Origin of Life

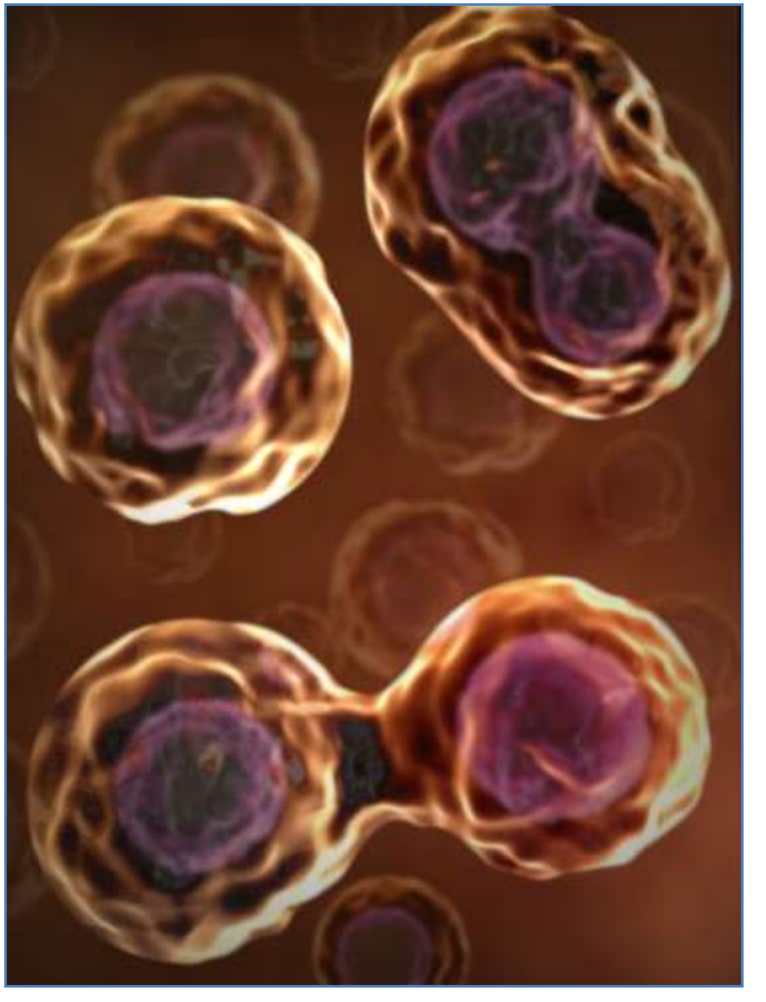
Essential Questions

- If the work of many scientists has shown that spontaneous generation does not occur, and the idea of biogenesis is true, how do we explain the origin of the first living things?

How did life begin on Earth?

Remember...

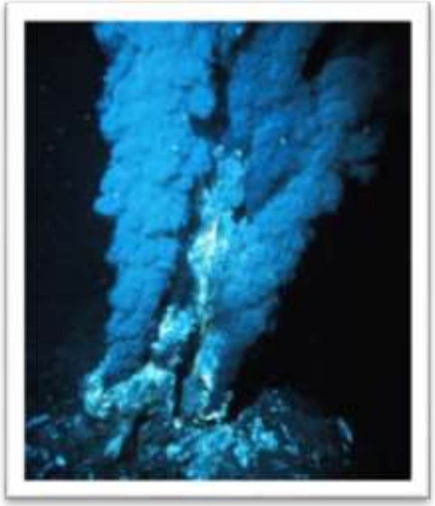
- According to the cell theory, life only comes from life, new cells only come from pre-existing cells. This is called ***biogenesis***.
- If this is true, then how did life on Earth first begin?



How did life begin?

Hydrothermal Vents

- ✓ These vents release important hydrogen-rich molecules
- ✓ Mineral catalysts could have made critical reactions occurs faster
- ✓ Discover of Archaea bacteria may be evidence of this



Electric Spark

- ✓ Can generate amino acids and sugars from an atmosphere loaded with water, methane, ammonia and hydrogen
- ✓ Demonstrated in the famous Miller-Urey experiment reported in 1953
- ✓ New evidence suggest that it may have occurred in volcanic clouds

How did life begin?

Panspermia

- ✓ Life could have come from outer space in a comet or meteorite.

Community Clay

- ✓ Clay may have provided the foundation for first organic compounds.
- ✓ Mineral crystals in clay could have arranged organic compounds into organized patterns.

