**Future perspectives.**
Parkinson's disease is a devastating condition that causes gradual reduction in muscle coordination and control within its victims. Parkinson's patients often lose the ability to walk, play sports, or even communicate.

Dr. Clemens Scherzer and his team at the Center for Neurologic Diseases at Harvard Medical School actively study Parkinson's disease. Their research suggests that there is a link between Parkinson's disease and mitochondria. After analyzing the DNA from more than 400 brain samples, Dr. Scherzer's group was able to link the onset of Parkinson's disease with genes that control mitochondrial function and energy production. They found that a number of genes are underexpressed in Parkinson's patients. This means that the proteins encoded by these genes — proteins that are responsible for energy generation and other mitochondrial functions — are made in amounts too small to adequately perform their duties. In Parkinson's patients, it appears that not having enough of these proteins results in a shortage of ATP and damage to the mitochondria. Amazingly, drugs already in use for other diseases, like type 2 diabetes, appear to reverse the underexpression of key proteins and partially reverse the symptoms of Parkinson's disease.

**Eukaryotic cells contain a number of other structures.**

**Peroxisomes** serve several functions, including detoxifying cells when they are exposed to substances such as alcohol, phenol, or formaldehyde.
(Figures 10 and 11). Peroxisomes contain enzymes that break down toxic molecules by removing hydrogen via a set of oxidation reactions. The hydrogen atoms react with molecular oxygen (O₂) within the peroxisome, producing hydrogen peroxide — this product is the inspiration for the organelle’s name. Hydrogen peroxide can also be toxic to cells, and the peroxisome must immediately convert excess hydrogen peroxide into water. Peroxisomes are a great example of the compartmentalization of harmful materials and volatile chemical reactions within a membrane-bound organelle.

**Figure 10: Peroxisomes.**
The peroxisomes (shown in pink inside an animal cell) manage the hazardous waste in the cell by converting hydrogen sources into hydrogen peroxide, which is then converted into water. © 2011 Nature Education All rights reserved.

**Figure 11: Peroxisomes under the microscope.**
Peroxisomes are found in nearly every eukaryotic cell. The arrow indicates the location of a peroxisome in this transmission electron micrograph of a rat liver cell. Don W. Fawcett/Science Source.

**Vacuoles** are vesicles, derived either from the ER and Golgi membranes or from the plasma membrane. They serve as the cell's storage tanks. Food vacuoles, as mentioned previously, form around food that is engulfed by
cells. Many freshwater protists possess another kind of vacuole, called a contractile vacuole (Figure 12). The contractile vacuole counterbalances the continual diffusion of fresh water (osmosis) into cells by pumping out excess water.

Figure 12: Vacuoles.
Light micrograph of a paramecium showing two contractile vacuoles (star-shaped objects). Magnification = 300x

Walter Dawn/Science Source.

In plant cells, a large central vacuole can take up most of the cytoplasm. The membrane surrounding the central vacuole is called a tonoplast. Plants store ions in the central vacuole, which causes water to diffuse into the vacuole. The filled vacuole presses against the cell wall, making it rigid. This gives the plant cell, and therefore the entire plant, a firm and turgid structure. When not enough water is available, the central vacuoles in many of the plant's cells shrink, the plant cells become flaccid, and the plant wilts.

Test Yourself

Which two cellular structures give shape and support to plant cells?

Submit
WHY DOES THIS TOPIC MATTER?

Stem Cells

Stem cells are powerful tools in biology and medicine. What can scientists do with these cells and their incredible potential?

Cancer: What's Old Is New Again

Is cancer ancient, or is it largely a product of modern times? Can cutting-edge research lead to prevention and treatment strategies that could make cancer obsolete?

PRIMARY LITERATURE

Mitochondria change shape to help the cell survive

During autophagy mitochondria elongate, are spared from degradation and sustain cell viability.

View | Download

SCIENCE ON THE WEB

The Cellular Empire

How do eukaryotic cells differ from bacteria and archaea cells?

Name That Organelle

See how fast you can recognize eukaryotic organelles

How Do Proteins Move through the Golgi?

Watch proteins move through the Golgi in Figure 3 of this Scitable article

Cell Biology at Scitable

Browse a library of articles about organelles

Mitochondria and Medicine

Read an article about mitochondria's role in Parkinson's disease

Active Mitochondria

Learn how mitochondria are in a constant state of fusion and division
Diverse Form and Function of Eukaryotic Cells

In the animation below (Figure 13), notice how some of the organelles in the white blood cell change shape as they phagocytose a bacterium. When scientists examine real images of cells, they look nothing like this animation. We must remember that as cells move and act, the cell and its organelles appear differently depending on their state of activity. When we draw diagrams and illustrations to show this activity, it is merely an interpretation of a snapshot in time.

