Origin of Life

How life formed on Earth?

How different kinds of organisms are formed in the world?

Key points to note

Earth and other planets in solar system came to existence around 4.5-5 billion years ago.

- Lithosphere (solid mass)
- Atmosphere (gaseous envelope)
- Hydrosphere: (Water: Temperature reduced)

- Primitive earth with little or no oxygen. The earth originally had a reducing environment due to presence of hydrogen and hydrogen compounds (such as CH_4) and ammonia (NH_3)

Theories of origin of LIFE

Took almost 1 billion years from the formation of earth to appearance of life.

- Theory of Special Creations
- Theory of spontaneous generations
- Theory of catastrophism
- Theory of Cosmozoic
  - (theory of panspermia or spore theory)
- Theory of eternity of Life (steady state theory)
- Modern theory (chemical theory or theory of primary abiogenesis)

Theory of special Creation (Father Suarez)

- Life on earth is created by supernatural power
- GOD created everything in six natural days
  - 1st Day: heaven and earth
  - 2nd Day: Sky and water separated
  - 3rd Day: Dry land and planet
  - 4th Day: Sun, moon and stars
  - 5th Day: Fish and Birds
  - 6th Day: Land animals and HUMANS
    - (Brahma the creator of universe)

- All living organisms inhabiting on land were created same day
- They were created in the present form
- Their bodies and organs are fully developed

Scientific comments:

- It was purely based on religious belief.
- There was no experimental evidences to support the assumptions.
- The age of different fossils proves that living organism appear on earth in different time frame.

Theory of spontaneous generation (Greek philosopher: Thales, plato and aristotle)

- Abiogenesis
- Non living material → life
- Rotten meat gave rise to fly larvae
- Mud of Nile river + sun→ frogs, snake, mice, crocodiles
- Dirty shirt + wheat grains → mice
  - Van Helmontz (1577-1644)

Experiments to disprove:

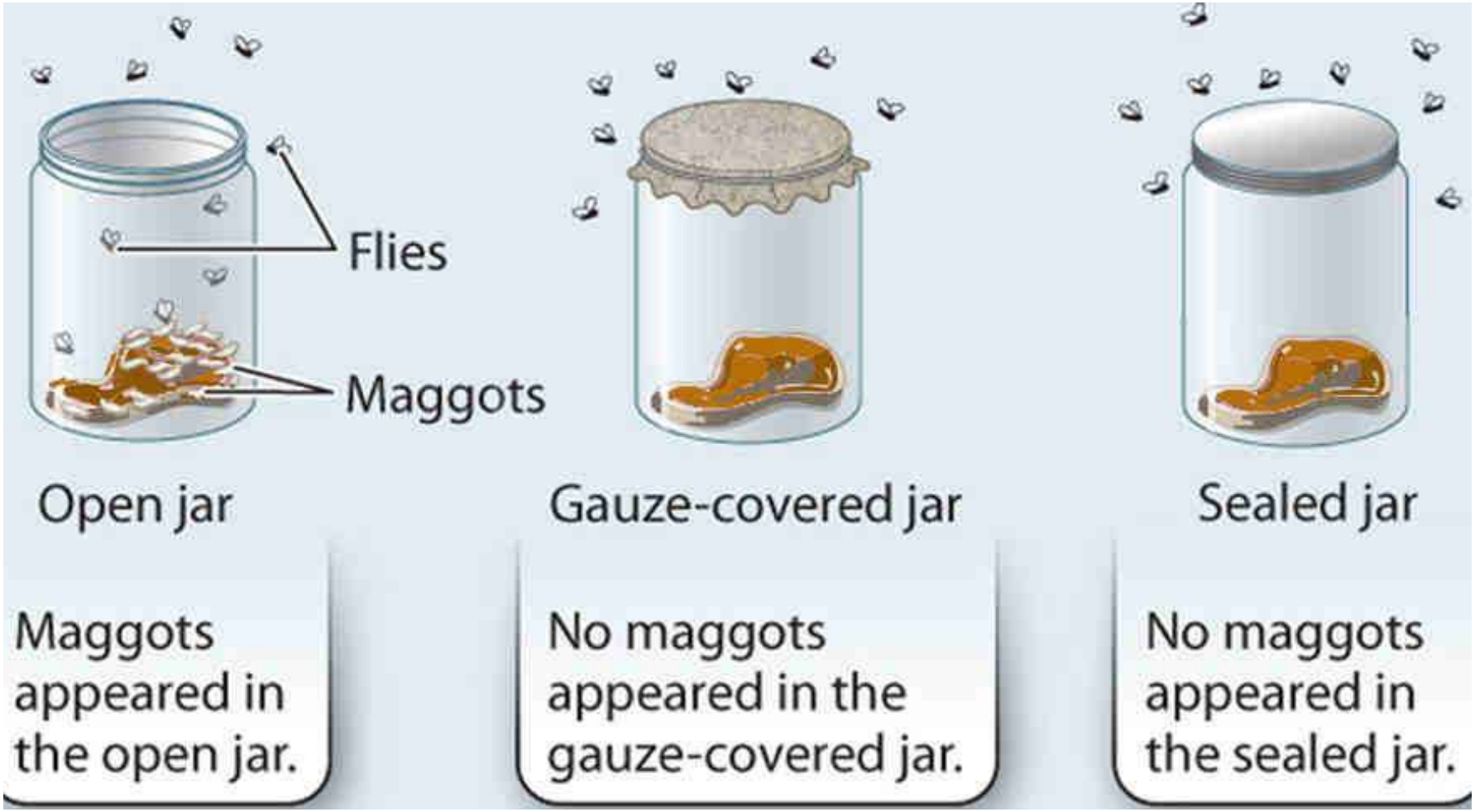
- Redi's Experiment
- Spallanzani's Experiment
- Louis Pasteur Experiment

