Alternative Ideas for the Origin of Life
Something else…

- Neither the chicken nor the egg came first
- Transitional forms that were later discarded
- Remember genetic takeover
Maybe the “egkin”?  

Some experiments with peptide nucleic acid (PNA).  

PNA: Peptide backbone with bases  

Can act as template for polymerization of RNA  
From activated nucleotides  
(Böhler, et al., *Nature*, 376, 578  
& comments by Piccirilli, pg. 548}  17 Aug. 1995  

PNA could be simpler to form under prebiotic conditions  
Main point is that a simpler thing (not necessarily PNA)  
could have preceded RNA
PNA
Threose Nucleic Acid (TNA)

- Threose is one of two sugars with a four-sided ring
- Fewer issues with incorrect linkages, selection of correct handedness
- Replace ribose sugar in RNA with threose
- Can base pair with RNA
- Could have preceded RNA
Membranes

• Membranes provide enclosure
  – Also fundamental for metabolism
• Membranes never arise from scratch
  – Always passed down and added to
  – All derived from ancestral cell
• T. Cavalier-Smith proposes membranes first
  – Plus nucleic acid formed “ob-cell”
  – Merger of 2 ob-cells formed first cell
Focus on Energy

G. Wächtershäuser
Inorganic - organic connection
FeS$_2$ (Iron pyrite)

Attracts negatively charged molecules
Surface catalysis provides energy via formation from
FeS + H$_2$S

Scene is hot sulfur vents on sea floor
Some successes in simulations
Amino acids formed peptide bonds
Thioester World

1. Need precursor to RNA world

2. Need energy conversion
   Protometabolism

Background:

C. de Duve
In Vital Dust

\[
\text{Hydroxyl} + \text{Carboxyl}
\]
Thiols involved in metabolism, particularly in ancient pathways

Also can catalyze ester formation by group transfer
Reactions
e.g. peptide bonds
Catalytic Multimers

“Multimer” short peptides and esters

(NH$_2$) (OH)

of amino acids and hydroxy acids

Will form from thioesters. Assume some catalytic ability, lead to protometabolism
Energy Sources

Basic need is hydrogen atoms (or electrons in excited states)

In pure water: \[ \frac{H^+ + OH^-}{H_2O} \] more if acidic

\[ e^- + H^+ \rightarrow H^* \] excited H

Now chlorophyll + sunlight
On early Earth?

1. UV light + Fe$^{+2}$ → Fe$^{+3}$ + e$^-$
   e$^-$ + H$^+$ → H$^*$ → H for reactions

2. H$_2$S in H$_2$O → SH$^-$
   2SH$^-$ → S$_2$$^{-2}$ + H$_2$
   Fe$^{+2}$ + S$_2$$^{-2}$ + FeS$_2$ iron pyrite
Transition to Phosphate

Remember that energy currency in life now is ATP

**Adenosine Triphosphate**

used to make bonds, remove $H_2O$

Earlier, inorganic phosphate

$\text{p–p diphasphate or polyphosphate}$

still involved in ATP reactions

![Diagram of ATP cycle with Multimers, Catalysts, FeS$_2$, Thioester, and RNA World]
age—will be followed by GUC. This AGUC sequence is complementary to the terminal sequence written in antiparallel fashion, and will cause the chain to double up as follows:

---C-C-A-G-A-G-U-C---

---U-C-A-G---

Assume now that this folded chain is subject to elongation, by the addition of new nucleotides, from right to left, to the U end. The presence of G next to the A paired with the terminal U is likely to favor the addition of a complementary C over that of the other three possible nucleotides. Repeat the process and you get U added opposite A, G opposite C, G again opposite the next C, and so on. What you get is the formation of a stretch complementary over all its length to the other end of the molecule:

---C-C-A-G-A-G-U-C---

---G-G-U-C-U-C-A-G---
# Summary of Proto-Life Development

<table>
<thead>
<tr>
<th>Stage</th>
<th>Proteins</th>
<th>Halfway #1 Peptide Nucleic Acids</th>
<th>Halfway #2 RNA Ribozyme</th>
<th>Nucleic Acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monomers</td>
<td>Amino Acids</td>
<td>Bases</td>
<td>Ribose Sugars Bases</td>
<td>Ribose Sugars Bases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amino Acids</td>
<td>Phosphates</td>
<td>Bases Phosphate</td>
</tr>
<tr>
<td>Polymerization</td>
<td>Proteinoids</td>
<td>Short strands of PNA’s</td>
<td>Short strands of RNA + amino acids</td>
<td>Short strands of RNA</td>
</tr>
<tr>
<td>Replication</td>
<td>?</td>
<td>Affinity for complementary bases + ease of peptide bonding</td>
<td>Affinity for complementary bases</td>
<td>Affinity for complementary bases</td>
</tr>
<tr>
<td>Pre-life</td>
<td>Proteinoids + RNA?</td>
<td>Separation of proteins and nucleic acids</td>
<td>Separation of nucleic acids and protein parts</td>
<td>RNA adapts proteinoids as needed</td>
</tr>
<tr>
<td>Life</td>
<td>Proteins</td>
<td>Disappears</td>
<td>Disappears</td>
<td>DNA and RNA</td>
</tr>
</tbody>
</table>
Other ideas

A different initial genetic substance + genetic takeover
  e.g., clay life

Panspermia
Various versions

Creationism
Clay Life

Silicate Life?

Early Genetic Material

\[ O = Si = O \text{ but } O \text{ can make another bond instead} \]

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{Si} \\
\text{O} \\
\text{O}
\end{array}
\]

Silicates can provide a variety of minerals

Layers - clay

Also occasional impurity (Al, Mg, …)

Can grow by adding dissolved material

Tends to copy pattern of impurities in adjacent layers.

Could this be a kind of reproduction?

A. G. Cairns-Smith
Defects - different impurity, … (mutations?)

Sheets can separate - move - and then “reproduce”

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay clearly present</td>
<td>How to get to life as we know it</td>
</tr>
<tr>
<td>Simpler genetic structure</td>
<td></td>
</tr>
<tr>
<td>Crystal growth occurs naturally</td>
<td></td>
</tr>
</tbody>
</table>
Clay Life $\rightarrow$ Life

Clay life begins to synthesize, use “organic” [carbon] molecules

Clays do have some catalytic activity

Genetic takeover

organics $\rightarrow$ protein/RNA mechanisms

Clay discarded
Tests

1. Surviving clay life - unlikely

2. New clay life - maybe in some places

3. Demonstrate in lab

Not much further development of this idea.
Panspermia

• Life arose elsewhere and was delivered here
  – Original idea was bacterial spores
  – Hoyle and Wickramasinghe
    • Life originates on dust grains, comets, …
  – Or on another planet (meteorites from Mars)
  – Borates help form RNA
  – Evaporated seas, more common on Mars
• Directed panspermia
  – Crick and Orgel (tongue in cheek)
  – Earth seeded by intelligent ET
Creationism

- Traditional biblical literalism
- Intelligent design
  - Seeks evidence of design in complexity
  - Current version of creationist movement
  - Hoyle and Wickramasinghe later ideas
    - Life designed by silicon chip
    - Where did the chip come from?
- None of these are scientific theories
  - The key is whether they can be tested
### Uniformitarianism
- Matter existed in the beginning
- Sun and stars before the earth
- Land before the oceans
- Sun, earth’s first light
- Contiguous atmosphere and hydrosphere
- Marine organisms, first forms of life
- Fishes before fruit trees
- Insects before birds
- Sun before land plants
- Reptiles before birds
- Woman before man (by genetics)
- Rain before man
- “Creative” processes still continuing
- Struggle and death necessary antecedents of man