Figure 13: Eukaryotic phagocytosis.
A foreign bacterium becomes attached to a neutrophil in the blood. The neutrophil engulfs the bacterium through the process of phagocytosis. Red blood cells have a different shape than white blood cells because they have a different function.
Cancer: What's Old Is New Again
modern times? Can cutting-edge research lead to prevention and treatment strategies that could make cancer obsolete?

PRIMARY LITERATURE
Mitochondria change shape to help the cell survive
During autophagy mitochondria elongate, are spared from degradation and sustain cell viability.

View | Download

SCIENCE ON THE WEB
The Cellular Empire
How do eukaryotic cells differ from bacteria and archaea cells?

Name That Organelle
See how fast you can recognize eukaryotic organelles

How Do Proteins Move through the Golgi?
Watch proteins move through the Golgi in Figure 3 of this Scitable article

Cell Biology at Scitable
Browse a library of articles about organelles

Mitochondria and Medicine
Read an article about mitochondria’s role in Parkinson’s disease

Active Mitochondria
Learn how mitochondria are in a constant state of fusion and division
Summary

**OBJECTIVE** Identify cellular structures on a micrograph or diagram and name their functions.

**A typical animal cell.**
A view inside an animal cell. Notice the structures that are not present in plant cells: the centrosome, centrioles, and lysosomes (see Figure 2). Remember that cells are dynamic. The position and shape of many cell structures change from one moment to the next.

**A typical plant cell.**
Cross-section of a typical plant cell. Notice the structures that are not present in animal cells: chloroplasts, the central vacuole, the cell wall, and plasmodesmata. Remember that cells are dynamic. The positions and shapes of many cell structures change from one moment to the next.
OBJECTIVE  Relate the forms of different cell structures to their functions.
Eukaryotic cells have a nucleus and membrane-bound organelles. Prokaryotes do not possess any of these structures. The nucleus contains chromosomes, made of DNA and associated proteins. DNA contains the instructions for creating proteins required by the cell. The nucleus also contains the ribosome-subunit-producing area called the nucleolus. Structures of the nucleus are enclosed by the double-layered nuclear envelope. During protein synthesis the instructions for making a protein are transcribed from DNA onto a messenger RNA molecule. The mRNA then leaves the nucleus and combines with small and large ribosomal subunits to form a ribosome. The ribosome constructs proteins based on the instructions on the mRNA transcript. Proteins produced in the rough endoplasmic reticulum are typically membrane-embedded or destined for secretion outside of the cell or into the lumen of organelles. These proteins are placed in a membranous transport sac called a transport vesicle, which travels to the Golgi apparatus. In the Golgi apparatus, the proteins are modified and then placed into another vesicle. The vesicle fuses with the cell membrane or with other organelles of the endomembrane system. The smooth endoplasmic reticulum is responsible for synthesizing lipids and detoxifying the cell. Lysosomes are vesicles containing digestive enzymes. Lysosomes fuse with food vacuoles brought into the cell by phagocytosis. The enzymes digest the food item, after which the nutritive molecules diffuse into the cytoplasm. Mitochondria use energy derived from the breakdown of carbohydrates and lipids to produce ATP. Peroxisomes contain enzymes that break down toxic substances within the cell.

OBJECTIVE  Compare and contrast the structure and function of organelles found in animal and plant cells.
Chloroplasts and mitochondria likely arose in eukaryotic cells through symbiotic relationships between early prokaryotes as proposed by the endosymbiotic theory. Chloroplasts perform photosynthesis, a process that uses the energy from sunlight to make organic molecules from CO₂. Plasmodesmata are gaps in the cell walls of adjacent plant cells that allow cell-to-cell communication to occur. Vacuoles are membrane-bound organelles used to store substances within the cell. The central vacuole surrounded by the tonoplast retains water to give the plant cell rigidity and support.
Key Terms

autophagy 
Process of breaking down and recycling malfunctioning or worn out cell parts.

central vacuole 
A large vacuole found only in plant cells.

chlorophyll 
Primary pigment in plants; absorbs light in photosynthesis.

chloroplast 
Organelle that contains chlorophyll and carries out photosynthesis.

contractile vacuole 
Found in freshwater protists, pumps out excess water to prevent the cell from bursting.

cristae 
Pockets formed by folding of inner membrane of the mitochondria.

endomembrane system 
A system of membranes in eukaryotic cells that are derived from the same source.

endoplasmic reticulum (ER) 
Extensive series of membrane enclosed compartments throughout the cell; comes in two forms: smooth and rough.

endosymbiotic theory 
Widely accepted theory that states mitochondria and chloroplasts were once free-living prokaryotes prior to incorporation inside cells.

food vacuole 
Vacuole containing material to be broken down and absorbed by the cell; result of (usually) phagocytosis.

