Introduction to Archaea and Bacteria – Note that the kingdom Monera no longer exists.

I. The Domain Archaea – Organisms in the Domain **Archaea** (arch = ancient) were formerly classified as **archaeobacteria** and some of the terminology associated with Archaea reflects this history. The Archaea are believed to have evolved quite independently of other cell types, and were initially isolated from extreme environments not formerly thought to support life. Though often considered **extremo-philes**, Archaea are now recognized as being ubiquitous (like bacteria).

The Archaea are unlike bacteria in that:
1. Their cell walls do not contain peptidoglycan.
2. Their cell membranes contain ether-linked lipids (isoprenes) instead of ester-linked fatty acids, and their glycerol molecules are mirror images of those found in bacteria and eukaryotic cells.
3. Their ccc-DNA molecules often contain introns and are associated with histone proteins (characteristics of eukaryotic chromosomes).
4. The nucleotide sequences of their 5S, 16S and 23S r-RNA molecules are unlike those of bacteria.

Some groups of Archaea recognized as being of particular significance include the following:
1. The **methanogenic** (methane producing) Archaea – These organisms produce methane by combining hydrogen gas with carbon dioxide. Although the methane produced is a potential air pollutant, it is important as a potential energy source because it can be captured, burned to generate heat and to run steam-driven turbines that generate electricity.
2. The **Extreme Halophiles** – These organisms grow only in environments having high levels of salt (17-23%). Members of the genus *Halobacterium* produce ATP via photophosphorylation using a pink/purple pigment called **bacteriorhodopsin**. Because this molecule is very similar to the rhodopsin found within the human retina, it can be used to study eye function. Bacteriorhodopsin has been incorporated into artificial retinas, and specially designed optical computers.
3. The **Thermoacidophiles** – These organisms thrive in acidic, sulfur-rich hot springs where they tolerate highly acidic conditions and high temperatures. Because they maintain their activity under extreme conditions, the enzymes produced by these archaea are useful in industrial processes.

II. The Domain Bacteria – Not all phyla are included here:

1. **Deinococcus-Thermus –** Organisms in the genus *Deinococcus* are highly resistant to heat, pressure, dessication and exposure to radiation (both ultraviolet and ionizing). *Deinococcus radiodurans* is considered a polyextremophile, and one of the toughest types of bacteria known. Organisms in the genus ***Thermus*** are **hyperthermophiles** associated with hot springs and deep sea hydrothermal vents. Enzymes produced by these bacteria are capable of functioning at high temperatures and have various applications. ***Thermus aquaticus*,** are the source of **Taq-polymerase**, the enzyme used in our PCR activities.

2. **Cyanobacteria** –The Cyanobacteria (formerly called blue-green algae) are **oxygenic** (oxygen producing), **photoautotrophs** of large size. They contain green chlorophyll pigments and share a common ancestor with chloroplasts. Cyanobacteria often form symbiotic relationships with other organisms (as in lichens), and several forms produce **heterocysts** and **akinetes**. Cyanobacteria can produce **microcystins**, highly toxic peptides that when ingested can cause severe liver damage.

3. **Anoxygenic phototrophic bacteria** - These produce ATP by means of photophosphorylation, but are **anoxygenic**, i.e., **do not produce oxygen**. They live in mud and make green and purple pigments as visible within the Winogradsky-window displayed in the laboratory. The sulfur bacteria (green and purple) are named for their ability to form elemental sulfur from hydrogen sulfide.

4. **Rickettsia and Orientia** – Bacteria in these genera are **hypotrophs** that live within endothelial cells and RBCs. They are transmitted from one host to another by biting lice or ticks and enter their host's cells through phagocytosis. Example organisms include *Rickettsia rickettsii*, the causative agents of Rocky Mountain Spotted fever, and *R. prowazekii*, the causative agents of epidemic typhus (both spotted fevers). *Orientia tsutsugamushi*, and are the causative agents of scrub typhus.

5. **Wolbachia** – Organisms in the genus *Wolbachia* are insect parasites primarily, but also infect roundworms. Within their arthropod hosts, *Wolbachia* species cause reproductive changes resulting in death, feminization, parthenogenesis, or cytoplasmic incompatability, i.e., leaving infected individuals unable to mate. *Wolbachia* species significantly impact human health worldwide because they infect a variety of roundworms known to parasitize humans. Inflammation within the human host is largely due to the immune systems response to *Wolbachia*.

6. **Rhizobium** – Organisms in the genus *Rhizobium* are nitrogen "fixers" that form symbiotic relationships with the roots of legumes (e.g., beans, peas, alfalfa, soybeans, clovers and lupines). The plants assist *Rhizobium* by forming **leghemoglobin**, a red-colored, oxygen-absorbing pigment. This improves the nitrogen fixing ability of the bacteria. Farmers plant legumes to increase nitrogen levels in soil, but it is really *Rhizobium* doing the work.

