Astrobiology

Terrestrial Life: properties and definition

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Definition of "astrobiology"

Study of the origin, distribution, evolution and destiny of life in the universe

Short definition: study of the living universe

Astrobiology

- Term used in space missions of the National Aereonautics & Space Administration (NASA)
- Adopted by the community of biologists and chemists interested in the study of the origin of life (ISSOL)
- Now commonly adopted in most studies of life in the universe

Astrobiology

Classic research fields

Origin of life

Appearance of life in the primitive Earth

Laboratory experiments of prebiotic chemistry

Delivery of organic material from space (comets and meteorites)

Terrestrial life in extreme conditions

Terrestrial habitats with extreme physico/chemical conditions

Search for life in the Solar System

Space missions in the Solar System

Astrobiology

Recent research fields

Exoplanets

Search for habitable exoplanets

Search for atmospheric biomarkers in extrasolar planets

Protoplanetary disks

Formation history of habitable planets

Delivery of water and organic material on terrestrial-type planets

Terrestrial Life

To introduce astrobiology it is necessary to get familiar
with the main properties of terrestrial life

So far, terrestrial life is the only reference for astrobiological studies:
"life-as-we-know-it"

Properties of terrestrial life

Terrestrial life is characterized by a set of properties

Different authors use different lists of properties to describe life

A possible (but certainly not unique) list is:

Metabolism
Reproduction
Information coding and transmission
Self organization
Adaptation
Evolution

Metabolism

Network of the physical and chemical processes taking place at the molecular level in a living organism

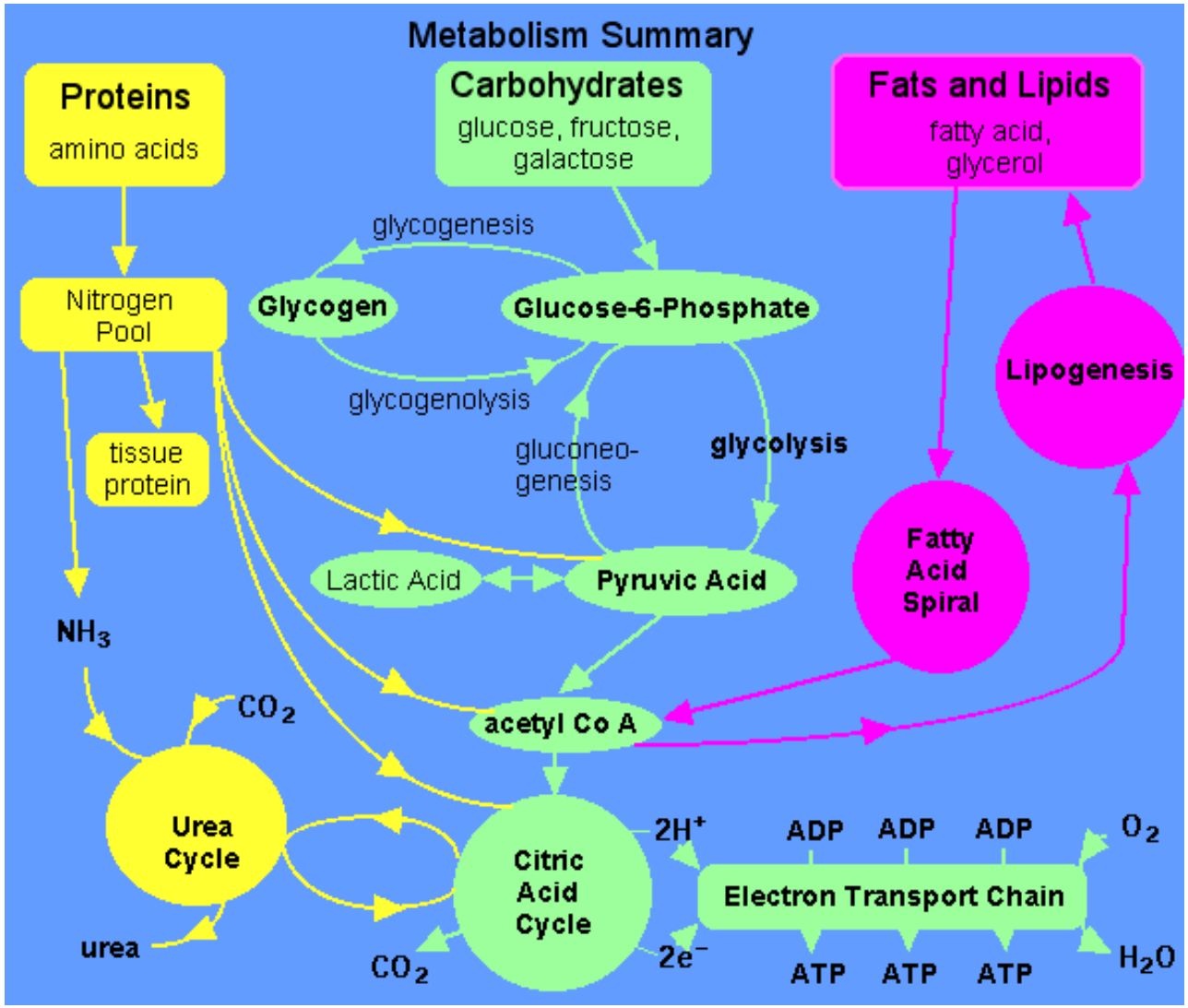
Used to produce, maintain and destroy the molecular constituents and to exchange and store energy

