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

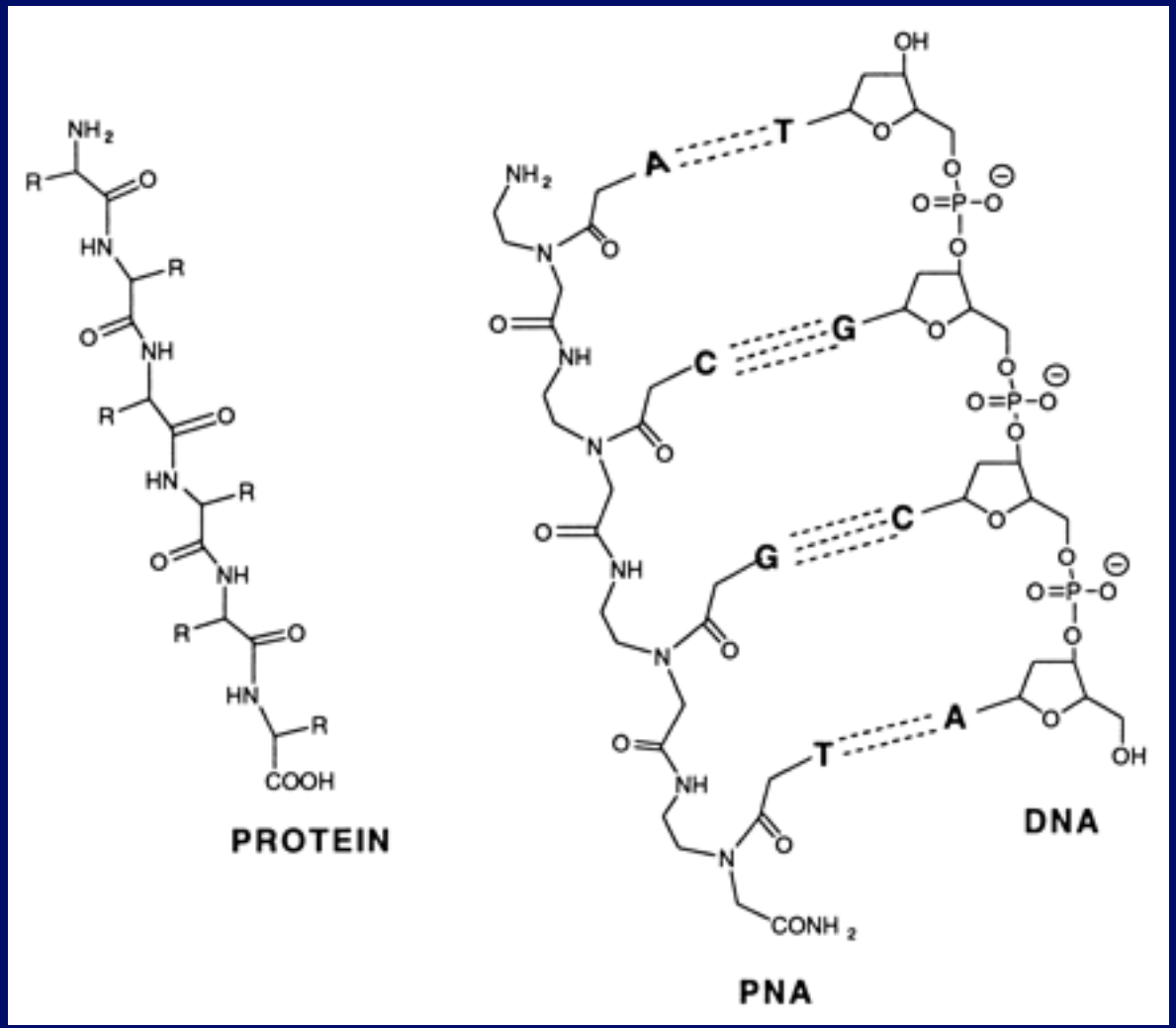
From activated nucleotides

(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

$FeS + H_2S$

Scene is hot sulfur vents on sea floor

Some successes in simulations

