ET: Astronomy 230

This Class (Lecture 16):

Nature of Life

Next Class:

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Rachael Sherwood
Eric Ou

HW #4 is due today.

Presentations Monday Oct 3rd
David Bradbury
Rachael Sherwood
Eric Ou

Presentations Friday Oct 7th
Sujay Javdekar
Christopher Norman
Mark Lenkowski

Music: *The Universe Song* – Animaniacs

Outline

- Carbon, oh Carbon
- Build up proteins (structural and enzymes) and nucleic acids. The essentials for life.
- Amino Acids
- Proteins
- DNA/RNA

Drake Equation

= 0.42

Earth-like planets /year

Earth Chauvinism?

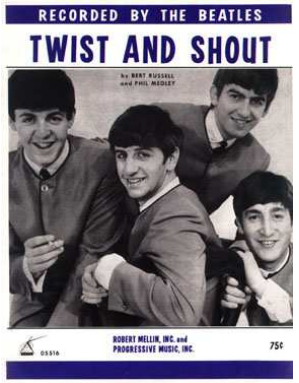
Frank Drake

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Rate of star formation	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	10 stars/ yr	0.38 systems/ star	0.11 planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

Good News

- H,O,N,C is very common in universe everywhere as far as we can tell
  - If life were based totally on rare elements, we might expect its occurrence to be extremely rare…
- So, we expect ET life to be based primarily on HONC.
  - The four primary chemical elements of life with some other simple components can produce staggering complexity.
- But, each planet will feature its own environment of trace elements giving each planet's life a unique twist to the standard HONC chemistry



http://www.rarebeatles.com/sheetmu/smtwist.jpg

Nature's Complexity

- The workings of biological molecules are an absolute marvel
  - How did this complexity develop?
  - How did it evolve?
- As complex and mysterious as life on Earth may be, we can begin understand it
- Start with the basics:
  - Why are H,O,N,C the basis for living organisms?
  - How do the molecules formed by these (and other elements) work to make DNA, proteins, life?

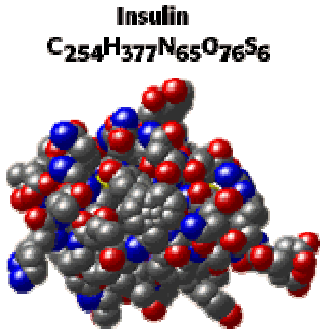
http://europa.eu.int/comm/environment/life/toolbox/logo_life_high_resolution_2.jpg

We Are Special Stuff?

- Why is Earth-life based on H,O,N,C instead of the more abundant elements found on Earth?
  - Suggests that the formation of life is not able to be formed just out of anything lying around.
  - The selection of H,O,N,C seems to be a necessity of the chemistry of life.
  - In general, Earth life is a carbon based life. Carbon is the main backbone of the chemistry.
- Is this good news?

Why Carbon Based Life?

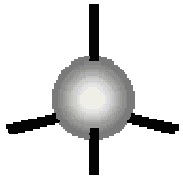
- Carbon's electronic structure allows it to form long chains
  - Chains of atoms and chains of molecules– complexity
  - Life needs bonds to be stable but breakable
- Good for us, at temperatures at which water is liquid, carbon bonds are stable but breakable
- Organic chemistry is the special branch devoted to carbon chemistry.



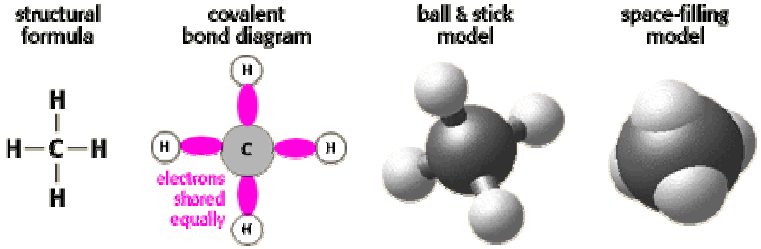
http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page2.html

