A Thermodynamical Approach to Life

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PART 1

Emergence of Life

- E.Smith and H.J.Morowitz: Energy flow and the organisation of life
- E.Smith: Thermodynamics of natural selection I
- E.Schrödinger: What is life? Mind and Matter

The Biosphere

The Biosphere

- Self organized system:
  - State with less entropy is statistically favored and remains under pertubation

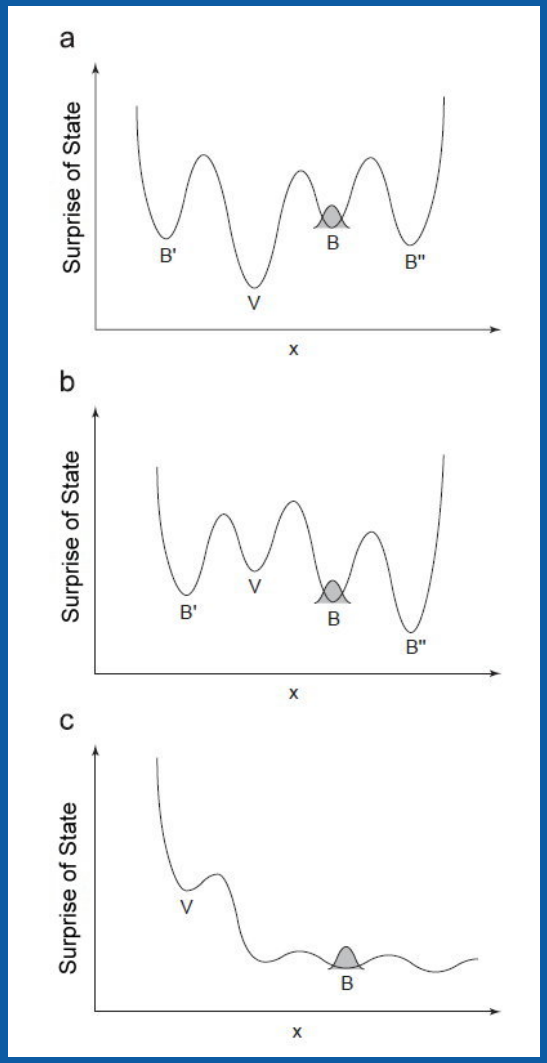
→ Implies that:

- Life rejects entropy

→ Possible Defintion:

- Life is everything which is not in thermodynamic equilibrium with its environment

Probability distributions for the emergence of the biosphere



Inevitable Life ?

Life => Free Energy !

Free Energy => Life ?

Inevitable Life ?

- Source of Free energy on earth:
  1. Light
     - Energy can scatter into space
  2. Fission
     - High activity in earth core
     - A high amount of ionized matter is produced = reductive potential
     - Reductive potential is kept on earth and can not be equilibrated