Amino acids formed peptide bonds

Thioester World

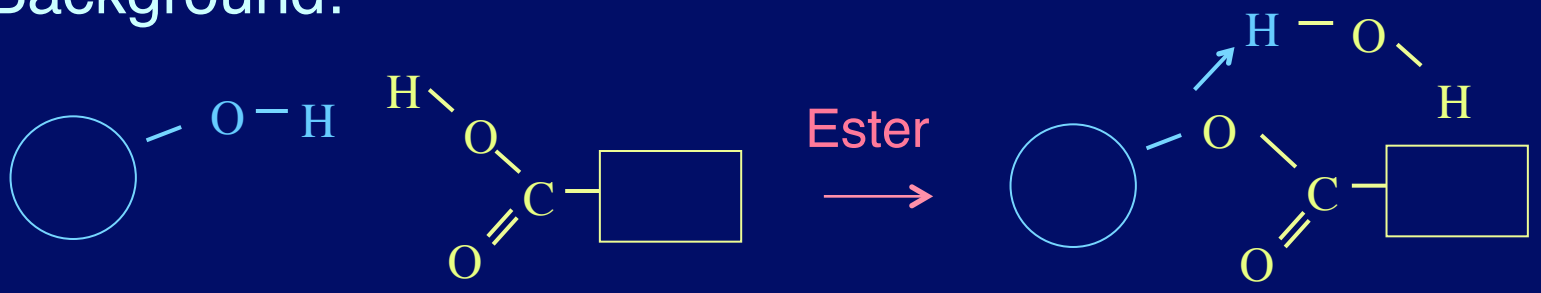
1. Need precursor to RNA world

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

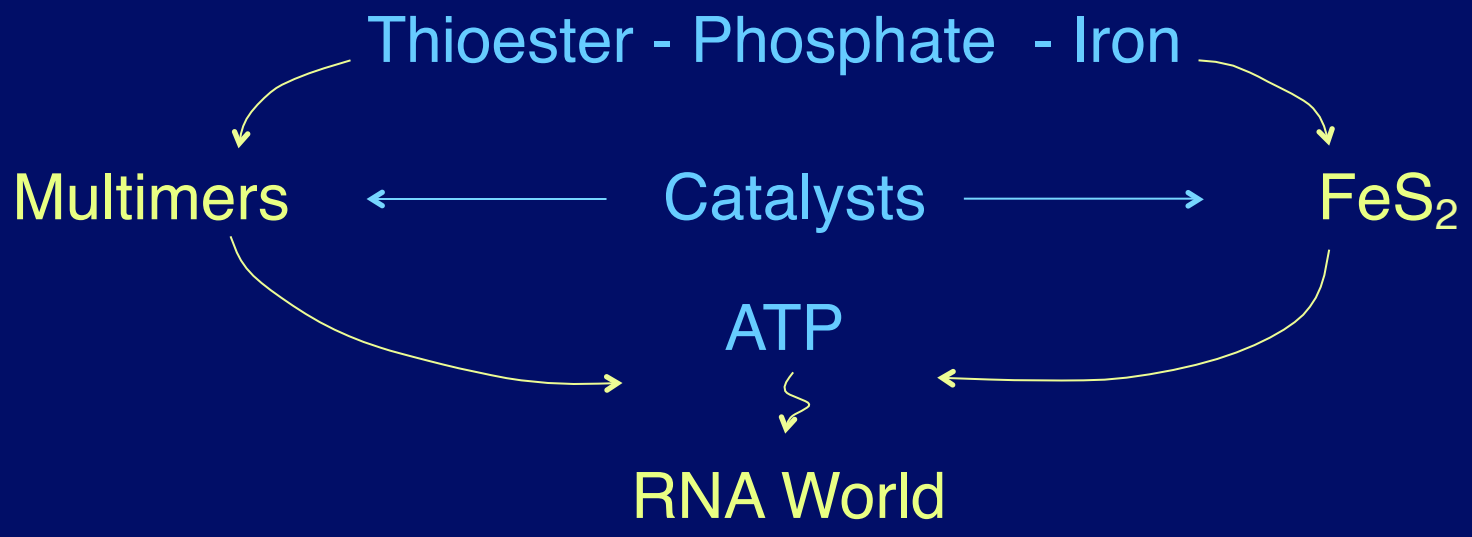
Adenosine Triphosphate

used to make bonds, remove H_2O

