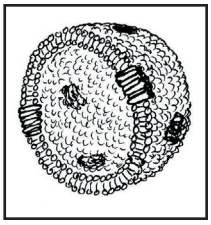
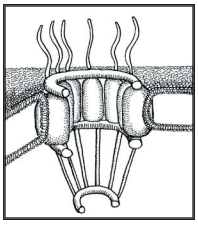
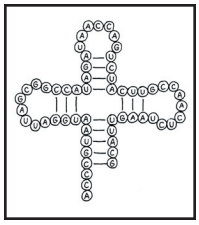
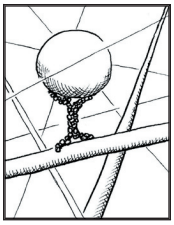
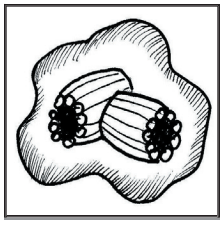
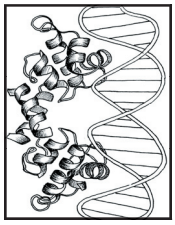
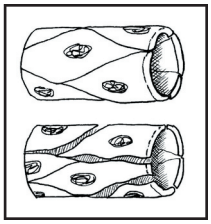
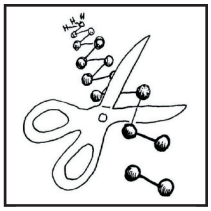
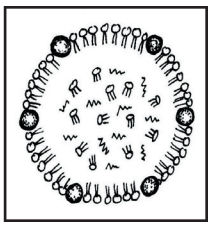







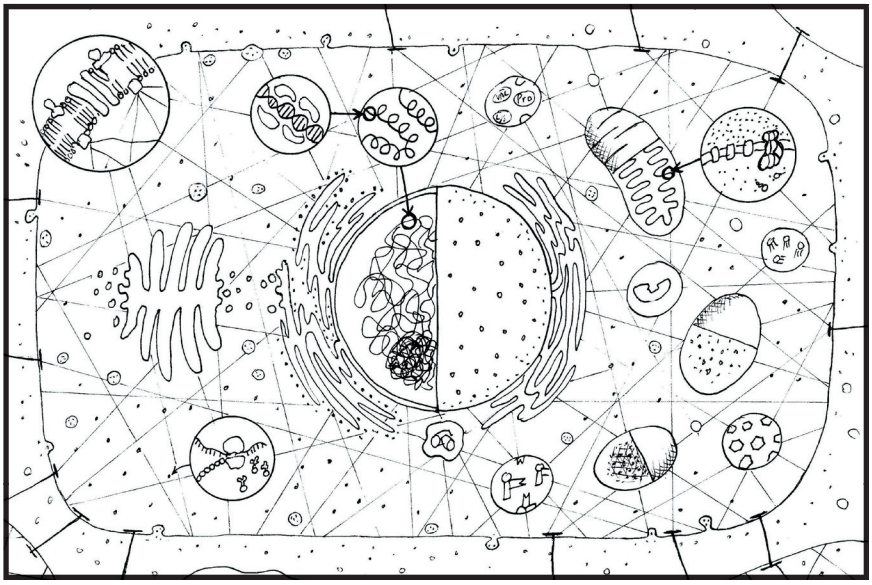




CELLS

An introduction to the anatomy and physiology of animal cells

Anatomy means “what the parts are”
Physiology means “how they work”

by Ellen J. McHenry



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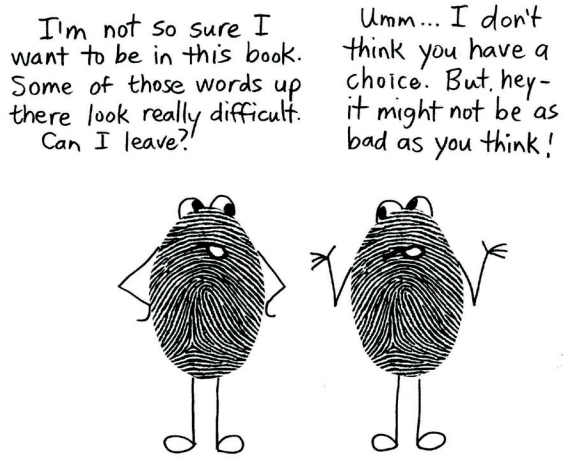
NOTE ABOUT INTERNET LINKS: For your convenience, all the video links in this booklet have been posted as a YouTube playlist on Ellen McHenry's YouTube channel. This means you don't have to be bothered with annoying comments or distracting sidebars. Your parents and teachers can be assured that you're in a "safe zone" on the Internet.

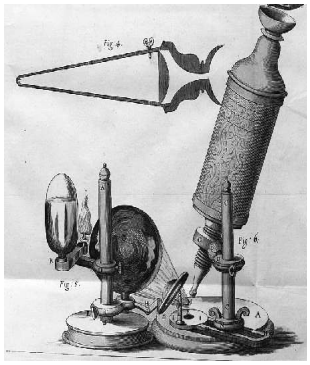
YouTube.com/eejm63



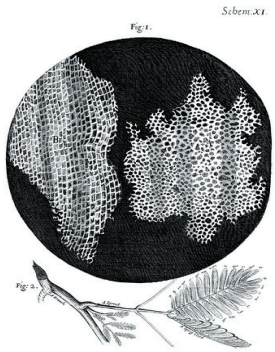
CHAPTER 1: HOW DID WE FIND OUT ABOUT CELLS?

There was a time in the not-too-distant past when not a single person on earth knew that cells existed. Galileo, who used lenses to view distant planets, knew nothing of cells. It was in the decades following Galileo (the late 1600s) that someone figured out how to use lenses to make very small things visible. Two lenses were used, one at each end of a tube, forming a ***compound microscope***.

Englishman Robert Hooke was perhaps the first to observe cells. One day he sliced an extremely thin piece of cork and put it under his microscope. What did he see? Rows and rows of little box-like shapes that reminded him of the tiny rooms, or ***cells***, in monasteries (where monks lived). Today we don't use the word "cell" very much when referring to a room, except when we talk about prison cells. But in Hooke's day the word "cell" was commonly used for a small room, so it was natural for him to use the word "cell" to describe these little compartments he saw in the cork. He didn't really know what these cells were made of or how they functioned, but the name he gave them has been used ever since.



Hooke's compound scope



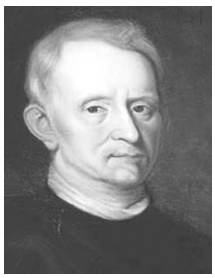
The famous cork cells

Hooke eventually wrote a book called Micrographia telling about his amazing microscopic discoveries. He drew pictures of cells, parts of insects, hairs, specks of dirt and many other things that fascinated him. He discovered that no matter how sharp he made the point of a needle, the end of it still looked dull when viewed under his microscope! The only objects that still looked sharp when viewed under magnification were the tiny claws on the ends of insects' legs and the almost invisible "hairs" he found on the stems and leaves of plants.

A fly's foot

Hooke was a brilliant man. He was also a surveyor, an architect, an astronomer and a physicist. He was working on the principles of motion and gravity at the same time that Isaac Newton was. He didn't really want to go down in history as the man who named cells. He would rather have been known for one of his other achievements: figuring out the laws of gravity and motion, or helping to re-design London after the fire of 1666, or proposing the the wave theory of light. But as history would have it, most people know him as the man who gave us the word "cell."

