Lecture Outline: Early Life And The Diversification Of Prokaryotes

I. **Early Life and the Origin of Cells**

A. Conditions on Early Earth

1. The Hadean Eon was characterized by extremely hot temperatures.
2. The oldest known fossils are **Stromatolites**, which are the fossilized remains of colonial early prokaryotic cells.

B. Cell Requirements and Formation

1. The cell is the functional unit of life; a minimum of one cell is required to be an organism.
2. All cells are composed of four categories of biological **macromolecules**:
   a. Lipids
   b. Polysaccharides (large carbohydrates, distinct from small sugars/monosaccharides)
   c. Proteins
   d. Nucleic acids
3. Origin of Organic Compounds
   a. Organic molecules contain carbon, and usually hydrogen, oxygen, and nitrogen.
   b. Early experiments mimicked early Earth conditions (heat, inorganic materials, lightning energy) to demonstrate that complex organic molecules, like amino acids (protein precursors), could form spontaneously.
   c. The accumulation of these molecules served as raw material for the first cell.
4. Formation of Vesicles (Precursors to Cells)
   a. The chief molecular component of a plasma membrane is the **phospholipid**.
   b. Phospholipids are **amphipathic**, meaning they have both polar (heads) and non-polar (tails) parts.
   c. Phospholipids self-assemble in water into a spherical **phospholipid bilayer** (vesicle) with non-polar tails facing inward, hiding from the water.
   d. Volcanic clay acted as a catalyst, speeding up the creation of vesicles.
5. The First Cell
   a. The first successful lineage of cells developed sustained **metabolism** (life's specialized chemistry).
   b. The original ancestor to all life was a **prokaryotic cell**.

C. Timeline

1. Life existed at least 3.5 billion years ago, based on dating of stromatolites and individual prokaryotic cell fossils.
2. Prokaryotes were the only organisms in existence for a long time before eukaryotic cells evolved.

II. **Characteristics and Domains of Prokaryotes**

A. General Success and Distribution

1. Prokaryotes are the most successful cell type and vastly outnumber other organisms.
2. Prokaryotes are **ubiquitous** (found everywhere that life exists, or the biosphere).
3. The human body contains 10 to 100 times as many bacteria cells as human cells.

B. Domains of Life

1. Prokaryotic organisms are grouped into two of the three domains: **Bacteria** and **Archaea**.
2. Bacteria and Archaea look identical under a light microscope but have important molecular differences.

C. Prokaryotic Structure and Motility

1. Bacteria have limited morphological variety, generally classified as spherical, rod-shaped, or spiral.
2. Cellular Components:
    a. All cells have a plasma membrane.
    b. Bacteria have a thick, tough **cell wall** exterior to the plasma membrane.
    c. Some bacteria possess a **capsule** (mucous-like layer, often polysaccharides) outside the cell wall that allows them to stick to surfaces.
3. Specialized Structures:
    a. **Fimbriae** are hair-like structures used for sticking in place.
    b. **Flagella** (singular: flagellum) are helical structures used for locomotion (**taxis**).
        (1) Flagella propel the cell through water via propeller motion, spinning using energy from ATP.

D. Metabolism and Biochemistry

1. The true claim to fame of prokaryotes is their **biochemical versatility** (they can perform all known biochemical processes).
2. Nutritional Modes (Autotrophs and Heterotrophs):
    a. All organisms require both an energy source and a carbon source.
    b. Four categories of nutritional modes exist:
        (1) **Photoautotrophs** (Energy: Light; Carbon: Inorganic, e.g., CO_{2})
        (2) **Chemoautotrophs** (Energy: Chemical; Carbon: Inorganic, e.g., CO_{2})
        (3) **Photoheterotrophs** (Energy: Light; Carbon: Organic compounds)
        (4) **Chemoheterotrophs** (Energy and Carbon: Organic compounds/Food)

c. Prokaryotes are the only group of organisms that includes individuals representing all four nutritional modes. Humans are chemoheterotrophs.