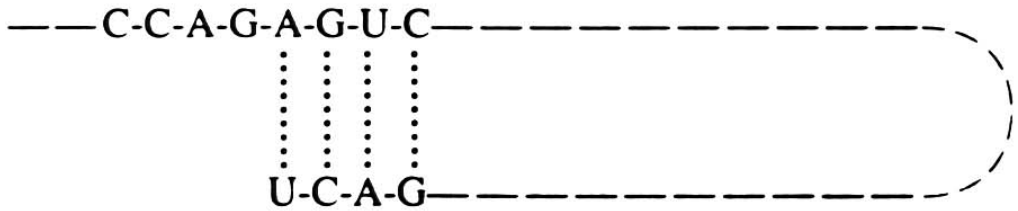
Earlier, inorganic phosphate

p–p diphosphate or polyphosphate

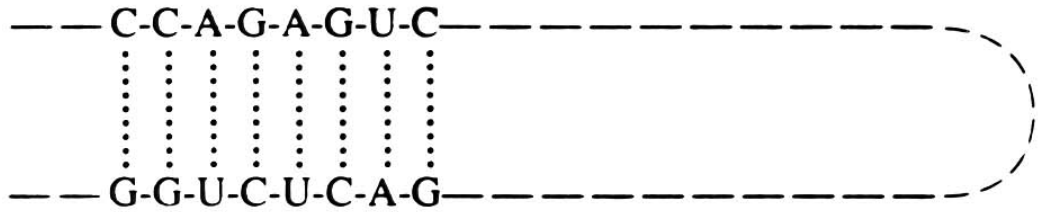
still involved in ATP reactions



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

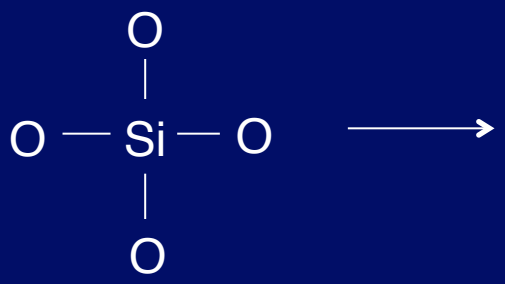