Hooke in a wig

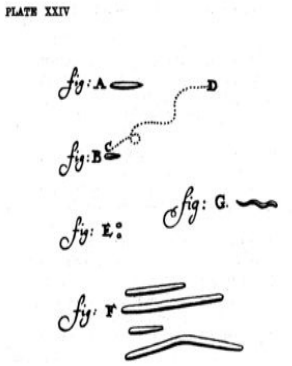


Hooke without his wig

Antoni van Leeuwenhoek of Delft

Following after Hooke came Antoni van Leeuwenhoek *(LAY-ven-hook)*, who lived his whole life in the Dutch town of Delft. He bought a copy of Hooke's Micrographia while on a trip to England in 1665 (the only time in his life that he left Holland), and soon afterward began making single-lens microscopes the likes of which have never been equaled. Leeuwenhoek perfected the art of making tiny lenses, but was careful to keep his technique a secret. He never wrote down his method, so we can only guess what he did. Modern glass making experts are fairly sure that Leeuwenhoek probably heated a glass rod and stretched it until it was a thin string. Then he would take the very thin strand of glass and put it back into the flame and let the end melt until it formed a tiny round ball. This tiny round ball would be trimmed off and used as his lens. Other lens crafters of his day would spend hours grinding and polishing their lenses to get them into the right shape. Leeuwenhoek

Leeuwenhoek's microscopes were about the size of your hand.



Leeuwenhoek observed bacteria

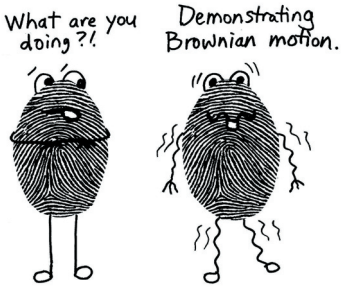
just took advantage of the natural physics of hot glass. He could make these tiny glass beads fairly quickly and easily; he managed to make over 500 of these little microscopes while keeping up with a full-time job as a cloth merchant. He mounted his lenses in silver panels and attached a screw mechanism on one side. With this simple magnifier, he was able to achieve magnification of at least 300 times larger than life size!

Leeuwenhoek was an incredibly patient person. He would sit for hours watching the specimens he had mounted on his microscope. He watched long enough to be able to observe the behavior and life cycles of microorganisms. He observed the microscopic food chain and knew what each little "animalcule" would eat. He saw eggs hatch. He saw blood cells circulate inside tiny circulatory systems. He observed sperm cells swimming. Once he kept a colony of fleas in a pouch inside his sock (to keep their eggs warm) and every hour or so he would check on them to see what changes had occurred. He spent several decades reporting all his findings to the Royal Society in London. At first, his descriptions of bizarre invisible creatures were almost too much to believe. The Royal Society had to send some of their members to visit Leeuwenhoek to verify that what he was saying was true, and he wasn't just imagining his microscopic "zoo." The visitors from the Royal Society looked through the little microscopes and were amazed to see exactly what Leeuwenhoek had written about. From then on, Leeuwenhoek's reports were treated as valid science. Prominent scientists and politicians began visiting Leeuwenhoek. Peter the Great of Russia put Delft on his European travel itinerary so that he could see Leeuwenhoek's little "animalcules." Today, Leeuwenhoek is generally considered to be the father of modern microscopy.


The man in "The Geographer" by Verneer is probably Antoni van Leeuwenhoek.

In the early 1800s, a Scottish botanist named Robert Brown made the next advances in our understanding of cells. Brown didn't have to make his own microscopes; by this time there were technicians who specialized in making optical devices such as microscopes. Since Brown was a botanist, it was plant cells he observed. He noticed that inside every cell there was a dark blobby thing. He called this the ***nucleus*** but he didn't have a clue what it did. Today we know that the nucleus contains the cell's DNA.

In 1827, Brown made another important microscopic discovery. While observing pollen grains under his microscope, he noticed that tiny particles inside the pollen grains were vibrating. He wondered if these particles were alive, since they were inside a plant cell. He tried a similar experiment with dust particles and saw the dust particles moving in the same way. He knew the dust particles were not alive, so he concluded that the motion must be due to a law of physics, not biology. He was right. Molecules are in constant motion and often collide. It is these molecular collisions that cause tiny particles to look like they are moving. We call this motion ***Brownian motion***, after Robert Brown.

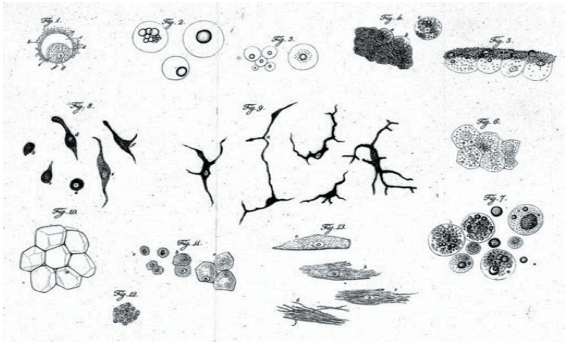


As an interesting historical side note, an ancient Greek named Lucretius was the first person to conceive of the idea of Brownian motion. In 60 B.C. he said something like this:

Observe the dust particles in sunbeams. You will see a multitude of tiny particles moving in a multitude of ways. Their motion is an indicator of underlying movements of matter that are hidden from our sight. It originates with the atoms which move of themselves. Their collisions set in motion slightly larger particles, and so the movement mounts up from the atoms and gradually emerges to the level of our senses, so that those particles we see in sunbeams are moved by blows that remain invisible.

In 1837, a German scientist named Theodor Schwann developed a theory that we now call "cell theory." Schwann came to realize that all living things are made up of cells that are very similar in basic structure. He also observed that cells only came from other cells. Cells could not come out of nowhere. This sounds obvious, but until Schwann's time many people still believed that living things could come from nowhere. They saw flies appear seemingly from nowhere when fruit or meat spoiled. No one knew that the flies had hatched from microscopic fly eggs.

Schwann had a friend named Matthias Schleiden who was also a botanist. Together, they figured out that the nucleus played some role in cell division. They also observed the cytoplasm (fluid) inside the cell and saw that the organelles inside the cells moved around. Schleiden is considered to be the co-founder of ***cell theory***, along with Schwann. Cell theory says that cells can only come from other cells---they can't just pop into existence from nothing or from inorganic materials. (Ironically, Schleiden also accepted the theory of evolution--a theory that seemed to contradict his own cell theory.)



Cells drawn by Theodor Schwann

By the late 1800s, many different types of cells had been observed. There were fairly accurate pictures of plant cells, animal cells, and free-living single-celled organisms. The big question now was how the cells worked inside. Scientists knew that cells had some little "organelles" inside of them, but no one really knew what they did. The most obvious organelles were the nucleus (present in all cells) and chloroplasts (found only in plant cells). The chloroplasts were easy to spot because they were green. Other little spots and dots could be seen floating around inside the cell, but even the highest power on the microscopes could not enlarge them enough so that they could be studied. Another problem was that some of the little organelles were almost transparent. How can you study something you can hardly see?

A major breakthrough came when cell scientists learned how to stain cells before putting them under the microscope. The most famous "stain scientist" was Hans Christian Gram from Denmark. His technique of staining bacteria cells is still used today and bears his name: ***the Gram stain***. This stain will be absorbed by some kinds of bacteria but not by others. This helps to identify what kind of bacteria you are working with. Other stain experts developed stains that would penetrate the nucleus or other organelles, making them highly visible so they could be studied more easily. Then an Austrian scientist named Camillo Golgi discovered how to use a silver compound to stain nerve cells. His stains brought to light many discoveries about nerve cells and how the nervous system works. Golgi's most famous discovery was another type of organelle found in almost all cells: the Golgi apparatus (or Golgi body).