Bond, Carbon Bond

- Carbon has 6 protons, 6 neutrons, and 6 electrons
  - Electrons distribute themselves in "shells"
    - Pauli exclusion principle
    - 1st (inner-most) shell wants to be filled by 2 electrons
    - 2nd shell wants to be filled with 8 electrons
    - BUT, Carbon only has 6 electrons!
      - So, Carbon has 2 electrons in inner shell and 4 in 2nd shell
      - It likes to bond: to "fill" second shell by sharing with four other electrons



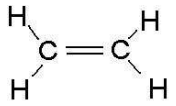
The Simplest C Bond– Methane

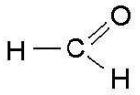


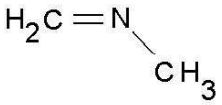
Not many other elements can share 4 bonds.
Silicon, which is much more abundant, can.
Silicon based life?

http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page2.html

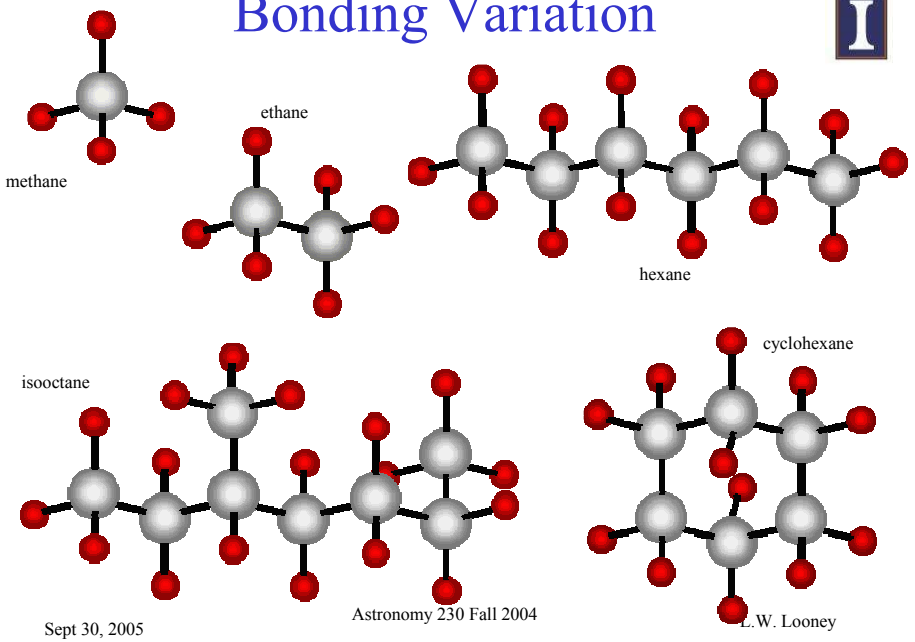
More Bonds





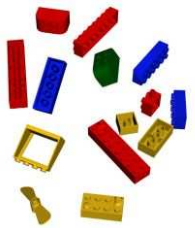


Bonding Variation



Monomers and Polymers

- All of the fundamental chemicals of life are organic polymers
  - A monomer is a small *molecule* (like carbon bonds we have seen).
  - A polymer is a number of monomers joined together to form larger, more complex molecules. Making large structures out of simple building blocks.
  - Polymers are nice for life, as they can form complex and repetitive sequences.



http://www.iit.bme.hu/~szirmay/webdemo/modellek/3ds/object/legos.jpg

Unique?

