Astronomy 330

This class (Lecture 13):

Origin of Life

Next Class:

Life in the Solar System

HW 5 is due Sunday

Music: *Life Begins at the Hop*– XTC

Outline

- The molecular basis of life.
  - Proteins
  - Nucleic acids
- Chirality (we are left-handed life!)
- How to make the monomers of life?

Drake Equation

Frank Drake

That's 0.36 Life-liking systems/year

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

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	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
	20 stars/ yr	0.12 systems/ star	1.25 x 0.12 = 0.15 planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

Molecular Basis of Life

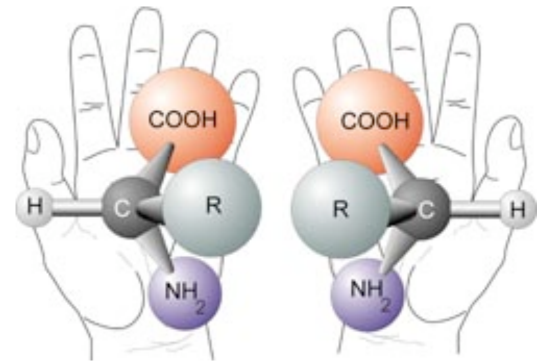
1. Atoms needed are H,O,N, and C with small amounts of P and S.
2. 2 basic molecules are essential for life: proteins and nucleic acids
3. Both are polymers– made of simpler monomers that make up the "alphabet" or code of life. These direct the transcription and translation of the proteins from the code.
4. Proteins and nucleic acids are closely linked at a fundamental level. Communicating through the genetic code that must have originated very early. In most cases, the same code is used by different messages for chicken or shark or human or even Elvis.

Molecular Basis of Life

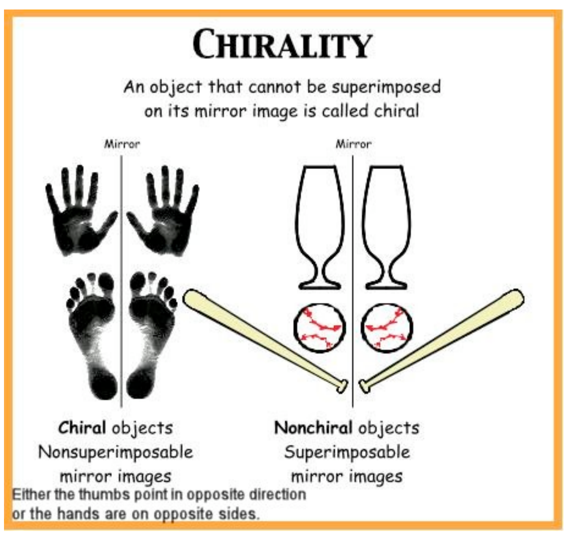
5. #4 rises an important question.
   - Proteins synthesis must be directed by nucleic acids, but nucleic acid transcription requires enzymes (proteins).
   - Chicken or the egg problem?
   - Did proteins arise on Earth first and give rise to nucleic acids, or vice versa?

Chirality

Handedness: Some molecules exist in two versions based on the position of the bonds. One molecule is the mirror image of the other, but they are not similar.



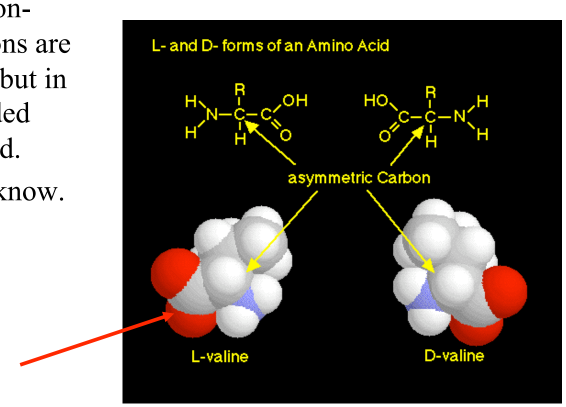
Chirality



http://universe-review.ca/I15-32-chirality.jpg

We are Left-Handed

- Amino acids in non-biological situations are mixtures of both, but in life only left-handed molecules are used.
- Why? We don't know.