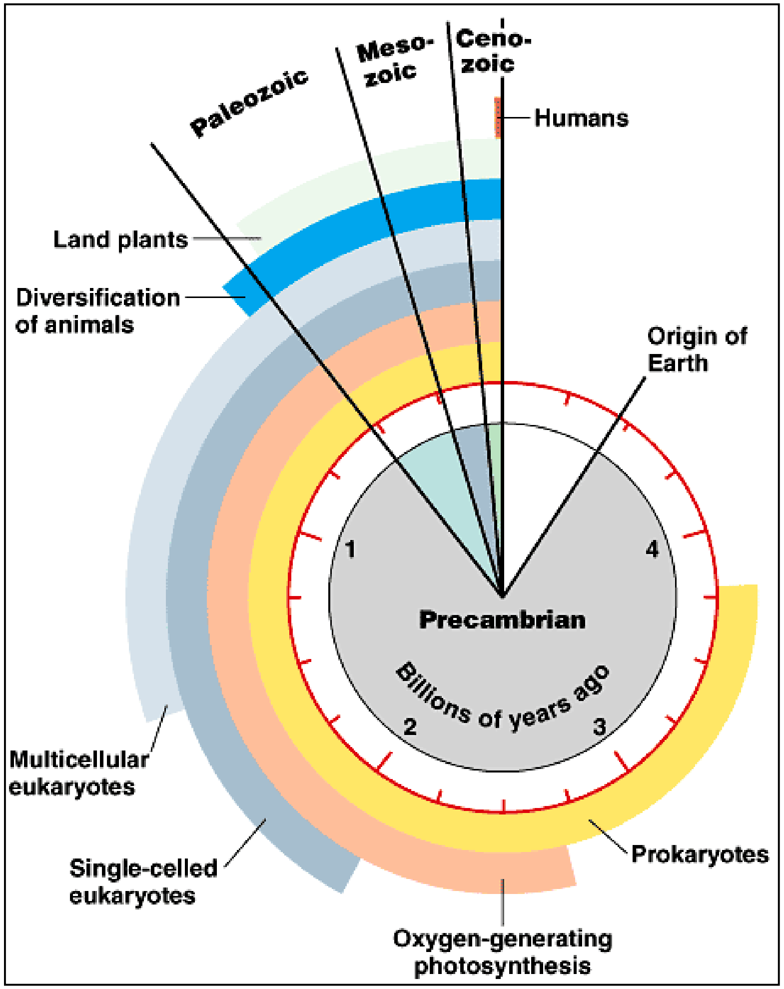
Ice Earth

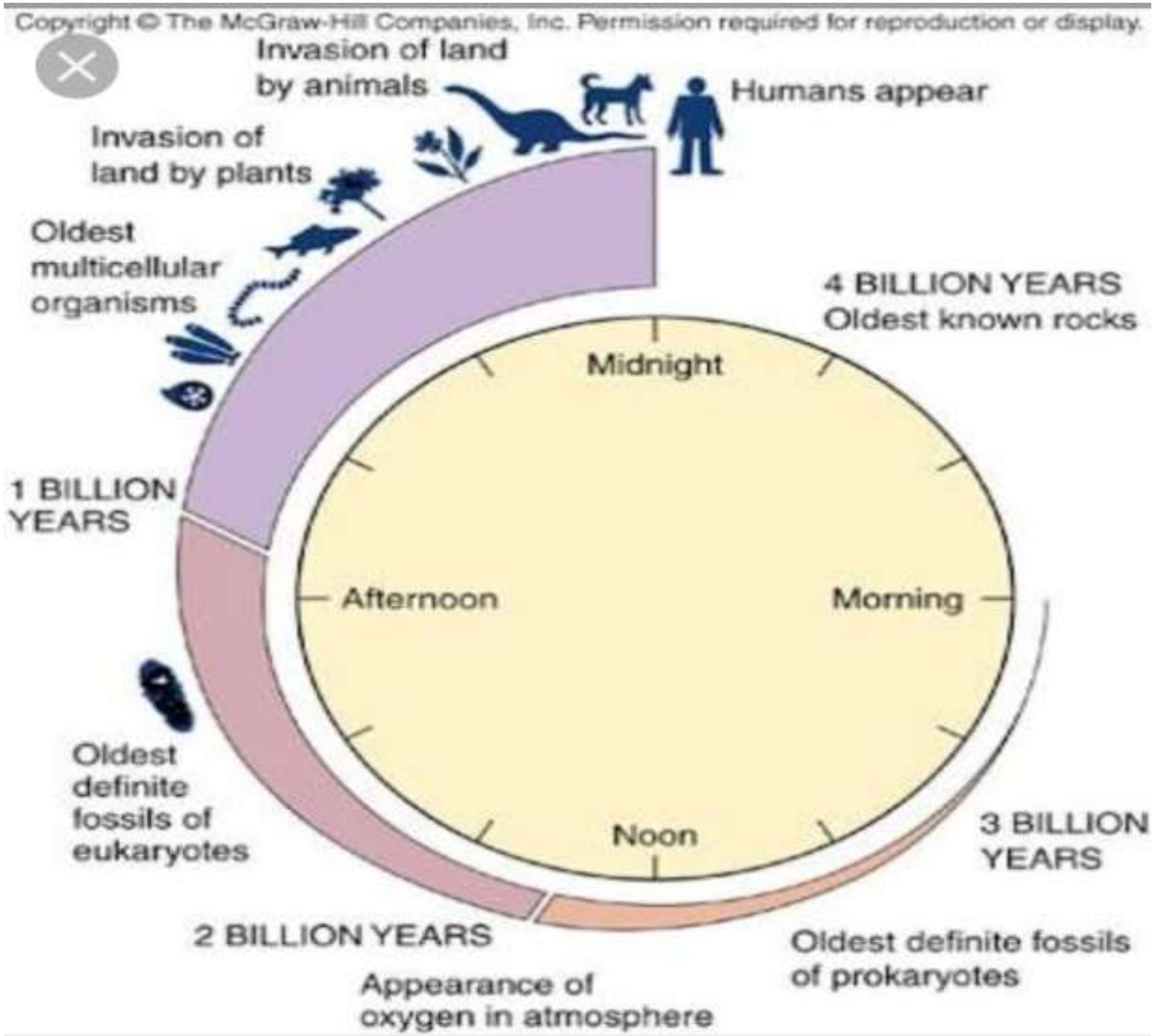
- ✓ 3 billion years ago ice might have covered the oceans.
- ✓ Protected from UV light, organic compounds may have formed and reacted with one another.

Early Earth

- The Earth was formed about 4.5 billion years ago.
- The oldest fossils of microorganisms are about 3.5 billion years old.

But where did they come from???

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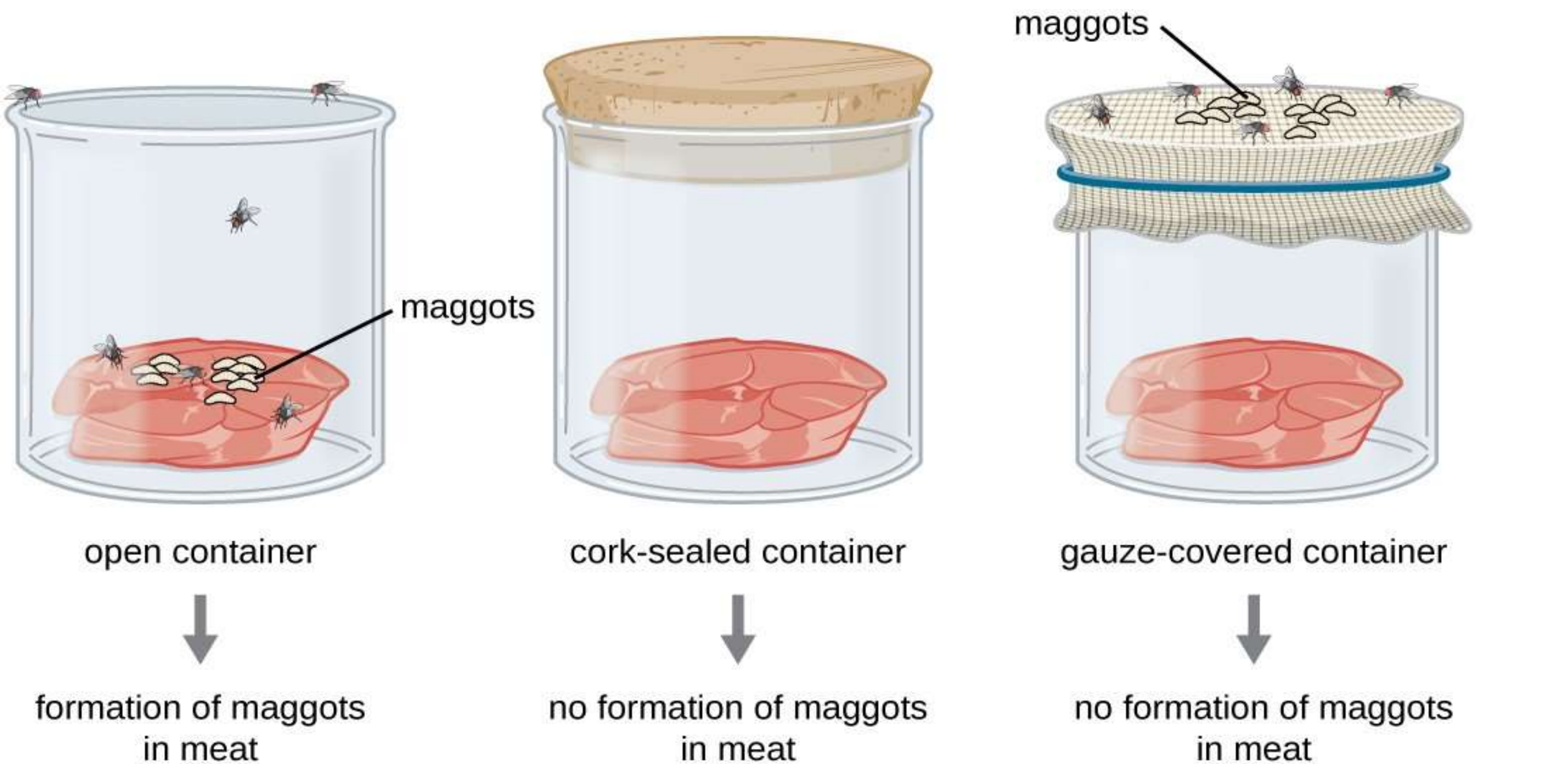
Invasion of land by animals
Humans appear
Invasion of land by plants
Oldest multicellular organisms
4 BILLION YEARS
Oldest known rocks
Midnight
1 BILLION YEARS
Afternoon
Morning
Oldest definite fossils of eukaryotes
Noon
3 BILLION YEARS
2 BILLION YEARS
Oldest definite fossils of prokaryotes
Appearance of oxygen in atmosphere