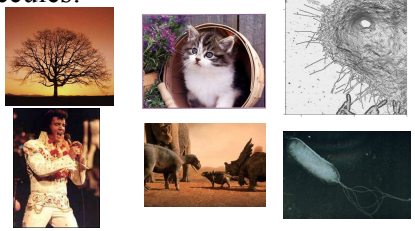
- As far as we know, the complexity of terrestrial biochemistry can only be achieved with carbon-based molecules.
  - Especially considering the need for liquid water
    - Which puts restrictions on the temperature in which the chemical reactions occur

Nitrogen

- Actually plays a central role in organic chemistry.
- It is prominent in biological compounds due to its reactivity with carbon and its propensity to form chains in organic compounds

Molecular Basis of All Life

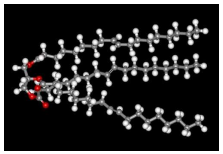
- Great diversity of Life on Earth, but still it is 70% water and 24% four large molecules:
  - Proteins
  - Nucleic Acids
  - Lipids
  - Carbohydrates

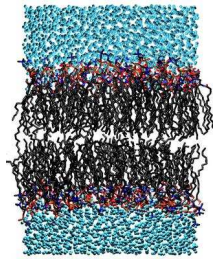


- Not completely true. The simplest life, viruses, can have a single molecule of nucleic acid surrounded by a protein coating.

Lipids

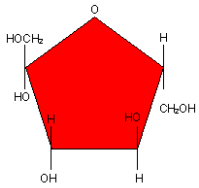
- Lipids are almost entirely composed of carbon and hydrogen with some oxygen.
- The group of fats, oils, waxes, etc. — hydrophobic
- Lipids are essential for cell membranes.





Carbohydrates

- Carbohydrates are comprised of sugar molecule chains.
- Carbohydrates are used for energy storage in cells.
- In this class, we will concentrate on **proteins** and **nucleic acids** as the crucial bits for life.
- That's enough for viruses, and probably protolife was similar?



(Fructose, a monosaccharide)
(The pentagon structure represents five carbon atoms.)

http://www.n101.com/HealthNotes/HNs/Diet/Carbohydrate_Loading_Diet.htm

http://library.thinkquest.org/12090/carbo.html

Proteins vs Nucleic Acids

Proteins are either structural elements or they provide catalytic reactions (enzymes).

Nucleic acids (DNA/RNA) carry the genetic information– Replication of nucleic acid is crucial to reproduction of organism.

- They are the polymers of life!
- They form complex, repetitive sequences.
- The order of the monomers determines the function of the polymers.
- Monomers are the letters and words in the molecular basis of life, and polymers are the messages.

How is Life Put Together?

- Living things are not just bags of large molecules and polymers mixed in a big soup
  - Living things have structure
  - Plants, animals have different parts
    - Skin, Hair, Leaves, Hearts, etc.

How do these structures relate to the complex organic polymers and DNA?

http://www.shopnatural.com/product/1644.jpg

DNA Based Life

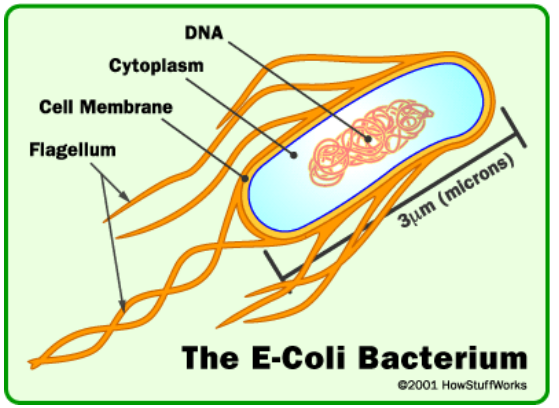
- All life is based on DNA. What does this mean?
  - The basic reproducible unit of all living organisms is centered around the complex DNA molecule.
  - DNA lives in cells
    - Except in viruses, which are basically pure DNA
  - Cells of different types form different parts of each organism based on the instructions of the DNA
    - Heart cells different from blood cells.
    - Leaf cells different from root cells.