Examples:

- Photosynthesis (carbon fixation)
- Catabolism (breaking of organic molecules)
- Anabolism (synthesis of organic molecules)
- Respiration (extraction of chemical energy)

The energy is extracted through electron transfer and stored in molecules that are later used to exchange energy

Metabolic networks are extremely complex

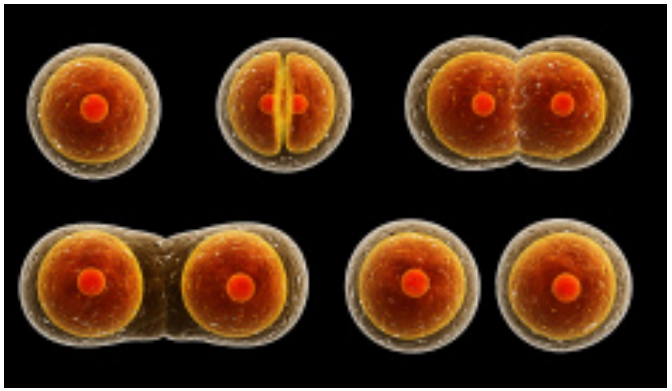


Reproduction

Capability of generating new organisms of the same species

At the molecular level, reproduction implies some form of replication of part of the molecular constituents

Reproduction is essential for the long-term perpetuation of life



