Alternative Ideas for the Origin of Life

Something else…

- Neither the chicken nor the egg came first
- Transitional forms that were later discarded

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

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

$FeS + H_2S$

Scene is hot sulfur vents on sea floor

Some successes in simulations

Amino acids formed peptide bonds

Thioester World

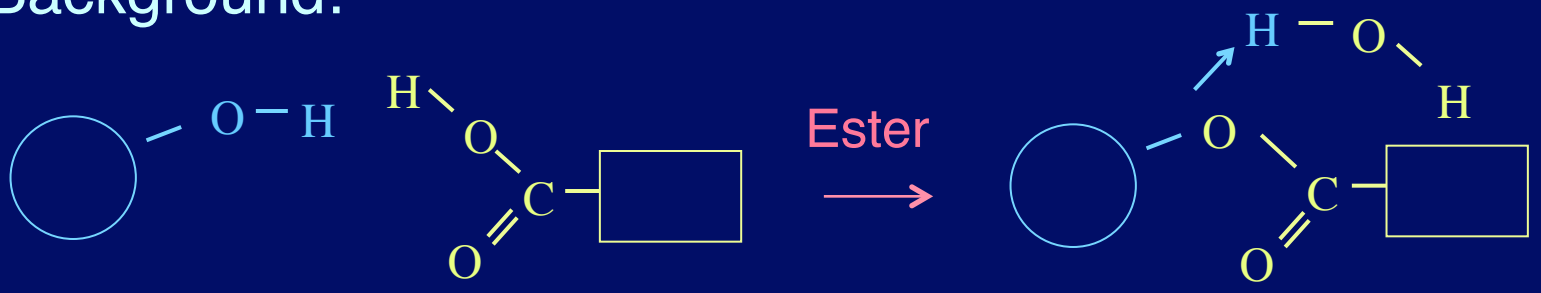
1. Need precursor to RNA world

C. de Duve

2. Need energy conversion
   Protometabolism

In Vital Dust

Background:



Hydroxyl + Carboxyl

Thiol + 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

C. de Duve

(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

$$e^- + H^+ \longrightarrow H^*$$ excited H

Now chlorophyll + sunlight

On early Earth?

