SGCEP BIOL 1010K
Introduction to Biology I
Spring 2012 Sections 20585 & 20586

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Now, what is a cell?

Ultrastructure and membranes

The meaning we’ll be discussing is number 4 in Webster’s:

“a small usu. microscopic mass of protoplasm bounded by a semipermeable membrane, usu. including one or more nuclei and various nonliving products, capable alone or interacting with other cells of performing all of the fundamental functions of life, and forming the least structural unit of living matter capable of functioning independently”

Whew! How close to reality is that?

Many texts define them as “the smallest unit of life that can function independently.” Webster’s sorta says that... let’s see what else they are.
The historical perspective

1660 - Robert Hooke was the first person to see outlines of cells (in cork). He used the word cell to describe what he saw based on the Latin "cellae," which means cubicle.

1673 - Antony van Leeuwenhoek improved lenses and drew his observations.
Leeuwenhoek:

“To my great surprise, I found that it contained many very small animalcules, the motions of which were very pleasing to behold. The motion of these little creatures, one among another, may be likened to that of a great number of gnats or flies disporting in the air.”

— uttered upon checking out the tartar on his own teeth!

http://science.discovery.com/videos/100-greatest-discoveries-shorts-microorganisms.html
The Cell Theory!

Robert Brown in 1830’s – coined the term “nucleus” as the ‘blob’ in the middle of cells. Then others called the rest “cytoplasm,” which we now know consists of a watery soup of dissolved substances, organelles and cytoskeleton.

Schleiden and Schwann (1839) – cells are the “elementary particles of organisms, the unit of structure and function.” They proposed that:

- All organisms are made of one or more cells; and . . .
- The cell is the fundamental unit of life. Then . . .
- Virchow (1855) – All cells come from preexisting cells; therefore, . . .
- Spontaneous generation is impossible! Proven indisputably by Pasteur (1859).
The tools of cell biology . . .

* **Microscopes**

* **Light microscopes**
  a. Compound light microscope - glass lenses focus visible light, 0.2 µm resolution
  b. Confocal microscope - enhanced resolution using white or laser light
Electron microscopes (and scanning probe scopes)!

* Greater magnification and better resolution, but the specimen must be dead (or will be shortly after the procedure has begun!)

a. Transmission Electron Microscope (TEM) – uses beam of electrons focused by magnetic field that go through the specimen onto a receiver.

b. Scanning Electron Microscope (SEM) – scans beam of electrons over metal coated specimen, which reflect back to a receiver.

c. Scanning probe microscope – an electronic probe moves over the surface of the specimen giving exquisite detail.
Some examples of size scale:

Obviously the pictures are not to scale!

Also see - http://www.cellsalive.com/howbig.htm
Features common to all cells:

- Genetic information, DNA.
- Proteins carry out the cell’s work.
- RNA participates in producing proteins.
- Ribosomes manufacture proteins.
- Cytoplasm (the gel-like ‘stuff’ in the cell).
- Cell membrane (holds it all in).
- Complex cells also have organelles – compartments for specialized functions.
And be sure to check out the Virtual Cell:

http://vcell.ndsu.nodak.edu/animations/flythrough/movie-flash.htm, as well as Biology4kids.com:
Why are cells generally quite small? Because the...

- Surface area to volume ratio really matters!
- Cells require a large surface area for nutrients, gases, and wastes to enter and leave, but there's a...
- Surface area limitation on the size of a cell — volume increases faster than surface area in any system.
- This may be avoided through:
  - Flattened shapes, ...
  - Fingerlike extensions, and/or ...
  - Specialized organelles to improve efficiency (which explains why animal and plant cells are generally much larger than bacterial cells).
Surface area to volume relationship:

As the boxes get bigger the amount of surface area relative to the amount of volume decreases.

<table>
<thead>
<tr>
<th>Size of cube</th>
<th>Surface area</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cm</td>
<td>6 cm²</td>
<td>1 cm³</td>
</tr>
<tr>
<td>2 cm</td>
<td>24 cm²</td>
<td>8 cm³</td>
</tr>
<tr>
<td>3 cm</td>
<td>54 cm²</td>
<td>27 cm³</td>
</tr>
</tbody>
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Ratio of surface area to volume:

<table>
<thead>
<tr>
<th></th>
<th>6.0</th>
<th>3.0</th>
<th>2.0</th>
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The cell membrane holds it all in ... and keeps other stuff out, only letting the right things in and out.

* It’s made of both lipids and proteins.
* The lipids are phospholipids:
  * Which consist of glycerol, two fatty acids, and a phosphate group. The ...
  * Head is hydrophilic, & tails are hydrophobic.
  * Spontaneously form a phospholipid bilayer.
* Fluid mosaic model – proteins and phospholipids are free to move laterally within the bilayer.
What's a phospholipid look like?