Theories - Disproving Spontaneous Generation

Francisco Redi (1668) – Rotten Meat Experiment



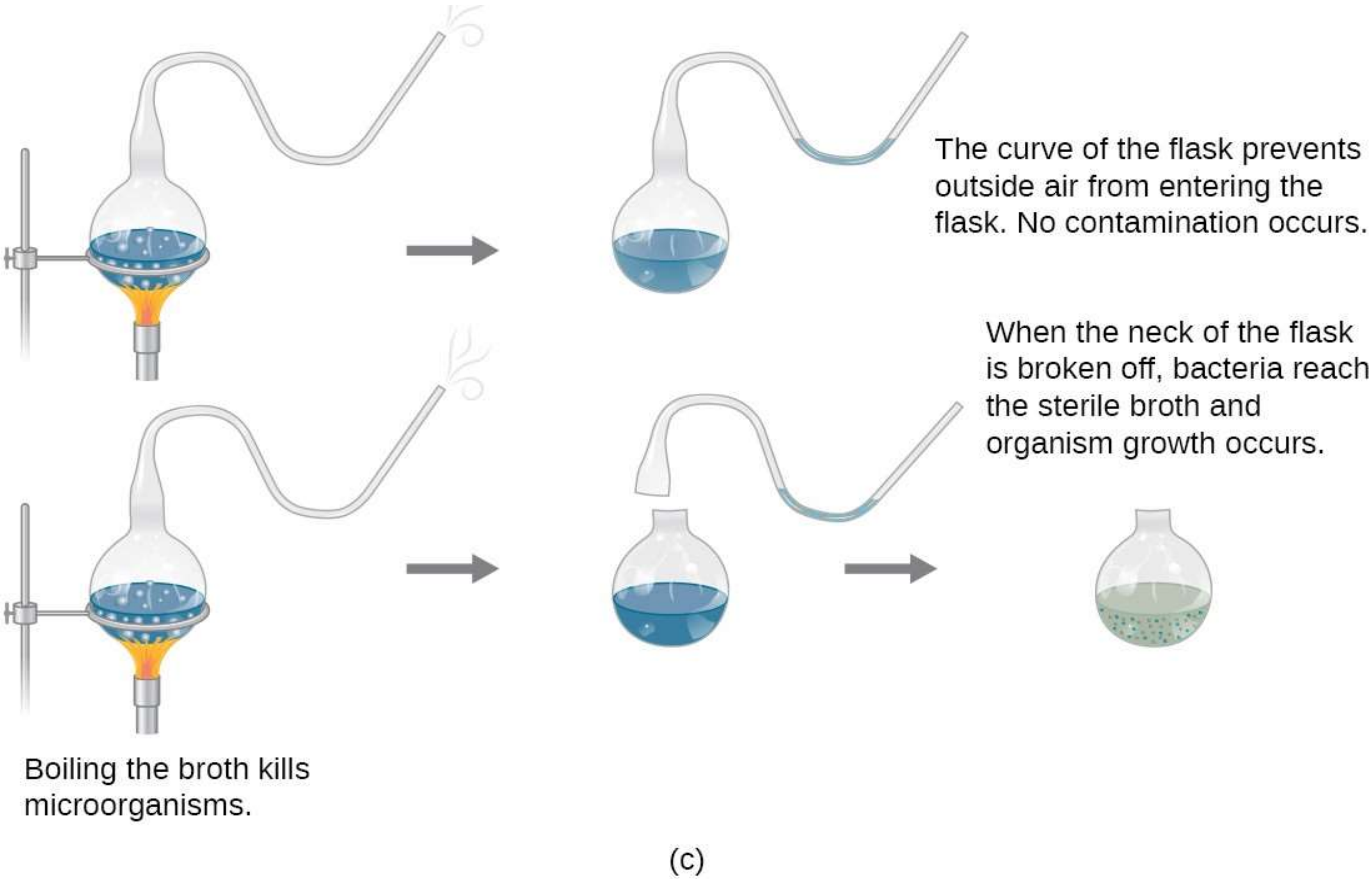
Italian physician Francesco **Redi** (1626–1697), performed an experiment in 1668 that was one of the first to refute the idea that maggots (the larvae of flies) spontaneously generate on meat left out in the open air.

He predicted that preventing flies from having direct contact with the meat would also prevent the appearance of maggots. Redi left meat in each of the three containers. One was open to the air, One was covered with gauze, and One was tightly sealed. His hypothesis was supported when maggots developed in the uncovered jar, but no maggots appeared in either the gauze-covered or the tightly sealed jar.

He concluded that maggots could only form when flies were allowed to lay eggs on the meat, and that the maggots were the offspring of flies, not the product of spontaneous generation.

Theories – Disproving Spontaneous Generation from non-living matter

Louis Pasteur (1864) – Curved Flask/Swan neck Experiment



Pasteur made a series of flasks with long, twisted necks ("swan-neck" flasks), in which he boiled broth to sterilize it. His design allowed air inside the flasks to be exchanged with air from the outside, but prevented the introduction of any airborne microorganisms, which would get caught in the twists and bends of the flasks' necks.

If a life force besides the airborne microorganisms were responsible for microbial growth within the sterilized flasks, it would have access to the broth, whereas the microorganisms would not. He correctly predicted that sterilized broth in his swan-neck flasks would remain sterile as long as the swan necks remained intact. However, should the necks be broken, microorganisms would be introduced, contaminating the flasks and allowing microbial growth within the broth.

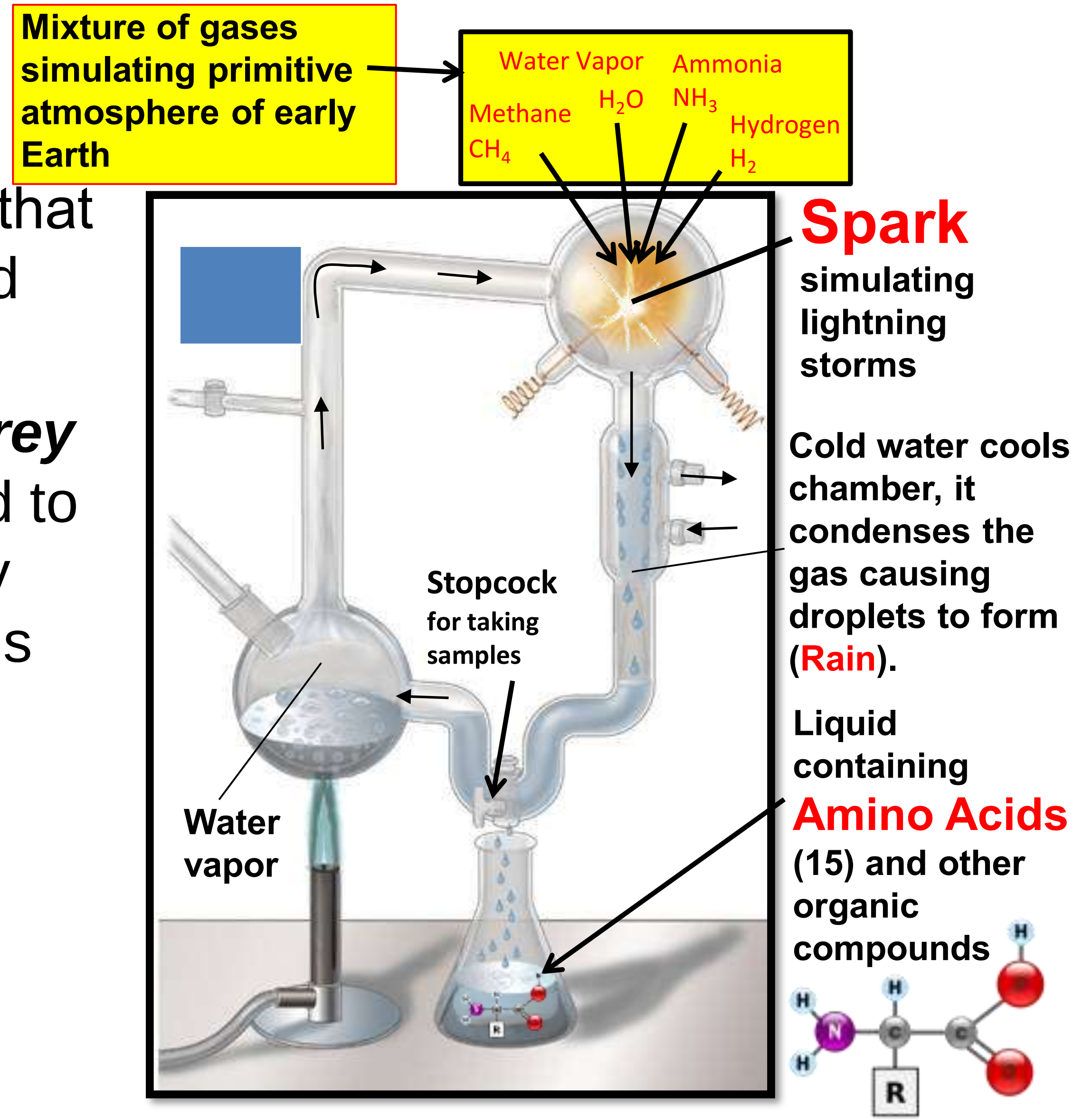
Theories - Chemical Evolution

- Conditions on the early Earth were very different from the Earth we know today.
- The early atmosphere contained no free oxygen and probably contained hydrogen cyanide, carbon dioxide, carbon monoxide, nitrogen, hydrogen sulfide and water.
- Energy for chemical reactions between these gases could come from electric discharge in storms or solar energy (no ozone layer).

Could organic molecules have evolved under these conditions?

Theories - Chemical Evolution

- ***Alexander Oparin*** (1920's), hypothesized that organic molecules could form.
- In the 1950's ***Harold Urey*** and ***Stanley Miller*** tried to answer that question by simulating the conditions on the early Earth in a laboratory setting.



