Astronomy 230

Section 1– MWF 1400-1450

106 B6 Eng Hall

<u>This Class (Lecture 11):</u>

Nature of Life.

<u>Next Class:</u>

Nucleic Acids.

Some Oral Presentation on Feb 16th and 18th!

Mike Somers
Chris Kramer
Sarah Goldrich

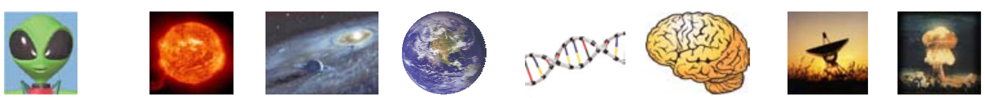
Emily Beal
Adam Quinn
Chris Hall

Outline

- What is n_e?
- Time to turn to life on Earth.
- What are the main properties of life?
- H, O, C, and N are the main elements of life. Why?
- Carbon has 4 bonding sites.
- Amino Acids
- Build up proteins (structural and enzymes) and nucleic acids. The essentials for life.

Drake Equation

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	Rate of formation of Sun-like stars	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	**0.34**					
	Stars/year						

Earth Chauvinism?

n_e

- Complex term, so let's break it into two terms:
  - n_p: number of planets suitable for life per planetary system
  - f_s: fraction of stars whose properties are suitable for life to develop on one of its planets

$$n_e = n_p \times f_s$$

$$n_p = 1.3$$

http://nike.cecs.csulb.edu/~kjlivio/Wallpapers/Planets%2001.jpg

Adding it all up

Stellar Requirement	*Mass Limit*	*Fraction OK*	*Cumulative Fraction*
Heavy Elements	…	0.9	0.9
Main Sequence	…	0.99	0.891
Main Sequence Lifetime	$M < 1.25\ M_{sun}$	0.90	0.890
Synchronous Rotation/ Flares	$M > 0.5\ M_{Sun}$	0.25	0.200
Wide Binary Separation	…	0.50	0.1
Not a Binary	…	0.30	0.06

f_s

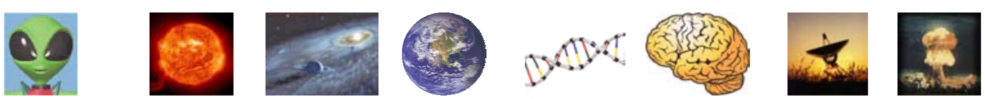
- Can range from 0.06 to 1.0.
- In this class, we estimated a value of $f_s = 0.16$

Then, we can estimate n_e

$$n_e = n_p \times f_s = 1.3 \times 0.16 = 0.208$$

Drake Equation

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	Rate of formation of Sun-like stars	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	**0.34**	**0.208**				
	Stars/year	Planetary System/star	Livable Planets /Planetary System				

= 0.70

Livable Planets /year

So Far, We have Studied

- The Universe
  - Big Bang
    - Creation of hydrogen, helium…
  - Galaxy formation
    - Swirls of elements embedded in self-gravitating cloud of dark matter
  - Star birth
    - Energy generation and element production in self-gravitating mass of gas
  - Planets
    - Ice, rock, gas surrounding star form planetesimals, then planets

Life on Earth

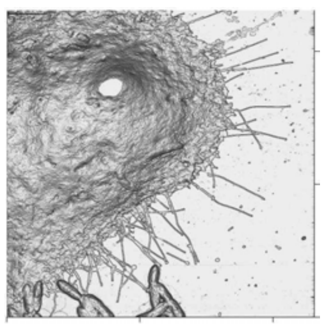
- Time to examine terrestrial evolution.
- Need to understand what is needed for life to arise.
- Again, some Earth chauvinism.
- Relies on chemical evolution
- Eventually life began?
- In our scientific approach, we look at life as a result of chemical evolution of complexity.
- We will view the formation of “life” on planets as we did star formation
  - A natural consequence of natural laws
  - More specifically, as a consequence of the complex chemistry that is sometimes achieved.

Cosmic Imperative?

- But is life a cosmic imperative?

- Just like gas forms galaxies, and in galaxies stars and planets form, do chemicals on some planets form molecules that lead to life?

All Made from the Same Stuff



Element Basis of Life

- About 95% of the mass of all terrestrial organisms is composed of only 4 out of 90 elements
  - Hydrogen (61% in humans)
  - Oxygen (26% in humans)
  - Carbon (10.5% in humans)
  - Nitrogen (2.4% in humans)

- HOCN is essential to life and it is common in space.