Cell Bits

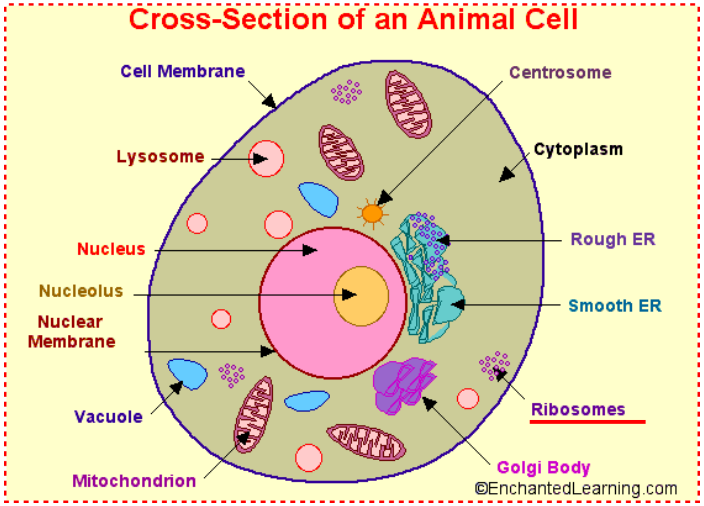
- The cell function directly relates to a different organic polymer:
  - Proteins: Polymers made of amino acid monomers that form the structural components of the cell or form enzymes that do all the real chemical work inside the cell.
  - DNA/RNA (nucleic acids): The genetic coding molecules that controls enzyme and cell reproduction. Polymers made of a sugar, phosphate, and nucleotides
  - Sugars: The energy source of cells

Bacteria Cells

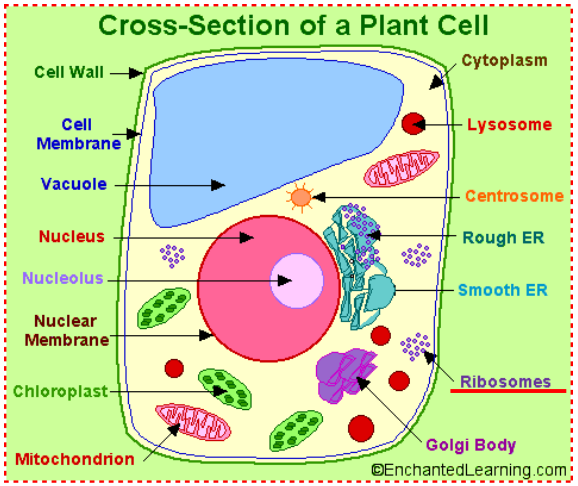
- Simplest cell that exists today.
- Completely self-contained organism.
- Human cells are much more complicated.
- 1 trillion cells in a typical human and they're usually 10 microns in diameter.



Animal Cells



Plant Cells

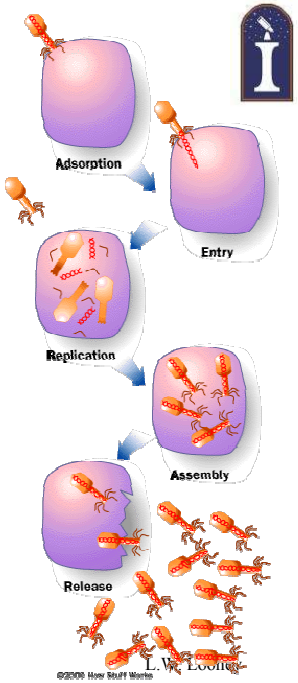


Cell Variation

- Bacterial cells lack a nuclear membrane enclosing the cell's nucleus
- Animal cells have a nuclear membrane but lack a distinct cell wall
- Plant cells have both a nuclear membrane and a cell wall

Is a Virus Alive?

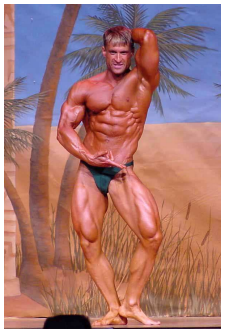
- Straddles between the living and non-living
- The protein protects the virus until it enters a living cell, where the nucleic acid is released.
- Using the cell's machinery, the nucleic acid reproduces itself.
- They are all parasites, so thought to be from free-living organisms and not descendents of early life.