Franesco Redi

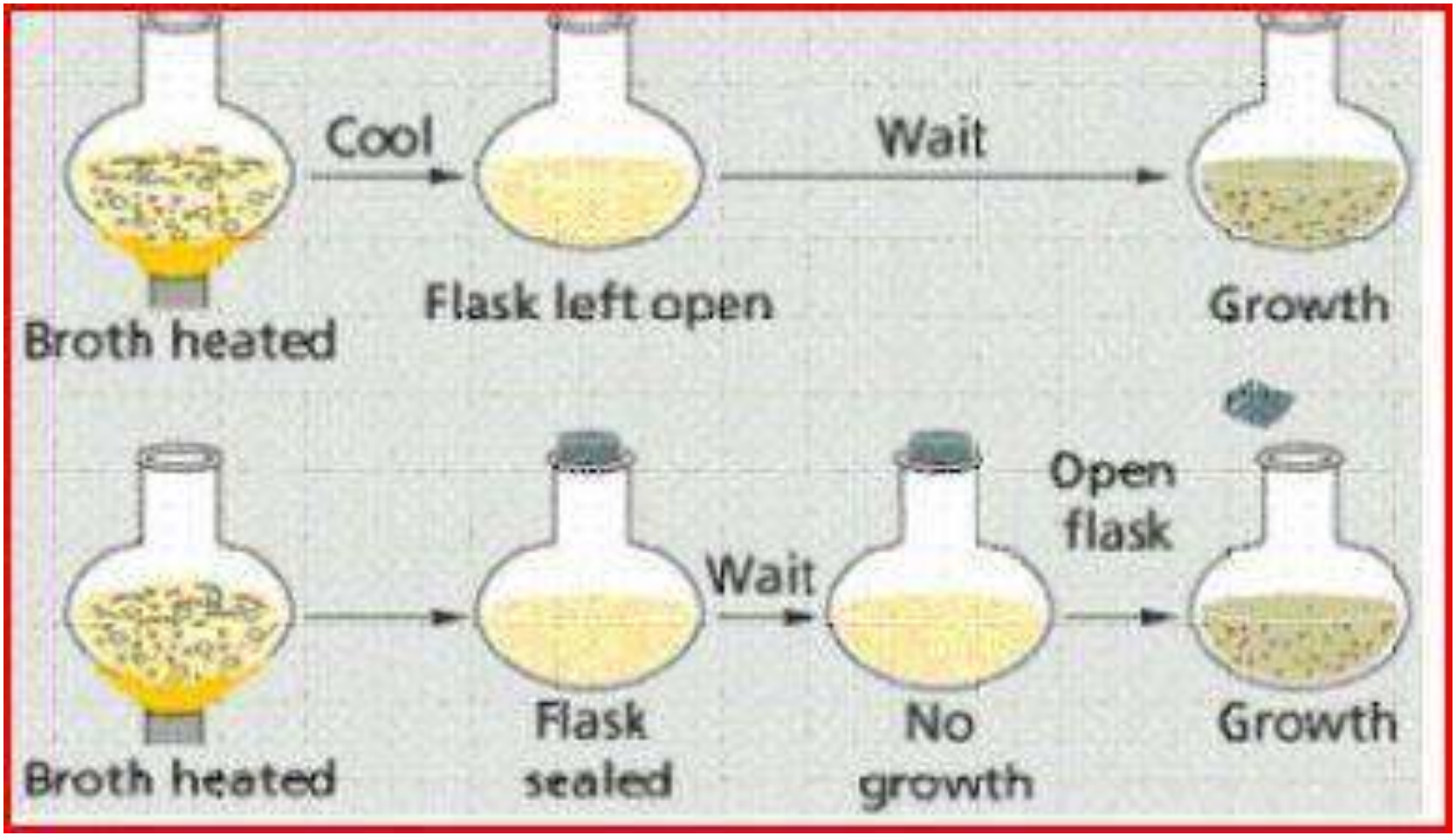
Lazzaro Spallanzani

Italian physician and scientist

Redi's Experiment



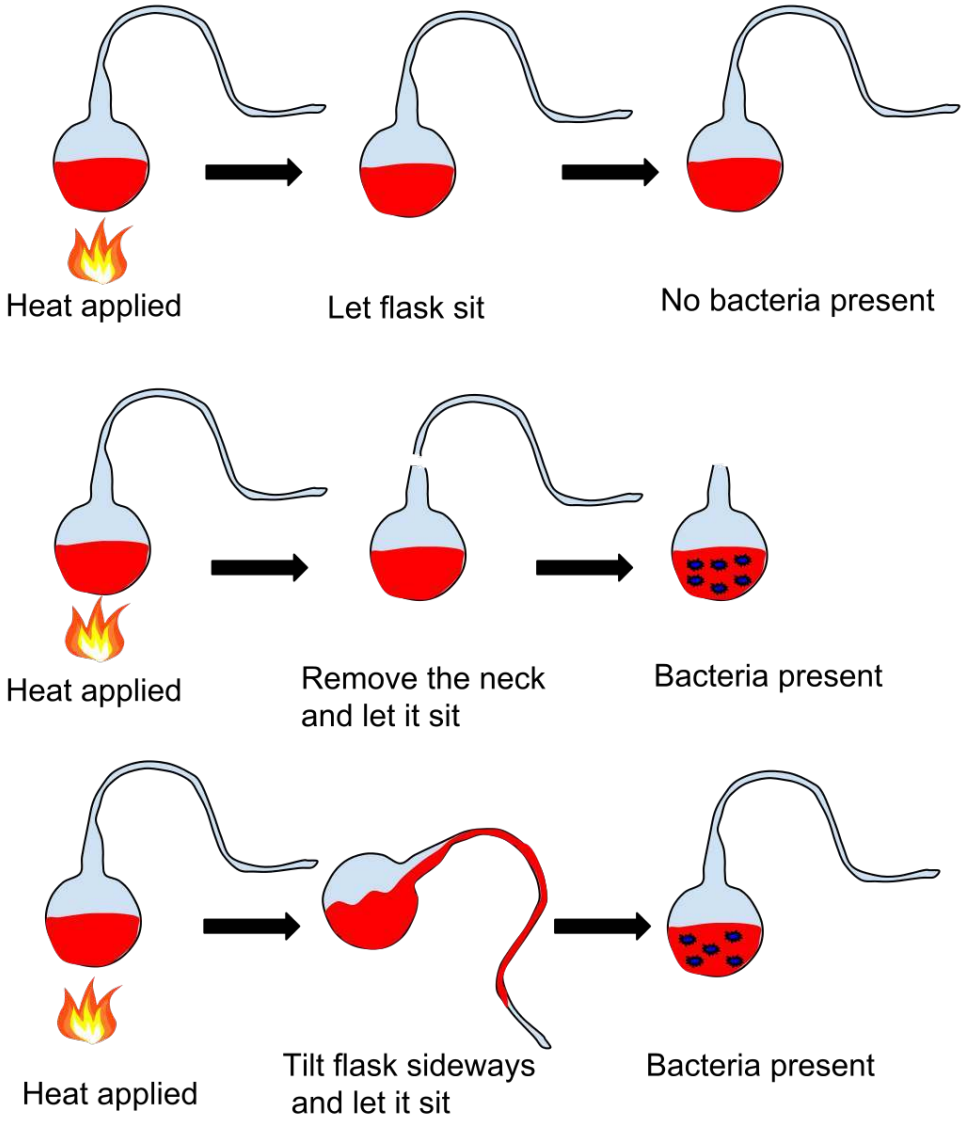
Spallanzani's Experiment



Louis Pasteur

French scientist

Louis Pasteur Experiment



THEORY OF CATASTROPHISM

Georges Cuvier 1769-1832

- modification of the theory of Special Creation.
- It states that there have been several creations of life by God, each preceded by a catastrophe resulting from some kind of geological disturbance.
- According to this theory, since each catastrophe completely destroyed the existing life, each new creation consisted of life form different from that of previous ones.

Theory of cosmozoic: Panspermia?

Richter (1865)
Arrhenius (1908)

- Panspermia = life originated elsewhere and migrated to Earth
- Life began in rock, then kicked off the planet by an impact
- Support: organic material is everywhere, and some bacteria can withstand large amounts of radiation and go dormant under low atmospheric conditions

Panspermia

- 2 schools of thought
- School 1: life did not evolve as easily as imagined on early Earth in timescales we've determined
- Problem: entire solar system was under heavy bombardment at the same time
- Other possibility: interstellar migration
- School 2: life evolved easily and was everywhere with suitable conditions
- Earth was not first planet with suitable conditions
- Migration of life from another planet (say Mars) dominated before early life on Earth could
  - We're Martians!!!!
- Martian meteorites
- Both have possible fossil evidence of life on Mars

Philosophical Theory of Eternity

Preyer in 1880

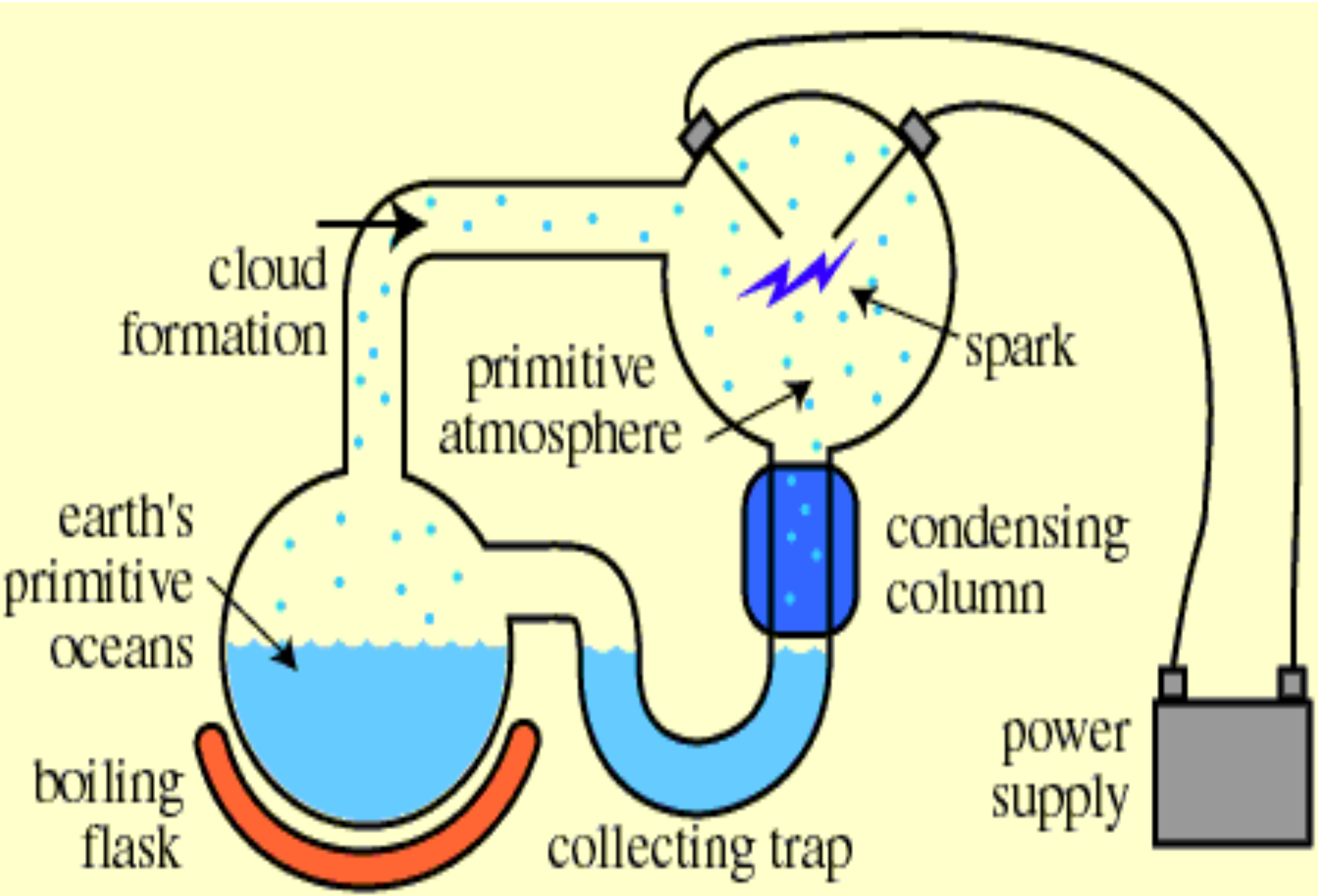
- life has a beginning and no end; life has been here right from the very beginning of time

Organic Chemistry on Early Earth

- In 1920's, scientists hypothesized that the chemicals in the early atmosphere, fueled by sunlight, would spontaneously create organic molecules
- Tested by Miller-Urey experiment 1950's
  - (Stanley Miller and Harold Urey)

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


cloud formation
primitive atmosphere
spark
earth's primitive oceans
condensing column
power supply
boiling flask
collecting trap

1. Formation of HCN, HCHO etc:

$CO_2 \rightarrow CO + [O]$ (atomic oxygen)----------[Eq 4.1]

$CH_4 + 2[O] \rightarrow CH_2O + H_2O$ ----------[Eq 4.2]

$CO + NH_3 \rightarrow HCN + H_2O$ ----------[Eq 4.3]

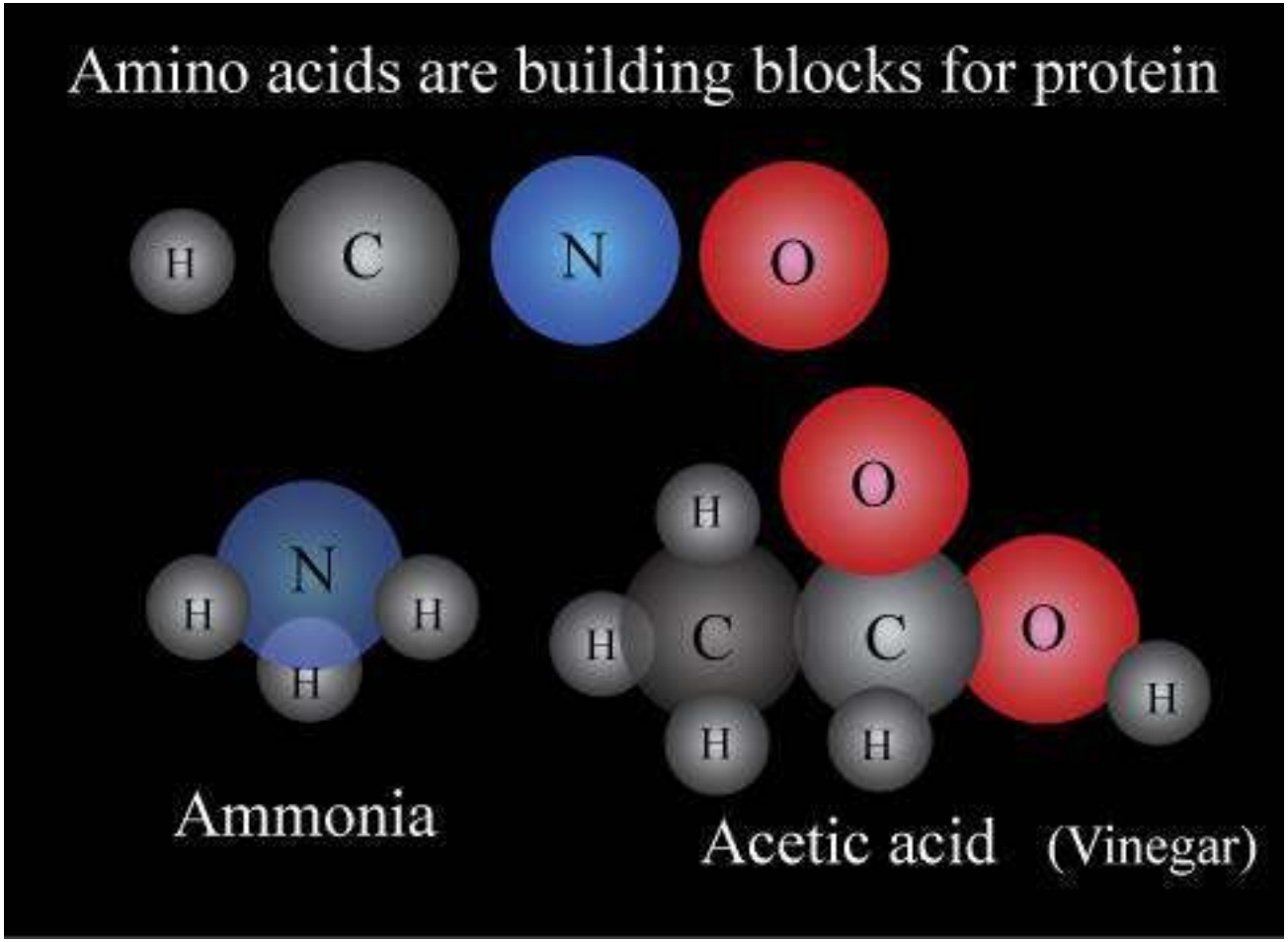
$CH_4 + NH_3 \rightarrow HCN + 3H_2$ ----------[Eq 4.4]

