# Astronomy 230

## Section 1– MWF 1400-1450

## 106 B6 Eng Hall

This Class (Lecture 14):

Origin of Life – Part II

Next Class:

Alternatives

*Midterm is March 12!*

*The Exam will be in the Astronomy Building Classroom, room number 134.*



# Outline

- Origin of life?
- The Miller-Urey Experiment.
- Early monomers
  - Formed in the atmosphere?
  - Around hydrothermal vents?
  - In space?
- Early polymers ?
- Early Nucleic acids ??



# Chemical Evolution

- Chemical basis of life obviously crucial.
- Apparently evolution of life is a continuation of tendencies toward greater complexity
- Chemical evolution has 3 steps:
  - Synthesis of monomers
  - Synthesis of polymers from the monomers
  - Transition to life.



# First Life

- We currently think that life appeared on Earth around 3.8 x $10^9$ years ago, or only 0.7 x $10^9$ years after the formation of the Earth.
- That is about the same time as the heavy bombardment ended. So, that means life was fast– perhaps only a few 100 million years.

# Synthesis of Monomers

- Life arose under the following conditions
  - Liquid water
  - Some dry land
  - A neutral or slightly reducing atmosphere (This is somewhat new).
    - Reducing has elements that *give up* electrons, e.g. hydrogen. A good example is the atmosphere of Jupiter.
    - Oxidizing has elements that *take* electrons, e.g. oxygen. A good example is the atmosphere of Mars.
    - Neutral is neither.
  - Energy sources, including UV light.



# Miller and Urey Experiment

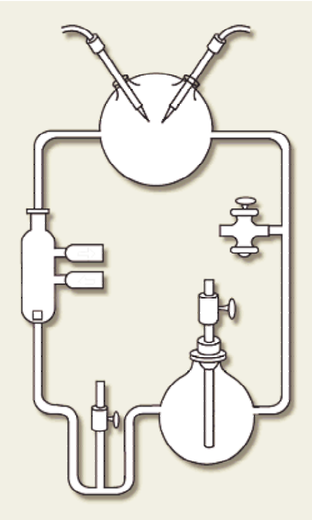
- In 1953, Miller and Urey (UC) tried to duplicate conditions that they believed existed on the Early Earth– a heavily reducing atmosphere.
- They Mixed $CH_4$, $H_2$, and $NH_3$ gases in a flask for the atmosphere, and connected that to a flask with water for the oceans. A spark was used in the atmosphere flask to simulate lightning.
- They found interesting organic molecules in the "ocean".

http://physicalsciences.ucsd.edu/news_articles/miller-urey-resurrected051903.htm



# Miller and Urey Experiment

- In particular 4 amino acids were made: glycine, alanine, aspartic acid, and glutamic acid. Also nucleotide bases, and acetic acid.
- It has been shown that ALL 20 amino acids needed for life can form in this way.
- http://www.ucsd.tv/miller-urey/
- Does not produce directly all monomers of nucleic acids, but intermediates were produced.



http://www.vobs.at/bio/evol/e05-millerurey.htm



# Early Monomers

- We do not have a detailed theory of how all the monomers arose on the early Earth.
- General conclusion is that many of the monomers needed for life can be produced in a strongly reducing atmosphere, but that different environments are needed to get specific monomers.
- Don't forget that after the monomers are formed they MUST come together to form the polymers of life.

# Early Monomers

- Still, the Miller-Urey experiment legitimized the scientific study of life. The production of amino acids under the presumed conditions of the early Earth was exciting.
- But the assumptions of the experiment have been questioned.
  - Early notions of methane-rich reducing atmosphere are wrong
  - We still don't know early atmospheric composition well enough to make stronger case
  - We still don't know how this leads to DNA, the basis of all terrestrial life
- Recently, a group in Japan has showed that with enough energy, you can still get significant yields of amino acids in a mildly reducing environment.



# Other places

- Maybe if we require (still not sure) a strongly reducing environment, we have to look elsewhere.
  - Area around undersea hot vents, some of which have $CH_4$, $NH_3$, and other energy-rich molecules like hydrogen sulfide.
  - Interstellar space.