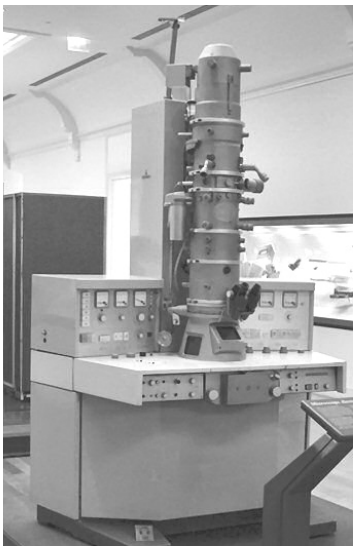
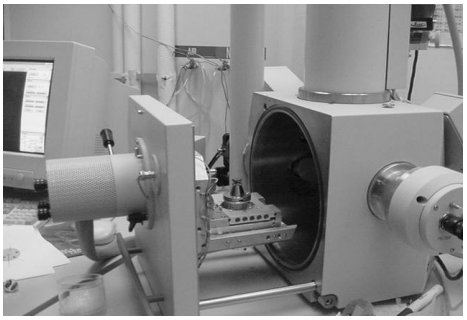


Photo credit: http://en.wikipedia.org/wiki/Scanning_electron_microscope

An electron microscope from the 1970s (now in a museum).

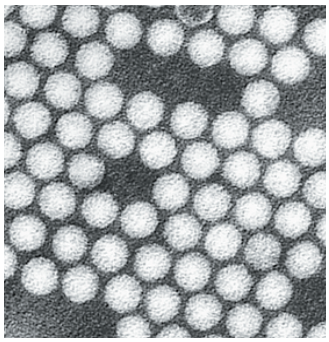
Then cell science "hit a wall," so to speak. Even the very best microscopes in the world could not magnify something beyond about 1000 times. Cell scientists knew that many mysteries of the cell would not be discovered until there was a way to achieve magnifications beyond 1000. Then, in the mid 1900s, a completely new type of microscope was invented: the ***electron microscope***.

Regular microscopes use light and lenses to make things look larger. Electron microscopes work on an entirely different principle; they use electrons instead of light. Electrons from a tungsten filament are "fired" at the sample being studied, and the electrons either go through it (in the case of transmission electron microscopes, or TEM) or they bounce off at various angles (in the case of scanning electron microscopes, or SEM). In both TEM and SEM, the electrons then hit a screen to form a visible image. Pictures from electron microscopes (which are known as ***micrographs***) are always in black and white. Color requires light, and electron microscopes don't use light. Colored micrographs are made by adding the color afterward. (They use computer programs to adjust the graphics, just like you might use a program like Photoshop®.)

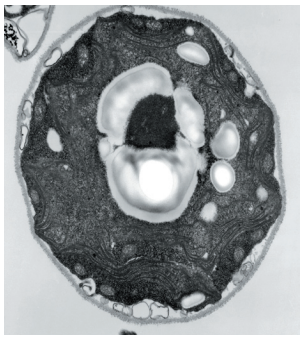


An SEM microscope opened up to show you the vacuum chamber where the sample goes

Modern electron microscopes can provide images that are up to 500,000 times larger than life. That's large enough to be able to see even the tiniest parts of the cell. However, electron microscopes have a big drawback. The samples being studied must be put into a vacuum chamber--no air, like outer space. Big problem for living cells. Basically, only dead specimens can be studied. Maybe really, really freshly dead specimens, but nothing alive and moving. Often you have to prepare the specimens by spraying them with an ultra-thin layer of gold or some other metal, so that means you can't sit and watch little critters moving around under an electron microscope like you can with a regular (compound) microscope. You can't watch as a cell eats or grows or divides. You only get one picture of a cell at one moment in its life. So cell scientists must collect lots and lots of still pictures, then use "detective skills" to draw conclusions based on comparing all the pictures. Sometimes scientists can think of a way to test their theories about cells by "tagging" particular molecules with radioactive or fluorescent dyes that will show up on the screen. In the next chapter, we'll read about a cell part that was discovered in this way.

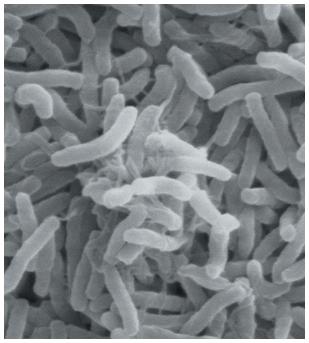


viruses

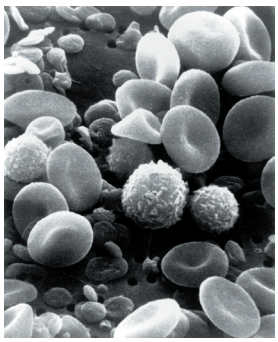


a single-celled organism

TEM images look flat



bacteria

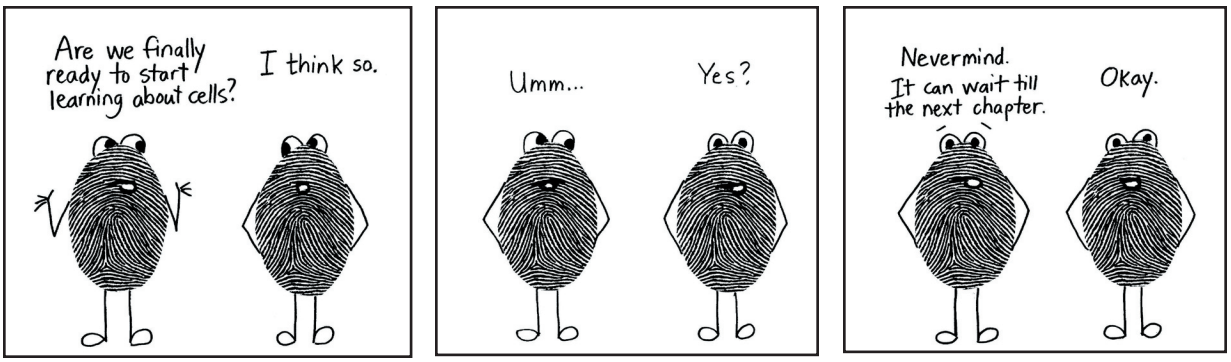


blood cells

SEM images look 3D

Images produced by TEM electron microscopes look flat. The electrons pass through the sample in much the same way that light passes through samples on a regular (compound) microscope. This type of image can be very good for studying the insides of cells. SEM electron microscopes produce 3D images. SEMs let you see textures and shapes. It takes both types of images to give us enough information to be able to understand what a cell is really like. Scientific illustrators try to create pictures that combine information gained from both types of images. Books about cells often contain many images made by scientific illustrators.

Electron microscopes are used for more than just biology. They can be used in the fields of material science (metals, crystals and ceramics), nanotechnology, chemistry, and forensics. They have become an essential tool for many branches of science.



Don't forget--all these videos are posted on YouTube.com/eejm63, on the "Cells" playlist.