2. Formation of Glycine: The formaldehyde, ammonia, and HCN then react to form glycine.

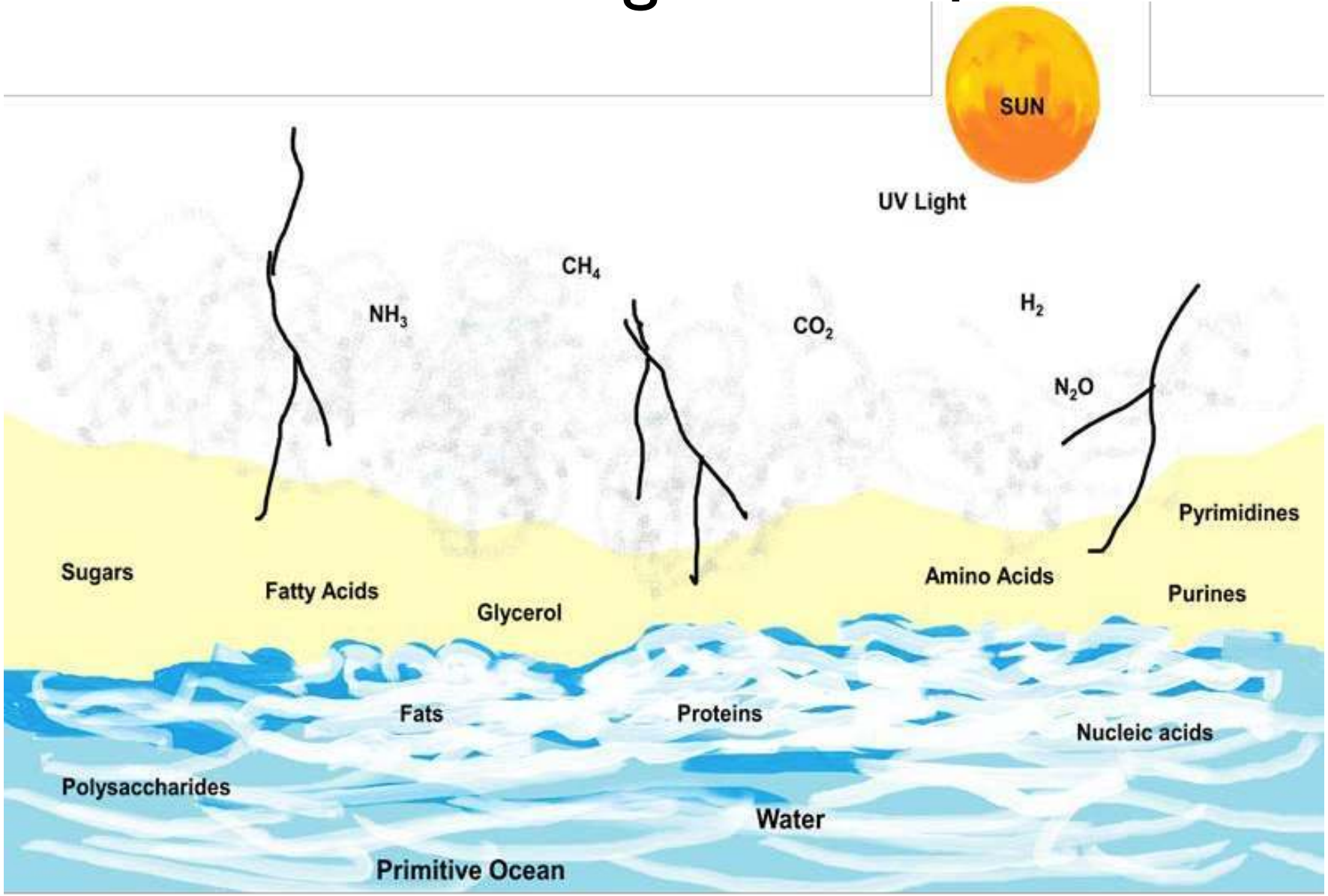
$CH_2O + HCN + NH_3 \rightarrow NH_2\text{-}CH_2\text{-}CN + H_2O$ ----------[Eq 4.5]

$NH_2\text{-}CH_2\text{-}CN + 2H_2O \rightarrow NH_3 + NH_2\text{-}CH_2\text{-}COOH$ ----------[Eq 4.6]

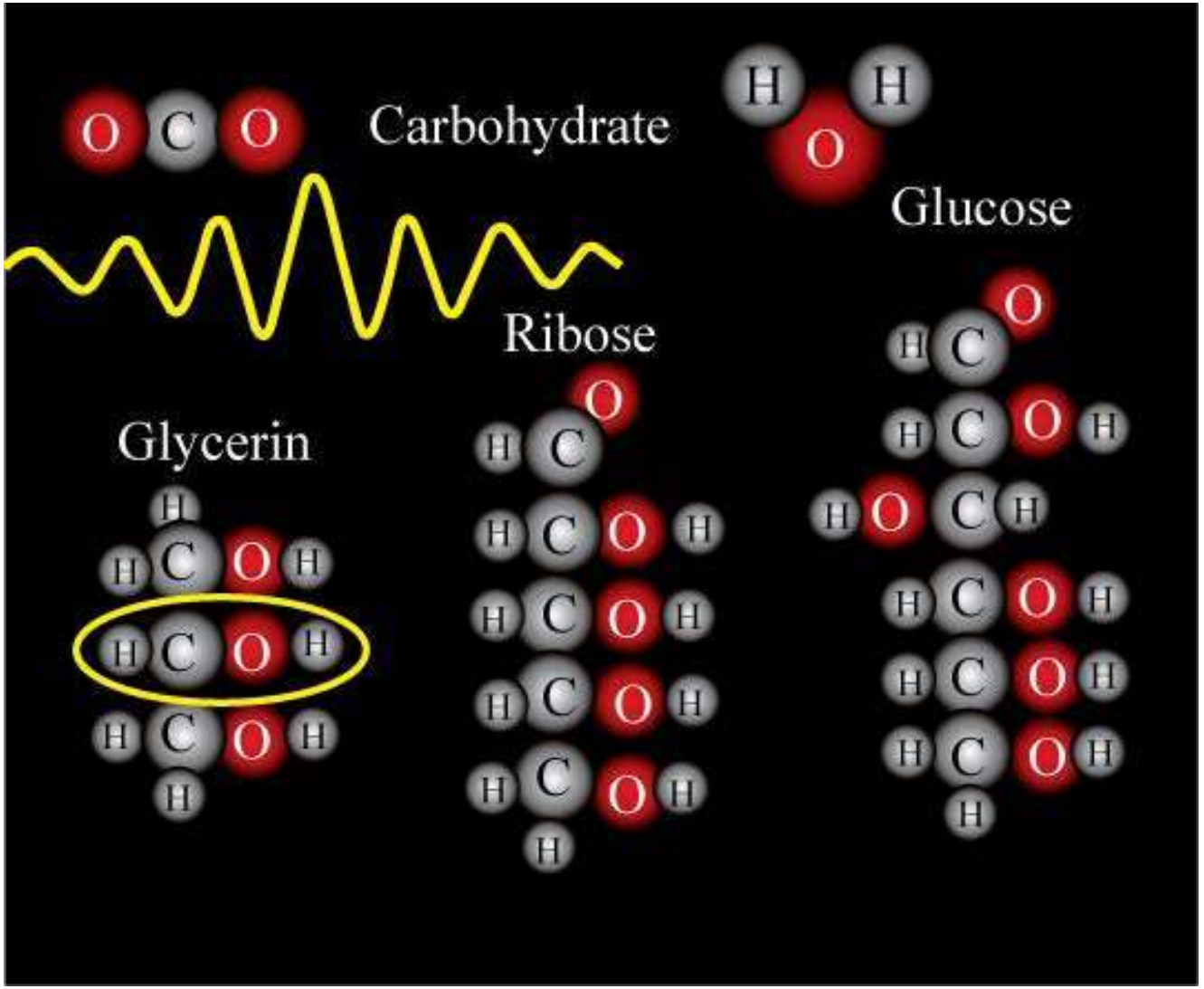
(1) Formation of Inorganic molecules:



