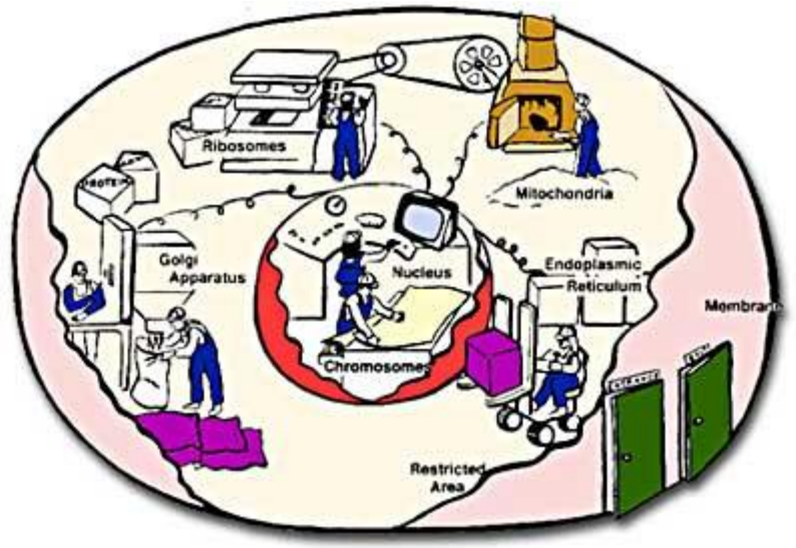
4a. A Busy Factory



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A cell can be thought of as a "factory," with different departments each performing specialized tasks.

Imagine a bustling factory manufacturing the latest must-have gadget. Whether they make bicycles, cell phones, or hot air balloons, most factories are set up in essentially the same way.

All factories have exterior walls that protect and support them and interior walls that create separate work areas. They usually have some kind of production line where a product is assembled and an executive department that decides what product is made. A finishing department processes and prepares the product for shipping, and a packaging department wraps the product.

In addition, a factory has a receiving department that brings in the components it needs to make its product, a communications department that allows it to contact suppliers, and a power plant that provides the energy it needs to run. Finally, a custodial staff keeps everything clean and in good working order.

Cells are very similar to factories. To stay alive and function properly, cells have a division of labor similar to that found in factories. Here, we will examine cells as protein-producing factories.

Cell Structure: An Overview

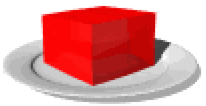
A cell's plasma membrane regulates what enters or leaves the cell.

All eukaryotic cells are composed of a plasma membrane, a nucleus, and cytoplasm. These structures can be compared with a factory's departments.

The **PLASMA MEMBRANE** regulates what enters or leaves the cell. It is analogous to the shipping and receiving department of a factory. The plasma membrane also functions as the communications department because it is where the cell contacts the external environment.

The **NUCLEUS** (or the executive department) runs the cell factory and controls all cell activity. It determines what proteins are to be made and stores all the plans for any proteins that the cell currently makes or has made in the past.

The **CYTOPLASM** includes everything between the cell membrane and the nucleus. It contains various kinds of cell structures and is the site of most cell activity. The cytoplasm is similar to the factory floor where most of the products are assembled, finished, and shipped.

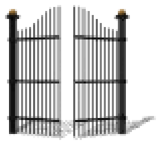


Cytoplasm is the gelatin-like material that is found inside the cell membrane.

Why is it so important for the cell to be a busy factory? Remember how the second law of thermodynamics states that all things tend to be moving toward a state of disorder? Life, and the cell in particular, beats these odds by continuing to take in "ordered" supplies. It creates more ordered products from raw supplies. It also replaces old and degraded supplies. A cell accomplishes all these tasks by utilizing energy converted from the Sun.

The cell "factory" on this tour contains many interesting departments, all of which are directly or indirectly powered by solar energy. Without energy from the Sun, no life could exist.

4b. The Plasma Membrane



Cell membranes are like gates.

What if you needed to find a job in the factory? What could you do? If you do not have any manufacturing skills, and you are not management material, you would probably be placed in an entry-level position.

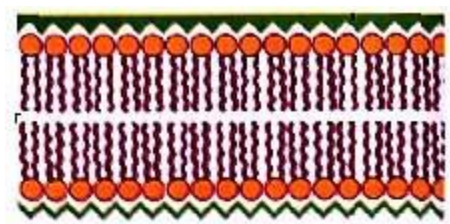
Perhaps you'd be assigned to the warehouse. Here, you would be responsible for shipping and receiving. A factory requires a constant supply of raw materials, as well as a way to send out the finished product. This department is usually located along an outside wall of the factory. Working here, you would be one of the factory's contacts with the outside world.

You might take a job as a receptionist and sit at a desk near the front door of the factory. A phone would allow you to contact anyone else in the building. Also, all incoming and outgoing calls would go through you. As a receptionist, you may speak for the factory and allow it to communicate with the outside messengers.

