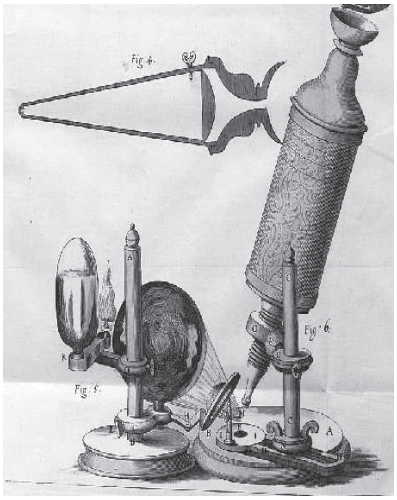
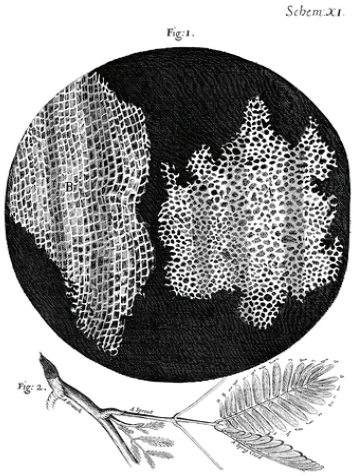
CHAPTER 1: HOW DID WE FIND OUT ABOUT CELLS?

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***.

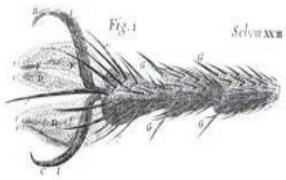
Englishman Robert Hooke (1635-1703) was probably the first person to observe cells. One day he sliced an extremely thin piece of cork and put it under his microscope. What did he see? Rows and rows of little box-like shapes that reminded him of the tiny rooms, or ***cells***, in monasteries (where monks live). Today we don't use the word "cell" 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

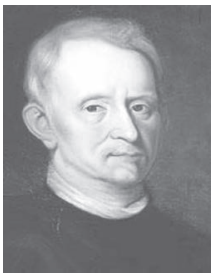


A fly's foot

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.

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, helping to re-design London after the fire of 1666, or proposing the wave theory of light. But as history would have it, most people know him as the man who gave us the word "cell."

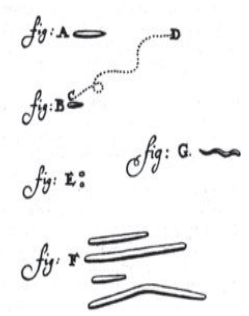
Hooke in a wig



Hooke without his wig

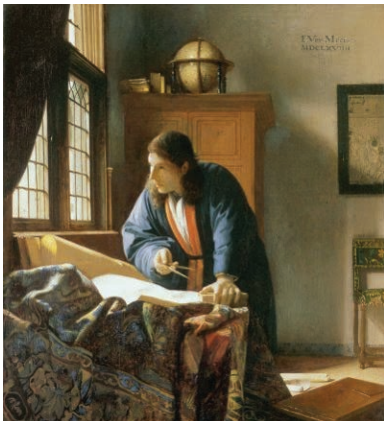
Then along came Antoni van Leeuwenhoek *(LAY-ven-hook)*, who lived his whole life in the Dutch town of Delft. He bought a copy of Hooke's Micrographia while on a trip to England in 1665, the only time in his life that he left Holland. Not long after reading Micrographia, Leeuwenhoek began making single-lens 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 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.

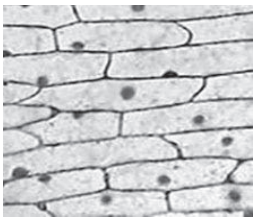


Leeuwenhoek observed bacteria

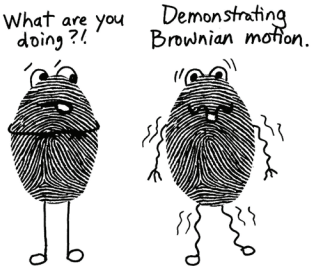
Leeuwenhoek was an incredibly patient person. He would sit for hours watching the specimens he had mounted on his microscope. He watched long enough to be able to observe the behavior and life cycles of microorganisms. He observed the microscopic food chain and knew what each little "animalcule" would 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.