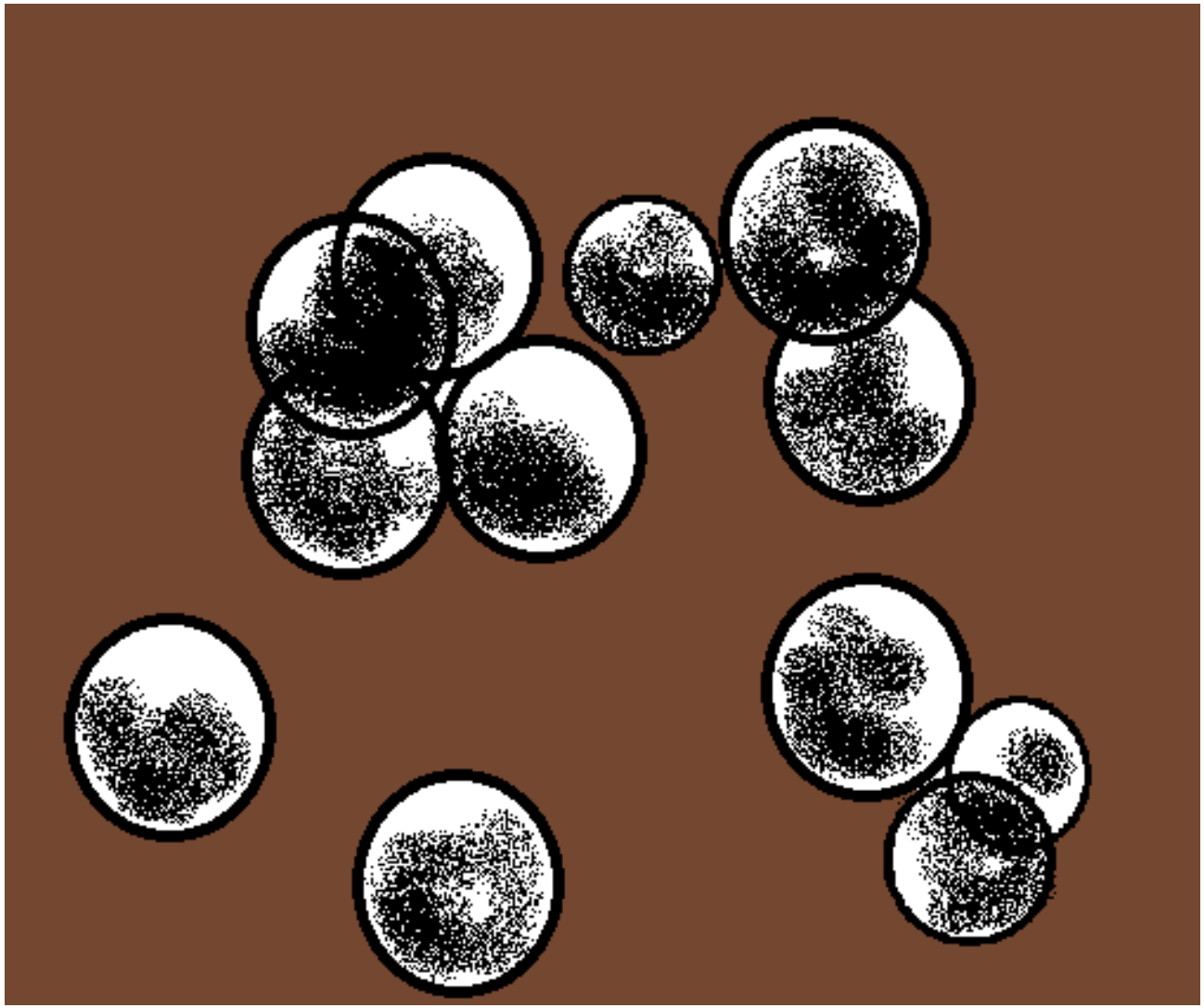
(2) Spontaneous formation of monomeric organic compounds:



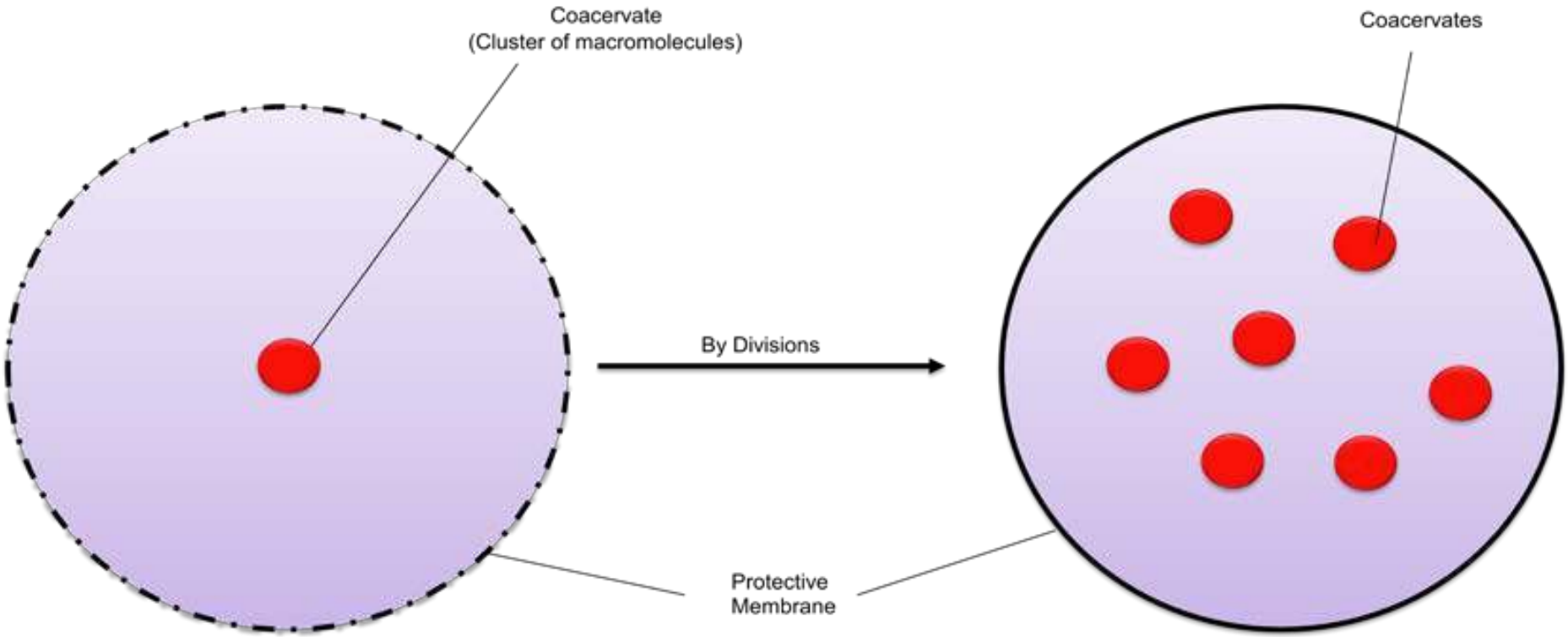
(3) Spontaneous formation of complex organic compounds:



(4) Spontaneous formation of molecular aggregates:

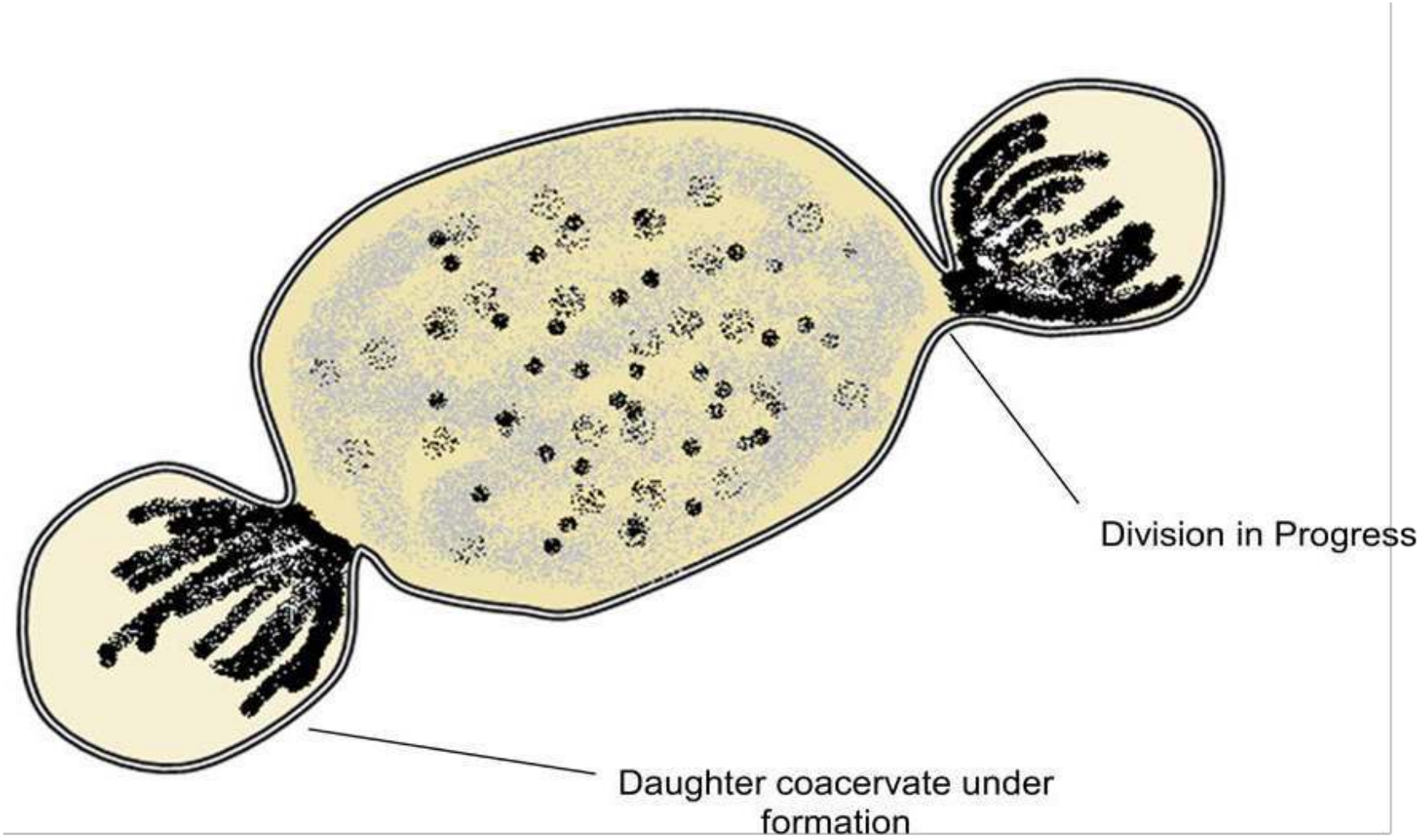


colloidal aggregates called as **coacervates**



Coacervate formation

Coacervate formation and division to form protocell.