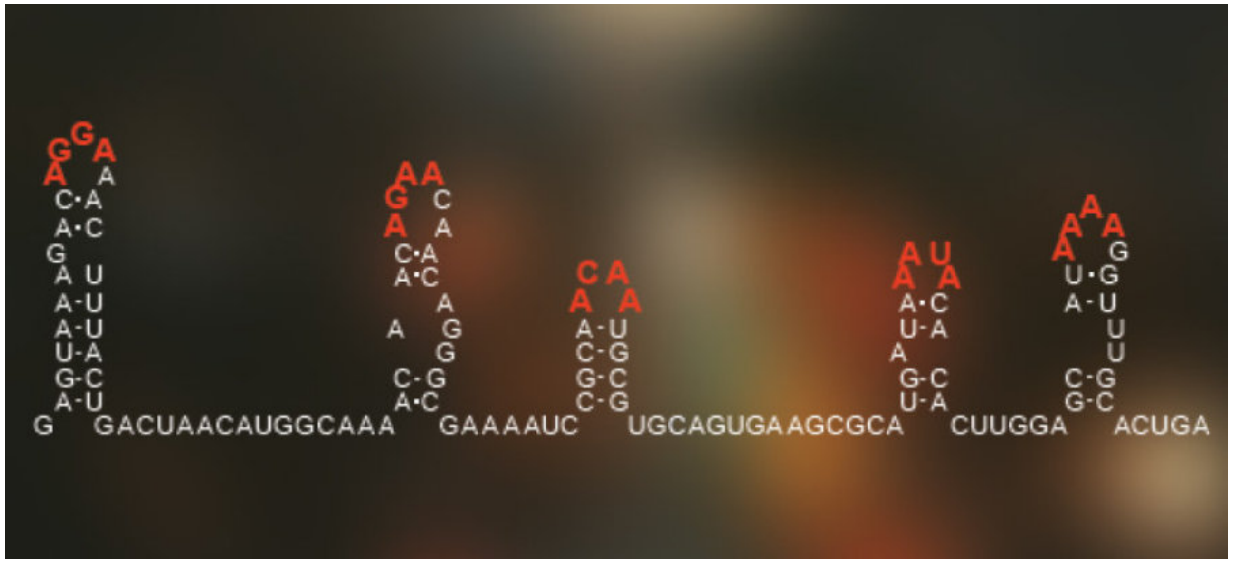
Information coding and transmission

Living organisms carry the instructions used to drive their functions (metabolism and reproduction)

The instructions are transmitted to the next generation

Such instructions constitute the genetic information of life

The amount of information stored in organisms is extremely high

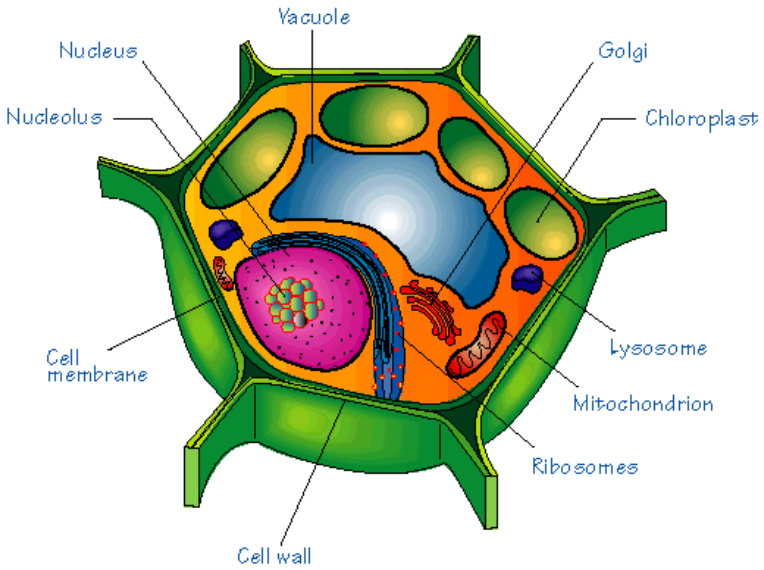


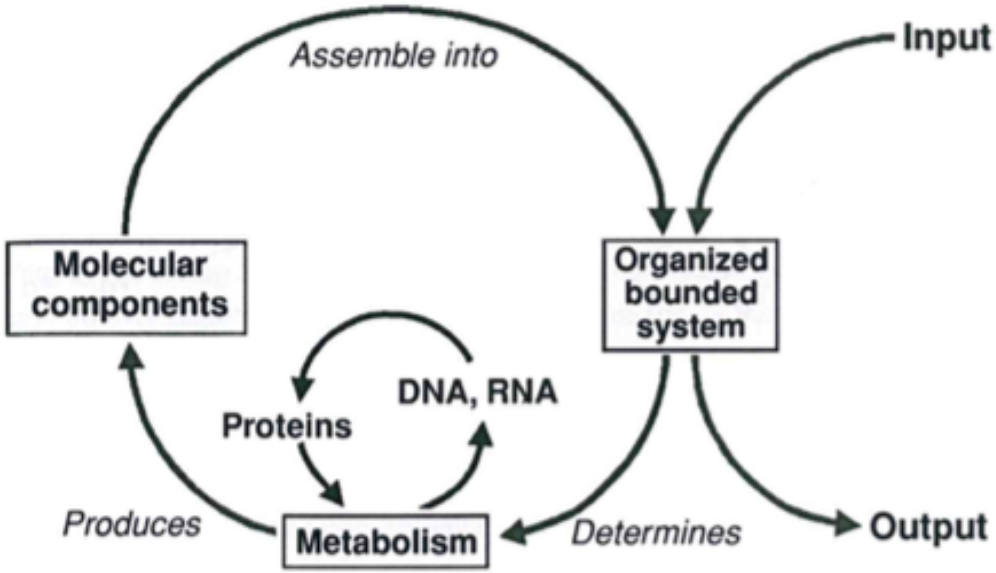
Self organization

Living organisms organize themselves autonomously, creating a network of substructures which cooperate to carry out the metabolic, genetic and reproduction functions