ACTIVITY 1 Watch some informative-yet-entertaining videos about early cell scientists

Video showing Hooke, Leeuwenhoek, Schwann and Schleiden ("Cell Theory" on YouTube playlist)
http://www.youtube.com/watch?v=dscY_2QQbKU

About just Leeuwenhoek ("Microbiology Bytes" on YouTube playlist)
http://www.youtube.com/watch?v=Q2ezDdKyRUc

ACTIVITY 2 Watch some brief explanations of how electron microscopes work

TEM: Transmission Electron Microscope ("Structure and function of Electron Microscope" on playlist)
http://www.youtube.com/watch?v=fToTFjwUc5M

SEM: Scanning Electron Microscope ("Scanning Electron Microscope" on YouTube playlist)
http://www.youtube.com/watch?v=lrXMIghANbg

ACTIVITY 3 (Optional) A more in-depth video about electron microscopes

Do you really, really want to know exactly how an SEM microscope works? Here's a video "field trip" to the University of Washington's Nanotech User Facility. A fellow named Scott will give you almost an hour of instruction on how to operate an SEM. He'll show you step by step how to run his SEM machine. (If you love technical stuff, you'll think this is awesome. For the rest of you, you might want to watch just the first five minutes or so.)
http://www.youtube.com/watch?v=c7EVTnVHN-s ("SEM part 1 of 6")

ACTIVITY 4 Watch "Brownian motion"

This is what Brownian motion might look like under a microscope:
http://www.youtube.com/watch?v=s6EPQJfXpb4 ("brownian motion")
http://www.youtube.com/watch?v=2Vdjin734gE ("Brownian Motion")

This is a computer animation of the atomic motion that creates Brownian motion:
http://www.youtube.com/watch?v=6VdMp46ZIL8 ("Brownian Motion HD")

This shows Brownian motion inside a single-celled microscopic organism:
http://www.youtube.com/watch?v=znGTevIPKHE ("Brownian Motion inside diatom")

ACTIVITY 5 Look at some really neat electron microscope images

If you'd like to see some fascinating images of very small things, set your search engine to "images" and then use key words "TEM images" or "SEM images."

Can you remember what you read? If you can't think of the answer, go back and read that part of the chapter again until you find the answer.

1) The first person to ever see a cell was:
a) Galileo b) Hooke c) Lucretius d) Leeuwenhoek

2) Which one of these did Hooke NOT do?
a) develop theories about gravity and motion b) propose a wave theory of light
c) help to redesign London d) develop cell theory

3) About how many microscopes did Leeuwenhoek make?
a) less than 10 b) about 100 c) about 500 d) thousands

4) TRUE or FALSE? The Royal Society immediately made Leeuwenhoek a member, as soon as they read his descriptions of "animalcules."

5) What is Brownian motion?
a) a physical phenomenon caused by the constant motion of molecules
b) the movement of dust particles in air
c) a biological phenomenon found only in living things
d) the movement of cells under the microscope

6) TRUE or FALSE? Schwann and Schleiden proved that life could come from nonliving things.

7) TRUE or FALSE? By the late 1800s, scientists had seen many different types of cells.

8) TRUE or FALSE? One problem with looking at cells is that many of their parts are transparent.

9) Who is the most famous "stain" scientist?
a) Antoni Leeuwenhoek b) Theodor Schwann c) Camillo Golgi d) Hans Christian Gram

10) What is the maximum magnification you can get with most ordinary (compound) microscopes?
a) 100x b) 500x c) 1000x d) 100,000x

11) TRUE or FALSE? TEM images look 3D.

12) What type of metal is often used as the filament in the electron "gun" in electron microscopes?
a) platinum b) tungsten c) gold d) iron

13) TRUE or FALSE? Electron microscopes can let you watch a cell as it divides.

14) For electron microscopy, what do the specimens have to be in?
a) a vacuum b) suspended animation c) a frozen state d) high temperature environment

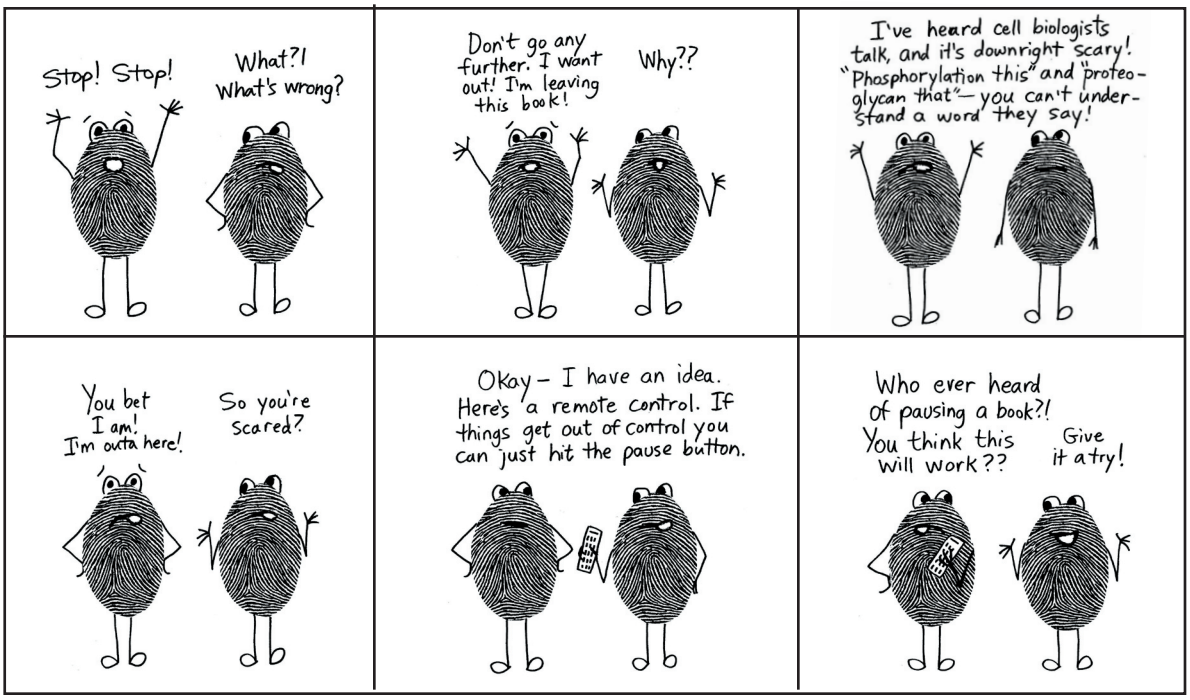
15) TRUE or FALSE? There is a special kind of electron microscopy that can show you both a flat image and a 3D image at the same time.

16) What does SEM stand for? _____ _____ _____

17) TRUE or FALSE? Electron microscopes are used exclusively for biology.

CHAPTER 2: THE CELL MEMBRANE and CYTOSKELETON

So now that we know a little bit about how cells were discovered, let's start learning about what cells are made of and how their insides work. We'll start with the outer surface, the ***plasma membrane***.

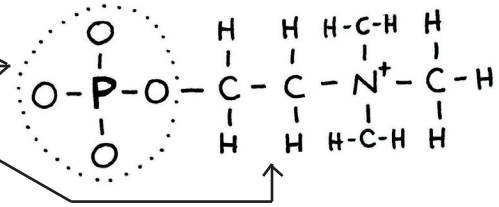


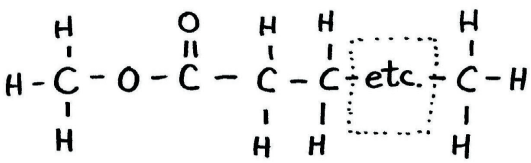
Okay, we're ready now?

