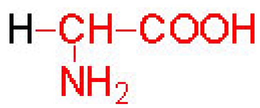
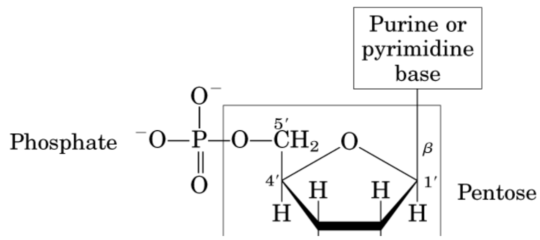
BIOL 300 – Foundations of Biology
Summer 2017 – Telleen
Lecture 5

Life on Earth and Cells

I. What is Life?
  A. Organic Molecules: Life’s Chemical Building Blocks
    1. Scientific evidence supports the idea that life is a natural process and was probably inevitable given the time frame involved
    2. Life on Earth is based on carbon chemistry (organic chemistry)
    3. All terrestrial life is composed primarily of carbon (C) linked to hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), and sulfur (S)
    4. In 1953, Urey and Miller showed that simple organic molecules (like amino acids) form naturally when the conditions of the early Earth are mimicked in the laboratory
    5. Since then, other scientist have shown that amino acids (which make up proteins) and nucleotides (which make up nucleic acids) form under conditions approximating the early atmosphere w/ heavy asteroid/comet bombardment



Glycine, the simplest of all amino acids



The basic structure of a nucleotide

  B. From Organic Molecules to Cells
    1. This process is a bit more of a mystery, but we are slowly gaining a better understanding of it
    2. Possible steps:
      a. Concatenation of building blocks (monomer like amino acids and nucleotides)
      b. Joining together of the monomers to form polymers
      c. Formation of a membrane (made of lipids) which provides a micro environment separated from the outside for metabolism to occur. Lipids form micelles and bilayer membranes spontaneously in H_2O
      d. Development of a way to get energy to drive order. (eg. Concentration gradients, proton pumps, etc.)
      e. Ability to replicate and transfer information (eg. DNA and heredity)
      f. Mistakes in information transfer (eg. mutations)
      g. Building blocks get used up an become scarce
      h. Differential survival of primitive cells that are more stable, reproduce better, and live longer (we’re starting to get at evolution in general terms here)
  C. The Tree of Life
    1. All terrestrial life (that we know of) is related
      a. Utilize DNA as the information molecule
      b. Utilize only left-handed (L) amino acids even though right-handed (D) amino acids exist in nature
      c. Utilize only (D) sugars

d. Evidence of interconnectedness can be traced in DNA sequences to create the tree of life
e. Evidence of evolution is in the DNA sequences also and isn't exclusively shown in the fossil record, which can be less reliable

2. Almost all genetic diversity on our planet is in single celled microbes
3. Eukaryotes are more closely related to the Archea than the Bacteria
4. For most of Earth's history, only Archea and Bacteria were present (first 2.5-3 billion years)
5. Humans are only ~150,000 years old
6. Industrial age is <200 years old
7. The evolution of like has almost been curtailed many times (mass extinctions, etc)

II. The **Cell Theory**

A. A **cell** is a membrane bound unit that contains DNA and **cytoplasm**, and that originated from another cell
B. Since cells are very small (relative to us at least!), they were not observed directly until after microscopes were invented (mid-17th century)
C. Robert Hooke first described cells in 1665. He was examining a piece of cork (plant tissue that is no longer alive) and saw many tiny, empty compartments. He called these cells (because they looked like Monks' quarters)
D. However, biologists didn't recognize the importance of cells until 1838 when Matthias Schleiden, who was studying plant tissue, developed the first cell theory. He wrote: All plants "are aggregates of fully individualized, independent, separate beings, namely the cells themselves."
E. In 1839, Theodore Schwann observed and reported that all animal tissues also consisted of cells
F. The Cell Theory states:
   1. All organisms are composed of one or more cells in which life processes occur
   2. Cells are the smallest living things (nothing smaller is considered alive)
   3. Cells arise only from the division of previously existing cells. Although the first cell(s) must have occurred spontaneously, no evidence for new cells that have arisen *de novo* exists. All life on Earth represents a continuous line of descent from the original cell(s).

