BIOL 1010 Introduction to Biology: The Evolution and Diversity of Life. Spring 2011 Sections A & B

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First another in-class assignment, this time regarding . . .

The Student Success Center’s talk.

On a piece of paper — name, date, class and section, and . . .

Did you think their presentation was worthwhile? Did you learn anything new? What new technique or techniques did you learn about in that session, for learning biology, that you hadn’t yet tried, but that you are willing to start trying?

Quietly work on this by yourself for the rest of the class period — come up with no more than one page — and get it to me as you leave.

Sunday, February 6, 2011
More different, more prevalent, and more ancient than you ever imagined!

Bacteria and Archaea are more varied than all eukaryotes combined, even though you would never think so just ‘looking’ at them; they live in every conceivable habitat, and some you would never even conceive of; and their ancestors are more ancient than all other life on earth.
Bacteria and Archaea are . . .

* Often called Prokaryotes, yet the term is actually a misnomer, as it does not reflect a phylogenetically cohesive grouping, i.e. it’s not a clade.

* They are all single-celled organisms that lack a nucleus and membrane-bound organelles. The DNA is ‘loose’ in the cell.

* At least 100,000-10,000,000 species exist, though it’s hard to say as more are discovered through “metagenomics” studies every day!
The first cells on earth . . .

- Were unnucleated and unicellular, and . . .
- They made a huge difference, including:
  - Those photosynthesizers that changed the primordial atmosphere from a reducing mix to the oxygen rich mixture so many modern organisms depend upon, and which created the ozone layer that protects the earth from UV.
  - The aerobic ones that became mutualists with other cells as mitochondrion, and . . .
  - The photosynthesizing ones that became mutualists with other cells as chloroplasts.
**Structural commonalities:**

* All Bacteria and Archaea are...
* Bounded by a cell membrane, which...
* Encloses cytoplasm, DNA, and ribosomes.
* They are generally 10-100 times smaller than most eukaryotic cells. And all of them...
* Lack membrane-bound organelles.
* They typically have one circular ‘chromosome,’ though structurally it’s not at all like a Eukaryotic chromosome. And they often have plasmids, which are smaller circular DNA molecules that often have genes for drug resistance and sex on them.
A ‘typical’ bacterium, though there is no such thing!

Plasmids can code for drug or toxin resistance, cause disease, or alter a cell’s metabolism. They are often used in recombinant DNA technology. The ribosomes are structurally different from Eukaryotes, and some antibiotics exploit this difference.
Most of them have a cell wall.

* It’s a rigid barrier outside the cell membrane (which is different in Bacteria than Archaea).
* It’s made out of peptidoglycan in Bacteria, but not in Archaea where it is often protein.
* The Gram stain differentiates between two nonphylogenetic (they are not clades) groups of bacteria based on cell wall structure (but has nothing to do with Archaea).
* Gram-positive - appear purple due to thick peptidoglycan layer.
* Gram-negative - appear pink due to thinner cell walls and an outer membrane covering.
Gram stained Bacteria of both types
Many of them also have . . .

- A glycocalyx:
  - Caspule or slime layer of protein and/or polysaccharide;
  - It’s a sticky layer outside the cell wall; involved in . . .
  - Attachment, anti-desiccation, & evasion of immune systems.

- Pili (singular pilus):
  - Short, hairlike projections, that . . .
  - Adhere to objects; including, in some species, to other nonnucleated, unicellular organisms, where . . .
  - Sex pili can transfer DNA between the two.

- Flagella (singular flagellum):
  - A whiplike extension that can move cells around based on a response called . . .
  - Taxis – to move toward or away from a stimulus. They are . . .
  - Not homologous to Archaea or Eukaryotic flagella.
Here's some examples in Bacteria.

* The capsule around a Bacteroides cell.

* Pili on Escherichia coli.

* Flagella on Proteus mirabilis.
Some Bacteria make Endospores (but not Archaea).

* Dormant, thick-walled structures that survive long, harsh conditions.
* Withstand boiling, drying, UV, and disinfectants.
* When environmental conditions improve, normal bacterial form comes back.
* Examples include: Clostridium botulinum Botulism; and Bacillus anthracis Anthrax.
Bacteria and Archaea classification . . .