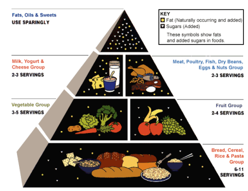
http://www.sp.uconn.edu/~bi107vc/fa02/terry/proteins.html

We are Left-Handed

- To match, sugars in life are right-handed
- Suggests a common ancestor for life.
- The opposite should have worked just as well, and this arrangement probably arose out of chance. Once a preponderance of one chirality occurred it was replicated

ET's Food Limitations

An ET organism may be made of the same stuff, but if they are made of right-handed amino acids, they couldn't eat our food. Bummer.



Question

Imagine that we receive our first ET visitor, but their stomachs do not agree with Earth food. Why might this be true?

a) They actually eat humans, but are too polite to destroy our race.

b) As we are farther out in the Galaxy, our food has less iron.

c) ETs will probably be allergic to water, and our food is mostly water.

d) Chirality: they are right handed life.

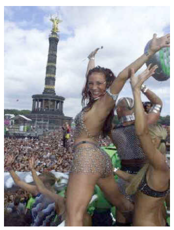
e) None of the above.

From Space?

- The Murchison meteorite (Australia 1969) contained 70 different amino acids!
  - From space!
- Approximately even amount of left and right amino acids were found, but only 6 are used in living organisms.
- Recent results show that 4 of the amino acids had a slight excess of left-handed types.

First Life

- We currently think that life appeared on Earth around 3.8 billion years ago, or only 700 million years after the formation of the Earth. (Based on fossil evidence)
- That is about the same time as the heavy bombardment ended. So, that means life was fast– perhaps only a few 10-100 million years from sterile planet to party town.



http://youconnect.canon-europe.com/swedish/2003-10/images/earth/love_parade.gif

Life

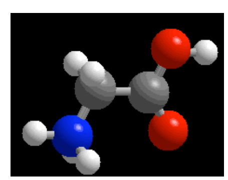
- The most crucial monomers required for life are:
  - Amino acids (20 flavors) for **proteins**
  - The nucleotides: sugar, phosphates, and nitrogenous bases for **DNA/RNA**.
- How did they occur in a useful configuration so **fast** on the early Earth?
  - Remember the early Earth is not a fun place.
    - Poisonous gas atmosphere, hot, lots of meteorites, and cable TV is still 3.8 billion years away.

Molecular Basis of Life

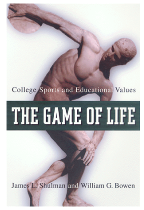
i. Two basic molecules are essential for life: proteins and nucleic acids
ii. Both are polymers– made of simpler monomers
iii. Proteins and nucleic acids are closely linked at a fundamental level.
iv. Did proteins arise on Earth first and give rise to nucleic acids, or vice versa? Or from space?
v. This leads us to the chemical evolution of life.

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.



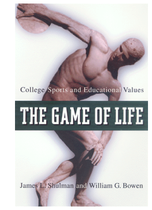
Synthesis of Monomers



Life arose under the following conditions
- Liquid water
- Some dry land
- Energy sources, including UV light, lightning, geothermal.
- A neutral or slightly reducing atmosphere (This is somewhat new). Remember no OXYGEN, mostly methane (CH_4) and CO_2.

http://origins.jpl.nasa.gov/habitable-planets/images/ra6-early-earth-th.jpg
http://www.pupress.princeton.edu/titles/6903.html

Reducing/Oxidizing?

