

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).

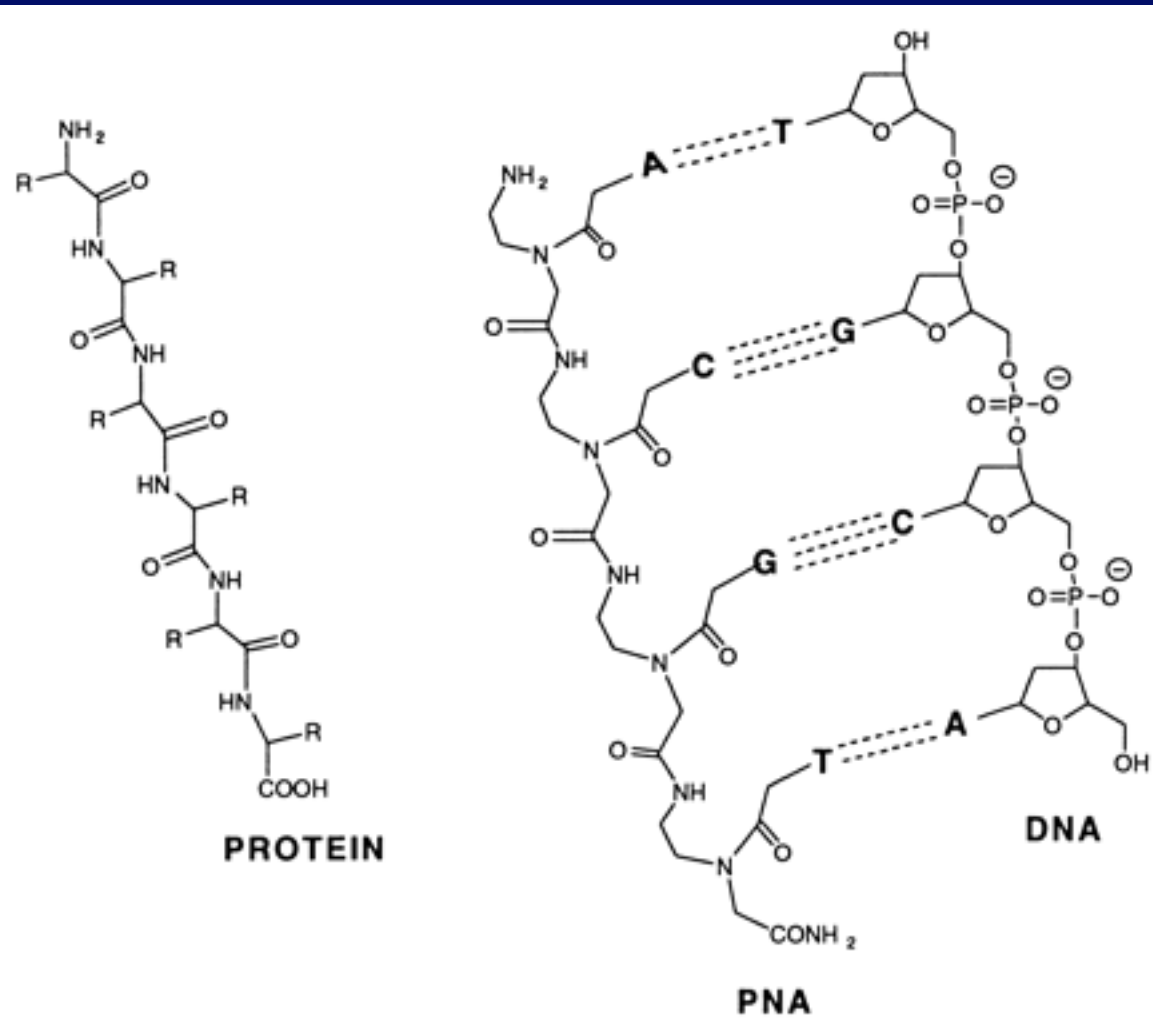
PNA: Peptide backbone with bases

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
 $\text{FeS} + \text{H}_2\text{S}$

