BIOLOGICAL CHEMISTRY I (BIOL 157)

Lecturer: **Christopher Larbie, *PhD***

Lecture 2:

Evolution of Living Organisms

OBJECTIVES

- In this lecture, the following would be learnt:
  - Definition of Life
  - Life is not possible on all planets.
  - An account of the various ideas about the origin of life.
  - The simplest structure within which life is invested is a cell with a well defined boundary

Various views on origin of life

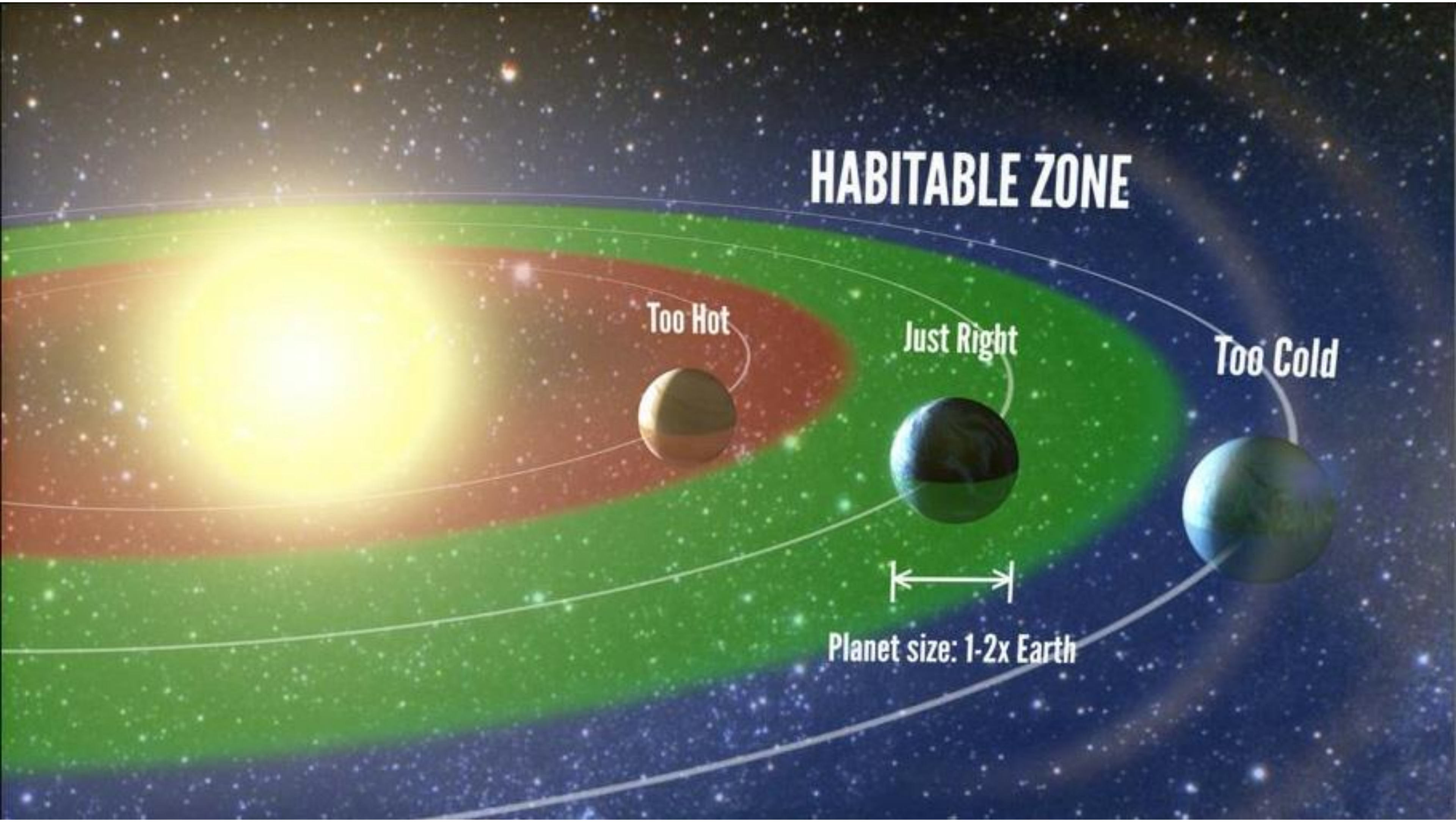
- Life is a process which is capable of self-sustenance, replication and mutation.
    - Self-sustenance ensures that some damage or loss of material may occur, and these have to be made up for.
    - Replication is to ensure the continuity of life so that it does not become extinct.
    - Mutation permits the emerging progeny to change under the pressure of natural selection in order to compete efficiently for matter and energy in an increasingly changing environment.