III. How big are cells?

A. Cells vary in size (but most are very small).
B. One marine algae (*Acetabularia*) can have cells that are up to 5 cm long
C. Cotton fibers are single cells\
D. Human cells are typically 5-20 um (micrometers, or 10^{-6} meters). At this size, it would take 100-400 cells to span the head of a pin
E. Bacteria are even smaller (<0.2 um)
F. Why are cells so small? It turns out there is an easy answer to this: **Surface to volume ratio**
G. Imagine a round, spherical cell. As the cell grow, the surface area increases as the square of the radius ($SA=4(pi)r^2$). However, the volume increases as the cube of the radius ($Vol=4/3(pi)r^3$). This means that as a cell grows the volume inside increases much faster than the surface area on the outside.
H. Since all building materials and waste must pass through the membrane (surface area) of the cell, eventually a point is reached in which the volume inside is too big to be supported by the surface area and the cell cannot function
I. Some cells get around this limitation using special structural feature:
   1. Nerve cells are long and narrow which alters the SA/Vol ratio

2. Plant cells have cytoplasm that is mostly only along the outer surface of the cells, so the functional volume is smaller
3. Microvilli are small projections on the surface of cells (such as in our digestive tracts) that increase the surface area without an increase in volume

IV. Looking at cells

A. It is not always easy to look at things that are very small, like cells. To examine this problem, we need to think about how we see things.
B. Resolution refers to the minimum distance between two points such that the points can be observed to be distinct. For example, the resolution of the human eye is about 100 um. Imagine we are looking at two dots on a piece of paper. If the dots are 100 um of more apart, we will see each dot distinctly. If they are closer together than that, we will only see a single point with our naked eye.
C. Magnification allows us to get around this limitation. Magnifying glasses and microscopes allow us to magnify images and increase our resolution. However, in this case we are still limited by the resolution of light (which is a few hundred nm (nanometers, or 10^{-9} meters). So even light microscopes can only take us so far.
D. To observe things even smaller than that, electron microscopes were developed. They use electrons instead of light to create images and have resolution as small as 0.2 nm!
E. In addition to magnification, cells are often stained with dyes so that the parts are visible. Many subcellular structures are clear and cannot be seen without staining.

VI. General Cell Structure

A. Cells are membrane bound sacks of fluid
B. Cells are surrounded by a **plasma membrane** that controls the entry of water and other substances into the cell
C. The inside of the cell is called **cytoplasm**. It is often highly organized and compartmentalized.
D. The plasma membrane is about 7 nm thick (~10,000 membrane piled on top of each other would be as thick as a piece of paper)
E. Our working theory of the plasma membrane is the **Fluid Mosaic Model** which states that membranes are sheets of lipids with proteins embedded in them. The phospholipids form a **bilayer**, which is hydrophilic on the outsides and hydrophobic on the inside. This layer is not homogenous and can contain other lipids such as cholesterols and steroids.
F. Membrane proteins float in the bilayer. Some span the entire membrane (such as receptors, channels, and transporters), while others only protrude on one side. Some float freely, while others are fixed by attaching to the cytoskeleton. Often surface proteins are markers that can be used to identify certain types of cells (such as the CD4 receptors on white blood cells that the HIV virus uses to infect them)

VII. **Prokaryotic** Cells

A. Although we won't talk about them much, most life is prokaryotic
B. Prokaryotes are the bacteria and the archaea
C. Prokaryotic cells do not have membrane bound organelles
D. Prokaryotic genomic DNA is circular and located directly in the cytoplasm
E. The plasma membrane is used directly for electron transport/energy production
F. The only organelles in prokaryotes are **ribosomes**, which are the structures that synthesize (translate) new proteins from amino acids based on the sequence on an RNA molecule called a transcript
G. Transcription and translation are coupled rather than spatially separated as in eukaryotes
H. Prokaryotes usually have some form of cell wall outside the plasma membrane, but the structure varies.
I. The cytoskeleton is present in prokaryotes

J. These are the simplest organisms. They are also the original cells, which were the only cells for the first billion years of life on Earth