Miller-Urey Experiment

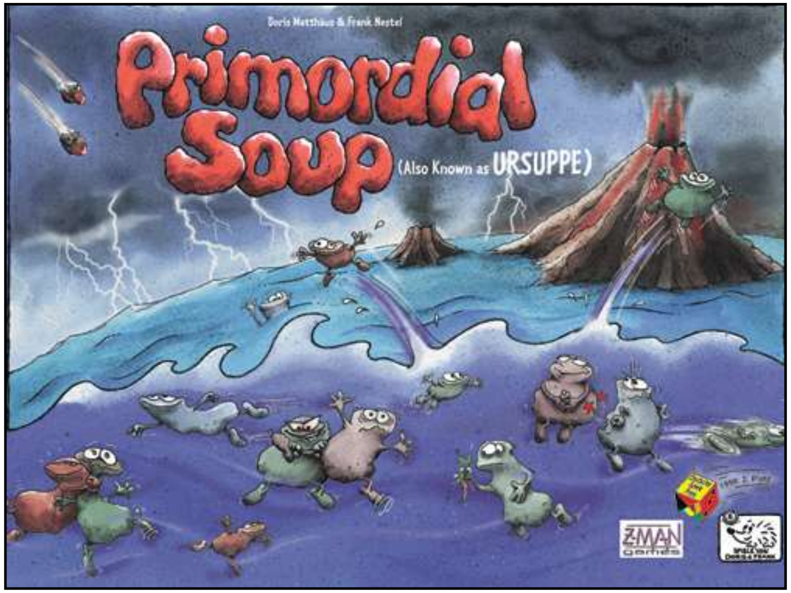
- First flask partially filled with water and heated to produce water vapor (sea)
- Water vapor was moved to a second flask where methane and ammonia vapor was added (atmosphere)
- Electric sparks (lightening) in second flask was energy source for chemical reactions
- Below second flask, water vapor cooled (rain) and recycled to first flask (sea)
- **Result**: turned brown with amino acids and other complex organic molecules

Miller and Urey did not create life from non-life (like the idea of maggots coming from meat). They simply created the ingredients for life (organic molecules), from inorganic molecules.

Scientists believe that we do not see this process occur in nature today because present day conditions on Earth are so different from the conditions present on early Earth

Theories - Chemical Evolution

- Miller and Urey's experiments suggested how mixtures of the organic compounds necessary for life could have arisen from simpler compounds present on a primitive Earth.
- This formation of organic molecules (such as amino acids, sugars, fatty acids, and nucleotide bases) from inorganic molecules is also known as ***abiogenesis***.



- Why were scientists trying to synthesize basic organic compounds in a simulated primitive Earth’s atmosphere?
- Because basic amino acids are the building blocks of all Life on Earth. It gives evidence that living things could have started on Earth from these simple molecules.

The First Cells

- Geological evidence suggests that cells similar to modern bacteria were common 3.8 billion years ago.
- However the stew of organic molecules suggested by Miller and Urey is a long way from a living cell.

So how could the first cells on Earth have originated?

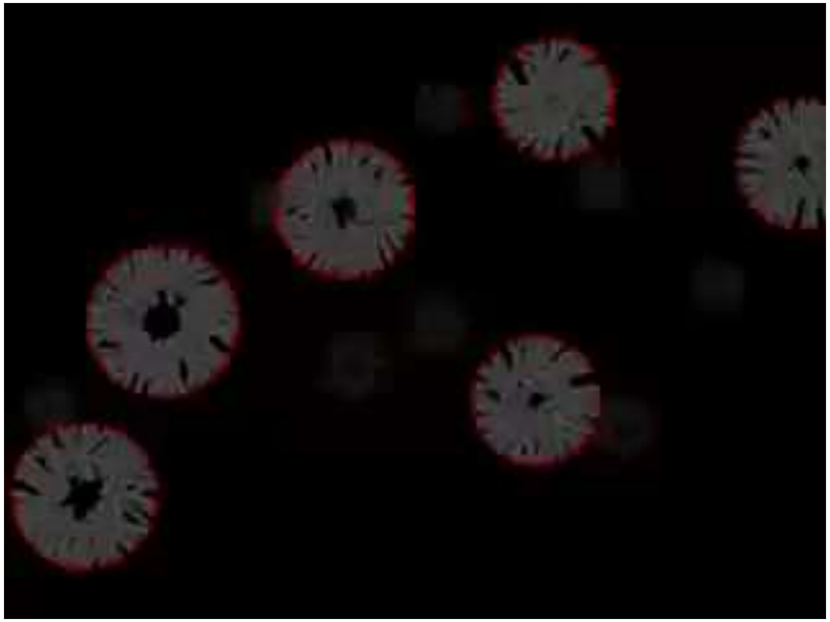
- ***Sydney Fox*** (1950’s) and others have done extensive research on the structures that may have given rise to the first cells.

The First Cells

- Organic molecules have a tendency to aggregate.

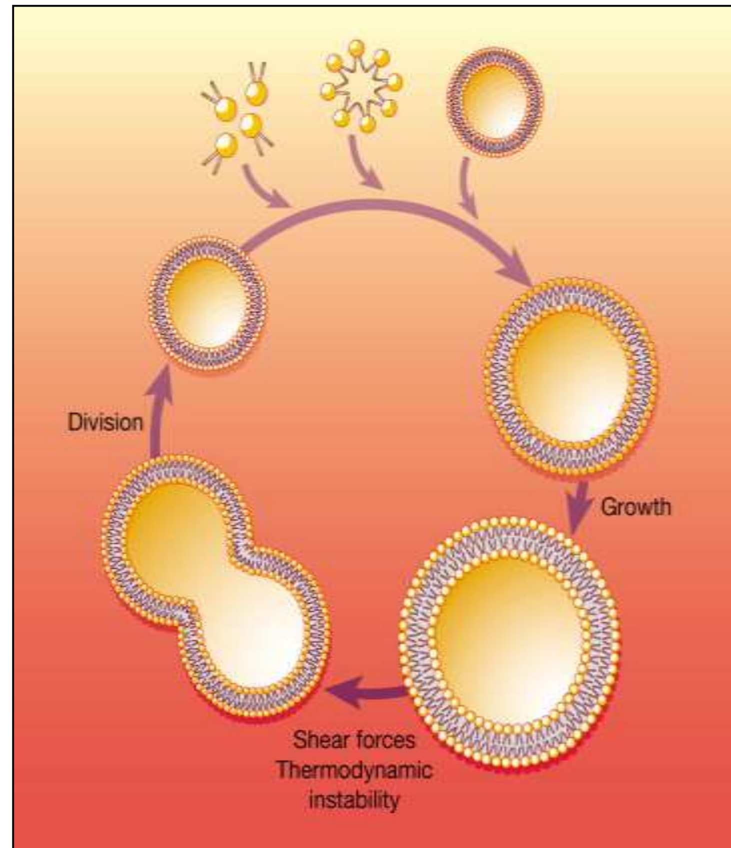
Remember…

- Phospholipids form lipid bilayers when they are surrounded by water.
- As a result, membrane-like vesicles called coacervates, form easily under certain conditions.



Coacervates

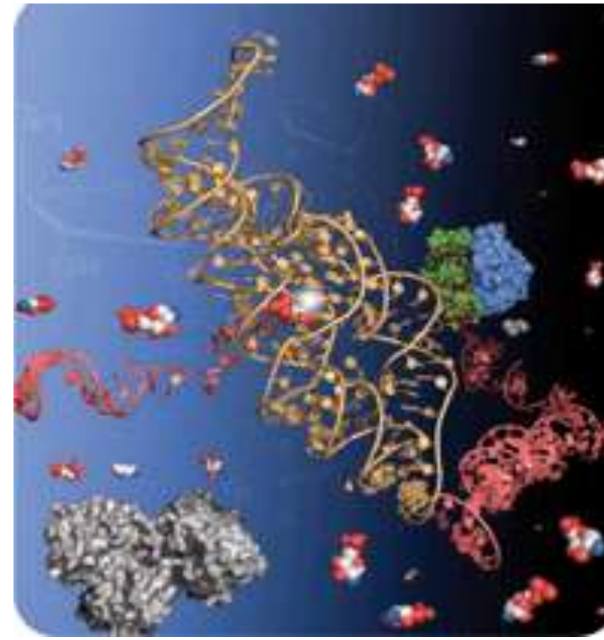
- Coacervates are made mostly of aggregated lipids.
- They grow by adding new polymers.
- They form a semi-permeable membrane.
- When they get too big they divide.
- Hypotheses suggest that structures similar to microspheres might have acquired more characteristics of living cells.



The Origin of Heredity

Remember…

- One of the characteristics of life, is that all living things contain hereditary information (DNA) which is passed from cell to cell during cell division.