Let's look at the outside of the cell first. The outer layer of a cell, the layer that separates the inside of the cell from the outside environment, is called the ***membrane***. In plant cells there is an extra layer outside the membrane--a thick outer coating made of tough ***cellulose***. We'll discuss cellulose later when we take a closer look at plant cells. In this chapter we're only going to talk about the membrane. The membrane is so thin that it would take 10,000 of them stacked on top of each other to be as thick as a sheet of paper. That's pretty thin. In fact, it's the ultimate in thin--it's only two molecules thick! The molecules that form a cell membrane are a particular type of molecule called a ***phospholipid***.

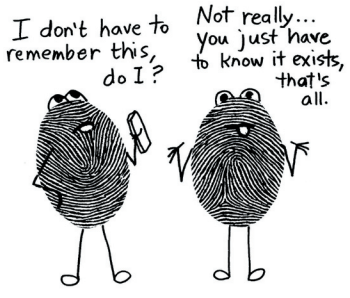
WAIT! DON'T PAUSE THE BOOK!

Let's look at this word and figure out what it means. The second part of the word, "lipid," basically means "fat." You know what fats are--those white streaks in your meat, the oil you use to fry your French fries, even the cream on top of fresh milk. Lipids are greasy and oily and don't mix with water. Now what about "phospho"? "Phospho" is short for "phosphate," which means some oxygen atoms attached to a phosphorus atom. You can see that there are also some carbons, hydrogens and a nitrogen off to the side. This second group has a separate name, but for the sake of simplicity, we are going to consider both of them together as the phosphate part of our phospholipid molecule. This clump of atoms stays together and functions as a group.



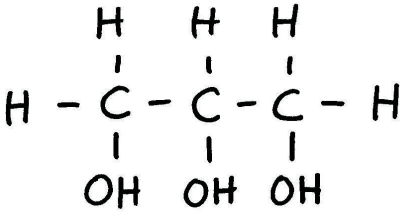


The lipid part of the molecule is made of two long chains of carbon and hydrogen atoms (with a few oxygens thrown in).



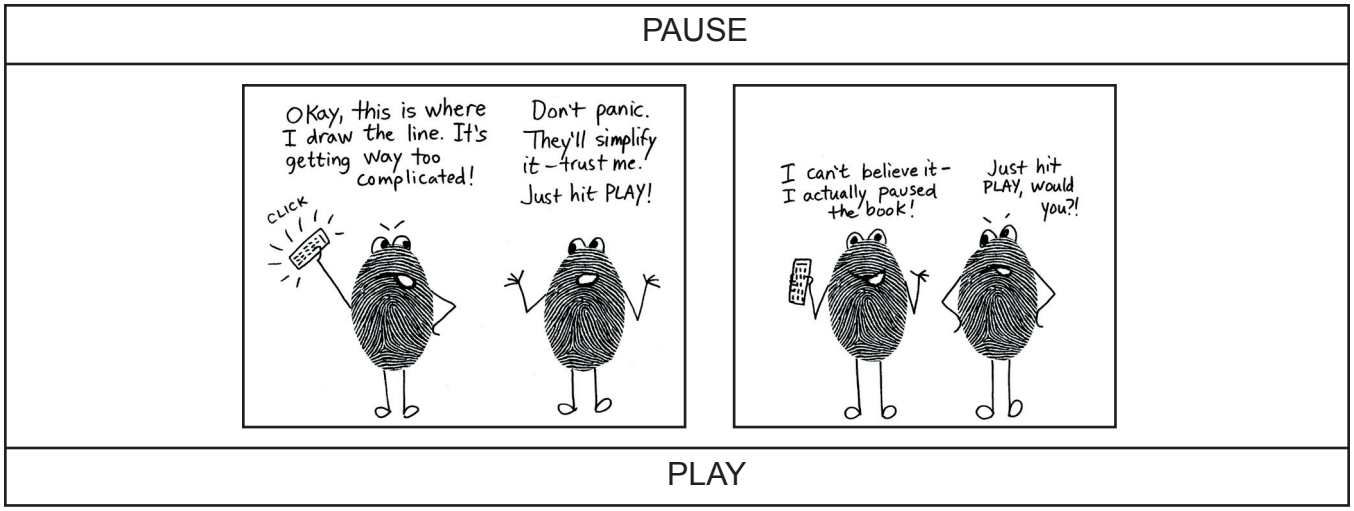
The most important difference between the phosphate and the lipid is their reaction to water molecules. Phosphates are said to love water. Yes, scientists really do use the term "love"-- but they say it in Greek, of course. They say "hydrophilic," which means "water-loving." The lipids are the opposite; they hate water. In fact, they have a phobia (fear) of water. Lipids are said to be "hydrophobic." So one wants to run away from water and the other loves it. (How could they ever vacation together?!) What holds them together?

A little clump of atoms called ***glycerol*** *(GLISS-er-ol)* holds them together. Glycerol looks very similar to the lipid, doesn't it? Just a bunch of carbons and hydrogens and oxygens. It's strange but true; everything in our bodies boils down to things that look like this. Like it or not, your body is nothing more than a really, really big clump of molecules! (But don't try that as an excuse--your parents won't buy it.)



Glycerol

Now, what would it look like if we connected all these molecules together and made a phospholipid?

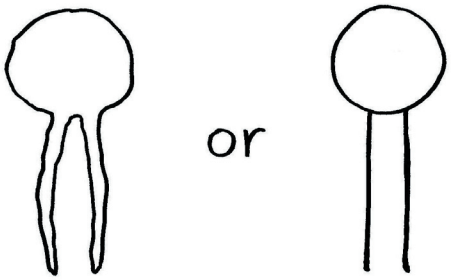


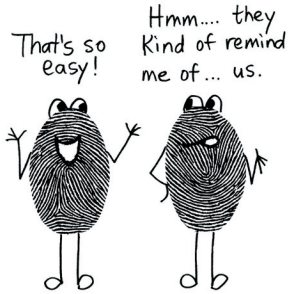
Don't worry, not even cell biologists want to draw the phospholipid molecule! So they draw a very simple picture that doesn't have any letters in it. (But they know that all the carbons and hydrogens and oxygens and phosphoruses are there.) This is the way they draw a phospholipid:

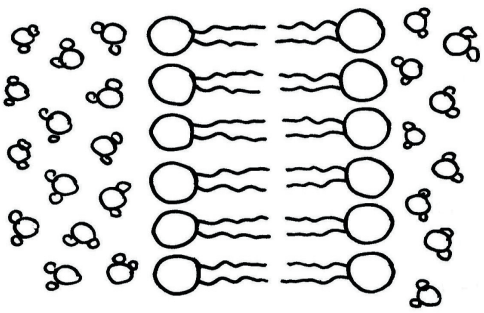
The round part at the top is the phosphate part. They call it the **HEAD**.

The **TAILS** on the bottom are the lipid chains.

They don't even bother to draw the glycerol connecting them.