* Traditionally relied on observable (microscopic) characteristics. For example . . .
* Three common shapes – cocci (spherical), bacilli (rod-shaped), and spirilla (spiral);
* Cell arrangements – pairs, clusters (staphylo-), or chains (strepto-);
* Gram stain, positive or negative; and . . .
* Other stains for flagella, endospores, or glycocalyx.
Here's some **Bacterial examples** ...

- **Spheres (cocci)**: Micrococcus, rods (bacilli) Bacillus megaterium, and spirals (spirilla) Rhodospirillum rubrum.
But other forms are out there too.

* For example:
  * Long filaments (> 100 µm = 0.1 mm common, e.g. Beggiatoa, Thioploca)
  * Branched filaments (e.g. Streptomyces)
  * Star-shaped (Stella)
  * Amorphous-shaped (e.g. Sulfolobus)
  * Flat-looking (e.g. Haloarcula)
* Furthermore, individual cell morphologies are usually emphasized, but most species actually live as communities in “biofilms” or “mats” on surfaces.
And metabolism is often used, e.g.

- **Carbon source:**
  - Autotrophs – acquire carbon from inorganic sources; versus...
  - Heterotrophs – carbon from organic molecules.

- **Energy source:**
  - Phototroph – energy from the sun; versus...
  - Chemotroph – oxidize inorganic or organic chemicals.

- And you can combine the terms:
  - Photoautotroph or...
  - Chemoheterotroph, and on and on.

- **Oxygen requirements:**
  - Obligate aerobe – requires oxygen; versus...
  - Obligate anaerobe – oxygen is toxic; or...
  - Facultative anaerobe – can live with or without oxygen.
These traditional classification methods remain in widespread use because they are based on easy to observe characteristics, and they are taught in medical training.

- But they’re all messed up!
- They are not based on phylogeny. They do NOT sort organisms into clades.
- Many (most!) Bacteria and Archaea cannot even be grown in culture, so most of these methods can’t be used with them at all.
- We NEED to use molecular methods.
- Ribosomal RNA (rRNA) was first, but now whole genomes are being used.
This guy single-handedly turned the world of taxonomy on its head in 1977 through the study of rRNA. People were not happy – it took a lot to convince them.
He invented the term “domain” to describe the new level of taxonomy.

And waited until 1990 to publish [http://www.pnas.org/content/87/12/4576.full.pdf](http://www.pnas.org/content/87/12/4576.full.pdf) the seminal paper.
Similarities and differences...

**Table 18.2  Bacteria and Archaea Compared**

<table>
<thead>
<tr>
<th>Similarities</th>
<th>Bacteria</th>
<th>Archaea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predominantly unicellular</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cell size</td>
<td>1–10 μm</td>
<td>1–10 μm</td>
</tr>
<tr>
<td>Nucleus and other membrane-bounded organelles</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Circular chromosome</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Able to grow at temperatures above 80°C</td>
<td>Yes (some)</td>
<td>Yes (some)</td>
</tr>
<tr>
<td>Nitrogen fixation?</td>
<td>Yes (some)</td>
<td>Yes (some)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Differences</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell wall composition</td>
<td>Peptidoglycan</td>
<td>Pseudopeptidoglycan, protein</td>
</tr>
<tr>
<td>Membrane composition</td>
<td>Based on fatty acids</td>
<td>Based on nonfatty acid lipids (isoprenes)</td>
</tr>
<tr>
<td>Use chlorophyll in photosynthesis</td>
<td>Yes (some)</td>
<td>No</td>
</tr>
<tr>
<td>Generate methane as byproduct of metabolism</td>
<td>No</td>
<td>Yes (some)</td>
</tr>
<tr>
<td>Sensitive to streptomycin</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Introns</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

You only need to know some of these, not all of them.
“The incredible diversity of life on this planet, most of which is microbial, can only be understood in an evolutionary framework.” (Carl Woese, 2000)

- Bacteria and Archaea have all sorts of metabolisms, many being able to use different pathways depending on the environment they may be in at any particular time and place.
- And they live all over the place: from in distilled water to salt saturated brines; from \(-30^\circ C\) to \(120^\circ C\); from a pH of less than 0 to a pH of 11; all over the Earth, from deep below the surface of the oceans and the continents, to clouds high in the sky!
Some Bacteria and Archaea are known as Extremophiles because of where they live. Know the words.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Environment</th>
<th>Sample Habitats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidophile</td>
<td>Low pH (1.0–5.4)</td>
<td>Hot springs</td>
</tr>
<tr>
<td>Halophile</td>
<td>Extreme salt (3.5–30%)</td>
<td>Ocean, Dead Sea, evaporation ponds</td>
</tr>
<tr>
<td>Thermophile</td>
<td>Extreme heat (50°C–110°C)</td>
<td>Compost heaps, boiling springs</td>
</tr>
</tbody>
</table>
Some impressive statistics:

- There are an estimated $5 \times 10^{30}$ microbial cells in, on and around the Earth.
- About half of the Earth's organic carbon is tied up in microbial life.
- Another way to think about this is microbial biomass is 10,000 times more than the total human biomass of the earth. And less than 1% of that life is able to be cultured in the laboratory!
- Just the top 150 meters of open ocean contain up to 1,000,000 cells per milliliter, about half are Archaea; ocean sediments contain about 1,000,000,000 cells per gram; topsoil contains about 10,000,000 cells in 5,000 distinct genomes per gram (numbers typical of Whitman, et al. 1998).
This guy, Craig Venter . . .

The star bio-entrepreneur of human genome fame, completed a survey in 2004 of all the microbial life in the Sargasso Sea finding almost 1,500 different microbial species of which 150 had not yet been identified (2004).
A 2005 article in *Science* highlighting the human gut, states that almost 100 trillion individual organisms, around 10 times the number of human cells in your body, represented by almost a 1,000 different species, live in the human gastrointestinal tract. Our feces is almost half microbes by weight!
More fun stuff (microbes means Bacteria, Archaea, and protists here) —

- Most microbes do not cause disease.
- Microbes first appeared on earth about 3.8 billion years ago. They are critically important in sustaining life on our planet.
- Microbes make up most living matter and display tremendous diversity, yet less than 1% have been cultured (grown in the laboratory) and studied.
- Microbes drive the chemistry of life and affect the global climate.
- Microbial cycling of such critical chemical elements as carbon and nitrogen helps keep the world inhabitable for all life forms.
- Microbes generate at least half the oxygen we breathe.
And more . . .

- Microbes offer unusual capabilities reflecting the diversity of their environmental niches. These may prove to be useful as a source of new genes and organisms of value in addressing bioremediation, global change, biotechnology, and energy production.

- Microbial studies will help us define the entire repertoire of organisms in specialized niches and, ultimately, the mechanisms by which they interact in the biosphere.

- Diversity patterns of microorganisms can be used for monitoring and predicting environmental change.

- Microbes are at the roots of life's family tree. An understanding of their genomes will help us understand how more complex genomes developed.

- Microbial genomes are modest in size and relatively easy to study (usually no more than 10 million DNA bases, compared with some 3 billion in the human or mouse genomes).

- Microbial communities are excellent models for understanding biological interactions and evolution.

All from [http://microbialgenomics.energy.gov/primer/facts.shtml](http://microbialgenomics.energy.gov/primer/facts.shtml)
Explore a microbial mat!

What would it be like to actually be inside a microbial mat? Take a ride on the Stromatolite Explorer. Explore live mats being used to conduct research in Greenhouse One at NASA’s Ames Research Center.

* This is way cool — ala the old ‘60’s film Fantastic Voyage.
* NASA’s Astrobiology group has a slew of neat microbial diversity stuff.
* http://microbes.arc.nasa.gov/movie/large-qt.html
Visit the Microbe Zoo, Dennis Kunkel’s micrographs, the National Academies Metagenomics site, and the Marine Biological Laboratory’s Microscope site:

* [http://commtechlab.msu.edu/sites/dlc-me/zoo/index.html](http://commtechlab.msu.edu/sites/dlc-me/zoo/index.html)
* [http://www.denniskunkel.com/](http://www.denniskunkel.com/)
* [http://dels-old.nas.edu/metagenomics/](http://dels-old.nas.edu/metagenomics/)
Microbial diversity is real; it’s all around us.

- And we’ll be spending the next few weeks exploring it.
- A lot of this stuff is NOT in the textbook; therefore, it is essential that you pay particular attention to my lecture notes.
- This stuff WILL be on the Section II exam, though, as usual, it’s not the little details that matter, it’s the big concepts.
But we’re not done yet. Before leaving for today we need to survey the major phyla of Bacteria and Archaea. Therefore, we’ll move on to the next lecture now.