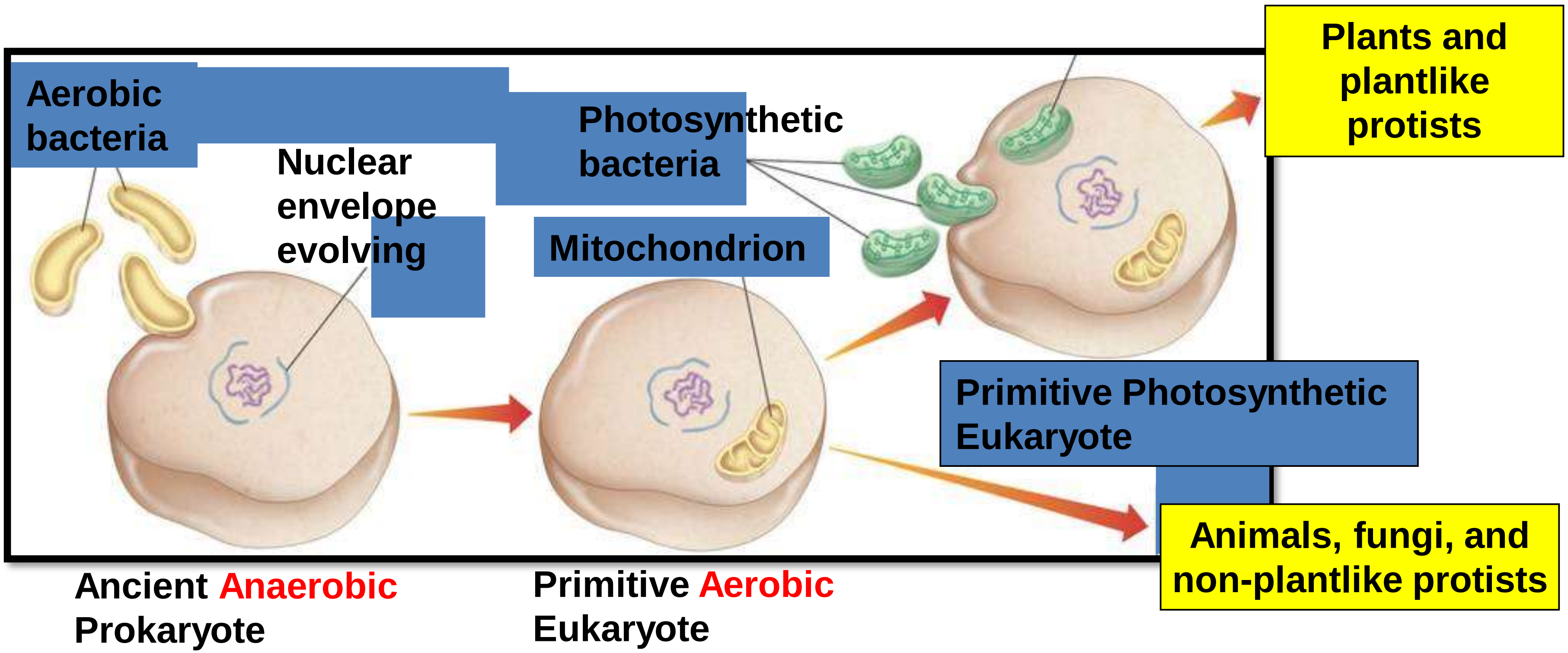
- Scientists speculate that *RNA may actually have been the first hereditary molecule*.
- There are several hypotheses for how RNA could have evolved into modern cellular life.

Life Begins

- First cells were anaerobic, heterotrophic, prokaryotes
- Diversification led to different forms of cells.
- Primitive photosynthesis evolved and added free oxygen to the environment.
- Oxygen in the atmosphere killed off most cells. Survivors were aerobes.

The First Eukaryotic Cells

- The ***Endosymbiotic Theory***, proposed by ***Lynn Margulis*** in 1967, proposes that eukaryotic cells arose from living communities formed by prokaryotic organisms. According to the theory, eukaryotic cells formed from a symbiosis among several different prokaryotes.



Evidence of endosymbiotic theory

- Chloroplasts and mitochondria …
  - are approximately the same size as bacteria
  - divide independently of the cell.
  - have a double membrane.
  - have DNA that is different from that in the cell’s nucleus

What’s important

- Chemical Evolution – the early Earth was very different from today. It had certain toxic gases and water vapor in the atmosphere and was highly charged with energy. These conditions allowed the formation of organic molecules from inorganic molecules. (Miller-Urey experiment)
- Once organic molecules appeared (in the primordial soup), they reacted together to form bigger organic molecules, then more sophisticated cell-like structures that metabolized materials and even divided in two. Once genetic material entered these structures, they actually began to pass on their genetic material when they divided. Now these structures had all of the characteristics of life and where the first living things (primitive bacteria-like cells - prokaryotic).
- Endosymbiotic theory: Some of these cells engulfed other cells. The smaller cells started to live in the bigger cells. After many millions of years of this co-existance, they became, a single, more complex cell (eukaryotes)

Search for Self-Replicating Molecule

- Work backward from organisms that live today
- DNA is double-stranded = complicated
- RNA obvious candidate, more simple than DNA
  - Hereditary information
  - Can serve as template for replication
  - Fewer steps to produce backbone structure

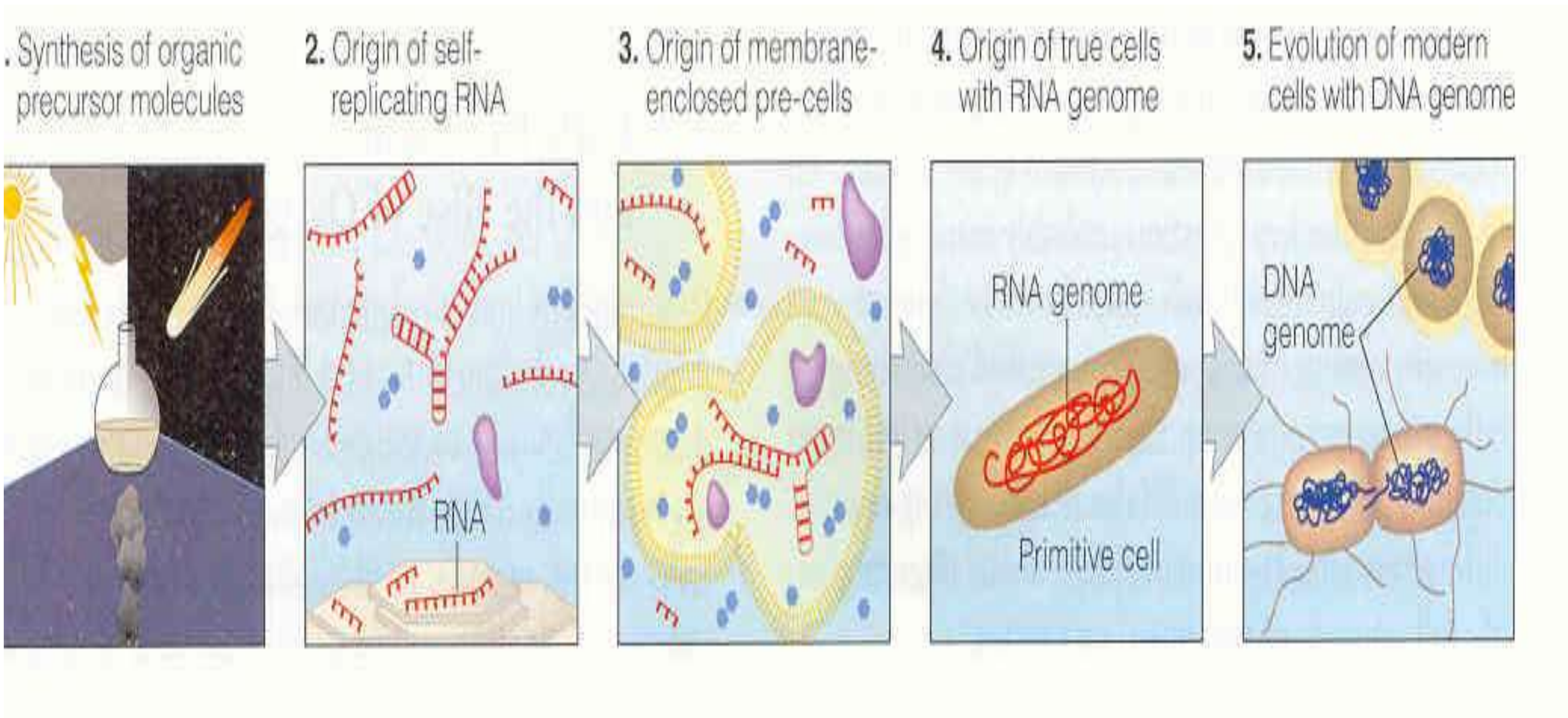
Search for Self-Replicating Molecule

- Problem: RNA and DNA require enzymes to replicate
- In 1980’s determined that RNA might catalyze their own replication instead of other enzymes
- *Early Earth was an RNA-world*