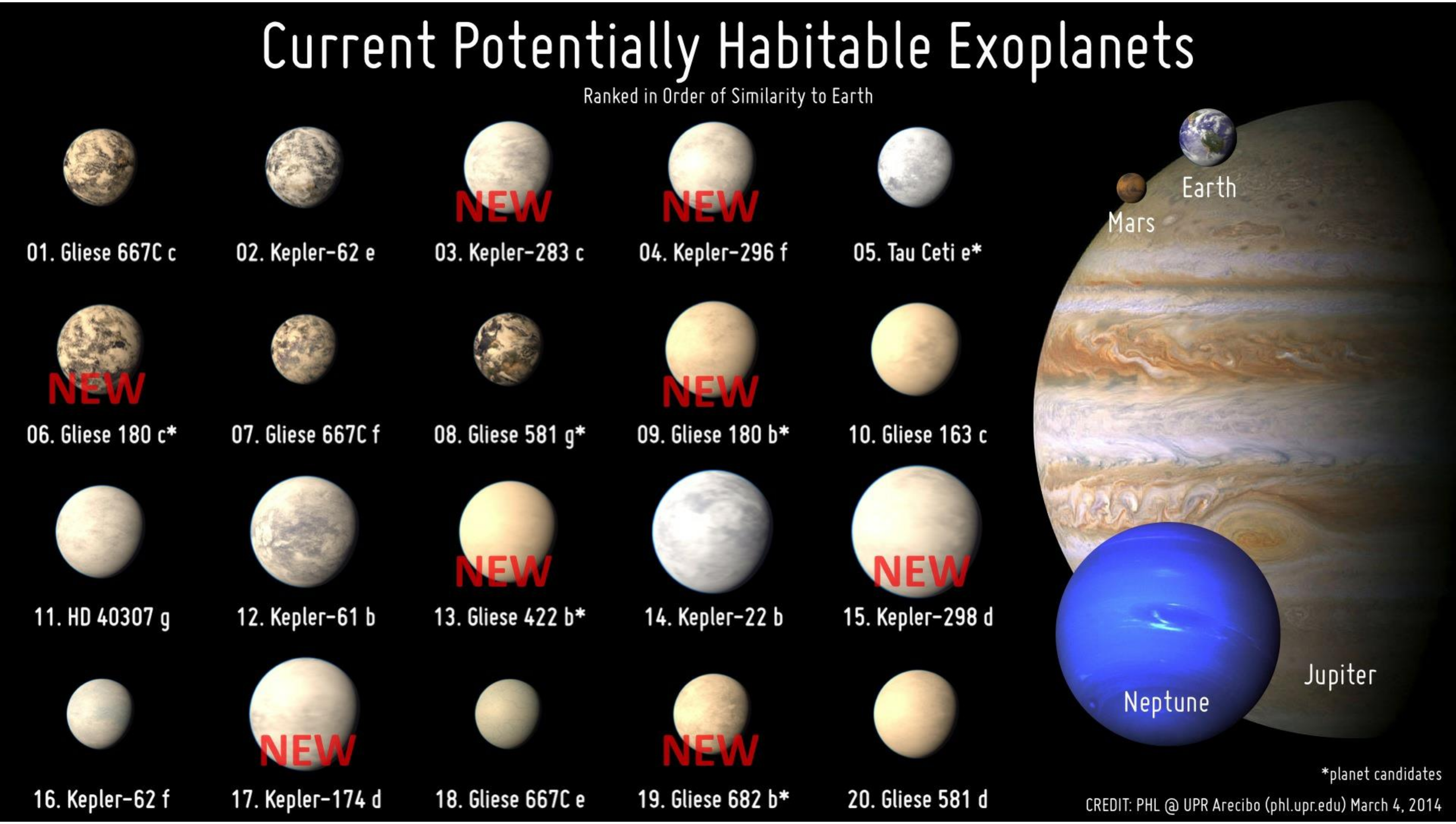
Is life possible on all planets?