Molecular constituents lie at the lowest level of self organization

Life tends to maintain its internal organization despite exchanges of matter, energy and entropy with the external world





Adaptation to the environment

Life responds to variations of ambient conditions in many different ways and over different time scales

We can make a distinction between physiological (short-term) and genetic (long-term) adaptation

Physiological adaptation

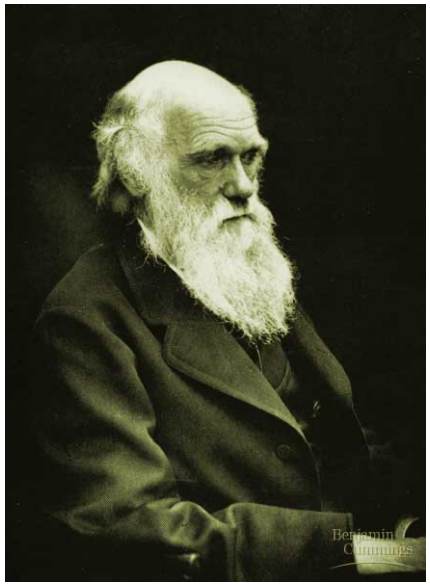
- Short term adaptation of metabolic processes
- Feedback mechanisms that allow organisms to tune their metabolic functions in response to changes of ambient conditions

Evolution

Long-term adaptation to the environment

Genetic adaptation

- Long term adaptation of genetic material
- Modification and natural selection of the genetic pool in response to changes of ambient conditions
- Takes place in the course of many generations, leading to Darwinian-type evolution
- This adaptation results from a gradual accumulation of changes in the genetic pool
- The genetic changes that provide best adaption to new ambient conditions are preserved



What is life ?

Can we use the properties of terrestrial life to define life?

There is no commonly accepted definition of life

The definition is still the subject of ongoing scientific debate

Problems with the definition of life

There is no single property that is intrinsic and unique to life

Several life properties, if considered one by one, can be present also in the non-biological world

There is no sharp separation between living and non-living systems

The problem of life definition

Metabolism is not sufficient to define life

In the non-biological world there are examples of chemical reactions with transfer of electrons and storage of energy, similar to the ones that take place in the biological world

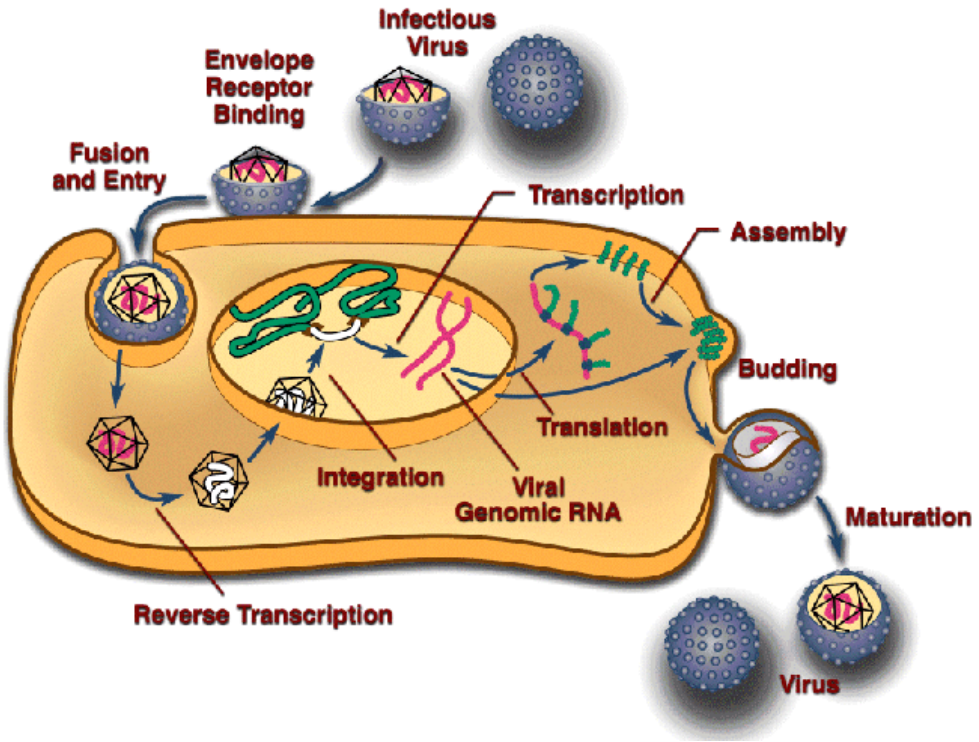
Reproduction is not sufficient to define life