The 'head' has a slew of polar bonds so it's hydrophilic. The 'tail' consists of fatty acids with mainly non-polar bonds, so it's hydrophobic.
These self-assemble to form micelle bilayers in water!

And in life compose much of the cell membrane. See e.g. http://www.johnkyrk.com/cellmembrane.html
What else is in a cell membrane?

- Lots of different sorts of proteins:
  - Transport proteins (get stuff in and out),
  - Adhesion proteins (sticks to others),
  - Enzymes (catalyze reactions),
  - Receptor proteins (bind things → an effect),
  - Recognition proteins (self vs. non-self); and,
  - Sterols (a type of lipid), including cholesterol (in animals), which modulates membrane fluidity.

One third of a typical “proteome” are membrane proteins. These are the ‘guys’ that many drugs target, so they are the subject of big Pharma’ research bucks!
These guys are very important!

For example, in photosynthesis: Membrane bound organelles called chloroplasts have light receptor protein complexes embedded in their membranes.
And other receptors are involved in signal transduction:

A cell receives an external “message” and converts it into an internal signal.

A stimulus molecule, the first messenger, binds to the receptor protein.

This triggers a chemical reaction whose product is the second messenger.

The second messenger provokes a cell’s response — e.g. activating particular genes or enzymes.
And in a ‘typical’ plant cell membrane . . .

There’s a cellulose mesh outside the membrane — the cell wall — but there’s no cholesterol at all.
Whereas a ‘typical’ animal cell membrane . . .

Has cholesterol in its cell membrane, as well as glycoproteins, i.e. the proteins have sugars sticking out from them.
We’ll spend an entire lecture on membranes in a few days.

* For now let’s go on to look at the three basic types of cells, those that define what domain of life a cell belongs to.

* And we’ll look at all those crazy organelles inside the eukaryotic cell.
Life can be divided up based on the type of cells it has.

- Outdated categories based on microscopy: prokaryotes (without nucleus) and eukaryotes (with nucleus). This classification is not based on evolution and really shouldn’t be used.

- Now we know that life actually has three primary domains: Bacteria, Archaea, and Eukarya. Archaea were ‘discovered’ by Carl Woese (1990) through ribosomal RNA (rRNA) analysis. Neither Archaea nor Bacteria have nuclei, but they are as unlike one another as much as either are to Eukaryotes.
One of my heroes, Carl Woese, and the sort of rRNA data that led to his proposal, that is, Bacteria and Archaea are not the same!
Nobody knew anything about there even being Archaea until 1977 when Woese realized that his rRNA molecules were telling decidedly different stories depending on what ‘bugs’ he was looking at, and nobody believed it for many, many years. (Some hardcore microbiologists still don’t!)
Let’s look a bit more at how he did it.

* Woese used the 16S subunit of ribosomal RNA (rRNA), a vital part of the ribosome, and abundant and well-conserved in all living organisms.

* In the beginning he didn’t directly sequence the rRNA — he built what was called oligonucleotide catalogs.

* DNA/RNA sequencing was in its infancy; Sanger dideoxy sequencing had just been invented in 1975!
How’d he do that?

Oligonucleotide cataloging reconstructs the 16S rRNA sequence by digesting the nucleic acid with T1 RNAse, which cuts after every guanine residue. He also did other digestions with enzymes that cut after the adenine, cytosine or uracil residues.

This produces an assortment of very short chunks of rRNA from which partial sequences can be reconstructed.

But it is incredibly tedious!
So nobody does it that way anymore.

* Full length, or nearly so, 16S sequences, other genes, or complete genomes are now used.

* And the Ribosomal Database Project at Michigan State University presently has almost 10,000 Archaeal nearly complete 16S sequences. The German ARB/Silva repository has almost 20,000!

The American Society for Microbiology has a lovely video from PBS on microbial diversity that features Carl.

http://cdn1.libsyn.com/microbeworld/Episode_2__Solving_The_Puzzle.mp4
And on my site:  http://www.bio.fsu.edu/~stevet/VSU/Biol1010/ASM.Woese.mp4
Woese has received a slew of awards over the years (now that people finally acknowledge his genius)!

* A pretty cool recent one was featured by Bill Nye, the science guy, on the Science Channel in “100 Greatest Discoveries, The Big 100.”