1. UV light + Fe^{+2} $\longrightarrow$ Fe^{+3} + e^-

   e^- + H^+ $\longrightarrow$ H^* $\longrightarrow$ H for reactions

2. H_2S in H_2O $\longrightarrow$ SH^-

   $2SH^- \longrightarrow S_2^{-2}$ + H_2

   Fe^{+2} + S_2^{-2} + FeS_2 iron pyrite

Transition to Phosphate

Remember that energy currency in life now is ATP

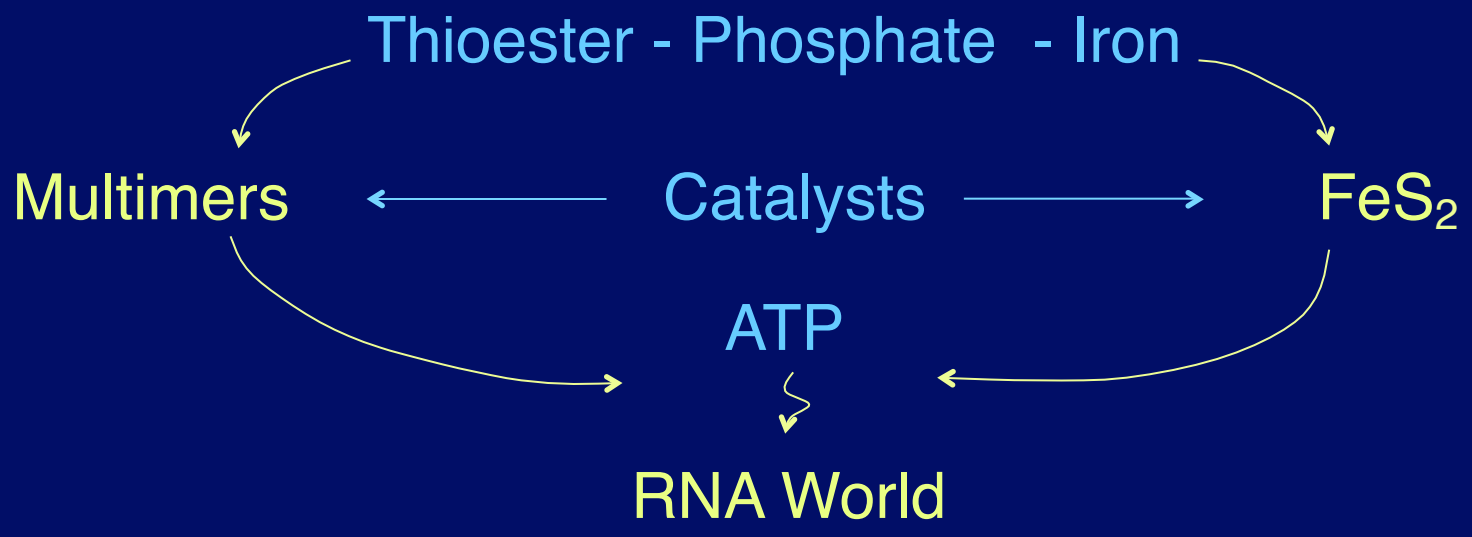
Adenosine Triphosphate

used to make bonds, remove H_2O

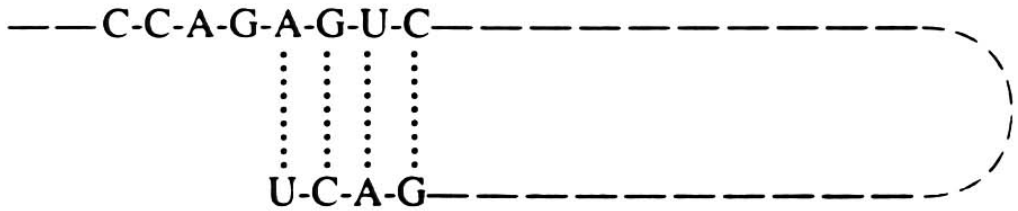
Earlier, inorganic phosphate

p–p diphosphate or polyphosphate

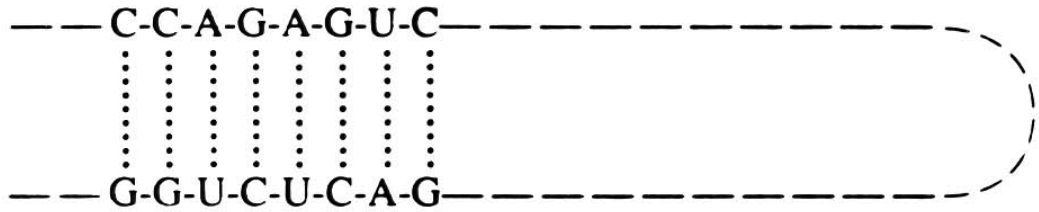
still involved in ATP reactions



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:



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:



Summary of Proto-Life Development

Stage	**Proteins**	**Halfway # 1** Peptide Nucleic Acids	**Halfway # 2** RNA Ribozyme	**Nucleic Acids**
Monomers	Amino Acids	Bases Amino Acids	Ribose Sugars Bases Phosphates Amino Acids	Ribose Sugars Bases Phosphate
Polymerization	Proteinoids	Short strands of PNA's	Short strands of RNA + amino acids	Short strands of RNA
Replication	?	Affinity for complementary bases + ease of peptide bonding	Affinity for complementary bases	Affinity for complementary bases
Pre-life	Proteinoids + RNA?	Separation of proteins and nucleic acids	Separation of nucleic acids and protein parts	RNA adapts proteinoids as needed
Life	Proteins	Disappears	Disappears	DNA and RNA

