The Origin of Life

Darwin (1871):

> **"... in some warm little pond with all sorts of ammonia and phosphoric, - light, heat, electricity, etc. present, that a protein compound was chemically formed, ready to undergo still more complex changes, at the present day such matter would be instantly devoured, or absorbed, which would not have been the case before living creatures were formed."**

The Origin of Life

0. Definitions of Life.

I. Conditions for the “life-conditions”/ “Warm Little Pond” as we know it.
Habitability.

II. Chemical evolution
Experiments (i.e. Miller,Urey 1953)
Origin of the Building Blocks: amino acids, nucleotides, sugars, lipids.
Chirality
Self-Reproducing Sets of Molecules.
Robustness of Life: Temperature, Pressure, Chemical Environment,….
History (i.e. earliest signs of life & where)

III. First living systems
Why RNA World?
Hypercycles
Life on surface, the pyrite-world

IV. From surface life to cellular life
Chemoton
The stochastic corrector

V. From RNA world to protein world
RNAs as enzymes
Amino acids as cofactors

Definitions of Life.

Physically connected unit that has metabolism, can reproduce and evolve by natural selection.

Metabolism:

Thermodynamically open system

Makes complex molecules from simple monomers

Heredity/variability:

Balance between fidelity and variability

Unlimited possible combination needed

Definitions of Life.

As we know it, it will have:

- Genetic Material
- Metabolism
- Cell membrane

More Earth centred still:

- Carbon based
- Necessitates presence of fluid water & solid core.
- Stability for Billions of Years.

Creating a “Warm little Pond”

In the right kind of Universe

Creation of Stars with Planetary System

Long Term Stability of Planets in a Habitable Zone (HZ)

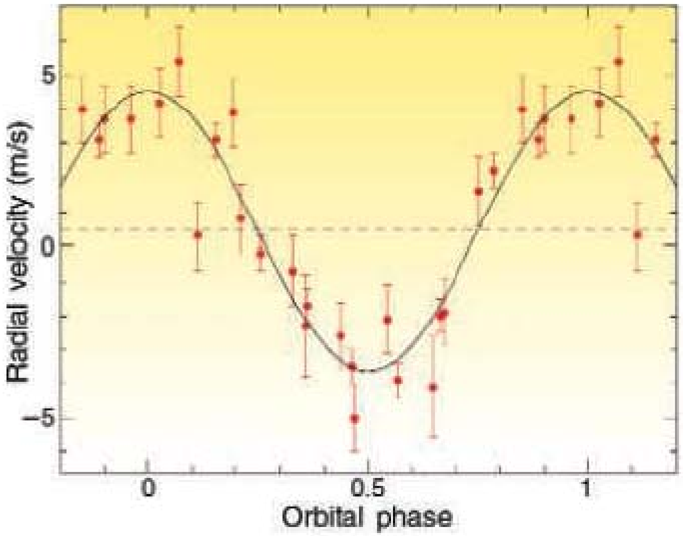
- Right Kind of Star
- Right Kind of Planet:
  - Size
  - Distance from Sun
  - Big Moon
  - No comet/meteor storm, i.e large outer planets.

Alternatives: Dark Side of Mercury like planet, Moons of Hot Giants, Hot vents anywhere powered by gravitational friction

Methods for Searching for Extra-Solar Planets

A. Perturbation of star path.

- $Q = (mp/M)(r/D) = (mp/D)(P/M)^{2/3} = .5*10^{-8}$
- Q - amplitude (present resolution ~10^{-9})
- mp - mass of planet - $1.9*10^{30}$ g.
- M - mass of Star - $1.3*10^{33}$ g.
- r - radius of orbit - $8.15*10^{11}$ m - 6 AU.
- P - orbital period - 4332 days - 12 years.
- D - distance from observer - 10^{16} m - 1prc.
- Radial velocity $v = 30\ mp*\sin(i)/(rM).5 = 3*10^{-4}$ km/sec.
- Observation: Wobbling or Dobbler Effect.
- Present limit to DE : 0.5 m/s. Earth induces 10cm/s.



Planetary pull. A Uranus-size body tugs back and forth on the star μ Ara as it orbits.

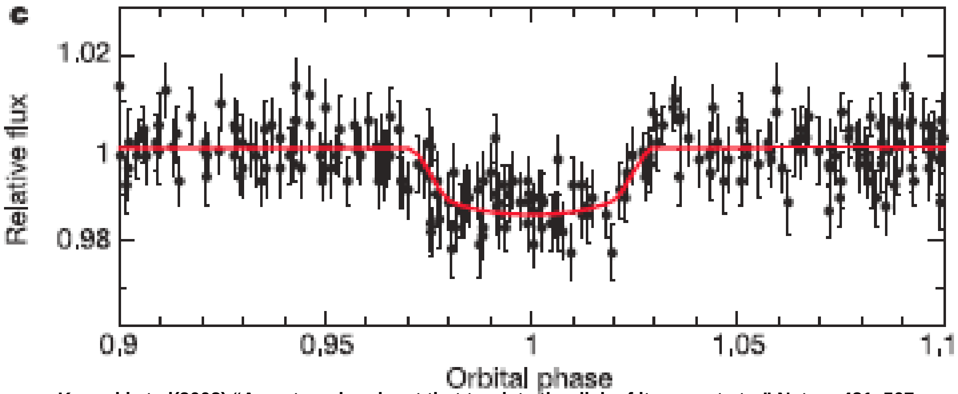
Planet gets Rocky as Teams clash over small Worlds (2004) Science 305.382-

B. Radiation

i. O_2/O_2
ii. Chirality
iii. H_2O

C. Fluctuation in luminosity.

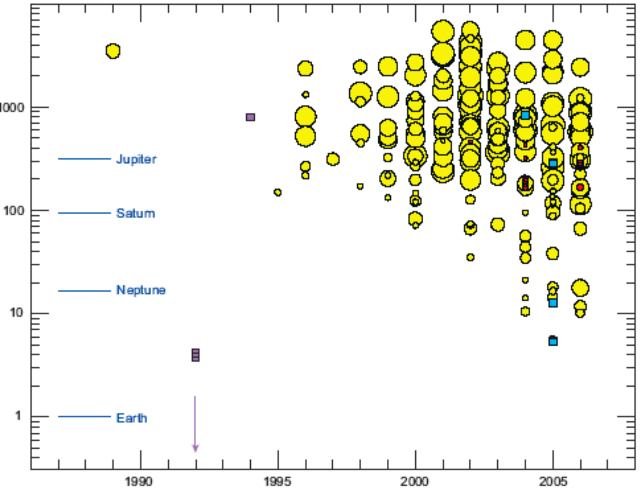
D. Seeing it

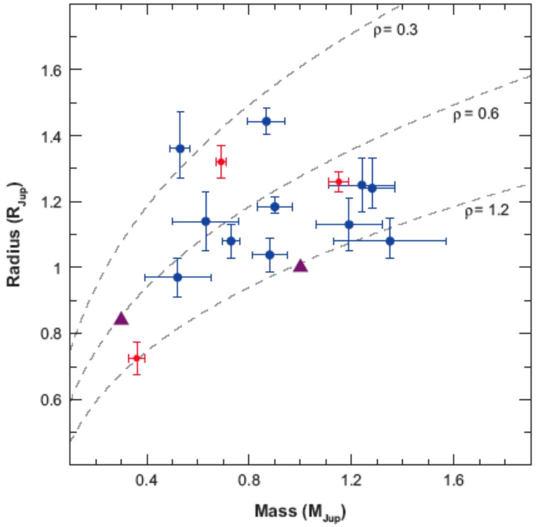


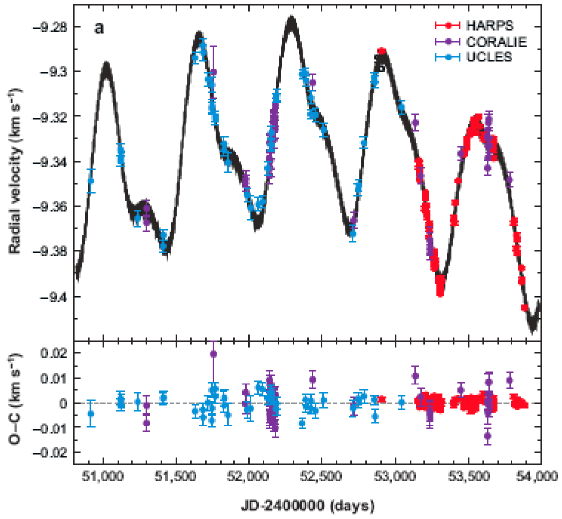
Konacki et al(2003) “An extrasolar planet that tranists the disk of its parent star” Nature 421. 507-

Statistics over Extrasolar Planets

4.07.06:136 planetary systems, 172 planets, 18 multiple planet systems, 14 transiting





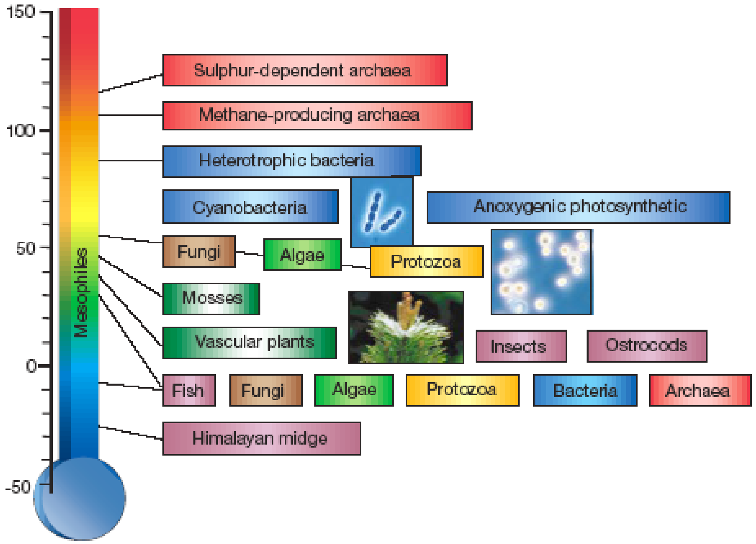


- *Clearly a trend towards smaller planets.*
- *Transiting planets additionally allows diameter and atmosphere measurements.*
- *Multiple planets - Keplerian system with many bodies constrained by stability requirements.*

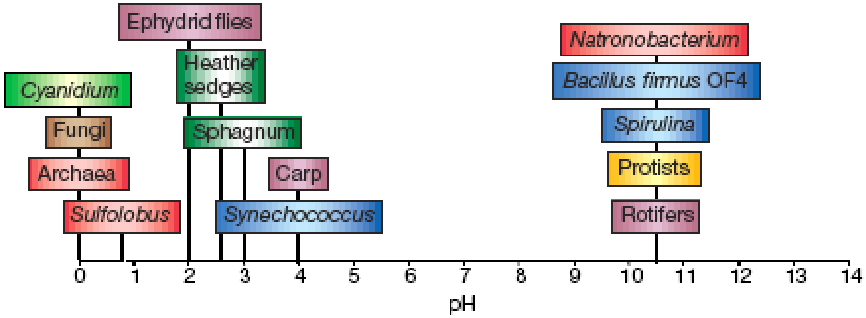
From http://exoplanets.org/massradiiframe.html and Annual Review Astro (2007) Udry

Robustness of Life - Ranges

Temperature:



Acidity:



Pressure:

>1200 atmospheres

Vacuum as spore, but reproducing at how low pressure?