Maybe you wouldn't want to lift heavy crates in the warehouse or answer phones . Another possibility might be to take a job with the security department. Security personnel are posted at every entrance to the building. You would be responsible for checking ID cards and admitting only those individuals who belong in the factory.

Mail, reception, and security are separate departments in a real factory. But in a cell, these jobs are all performed by the plasma membrane.

Plasma Membrane Structure

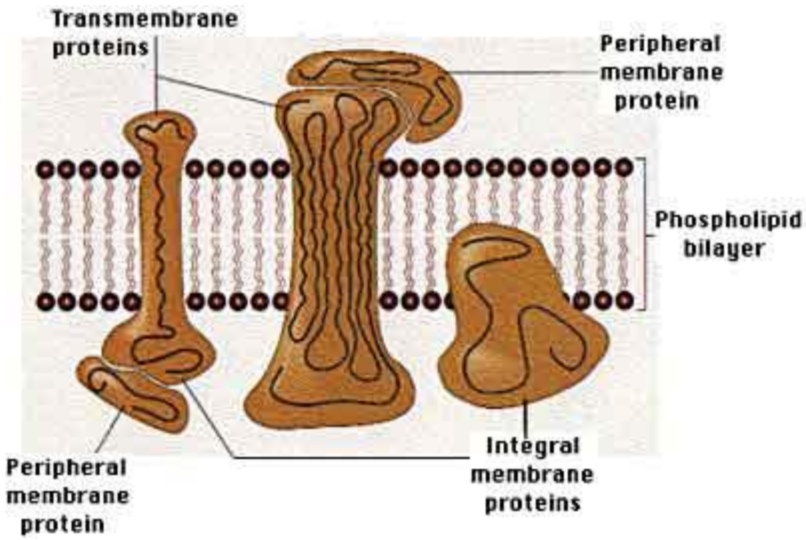


Plasma membrane phospholipid bilayer

The plasma membrane consists of a combination of phospholipids and proteins. These proteins are not fixed in any rigid pattern. Instead they float around in the membrane. This is called the **FLUID MOSAIC MODEL** of the cell membrane. The key to understanding the function of the cell membrane lies in the understanding of these specialized parts.

Phospholipids have a hydrophilic end that is attracted to water and a hydrophobic end that repels water. When mixed with water, phospholipids line up in double layered spheres. These structures are stable and accommodate the needs of both the hydrophilic and the hydrophobic ends of the molecule. The hydrophilic ends are in contact with water, while the hydrophobic ends face each other and do not touch the water.

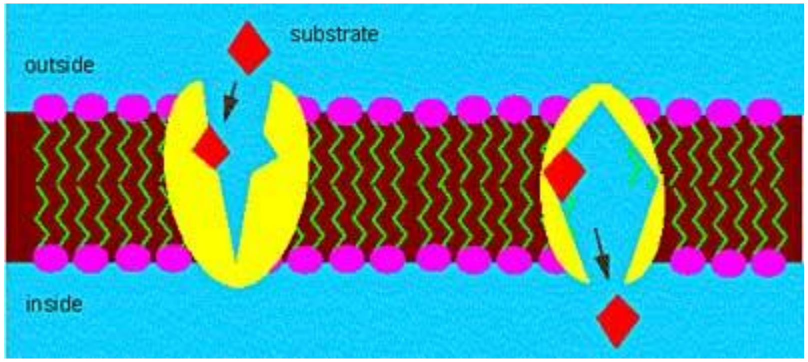
Membrane Proteins



Integral and peripheral membrane proteins

Floating in the phospholipid bilayer are many types of proteins. **PERIPHERAL PROTEINS** lie on the surface of the membrane. Other proteins, called **INTEGRAL PROTEINS**, extend into and sometimes completely through the membrane. Generally, integral proteins fit into three categories: marker proteins, transport proteins, and receptor proteins.

MARKER PROTEINS are like nametags that identify the cell to other cells. Each organism has its own unique marker proteins on its membranes. One of the functions of marker proteins is to enable a person's immune system to distinguish its cells from those of invading cells.



Active transport requires the use of energy.

TRANSPORT PROTEINS are materials in allow pumps that process

responsible for shipping and receiving. They move and out of the cell. Some of them function as pores that substances to diffuse through the membrane. Others act as use energy to pull molecules across the membrane, a called as **ACTIVE TRANSPORT**.

RECEPTOR PROTEINS extend through the cell membrane. As the communication office of the cell, they allow the cell to interact with other cells. The part of the receptor protein on the exterior of the cell surface binds to a molecule. This causes the portion of the protein on the inside of the cell to change shape, triggering a reaction within the cell. The specificity of receptor proteins allow the cell to respond to the outside environment in many different ways.

These three classes of proteins are the real workers of the plasma membrane. They allow the membrane to be a dynamic structure that allows materials to be transported and messages to be communicated to the cell.

So it is evident that proteins do much of the work in a cell. But who makes the decisions?