Search for Replicating Molecule

- On Early Earth, short strands of RNA-like molecules were produced spontaneously partially or completely
- RNA-like molecules that could replicate faster with less errors soon dominated population
- Copying errors introduced mutations, ensuring the production of many variations of successful molecules
- Allowed molecular evolution to continue
- RNA-world gave way to DNA-world
  - DNA less prone to copying errors
  - DNA more flexible hereditary material
  - RNA kept some of its original functions

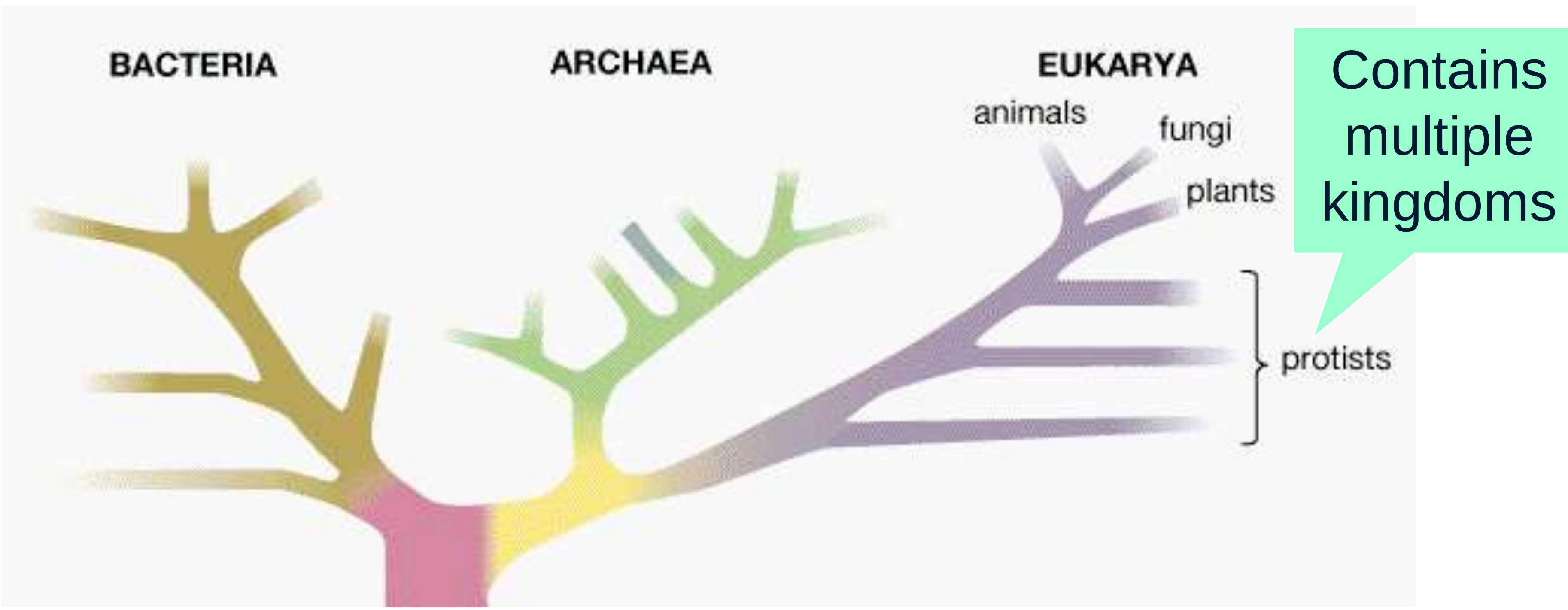
Quick Summary



The Unity and Diversity of Living Things

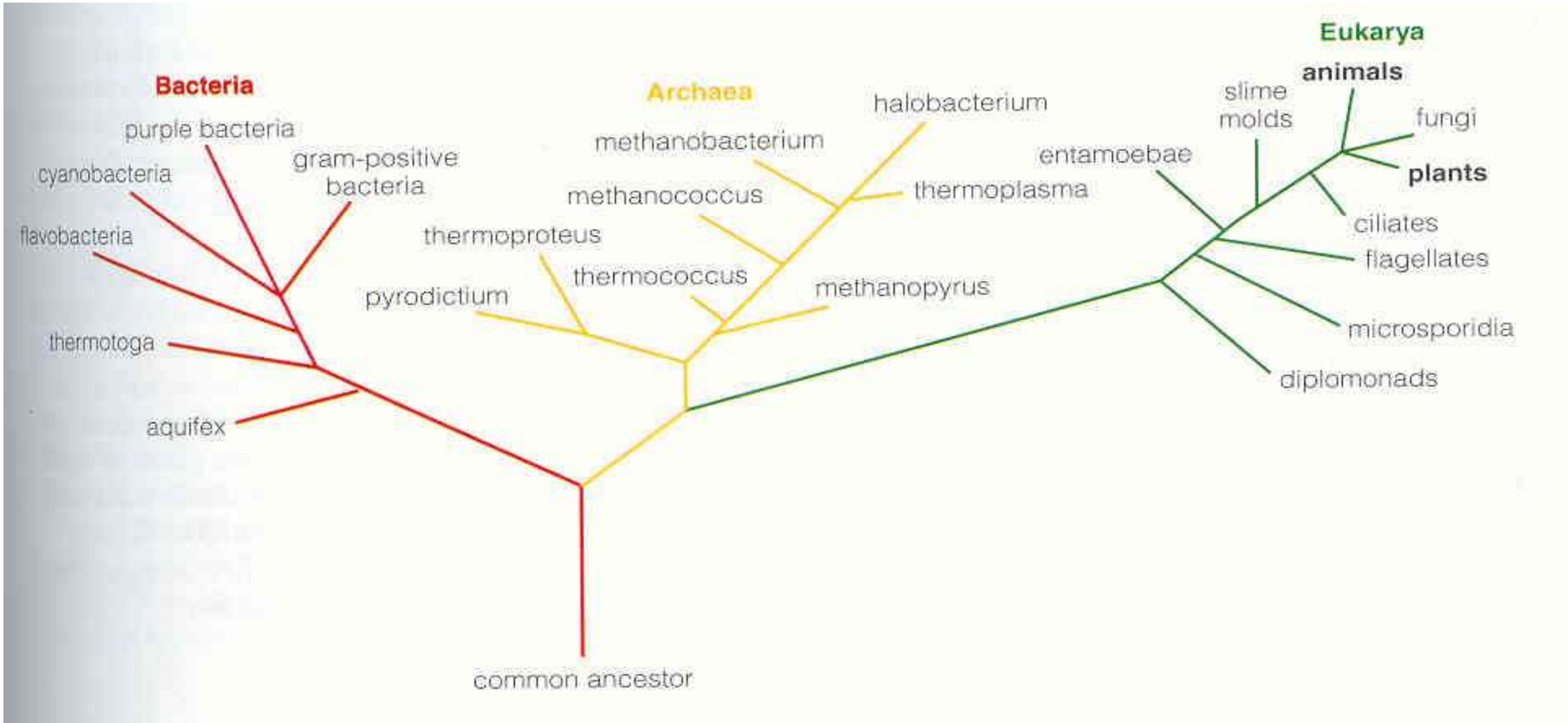
An Evolutionary Tree of Life

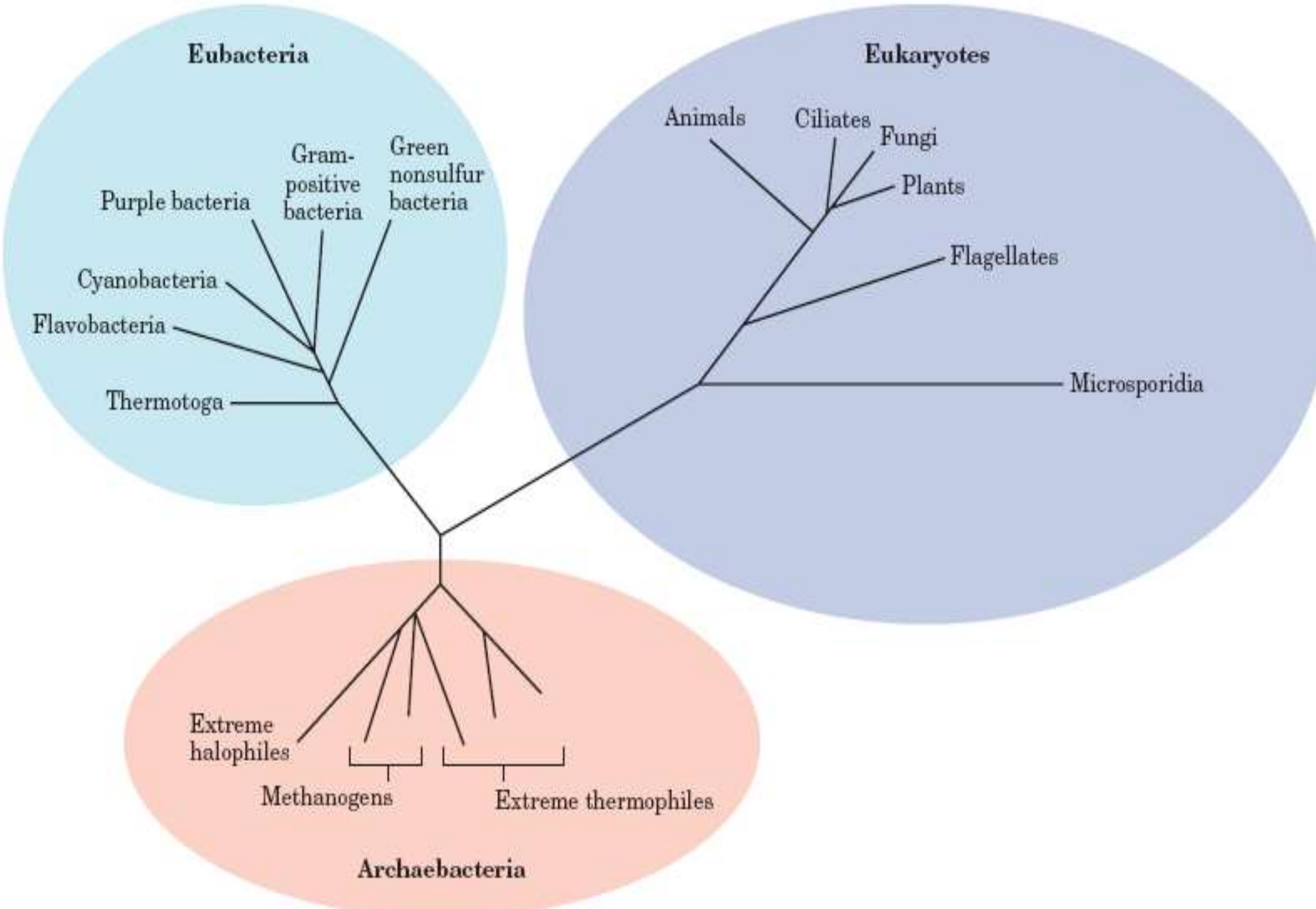
The Three <u>Domains</u> of Life Represent the Earliest Branches in Evolutionary History



Living Fossils

- Bacteria and Archaea: genetic material NOT separated from rest of cell
- Eukarya: DNA separated from rest of cell by membrane
- Extremophiles (live near deep-sea vents or in hot springs) closest to root of tree of life





Eubacteria
Purple bacteria
Gram-
positive
bacteria
Green
nonsulfur
bacteria
Cyanobacteria
Flavobacteria
Thermotoga
Eukaryotes
Animals
Ciliates
Fungi
Plants
Flagellates
Microsporidia
Extreme
halophiles
Methanogens
Extreme thermophiles
Archaebacteria

Classification of living organisms

1. **Bacteria:** These are a group of unicellular, prokaryotic microorganisms that are present in every habitat on earth. They are usually a few micrometers in length and have a range of shapes such as rods, spheres, and spirals. Bacteria are one of the most ancient life forms, believed to have been present over 3 billion years ago. These organisms lack a defined cell-nucleus and other cellular organelles, due to which they are classified as prokaryotes.

2. **Archae:** Archae are a group of single-celled microorganisms that are also classified as prokaryotes due to their lack of cellular organelles and a nucleus. They were originally classified as bacteria but now form their own separate domain due to several genetic and metabolic differences, in which they more closely resemble eukaryotes. Unlike eukaryotes however, they are capable of obtaining their energy from various sources such as organic compounds, sugars, ammonia etc.

3. **Eukaryotes:** These are multicellular organisms whose cells contain complex structures including a well-defined, membrane-bound nucleus carrying the genetic material. Eukaryotic cells are typically larger than prokaryotes and contain several other membrane-bound organelles which carry out complex metabolic & cell division processes.