Creationism

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

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

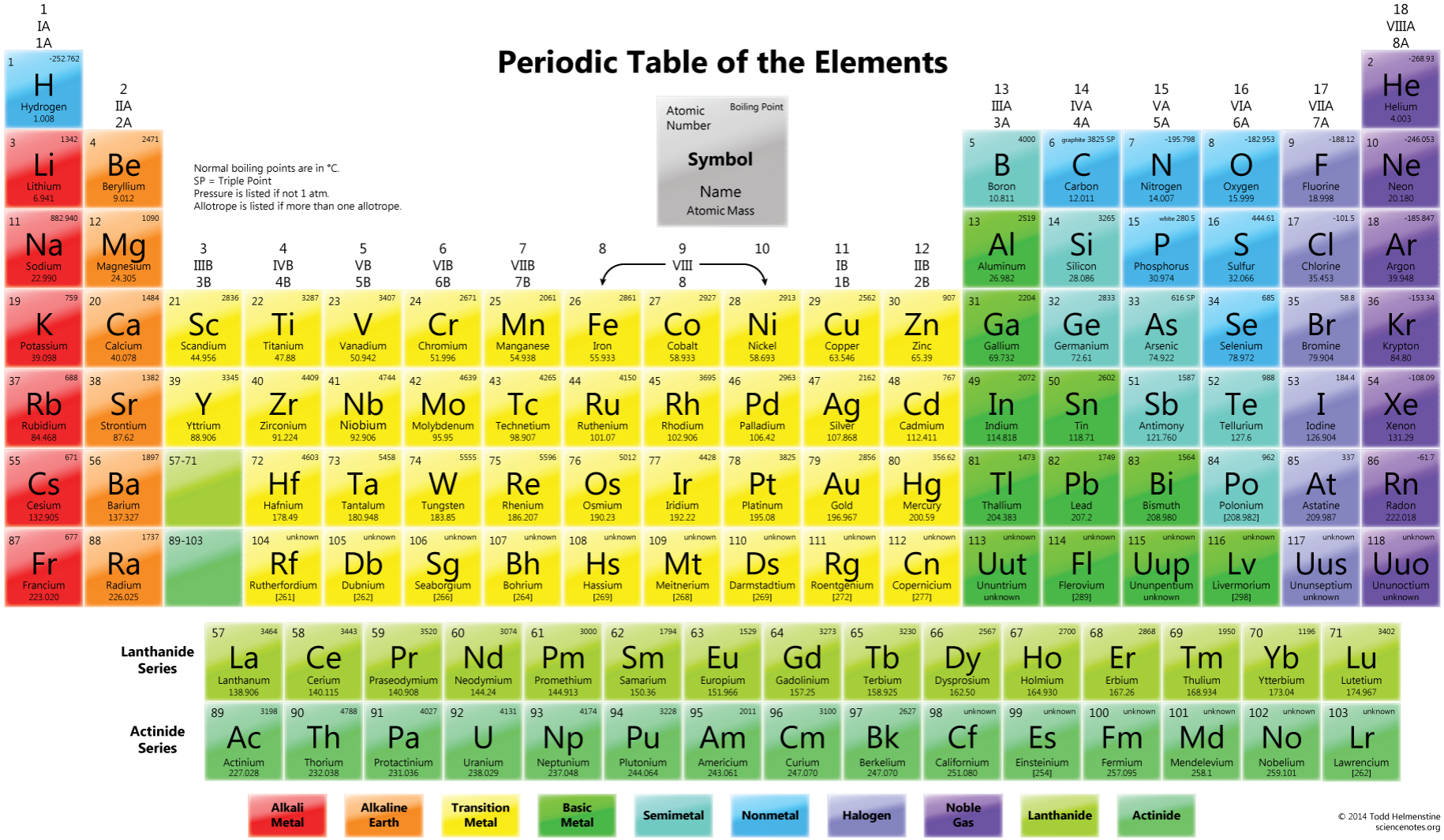
d. C + O forms CO or CO_2 (gas - further reacts)

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?