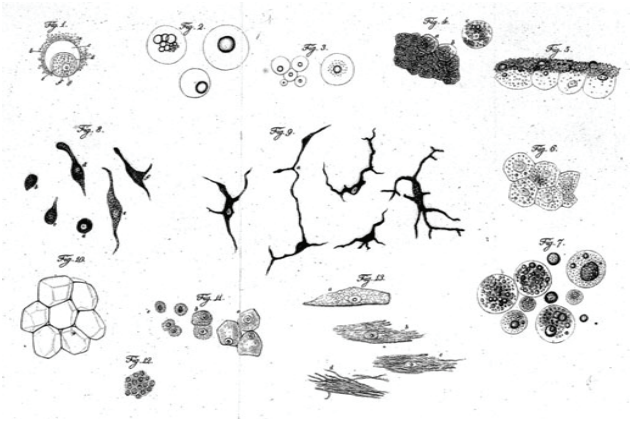
In 1827, Brown made another important microscopic discovery. While observing pollen grains under his microscope, he noticed that tiny particles inside the pollen grains were vibrating. He wondered if these particles were alive, since they were inside a plant cell. He tried a similar experiment with dust 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 actually the first person to conceive of the idea of Brownian motion. In 60 BC, almost 2,000 years before Brown was born, Lucretius said 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 to us, but until Schwann's time many people still believed that living things could just suddenly appear. They saw flies appear seemingly out of nowhere when fruit or meat spoiled. Most people did not know that the flies had hatched from eggs because fly eggs are too small to see.

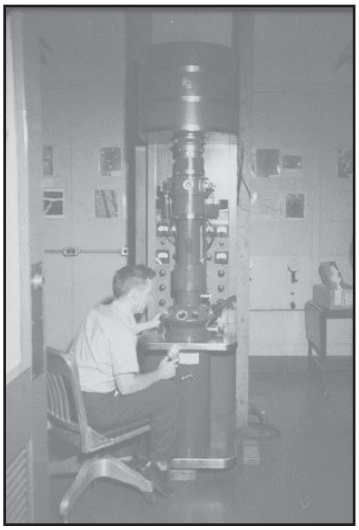


This is a drawing that Schwann made of different types of plant and anaimal cells he observed under his microscope.

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, which suggested that cells did originally come from inorganic materials. He believed a theory that contracted his theory?)

By the late 1800s, many different types of cells had been observed. There were fairly accurate pictures of plant cells, animal cells, single-celled organisms such as protozoa and bacteria. The big question now was how 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 their 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 made possible 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).



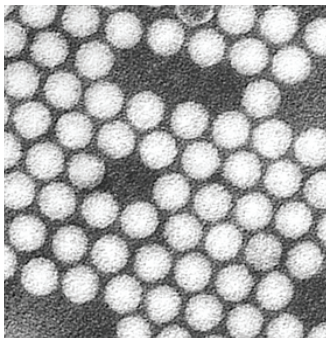
An electron microscope from the 1930s

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. 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***.

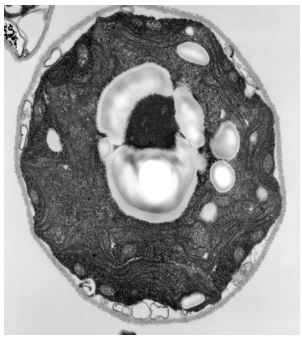
Regular microscopes use light and lenses to make things look larger. Electron microscopes work on an entirely different principle; they use electrons instead of light. Electrons from a tungsten filament are "fired" at the sample being studied, and the electrons either go through it (in the case of transmission 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 a million 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 where there is not a single molecule of air (like outer space). Living cells need air. so basically, only dead specimens can be studied. The specimens can be killed and preserved only minutes before loading them into the machine, but nothing alive and moving can be viewed. Usually, the specimens have to be prepared by spraying them with an ultra-thin layer of gold, or some other metal. This means that 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. 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.