- Life does not occur on all planets because conditions in most of the planets do not support life.

- Conditions on the planet earth are right for the occurrence, sustenance and perpetuation of life.
  - The presence of moisture, air and suitable temperatures are just the right conditions for life.

Habitable zones of the milky way





Current Potentially Habitable Exoplanets
Ranked in Order of Similarity to Earth
NEW
01. Gliese 667C c
02. Kepler-62 e
03. Kepler-283 c
04. Kepler-296 f
05. Tau Ceti e*
06. Gliese 180 c*
07. Gliese 667C f
08. Gliese 581 g*
09. Gliese 180 b*
10. Gliese 163 c
11. HD 40307 g
12. Kepler-61 b
13. Gliese 422 b*
14. Kepler-22 b
15. Kepler-298 d
16. Kepler-62 f
17. Kepler-174 d
18. Gliese 667C e
19. Gliese 682 b*
20. Gliese 581 d
Earth
Mars
Jupiter
Neptune
*planet candidates
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) March 4, 2014

Views on the Origination of Life

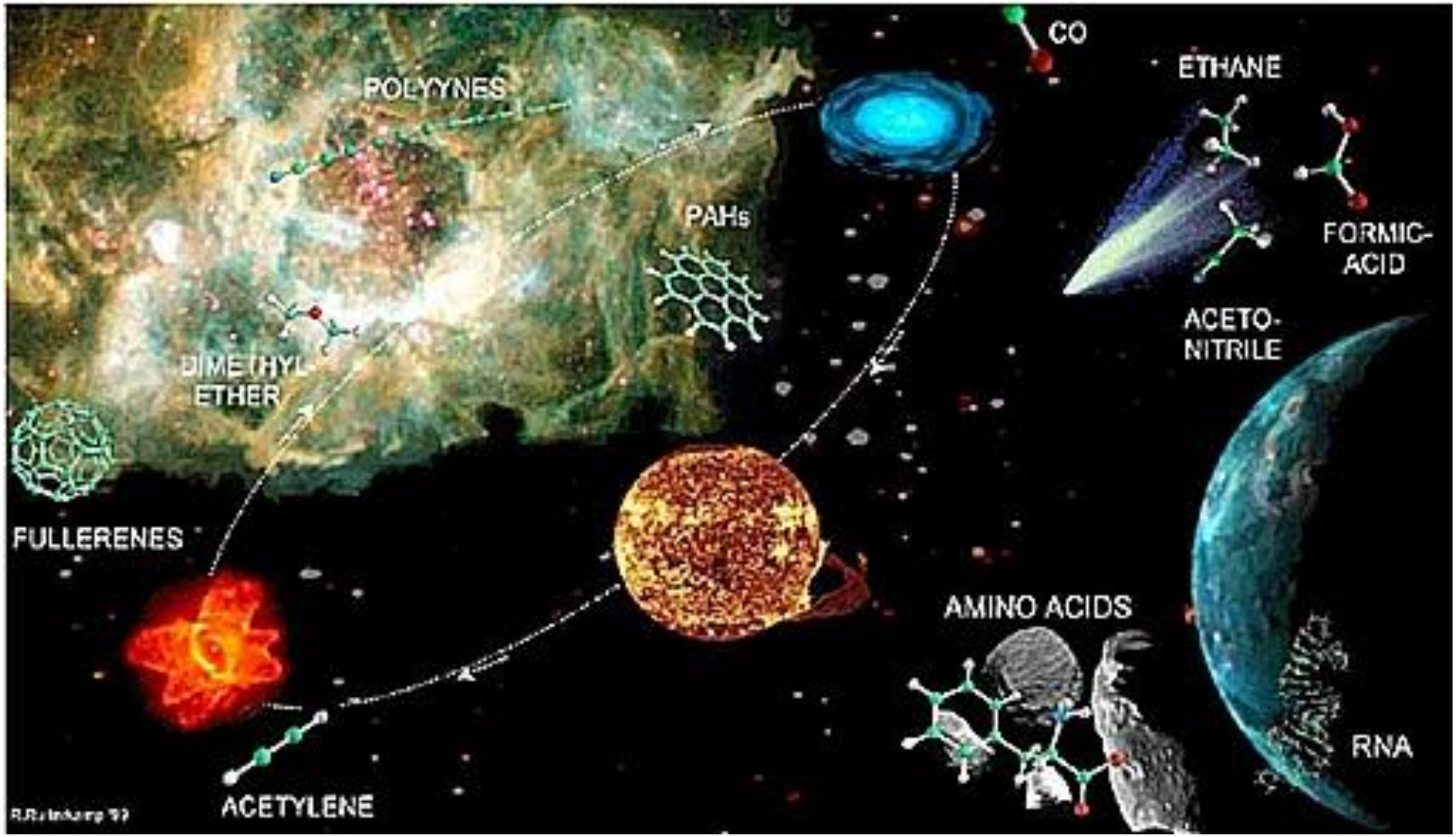
Special creation

- Life is so complex that it required a supernatural force to generate it.
  - This is the Christian, Moslem, and African traditionalist views.

- The problem some scientists have for this view is that it is mystical and cannot be proved.
  - It does not obey the natural laws.

Colonisation theory (Theory of Panspermia)

- Life might have arisen from some life forms that came from elsewhere in the universe.
  - It was suggested that life in the form of living spores could have been driven to the earth by the pressure of light from the star of another planetary system.
- Other scientists, like Francis Crick and Leslie Orgel proposed that
  - the transport of life from elsewhere might have been directed by some intelligent forces.
- The colonization theory can neither be proven nor refitted since it begs the question as to the origin of life.
- The colonization theory espouses the extra-terrestrial origin of life.



CO
ETHANE
POLYYNES
PAHs
FORMIC-
ACID
ACETO-
NITRILE
DIMETHYL
ETHER
FULLERENES
AMINO ACIDS
RNA
ACETYLENE

Spontaneous generation theory

- This theory asserts that life arose abiogenically.
  - Aristotle (384-322 BC) had suggested that when soil, straw or refuse that was free of life was left for a period of time, living organisms could emerge from them spontaneously if condition were right.
  - Van Velmont (1577 - 1644), a Dutch Scientist supported it.

- The first blow to the spontaneous generation idea was from the work of Francesco Redi (1626-1697).

- The invention of microscope by Anton van Leeuwenhoek in 1675 paved the way for the study of Spontaneous generation of microbial life.

