

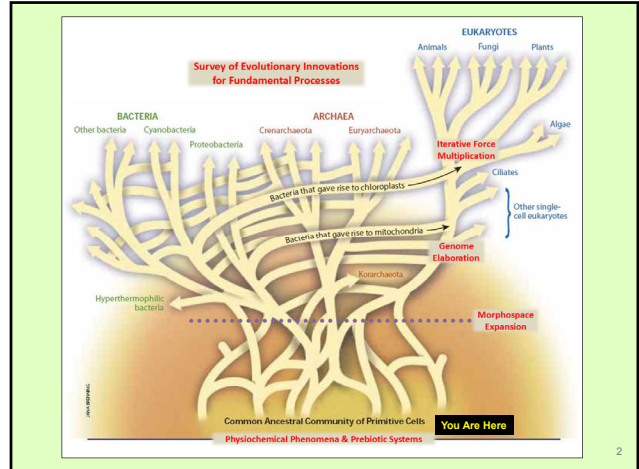
## Emergence of Life on Earth



www.pinterest.com

www.beyondbooks.com

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## Life's Origins – 3 Problems

- Earliest steps cannot be directly observed
- Even simplest extant life forms are very complex
- Unclear which organic molecules were used to store information (DNA, RNA, or proteins)

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## Protobionts & Life's Origins

- Protobionts – aggregations of abiotically produced molecules
- Requirements for evolution of life
  - Abiotic formation of organic molecules
  - Spontaneous organization
  - Growth & reproduction
  - Metabolism

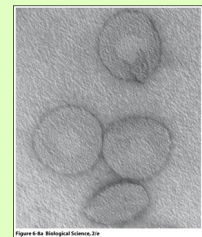


Figure 14.10. Biological Science, 3rd Edition, © 2004 Sinauer Associates, Inc.

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## Abiotic Organic Molecules

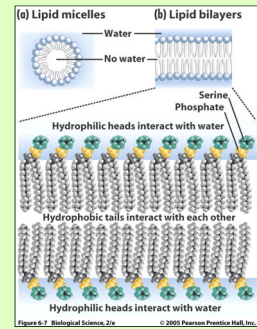
- Experiments of simulated conditions on early Earth
  - Energy source + inorganic molecules = diverse range of organic molecules
- Organics molecules abundant in space
  - Murchison meteorite
  - Interstellar ice



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## Spontaneous Organization

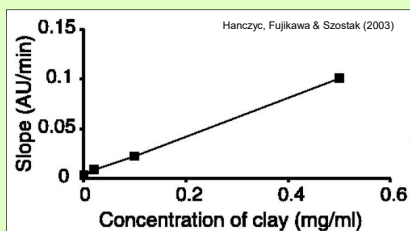
- Hydrophobic interactions of amphipathic lipids
- Biological order at expense of universal disorder
  - Major area of study in past decade



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## Spontaneous Organization

- Enhanced by the presence of clay particles
  - Catalytic – provides nucleation sites



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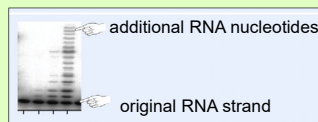
## Spontaneous Organization

- Problem: Which information storage molecules were used by early systems?
  - DNA
    - More stable
    - Unable to catalyze reactions
    - Proteins required for information transfer
  - RNA
    - Less stable
    - Can catalyze reactions – ribozymes
    - Proteins not necessary for information transfer

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## Spontaneous Organization

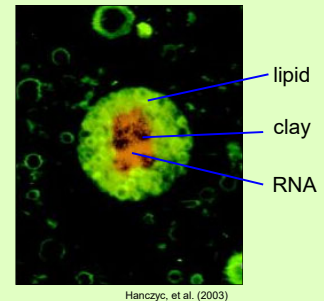
- RNA World
  - RNA carries genetic information (like DNA)
  - RNA can catalyze reactions (like proteins) – including RNA
  - Selection favors variants with effective replication & control



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## Spontaneous Organization

- RNA World
  - RNA binds to clay particles
  - Structured aggregations
    - Clay particles
    - RNA attached to clay
    - Amphipathic lipid barrier

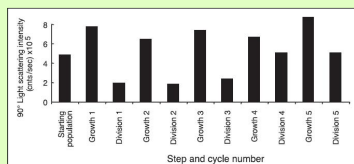
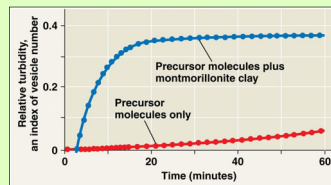


Hanczyc, et al. (2003)

