Hard problems of the origin of life

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Chemical evolution

![Chemical reaction diagram]

**Diagram a:**
- **Ribose** + **Nucleobase** → **Ribonucleotide**

**Diagram b:**
- **2-Aminooxazole** → **Several steps** → **Ribonucleotide**
Units of evolution

1. multiplication
2. heredity
3. variation

hereditary traits affecting survival and/or reproduction
Gánti’s chemoton model (1974)

ALL THREE SUBSYSTEMS ARE AUTOCATALYTIC
The latest edition: OUP 2003

- After several editions in Hungarian
- Two previous books (the *Principles* and *Contra Crick*) plus one essay
- Essays appreciating the biological and philosophical importance
Pathways of supersystem evolution

INFRABIOLOGICAL SYSTEMS
What about replication?

- Replication from a chemical point of view always rests on autocatalysis.
- The basic form is $A + X \rightarrow 2A + Y$.
- Very important for biology.
- Much more general than DNA.
The formose ‘reaction’

formaldehyde

glycolaldehyde

autocatalysis

Butlerow, 1861
Replication in the formose reaction

- Replication is non-informational
- Autocatalysis – YES
- Heredity – NO
- Good for metabolism
- Not good for genetics
- Butlerow was born on the 15th Sept, 1829
- He was regarded as one of the best lecturers of his time. His lectures were lucid and thorough, yet his language was colourful. Local society often preferred his lectures to the theatre
Primitive ancestry of the reverse citric acid cycle

- Was proposed by Günter Wächtershäuser (1990)
- Coupled to CO$_2$ fixation and pyrite formation around deep-sea hydrothermal vents
The main problem of the origin of life is metabolite channelling

- Enzymes speed up reactions *relative to* the unwanted reactions
- Spontaneous decay reactions abound
- Maintenance, not only reproduction, requires autocatalysis

\[
\frac{dx}{dt} = k x - d x = 0
\]
All network models neglecting side reactions were seriously incomplete

- E.g. protein networks
- In model assumptions, a reaction is either good or neutral for the system – but the number of harmful transformations is in fact much higher
- Did life emerge from a chemical canyon?
Chemical evolution was a race between tar formation and life formation.

Chemical networks

- Life
- Tar

What fraction of planets would end up with just tar?
Another case: von Kiedrowski’s replicators
Von Kiedrowski’s replicator

A Self-Replicating Hexadeoxynucleotide
Peptide replicator networks
A Stochastic Model of Non-Enzymatic Nucleic Acid

Replication: ‘Elongators’ Sequester Replicators

Chrisantha Fernando¹,²,³, Günter Von Kiedrowski⁴, Eörs Szathmáry²

- Theory with experiment
- *J. Mol. Evol.*,.
Does temperature cycling work?
Elongation taxes the system badly
### Classification of replicators

<table>
<thead>
<tr>
<th>Method</th>
<th>Limited Heredity</th>
<th>Unlimited Heredity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holistic</td>
<td>formose</td>
<td></td>
</tr>
<tr>
<td>Modular</td>
<td>Von Kiedrowski</td>
<td>genes</td>
</tr>
</tbody>
</table>

Limited (number of individuals) > (number of types)

Unlimited (# of individuals) << (# of types)
A crucial insight: Eigen’s paradox (1971)

- Early replication must have been error-prone
- Error threshold sets the limit of maximal genome size to <100 nucleotides
- Not enough for several genes
- Unlinked genes will compete
- Genome collapses
- Resolution???
Molecular hypercycle (Eigen, 1971)

autocatalysis

heterocatalytic aid
Parasites in the hypercycle (JMS)
The stochastic corrector model for compartmentation


Dynamics of the SC model

- Independently reassorting genes
- Selection for optimal gene composition between compartments
- Competition among genes within the same compartment
- Stochasticity in replication and fission generates variation on which natural selection acts
- A stationary compartment population emerges
Group selection of early replicators

- Many more compartments than templates within any compartment
- No migration (fusion) between compartments
- Each compartment has only one parent
- Group selection is very efficient
- Selection for replication synchrony → Chromosomes!
Kauffman: Reflexively autocatalytic protein networks (1986)
Current investigations

- Evolvability is possible only in compartments
- Occasionally new autocatalytic loops appear
- Can be inherited from one cell to the daugther
- Can be selected for, give some evolution
- GARD is shadow of protein networks is a shadow of template replicators
Open questions

• Origin of efficient replication
• Origin of full protocells
• Origin of transcription
• Origin of highly specific enzymes
• Origin of translation