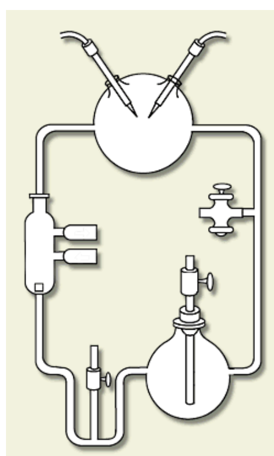


- Reducing atmosphere has elements that *give up* electrons, e.g. hydrogen. A good example is the atmosphere of Jupiter: CH_4, NH_3.
- Oxidizing atmosphere has elements that *take* electrons, e.g. oxygen. A good example is the atmosphere of Mars or modern Earth.
- Neutral is neither.

http://origins.jpl.nasa.gov/habitable-planets/images/ra6-early-earth-th.jpg
http://www.pupress.princeton.edu/titles/6903.html

Miller and Urey Experiment

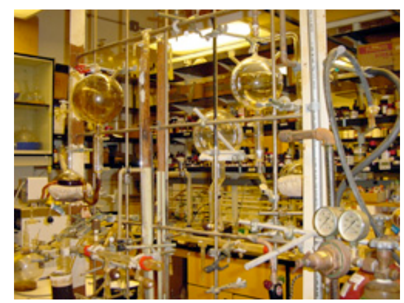
- In 1953, Miller and Urey (UC) tried to duplicate conditions that they believed existed on the Early Earth– a heavily reducing atmosphere.
- They Mixed CH_4, H_2, and NH_3 gases in a flask for the atmosphere, and connected that to a flask with water for the oceans. A spark was used in the atmosphere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



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

Miller and Urey Experiment

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



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

Miller and Urey Experiment

http://www.ucsd.tv/miller-urey

Early Monomers

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.

Early Monomers

- But the assumptions of the experiment have been questioned.
  - Early notions of methane-rich reducing atmosphere are wrong; Earth's early atmosphere was more likely CO_2, N_2, and H_2O vapor.
  - 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, one can still get significant yields of amino acids in a mildly reducing environment.

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.

Question

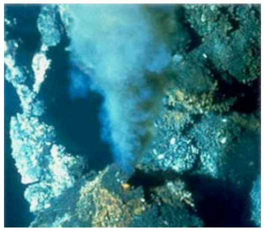
Arguably, the most important legacy of the Miller-Urey experiment is that

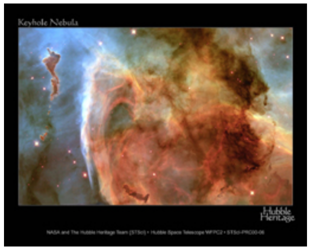
a) we now know how some amino acids were formed on the early Earth.
b) it legitimized the scientific study of the origin of life.
c) it proved the early atmosphere was mostly methane.
d) somehow a glass flask was necessary.
e) None of the above.

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.

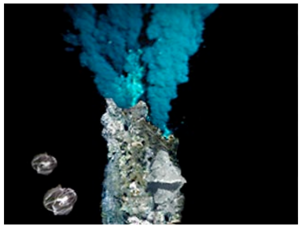
http://www.noaanews.noaa.gov/magazine/stories/mag114.htm
http://www.chl.chalmers.se/~numa/photo/keyhole-small.jpg





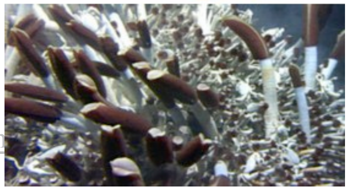
The Underwater Vents

- 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?



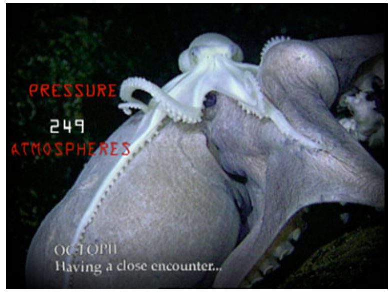
The Underwater Vents

- 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.
- http://www.xenon.com/ventsmovie.htm



The Hot Origins Theory

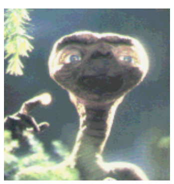
- Vents are examples of a food chain that does not rely ultimately on photosynthesis.
- Demonstrates that pre-biotic synthesis can occur, but did life begin there?
- And current vents are short-lived– a few decades.
- And hot– if synthesis first occurred there, it might have been quickly destroyed.



http://www.xenon.com/vents.html

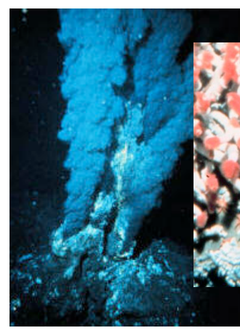
The Hot Origins Theory

- But life 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?