- Needham and Buffon - mutton broth is heated to boiling, it could still support the growth of microbes.
  - Lazzaro Spallanzani (1729-1799) detected loopholes in the experimental set-up of Needhan and Buffon.
- Louis Pasteur (1822-1895) was the person who gave the last blow to the spontaneous generation idea.
  - He showed that air was a suspension of microbes that could infest sterile broths.

Long-term spontaneous generation

- In the twentieth century, two prominent scientists; JBS Haldane, a British Biochemist and AL Oparin, a Russian Biochemist suggested that life once evolved from non-living matter.
  - In the period for the chemical evolution, raw materials present on the primitive earth were used to synthesize both monomers and macromolecules for living cells.
  - The raw materials were readily available together with the suitable energy sources.

- The largest source of energy was sunlight.
- Another source of energy was electrical discharges from lightning.

- The major starting materials for prebiotic synthesis came from the atmosphere.

- Simple molecules present in the primitive atmosphere included hydrogen, methane, water vapour, ammonia and probably hydrogen sulphide.

- The earth crust contained metallic sulphide and mineral phosphates. It is also possible that the raw materials could have been transported to the earth by extraterrestrial bodies like meteors and comets.

- The carbonaceous meteorites contain organic molecules like those contained in biological molecules, for example, alcohols, aldehydes, amines, amino acids, purines, pyrimidines, etc.

- Some meteorites also contain clays.

- Comets also could have served as good sources of carbon, hydrogen and nitrogen compounds on the primitive earth.
-
- Comets are heavenly luminous bodies with gaseous tails.
  - Those comets, with irregular orbits could collide with the earth, depositing their contents on the earth.

Chemical and Biological evolution

- Chemical evolution refers to the formation of complex organic molecules from simple molecules.
- Biological evolution is the formation of a self-sustaining, self-replicating system from the complex organic molecules.
- We can identify the following steps in chemical and biological evolution:
  - Formation of biologically important monomers like sugars, amino acids, organic bases etc from simple compounds like CH_4, NH_3, H_2O.
  - Polymerization of the monomers into biopolymers like proteins and nucleic acids.
  - Aggregation of biopolymers into prototypes of cells.
  - Development of some type of reproductive machinery to ensure that progeny cells possess all the metabolic potentials of the parent cell.