7. **Agrobacterium** – Bacteria in the genus *Agrobacterium* are plant pathogens capable of transferring genes between their cells and those of plants. *Agrobacterium tumifaciens* causes crown gall disease in plant roots (see galls or roots at back of lab). *Agrobacterium* plasmids have been modified and are now used to transfer genes into plants without causing disease.

8. **Sphaerotilus** – Bacteria in the genus *Sphaerotilus* reside within tube-like structures called sheaths that are made of organic material and resemble underwater spider webs. The sheaths made by *Sphaerotilus* can disrupt water flow (they plug up well pumps and fishtank filters); but the bacteria do not pose a health hazard.

9. **Thiobacillus** – Bacteria in the genus *Thiobacillus* are **chemoautotrophs** important in maintaining environmental mineral cycles called **biogeochemical cycles**. *Thiobacillus ferrooxidans* are acidophiles used in commercial mining operations. These organisms use hydrogen sulfide as an energy source and release sulfuric acid that can dissolve minerals such as copper and uranium from low-grade ores making the recovery of these materials cost effective. *Thiobacillus* can also be used to remove sulfur from coal, thereby reducing the potential for air pollution when coal is burned.

10. **Pseudomonas** – Members of the genus *Pseudomonas* are unique in their ability to utilize a remarkably diverse assortment of organic compounds as carbon and energy sources, so are often engaged in environmental cleanup. Humans employ *Pseudomonas* species in **bioremediation**, i.e., we use them to consume toxic chemical pollutants, thus eliminating the necessity of storing them, or illegally dumping them into the environment. *Pseudomonas syringae* produce cell surface protein molecules that promote the formation of ice crystals. These organisms are often used as nucleating centers in large scale "snow" making operations associated with ski resorts.

11. **Photobacterium** – Members of the genus *Photobacterium* form symbiotic relationships with **bioluminescent** squids and fish. **Bioluminescent** organisms emit light, but light production involves *Photobacterium phosphoreum*. These bacteria produce pigments called **luciferins** (Lucifer = light bringer) that serve as substrates for **luciferase enzymes** encoded by **lux genes**. The enzymes act on the luciferins, causing them to convert chemical energy into light energy, which is then released as a blue-green light. Fish and other organisms support patches of *Photobacterium* in

regions called "light organs", and can "turn" these lights off and on by covering and uncovering the bacteria. The fish use the light to attract prey species or potential mates, and the bacteria are provided with a living space and food supply (mutualism). Lux genes are used extensively in genetic manipulation and have multiple applications. By genetically modifying tobacco plants with lux genes, researchers were able to create a tobacco product that would "light by it-self".

12. **Escherichia coli** – *Escherichia coli* are part of the "normal flora" found within the large intestine or colon of humans and other animals, and so are referred to as **coliforms**. Some strains are serious human pathogens, but most live as normal flora and are far more beneficial than harmful (producing vitamin K and colicins). Some important human applications of *Escherichia coli* include: a) water testing, i.e., using *E. coli* as indicators of fecal contamination in water, b) research, i.e., *E. coli* strains have served as common subjects in genetic research, c) recombinant protein production, i.e., *E. coli* strains can be genetically modified and grown commercially to produce proteins initially found in other organisms, including humans. Proteins including human insulin (humulin), human growth hormone (Nutropin or Humatrope) and Factor VIII (Kogenate) can be produced by *E. coli*.

13. **Bdellovibrio** – Bacteria in the genus *Bdellovibrio* can attack and kill other Gram-negative bacteria (bdella = leech and vibrio = comma-shape). Initially thought to be intracellular parasites, Bdellovibrio cells actually feed on host polymers (proteins and nucleic acids) from within the periplasmic space, and do not actually enter the cytoplasm.

14. **Clostridium** – Bacteria within the genus *Clostridium* are primarily anaerobic, endospore-forming bacilli, typically associated with soil and/or water. Several species including *Clostridium tetani*, *Clostridium botulinum*, and *Clostridium perfringens* are important human pathogens know to form potent exotoxins encoded by viral genes. Common gut inhabitants identified as *Clostridium difficile* can cause serious diarrhea and potentially death in patients taking antibiotics because eliminating normal flora allows virulent strains to overgrow and produce damaging levels of toxins.

15. **Mycoplasma** – Bacteria in the genus *Mycoplasma* lack peptidoglycan, are tiny (0.1 to 0.25µm in diameter), often pass through bacterial filters and were initially thought to be viruses. They are now believed to represent the smallest self-replicating life forms and some cause pneumonia.

16. **Bacillus** – Bacteria in the genus *Bacillus* are common endospore-forming bacilli found in soil and rotting vegetation. The genus *Bacillus* has recently been divided, and some species moved to related genera including *Paenibacillus*, *Lysinibacillus*, *Brevibacillus,* etc. *Bacillus thuringiensis* are significant insect pathogens used as biological insecticides (sometimes sold as BT or Dipel). *Bacillus anthracis* are recognized as important pathogens, and *Bacillus subtilis* is the source of the antibiotic bacitracin. Bacteria identified as *Paenibacillus polymyxa* (formerly *Bacillus polymyxa*) produce antibiotics called polymyxins.