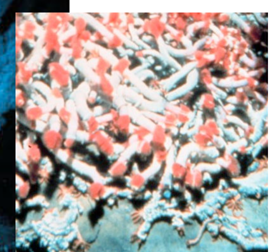


Not your Parent's ET-- Extremophiles

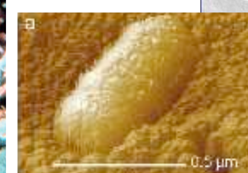
- These are microbes that live in the most extreme places on Earth.
- Temperature extremes
  - boiling or freezing, 100^0C to -1^0C (212F to 30F)
- Chemical extremes
  - vinegar or ammonia (<5 pH or >9 pH)
  - highly salty, up to ten times sea water
- They are exciting, as they are the most likely candidate for extraterrestrial life.
- Probably dominated life on early Earth until fairly recently.



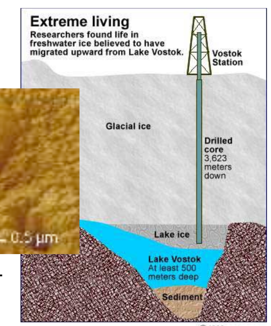
Hydrothermal vent

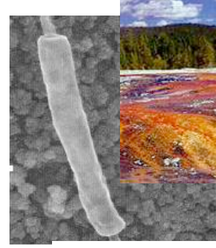


Tubeworms



Lake Vostok - Antarctica

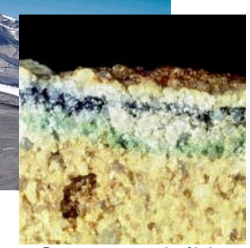




Thermophilic bacteria

Hot springs

Antarctic dry valley



Cryptoendoliths

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 back to the Earth.

http://stardust.jpl.nasa.gov/science/images/pach7.jpg

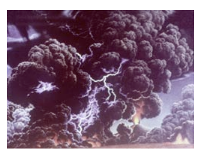
Comets

- 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 (e.g. the Murchison meteorite).
- Can life get transported?
- Panspermia again.

http://stardust.jpl.nasa.gov/science/images/num2.jpg

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



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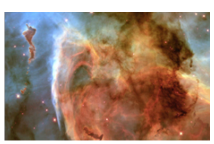
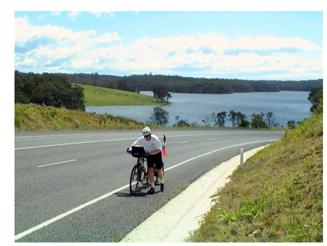


Synthesis of Polymers

- 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. Sort of kinda.

http://www.thanhniennews.com/society/?catid=3&newsid=6557

Polymer Pressure

- 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, even water wanted to pull them apart.

http://www.thanhniennews.com/society/?catid=3&newsid=6557

Making Them Hook Up.

- One idea is for the early soup to quickly evaporate into a condensed soup– so the monomers can join up.

http://www.physics.uc.edu/~hanson/ASTRO/LECTURENOTES/ET/Earth2/PrimordialSoup2.jpg

Making Them Hook 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?

http://www.physics.uc.edu/~hanson/ASTRO/LECTURENOTES/ET/Earth2/PrimordialSoup2.jpg

Hooking up Dirty?

- Polymerization 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.

http://www.clw.csiro.au/education/soils/images/clay_soil.jpg

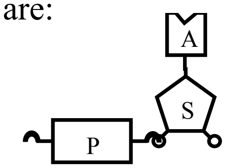
Totally Tidal

- 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.
- Think of the ocean tides fueling the polymerization.

So… And RNA/DNA?