Transition from chemistry to biology

- Organic molecules are building blocks of life.
- Low probability of forming life even if repeated several times.
- Intermediate steps of high probability are necessary

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

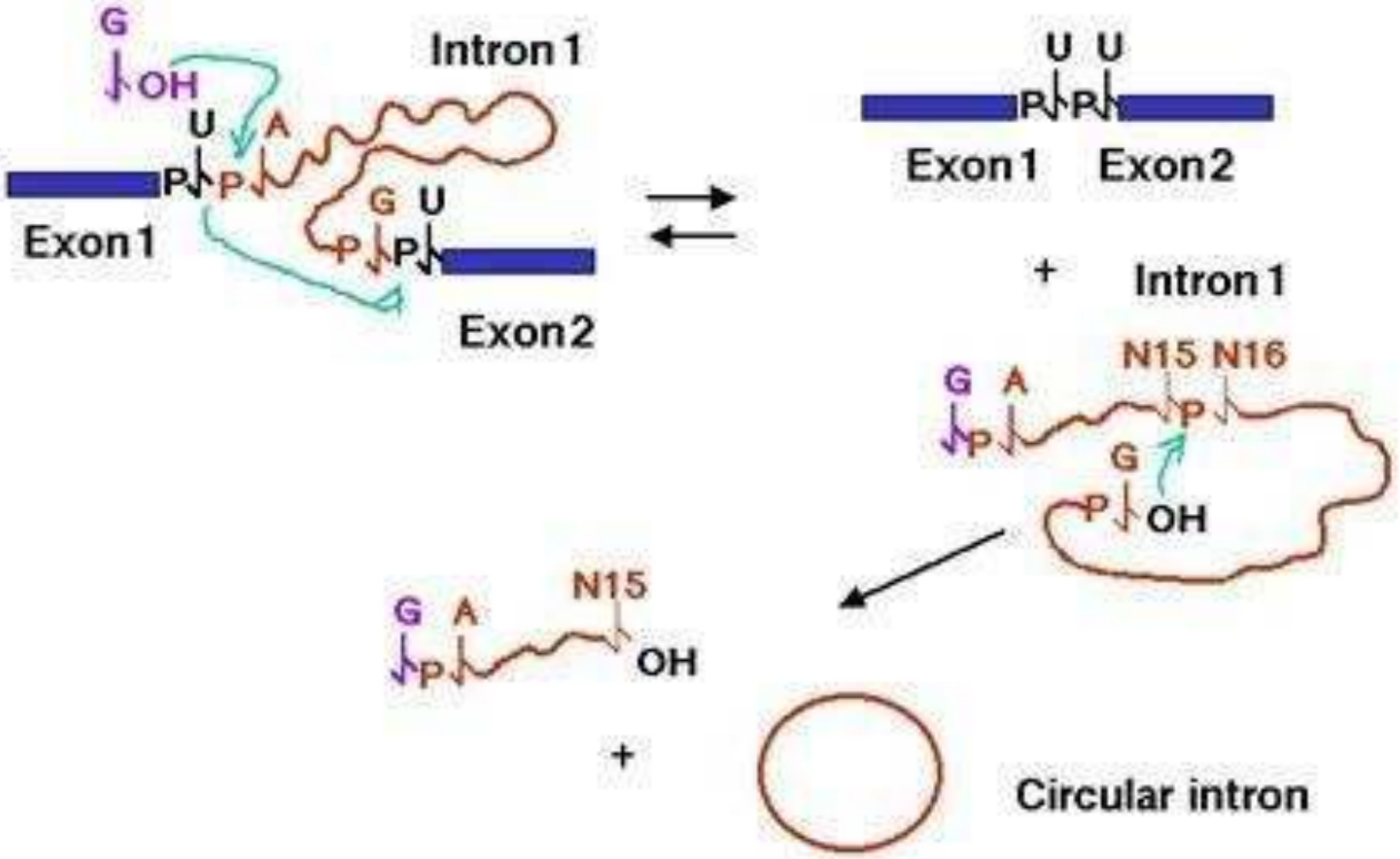
Search for Self-Replicating Molecule

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

Self-splicing by a phosphoester transfer mechanism

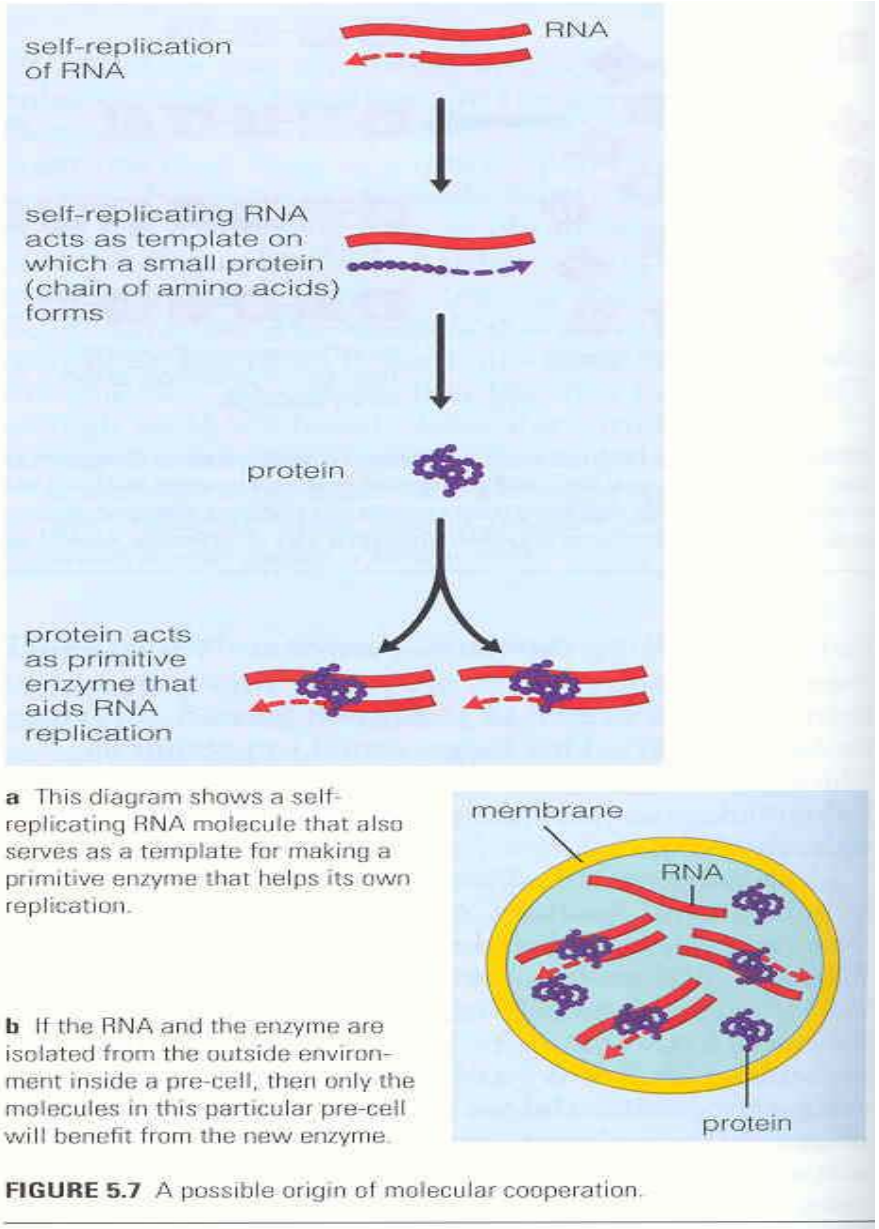


Assembling Complex Organic Molecules

- *Organic soup was too dilute to favor the creation of complex organic molecules*
- Lab experiment with possible solution: When hot sand, clay or rock is placed in dilute organic solution, complex molecules self-assemble
  - Organic molecules stick to surface of clay
  - Increases density and likelihood of reactions
  - Strands of RNA up to 100 bases have been produced this way

Early Cell-like Structures

- Advantages to enclosing enzymes with RNA molecules
- Close proximity increases rate of reactions between them
- Isolate contents from outside world



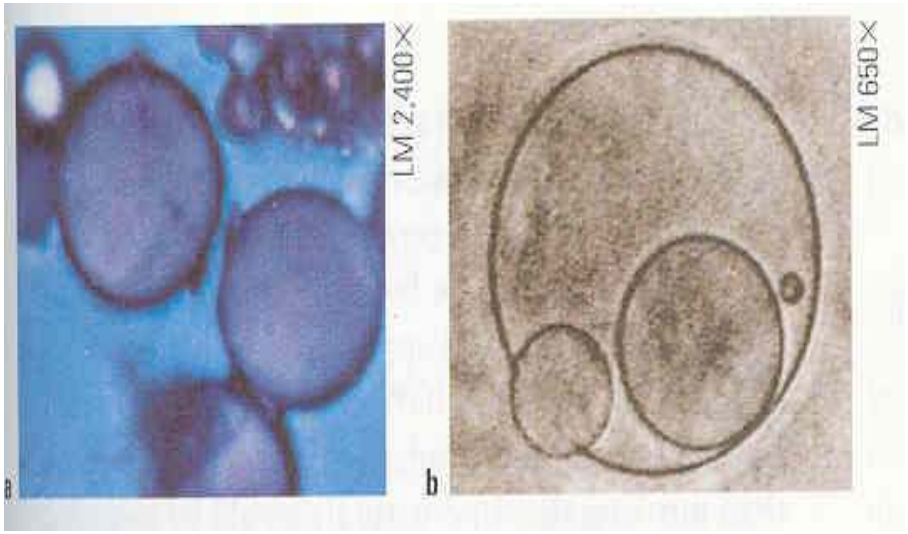
a This diagram shows a self-replicating RNA molecule that also serves as a template for making a primitive enzyme that helps its own replication.

b If the RNA and the enzyme are isolated from the outside environment inside a pre-cell, then only the molecules in this particular pre-cell will benefit from the new enzyme.