Extremophiles

Life on the edge

Life at High Temperatures, Thomas M. Brock

Extremophile

- Definition - Lover of extremes
- History
  - Suspected about 30 years ago
  - Known and studied for about 20 years
- Temperature extremes
  - boiling or freezing, 100^0C to -1^0C (212F to 30F)
- Chemical extremes
  - vinegar or ammonia (<5 pH or >9 pH)
  - highly salty, up to ten times sea water

nature
International journal of science

From: Life in extreme environments

Table 1 Classification and examples of extremophiles

Environmental parameter	Type	Definition	Examples
Temperature	Hyperthermophile Thermophile Mesophile Psychrophile	Growth >80 °C Growth 60–80 °C 15–60 °C <15 °C	*Pyrolobus fumarii*, 113 °C *Synechococcus lividis* *Homo sapiens* *Psychrobacter*, some insects
Radiation			*Deinococcus radiodurans*
Pressure	Barophile Piezophile	Weight-loving Pressure-loving	Unknown For microbe, 130 MPa
Gravity	Hypergravity Hypogravity	>1*g* <1*g*	None known None known
Vacuum		Tolerates vacuum (space devoid of matter)	Tardigrades, insects, microbes, seeds
Desiccation	Xerophiles	Anhydrobiotic	*Artemia salina*; nematodes, microbes, fungi, lichens
Salinity	Halophile	Salt-loving (2–5 M NaCl)	Halobacteriaceae, *Dunaliella salina*
pH	Alkaliphile Acidophile	pH > 9 low pH-loving	*Natronobacterium*, *Bacillus firmus* OF4, *Spirulina* spp. (all pH 10.5) *Cyanidium caldarium*, *Ferroplasma* sp. (both pH 0)
Oxygen tension	Anaerobe Microaerophile Aerobe	Cannot tolerate O_2 Tolerates some O_2 Requires O_2	*Methanococcus jannaschii* *Clostridium* *H. sapiens*
Chemical extremes	Gases Metals	 Can tolerate high concentrations of metal (metalotolerant)	*C. caldarium* (pure CO_2) *Ferroplasma acidarmanus* (Cu, As, Cd, Zn); *Ralstonia* sp. CH34 (Zn, Co, Cd, Hg, Pb)

Extreme Temperatures

- **Thermophiles** - High temperature
  - Thermal vents and hot springs
  - May go hand in hand with chemical extremes
- **Psychrophiles** - Low temperature
  - Arctic and Antarctic
    - 1/2 of Earth's surface is oceans between 1^0C & 4^0C
    - Deep sea -1^0C to 4^0C
    - Most rely on photosynthesis

Thermophiles

Obsidian Pool, Yellowstone National Park
Hydrothermal Vents

Psychrophiles

Chemical Extremes

- **Acidophiles** - Acidic
  - Again thermal vents and some hot springs
- **Alkaliphiles** - Alkaline
  - Soda lakes in Africa and western U.S.
- **Halophiles** - Highly Salty
  - Natural salt lakes and manmade pools
  - Sometimes occurs with extreme alkalinity