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

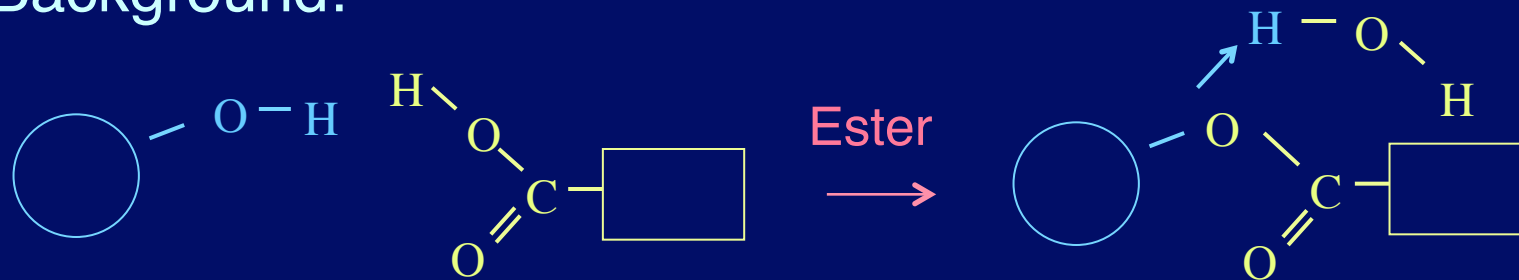
2. Need energy conversion

Protometabolism

C. de Duve

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

(NH₂)

(OH)

of amino acids and hydroxy acids

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

Energy Sources

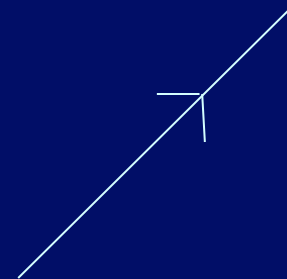
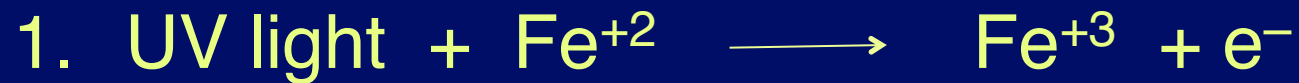
Basic need is hydrogen atoms
(or electrons in excited states)

In pure water $\frac{\text{H}^+ + \text{OH}^-}{\text{H}_2\text{O}}$ more if acidic



Now chlorophyll + sunlight

On early Earth?