Other ideas

A different initial genetic substance + genetic takeover

e.g., clay life

Panspermia

Various versions

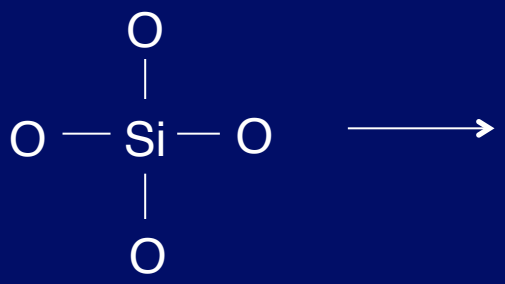
Creationism

Clay Life

A. G. Cairns-Smith

Silicate Life? Early Genetic Material

O = Si = O but O can make another bond instead



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?

Defects - different impurity, … (mutations?)

Sheets can separate - move - and then "reproduce"

Advantages	Problem
Clay clearly present	How to get to
Simpler genetic structure	life as we know it
Crystal growth occurs naturally	

Clay Life $\xrightarrow{?}$ Life

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

Clays do have some catalytic activity

Genetic takeover

organics $\longrightarrow$ 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

From "Scientific Creationism" by Henry Morris

Uniformitarianism	Bible
Matter existed in the beginning	Matter created by God in the beginning
Sun and stars before the earth	Earth before the sun and stars
Land before the oceans	Oceans before the land
Sun, earth's first light	Light before the sun
Contiguous atmosphere and hydrosphere	Atmosphere between two hydrospheres
Marine organisms, first forms of life	Land plants, first life forms created
Fishes before fruit trees	Fruit trees before fishes
Insects before birds	Birds before insects
Sun before land plants	Land vegetation before the sun
Reptiles before birds	Birds before reptiles
Woman before man (by genetics)	Man before woman (by creation)
Rain before man	Man before rain
"Creative" processes still continuing	Creation completed
Struggle and death necessary antecedents of man	Man, the cause of struggle and death

Myth (Mythos)

Revealed truth unquestioned

Two strands in Creation Myths:

Creator "Western"

Spirit in Matter "Eastern"

Creationism

spontaneous generation

self-organization of matter

Science (Logos)

Provisional truth

Skepticism essential (falsifiability)

Method important

Interplay:

Theory

Experiment/ observation

Paradigm

Chemical Evolution

related?

Artificial Life?