Radiation:

D. Radiulans ~150.000*

Rothchild,L and Mancinelli (2001) Life in extreme environments. Nature 209.1092-, Sharma et al.(2002) "Microbial activities at GigaPascal pressueres" 295. 1514-

Habitability. (Franck,2001)

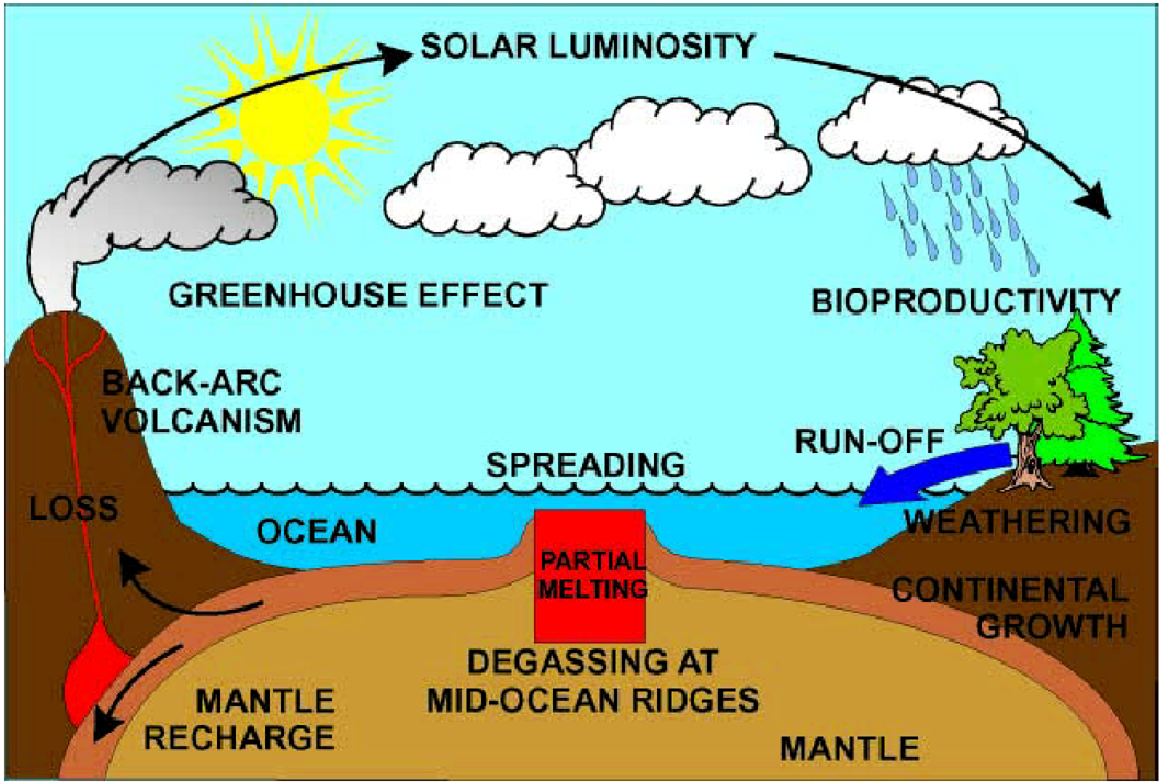
Equilibrium Temperature

$\sigma T_e^4 = (1\text{-}A)S/4$ where A is albedo (the fraction reflected), S the amount of solar insolation and σ is the Stefan-Boltzmann constant.

Important Climatic Factors

- Water
- $C0_2$
- Tectonics

(Franck et al.,2001)



The Atmosphere

(Rampino & Caldeira,1994, Kasting & Catling,2003 & Alonso-Finn,1968)

Escape velocity: Sqr(2GM/R) in Km/sec

Earth	Moon	Jupiter	Sun
11.2	5.0	59.5	1800

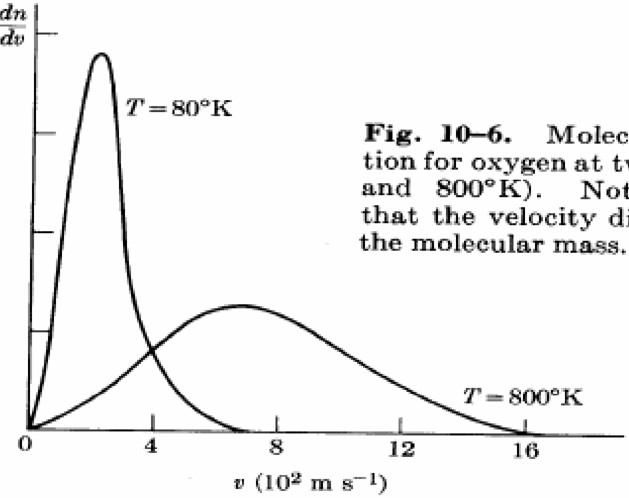


Fig. 10–6. Molecular velocity distribution for oxygen at two temperatures (80° K and 800° K). Note, from Eq. (10.45), that the velocity distribution depends on the molecular mass.

Density : $4\pi N(m/2\pi kT)^{3/2} v^2 e^{-(mv*v/2kT)}$

m mass of particles, v velocity, k Boltzman's constant and N .

1. Temperature proportional to kinetic energy of particles ($mv^2/2$),

2. Velocity of particles increases roughly like square root of T.

3. Velocity of particle inversely proportional to weight of particles.

Exobase – collision free: >500 km

Homopause – no turbulence: ~100 km

Green House Effect (Celsius)

Venus	Earth	Mars
4-500	50-60	7-10

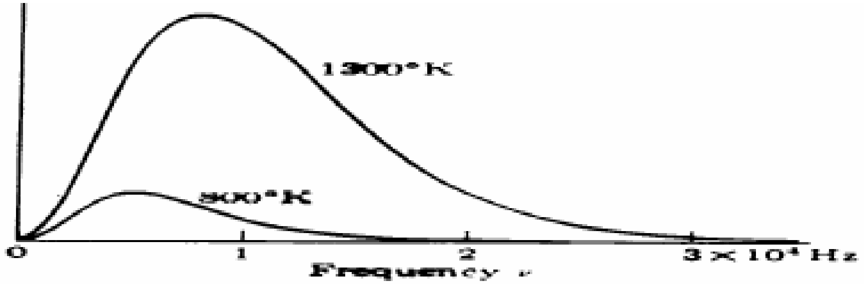
Climate simulations: http://vortex.bd.psu.edu/~williams/LExEn/table.html

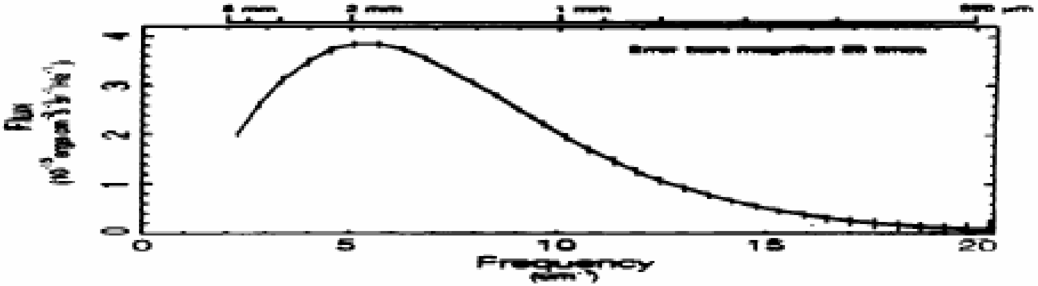
Black body & Background radiation.

Distribution from body of temperature *T*, *h* planck's constant, *c* velocity of light, λ wavelength, *k* Boltzman's constant and *x* = hc/λkT.

$$(8\pi k^5T^5/c^4h^4)*(x^5/e^x-1)$$

1. T*(peak λ) = constant.
2. Total Energy : constant*T^4
3. Redshifted Planck distribution becomes a planck distribution at another temperature.





Figur 2.6. COBE-spektrum af den kosmiske baggrundsstråling. Som funktion af 1/λ er vist den målte flux, samt det bedste fit til en Planck-fordeling ($T_{\gamma 0}$ = 2.735K). Bemærk at usikkerhederne er forstørret 20 gange for at kunne ses! Se også figuren på omslaget, hvor andre målinger er indtegnet sammen med COBE-dataene. (COBE Science Working Group, 1993).

Habitability.

Venus - No H_2O = > no removal of CO_2 from atmosphere by weathering.

Earth - The CO_2 is tied up in $CaCO_3$

Mars - Too low temperature & gravity, so no greenhouse developed. No tectonics=> no return of CO_2 to atmosphere.

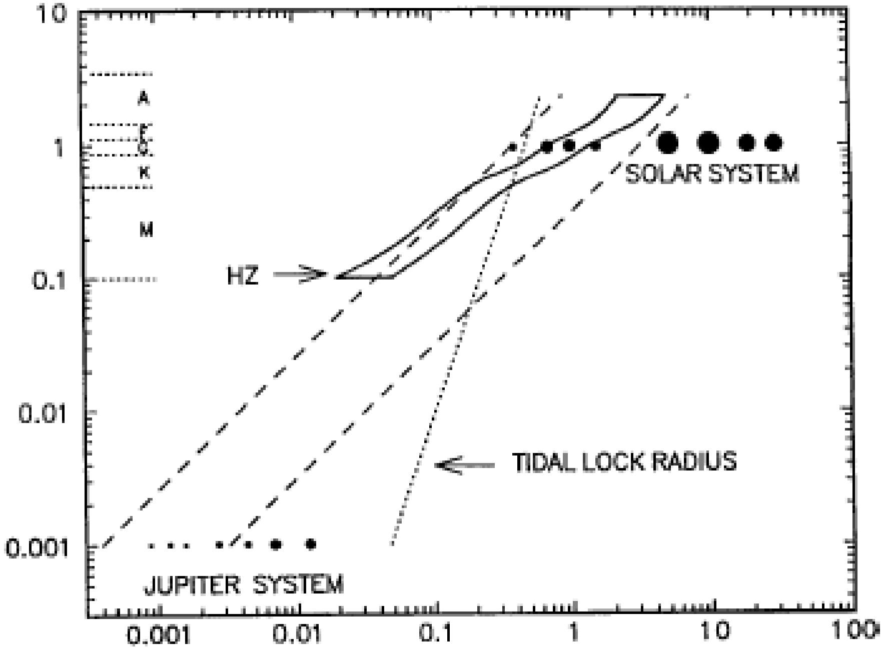
Continuously Habitable Zone - (CHZ)- Water for Billions of Years:

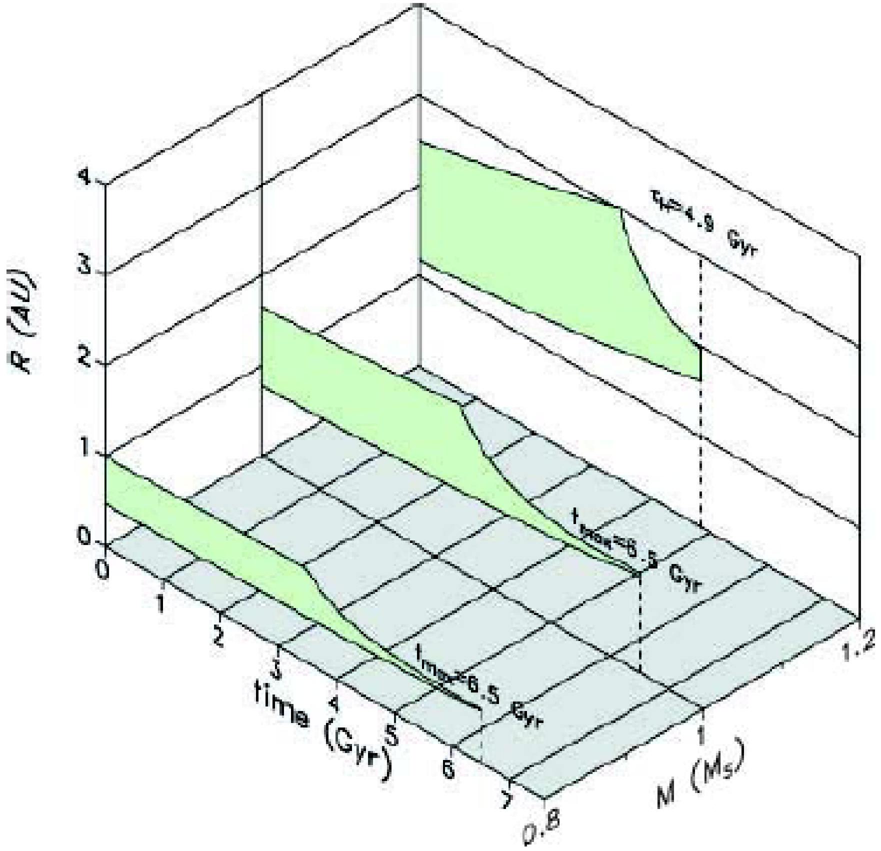
HZ: .95-1.37 AU   CHZ:.95-1.15

Main Problem: The Sun's increasing luminosity means that the HZ should move out through the solar system.

$S(t) = S_0/(1-.38t/\tau_0)$ -4.5 Gyr $< t < 4.77$ ($\tau_0 = 4.55$ Gyr)

Right Kind of Star





- *Smaller stars have very long life times, but narrow HZ*
- *Tidal lock creates interesting weather.*

Frank (2001) Naturwissenschaften and Kasting (1993)

No comet/meteor storm.

(from Thomas et al.,1997)

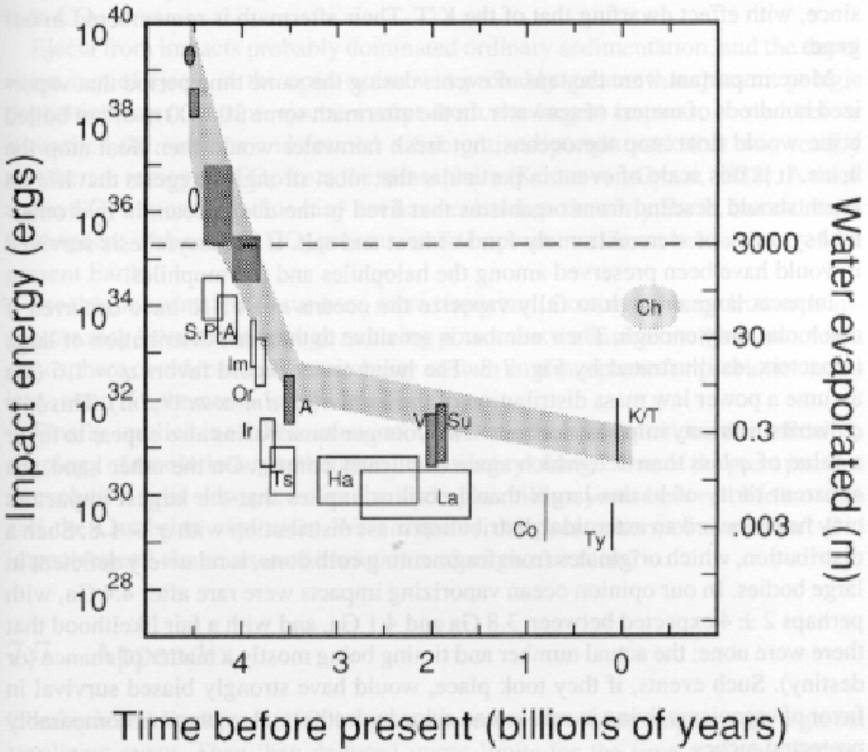


FIGURE 7.4. The largest impacts before the present for the Moon and Earth. Open boxes are lunar, shaded boxes are terrestrial. The dimensions of the boxes indicates range of uncertainty. The stipled region shows the inferred largest impacts on Earth. The right-hand axis is the depth of ocean vaporized by the impact. The three earliest events (4.5 Ga) shown are the energies of the Earth and Moon formation and the moon-forming impact. Energies of basin-forming impacts (3.8–4.3 BY) are discussed in the text. The lunar craters are Tycho, Copernicus, Langrenus, Hausen, Tsiolkovskiy, and Iridum; diameters and approximate ages are adapted from Wilhelms (1987). Size and dates of terrestrial impacts at Sudbury and Vredevort are taken from Grieve (1982). The Chicxulub crater (the K/T crater, 65 Ma) is at least 180 km diameter (Hildebrand et al., 1991). The biological crater is consistent with a 10^{31} erg event (Melosh et al., 1990). Chiron remains a potential source of future troubles.

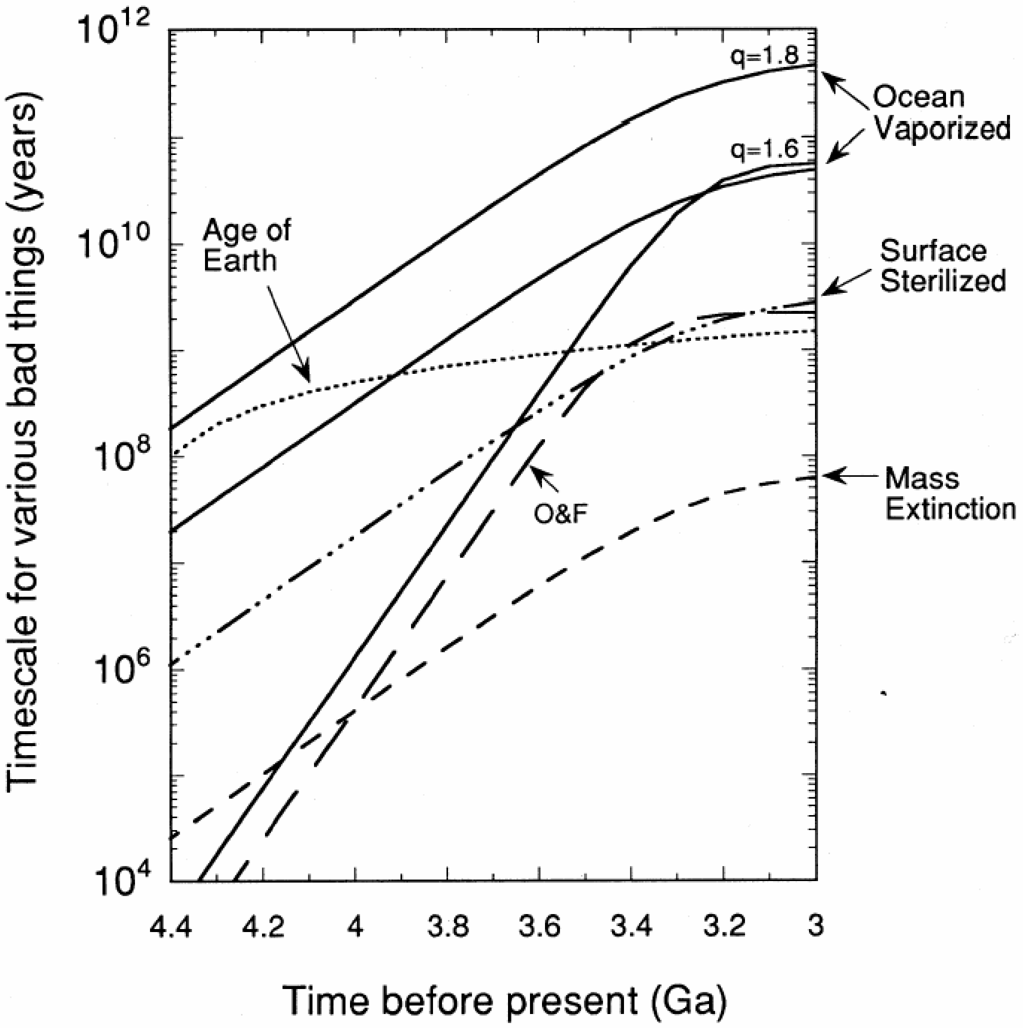


FIGURE 7.5. This figure revises Fig. 2 of Maher and Stevenson (1988). It is an ambitious extrapolation backward in time. The categories are defined in Table 7.1. The curves labeled "Ocean Vaporized" are often taken to refer to global sterilization; we leave their interpretation to the reader. We show two characteristic timescales for the decline of the heavy bombardment, $\tau = 0.144$ Ga (Chyba, 1991) and $\tau = 0.07$ Ga (Maher and Stevenson, 1988). The latter have the more agressive slope. We favor the former. The curves are prepared with $q = 1.6$, except for the uppermost curve, which with $q = 1.8$ describes a considerably safer Earth. Also shown is the corresponding curve calculated according to Oberbeck and Fogleman (1990). This curve, labeled "O&F," equates a much smaller crater with ocean vaporization; it also uses $q = 1.5$. The "Age of the Earth" assumes that the clock started at 4.5 Ga.

Craters

v - velocity (8-15 km/sec - max 70), m - mass (example 1km about 10^{15} kg), g - constant (surface gravity, angle, meteor density) (Moon - $1.6*10^{3}$kg s-1.67 m-2.13)m= g $v^{-1.67}$ Di 3.80 Energy Released $.5mv^{2}$

Categories of Bad Things.

Evaporating the Oceans: 500 km 14km/s - 1500 km crater 10^{34} ergs.
Imbrium type 3.8Gy: 10^{34} ergs - boil 40 m water, surface temp 150.