4c. The Nucleus

Electron micrograph of the nucleus.

In a factory, the chief executive officer controls everything that happens. What would it be like to have this job in a cell factory?

You would have your own office (which would be nice) but you would also have many responsibilities. You would need to keep track of all the blueprints kept in your office. And you would tell the workers which products to build and when to build them.

The cell factory contains a large inventory of blueprints dating all the way to its founding. Some of these blueprints are out of date, and some are for parts and products that are no longer made. Part of your job would entail sorting through everything, finding the correct blueprints, copying them, and sending the copies out to the assembly line at the correct time.

When the factory gets too large, it is difficult to run properly; thus, another factory must be built. To prepare for this, you have to provide the new factory with its own set of all the blueprints.

Sounds a bit daunting? Now you may have a better appreciation for what the nucleus does in the cell.

Nuclear Function

The **NUCLEUS**, often referred to as the headquarters of the cell, controls all cell activity by regulating what proteins are made. It is a large **ORGANELLE** that is easily seen with a light microscope. The nuclear membrane contains the blueprints of the cell. The information for the manufacture of proteins is encoded in a series of bases along the DNA found in the nucleus.

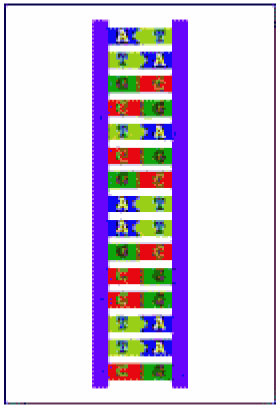
All cells contain much more DNA than they actually use. A small percentage of this DNA is active, and the rest of it is outdated (or nonsense DNA) that the organism no longer uses. As a species evolves over time, mutations change the DNA. Just as outdated blueprints in a factory are kept on file, outdated genetic information is never thrown out. The entire evolutionary history of an organism is written in its DNA. The processes of transcription and translation (which will be discussed in more detail later) allow the cell to decode this information to construct proteins.

When a cell has grown to a certain size it becomes less efficient. To increase its productivity, the cell divides into two new cells in a process called mitosis. The mother cell must have two copies of its DNA to pass on to the daughter cells that are created. This ensures that every new cell has a correct and complete set of DNA blueprints.

Nucleus Structure

The nucleus is composed of a nuclear membrane and nucleoplasm. The **NUCLEAR MEMBRANE** is a double membrane that contains the nucleoplasm. The **NUCLEOPLASM** contains **CHROMATIN**, a combination of DNA and proteins. Within the nucleoplasm, the **NUCLEOLUS** manufactures **RIBOSOMES**, structures in which proteins are assembled.

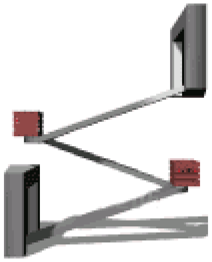
But where does protein production occur?



DNA transcription into mRNA (or "messenger RNA", a form of RNA) occurs in the nucleus.

4d. The Ribosomes and the ER

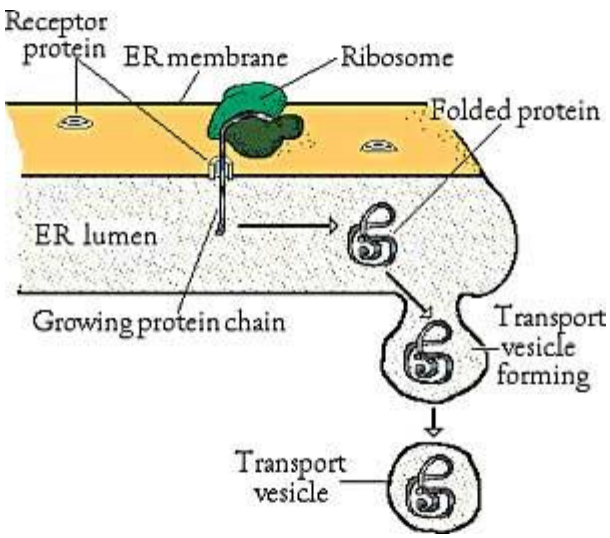
The Cytoplasm: The Factory Floor



The endoplasmic reticulum is like a factory conveyor belt.

The real work of the cell occurs in the cytoplasm, the cell's "factory floor." The term "cytoplasm" refers to everything between the cell membrane and the nuclear membrane. It consists mostly of water, salts, some proteins, and many small structures called organelles (or little organs).

These structures perform several different functions for the cell which generally fall under the categories of production, maintenance, and energy transformation. This tour of the cell includes several stops on the "factory floor." Let's start with the production team.



The steps involved in building a protein.