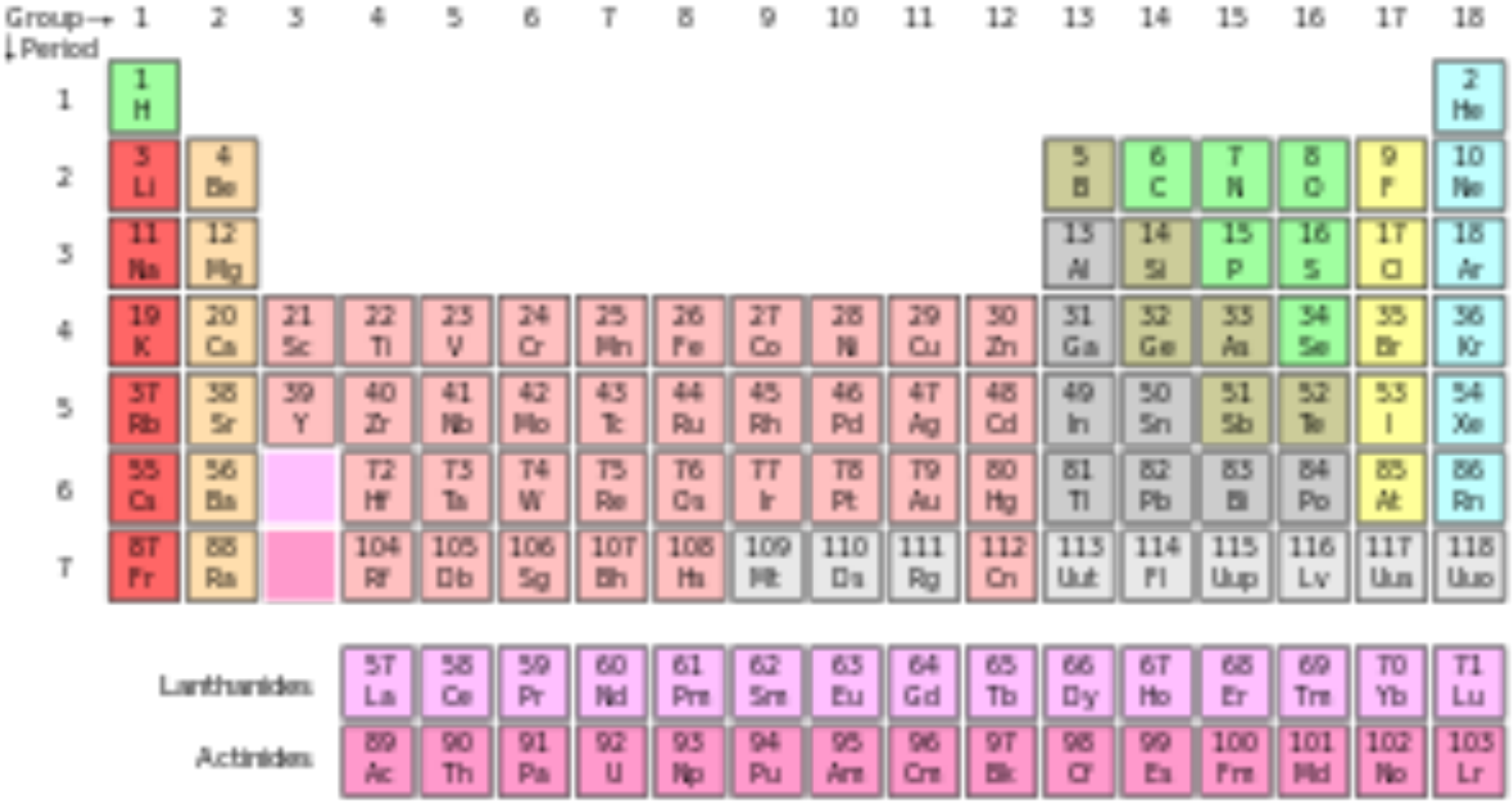
- Polio virus constructed from “scratch” in 2002
- Entire bacterial genome (not the bacterium) constructed from scratch in 2008
  - 582,970 base pairs
- Could we create a bacterium from scratch?
- Far too complex for current abilities
- Chromosome (272,871 base pairs) for a eukaryote (yeast) constructed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


Group→ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
↓Period
1 1 H 2 He
2 3 Li 4 Be 5 B 6 C 7 N 8 O 9 F 10 Ne
3 11 Na 12 Mg 13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
4 19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
5 37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
6 55 Cs 56 Ba 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po 85 At 86 Rn
7 87 Fr 88 Ra 104 Rf 105 Db 106 Sg 107 Bh 108 Hs 109 Mt 110 Ds 111 Rg 112 Cn 113 Uut 114 Fl 115 Uup 116 Lv 117 Uus 118 Uuo
Lanthanides 57 La 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu
Actinides 89 Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No 103 Lr

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 $\longrightarrow$ SiO_2 - silicate rocks

$\Rightarrow$ 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

Alternatives:		T_{freeze}	T_{boil}
Ammonia	NH_3	195	240
Methyl Alcohol	CH_3OH	179	338
Methane	CH_4	91	109
Ethane	C_2H_6	90	184

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? $\tau \sim 10^{-15}$ s

Gravity?

Estimates for f_ℓ

- 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_ℓ

- 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_ℓ from early origin of life?

Very ancient microfossils (now disputed)

$\Rightarrow$ Life arose as early as 3.8×10^9 yr ago

[soon after end of heavy bombardment]

Lineweaver & Davis argued:

Early origin $\Rightarrow f_\ell > 0.33$

For suitable planets older than 1×10^9 yrs.

Statistics from <u>one</u> example!

Others have disputed this conclusion

What is your choice and why?

- The most uncertain factor so far (f_ℓ)
- 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.