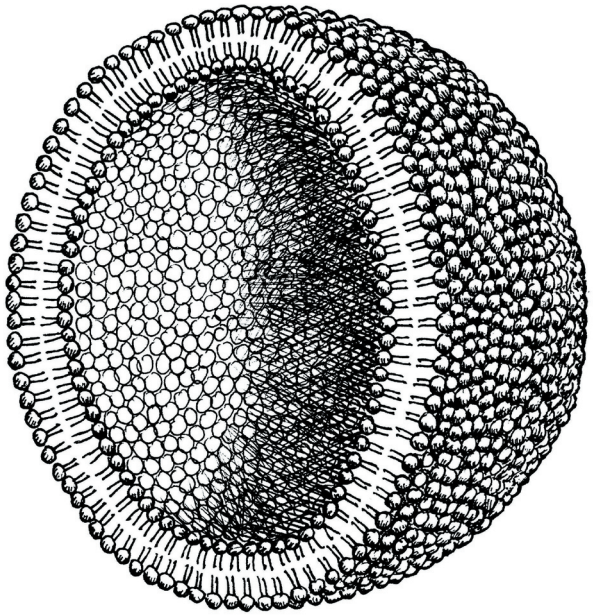






Now what happens when you throw a whole bunch of these phospholipid molecules into water? Well, the water-hating tails freak out. Then they have to find a way to cooperate so that not a single tail is in contact with the water. The molecules all line up so that the tails are facing each other (they like each other) and only the heads are in contact with the water. You can see that there are still small gaps between the phospholipid molecules, and water does sometimes sneak through. But the tails are generally pretty happy so it works out well.

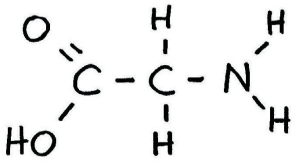
The picture on the previous page shows only a dozen phospholipid molecules and has only two dimensions. But real membranes are three-dimensional. So what would thousands of phospholipids look like in three dimensions? They'd form a ball with an inside layer and an outside layer. Here is a cut-away view of the ball, so you can peek inside.



Look at the cut-away edge. Can you see all the individual phospholipid molecules lined up tail to tail? On the inside and outside of the sphere you can't see the tails at all, just heads. This is important to remember. In some pictures we will be looking at in future chapters, you won't be able to see the tails; you'll see only an endless "sea" of heads.

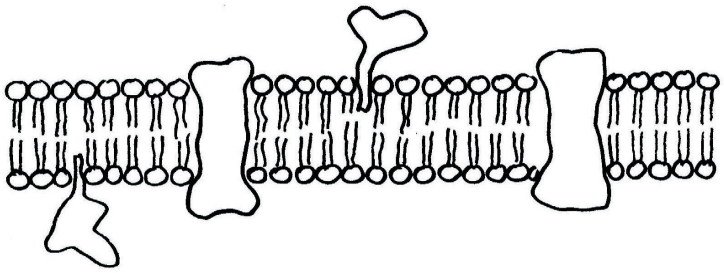
This phospholipid structure is the basic structure of a cell. It's not only what the outer membrane is made of, it's also the outer layer of many other cell parts.

Now we have a nice, tight, almost-leak-proof ball. Very small molecules can sneak through the cracks, but large molecules don't stand a chance of getting inside. Only one problem--the cells need to be able to bring in food molecules, get rid of waste molecules, and send molecules to other cells. The cell needs portals at various places--"gates" that let good things in and keep bad things out. The cell's gates are made out of ***proteins***. This is what a simple protein looks like:



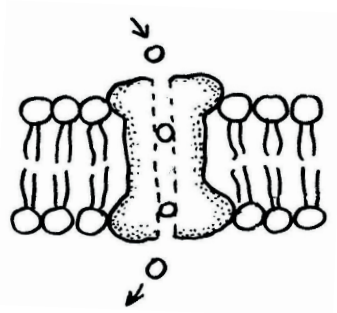
Not all proteins look just like this. But this gives you a general idea of what kind of atoms they are made of.

A protein doesn't look much different from a lipid or a glycerol, does it? It's made mostly of the same stuff--carbons, hydrogens and oxygens. But that letter N makes all the difference. It is a nitrogen atom. It's the nitrogen atom that makes this group of letters into a protein. But since this isn't a chemistry book, we're going to stop right here and not go any further into the chemical structure of proteins. From now on, proteins will look like little odd-shaped blobs. Let's put some protein "gates" into our phospholipid membrane:

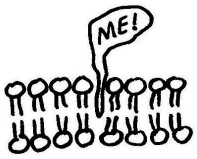


Those funny-shaped things are the proteins. (You recognize the phospholipids, right?) Some proteins go all the way through the membrane. These are the "gates." Other proteins are stuck on either the outside or the inside layer of the membrane. All of these proteins are called ***membrane-bound proteins*** because they are bound (fastened tightly) to the membrane.

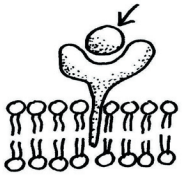
The proteins that <u>go all the way through the membrane</u> are the ones that act as gates, letting certain molecules in or out. Things that the cell would want to let in would be food molecules needed for energy (like very simple sugar molecules that your body has already digested from your food), protein molecules that the cell needs as raw materials to build other proteins, or perhaps a special message molecule from another cell.



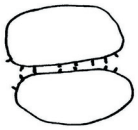
The proteins attached to the outer surface might do one of the following jobs:



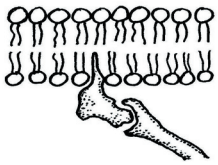
1) Act as a "flag" identifying the cell as belonging to the organism it is part of, so that it doesn't get attacked by other cells whose job it is to kill foreign invaders (such as bacteria). Cells don't have eyes, so they can't "see" each other. The way they identify each other is through the proteins on their surfaces.



2) Receive messages. Cells are usually part of a larger organism and they must all work together to keep the organism alive. Cells need to be able to communicate. They don't have ears or vocal cords so they can't talk to each other. The "messages" they send are actually molecules that travel back and forth between the cells.

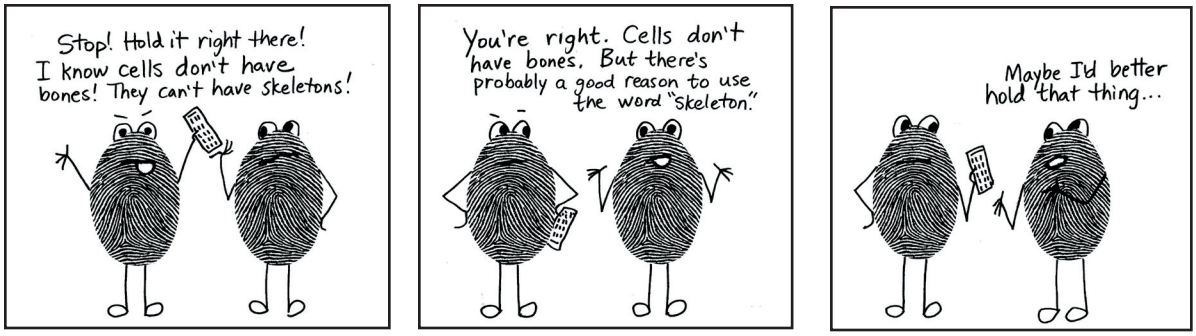


3) Allow the cell to stick to other cells. The proteins can grab and hold onto the outer proteins of other cells. (You could think of them as being a bit like Velcro™ proteins.) These proteins can hold cells tightly together, or loosely together.