Famous Craters

3.8-4.1 GA 10 major (i.e. Imbrium) on Moon (>100 on Earth)
Permian Extinction (225 Myr 120 km)
Cambrian-Tertiary (Yukatan - 65 Myr - 10 km - D 180 km)
Arizona (50 Kyr 1,2 km)
Tunguska (30.6.1908) (60m stony meteorite, 10-20 MT)

Giordano Bruno (Moon - 18.6.1178 - 110 km)
"Suddenly the upper horn split into two. From the midpoint of this division a flaming torch sprang up, spewing out over considerable distance fire, hot coals and sparks. Meanwhile the body of the moon which was below writhed as if it was in anxiety ... and throbbed like a wounded snake"

The Earliest Fossils

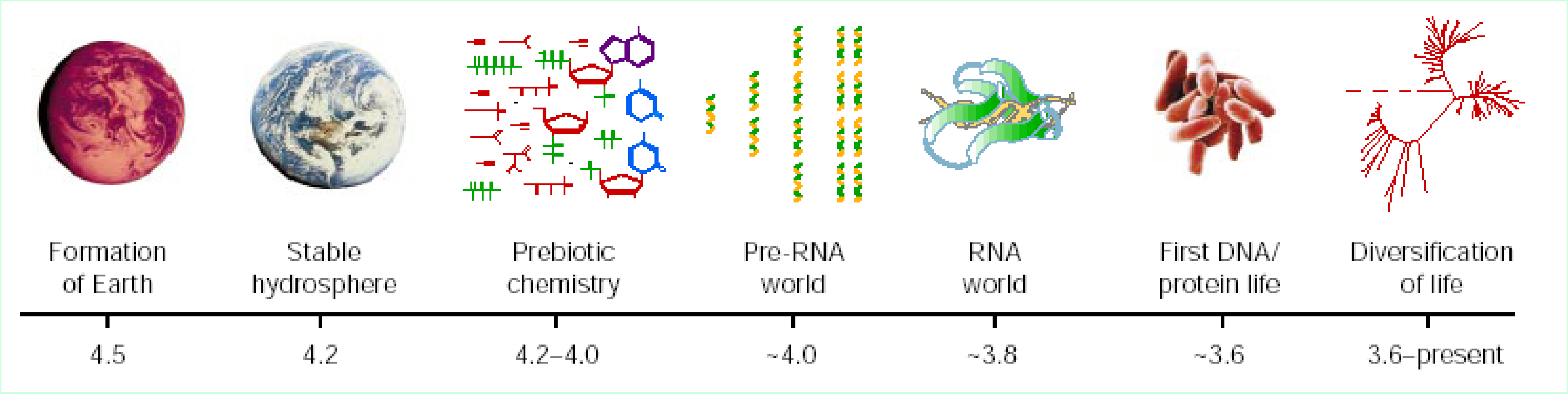


Figure 1 Timeline of events pertaining to the early history of life on Earth, with approximate dates in billions of years before the present.

From Joyce, 2002

Schopf et al.(2002) 3.45 Byr

Brasier et al. (2006) no proof earlier than 3.0 Byr

Creating Life in the “Warm little Pond”

Creating the Monomers

Making Polymers

Making Systems

Oparin-Haldane (late 20s) (from Fenchel, 1998)

1. **Buildup of building blocks in solution.**
2. **Formation of Coacervates.**
3. **Heterotrophic.**

Problems.

1. **Low concentration of building blocks.**
2. **Hydrolysis favoured.**
3. **No reasonable pathway to the nucleotides.**
4. **Chirality.**

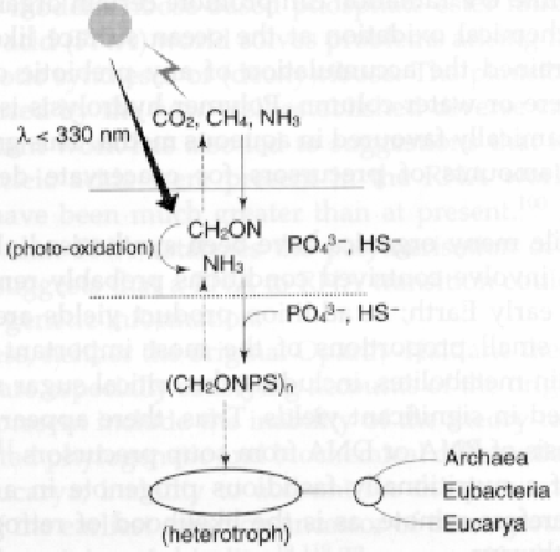


Figure 10.7 Simplified conceptual representation of the Oparin–Haldane model for origins of life. UV, lightning discharges or other energy sources result in organic matter synthesis from the constituents of a reducing atmosphere. Some photooxidation occurs in the upper layers of a primordial ocean with phosphate and sulphur incorporation and polymerisation taking place in lower layers. Evolution leads to a heterotroph initially. Phylogenetic development is unclear

The Building Blocks – The first experiment

Urey, Miller 1953 – from Schopf, 2002 & Smith, Szathmary,1995

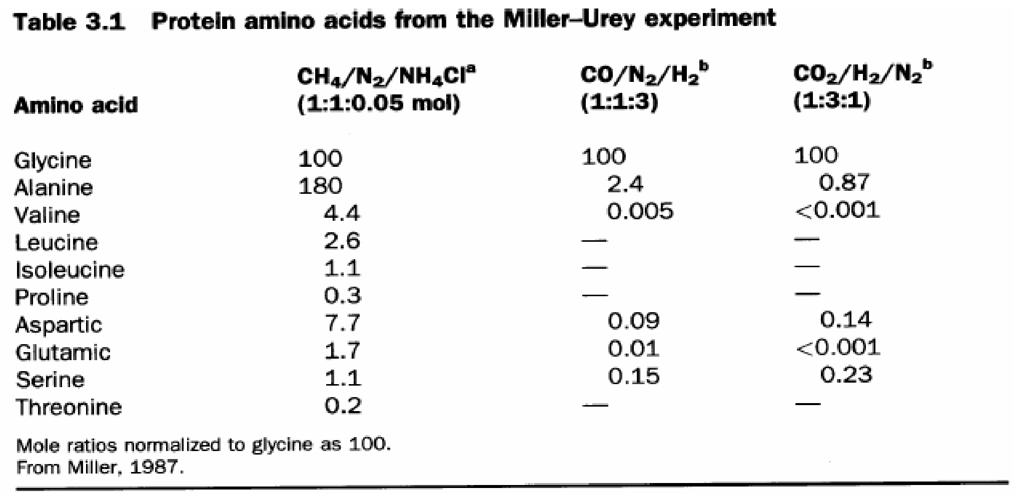
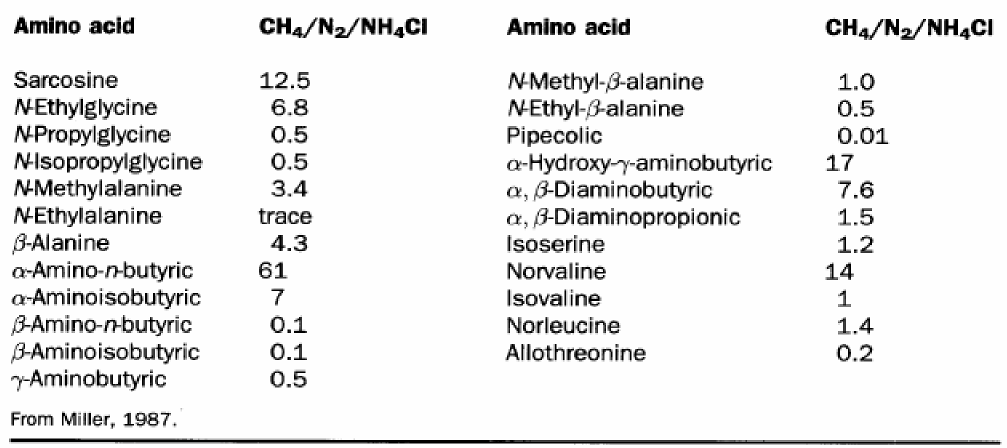


Table 3.1 Protein amino acids from the Miller–Urey experiment

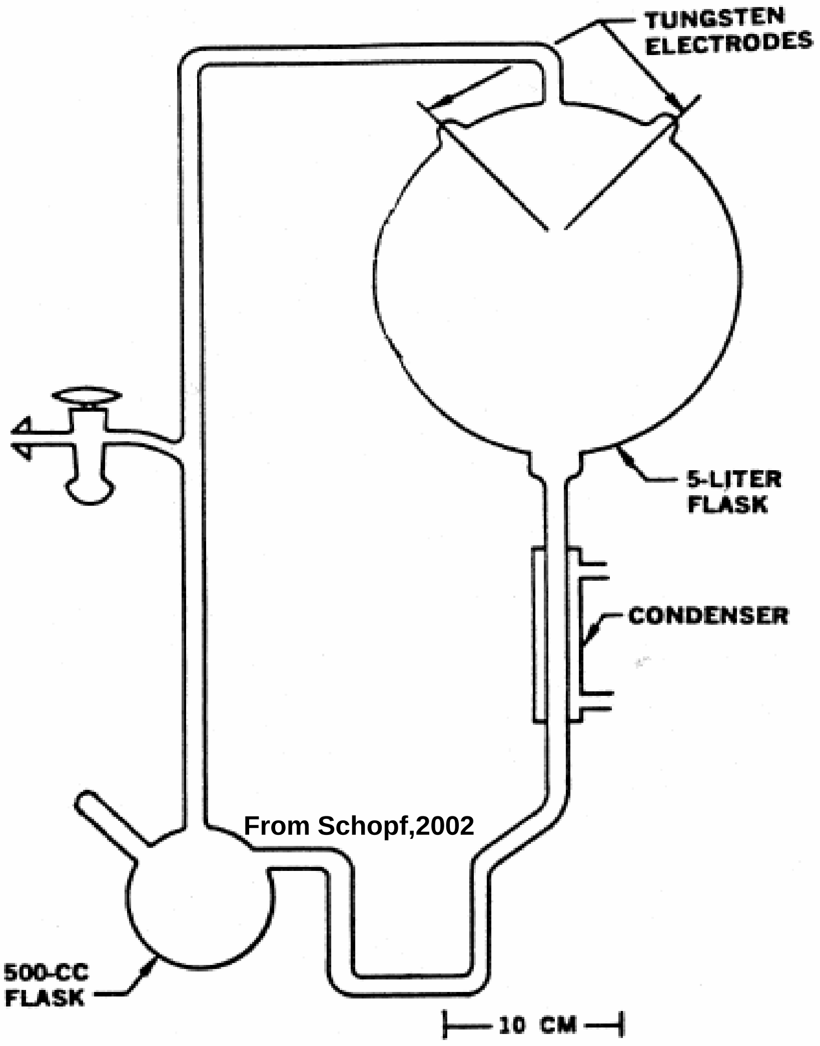
Amino acid	$CH_4/N_2/NH_4Cl^a$ (1:1:0.05 mol)	$CO/N_2/H_2{}^b$ (1:1:3)	$CO_2/H_2/N_2{}^b$ (1:3:1)
Glycine	100	100	100
Alanine	180	2.4	0.87
Valine	4.4	0.005	<0.001
Leucine	2.6	—	—
Isoleucine	1.1	—	—
Proline	0.3	—	—
Aspartic	7.7	0.09	0.14
Glutamic	1.7	0.01	<0.001
Serine	1.1	0.15	0.23
Threonine	0.2	—	—

Mole ratios normalized to glycine as 100.
From Miller, 1987.



Amino acid	$CH_4/N_2/NH_4Cl$	Amino acid	$CH_4/N_2/NH_4Cl$
Sarcosine	12.5	*N*-Methyl-β-alanine	1.0
N-Ethylglycine	6.8	*N*-Ethyl-β-alanine	0.5
N-Propylglycine	0.5	Pipecolic	0.01
N-Isopropylglycine	0.5	α-Hydroxy-γ-aminobutyric	17
N-Methylalanine	3.4	α, β-Diaminobutyric	7.6
N-Ethylalanine	trace	α, β-Diaminopropionic	1.5
β-Alanine	4.3	Isoserine	1.2
α-Amino-*n*-butyric	61	Norvaline	14
α-Aminoisobutyric	7	Isovaline	1
β-Amino-*n*-butyric	0.1	Norleucine	1.4
β-Aminoisobutyric	0.1	Allothreonine	0.2
γ-Aminobutyric	0.5		

From Miller, 1987.