Golgi apparatus 
Modifies proteins and synthesizes other molecules that are either associated with membranes or exported from the cell.

granum (plural: grana) 
Stack of thylakoids.

lumen 
Interior of an organelle.

lysosome 
Vesicle in the cell that digests and breaks down food and unwanted particles.

matrix 
Interior region of the mitochondrion, found inside the inner membrane.

mitochondria 
Powerhouse of eukaryotic cell; site of cellular respiration.

nuclear envelope 
Membrane of the nucleus.

nuclear pore 
An opening in the nuclear envelope that permits the movement of large molecules, such as ribosomal subunits and messenger RNA, out of the nucleus and the movement of other molecules into the nucleus.

nucleolus 
Darker staining region of the nucleus where ribosomal RNA is produced and ribosome subunits are assembled.

nucleus 
Membrane-bound control center of eukaryotic cells containing the DNA of the organism.

peroxisome 
An organelle that breaks down toxins and produces hydrogen peroxide.
phagocytosis
Engulfment process by which the plasma membrane surrounds and encases large materials to be brought into the cell.

photosynthesis
Use of light energy to convert carbon dioxide into complex organic molecules.

photosynthetic pigments
Pigments that trap light energy during photosynthesis.

ribosome
Protein-producing factories of the cell; consists of a small subunit and a large subunit, each of which consists of proteins and ribosomal RNA.

rough endoplasmic reticulum (RER)
Associated with ribosomes; site of protein synthesis in the cytoplasm.

secretory protein
Protein that is secreted from the cell.

smooth endoplasmic reticulum (SER)
Endoplasmic reticulum that does not contain ribosomes; involved in lipid synthesis, calcium storage, metabolism of carbohydrates, and the breakdown of toxic substances.

stroma
Region inside the inner membrane of chloroplasts; contains the thylakoids.

tonoplast
Membrane surrounding the central vacuole in plants.

vacuole
A subcellular vesicle that is usually derived from the Golgi apparatus or endoplasmic reticulum; allows for materials to be sequestered from the rest of the cell and transported into, out of, or through the cell; in plants, a stabilizing intracellular form that provides cell structure.

vesicle
Membrane-bound structure used to isolate and transport materials in a cell.
Test Your Knowledge

1. Eukaryotic cells possess which of the following traits?
   - compartmentalization
   - chromosomes that float freely in the cytoplasm
   - membrane-bound organelles
   - both compartmentalization and chromosomes that float freely in the cytoplasm
   - both compartmentalization and membrane-bound organelles

2. Which of the following is found in plant cells but NOT in animal cells?
   - lysosomes
   - mitochondria
   - a nucleus
   - central vacuole/tonoplast
   - rough endoplasmic reticulum

3. Which cell structure best exemplifies the compartmentalization of a chemical reaction that requires environmental conditions that differ from those of the cytosol?
   - ribosome
   - chromosome
   - lysosome
   - cytoskeleton
   - vesicle

4. In a biology lab, you prepare a microscope slide with cells from a wilted plant. You stain the slide with a green fluorescent protein that specifically attaches to the tonoplast. When you look through the microscope, what do you expect to see?
   - Shrunken cells and green mitochondria.
   - Shrunken cells and a shriveled central vacuole that is outlined in green.
   - Shrunken cells and shriveled chloroplasts outlined in green.
   - Shrunken cells and a shriveled green lysosome.
   - Bloated cells and a rough endoplasmic reticulum outlined in green.

5. Which of the labeled organelles would most likely be involved in calcium ion (Ca\(^{2+}\)) storage? Identity of organelles: A — mitochondrion, B — rough endoplasmic reticulum, C — smooth endoplasmic reticulum, D — lysosome, and E — Golgi apparatus.
6. Which of the following is NOT evidence that supports the endosymbiotic theory of the origin of mitochondria and chloroplasts?

- Chloroplasts and mitochondria have many cilia and are able to swim around freely.
- Chloroplasts and mitochondria contain prokaryote-like ribosomes.
- Chloroplasts and mitochondria contain prokaryote-like single circular chromosomes.
- Chloroplasts and mitochondria are surrounded by a double membrane.
- Chloroplasts and mitochondria divide independently by a process similar to binary fission.

Submit
Mitochondria change shape to help the cell survive
During autophagy mitochondria elongate, are spared from degradation and sustain cell viability.

SCIENCE ON THE WEB

The Cellular Empire
How do eukaryotic cells differ from bacteria and archaea cells?

Name That Organelle
See how fast you can recognize eukaryotic organelles

How Do Proteins Move through the Golgi?
Watch proteins move through the Golgi in Figure 3 of this Scitable article

Cell Biology at Scitable
Browse a library of articles about organelles

Mitochondria and Medicine
Read an article about mitochondria's role in Parkinson's disease

Active Mitochondria
Learn how mitochondria are in a constant state of fusion and division