First: Focus on Proteins

Note: the human body is about 20% protein.

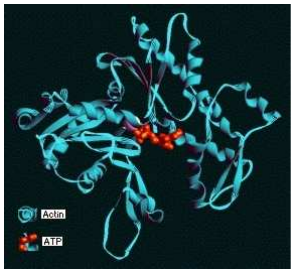
Type	Examples
• Structural	tendons, cartilage, hair, nails
• Contractile	muscles
• Transport	hemoglobin
• Storage	milk
• Hormonal	insulin, growth hormone
• Enzyme	catalyzes reactions in cells
• Protection	immune response



http://66.41.139.241:8000/fitam/muscle.JPG

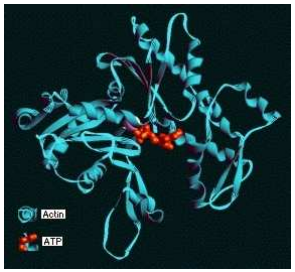
A Type of Protein: Enzymes

- All of the day-to-day work of life is being done by enzymes. Enzymes are little chemical-reaction machines.
- The purpose of an enzyme is to allow the cell to carry out chemical reactions very quickly.
- These reactions allow the cell to build things or take things apart as needed– grow and reproduce.



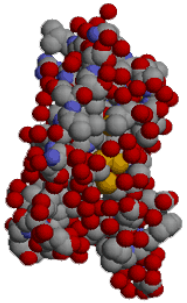
A Type of Protein: Enzymes

- E. coli has about 1,000 different types of enzymes floating around in it at any given time.
- To understand enzymes is to understand cells. To understand cells is to understand life on Earth.
- Maybe similar to life in space?
- Enzymes are made from 3-D structures of amino acids orchestrated by the DNA.



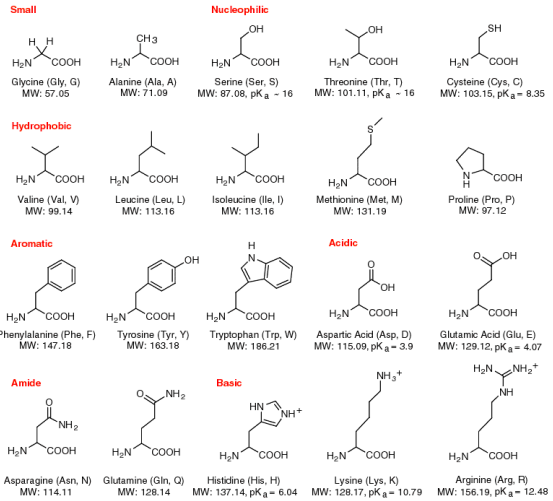
Focus on Proteins/Enzymes

- Proteins are large, very complex, and very numerous.
- All proteins in living organisms are made from combinations of 20 types of amino acids (about 100 available though).



Amino Acids

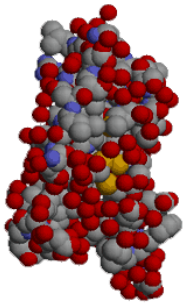
- Amino acids are the building blocks (monomers) of proteins (polymers) .
- Think of these as 20 amino acids as beads on a string that make up a protein.
- Or a 20 letter alphabet that makes a 100+ letter word, a protein



http://www.neb.com/neb/tech/tech_resource/miscellaneous/amino_acid.html

Proteins Focus

- Example: Enzymes (a type of protein) are made up of 100s to 1000s of those 20 amino acids, with a particular sequence.
  - This gives 20^{100+} possible combinations
    - How many 100 character sequence can you form from the alphabet?
- **BUT, arguably about 10,000 proteins are essential for life on Earth, maybe less.**