From Schopf,2002

Figure 3.2. The apparatus used in the first electric discharge–powered synthesis of amino acids and other organic compounds under conditions designed to simulate those of the primitive Earth. It was made entirely of glass, except for the tungsten electrodes (Miller 1953).

Problems

1. Early atmosphere probably didn't contain hydrogen H_2. This reduces the production of organics.

2. Most polymers are unstable at high temperature. Does not replicate by themselves reliably, when longer than 40-60 units.

3. A non chiral system cannot select among mirrored versions of the same molecule.

Schopf, 2002

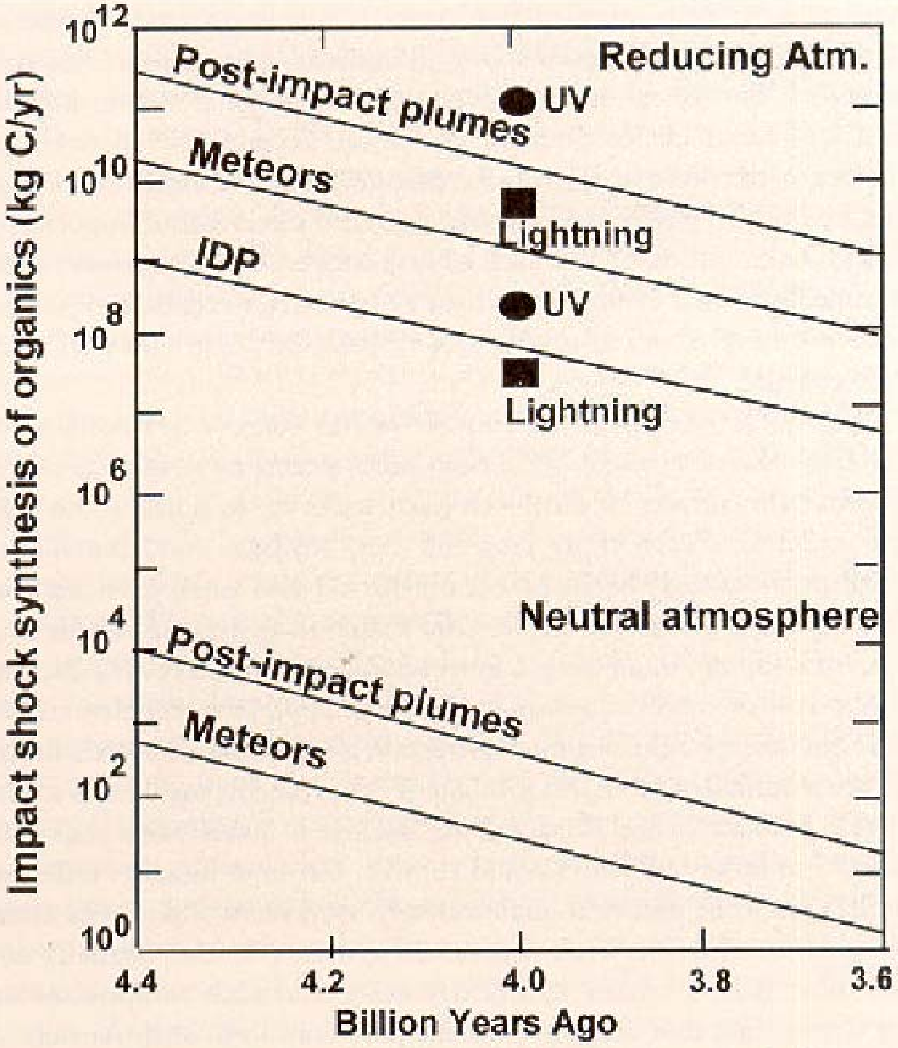


Figure 2.6. Estimated production rates (in kilograms per year) of organic carbon compounds from meteor shockwaves, high-temperature chemical reactions in impact plumes, and in-fall of interplanetary dust particles (IDPs) compared with such production from ultraviolet light and electric discharges. Two sets of data are shown: The lower for a "neutral" (CO_2–N_2–H_2O) atmosphere; the higher for a "reducing" (CH_4–N_2–H_2O) atmosphere. The IDP flux is independent of atmospheric composition. Overall, productivity decreases logarithmically over time as the frequency and size of impactors decreases. (Adapted from Chyba and Sagan 1992.)

Polymers (Joyce, 2002)

Figure 2 Prebiotic clutter surrounding RNA. Each of the four components of RNA (coloured green, red, purple and blue) would have been accompanied by several closely related analogues (listed in black type), which could have assembled in almost any combination. All possible building blocks for each of the components should be regarded as sorting independently; for example, the phosphodiester linkage may have comprised either a 3′,5′ linkage involving a phosphate or a 2′,5′ linkage involving a pyrophosphate.

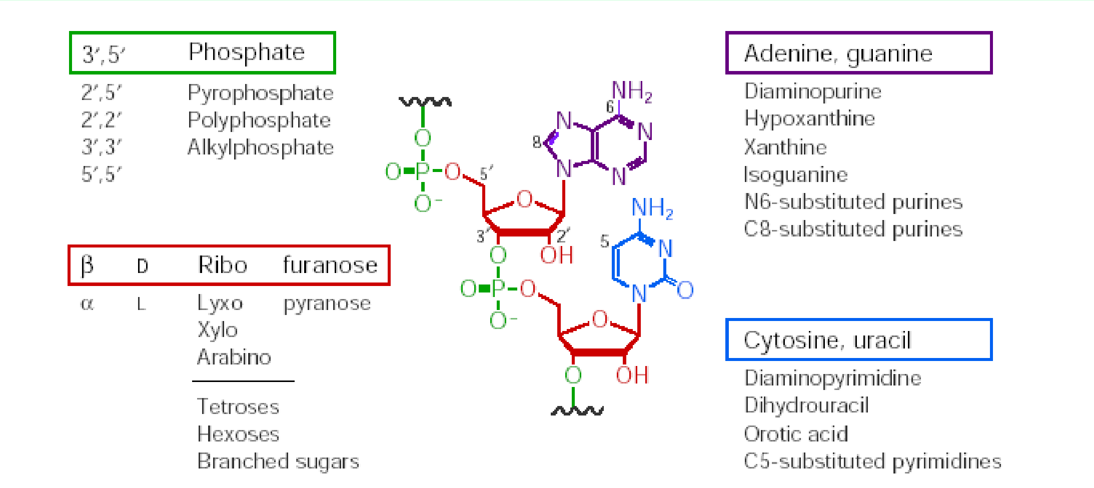
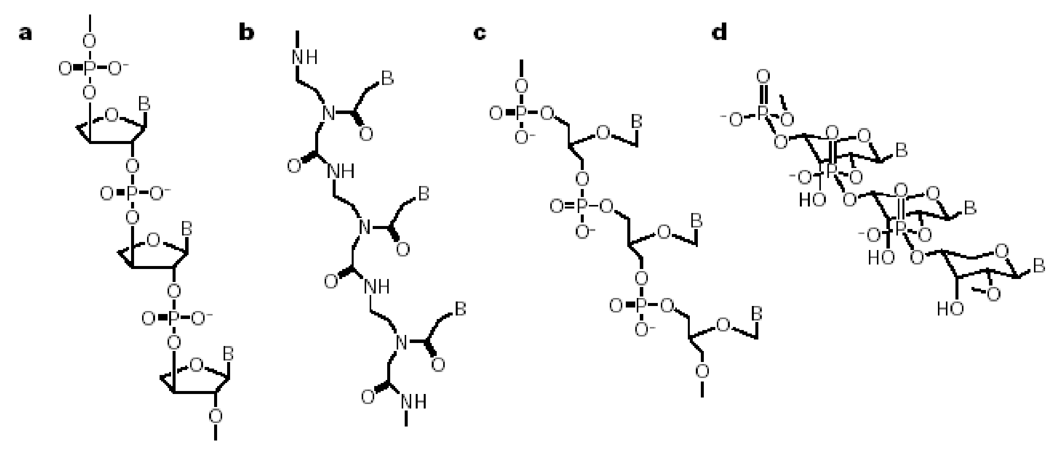


Figure 3 Candidate precursors to RNA during the early history of life on Earth. **a**, Threose nucleic acid; **b**, peptide nucleic acid; **c**, glycerol-derived nucleic-acid analogue; **d**, pyranosyl-RNA. B, nucleotide base.



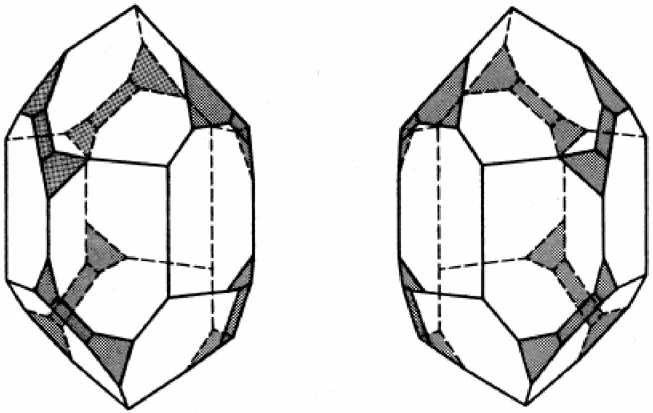
Chirality.

Biological Importance of Chirality:

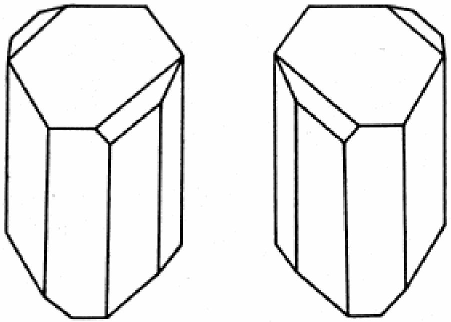
- **i. Is chirality a necessity for life?**
- **ii. Life will probably lead to chirality.**

Questions:

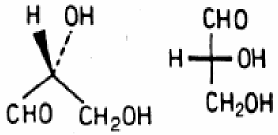
1. How Many "quasi-independent" chiral decisions have been taken in Earth Life? (at least L-amino Acids & D-Sugars. By "quasi-independent" is meant that the molecules are not likely do have influenced each other.



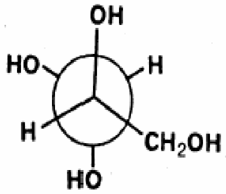
Quartz crystals



Sodium ammonium tartrate



D-(+)-glyceraldehyde



Preferred conformation of hydrated D-(+)-glyceraldehyde

Fig. 14.7 The absolute configuration of D-(+)-glyceraldehyde, with the corresponding Fischer projection structure, and the preferred conformation of hydrated D-(+)-glyceraldehyde in aqueous solution, stabilized relative to its L-(−)-enantiomer ($\sim 10^{-14}$ J mol^{-1}) by the electroweak interaction.

From Mason, 1990

The Fall of Parity

From Mason,1990

Chiral Forces - kinetic:
Polarized light
Magnetic fields.