Primitive earth simulation experiment (by Stanley Miller)

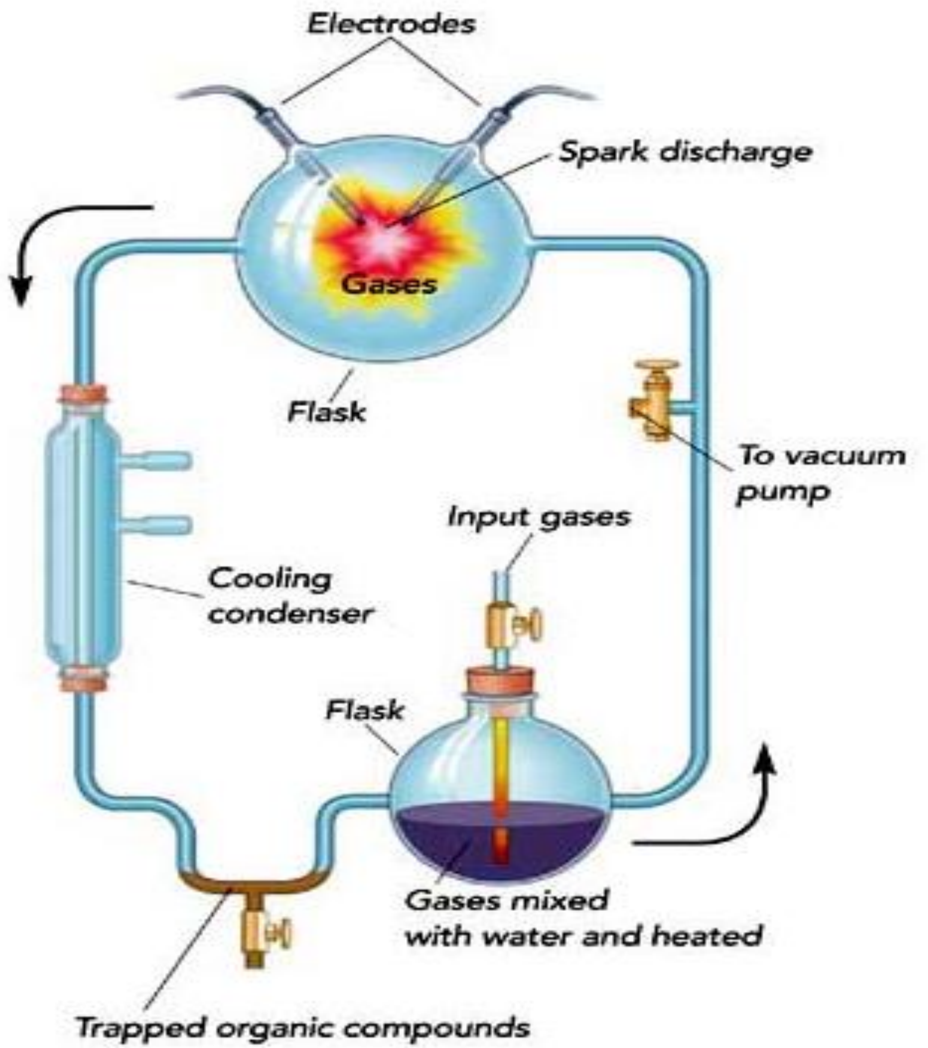
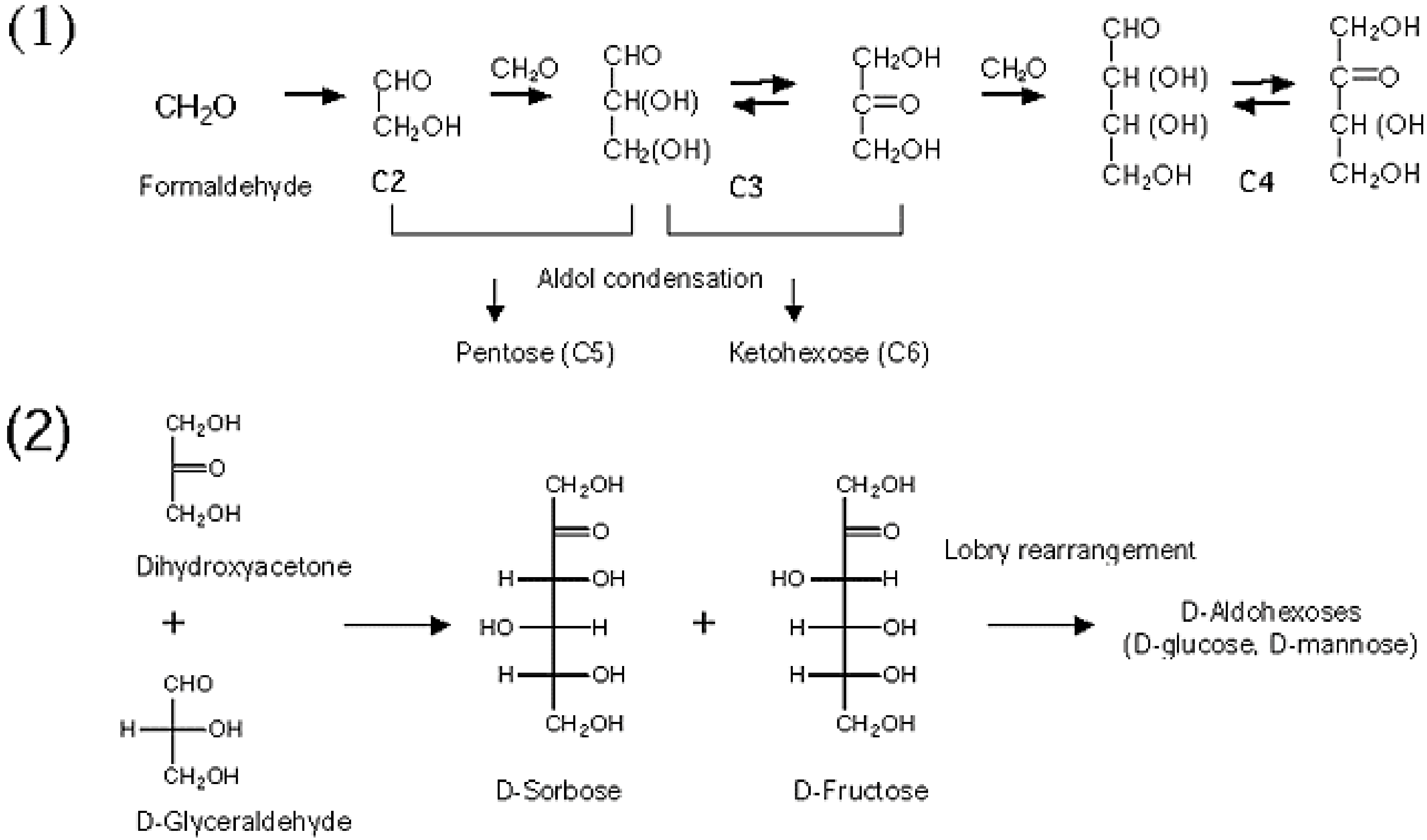