Trace Elements

In addition to HOCN, there are some other elements that are essential for life but in *smaller* amounts:

- Sulfur, magnesium, chlorine, potassium, sodium
  - These other elements make up about 1% of mass of living organisms
  - Exist in roughly the same concentration in organisms as in ocean water
  - Highly suggestive that life began in oceans
  - Furthermore suggests that the evolutionary processes occurred on Earth. Panspermia problems?

Good News

- H,O,C,N 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 more rare…
- So, we expect ET life to be based primarily on HOCN. 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 HOCN chemistry

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 to understand it
- Start with the basics:
  - Why are H,O,C,N the basis for living organisms?
  - How do the molecules formed by these (and other elements) work to make DNA, proteins, life?

Special Stuff?

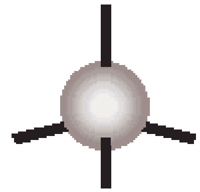
- Why is Earth life based on H,O,C,N instead of the more abundant elements found on Earth?
  - Suggests that the formation of life is not able to be formed just out of anything lying around.
  - The selection of H,C,N,O seems to be a necessity of the chemistry of life.
  - In general Earth life is a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

Why Carbon Based Life?

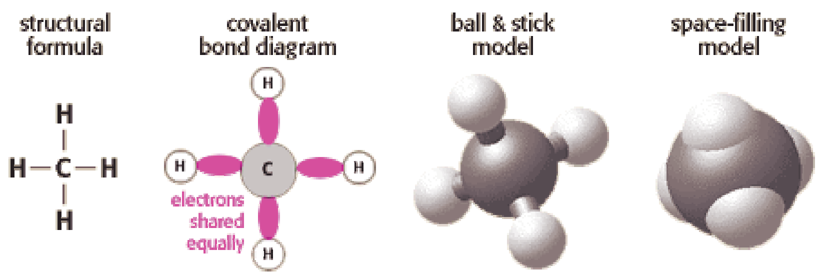
- Carbon's electronic structure allows it to form long chains
  - Chains of atoms and chains of molecules– complexity
  - Life needs bonds to be stable but breakable
- Good for us, at temperatures at which water is liquid, carbon bonds are stable but breakable
- Organic chemistry is the special branch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

Bond, Carbon Bond

- Carbon has 6 protons, 6 neutrons, and 6 electrons
  - Electrons distribute themselves in "shells"
    - Pauli exclusion principle
    - 1^{st} (inner-most) shell is filled by 2 electrons
    - The 2^{nd} shell would be 'filled' by 8 electrons, but its only got 4
      - So, Carbon has 2 electrons in inner shell and 4 in 2nd shell
      - It likes to bonds to "fill" second shell by sharing with four other electrons



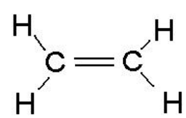
The Bond– Methane

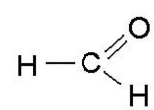


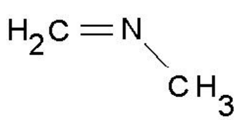
Not many other elements can share 4 bonds.
Silicon, which is much more abundant, can.