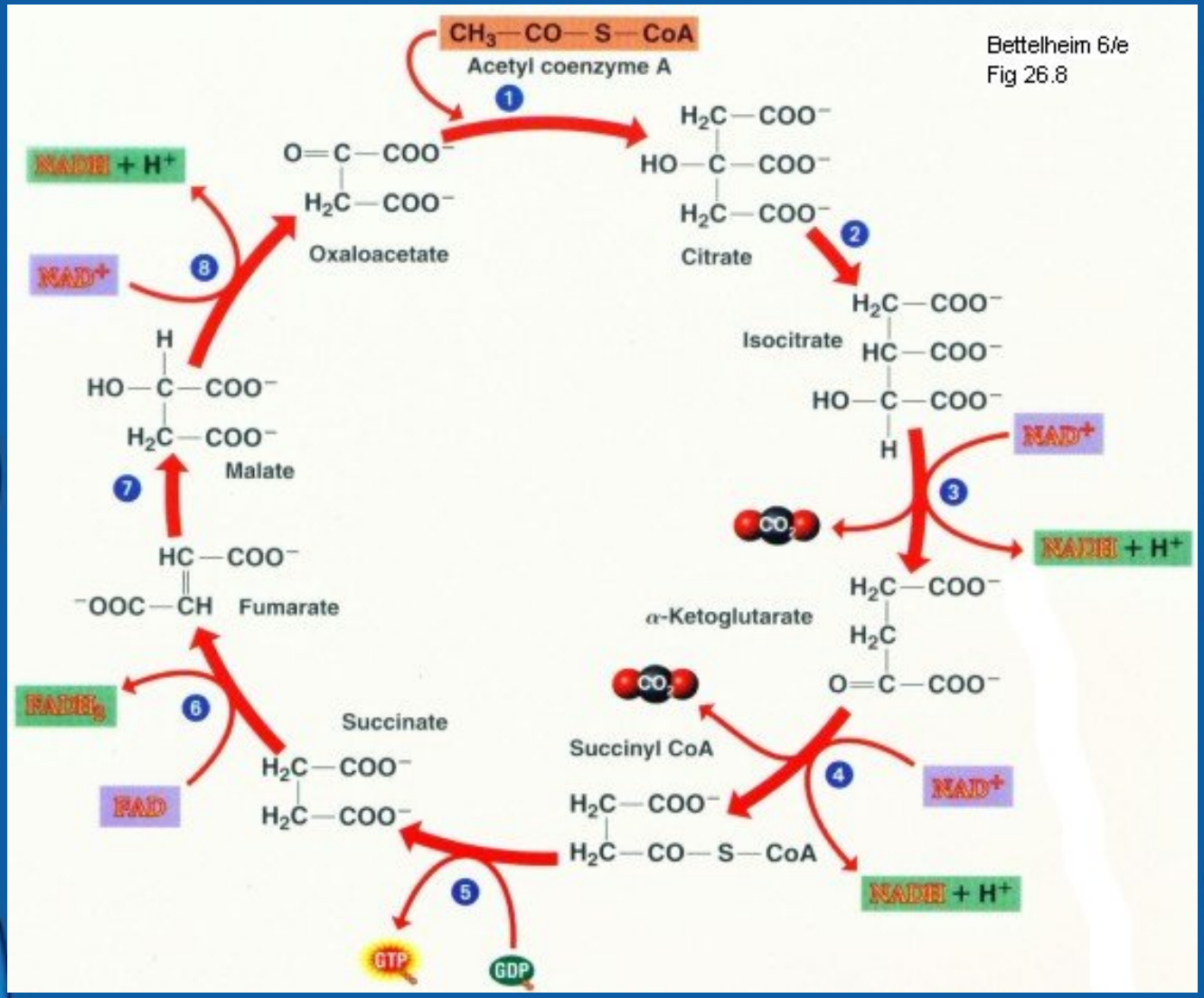
Inevitable Life ?

- A process reducing the reductive potential is kept working.
- Processes creating channels with higher order for higher efficiency are favored
- Life is such a process

Inevitable Life ?

- Hints for the theory:
  - Split biosphere into autotrophical ecosystems
  - Universal core of 500 small organic molecules [hypothesized to be the beginning of life]
  - Reductive chemo-autotrophs formed the first living system

Inevitable Life ?



Inevitable Life ?

- Entropy paradox:
  - Equilibrium entropy higher for a non-living system
  - „Living Earth“ is a driven system
  - Life-channel: higher order parameter => phase transition
    - → Biosphere can be considerd as an alloy of biotic and abiotic part, were the abiotic part serves as transport phenomenon

Inevitable Life ?

- Link between Darwin and Thermodynamics:
  - Cell physiology with a statistical path of least resistance is considered to be the fittest

Summary Part 1

- Definitions of life:

  Life is a transport phenomenon

  → Inevitable ?