17. **Staphylococcus** –Bacteria in the genus *Staphylococcus* are **catalase-positive** and in some cases form yellow-colored carotinoid pigments within their colonies. Various *Staphylococcus* species are found in association with humans and other animals, typically living on the skin and in nasal passages. *Staphylococcus aureus* are important pathogens capable of causing a variety of human disorders, and are often associated with **nosocomial** (hospital acquired) infections.

18. **Lactobacillus –** Organisms in the genus *Lactobacillus* are sometimes referred to as lactic acid bacteria because they form lactic acid as their primary fermentation product, different *Lactobacillus* species are used extensively in the production of cheese, yogurt, sauerkraut and sourdough bread. The unique flavor of San Francisco style sourdough bread is attributed to *Lactobacillus sanfranciscensis* (formerly *Lactobacillus sanfrancisco*).

19. **Lactococcus** – Organisms in the genus *Lactococcus* were formerly categorized within the genus *Streptococcus*, but are now considered to represent a unique species. *Lactococcus lactis* (subspecies *lactis* and *cremoris*) are organisms commonly used in the production of cheese.

20. **Streptococcus** – Organisms in the genus *Streptococcus* are **catalase-negative**, homofermentative short bacilli (cocci when grown in broth media), arranged in pairs or short chains. *Streptococcus thermophilus* are lactic acid bacteria important in the processing of various cultured foods including cheese and yogurt. Most *Streptococcus* live on the surfaces of humans and other animals, and several forms are pathogenic (*Streptococcus pyogenes* are the causative agents of strep throat, scarlet fever and rheumatic fever, while *Streptococcus pneumoniae* are the most common cause of bacterial pneumonia).

21. **Micrococcus** – Bacteria in the genus *Micrococcus* are non-motile, oxidative, **catalase-positive**, inhabitants of soil, water and the skin surfaces of humans and other animals. The genus formerly included a large number of species characterized by their ability to form distinctly colored colonies in pink, orange, yellow, or white when grown on nutrient agar. Most of these are now divided among other genera including *Arthrobacter, Kocuria, Kytococcus* and *Dermacoccus*. Species from these groups commonly form colonies on nutrient agar plates exposed to air, are easily grown in vitro, and are rarely pathogenic.

22. **Mycobacterium** – Bacteria in the genus *Mycobacterium* are Gram-positive, but are resistant to staining due to the high levels of **mycolic acid** (a wax-like lipid) in their cell walls. Once stained, these organisms resist decolorizing, even when exposed to acid-alcohol, so are acid-fast. Most *Mycobacterium* species grow slowly when cultivated and some can be grown only on living surfaces. *Mycobacterium leprae*, the causative agents of leprosy (Hansen's disease) and *Mycobacterium tuberculosis,* the causative agents of tuberculosis are of particular concern.

23. **Streptomyces** – Bacteria in the genus *Streptomyces* are Gram-positive, filamentous organisms commonly found in soil and rotting vegetation. Most species form asexual reproductive bodies called **conidia** at the tips of branching filaments. Members of the genus *Streptomyces* are a primary source for antimicrobial drugs, e.g., Tetracycline, Streptomycin, Neomycin, Erythromycin, Vancomycin and Chloramphenicol. Colonies of *Streptomyces* growing on agar plates emit a characteristic "earthy" odor. This is because *Streptomyces* species produce **geosmin** a volatile metabolite responsible for the pleasant odor of freshly tilled earth, or rain-soaked soil; dirt actually smells like *Streptomyces*.

24. **Chlamydia** – Bacteria in the genus *Chlamydia* are Gram-negative, but unlike most other bacteria, lack peptidoglycan in their cell walls. They are **hypotrophs**, but do not require vectors for transmission. Once thought to be unable to produce ATP, *Chlamydia* cells are now known to have limited ATP synthesis ability. *Chlamydia trachomatis* are the most important, causing both trachoma, an eye infection often resulting in blindness, and a sexually transmitted urethritis similar to gonorrhea. According to the CDC, *Chlamydia* were estimated to infect more than two billion people during 2006.

25. – **Spirochaetes** – Bacteria called spirochaetes are Gram-negative organisms with **flexible cell walls** and axial filaments or **periplasmic flagella**, i.e., flagella located within their periplasmic space. They are generally very thin, and so poorly visible with normal light microscopy. Some spirochetes are parasitic, and some are human pathogens, e.g., *Treponema* (the causative agents of syphilis), *Borrelia* (the causative agents of relapsing fever and Lyme disease), and *Leptospira* (the causative agents of systemic infections resulting in fever, jaundice, and meningitis).