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

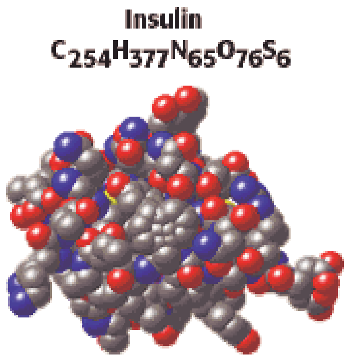
More Bonds





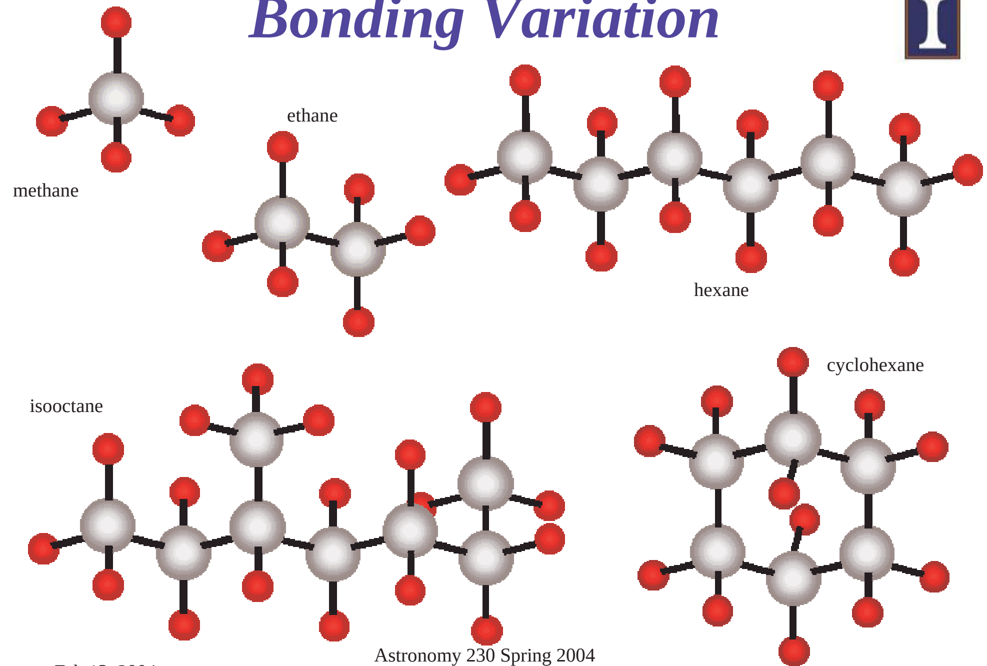


And More



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

Bonding Variation



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 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 and Carbohydrates

- Lipids are almost entirely composed of carbon and hydrogen with some oxygen.
- Lipids are essential for cell membranes.
- Carbohydrates are comprised of sugar molecules.
- Carbohydrates are used for energy storage of cells.
- But we will concentrate on proteins and nucleic acids as crucial for life.
- They are enough for viruses, and there may have been protolife that was similar?

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.
  - Polymers are nice for life, as they can form complex and repetitive sequences

Proteins and Nucleic Acids

- Proteins are either structural elements or catalyze reactions (enzymes).
- Nucleic acids carry the genetic information– Replication of nucleic acid is crucial to reproduction of organism.
- Both are made of polymers.
- Can 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?

DNA Based Life

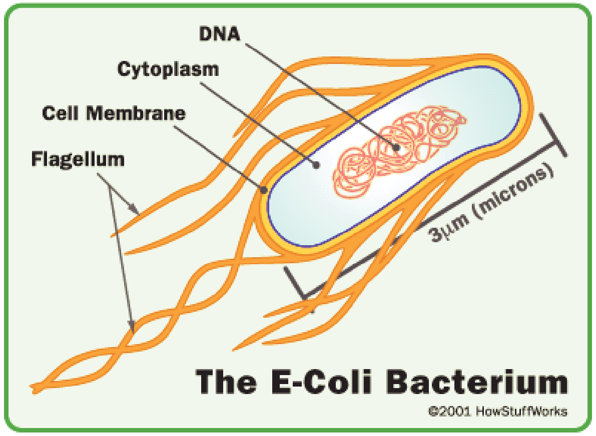
- All life is based on DNA. What does this mean?
  - The basic reproducible unit of all living organisms is centered around the complex DNA molecule.
  - DNA lives in cells
    - Except in viruses which are basically pure DNA
  - Cells of different types form different parts of each organism
    - Heart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

Cells

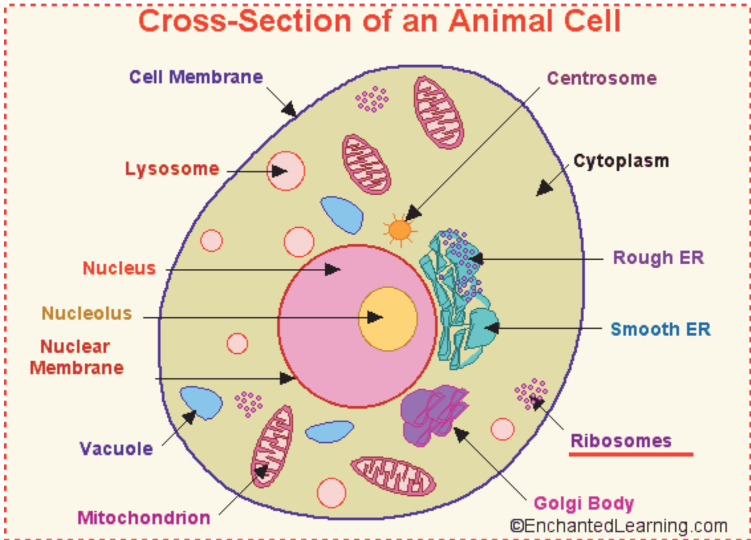
- The cell function directly relates to a different organic polymer:
  - <u>Proteins</u>: Polymers of amino acid monomers that form the structural components of the cell or form enzymes that do all the real chemical work inside the cell.
  - <u>DNA</u>: The genetic coding molecules that controls enzyme and cell reproduction
  - <u>Sugars</u>: The energy source of cells