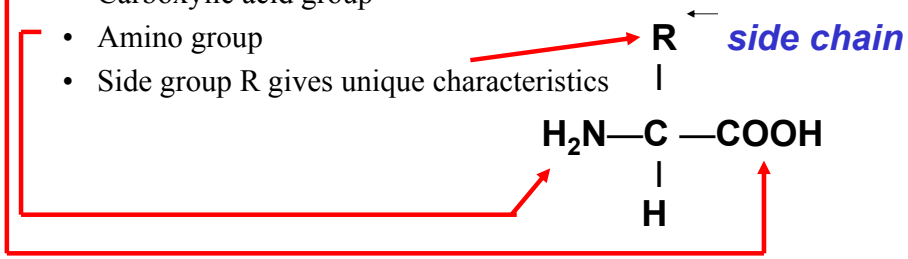


Protein Desert

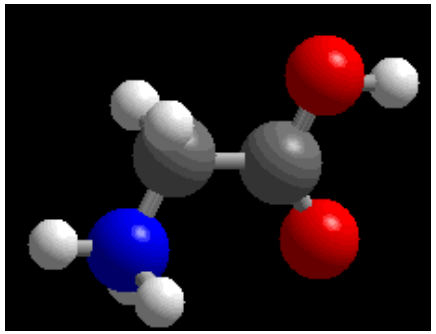
- The fact that only 10,000 of the billions+ of proteins are essential, suggests that life is a little picky.
- Only certain combinations seem to work?
- Does this mean that ET life would find the same useful permutations as Earth life found.
  - Many options were available
  - But, only a small fraction really worked?

Amino Acids

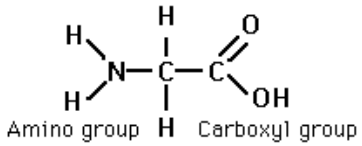
- Are the monomers from which proteins (polymers) are made– building blocks.
- Combinations of the amino acids make the proteins needed– only 20 amino acids used by life.
- Carboxylic acid group
- Amino group
- Side group R gives unique characteristics



Glycine

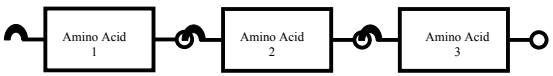


- Simplest amino acid. Just an H in the R position.
- Main ingredients are HONC– other amino acids contain Sulfur (S) as well.



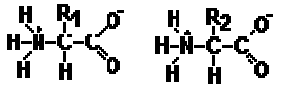
Getting Hooked Up

- Amino acids are monomers
- Proteins are polymers of amino acids of a certain type. A number of specific amino acids "hook up" to form a specific protein.
- As a chain grows, there is always a hook (the amino group) on one end and an eye (the carboxyl group) on the other.
- Really a peptide bond.



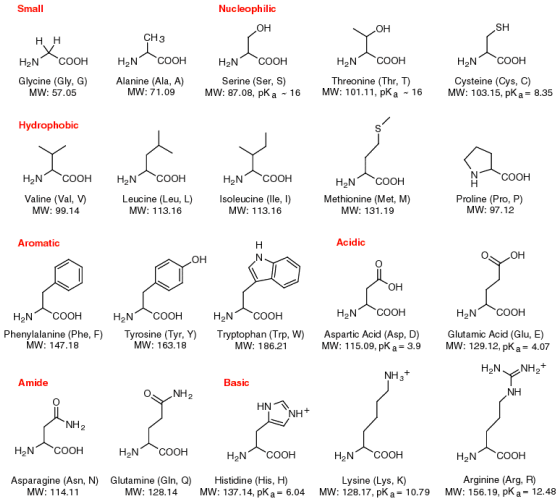
Peptide Bond

- When in a solvent (water), the OH loses an H, and the NH_2 gains an H.
- We have positive and negative attracted to each other.
- A peptide bond is formed! (Just think of the hook and eye.)
- Good bonding is very important to life– some of the nucleic acids can be huge (up to 10^{10} atoms)



So?

- Amino acids are essential for life– building blocks.
- But who orchestrates or writes the message (the special proteins) that the amino acids make up?
- Need something to teach them how to spell.



http://www.neb.com/neb/tech/tech_resource/miscellaneous/amino_acid.html