Transition to Phosphate

Remember that energy currency in life now is ATP

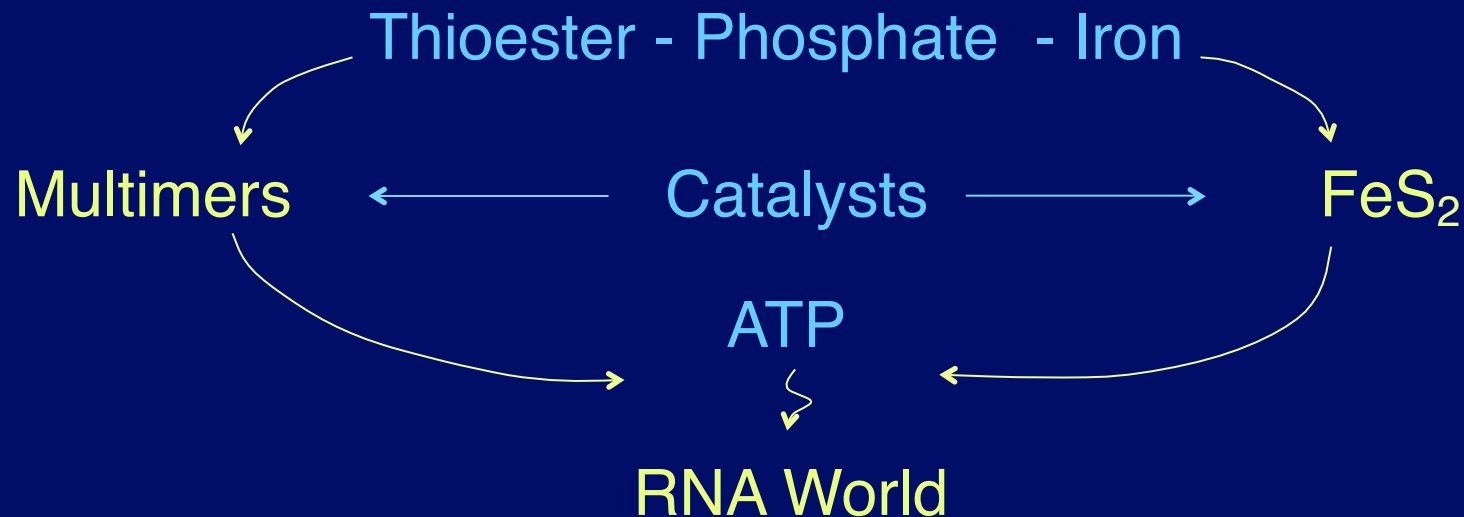
Adenosine Triphosphate

used to make bonds, remove H₂O

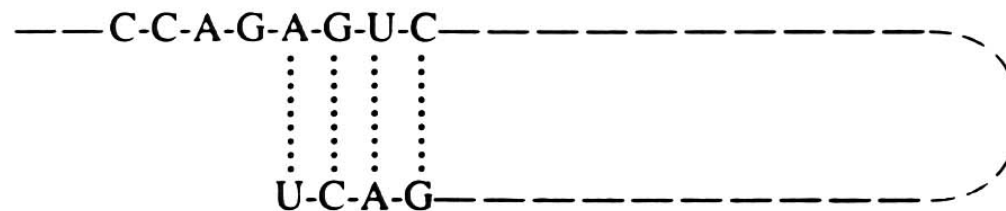
Earlier, inorganic phosphate

p-p diphosphate or polyphosphate

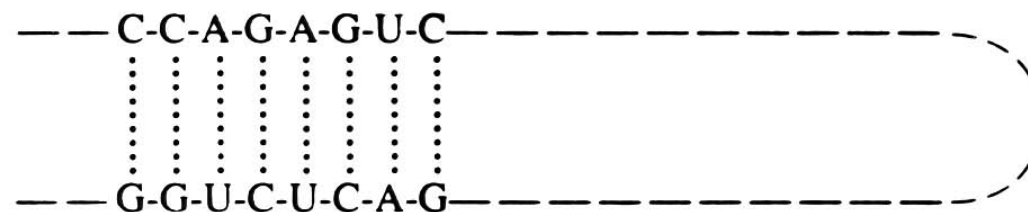
still involved in ATP reactions



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

<u>Stage</u>	<u>Proteins</u>	<u>Halfway # 1</u> Peptide Nucleic Acids	<u>Halfway # 2</u> RNA Ribozyme	<u>Nucleic Acids</u>
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

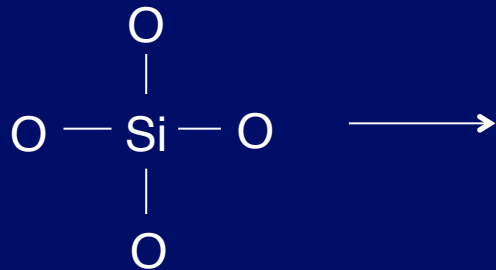
Clay Life

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

Clay clearly present

Simpler genetic structure

Crystal growth occurs naturally

Problem

How to get to
life as we know it

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

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
“Western”



Creationism

Spirit in
Matter

“Eastern”



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 × stronger than Si - Si
- b. Si - O stronger than Si - Si
 forms silicates, not .. Si - Si - Si ...
- c. C forms multiple bonds (e.g. $C \equiv N$)
 Si rarely does
- d. C + O forms CO or CO₂ (gas - further reacts)
 Si + O $\longrightarrow$ SiO₂ - silicate rocks

⇒ Si unlikely to replace C in “organic” molecules
but could forms of SiO₂ produce clay life?

Chemistry

Periodic Table of the Elements

Normal boiling points are in °C.
SP = Triple Point
Pressure is listed if not 1 atm.
Allotrope is listed if more than one allotrope.