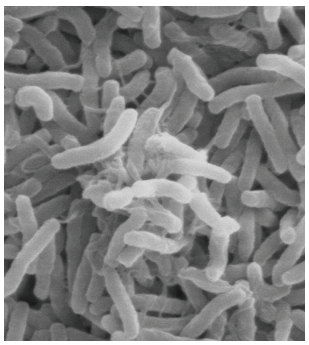


viruses

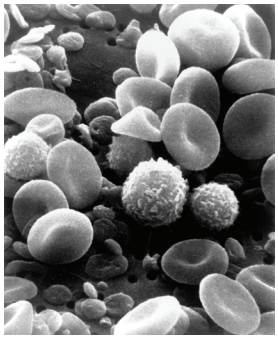


a single-celled organism

TEM images look flat



bacteria

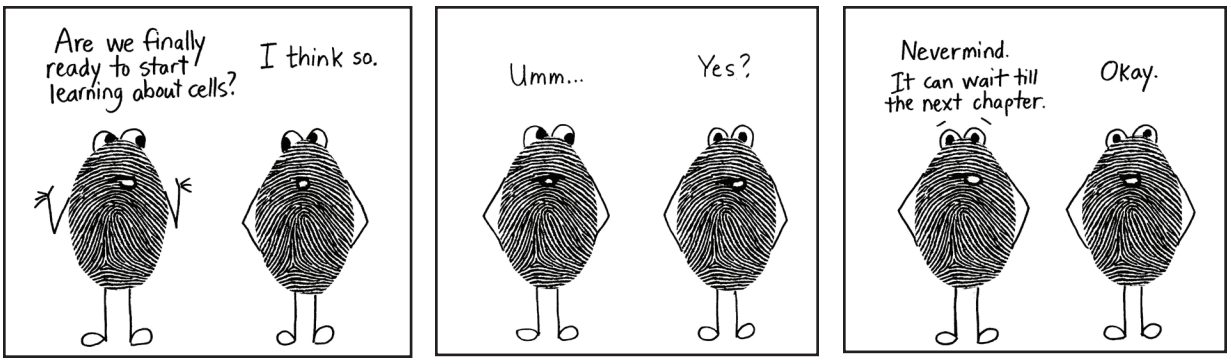


blood cells

SEM images look 3D

Images produced by TEM microscopes look flat. The electrons pass throug 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.



<u>Comprehension self-check</u> If you can't think of the answer, go back and read that part of the chapter again until you find the answer. If you need to check your answers, check the answer key.

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) millions

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) When was the idea of tiny invisible particles (atoms) first proposed?
   a) 60 BC b) 600 AD c) 1827 d) early 1900s

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

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

9) TRUE or FALSE? Many cells, and their inner parts, are transparent.

10) What is the most noticeable object found inside a cell?
    a) Golgi body b) nucleus c) DNA d) cytoplasm

11) Who has a staining method named after him?
    a) Antoni Leeuwenhoek b) Theodor Schwann c) Camillo Golgi d) Hans Christian Gram

12) The staining method named referred to in question 9 is used to stain _____.

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

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

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

16) 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

17) 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.

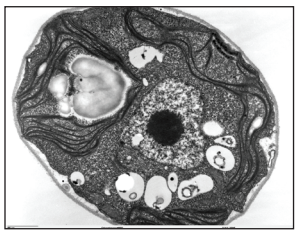
18) What does SEM stand for? _____ _____ _____

19) What metal is common used to spray samples that will be observed with electron microscopes? _____

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

Activity 1.1: Just for fun—can you guess what these are?