* He’s number three on the list of thirteen in Biology’s greatest:

  Carl Woese discovers bacteria are not the only simple-celled prokaryotes (unicellular organisms without a nucleus) on Earth. Many of the organisms classified in the new kingdom of Archaea are extremophiles. Some live at very high or low temperatures, others in highly saline, acidic or alkaline water. Some have been found in environments like marshland, sewage and soil. Archaea are usually harmless to other organisms and none are known to cause disease.”
Check it out!

“... something every microbiologist and biologist firmly believed in, and it wasn’t true. So it does make you smile, doesn’t it? Yeah. Look what I found!”

Of course Woese has gotten a bunch of ‘real’ awards too:

A MacArthur Fellowship in 1984, election to the National Academy of Sciences in 1988, the Leeuwenhoek Medal in 1992, the National Medal of Science in 2000, the Crafoord Prize from the Royal Swedish Academy of Sciences in 2003 (this was in lieu of the Nobel since there was no appropriate category), and in 2006 he became a foreign member of the Royal Society.
This is called a "phylogeny" - it shows the branching pattern of evolution.
In turn . . . a typical Bacterium:

Lacks a membrane bound nuclei. One circular DNA molecule is found as a nucleoid (but often plasmids too).

Ribosomes, RNAs, and proteins are all free to mix.

A rigid cell wall in most gives protection and shape.

Some have a capsule and flagella and/or pili.

Also see: http://www.cellsalive.com/cells/bactcell.htm
Bacteria have many morphologies.

Just a couple of examples: b. *Streptococcus pyogenes* (strep throat) and c. *Treponema palladium* (syphilis). But they’re not all bad guys — many are vital to other critters’ survival and to the entire ecosystem. They’re found everywhere!
The Archaea (the ancient ones) . . .

Resemble bacteria, but only superficially. Phospholipids, rRNAs, cell walls, and flagella - are all unique.

About half of their genes are found in the other domains of life - the rest are unique.

Some are "extremophiles" but some Bacteria are too, and many are not.

This guy is Sulfolobus acidocaldarius — it lives in super acidic, super hot springs. Others are methanogens — they use CO₂ and H⁺ to make methane. Others love salt . . . and on and on . . . .
Everybody else is a Eukaryote (except viruses, which really aren’t usually alive).

- This consists of the mixed assemblage of Protists, plus all Fungi, Plants, and Animals.
- Eukaryotes have a huge diversity of forms life cycles, and organizational plans (from single-celled to multicellular).
- They are generally larger than Bacteria or Archaea.
- They have internal membranes that create organelles — compartmentalization — in particular, DNA in a nucleus, and aerobic mitochondria, and photosynthetic chloroplasts.
Endosymbiosis theory:
An ancient single-celled organism engulfed other organisms that stayed and became partners to become mitochondria and chloroplasts.
And see: http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Endosymbiosis.html
As in the 'typical' Eukaryote animal cell:

Also check out “Cells Alive,” e.g.: http://www.cellsalive.com/cells/cell_model.htm and http://www.johnkyrk.com/CellIndex.html and http://learn.genetics.utah.edu/content/begin/cells/insideacell/
Or, in the ‘typical’ Eukaryote plant:
And now all those organelles... ‘specialized factories’

Milk example of coordinated interactions between organelles

1. Milk protein genes transcribed to mRNA
2. mRNA exits through nuclear pore
3. At ribosomes on surface of rough ER, information in mRNA is used to produce milk protein
4. Enzymes in smooth ER manufacture lipids
5. Milk proteins and lipids are packaged into vesicles from both rough and smooth ER for transport to Golgi
6. Final processing of proteins in Golgi and packaging for export out of cell
7. Proteins and lipids released from cell when vesicles fuse with cell membrane
In turn... the nucleus with its double membrane:

- Contains DNA – which has the information specifying ‘recipe’ and the instructions for using that recipe for every protein that organism can make, but only certain cells make certain proteins at certain times!
- Nuclear pores through nuclear envelope let stuff in and out.
- And the nucleolus assembles ribosomes.
The endoplasmic reticulum...

- Originates at the nuclear membrane and winds throughout the cell.
- Rough ER — is studded with ribosomes making proteins destined for secretion (like milk).
- Proteins folded and modified within the ER.
- Smooth ER — synthesizes lipids, detoxifies drugs and poisons.
- Lipids and proteins made by ER exit in vesicles.
What's ER look like?

This is strewn throughout the interior of the cell. Stuff made in them is pinched off into vesicles, which move off to the Golgi apparatus.
Golgi, what?