Some living organisms lack the capability of reproduction

Example: mules

Even genetic information, one of the most distinctive features of life, is not sufficient, by itself, to define life

Example: viruses possess their own genetic information, but do not have an internal metabolism and can reproduce only in a host organism



A concise definition of life

Trifonov (2011)

Analysis of the vocabulary of 123 tabulated definitions of life
reveals nine groups of defining terms,
of which the groups (self-)reproduction and evolution (variation)
appear as the minimal set for a concise and inclusive definition:

"Life is self-reproduction with variations"

Life definition and origin of life

The definition of life is an attempt to distinguish the biological world from the non-biological one

The origin of life implies a transition between the non-biological and the biological world

The problem of defining life is strictly related to the problem of understanding its origin

The origin of life is central in astrobiology

Cells

The cell is the minimum structural unit which has all the properties that define life (e.g. metabolism, reproduction, evolution, etc.)

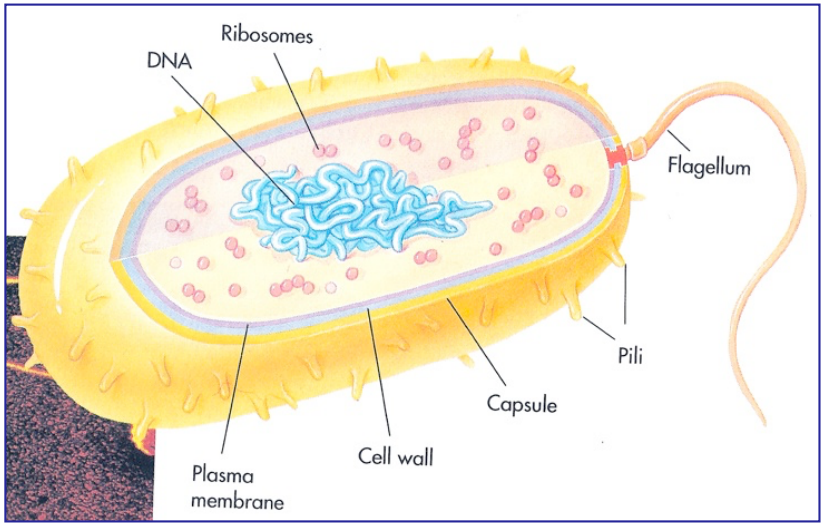
- Cells are bounded by a border that provides a separation from the external environment
  - The border allows for selective exchanges of energy and matter with the environment
    - In terrestrial life the border is a biological membrane

Cells organize themselves in colonies or multicellular organisms

- In colonies a large number of cells of the same type share some limited form of cooperation
- In multicellular organisms, differentiated cells (but with same genetic information) work in strong cooperation

Cells of terrestrial life

- Prokaryotic (archaea and bacteria)
- Eukaryotic
  - Eukaryotic cells have a high level of internal organization, featuring organelles with specific functional properties



Typical sizes

Prokaryotes: 1 – 5 μm

Eukaryotes: 10 – 100 μm