Thermodynamic reason for chirality
The Main Forces
i. Gravity
ii. Electro-Magnetic Force
iii.Weak Interaction: involved in β-decay.
iv. Strong Interaction.

Symmetries
T - Time
C - Charge
P - Parity (Space Mirroring)

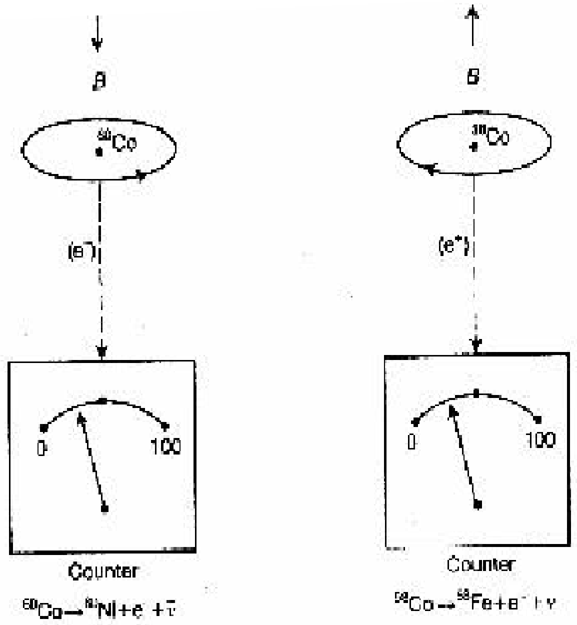
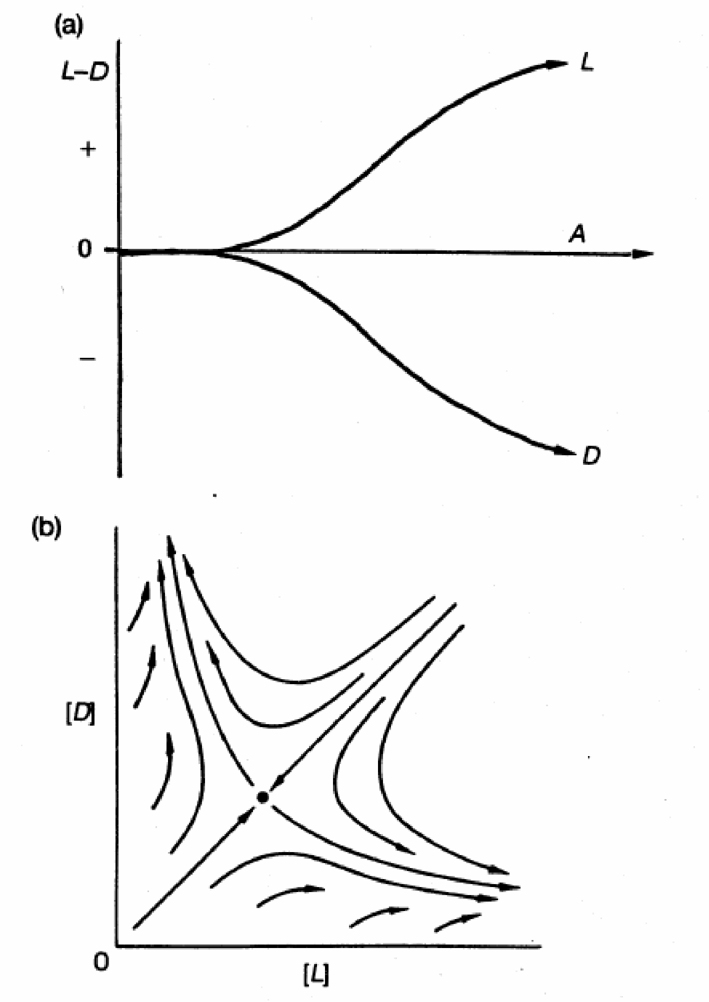


Fig. 14.5 Parity non-conservation in the weak interaction governing β-radioactivity. The β-decay emission of cobalt radionuclei aligned at liquid-helium temperatures by a magnetic field *B* lacks the equivalence along the two directions of the field axis, expected from parity conservation. A β-electron from ^{60}Co is projected preferentially in the direction antiparallel to its spin-axis vector, whereas a β-positron emitted from ^{58}Co has a preferred parallel orientation between its translation and spin-axis vector.

Frank (1953) Dynamics

From Mason, 1990

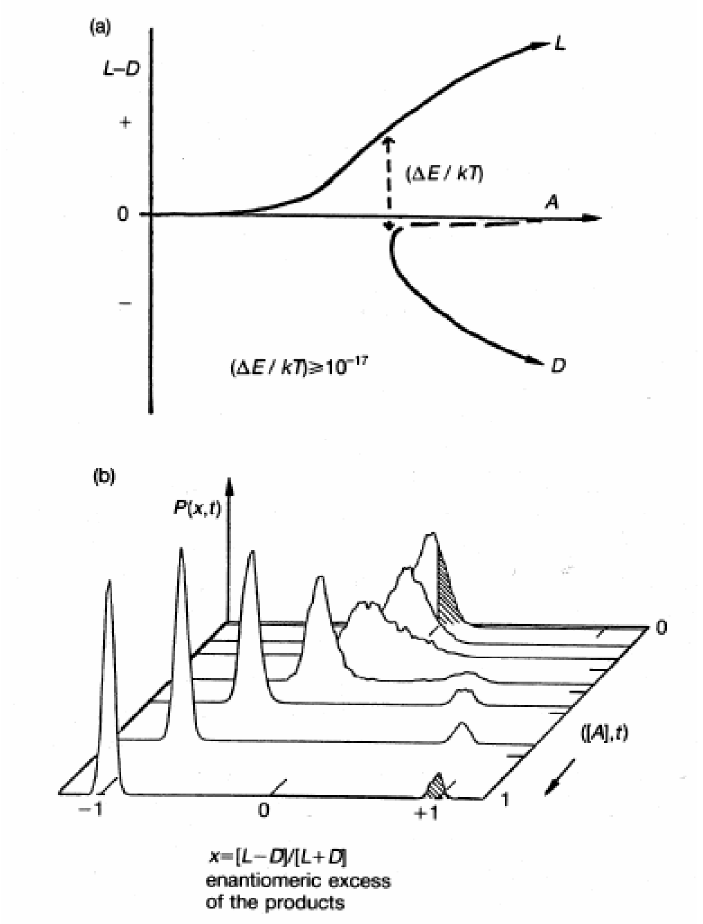
A - substrate
L (D) - enantiomeric molecule
P - product
1: A + L (D) <--- k_1,k_{-1} ---> 2L (2D)
2: L + D --k_2--> P



Frank Dynamics & The EW Interaction.

(Kondepudi & Nelson, 1985 – from Mason,1990)

$\Delta E e^{w/kT} = 10^{-17}$ eV. This corresponds to a tilt in direction of the favoured enantiomers of about 10^6 molecules if a mole ($6.06 * 10^{23}$) is present. Simulation of a lake 1 km in diameter, 4 m deep with 10^{-2} M AA corresponding to 10^6 years. This will create a probability of 98% of the favoured enantiomer.



Chirality in Murchison's Meteorite.

- 1990: More L-Valine than D-Valine
- Possibility of contamination great, since it is a biological amino acid.
- Racemization: 10^4 years at 50 C & 10^6 years at 0C.
- Much slower if the Hydrogen group is substituted with larger group.
- 1997: 4-9% Excess of L-form if H-> Larger group. Cause: Polarized Synchronic Radiation from Stars.

From Schopf, 2002

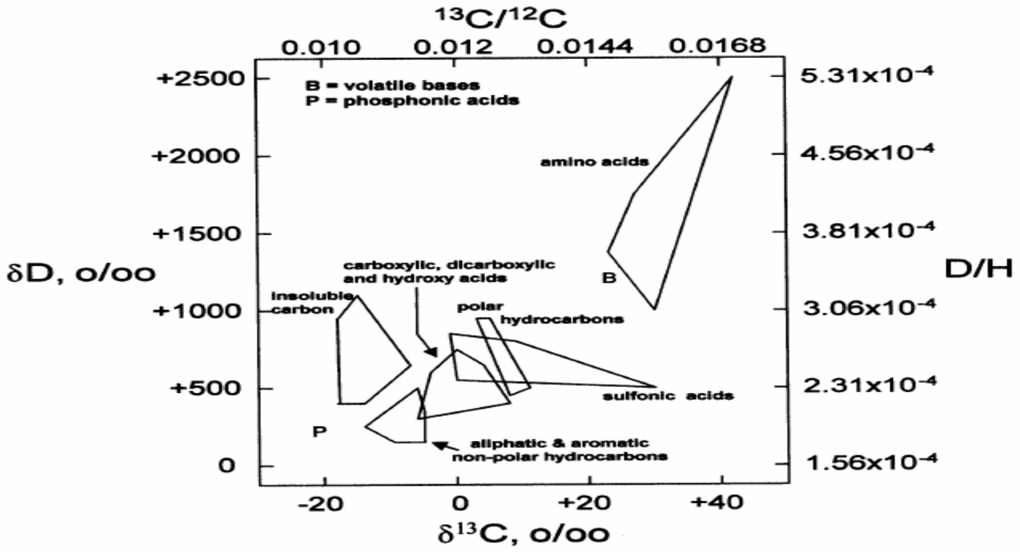


Figure 2.5. The organic components of the Murchison meteorite are composed of isotopes of carbon (^{12}C and ^{13}C) and hydrogen (^{1}H and D, deuterium) that vary widely and lie well outside the ranges of values found in organic matter on Earth.

From biochemical molecules to biochemical systems

Made by Isvan Miklos

Error threshold

$$q^N > a$$

$$N < \log_q a$$

***q*: probability that a nucleotide will be copied without error**
***N*: length of the polymer**
a: percentage of accurate copies

If $q = 0.99$, $a = ½$, then $N \approx 69$

This is too short for a complete genome!
Solution: separation into many short sequence.
But: reproduction rate will not be equal, one of them will spread.