The Endoplasmic Reticulum

In a factory, the assembly of parts takes place on the factory floor. The highly skilled craftspeople who assemble these components sit hour after hour at their stations, plugging away at their work. These workers are highly compensated because they can read plans and use that information to make different kinds of products. Each one of them has his or her own work platform, surrounded by tools. These workers do not create the product designs; rather, they read the plans sent from the executive department.
The cell has its own assembly line and workers. Within the cytoplasm is a series of large, flattened membranes that fold back and forth on each other and have a very large surface area. This collection of membranes is called the **ENDOPLASMIC RETICULUM**, or **ER**.

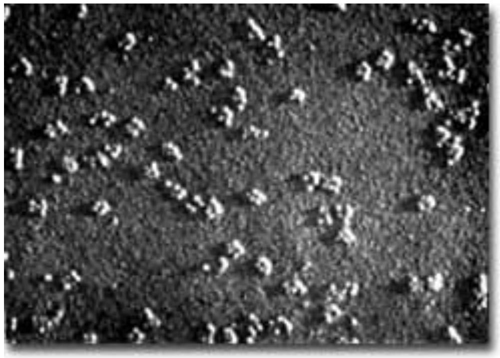
The smooth ER helps transport materials within the cell.

The ER stretches from the nuclear membrane to the plasma membrane. It serves as a pathway through the cytoplasm, as a support structure for the attachment of other organelles, and as a workstation for the ribosomes. The ER can be divided into two parts: the rough ER and the smooth ER.

The rough ER has ribosomes attached to it and provides a surface along which the process of protein assembly can occur. The smooth ER does not have ribosomes and is much more tubular in appearance. In some human cells, the smooth ER produces steroids; in others it regulates calcium levels. In a process that scientists still don't understand, the rough ER manufactures the membranes of the smooth ER.

The Ribosomes

Ribosomes, the workers that build proteins, are manufactured by the nucleolus. They consist of two separate subunits: a large, lower subunit and a small, upper subunit. Ribosomes attach to the rough ER . Now let's take a look at how final processing occurs.



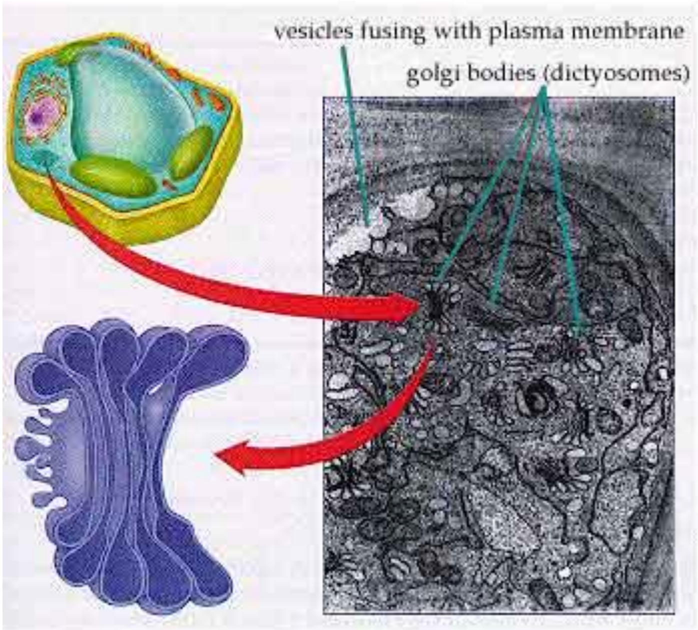
Ribosomes manufacture proteins.

4e. The Golgi Apparatus

What happens to all the products that are built on the assembly line of a factory? The final touches are put on them in the finishing and packing department.

Workers in this part of the plant are responsible for making minor adjustments to the finished products. They inspect the products for flaws, clean them of any extra material added during their manufacture, wrap them, and target them for packing. The Golgi apparatus performs all these tasks in the cell.

Golgi Apparatus Structure



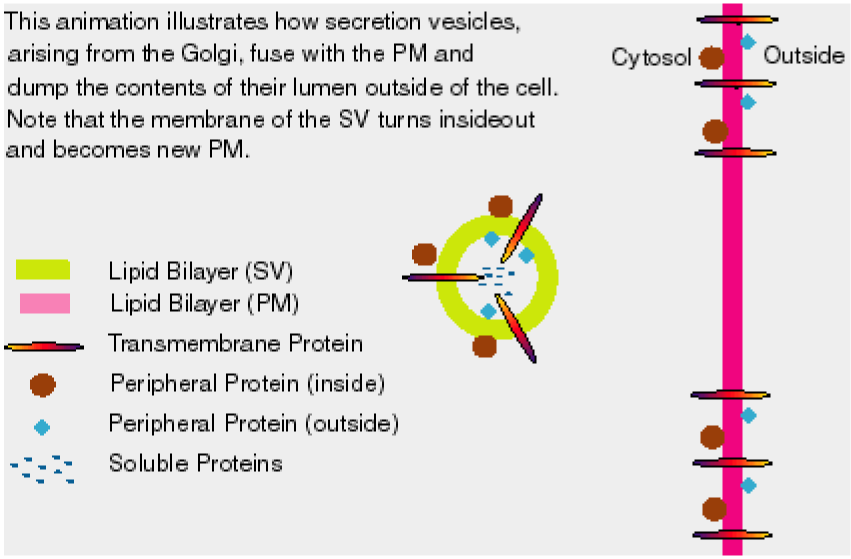
The Golgi apparatus receives ER proteins and modifies them prior to shipping.