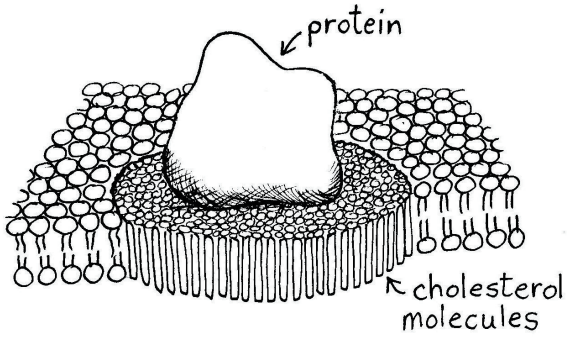
The proteins on the inner side of the membrane most often function as a place to attach things to, sort of like a hook or clip stuck into a wall. The most common cell part that needs to be anchored to the membrane is the cell's skeleton.

PAUSE



PLAY

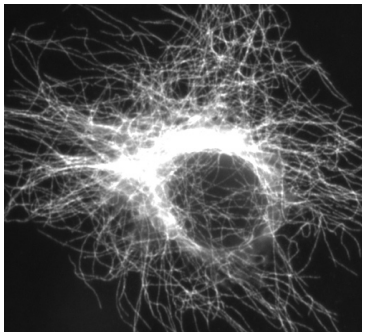
We'll come back to the skeleton in a minute. First, there's one more feature of the membrane that you need to know about: little "rafts" that can float around in the "sea" of phospholipid heads. They are called ***lipid rafts*** and they are made of ***cholesterol***. You've probably heard a lot of talk about cholesterol and how eating too much of it can be bad for you. Cholesterol is actually something your body needs--but in moderation. (Too much of anything, even a good thing, can be bad.) Here is a picture of a lipid raft with a protein riding on it. Is this cool, or what?!



It's not only the rafts that can move around. The proteins we mentioned above can also shift their position easily. The phospholipids are not locked together. You might want to imagine a bathtub filled with ping pong balls. The individual balls can move around but there is still a continuous layer of balls covering the water.

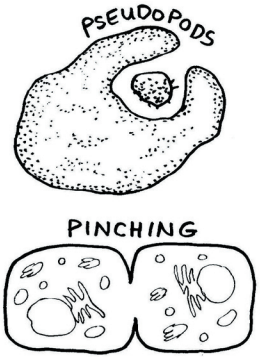
Now for the cell's skeleton...

Cells don't have bones. They are filled with a fluid called ***cytoplasm***. (The word "cyto-" means "cell." So cytoplasm basically means "cell gel.") Scientists have known about the cytoplasm for well over a hundred years. What they didn't know until fairly recently (the 1970s) is that an invisible framework exists in this cytoplasm. It's invisible because it's transparent and because it's made of extremely thin filaments. It's like trying to see a fishing line underwater. Both are transparent, and the fishing line is very thin. (That's the whole idea--the fish can't see it!) Somehow scientists started to suspect there was something there that they weren't seeing, but they had to figure out a way to make it show up on their electron microscope screens. First, they found a type of molecule (an antibody) that would attach itself to these almost-invisible cell parts (but explaining exactly how they did this is way beyond the scope of this book). Next, they stained these molecules with a fluorescent dye. When injected into a cell, these fluorescent molecules covered the mysterious invisible cell parts, thus making them visible to an electron microscope. The images produced by the electron microscopes were stunning; they revolutionized cell science. The images showed an organized network of filaments, like a three-dimensional system of "roads" and "highways" traversing the cell. It was obvious that this network of fibers acted as a structural support, helping the cell to maintain its shape. Because of this structural function, this network was named the ***cytoskeleton***. Just as we would be nothing but a pile of mush without our skeletons, cells would be flimsy and flat without their "skeletons."

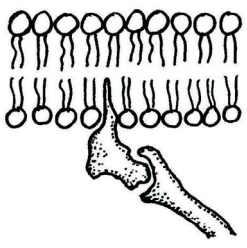


Micrograph of part of a cytoskeleton from nl.wikimedia. (Thanks, Jeffrey81!)

With further research, scientists discovered that the cytoskeleton also functions as a transportation system. It's like a little system of roads and highways. The roads come in three sizes: small, medium and large. The scientists who discovered them gave them these (boring) names: ***microfilaments, intermediate filaments and microtubules***. If we were to make a model of a cytoskeleton we might use thread, yarn, and drinking straws to represent them.

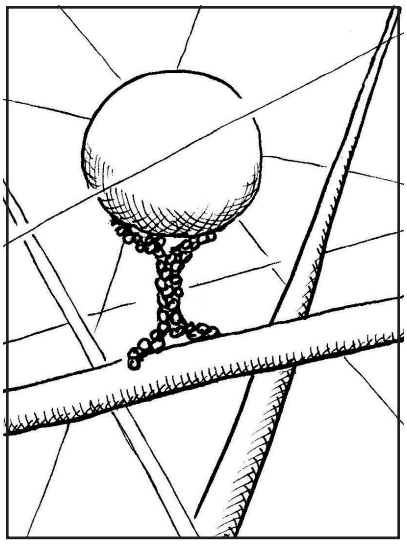


The smallest ones, the ***microfilaments*** (the threads in our model), are only a few molecules thick. They are very important in giving the cell its shape and helping the cell to change its shape. If a cell wants to move, it quickly builds a whole bunch of new microfilaments in that direction. The cell can build these at the rate of thousands per second. As the new little roads are built, they push the flexible membrane outward. Cytoplasm flows along with the microfilaments. Together they create what is called a ***pseudopod***, or "false foot." We have white blood cells in our bodies that form pseudopods in order to surround and capture bacteria and viruses. Microfilaments are also very important when it is time for the cell to reproduce by splitting itself in half. The microfilaments cause the cell to "pinch" in the middle, in preparation for the splitting process.



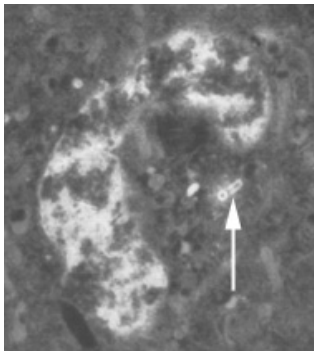
The shapes of the anchor proteins match the ends of the filaments a bit like like jigsaw puzzle pieces that fit together.

The medium-sized ***intermediate filaments*** (the yarn in our model) are especially abundant in nerve cells, skin cells, and muscle cells. They form a stretchy lattice inside the cell that help to give it strength. Remember how this lattice anchors itself to the cell membrane? The ends of the filaments hold on to certain proteins that stick out from the bottom side of the membrane. What would happen if something went wrong with those proteins? What if a cell made a mistake (and cells do make mistakes occasionally) and made those proteins the wrong shape so they could not hold on to the ends of the filaments? When this happens in muscle cells, it can cause a condition called muscular dystrophy. A person with muscular dystrophy has very weak muscles. Medical researchers are trying to find a way to help cells correct this mistake and fix these proteins.

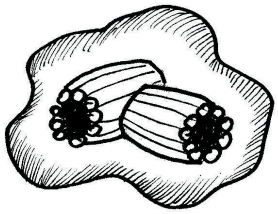


The largest filaments, the ***microtubules*** (the drinking straws in our model), really do look like tubes. These tubes are the "highways" that the cell uses to move things about. Cells make proteins, fats and enzymes for their own use or to ship out to other cells. But these proteins, fats and enzymes don't have any way to move. They just sit there. Something must carry them to where they should go. Further research revealed how these things are transported, and scientists could harldy believe their eyes when they saw it. They saw little proteins "walking" along these roads! They looked like they were putting one foot in front of the other. What a stunning discovery! These ***motor proteins*** travel along the microtubules carrying cargo. Their cargo can be just about anything a cell makes, and sometimes even the organelles themselves. How they know where to go is still a mystery. Every time a discovery is made in cell science, it answers some questions but also creates new questions!