### Bible
- Matter created by God in the beginning
- Earth before the sun and stars
- Oceans before the land
- Light before the sun
- Atmosphere between two hydrospheres
- Land plants, first life forms created
- Fruit trees before fishes
- Birds before insects
- Land vegetation before the sun
- Birds before reptiles
- Man before woman (by creation)
- Man before rain
- Creation completed
- Man, the cause of struggle and death
Myth (Mythos)  
Revealed truth unquestioned

Two strands in Creation Myths:
Creator                  Spirit in
“Western”                        Matter

Creationism               spontaneous generation

“Eastern”               self-organization of matter

Science (Logos)
Provisional truth
Skepticism essential (falsifiability)
Method important

Interplay:
Theory          Experiment/observation
Paradigm
Chemical Evolution
related?
Artificial Life?

• Polio virus constructed from “scratch” in 2002
• Entire bacterial genome (not the bacterium) constructed from scratch in 2008
  – 582,970 base pairs
• Could we create a bacterium from scratch?
• Far too complex for current abilities
• Chromosome (272,871 base pairs) for a eukaryote (yeast) constructed in 2014
Exotic Life Forms?

Antidote to Earth Chauvinism

1. Different organic molecules (e.g., PNA)
   possibility of life based on other polymers

2. Not based on Carbon
   Silicon (Si) instead of Carbon?
   (also 4 bonds)
   & more (135 ×) abundant on Earth
Negatives for replacing carbon with silicon:

a. C - C bond $2 \times$ stronger than Si - Si

b. Si - O stronger than Si - Si
   forms silicates, not .. Si - Si - Si ...

c. C forms multiple bonds (e.g. C ≡ N)
   Si rarely does

d. C + O forms CO or CO$_2$ (gas - further reacts)
   Si + O → SiO$_2$ - silicate rocks

⇒ Si unlikely to replace C in “organic” molecules
   but could forms of SiO$_2$ produce clay life?
3. Other Solvents

Earth: Liquid water 273-373 K

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>T\text{_freeze}</th>
<th>T\text{_boil}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia NH\textsubscript{3}</td>
<td>195</td>
<td>240</td>
</tr>
<tr>
<td>Methyl Alcohol CH\textsubscript{3}OH</td>
<td>179</td>
<td>338</td>
</tr>
<tr>
<td>Methane CH\textsubscript{4}</td>
<td>91</td>
<td>109</td>
</tr>
<tr>
<td>Ethane C\textsubscript{2}H\textsubscript{6}</td>
<td>90</td>
<td>184</td>
</tr>
</tbody>
</table>

Water is better solvent
Also better for temperature regulation
But others could play a role in colder zones
extend CHZ?
4. Non-chemical life?

Disembodied intelligence
Black cloud life?

Other forces
Strong nuclear force?  \( \tau \sim 10^{-15} \text{ s} \)

Gravity?
Estimates for $f_\ell$

- Possible range is very large
  - Perhaps $10^{-6}$ (one in a million) to 1 (all)
- Arguments for large value
  - Life part of overall evolution in complexity
  - Arises naturally from interplay of forces
Estimates for $f_\ell$

- Arguments for small value
  - May need more than liquid water
    - Large tides, so large moon
    - Dry land (for polymerization)
  - Life may be a fluke
    - A rare statistical event
Can we estimate $f_\ell$ from early origin of life?

Very ancient microfossils \hspace{1cm} (now disputed)
\Rightarrow Life arose as early as $3.8 \times 10^9$ yr ago Some evidence for life $4.1 \times 10^9$ yr ago (isotopes) [soon after end of heavy bombardment]

Lineweaver & Davis argued:
Early origin $\Rightarrow f_\ell > 0.33$
For suitable planets older than $1 \times 10^9$ yrs.

Statistics from one example!
Others have disputed this conclusion
What is your choice and why?

• The most uncertain factor so far ($f$)
• Think about various ideas for origin of life
• Put together a plausible story for the origin of life
  — Can use parts of various ideas, but need to be consistent.