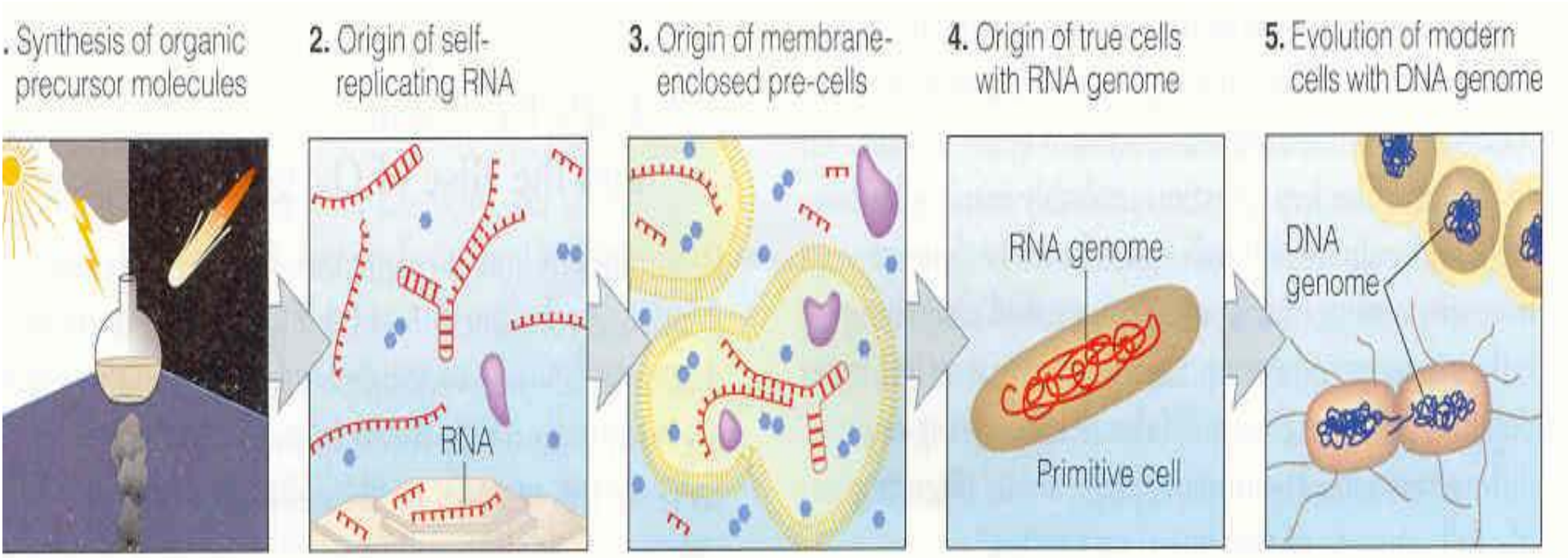
FIGURE 5.7 A possible origin of molecular cooperation.

Nonliving Pre-Cells have Lifelike Behavior

- Grow in size until unstable then split to form a 'daughter' cell
- Selectively allow other types of molecules to pass in/out of membrane
- Store energy in the form of electric voltage



A Summary


. Synthesis of organic precursor molecules
2. Origin of self-replicating RNA
3. Origin of membrane-enclosed pre-cells
4. Origin of true cells with RNA genome
5. Evolution of modern cells with DNA genome
RNA
RNA genome
Primitive cell
DNA genome

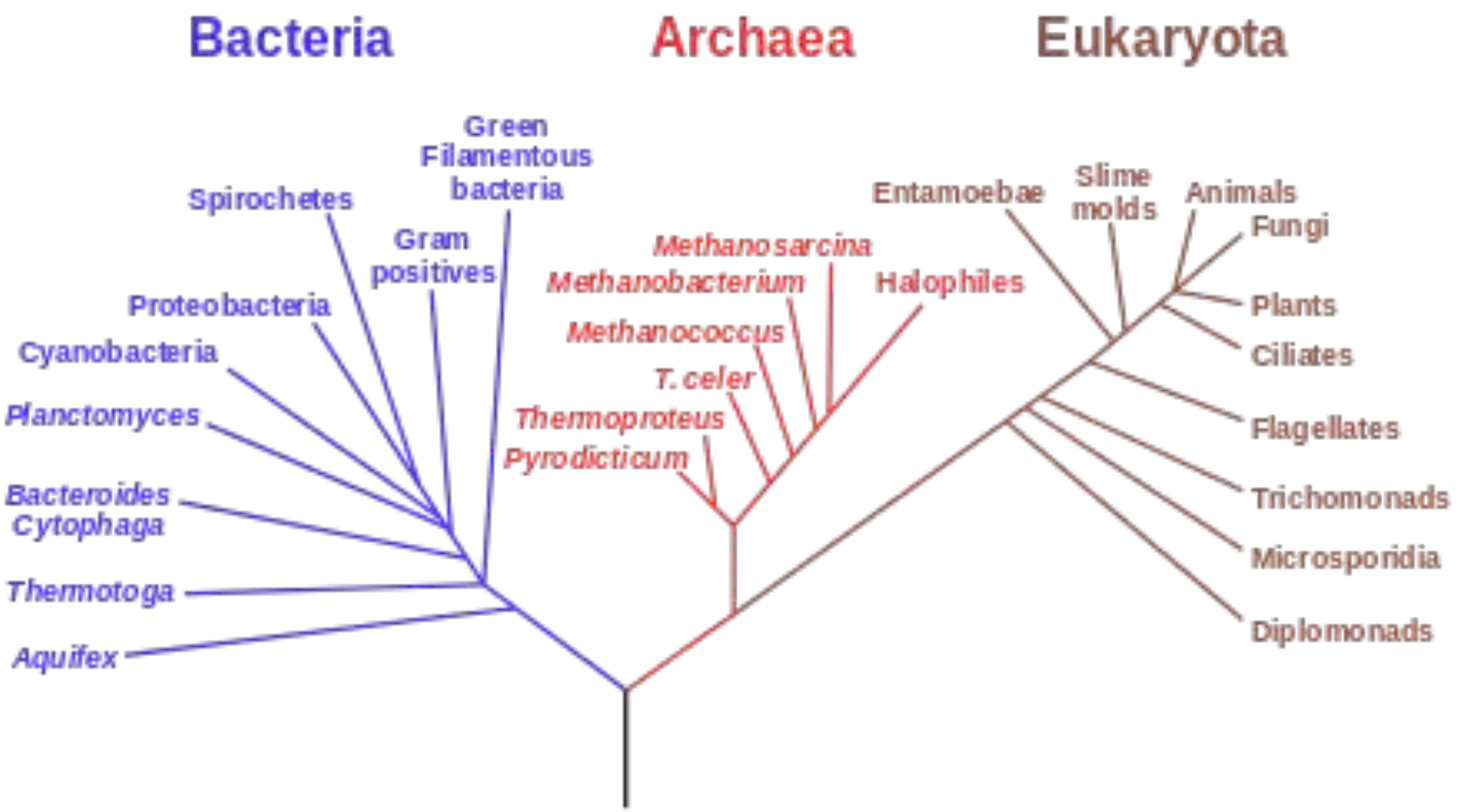
Early Evolution

- Natural selection probably resulted in rapid diversification
- Modern DNA has enzymes that reduce the rate of mutations
- RNA more likely to have copying errors
- Higher mutation rate in early evolution than now

Early Evolution and Rise of O_2

- First organisms had simple metabolism
- Atmosphere was O_2 free, must have been anaerobic
- Probably chemoheterotrophs
  - Obtained nutrients from organic material
  - Obtained nutrients from inorganic material
    - Modern archaea appear to be close to the root of the tree of life
    - Obtaining energy from chemical reactions involving hydrogen, sulfur and iron compounds (all abundant on early Earth)

Phylogenetic Tree of Life



Rise of O_2

- O_2 is highly reactive
- All initial O_2 would react with rock and minerals in water
- O_2 could not accumulate in atmosphere until surface rock was saturated
- Rocks 2-3 billion year old show atmosphere had <1% of current amount of O_2
- Rock evidence suggests that O_2 amounts in atmosphere began to rise about 2.0 bill.Yr ago
- Clear evidence of O_2 near current levels appears only 200 million yr ago
  - Indicates enough O_2 in atmosphere for fires to burn