Solutions

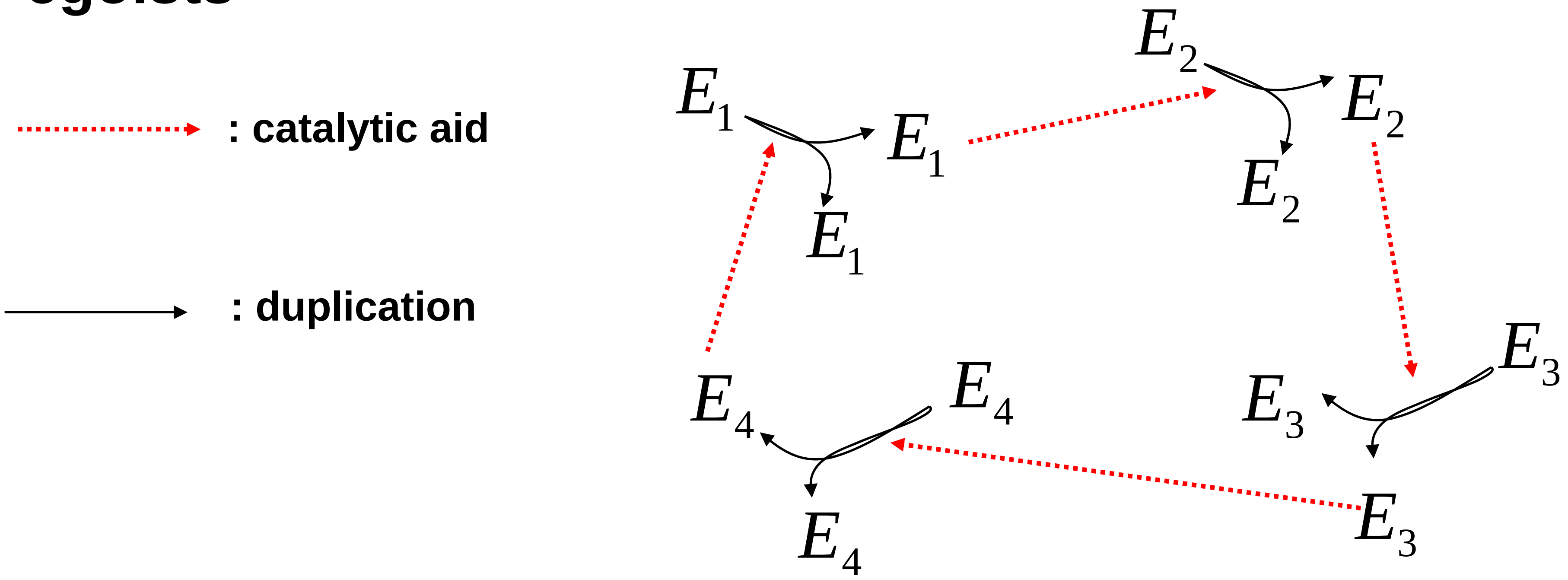
Quasi species, Hyper cycle (Eigen, 1970)

Made by Isvan Miklos

Quasi Species & Hyper-cycles

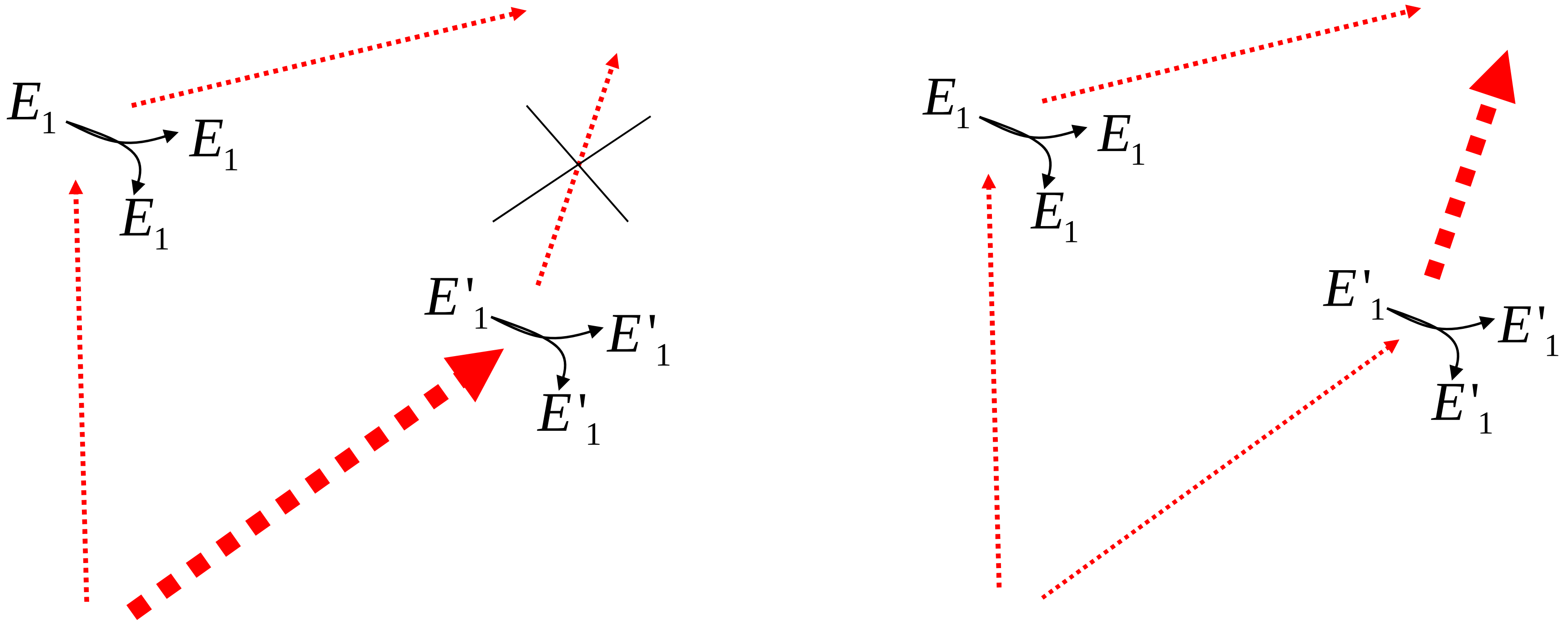
Quasi Species: Strings can replicate giving a distribution around a more fit **Master Sequence** in case error is below a given threshhold.

Hypercycles: Families of replicating strings can enhance each others reproduction and outcompete "egoists"



Made by Isvan Miklos

Selfish mutations in Hyper-cycles



Possible solutions: Spatial heterogeneity

Spatial waves
Surface life “pre-biotic pizza”
Compartments (stochastic corrector)

Made by Isvan Miklos

Minimal replication

Making covalent bound:
irreversible step

Monomers

Product

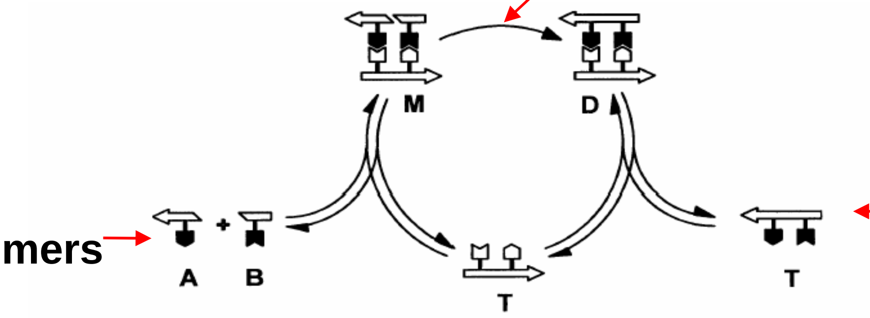


Figure 14.1. Schematic representation of a minimal self-replicating system.

Template

More complex systems: Cross catalytic self replication

Monomers

Templates

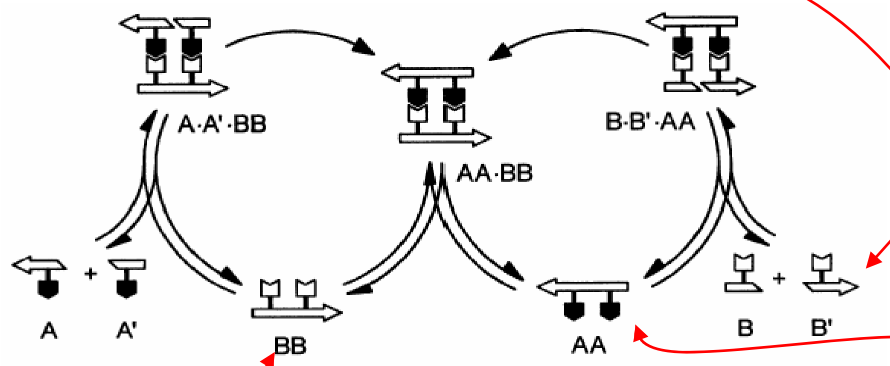


Figure 14.5. Minimal representation of a cross-catalytic self-replicating system.

Kiedrowski, from Burmeister.

More complex systems

Three starting materials: CCG, CG and G (A,B,C)

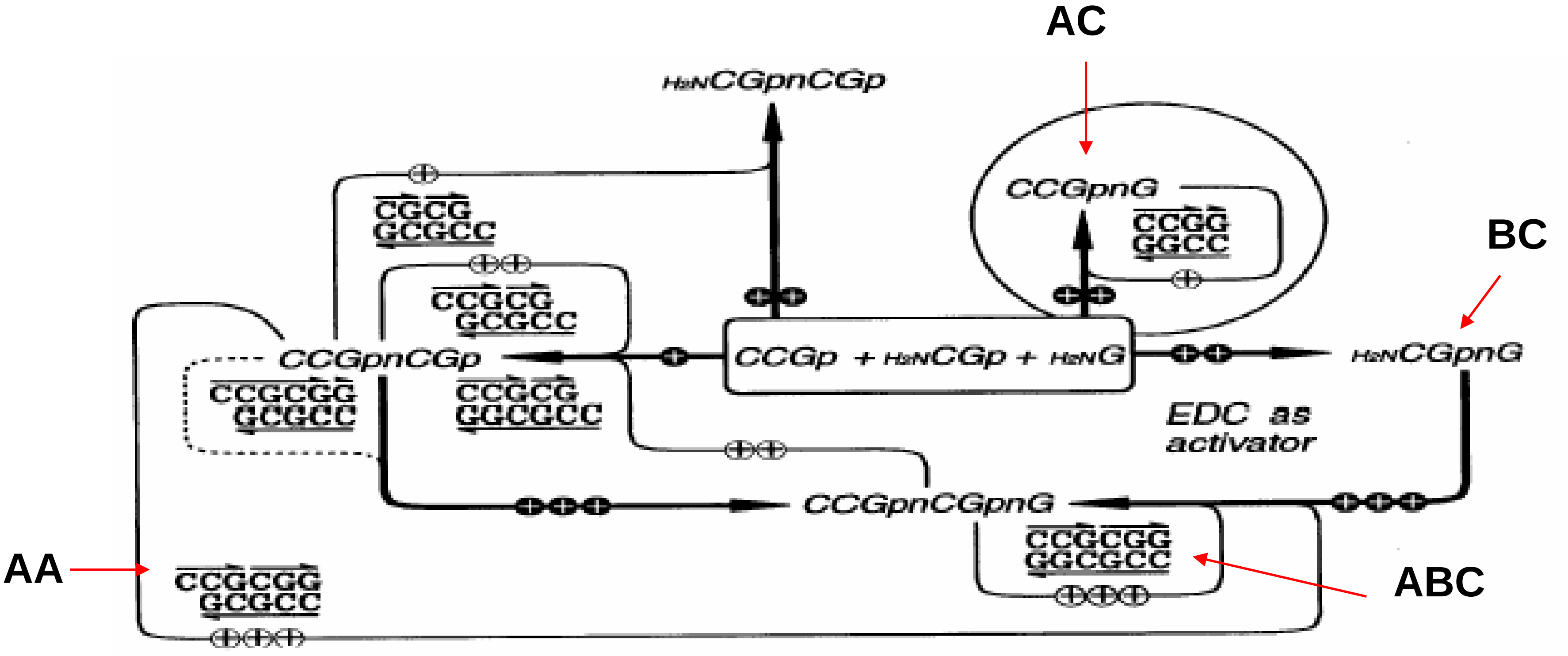


Figure 14.4. A self-replicating system from three starting materials: synthetic pathways and catalytic couplings.

Self-replication.

(Julius Rebek & von Kiedrowski)
Replication: Autocatalysis with molecular recognition.