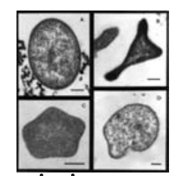
# The Underwater Vents

- Miles below the ocean surface, life lives on the edge! Places were sunlight never reaches.
- From regions of volcanic spreading of the floor, hydrothermal vents or black smokers, underwater geysers, spew mineral-rich superheated water.
- No plant life, but life thrives. So what does life live on?
- Chemical reactions or chemosynthesis to produce food instead of the Sun.
- Some life is bacteria, some eat the bacteria, some eat those that eat the bacteria, and some have bacteria inside them in a symbiotic relationship.



# The Hot Origins Theory

- Vents are rare examples of a food chain that does not rely ultimately on photosynthesis.
- Demonstrates that pre-biotic synthesis can occur, but did life begin there?
- But current vents are short-lived– a few decades.
- And hot– if synthesis first occurred there, it might have been quickly destroyed.
- But live is common in hot environments
  - Hot Springs (like in Yellowstone)
  - Hot oil reservoirs up to 2 miles underground.



- Many of those organism display old genetic characteristics, but some say not ancient enough.
- Did life start somewhere cushy and move there?

# Interstellar Space

- Another reducing atmosphere is space and the circumstellar disk from which our solar system formed.
- We have seen complex molecules in space.
- The ices would have been destroyed this close to the Sun, but farther out would have been fine.
- Comets could transport the molecular binding dust grains to the Earth.



# Comets

- Have similarities to interstellar ices
- Comets hit the Earth, and did so much more often in the past.
- About 5% of comets are carbonaceous chondrites, which contain about 1-2% of their mass in organic compounds, including amino acids of non-biological origins (remember the Murchison meteorite).
- Can life get transported?
- Panspermia again.




# So?

- We don't know the origin of the monomers that are needed for life.
- But, there are a variety of processes that could produce them.
  - In Earth's early atmosphere
  - Near hydrothermal vents
  - In interstellar space
- The next step is polymerization



# Synthesis of Polymers

- If we assume that the early monomers for proteins and nucleic acids existed on the early Earth, then is it plausible that they would polymerize?
- The standard idea of the prebiotic soup would suggest that it is easy to form polymers, but not so fast.
- The problem is that the separate monomers are a lower energy state. They like to be separate.
- It's an uphill battle for the early monomers to turn into polymers.

http://www.heartsong3.com/Images%202000/Uphill.jpg

# *Polymer Pressure*

- Hmm.. Does this mean that the key polymers that keep us alive are intrinsically unstable?
- Yes.
- But, we are constantly inputting energy into the system– our body.
- A simple pattern: simple components + energy leads to greater complexity
- But for early life, the problem was for polymers to stay together. Water helped pull them apart.



# *Making Them Hook Up.*

- One idea is for the early soup to quickly evaporate into a condensed soup– so the monomers can join up.
- Another idea, is to find an energy producing reaction that promotes polymerization.
  - Energy currency in life now is ATP (adenosine triphosphate), which is an adenine base, a ribose sugar, and a tail of 3 phosphates. The phosphates bonds are broken to provide energy and allow bonding.
  - Too complicated for early life, but there are other similar molecules that could do a similar job. Maybe produced in a Miller-Urey procedure.



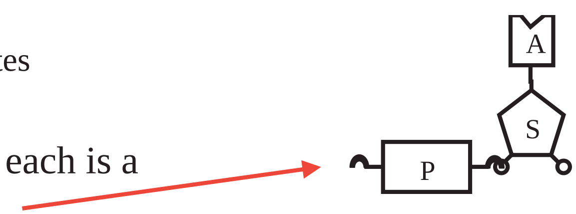
# *Hooking up Dirty*

- Another possibility for polymerization is in clay soils.
- Clay has layers of silicates and water.
- Add water, the layers expand and amino acids can move between layers.
- Remove water, the layers contract and the amino acids get absorbed onto the clay surfaces. Sort of like dust grains in space.
- Experiments have shown that certain clays, promote polymerization of 50 or more amino acids chains with high efficiency.
- Add water, and the polymers are released.
- Sort of like the tides of the ocean.