After leaving the production site of the ER, most products are transported to the Golgi apparatus. The **GOLGI APPARATUS** consists of several flattened saclike membranes. These sacs sit one on top of the other like a stack of pancakes, and all of the sacs are interconnected. The smooth ER manufactures the Golgi apparatus by pinching off parts of itself. These bits of membrane add themselves to the Golgi apparatus.

Golgi Apparatus Function

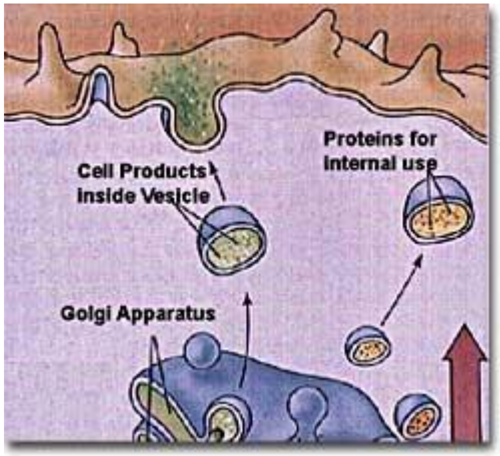
The Golgi apparatus is analogous to the finishing and packing room in a factory. Once the ribosome finishes manufacturing a protein in the rough ER, the protein needs to be prepared for use or export. Special enzymes will trim off any extra amino acids, and then the unfinished protein moves through channels in the smooth ER.

Eventually, some of the smooth ER membrane is pinched off as a **SPHERICAL VESICLE**. The proteins are either contained inside these structures or are carried on their surfaces. These vesicles are absorbed by the Golgi apparatus, and proteins are processed as they pass from one sac to the next. As the proteins move they are processed. When the protein is ready for export, it is pinched off of the Golgi and released into the cytoplasm.



Animation of exocytosis

What becomes of the final product of protein synthesis once it enters the cytoplasm? Some of these proteins eventually become membrane proteins and help with the functions of transport or self-recognition. These proteins are carried on the outside of the spherical vesicles and transported to the plasma membrane. Some of these proteins are retained within the cytoplasm for use by the cell.



Proteins are received by the cis face of the Golgi and exit through the trans face after modification.

Other proteins are stored inside the vesicles until they are needed for export. Hormones and enzymes are stored in this fashion until released though the plasma membrane in a process known as exocytosis. **EXOCYTOSIS**, a type of active transport, occurs when a vesicle inside a cell fuses with the cell's membrane and releases its contents to the outside environment.

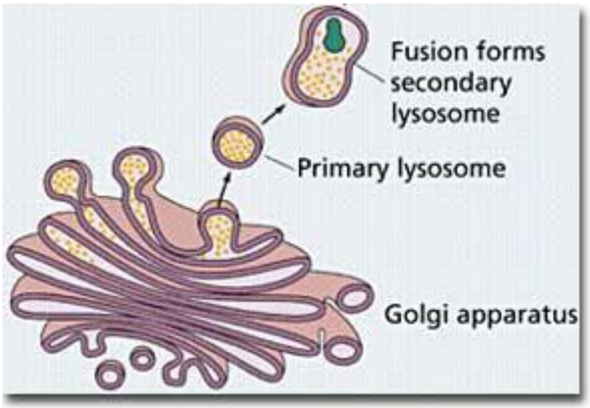
All of this production leaves behind quite a mess! Who cleans up the trash?

4f. Lysosomes and The Cytoskeleton

Any factory needs a good maintenance crew to keep everything orderly, to get rid of the trash, and to dismantle and dispose of outmoded machinery. The maintenance crew also functions as a second line of defense. If someone gets past the security guard at the front door, it is usually the maintenance crew who catches the trespassers and chases them out. In a cell, the role of building maintenance crew is filled by the lysosomes.

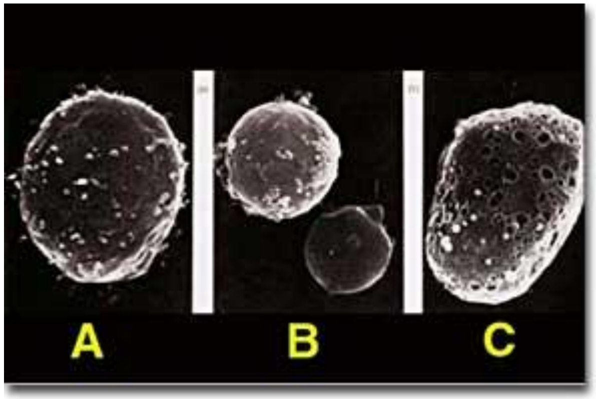
Lysosomes

The word "lysosome" is Latin for "kill body." This is a very colorful description for some of the most unusual organelles in the cell. **LYSOSOMES** are organelles produced by the Golgi apparatus that contain powerful protein digesting enzymes.