  Life rejects entropy

  →Biosphere is a self-organized system

PART 2

Entropy approach to natural selection

- H.J.Morowitz: Some order-disorder considerations in living systems
- E.Smith: Thermodynamics of natural selection I

Entropy of a cell

- N = # structural states
- Living cell corresponds to L of N possible states
- Probability for Life: $p = \frac{L}{N}$
- L << N → $p \cong \frac{1}{N}$

Entropy of a cell

- Defintions for Entropy:

$$\Delta S = k \log L - k \log N$$

$$I = \log_2 N - \log_2 L$$

- With: L << N
- Therefore: $I = \log_2 N$

Entropy of a cell

Experimental Data:

- Some cells withstand 95% drying
- Some cells withstand cooling down to 1.3K

→ no information, that is required to be alive, in water or motion of molecules

Entropy of a cell

- N_A= # Atoms
- n_i : atoms of ith type:

$$N_A = \sum n_i$$

- N_1 possibilities to put N_A Atoms in N_A boxes:

$$N_1 = \frac{N_A}{\prod n_i!}$$

Entropy of a cell

- # bonding states = B
  - B_i ways for an atom to distribute its bonds:

$$B < \prod_i B_i^{n_i}$$

- Total Entropy:

$$I = \log N < \log N_1 + \log B$$

Stirling

$$\cong \quad N_A \log N_A - \sum n_i \log n_i + \sum n_i \log B_i$$

- Assuming 6 Nearest Neighbors:
  - B_O=21 B_H=6 B_C=120….

- $I_{B.Coli}$=1.2 E 10 Bits

Entropy of a cell

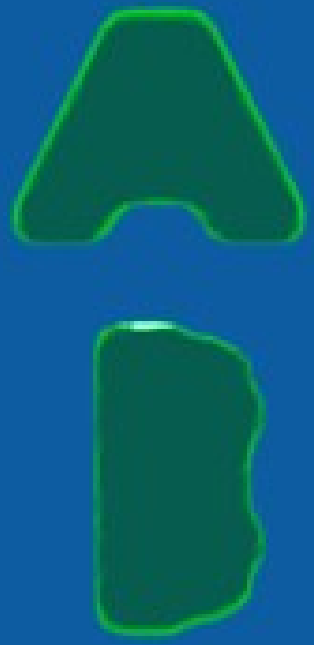
- Experiment:
  - Idea: Grow bacteria in water and measure temperature increase:

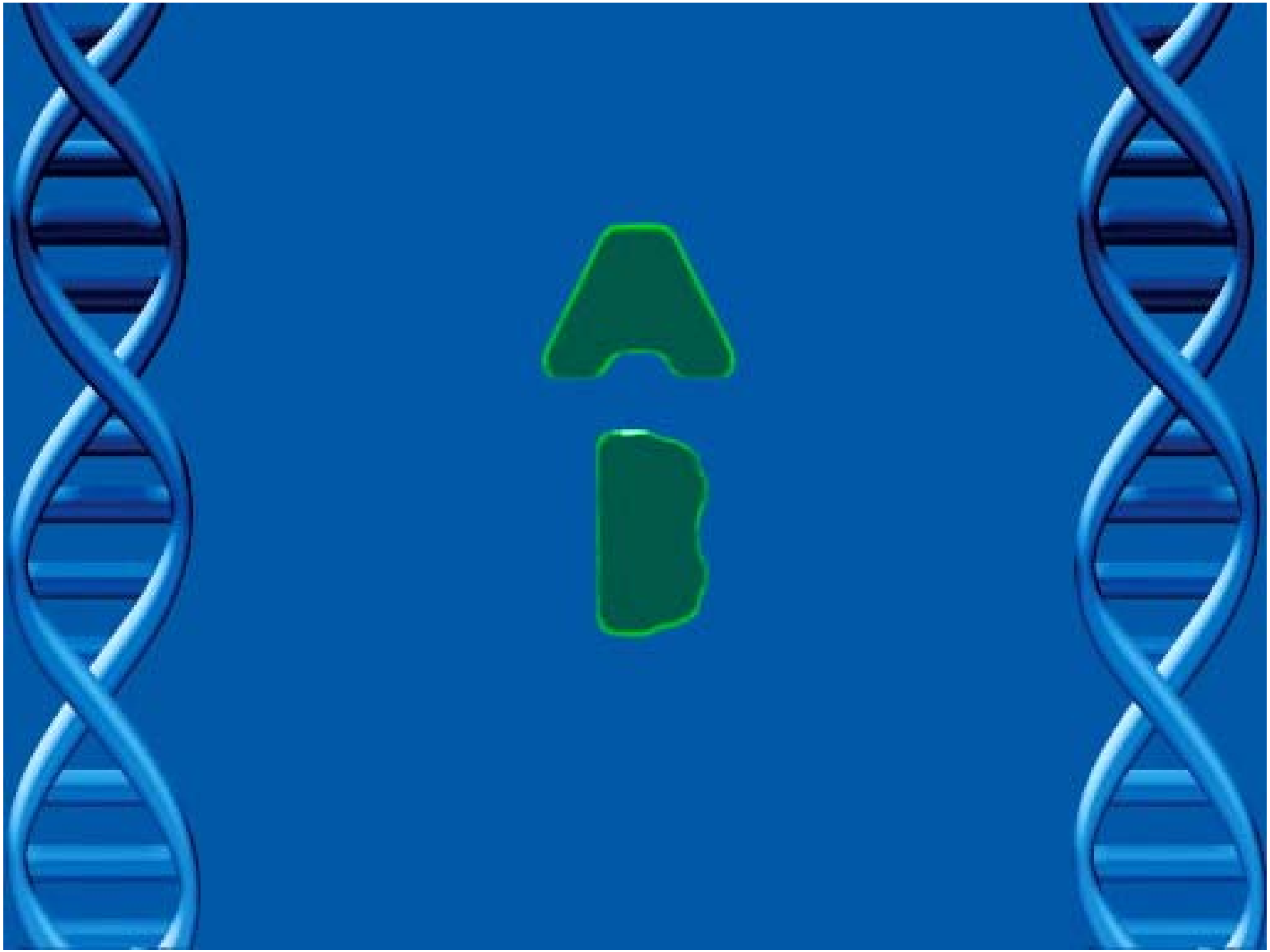
$$\Delta Q = T\Delta S = -Tk_B I \log 2$$