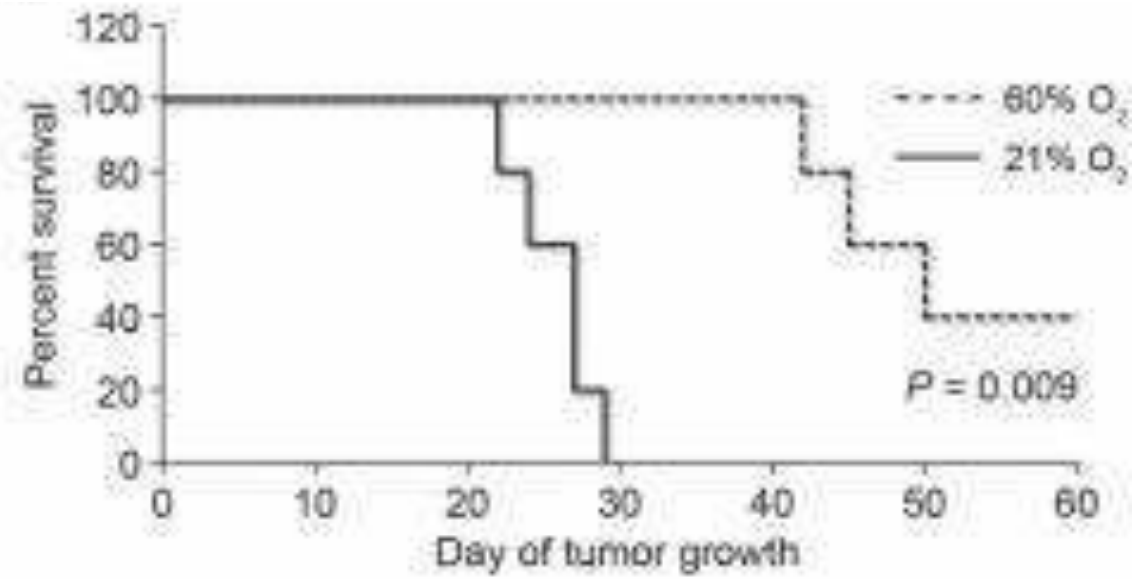

oxidation

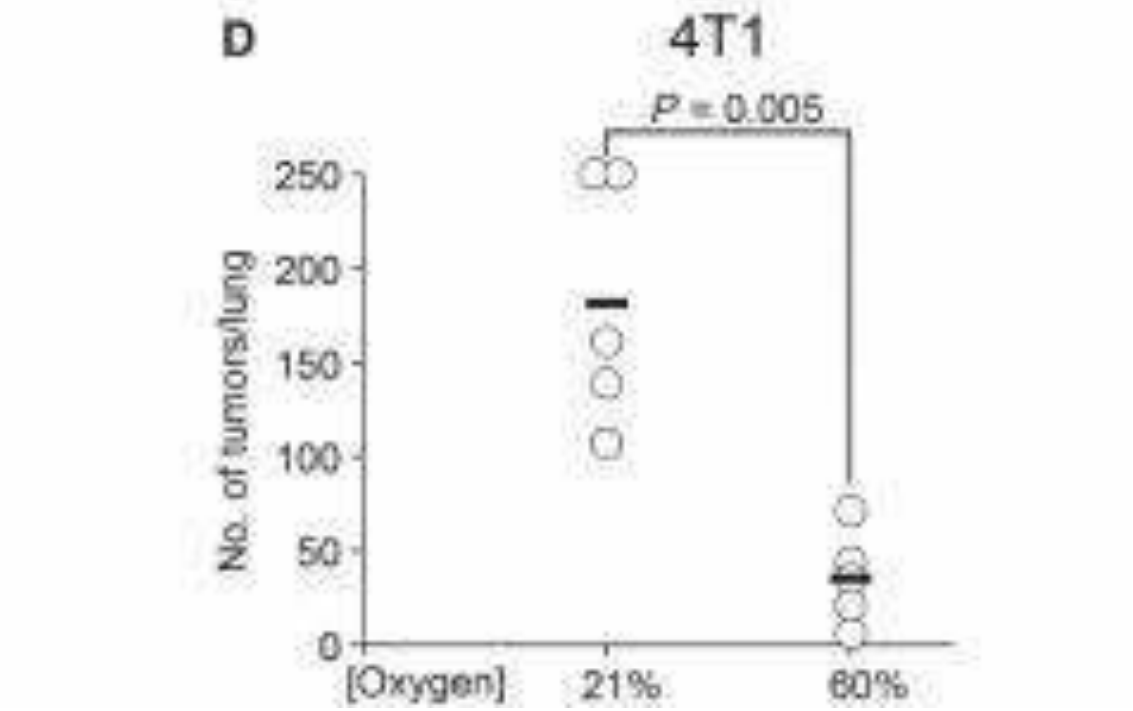
Rise of O_2

- Rise of O_2 would have created a crisis for life
- O_2 reacts with bonds of organic materials
- Surviving species avoided effects of O_2 because they lived or migrated to underground locations
  - Many anaerobic microbes found in such locales today

Hatfield S, Kjaergaard J, Lukashev D, Schreiber T, Belikoff B, Abbot R. "Immunological mechanisms of the antitumor effects of supplemental oxygenation." *Science Translational Medicine*, 2015.

Oxygen kills rapidly dividing cells

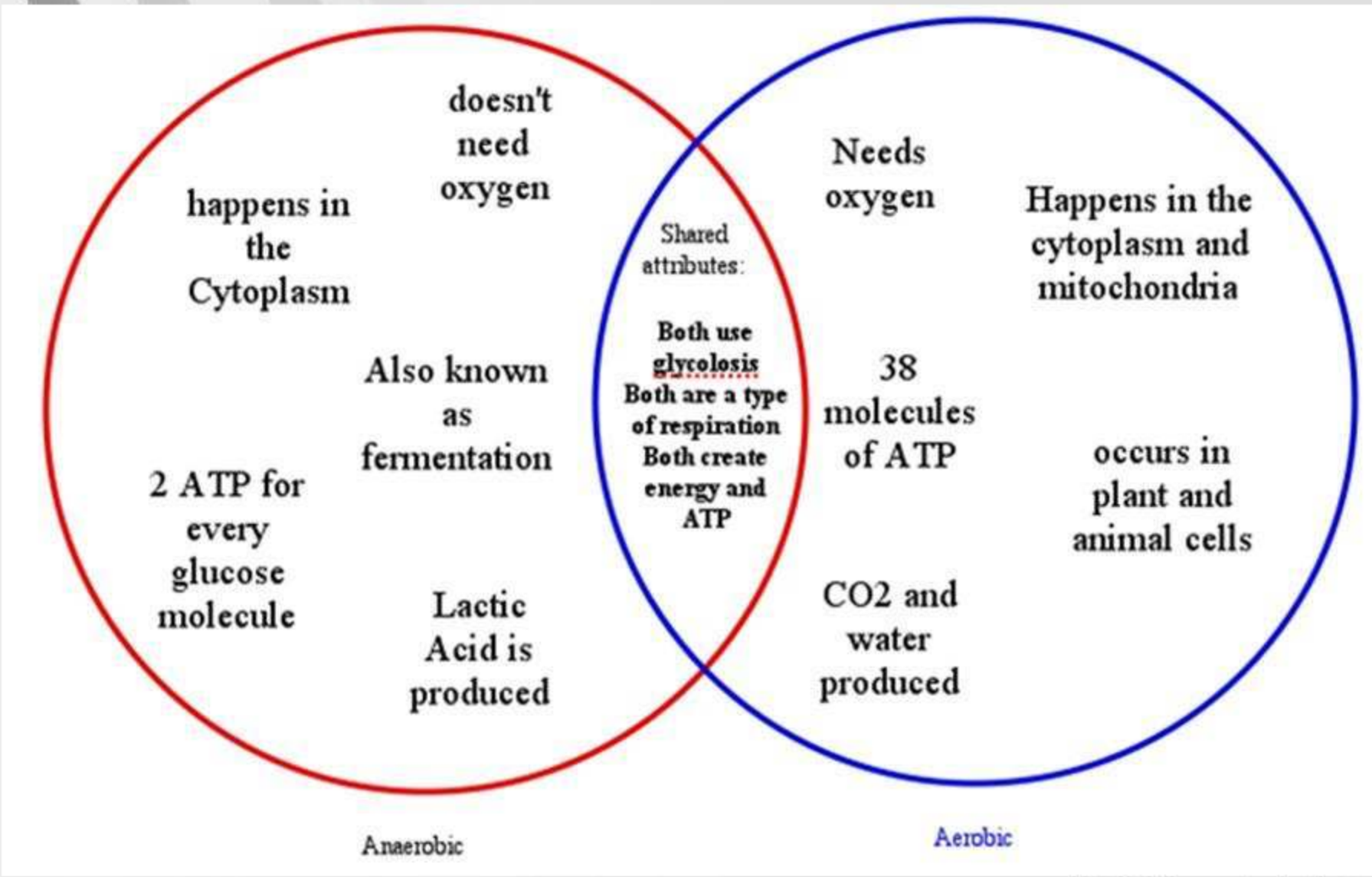


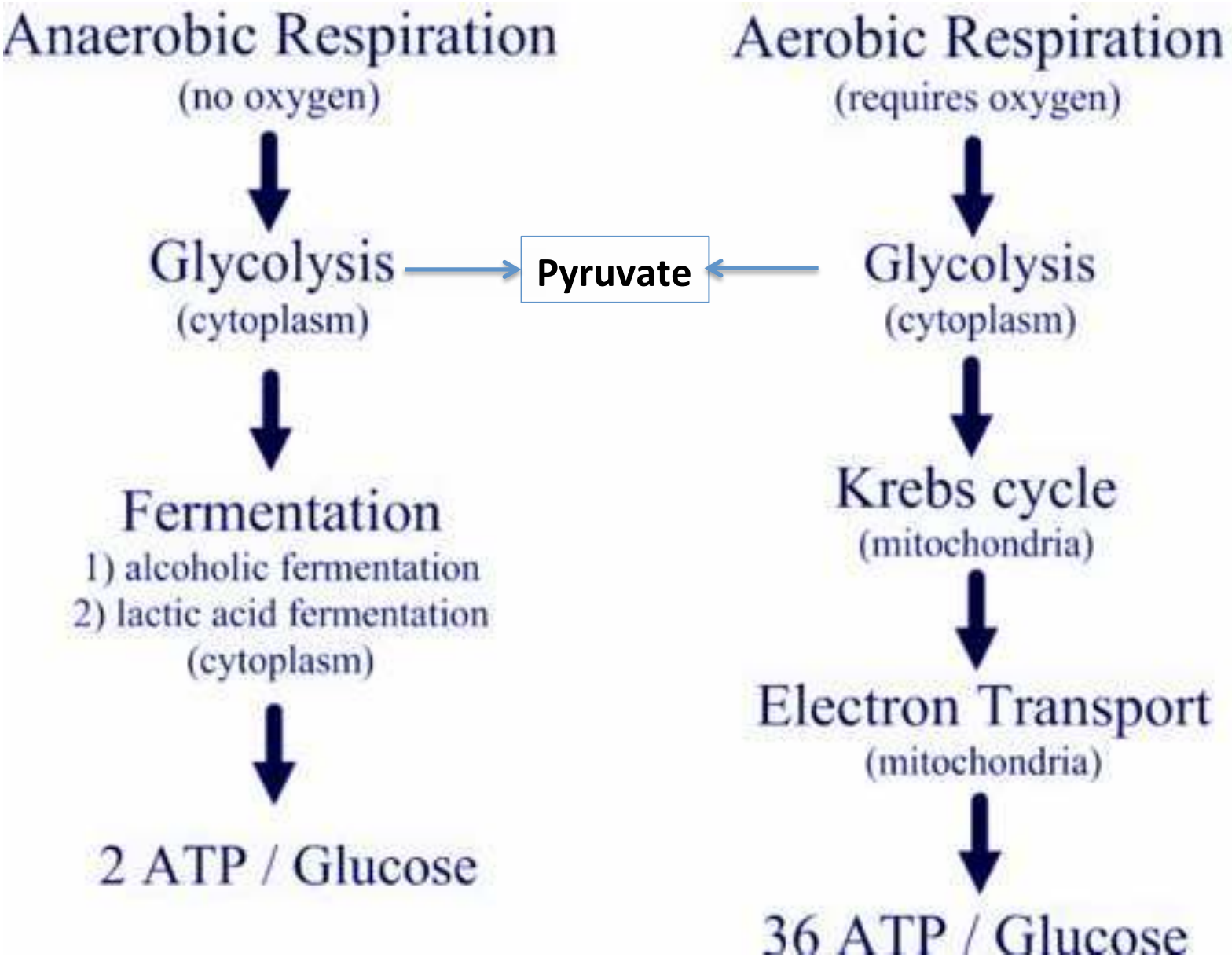


Early Eukaryotes

- Fossil evidence dates to 2.1 bill.Yr ago
- Dates to when O_2 rising in atmosphere
- DNA evidence suggests that prokaryotes and eukaryotes separated from common ancestor much earlier
- O_2 played a key role in eukaryote evolution
  - Cells can produce energy more efficiently using aerobic metabolism (38ATP) than anaerobic metabolism (2ATP)
  - Adaptations of aerobic organisms could develop adaptations that required more energy than would be available for anaerobic organisms