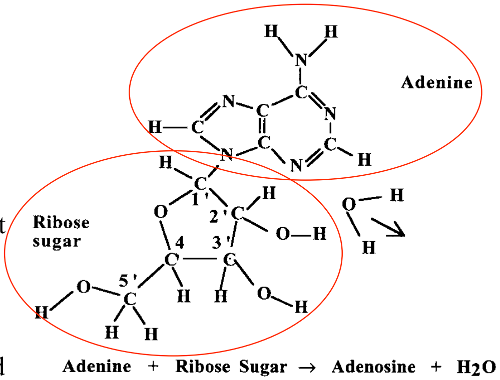
- There are a few ways that amino acids can hook-up and form polymers, but nucleic acids are more difficult to understand as they are more complex.
- What is the basic monomer of RNA or DNA?

- Remember the building blocks are:
  - Sugars
  - Phosphates
  - Bases



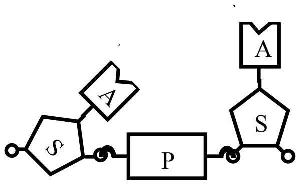
Synthesis?

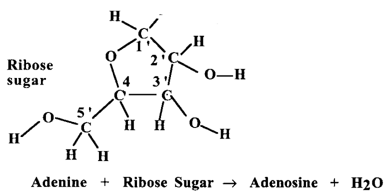
- Not well understood.
- Can number the carbon atoms in the ribose sugar.
  - It is essential that the base attach at the number 1 carbon only. Otherwise, it is not a nucleoside.
  - The base could attach at the 2 or 3 carbon too.
  - Why was bond 1 preferred on the early Earth?



Phosphate Issues

- And the phosphates **must** then 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 prevents long stands – warped.



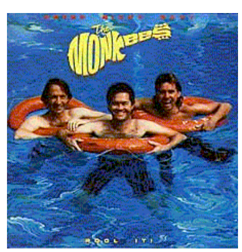


Nucleotide Synthesis

- Nucleotide synthesis is not very efficient
- Heating ribose sugar with some purine bases can produce a few nucleotides, and salt can produce a better yield.

Nucleotide Synthesis

- So, again, maybe an evaporating pool with geothermal energy– monkeys from the pool?
- But nucleotides with pyrimidine bases are more difficult.
- Some have argued for catalyst with metal ions can work.
- So, some ionized metals in the pool too?



http://www.themonkees.com/quizzes18.htm

Protein Probability

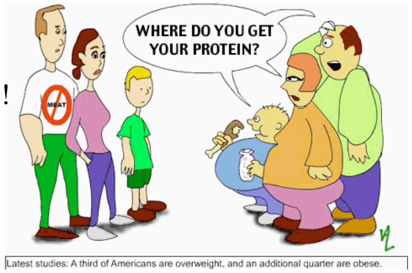
- Seems easiest to produce a protein, so what is the chance of getting a useful protein with the proper order of amino acids from chance?
- Toss of a coin. 50/50 (or ½) chance of heads or tails.
  - If you want 10 heads in a role you can multiply the chance of 1 throw (½) times 1 throw (½) times…etc… or $(½)^{10}$ or 1 time out of 1024 attempts.

http://cruel.org/kitchen/shrunken.html

Probability of Randomly Forming Life?

- 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!!!!

http://www.citypaper.net/hth/



Latest studies: A third of Americans are overweight, and an additional quarter are obese.

Getting Lucky?

- If we throw enough coins, we <u>will</u> get 10 heads in a row.
- And if there were very large numbers of monomers, then even a very unlikely event can happen.
- Perhaps **<u>time</u>** 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 $(1/20)^{200}$!

http://members.aol.com/LILAUTHOR1/hourglass.jpg

Pessimistic?

- A generous estimate of the number of trials that the early Earth had was about 10^{51}.
- But, maybe the early Earth only had a few amino acids at first. Then the odds are better for certain proteins.
- But, we require more than just 1 protein to be formed.
- And first life probably needed many proteins as well.

http://www.physics.brown.edu/Studies/Demo/solids/demos/1a2020.jpg

Pessimist?

- 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.

Poly 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.

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.