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## Growth & Reproduction

- RNA World
  - Hypertonic protobionts absorb other protobionts & increase size
  - Reproduction by physical disruption

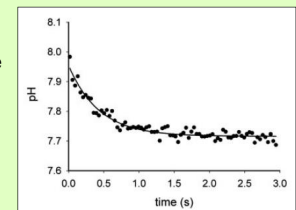


Hanczyc, et al. (2003)

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## Metabolism

- RNA World
  - Protobionts capable of producing proton gradient during growth
    - Based on insertion of new amphipathic lipids into membrane
  - Protobionts may have used simple redox reactions
    - Chemoheterotrophs
    - Chemoautotrophs

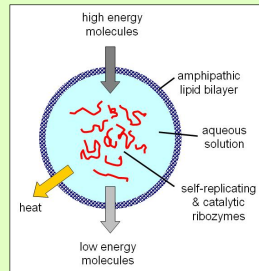


Chen & Szostak (2004)

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## RNA World

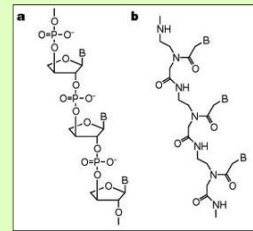
- Simplest life forms
  - RNA molecules for information storage
    - Catalytic
    - Self-replicating
  - Amphipathic lipid boundary – transport RNA molecules?
  - Hypertonic interior
  - Reproduction by physical disruption
  - Simple metabolism



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## RNA World

- Problem with non-coding substitutions
  - Initial formation of RNA
  - Self-replication of large RNAs
- A pre-RNA World?
  - Alternative nucleic acids
    - Threose nucleic acid (TNA)
    - Peptide nucleic acid (PNA)
  - Polypeptides

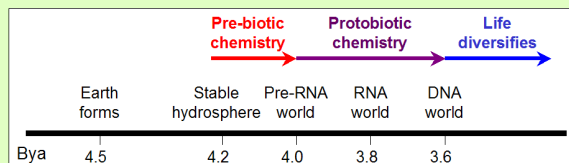


Joyce (2002)

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## Pre-RNA World

- Alternative nucleic acids & polypeptides
  - Form abiotically
  - Catalyze their own replication
  - Interact with RNA



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## From RNA World to DNA World

- RNA
  - Less stable & more error-prone
  - No redundancy (single strand)
  - Autocatalytic
- DNA
  - More stable & less error-prone
  - Inherent redundancy (double strand)
  - Not autocatalytic

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## From RNA World to DNA World

- Ancient role of RNA in living systems suggested by older cellular pathways
  - Required for DNA replication – RNA precursors used to synthesize deoxyribonucleotides
  - Required for protein synthesis
  - Ribonucleoside triphosphates (ATP, GTP) used as energy sources
- DNA better for long term information storage
- BUT... how did it occur?

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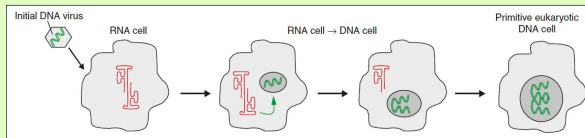
## From RNA World to DNA World

- Early catalysts
  - Metal ions – e.g.,  $Mg^{2+}$ ,  $Ca^{2+}$
  - Ribozymes
- Proteins evolve as enzymes
  - RNA required
  - Energetically less expensive to produce than RNA
  - Greater diversity of molecular structures – based on 20 different amino acids
  - Many use metal ion cofactors
    - $Fe^{3+}$  – nitrogenase, hydrogenase, catalase
    - $Zn^{2+}$  – alcohol dehydrogenase, carbonic anhydrase

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## From RNA World to DNA World

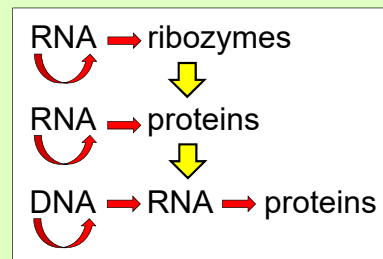
- Possible role of primitive viruses
  - RNA viruses – stable ribozymes infecting early RNA-based cells
  - DNA viruses – evolved from RNA viruses
    - More resistant to destruction by infected RNA cells
    - Reverse transcription of cellular RNA into more stable DNA



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## From RNA World to DNA World

- Building the central dogma



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## From RNA World to DNA World

- Life evolved within constraints imposed by physiochemical phenomena
  - Exploited 'easy' solutions to complex problems
  - No single origin of life – complex prebiotic, protobiotic & biotic transitions
  - Later innovations layered over older innovations

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