3. Cellular Respiration and Photosynthesis
   a. Both cellular respiration and photosynthesis evolved in prokaryotes long before eukaryotes existed.
   b. Prokaryotic cells lack **membrane-bounded organelles** (e.g., mitochondria and chloroplasts).
   c. These metabolic processes occur on the single **plasma membrane**, which is elaborately folded to create necessary reaction surfaces.
4. Oxygenation of the Atmosphere
   a. Early Earth lacked atmospheric oxygen.
   b. The evolution of **photosynthetic bacteria** created oxygen ($\text{H}_{2}\text{O} \to \text{O}_{2}$), gradually building up the atmosphere.
   c. Oxygen serves as the final electron acceptor in cellular respiration.

III. **Genetic Organization and Transfer**

A. Genetic Material
   1. In prokaryotes, the internal compartment is called the **cytoplasm**, where the DNA resides (no nucleus).
   2. A typical prokaryotic cell contains one single, **circular chromosome**, which contains all genes necessary for life.
   3. **Plasmids** are smaller, separate circular loops of DNA that are not essential but contain additional genes that grant extra abilities (e.g., resistance).

B. Cell Organization
   1. Prokaryotes are **unicellular** organisms (one cell is one individual).
   2. Some prokaryotes live a **colonial lifestyle**, often hooking cells together.
   3. Certain colonial prokaryotes exhibit specialization (e.g., heterocysts performing nitrogen fixation while other cells perform photosynthesis), blurring the line between colonial and multicellular life.

C. Horizontal Gene Transfer (HGT)
   1. HGT is the transfer of DNA between cells other than parent-to-offspring (vertical transfer).
   2. HGT is successful across different species because of the **universality of the genetic code**.
   3. Three major mechanisms of HGT in bacteria:
      a. **Transformation**: The uptake of **naked DNA** (DNA spilled from dead cells) from the environment.
      b. **Transduction**: DNA transfer mediated by a **virus** (a bacteriophage). The virus injects its

DNA, which can sometimes be incorporated by the host bacterium, giving it new genes.

c. **Conjugation**: DNA transfer involving physical joining (to conjoin or conjugate).

(1) A hollow tunnel, called a **conjugation tube** (or sex pilus/mating bridge), is formed between a donor cell (F^{+}) and a recipient cell (F^{-}).

(2) The ability to build the tube is coded for by genes on a plasmid.

(3) A replicated copy of the plasmid is passed through the conjugation tube to the recipient. The main circular chromosome is not transferred.

IV. **Archaea and Ecological Importance**

A. Archaea (Archaeans)

1. Many archaeans are **extremophiles**, or lovers of extremes.
2. Examples include:
   a. **Thermophiles**: Thrive in high temperatures (e.g., boiling point or above), such as those found in Yellowstone hot springs or hydrothermal vents.
   b. **Halophiles**: Thrive in extremely salty environments (e.g., the Dead Sea).
3. Archaeans can function as chemoautotrophs, supporting heterotrophic organisms in dark environments (e.g., ocean floor tube worms).

B. Phylogenetic Relationships

1. Evidence suggests that the domains Eukarya and Archaea are more closely related to each other than either is to Bacteria.
2. Bacteria represents the basal lineage in the overall tree of life.

C. Importance of Prokaryotes to Other Life and Humans

1. Essential for the environment, such as making nutrients (like potassium) available for uptake by plants via their roots.
2. Involvement in **Symbiosis** (the condition of living together in a close relationship between two different species).
   a. **Endosymbiosis** is a specific type where one species lives inside the other (e.g., bioluminescent bacteria living in the pouch of a headlight fish).
3. Negative impacts: Some bacteria cause human diseases (e.g., Lyme disease), though no known archaeans cause human disease.
4. Applications in Technology:
   a. **Biotechnology**: Using organisms to produce products for human use (e.g., using fermentation capacity to make industrial alcohol, or genetically engineering bacteria to produce human insulin).
   b. **Bioremediation**: Using organisms to clean up human pollution (e.g., spraying bacteria that consume organic waste like oil spills).