Production of lysosome by Golgi apparatus

Lysosomes are responsible for the breakdown and absorption of materials taken in by the cell. Often, a cell engulfs a foreign substance through **ENDOCYTOSIS**, another form of active transport. During endocytosis, the cell membrane puckers up, forms a pouch around materials outside the cell, and pinches off to become a vesicle. If the contents need to be destroyed, lysosomes combine with the vesicle and release their enzymes.



Autolysis: A. Cellular swelling B. Normal cells C. Swelling and rupture (notice holes on membrane) AD

When a white blood cell engulfs a bacterium, it is the lysosomes that digest the bacteria. Lysosomes are sometimes called "suicide sacks" because they are responsible for **AUTOLYSIS**, a process in which a cell self-destructs. Autolysis, incidentally, is Greek for "self kill." How does this happen? When a lysosome ruptures in a cell, it causes all of the cell's internal proteins to be digested. This action is not accidental; rather, it is regulated by signals that scientists do not fully understand. Autolysis allows an organism to eliminate worn-out cells.

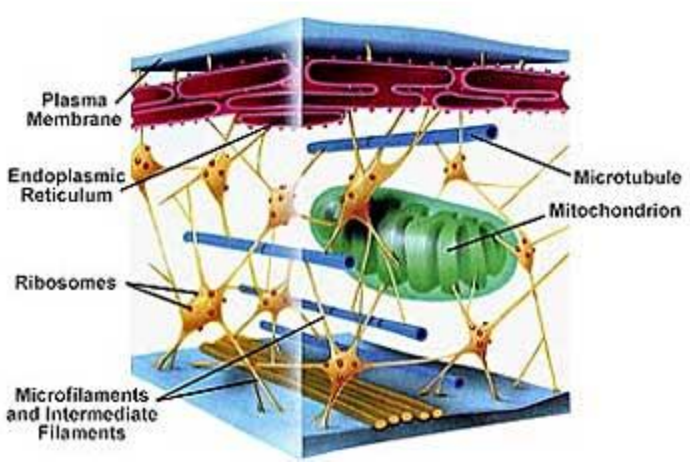
Maintenance crews do not get the glory of chief executive officers, or even that of the production worker, but they serve a very important purpose.

Without lysosomes, the cell would accumulate too much junk and would not be able to function for very long.

Support Beams

There is another major department in a cell factory, although it usually isn't given a department name in a regular factory. It's the walls, floors, and ceilings of a factory.

Within the cytoplasm of the cell are many protein fibers that act as support structures. These protein fibers, called **MICROFIBERS** are composed of a specialized protein called **ACTIN**.

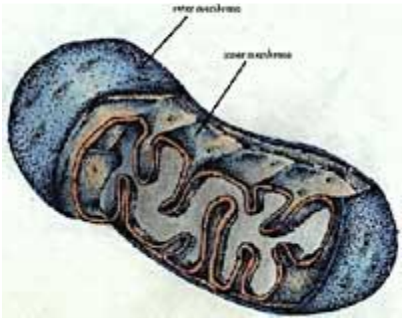


The cytoskeleton supports the cell.

Actin has the ability to link together to form fibers quickly. These fibers make up an invisible support structure inside the cytoplasm called the cytoskeleton. The **CYTOSKELETON** maintains the cell's shape and can be used to move the cell membrane. Thicker protein structures, called **MICROTUBULES**, are composed of several microfibers and allow movement within the cytoplasm.

Now, let's take a look at where a cell gets the energy it needs to survive and function.

4g. Mitochondria and Chloroplasts



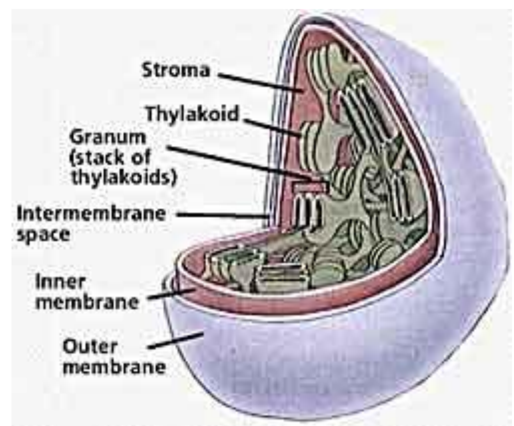
Mitochondria with inner and outer membranes shown

Any factory needs some sort of energy source. This energy must be in a usable form. Most factories have power plants in which generators burn fuel to produce heat. This heat energy is used to make steam, which is then used to make electricity.