Comparison between Aerobic & Anaerobic Respiration -Animals

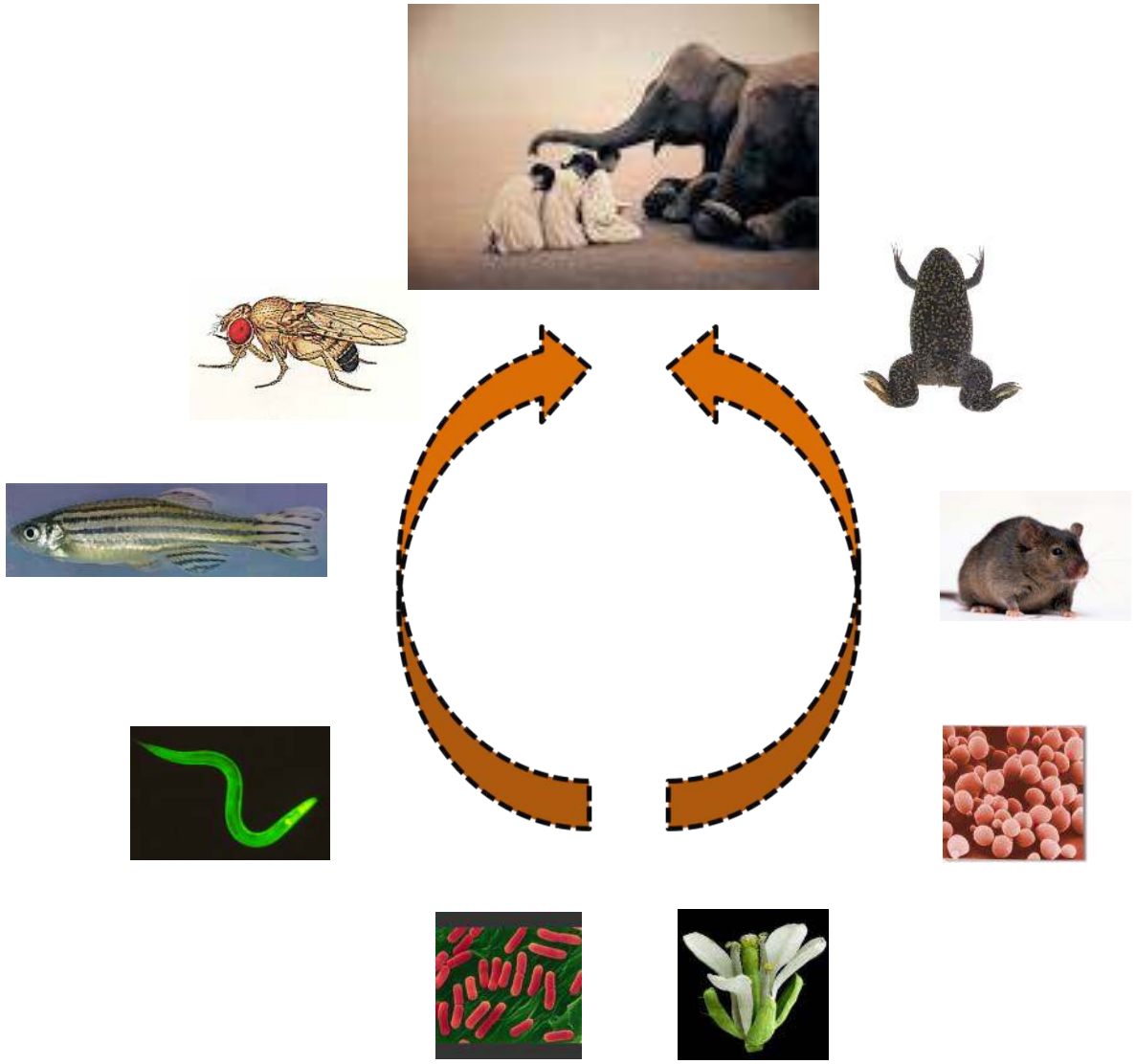



Anaerobic Respiration
(no oxygen)
Glycolysis
(cytoplasm)
Fermentation
1) alcoholic fermentation
2) lactic acid fermentation
(cytoplasm)
2 ATP / Glucose
Pyruvate
Aerobic Respiration
(requires oxygen)
Glycolysis
(cytoplasm)
Krebs cycle
(mitochondria)
Electron Transport
(mitochondria)
36 ATP / Glucose


Explosion of Life!

Current Models that are used for biological investigations

- Drosophila
- Xenopus
- Zebrafish
- Mouse
- C. elegans
- Yeast
- E. coli
- Arabidopsis



The Cambrian Explosion

The Cambrian Explosion is the supposed explosion of life in which only a few simple organisms immediately burst into a immense variety of more complex organisms. This was also a point in time when many organisms went extinct. The evidence and basis for this idea is that there are simpler fossils in the lower rock layers and in just a few layers above these there is a large variety of complex life forms fossilized in the higher Cambrian layers

- Animal branch of the tree of life
- Different classifications based on body plan
- All known body plans made appearance in fossil record in a time span of 40 million years
  - <1% of Earth's age
  - Animal diversity began 545 mill.Yr ago

Colonization of Land

- Life flourished where liquid water exist
- Life on land was more complicated
  - Had to develop means of collecting solar energy above ground and nutrients below
- Life in shallow ponds or edges of lakes
  - Water evaporates
  - Natural selection favored that which could withstand periods of drought
- DNA evidence suggests that plants evolved from an algae
- It took only 75 mill. Yrs for animals to follow plants out of water

Emergence of Humans

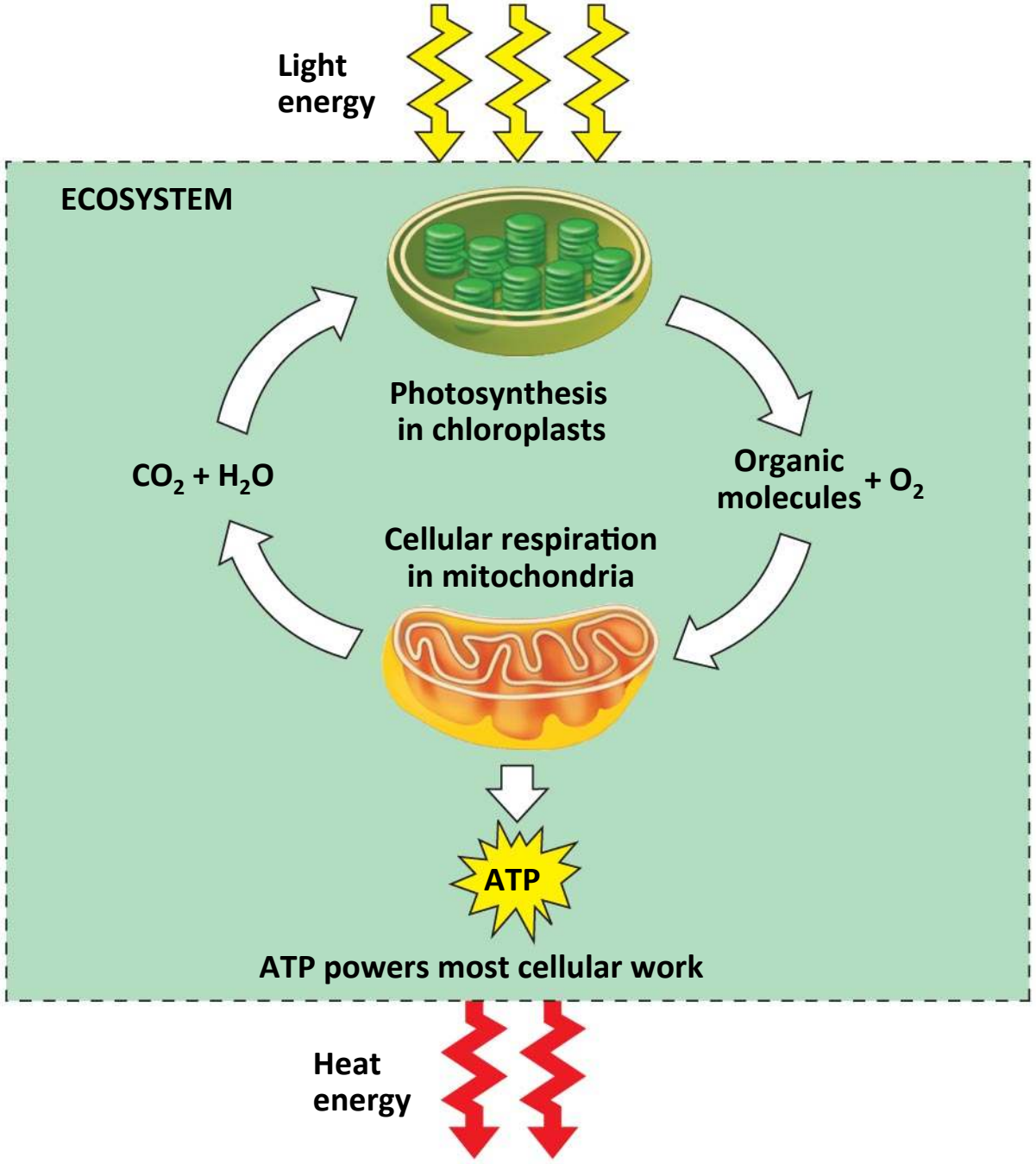
- Did NOT evolve from gorillas or monkeys
- Share a common ancestor that lived just a few million years ago
- 98% of human genome is identical to genome of the chimpanzee
- 2% difference in genome separates the success of humans verses chimps
  - Also indicates evolution of intelligence is complex

Cellular Respiration: Harvesting Chemical Energy

(Living cells require energy from outside sources)

- Energy flows into an ecosystem as sunlight and leaves as heat
- Photosynthesis generates O_2 and organic molecules, which are used in cellular respiration
- Cells use chemical energy stored in organic molecules to regenerate ATP, which powers work

Fig. 9-2



Catabolic Pathways and Production of ATP

- The breakdown of organic molecules is exergonic
- **Fermentation** is a partial degradation of sugars that occurs without O_2
- **Aerobic respiration** consumes organic molecules and O_2 and yields ATP
- Anaerobic respiration is similar to aerobic respiration but consumes compounds other than O_2

- **Cellular respiration** includes both aerobic and anaerobic respiration but is often used to refer to aerobic respiration
- Although carbohydrates, fats, and proteins are all consumed as fuel, it is helpful to trace cellular respiration with the sugar glucose:

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{Energy (ATP + heat)}$