Dynamics
No AC: A + B -> AB f([A],[B])
AC: A + B -> AB f([A][B][AB])

Test: Added Autocatalysis should accelerate output.

Examples
von Kiedrowski (1986) - 6-RNA ligating 2 3-RNAs
von Kiedrowski (1993) - 3- component self-replication.

Lee (1996) 32-peptide ligating 15mer & 17mer.
Lee (1997) Peptide Hypercycle.

Self-Reproducing Automata.

- Von Neumann mid 50s: “Universal Constructor. (published 1966 by Burks) CA
- Penrose & Penrose (1959) Self-Replicating Tiles
- Conway (1968) “Game of Life” CA
- Ganti (1970) The Chemoton

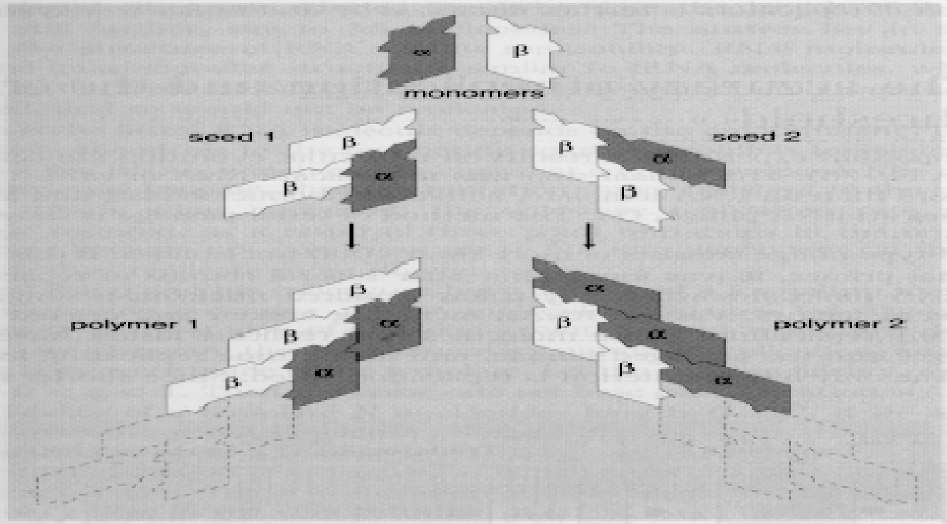


Fig. 4.2 Limited hereditary replicators. The same two monomers, α and β, can form two different polymers, depending on the nature of the initial seed (the rules for joining are as in Fig. 4.1).

Penrose & Penrose (1959) from Smith & Szathmary,1995)

Chemoton: The Simplest Organism

(Tibor Ganti, 1970, from Ganti, 1997)

Y – Waste, X – nutrient

V' – monomer of genetic material, pV_i – polymer

T' – precursor of membranogenic molecule.

A_i's – intermediates in metabolic cycle.

Metabolism generates: waste, membrane & genetic molecule.

The Chemoton has:

- **Metabolism**
- **Heredity**
- **Membrane**

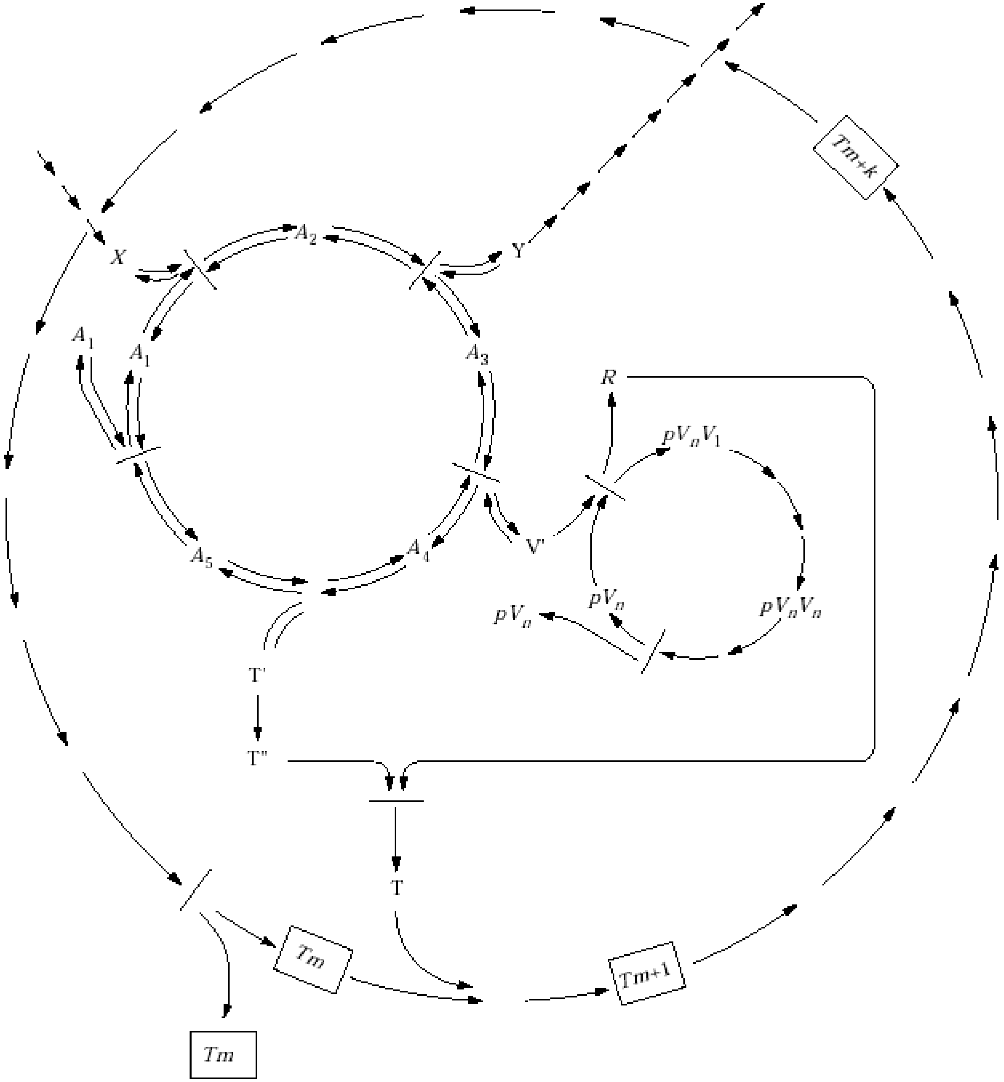


Fig. 1. The minimum model of chemotons. Three self-producing subsystems coupled stoichiometrically: Cycle $A \rightarrow 2A$, template polycondensation $pV_n \rightarrow 2pV_n$ and membrane formation $T_m \rightarrow 2T_m$. This coupling results in a proliferating, programme-controlled fluid automaton, known as a chemoton.

From RNA world to protein world

Fact: protein enzymes have better catalytic activity than RNA enzymes have.

(20 amino acids vs. 4 nucleic acids)

But: Evolution is myopic: an event happening now wouldn’t be selected for just because it will turn out advantageous million years later

Therefore we need a plausible scenario

Recent + & - factors for frequency of life.

“+”:	“-”:
Self replication easy	Hard to make proper polymerisation
Self assembly easy	No convincing scenario.
Many extrasolar planets	No testability

Increased Origin Research:

In preparation of future NASA expeditions.

The rise of nano biology.

The ability to simulate larger molecular systems

Summary of Origin of Life

I. Conditions for the "life-conditions"/ Warm Little Pond" as we know it.

Habitability.

II. Given "life-conditions" how does life arise?

Experiments (i.e. Miller,Urey 1953)

Origin of the Building Blocks: amino acids, nucleotides, sugars, lipids.
Self-Reproducing Sets of Molecules.
Robustness of Life: Temperature, Pressure, Chemical Environment,….

History (i.e. earliest signs of life & where)

III. Life "as we know it" theorizing.

From biochemical molecules to biochemical systems.

The RNA World.

The origin of genetic code and protein enzymes

References: Books & WWW

Books

(2001) Journals: “Astrobiology” & “International Journal of Astrobiology”

Bengtson ed. (1994) “Early Life on Earth” Nobel Symposium Very Good

Bennet et al.(2003) “Life in the Universe” Addison-Wesley A bit popular. Ignores the difficult problems. Pretty pictures

Brack, A. (ed.) (1998) “The Molecular Origins of Life” CUP

Cambridge Atlas of Astronomy (1995) CUP Great visual introduction to Astronomy - unfortunately on editions after 3rd.

Dick,S (1998) “Other Worlds” CUP Traces views on extra terrestrial life in literature and religions – surprisingly good.

Fenchel, T. et al. (1998) “Bacterial Biogeochemistry” 2nd Ed. Academic Press Ch.10 Good overview

Fenchel, T. et al. (2002) “Origins of Life and Early Evolution” OUP Good overview, not in depth about chemistry --> life transition

Ganti, T (1971, 2004) “Principle of Life” OUP

Lunine, J.(2003) Astrobiology - A Multidiciplinary Approach. Good all round text book. No detailed discussion of theories.

Mason, SF (1990) “Chemical Evolution” OUP Highly readable.

Maynard Smith,J & E.Szathmary (1995) “Major Transitions in Evolution.” Chapts.1-7 Excellent with focus on ideas.

Morowitz, H.(1992) “Beginings of Cellular Life.”

Schopf,W (ed.) (2002) “Origin of Life” California Good, basic – a bit old fashioned.

Sigmund, K.(1991) “Games of Life” Penguin chapt. 1 excellent introduction to self-reproducing automata

Thomas,P. et al. (eds)(1997) Comets and the Origin and Evolution of Life. Springer Good - somewhat specialized toward comets & “bad things”.

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Michael R Rampino and Ken Caldeira ”The Goldilocks Problem: Climatic Evolution and Long-Term Habitability of Terrestrial Planets” Annu. Rev. Astron. Astophys. 1994, Vol. 32: 83-114

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stochastic corrector model vs. hypercycles. J. theor. Biol. 217.167-181.

History of Origin of Life Research

1809 Haüy postulates isomophism between molecular shape and crystal shape.
1848 Pasteur surmises that the ability to rotate polarized light is related to *chirality* (handedness).
1853. Pasteur: Molecules with more chiral units lack mirror superimposability.
1858. Pasteur: Penicillum metabolizes + tartrate isomer, leaving - isomer behind.
1874 Le Bell & van't Hoff relates chirality to the 4 bonds in the carbon atom.
1880s Plants rotated to give reverse movement of sun, hoping that it would produce other enantiomers.
1929 First *enantio*-selective photolysis of *racemic* (cluster of grapes) mixture by Kuhn.
1953: Frank's Open Flow Reactor.
1953 - Urey-Miller experiments
1956: The Fall of Parity
1959 - Cocconi and Morrison proposed radio search for civilizations elsewhere
1960 - Drake publishes his famous/infamous equation for probability of intelligent life
1966 - von Neumann posthumously publishes the manuscript on self-replicating automata
1971 Ganti publishes his “Principles of Life” with the *Chemoton*
1977: Chiral production of L-alanine by polarized UV-light.
1977 Viking Experiments
1985: Kondepudi & Nelson combines neutral electroweak currents with Frank Dynamics.
1990: Chirality in Murchisons Meteorite of biological Amino Acids
1997: Chirality in Murchisons Meteorite of non-biological AAs.