Building proteins is the main function of cells. But for this to occur, a cell must have an energy source, and that energy must be in a form that the cell can use. The mitochondrion and the chloroplast are the two organelles responsible for energy *transformation* (neither organelle truly produces energy).

Like our factory's power plant, mitochondria and chloroplasts transform one form of energy to another. Remember that nearly all the energy used by living things on Earth comes from the Sun. This section discusses how energy is made available for cell processes.

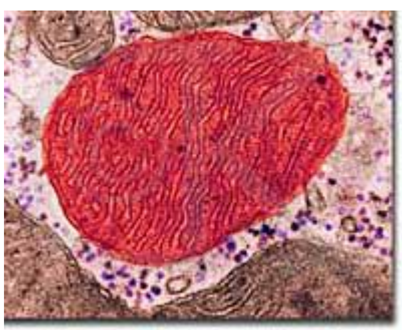
The Chloroplast



The parts of the chloroplast

Energy enters the food chain through the chloroplasts. Chloroplasts don't exist in animal cells; they are present only in plants and some protists. **CHLOROPLASTS** trap light energy and convert it into the chemical bond energy of sugar. Living things use sugars as their primary energy source. The chloroplast has an outer membrane and an inner membrane. Within the chloroplast is a cavity called the **STROMA** where a third set of membranes is located. These innermost membranes, called **THYLAKOIDS**, are arranged in stacks called **GRANA**. Most of photosynthesis occurs along the thylakoid membranes with the help of the pigment **CHLOROPHYLL**.

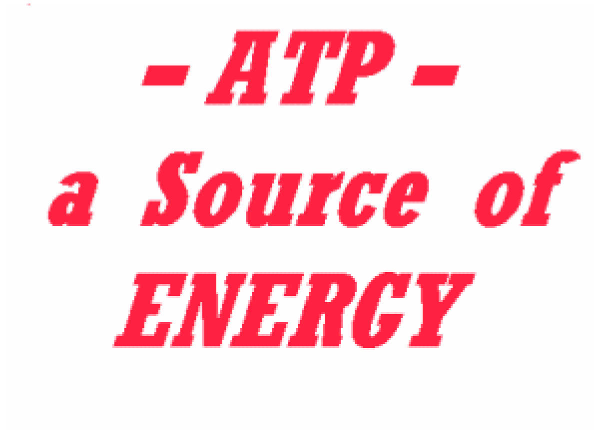
The Mitochondrion



Muscle cell mitochondria

Once energy is trapped in the form of sugar by photosynthesis, it must be converted into a form that the cell can easily use. Sugars are rich in energy, but the energy in their chemical bonds can't be released easily enough to be used in cell processes. Remember that the energy source cells use is a chemical called adenosine triphosphate (ATP).

Respiration releases the energy that was trapped by photosynthesis and converts it into the easily accessible, high-energy phosphate bonds of ATP. *All* living things (including plants) must respire to produce ATP. Eukaryotic cells have a special organelle called the mitochondrion that makes this process more efficient. The **MITOCHONDRION**, like the chloroplast, is a double membrane structure. The outer membrane of the mitochondrion is smooth, and the inner membrane is ruffled. The essential energy-releasing reactions of aerobic respiration takes place along these membranes.



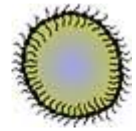
A chemical reaction involving ATP creates energy for the cell.

Origins

The mitochondrion and the chloroplast both have a number of unusual features that distinguish them from other organelles: they contain their own DNA that loops around like that of bacteria, they manufacture many of their own proteins, and they both reproduce by binary fission. This is very similar to what bacteria do. The similarity has led many scientists to conclude that these organelles may have evolved from independent bacteria that took up residence in early eukaryotic cells billions of years ago. These bacteria eventually became so dependent on their hosts, and vice versa, that they have essentially become one organism.

4h. Specialized Structures and Cells

With the exception of chloroplasts, all of the parts of the cell examined so far can be found in all cells. But now, as the discussion turns to more specialized **ORGANELLES**, the factory analogy will no longer apply. As cells become more specialized, they may contain organelles that are not common to all cells. Since they are not common to all cells, they are not necessary for all factories. Below are some cell structures that are *not* common to all cells.

				
Plastid	**Cell Wall**	**Vacuole**	**Centriole**	**Ciliate**
o Found in plants Stores food or pigments	o Found in plants o Supports and protects the cell	o Found in plants and some protists o Stores enzymes and waste products	o Found in animal cells and some protists o Protein fibers that aid in cell division	o Usually found in protists o Hair-like microtubules attached to the plasma membrane that often help in movement

Specialized Cells

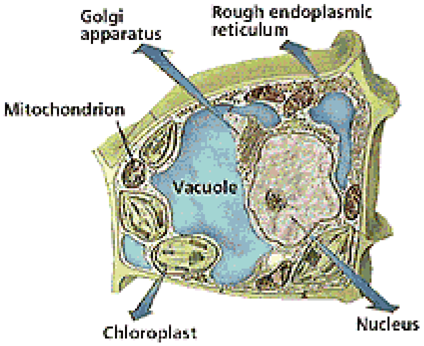
Cell specialization in blood: red blood cells, platelets (yellow) and T lymphocytes (green)

The discussion so far has been about typical cells, but most cells are anything but typical. The design and shape of a cell is very much dictated by its function and the conditions under which it works. Unicellular organisms tend to have fairly complex cells, which makes sense considering that these organisms must depend on only one cell to do everything.