There is a central "hub" for the microtubules, like a railway station from which all the train tracks branch out. This central station is called the ***centrosome***. (When you see the word root "som" or "soma," it just means "body" or "thing." So "centrosome" just means "central thing." Isn't it amazing how Latin and Greek make ordinary words sound more sciency?!) The centrosome helps to organize all the microtubules when the cell starts dividing in half. The centrosome was first seen under the microscope back in the late 1800s. They could not see the microtubules but they could see that the centrosomes were somehow causing the organelles to move around. In the micrograph shown here, the big whitish blob is the nucleus and the arrow is pointing to the centrosome.

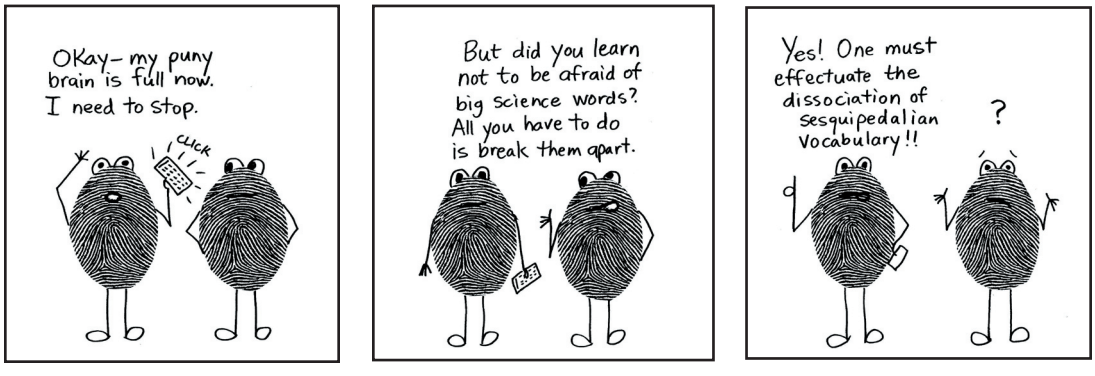


Further research on the centrosome has revealed that it is made of two parts: a pair of ***centrioles***, and a blob of protein surrounding them. The centrioles look like barrel-shaped things and they usually sit perpendicular to each other. They are made of microtubules-- the same as in the cytoskeleton. Even FURTHER research has found that the "barrels" are made of nine sets of tubes, with three tubes to a set. The cell is masterfully organized right down to the molecular level!



Two centrioles make one centrosome.

STOP



ACTIVITY 1 Watch "The Inner Life of a Cell"

This video is probably the best cell animation video in the world right now. A team of researchers and computer animation specialists at Harvard University put together this video to show us a view of the cell that you just can't get even with the best microscope in the world. You can't really see all these things going on in a cell. If you saw an electron microscope picture of these things, they wouldn't look like much. Molecules would just look like fuzzy blobs and they wouldn't be in color because electron microscopes produce only black and white images; the computer artists must add the colors. So you couldn't ever really "see" what this video shows. Don't let the fancy words scare you off--just enjoy the show and watch for things like phospholipid molecules, lipid rafts, microtubule highways, and lots of oddly-shaped proteins doing their jobs.

Go to **www.YouTube.com/eejm63** and clik on the "Cells" playlist, then on "Inner Life of a Cell."

ACTIVITY 2 Watch a white blood cell chase a bacteria

White blood cells use their cytoskeleton to change their shape very quickly. They can move around much like an amoeba. They build tubules out in the direction they want to go while dissolving the tubules at the rear. This combination of building and dissolving creates the pseudopods (which actually look more like oozy arms than they do "false feet.") In this video clip you can see a white blood cell actually chasing some bacteria. (If this address doesn't work for you, just type "white blood cell chases bacteria" into any Internet video search engine.)

http://www.youtube.com/watch?v=JnlULOjUhSQ ("White Blood Cell Chases Bacteria" on playlist)

If you want a slower video where you can watch the pseudopods form, try this one:

http://www.youtube.com/watch?v=KCpcHuC6cOE ("White Blood Cell in Action" on playlist)

ACTIVITY 3 Look at micrographs (still pictures, not videos) of the cytoskeleton

Here are some pictures that were taken with an electron microscope.

http://nanoprobenetwork.org/wp-content/uploads/2009/06/andrebrown-stem-cell-cytoskeleton-fluo-afm.jpg

ACTIVITY 4 Watch a few short videos about the cytoskeleton

Here is a brief video about the cytoskeleton and the various roles it plays in cells. (You'll also see single-celled organisms that use extensions of the cytoskeleton as locomotion devices.)

http://www.youtube.com/watch?v=5rqbmLiSkpk ("Cytoskeleton Microtubules" on playlist)

Intermediate filaments are what cells use to form "bridges" between cells, keeping them together. These bridges are called "desmosomes." (We'll officially meet them in chapter 7.) The main point of watching this video is to gain an appreciation of the ingenious design of these little filaments. The name "intermediate filaments" sounds boring and we might easily take them for granted. But they play a vital role in our bodies, especially in our skin. They give skin its resilience and elasticity.

http://www.youtube.com/watch?v=FoDniO676Dw ("Intermediate Filaments" on playlist)

Can you remember what you read? If you can't think of the answer, go back and read that part of the chapter again until you find the answer.

1) The most natural shape for the cell membrane molecules (phospholipids) to form is a:
a) flat surface b) ball c) long line d) cytoskeleton

2) The word "lipid" basically means:
a) protein b) fat c) sugar d) membrane

3) How many layers of molecules are in the cell membrane?
a) 2 b) 4 c) hundreds d) thousands

4) What do you call a phosphorus atom with some oxygen atoms attached to it?
a) a lipid b) a protein c) glycerol d) a phosphate

5) What does glycerol do in the phospholipid molecule?
a) keep the phosphate and the lipid together b) push the phosphate toward water
c) push the lipid away from water d) allow the cell to stick to other cells

6) Which hates water--the phosphate head or the lipid tail? _____

7) Where would you find a membrane-bound protein?
a) in the membrane b) stuck to the inside of the membrane
c) stuck to the outside of the membrane d) all of the above

8) TRUE or FALSE? One thing that lipid rafts can do is carry proteins around.

9) Which one of these can a membrane-bound protein <u>on the outer surface</u> NOT do?
a) allow the cell to stick to other cells b) act as an anchor for the cytoskeleton
c) act as a "flag" identifying the cell as belonging to the organism d) receive messages

10) What are lipid rafts made of? a) cholesterol b) proteins c) microfilaments d) wood

11) Which one of these does the cytoskeleton NOT do?
a) form new phospholipid membranes b) help the cell maintain its shape
c) transport things across the cytoplasm d) form pseudopods

12) Which one of these elements marks an organic molecule as a protein?
a) nitrogen b) hydrogen c) carbon d) oxygen

13) What is the fluid inside a cell called? _____

14) What cell part travels along the cytoskeleton "highway"? _____ _____

15) Which of these word roots means "body"? a) cyto b) soma c) pseudo d) pod

16) TRUE or FALSE? Very small molecules can squeeze through between the phospholipid molecules and therefore don't need to go through the "gates."

17) What does the centrosome do? a) act as a gathering point for proteins floating around the cell b) fight invading viruses c) act as a central point for the cytoskeleton d) send and receive messages

18) What object do the centrioles resemble? _____