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3 Li Lithium 6.941 1342	4 Be Beryllium 9.012 2471																	5 B Boron 10.811 4000	6 C Carbon 12.011 graphite 3825 SP	7 N Nitrogen 14.007 -195.798	8 O Oxygen 15.999 -182.953	9 F Fluorine 18.998 -188.12	10 Ne Neon 20.180 -246.053																																																																																																																																																																																																																																																																																																																																																																																
11 Na Sodium 22.990 882.940	12 Mg Magnesium 24.305 1090	13 Al Aluminum 26.982 2519	14 Si Silicon 28.086 3265	15 P Phosphorus 30.974 white 280.5	16 S Sulfur 32.066 444.61	17 Cl Chlorine 35.453 -101.5	18 Ar Argon 39.948 -185.847											19 K Potassium 39.098 759	20 Ca Calcium 40.078 1484	21 Sc Scandium 44.956 2836	22 Ti Titanium 47.88 3287	23 V Vanadium 50.942 3407	24 Cr Chromium 51.996 2671	25 Mn Manganese 54.938 2061	26 Fe Iron 55.933 2861	27 Co Cobalt 58.933 2927	28 Ni Nickel 58.693 2913	29 Cu Copper 63.546 2562	30 Zn Zinc 65.39 907	31 Ga Gallium 69.732 2204	32 Ge Germanium 72.61 2833	33 As Arsenic 74.922 616 SP	34 Se Selenium 78.972 685	35 Br Bromine 79.904 58.8	36 Kr Krypton 84.80 -153.34																																																																																																																																																																																																																																																																																																																																																																				
37 Rb Rubidium 84.468 688	38 Sr Strontium 87.62 1382	39 Y Yttrium 88.906 3345	40 Zr Zirconium 91.224 4409	41 Nb Niobium 92.906 4744	42 Mo Molybdenum 95.95 4639	43 Tc Technetium 98.907 4265	44 Ru Ruthenium 101.07 4150	45 Rh Rhodium 102.906 3695	46 Pd Palladium 106.42 2963	47 Ag Silver 107.868 2162	48 Cd Cadmium 112.411 767	49 In Indium 114.818 2072	50 Sn Tin 118.71 2602	51 Sb Antimony 121.760 1587	52 Te Tellurium 127.6 988	53 I Iodine 126.904 184.4	54 Xe Xenon 131.29 -108.09	55 Cs Cesium 132.905 671	56 Ba Barium 137.327 1897	57-71 Lanthanide Series	72 Hf Hafnium 178.49 4603	73 Ta Tantalum 180.948 5458	74 W Tungsten 183.85 5555	75 Re Rhenium 186.207 5596	76 Os Osmium 190.23 5012	77 Ir Iridium 192.22 4428	78 Pt Platinum 195.08 3825	79 Au Gold 196.967 2856	80 Hg Mercury 200.59 356.62	81 Tl Thallium 204.383 1473	82 Pb Lead 207.2 1749	83 Bi Bismuth 208.980 1564	84 Po Polonium [208.982] 962	85 At Astatine 209.987 337	86 Rn Radon 222.018 -61.7																																																																																																																																																																																																																																																																																																																																																																				
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Ununbium [978]	347 Uut Ununtrium [981]	348 Uuq Ununquadium [984]	349 Uub Ununbium [987]	350 Uut Ununtrium [990]	351 Uuq Ununquadium [993]	352 Uub Ununbium [996]	353 Uut Ununtrium [999]	354 Uuq Ununquadium [1002]	355 Uub Ununbium [1005]	356 Uut Ununtrium [1008]	357 Uuq Ununquadium [1011]	358 Uub Ununbium [1014]	359 Uut Ununtrium [1017]	360 Uuq Ununquadium [1020]	361 Uub Ununbium [1023]	362 Uut Ununtrium [1026]	363 Uuq Ununquadium [1029]	364 Uub Ununbium [1032]	365 Uut Ununtrium [1035]	