Multicellular organisms exhibit much greater specialization. **RED BLOOD CELLS**, for instance, have disklike flattened membranes. This shape gives them a maximum amount of surface area while still remaining smooth enough to slide through the smallest capillaries. Because red blood cells are manufactured for limited-time use, they have lost nearly all of their internal organelles, including nuclei.

NERVE CELLS are responsible for the rapid conduction of messages throughout the body. Consequently, they are very long and have branches that enable them to connect to other nerve cells.

GLAND CELLS, like the cells found in the pancreas, are filled with Golgi apparati. And muscle cells, which must generate large amounts of force, have huge mitochondria and many microfibers.



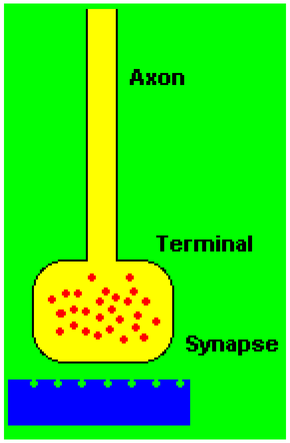
Plant cell showing Golgi apparatus, vacuole and chloroplast (a plastid)

Nerve cells, or neurons, have many long branches to deliver messages quickly.

CELL SPECIALIZATION occurs because many forms of life have many levels of organization. In most plants, animals, and fungi, cells are organized into different types of tissues. **TISSUES** are groups of cells that carry out a common function.

Because cells in tissues perform specific functions, they often contain organelles that are different from the ones found in a "typical" cell. That's why the factory analogy breaks down as cells become more specialized. Not all cells have to perform all of the functions of a factory if they are found in specialized tissues or organ systems.

4i. Cell-to-Cell Communication



Nerve cells send chemical signals to other cells.

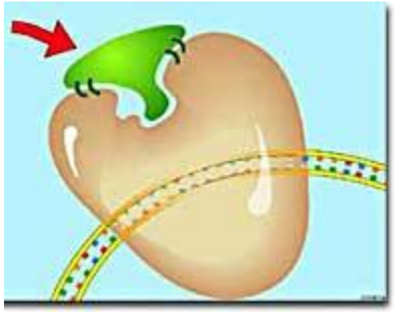
Imagine sitting in your room quietly doing your homework. Unexpectedly, the cat knocks a lamp to the floor. You are surprised; you leap to your feet. Your heart is pounding, and you are breathing hard. What caused this reaction in you? How can something you hear cause your heart to race?

The individual cells in a multicellular organism must be able to communicate with each other. Structures in the human ear convert sound waves into a nerve impulse; nerve cells then transmit those impulses from one cell to the next. When it reaches the brain, the nerve impulse sends a message to the adrenal gland to release the hormone adrenalin. This hormone travels through the blood and causes a person's heart to beat faster. Nerve impulses and hormones are different kinds of intercellular communication, each of which depends on the receptor molecules found on the membranes of cells.

Cells have receptor proteins on their membranes. These proteins extend across the lipid bilayer so that part of the molecule lies both inside and outside the cell. The portion of the molecule on the exterior of the cell has a unique shape that allows it to bind only to certain special molecules, in the same way a key fits a lock. In a nerve cell, the "key" is called a **NEUROTRANSMITTER.** In other kinds of cells, the "key" is called a **HORMONE.** When the correct signal protein links to the lock, it causes the part of the protein inside the cell to change shape. This change activates a signal inside the cell and generates a response from it.

This ability to communicate between cells is crucial to large multicellular organisms because it allows organisms to coordinate the activity of all their cells. Here concludes this tour of a cell. Stops along the way have included a large number of structures and functions of the cell. Remember that the cell is an incredibly complex unit of life. Why?

It needs to carry out all the functions of life. It must have many levels of organization, utilize energy, maintain stable internal conditions, grow, reproduce, and respond to its environment. This is achieved as many types of molecules (mostly proteins) enter the cell, communicate with it, leave the cell, and are processed by the cell. There's no doubt about it: cells are actually far more complicated than factories.


Lock and key model of cell communication

Soon, we'll take a closer look at some of the functions of a cell and investigate how plant cells transform energy, how all cells utilize cellular energy, and how cells grow and divide. Then, we'll examine the contents of the nucleus of the cell in great detail and see why DNA is such a powerful molecule.

Today, breakthroughs in genetic research occur every week. Some are a source of great controversy; others are a source of great hope. None of them would be possible without an understanding of cell theory.