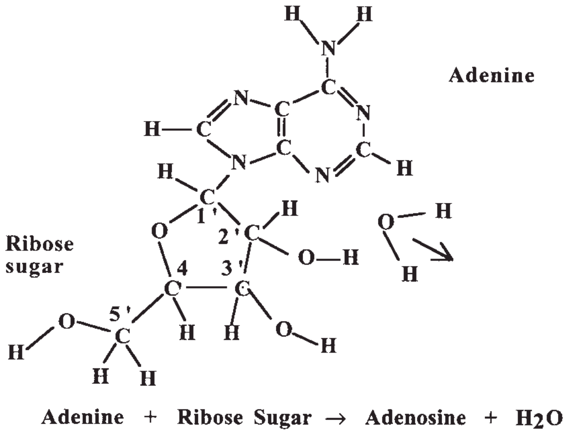
# *So… And RNA/DNA?*

- There are a few ways that amino acids can hook-up and form polymers, but nucleic acids are more difficult to understand as they are more complex.
- What is the basic monomer of RNA or DNA?
- Remember the building blocks are:
  - Sugars
  - Phosphates
  - Bases
- So, one of each is a <u>nucleotide</u>



# Nucleoside Synthesis

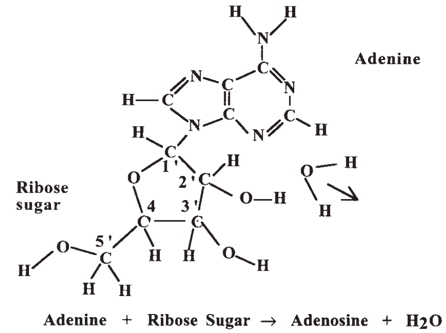
- Not well understood.
- Can number the carbon atoms in the ribose sugar.
- It is essential that the base attach at the number 1 carbon only. Otherwise, it is not a nucleoside.
- The base can attach at the 2 or 3 carbon.
- Why was bond 1 preferred on the early Earth?

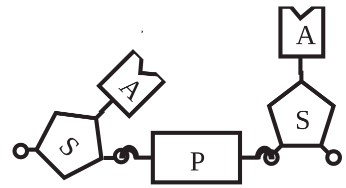





# Phosphate Issues

- To make a nucelic acid, the phosphates <u>must</u> attach at the 3 and 5 carbons.
- In the lab, the phosphates tend to attach to the 2 and 5 carbons.
- This causes a misalignment, which can prevent long stands.






# Nucleoside Synthesis

- Nucleoside synthesis is not very efficient
- Heating ribose sugar with some purine bases can produce a few nucleosides, and salt can produce a better yield.
- So, again, maybe an evaporating pool with geothermal energy.
- But nucleosides with pyrimidine bases are more difficult.
- Some have argued for catalyst with metal ions can work.
- So, some ionized metals in the pool too?



# Summary

- Polymerization of amino acids on the early Earth is plausible.
- Synthesis of nucleic acids seems to be much harder.
- Perhaps proteins from amino acid polymers played a role? Chicken came first?
- It is still more difficult, because life requires useful polymers. The order of the monomers determines the properties.

# Probability

- Seems easiest to produce a protein, so what is the chance of getting a useful protein with the proper order of amino acids from chance?
- Toss of a coin. 50/50 (or ½) chance of heads or tails.
  - If you want 10 heads in a role you can multiple the chance of 1 throw times 1 throw times…etc… or $(½)^{10}$ or 1/1024.
- The polymer game is more complex with 20 options of amino acids so if random, the chance of getting a single amino acid is 1/20.
- For a protein with a specific 10 amino acids in order.
  - $(1/20)^{10}$ or about $1/10^{13}$ or 1 chance in 10 trillion!!!!



# Getting Lucky?

- If we throw enough coins, we will get 10 heads in a row.
- And if there were very large numbers of monomers, then even a very unlikely event can happen.
- Perhaps time is the hero of the story?
- But, don't forget a typical protein can have easily more than 200 amino acids. That is a chance of success of $(1/20)^{200}$!
- A generous estimate of the number of trials that the early Earth had was about $10^{51}$.



# Pessimistic?

- But, maybe the early Earth only had a few amino acids at first. Then the odds are lower for certain proteins.
- But, we require more than just 1 protein to be formed.
- So, bottom line is that we can not expect life to arise from completely random combinations of molecules to make more complicated molecules.
- Something else must play a role.
- Some proteins might have a preferred assembly.



# Transition to Life

- Really the big question.
- How difficult is it for the collection of polymers to become life?
- The last step in chemical evolution is biological evolution.

# *Life – Gen Eds*

1. Precise way to reproduce instruction set (but not perfect)
2. Ability to control chemical reactions via catalysts.
3. A protective enclosure that separates the instructions and the catalysts from the environment. Becomes an individual not just a soup of chemicals
4. Method for acquiring and using energy.
5. Interconnections of the above.