366 Uuq Ununquadium [1038]	367 Uub Ununbium [1041]	368 Uut Ununtrium [1044]	369 Uuq Ununquadium [1047]	370 Uub Ununbium [1050]	371 Uut Ununtrium [1053]	372 Uuq Ununquadium [1056]	373 Uub Ununbium [1059]	374 Uut Ununtrium [1062]	375 Uuq Ununquadium [1065]	376 Uub Ununbium [1068]	377 Uut Ununtrium [1071]	378 Uuq Ununquadium [1074]	379 Uub Ununbium [1077]	380 Uut Ununtrium [1080]	381 Uuq Ununquadium [1083]	382 Uub Ununbium [1086]	383 Uut Ununtrium [1089]	384 Uuq Ununquadium [1092]	385 Uub Ununbium [1095]	386 Uut Ununtrium [1098]	387 Uuq Ununquadium [1101]	388 Uub Ununbium [1104]	389 Uut Ununtrium [1107]	390 Uuq Ununquadium [1110]	391 Uub Ununbium [1113]	392 Uut Ununtrium [1116]	393 Uuq Ununquadium [1119]	394 Uub Ununbium [1122]	395 Uut Ununtrium [1125]	396 Uuq Ununquadium [1128]	397 Uub Ununbium [1131]	398 Uut Ununtrium [1134]	399 Uuq Ununquadium [1137]	400 Uub Ununbium [1140]	401 Uut Ununtrium [1143]	402 Uuq Ununquadium [1146]	403 Uub Ununbium [1149]	404 Uut Ununtrium [1152]	405 Uuq Ununquadium [1155]	406 Uub Ununbium [1158]	407 Uut Ununtrium [1161]	408 Uuq Ununquadium [1164]	409 Uub Ununbium [1167]	410 Uut Ununtrium [1170]	411 Uuq Ununquadium [1173]	412 Uub Ununbium [1176]	413 Uut Ununtrium [1179]	414 Uuq Ununquadium [1182]	415 Uub Ununbium [1185]	416 Uut Ununtrium [1188]	417 Uuq Ununquadium [1191]	418 Uub Ununbium [1194]	419 Uut Ununtrium [1197]	420 Uuq Ununquadium [1200]	421 Uub Ununbium [1203]	422 Uut Ununtrium [1206]	423 Uuq Ununquadium [1209]	424 Uub Ununbium [1212]	425 Uut Ununtrium [1215]	426 Uuq Ununquadium [1218]	427 Uub Ununbium [1221]	428 Uut Ununtrium [1224]	429 Uuq Ununquadium [1227]	430 Uub Ununbium [1230]	431 Uut Ununtrium [1233]	432 Uuq Ununquadium [1236]	433 Uub Ununbium [1239]	434 Uut Ununtrium [1242]	435 Uuq Ununquadium [1245]	436 Uub Ununbium [1248]	437 Uut Ununtrium [1251]	438 Uuq Ununquadium [1254]	439 Uub Ununbium [1257]	440 Uut Ununtrium [1260]	441 Uuq Ununquadium [1263]	442 Uub Ununbium [1266]	443 Uut Ununtrium [1269]	444 Uuq Ununquadium [1272]	445 Uub Ununbium [1275]	446 Uut Ununtrium [1278]	447 Uuq Ununquadium [1281]	448 Uub Ununbium [1284]	449 Uut Ununtrium [1287]	450 Uuq Ununquadium [1290]	451 Uub Ununbium [1293]	452 Uut Ununtrium [1296]	453 Uuq Ununquadium [1299]	454 Uub Ununbium [1302]	455 Uut Ununtrium [1305]	456 Uuq Ununquadium [1308]	457 Uub Ununbium [1311]	458 Uut Ununtrium [1314]	459 Uuq Ununquadium [1317]	460 Uub Ununbium [1320]	461 Uut Ununtrium [1323]	462 Uuq Ununquadium [1326]	463 Uub Ununbium [1329]	464 Uut Ununtrium [1332]	465 Uuq Ununquadium [1335]	466 Uub Ununbium [1338]	467 Uut Ununtrium [1341]	468 Uuq Ununquadium [1344]	469 Uub Ununbium [1347]	470 Uut Ununtrium [1350]	471 Uuq Ununquadium [1353]	472 Uub Ununbium [1356]	473 Uut Ununtrium [1359]	474 Uuq Ununquadium [1362]	475 Uub Ununbium [1365]	476 Uut Ununtrium [1368]	477 Uuq Ununquadium [1371]	478 Uub Ununbium [1374]	479 Uut Ununtrium [1377]	480 Uuq Ununquadium [1380]	481 Uub Ununbium [1383]	482 Uut Ununtrium [1386]	483 Uuq Ununquadium [1389]	484 Uub Ununbium [1392]	485 Uut Ununtrium [1395]	486 Uuq Ununquadium [1398]	487 Uub Ununbium [1401]	488 Uut Ununtrium [1404]	489 Uuq Ununquadium [1407]	490 Uub Ununbium [1410]	491 Uut Ununtrium [1413]	492 Uuq

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?

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

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)

⇒ 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 ⇒ $f_\ell > 0.33$

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 (f₁)
- 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.