- The Golgi apparatus is the . . .
- Processing center for vesicle contents,
- Proteins complete their intricate folding and become functional,
- Some proteins will become membrane surface proteins,
- Others are packaged for secretion from the cell (like milk).
- Others operate within the cell.
And it looks like this:
**More organelles...**

**Lysosomes:**
- Contain enzymes that lyse (burst) substrates, such as captured bacteria, and worn-out organelles and other debris, recycling the constituent parts.
- The specific pH inside a lysosome prevents enzymes from damaging the cell. See [http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter03/lysosomes.swf](http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter03/lysosomes.swf)
Peroxisomes:

- Dispose of toxic substances and fatty acids.
- Some of these reactions produce hydrogen peroxide ($H_2O_2$), which is very toxic.
- An enzyme in peroxisomes changes this into harmless water.
Vacuoles:

* Found in all plant and fungal cells as well in some cells of other life forms. It has a similar job as lysosomes, i.e. . . .

* It houses enzymes that degrade and recycle materials, but, especially in plants, they are also . . .

* Very important in growth and in maintaining rigidity (turgor). This is why plants wilt when the need water.

* Also, contractile vacuoles, e.g. Parameciums . . .
The site of “primary production” — the chloroplast!

- Found in plants and many protists.
- This is the site of photosynthesis.
- Chloroplasts use energy from sunlight to produce glucose (a monosaccharide sugar).
- It occurs in a region called the thylakoid.
- Endosymbiosis theory support — chloroplasts have their own DNA, and it has many similarities to [Cyano] bacterial DNA.
And what's a chloroplast look like?

Inner and outer membranes

Stroma

Granum

DNA

Ribosome

Thylakoid membranes

Stroma

Granum

Cytoplasm

1 μm

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The cell's 'powerhouse' — the mitochondrion!

- Cellular respiration extracts energy from nutrients.
- Cristae contain enzymes for cellular respiration.
- Also contains its own DNA, which is inherited maternally in most mammals, and is similar to [Proteobacterial] bacterial DNA.
Here’s a nice short video about them...

http://www.youtube.com/watch?v=8NvK4PUgzmY
Not all cells do all things in multicellular organisms — specialization!

a. muscle cells, b. fat cells, c. leaf cells, d. root cells
Cytoskeleton — yes, even cells have a skeleton.

Three major components are distinguished by protein type, diameter, and aggregation:

1. Microtubules,
2. Microfilaments,
3. Intermediate filaments.
In turn... microtubules...

- Tubulin protein:
  - Forms hollow tubes 23 nm in diameter, with 9+2 geometry.
  - Can change length of tube by adding or removing tubulin monomer molecules.
  - Provides for many cellular movements, including chromosome motion during cell division. I.e. it’s a...
  - “Trackway” within a cell for moving stuff.
  - Plus... Cilia – short, many, and...
  - Flagella – long, few.
The other types of cytoskeleton molecules:

**Microfilaments:**
- Consist of the protein actin, which are...
- Long, thin rods 7 nm in diameter. They provide...
- Machinery to move, e.g. in muscles. And...

**Intermediate filaments:**
- Which are 10 nm in diameter (intermediate).
- They are made of different proteins in different specialized cell types. And they provide the...
- Internal scaffold for a cell.
Cells adhere and communicate to one another.

* Cell walls . . .
* Surround the cell membrane of nearly all bacteria, archaea, fungi, algae, and plant cells.
* It is not just a barrier.
* And it's built of different components.
* Plasmodesmata connect adjacent cells.
Animal cells lack cell walls.

They secrete a complex extracellular matrix.

Intercellular junctions:
1. Tight junctions form impermeable barriers.
2. Anchoring or adhering junctions connect cells by linking intermediate filaments.
3. And gap junctions link cytoplasms of adjacent cells.
In summary, cell junctions:

<table>
<thead>
<tr>
<th>Type</th>
<th>Function</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasmodesmata</td>
<td>Allow substances to move between plant cells</td>
<td>Plant cell walls</td>
</tr>
<tr>
<td>Tight junctions</td>
<td>Close spaces between animal cells by fusing cell membranes</td>
<td>Inside lining of small intestine</td>
</tr>
<tr>
<td>Anchoring (adhering) junctions</td>
<td>Spot weld adjacent animal cell membranes</td>
<td>Outer skin layer</td>
</tr>
<tr>
<td>Gap junctions</td>
<td>Form channels between animal cells, allowing exchange of substances</td>
<td>Muscle cells in heart and digestive tract</td>
</tr>
</tbody>
</table>
Again, a ton of material, but it’ll all get clearer as we proceed.

- Main points — What is a cell?
- The cell membrane and integral proteins.
- Life can be divided up based on the type of cell it has — Bacteria, Archaea, Eukaryote. What are the differences?
- All of the organelles of Eukaryotic cells — What are they and what do they do?
- And what is endosymbiosis?