Here are some SEM and TEM micrographs. Try to figure out what they are. (Answers are in the answer key.)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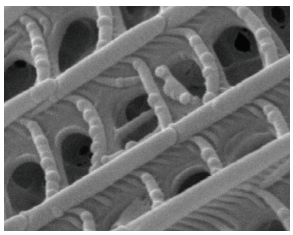
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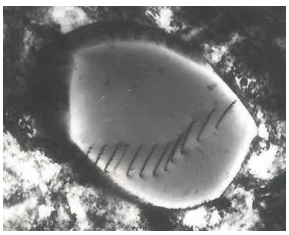
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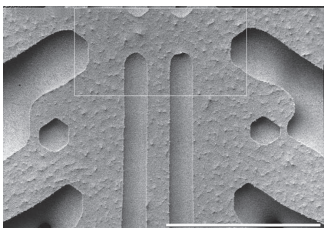
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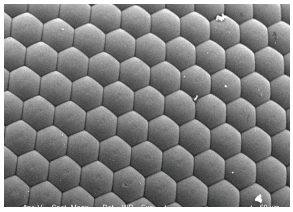
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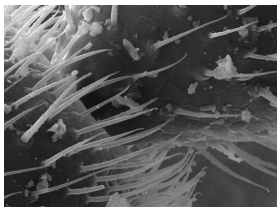
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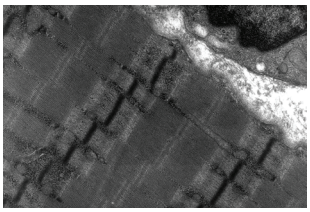
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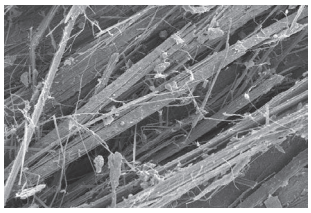
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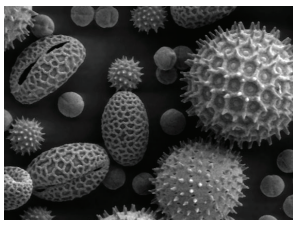
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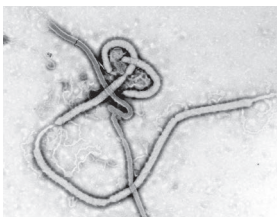
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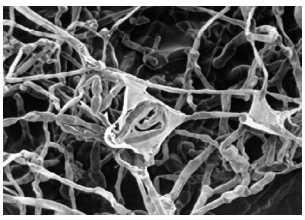
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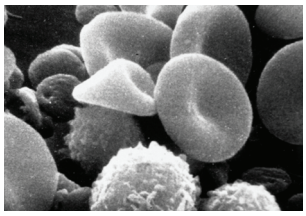
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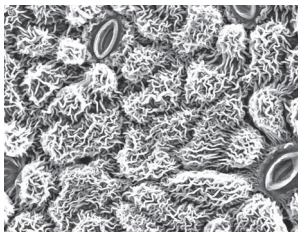
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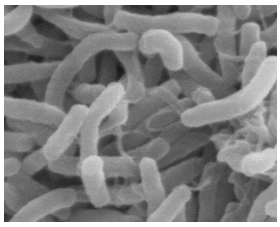
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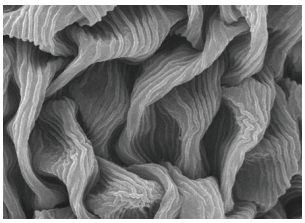
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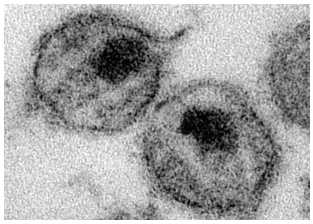
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1) Surface of leaf ____
2) HIV virus ____
3) Ebola virus ____
4) Blood cells ____
5) Flower petal ____
6) Chrysotile (asbestos) mineral ____
7) Insect eye ___
8) Pollen grains ____
9) Snowflake ____
10) Muscle fiber ____
11) Insect antenna ____
12) Algae cell ____
13) Scale from body of moth ____
14) Disease-causing mold ____
15) Cholera bacteria ____
16) Stess fracture in steel ____

Which 3 of these micrographs are TEMs? ____. ____, ____

Credit for steel micrograph:
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https://commons.wikimedia.org/w/index.php?curid=2353174

Activity 1.2: Watch some supplemental videos on the Cells playlist

This curriculum has a YouTube playlist. Go to www.youtube.com/TheBasementWorkshop. The Cells playlist might not be visible at first glance. Sometimes you have to click on "See all playlists" and then click on arrows to advance the list to see all the titles. The playlist is made of videos posted by various people around the world, and they have the right to take down the videos at any time, so occasionally there will be a blank spot. The author of this book tries to keep the playlist updated, but it is not possible to check it daily or even weekly. The videos that do appear on this list have been previewed by the author so they don't contain anything offensive and they hopefully aren't too boring. YouTube does not provide a way to label the videos to indicate which chapter they go with, but the will be in approximately the right order, so you can go down the list as you read the book.