VII. **Eukaryotic** Cells

A. Contain membrane-bound **organelles** and a **nucleus**
B. Many different functional compartments in each cell instead of one
C. Cells still have plasma membrane, but also have internal membrane systems
D. Organelles are specialized structures in the cytoplasm
E. The **Cytoskeleton**
   1. Made up of polymers of protein (monomers)
   2. Three types: actin filaments, intermediate filaments, and microtubules
   3. Functions:
      a. Establish cell shape
      b. Provide mechanical strength
      c. Locomotion
      d. Chromosome separation in mitosis/meiosis
      e. Transport of organelles within a cell
F. Eukaryotic cell walls
   1. Differ is structure from prokaryotic cell walls
   2. Only some eukaryotic cells have walls (e.g. plants and fungi)
   3. Made up of polymers of sugar molecules (e.g. cellulose and chitin)
G. The animal extracellular matix
   1. Animal cells have an extracellular matrix instead of a cell wall
   2. Attaches animal cells to each other
   3. Made up of a fibers of a triple helix of the protein collagen

VIII. Organelles

A. **Mitochondria** (singular: mitochondrion)
   1. Mitochondria are the power houses of the cell
   2. They are responsible for energy production (respiration) and electron transport
   3. They catalyze the conversion of organic molecules (such as sugars and lipids) to chemical energy the cell can use in the form of ATP (adenosine triphosphate)
   4. Mitochondria have an outer and an inner membrane
   5. Each mitochondrion has its own circular genome

A. Chloroplasts
   6. Chloroplasts are the sites of photosynthesis in plants and algae
   7. Only present in photosynthetic organisms, but in those organisms other forms of plastids exist for functions other than photosynthesis
   8. Like mitochondria, they are located in the cytoplasm and have their own circular genome
   9. They also have an inner membrane system
   10. Photosynthesis is the conversion of CO_2 and H_2O into Glucose (a sugar) and O_2 using energy from light:

chlorophyll
Carbon Dioxide + Water ---------------> Glucose + Oxygen
radiant energy (food)

B. The **Endosymbiont Theory** of the origin of mitochondria and chloroplasts
   1. These organelles are thought to originally have been autonomous prokaryotic cells that were engulfed by another prokaryote
   2. Evidence includes the circular genomes conservation of structure and metabolic activities from known prokaryotes
C. **Ribosomes**, which we have already talked about (see prokaryotes)

D. The **Endoplasmic Reticulum (ER)**
   1. The ER is a network of membranes that form channels in the cytoplasm
   2. The space inside the ER is called the lumen. In the lumen, proteins are folded, modified, and readied for transport to other locations
   3. Ribosomes are often associated with the outer surface of the ER creating rough ER (as opposed to smooth ER that has no ribosomes associated with it)
   4. Generally more dense around the nucleus

E. The **Golgi Apparatus**
   1. Sometimes called the Golgi Body
   2. Consists of a “stack” of membranes bound compartments
   3. The Golgi receives proteins from the ER via vesicles
   4. Proteins are modified (e.g. glycosylation) here as well as transported to their final destinations
   5. Many subcellular membranes are derived from the Golgi (e.g. Lysosomes)

A. Lysosomes
   6. Membrane enclosed vesicles that contain digestive enzymes derived from the Golgi
   7. Proteins are transported from the ER to the Golgi where they are packaged as vesicles, which then bud off to form the lysosomes
   8. Their function is to degrade cellular materials marked for destruction and recycling

B. Peroxisomes
   9. Formed from the ER
   10. Isolate specific chemical reactions from the rest of the cell
   11. Detoxify various potentially harmful molecules
   12. These reactions would be dangerous to the cell if not compartmentalized

C. Vacuoles
   13. Membrane bound sack in the cell
   14. Maintain turgor pressure in plant cells
   15. Stores H_2O and various chemicals
   16. Stores insoluble waste products

F. The **Nucleus**
   1. The largest organelle
   2. Surrounded by a double membrane with large pores to allow passage through
   3. Contains the chromosomes
   4. Site of transcription
   5. Nucleoli (singular: nucleolus) are dense regions where ribosomes are made before being exported to the cytoplasm to synthesize proteins

G. Chromosomes and Chromatin (are not organelles, but we want to review what they are)
   1. Chromosomes are made of chromatin (a complex of DNA and proteins called histones)
   2. Chromatin is sometimes visible as dark strands in the nucleus
   3. Condensed chromosomes are not present most of the time.
   4. They only condense to the form we are used to seeing during cell division
   5. If chromosomes were condensed all the time, RNA polymerase couldn’t get in to make mRNA transcripts!