Bacteria Cells

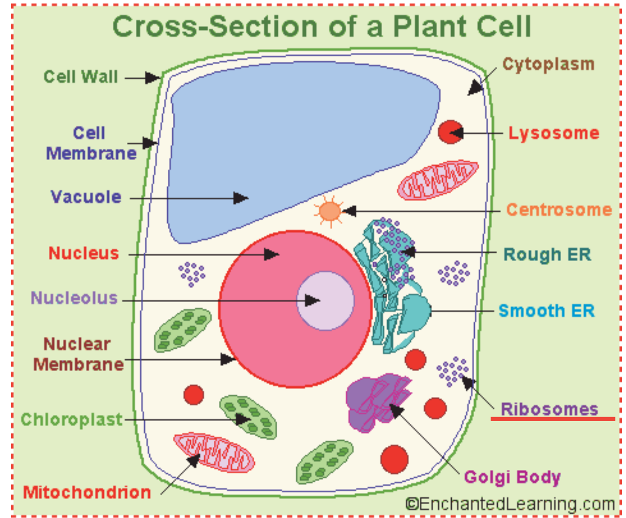
- Simplest cell that exists today.
- Completely self-contained organism.
- Human cells are much more complicated.
- 1 trillion cells in a typical human and they're usually 10 microns in diameter.



Animal Cells



Plant Cells

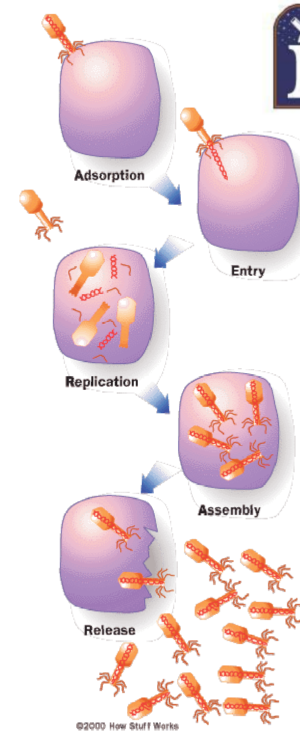


Cell Variation

- 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

Viruses

- 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.



Proteins

- Proteins can be large, very complex, and are very numerous.
- All proteins in living organisms are made from combinations of 20 types of amino acids (about 100 available though).
- Example: Enzymes are made up of 100s to 1000s of those 20, with a particular sequence and shape.
  - This gives 20^{100+} possible combinations
    - How many 100 character sequence can you form from the alphabet?
- BUT, only about 10000 proteins are used.
- The human body is about 20% protein.

General Protein Types

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

Protein Desert

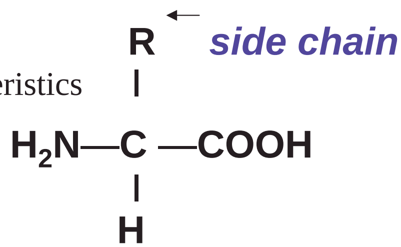
- The fact that only 10000 of the millions of proteins are used, suggests that life is a little picky.
- Only certain combinations seem to work?
- Does this mean that ET life would find the same useful permutations as Earth life found.
  - Many options were available
  - But, only a small fraction actually worked

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.
- 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 (so proteins) orchestrated by the DNA.

Amino Acids

- Are the monomers from which proteins & nucleic acids (polymers) are made– building blocks.
- Combinations of the amino acids make the millions of proteins needed
- The order of the amino acids determine the formed protein or nucleic acid
- Carboxylic acid group
- Amino group
- Side group R gives unique characteristics



Glycine