Chemistry


Periodic Table of the Elements
Atomic Number
Boiling Point
Symbol
Name
Atomic Mass
Normal boiling points are in °C.
SP = Triple Point
Pressure is listed if not 1 atm.
Allotrope is listed if more than one allotrope.
1 IA 1A
2 IIA 2A
3 IIIB 3B
4 IVB 4B
5 VB 5B
6 VIB 6B
7 VIIB 7B
8
9 VIII 8
10
11 IB 1B
12 IIB 2B
13 IIIA 3A
14 IVA 4A
15 VA 5A
16 VIA 6A
17 VIIA 7A
18 VIIIA 8A
1 -252.762 H Hydrogen 1.008
2 -268.93 He Helium 4.003
3 1342 Li Lithium 6.941
4 2471 Be Beryllium 9.012
5 4000 B Boron 10.811
6 graphite 3825 SP C Carbon 12.011
7 -195.798 N Nitrogen 14.007
8 -182.953 O Oxygen 15.999
9 -188.12 F Fluorine 18.998
10 -246.053 Ne Neon 20.180
11 882.940 Na Sodium 22.990
12 1090 Mg Magnesium 24.305
13 2519 Al Aluminum 26.982
14 3265 Si Silicon 28.086
15 white 280.5 P Phosphorus 30.974
16 444.61 S Sulfur 32.066
17 -101.5 Cl Chlorine 35.453
18 -185.847 Ar Argon 39.948
19 759 K Potassium 39.098
20 1484 Ca Calcium 40.078
21 2836 Sc Scandium 44.956
22 3287 Ti Titanium 47.88
23 3407 V Vanadium 50.942
24 2671 Cr Chromium 51.996
25 2061 Mn Manganese 54.938
26 2861 Fe Iron 55.933
27 2927 Co Cobalt 58.933
28 2913 Ni Nickel 58.693
29 2562 Cu Copper 63.546
30 907 Zn Zinc 65.39
31 2204 Ga Gallium 69.732
32 2833 Ge Germanium 72.61
33 616 SP As Arsenic 74.922
34 685 Se Selenium 78.972
35 58.8 Br Bromine 79.904
36 -153.34 Kr Krypton 84.80
37 688 Rb Rubidium 84.468
38 1382 Sr Strontium 87.62
39 3345 Y Yttrium 88.906
40 4409 Zr Zirconium 91.224
41 4744 Nb Niobium 92.906
42 4639 Mo Molybdenum 95.95
43 4265 Tc Technetium 98.907
44 4150 Ru Ruthenium 101.07
45 3695 Rh Rhodium 102.906
46 2963 Pd Palladium 106.42
47 2162 Ag Silver 107.868
48 767 Cd Cadmium 112.411
49 2072 In Indium 114.818
50 2602 Sn Tin 118.71
51 1587 Sb Antimony 121.760
52 988 Te Tellurium 127.6
53 184.4 I Iodine 126.904
54 -108.09 Xe Xenon 131.29
55 671 Cs Cesium 132.905
56 1897 Ba Barium 137.327
57-71
72 4603 Hf Hafnium 178.49
73 5458 Ta Tantalum 180.948
74 5555 W Tungsten 183.85
75 5596 Re Rhenium 186.207
76 5012 Os Osmium 190.23
77 4428 Ir Iridium 192.22
78 3825 Pt Platinum 195.08
79 2856 Au Gold 196.967
80 356.62 Hg Mercury 200.59
81 1473 Tl Thallium 204.383
82 1749 Pb Lead 207.2
83 1564 Bi Bismuth 208.980
84 962 Po Polonium [208.982]
85 337 At Astatine 209.987
86 -61.7 Rn Radon 222.018
87 677 Fr Francium 223.020
88 1737 Ra Radium 226.025
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116 unknown Lv Livermorium [298]
117 unknown Uus Ununseptium unknown
118 unknown Uuo Ununoctium unknown
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58 3443 Ce Cerium 140.115
59 3520 Pr Praseodymium 140.908
60 3074 Nd Neodymium 144.24
61 3000 Pm Promethium 144.913
62 1794 Sm Samarium 150.36
63 1529 Eu Europium 151.966
64 3273 Gd Gadolinium 157.25
65 3230 Tb Terbium 158.925
66 2567 Dy Dysprosium 162.50
67 2700 Ho Holmium 164.930
68 2868 Er Erbium 167.26
69 1950 Tm Thulium 168.934
70 1196 Yb Ytterbium 173.04
71 3402 Lu Lutetium 174.967
Actinide Series
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90 4788 Th Thorium 232.038
91 4027 Pa Protactinium 231.036
92 4131 U Uranium 238.029
93 4174 Np Neptunium 237.048
94 3228 Pu Plutonium 244.064
95 2011 Am Americium 243.061
96 3100 Cm Curium 247.070
97 2627 Bk Berkelium 247.070
98 unknown Cf Californium 251.080
99 unknown Es Einsteinium [254]
100 unknown Fm Fermium 257.095
101 unknown Md Mendelevium 258.1
102 unknown No Nobelium 259.101
103 unknown Lr Lawrencium [262]
Alkali Metal
Alkaline Earth
Transition Metal
Basic Metal
Semimetal
Nonmetal
Halogen
Noble Gas
Lanthanide
Actinide
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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 Some evidence for life 4.1×10^9 yr ago (isotopes)

[soon after end of heavy bombardment]

Lineweaver & Davis argued:

Early origin $\Rightarrow f_\ell > 0.33$

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

Statistics from one example!

Others have disputed this conclusion

What is your choice and why?

- The most uncertain factor so far (f_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.