Acidophiles

pH 0-1 of waters
at Iron Mountain

Alkaliphile

e.g. Mono Lake
alkaline soda lake, pH 9
salinity 8%

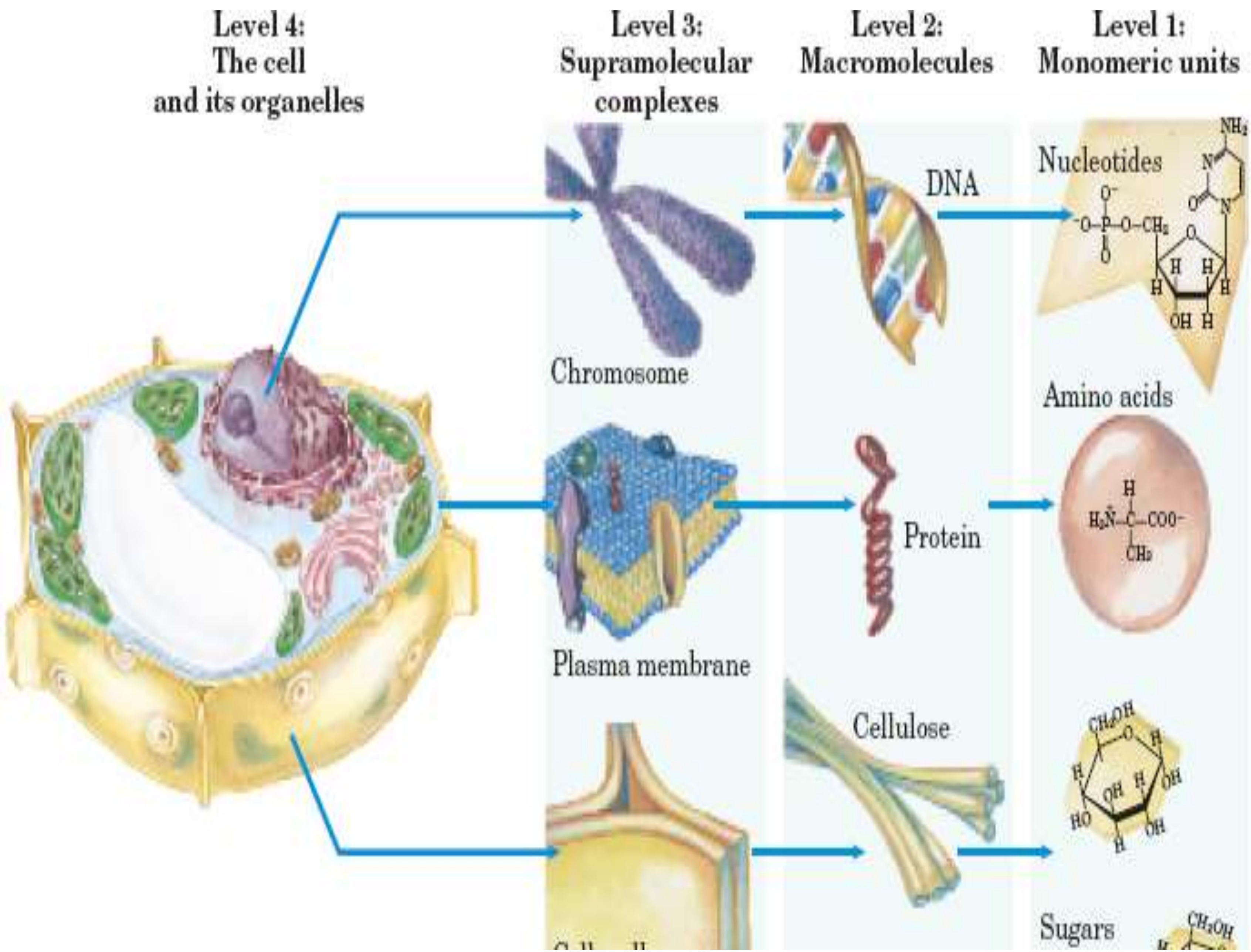
Halophiles

solar salterns
Owens Lake,
Great Salt Lake
coastal splash zones
Dead Sea

BIOCHEMICAL UNITY

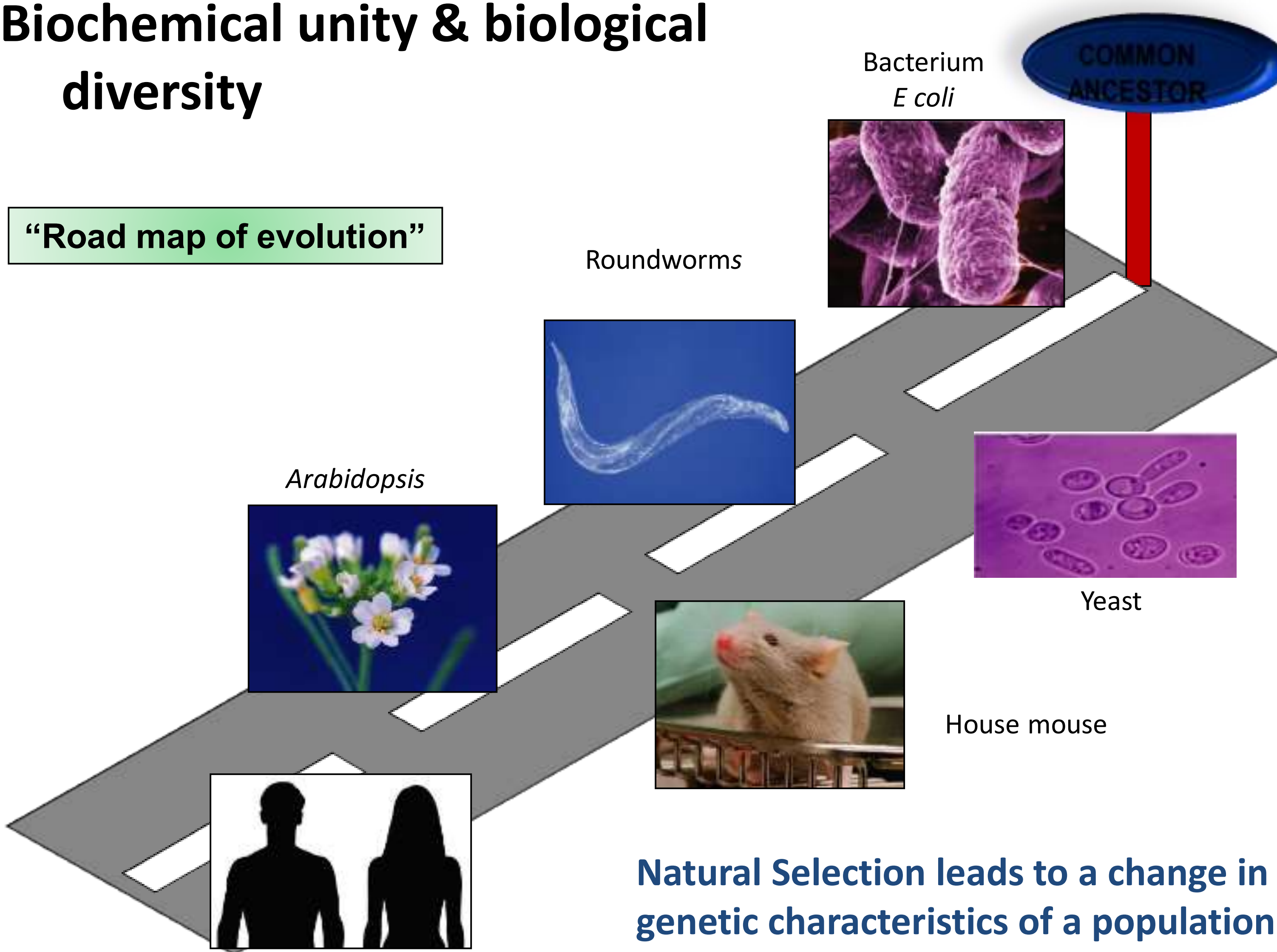
UNDERLIES

BIOLOGICAL DIVERSITY


Level 4:
The cell
and its organelles
Level 3:
Supramolecular
complexes
Level 2:
Macromolecules
Level 1:
Monomeric units
Nucleotides
DNA
Chromosome
Amino acids
Protein
Plasma membrane
Cellulose
Sugars

Biochemical unity & biological diversity

"Road map of evolution"



Natural Selection leads to a change in the genetic characteristics of a population →evolution

Biochemical unity & biological diversity

Evolution: The process by which various populations of organisms acquire and pass on their novel traits, in addition to other existing traits, from one generation to the next.

This explains the origin of new species of organisms and the vast diversity that is observed in the biological world.

However, it is believed that the origin of all organisms can be traced back to one common ancestor due to several underlying biochemical similarities.

Prokaryotic cells	Eukaryotic cells
Nuclear material concentrated in a specific region of the cytoplasm.	Nuclear material contained in membrane-bound organelle called nucleus.
Does not contain golgi complex & mitochondria.	Contains golgi complex & mitochondria
Majority are unicellular organisms.	Mostly multicellular organisms
Can reproduce through sexual & asexual means.	Reproduce through sexual means.