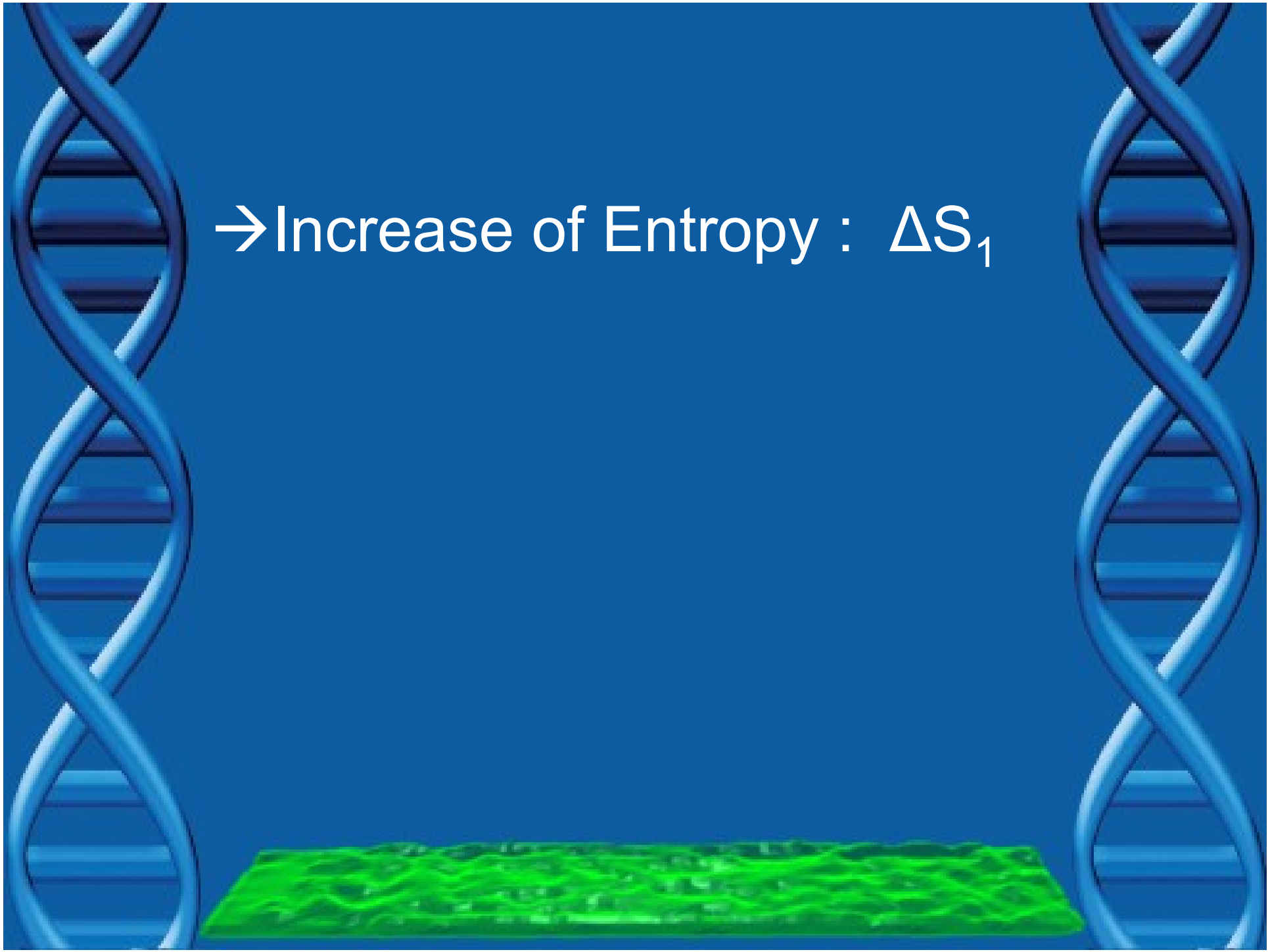
- Result:
  - I_{exp}=4 E 10 Bits

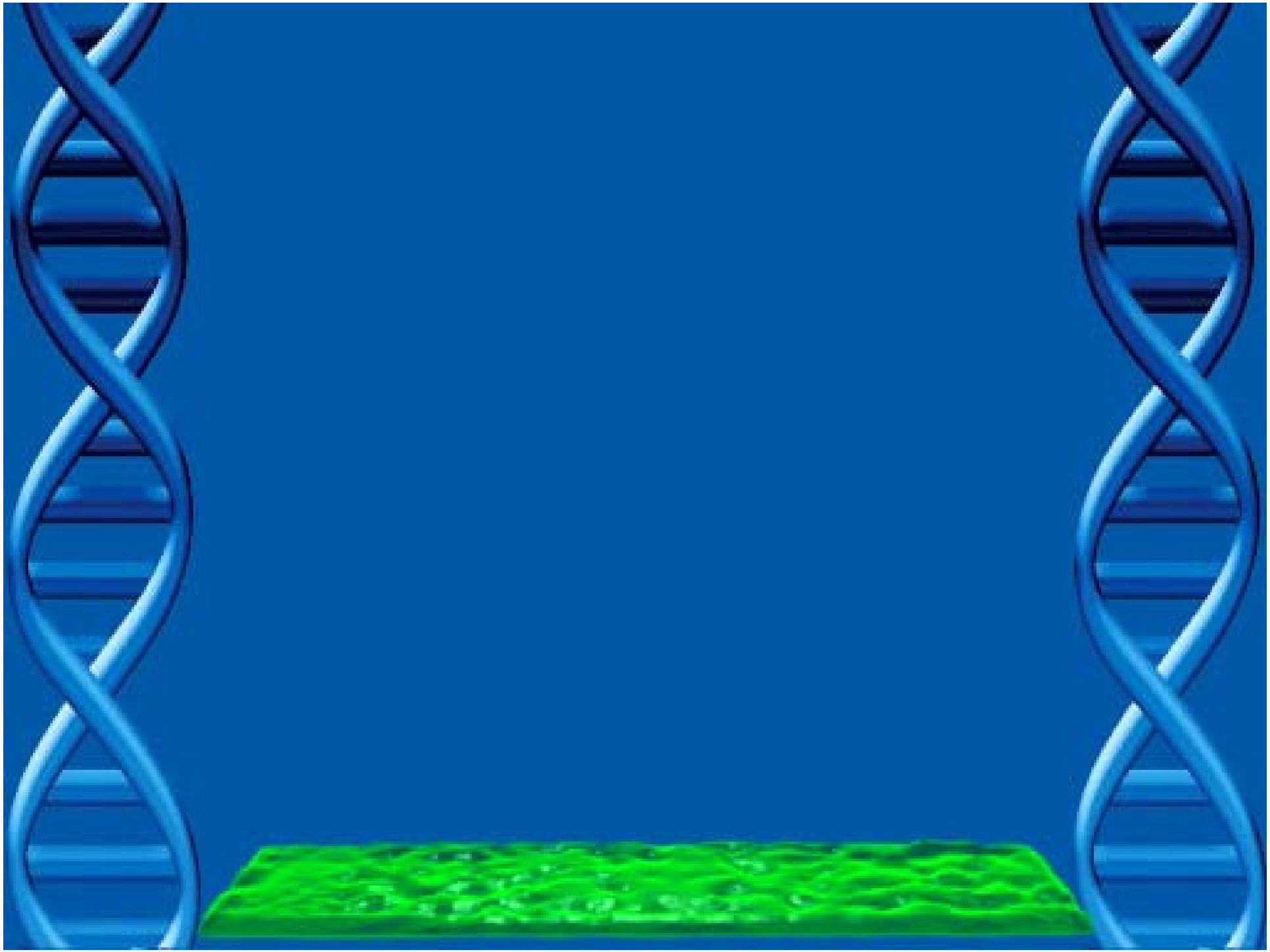
- Possible Reasons:
  - Real growth process is not reversible
  - Maintenance reduces entropy as well

Entropy in Natural Selection






→Increase of Entropy : ΔS_1



→Decrease of Entropy : $-\Delta S_2$

Natural Selection requires Energy as $\Delta S_2 > \Delta S_1$

Summary Part 2

- Entropy of an organism scales with # Atoms
- Entropy gives us various lower bounds for biological processes

PART 3

Growth and Aging

E.Smith: Thermodynamics of natural selection I

Aims of Part 3:

- Deduce links between energy balance, entropy and error correction

Summary

- Definitions of life:

  Life is a transport phenomenon

  → Inevitable ?

  Life rejects entropy

  →Biosphere is a self-organized system

- Entropy of an organism depends mainly on the # atoms.

- Entropy gives lower bounds for energy required for natural selection and growth

- The lifetime is bounded by error appearance and correction

References

- E.Smith: Thermodynamics of natural selection I : Journal of Theoretical Biology
- E.Smith and H.J.Morowitz: Energy flow and the organisation of life: Complexity
- H.J.Morowitz: Some order-disorder considerations in living systems: Bulletin of Mathematical Biophysics
- E.Schrödinger: What is life? Mind and Matter