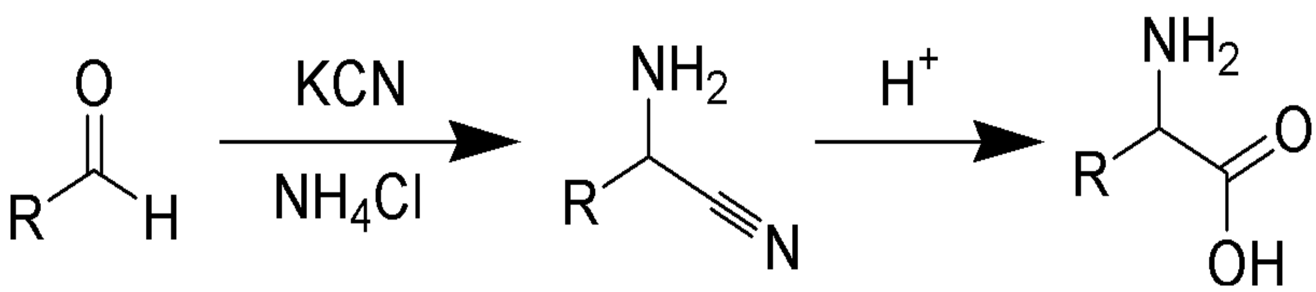
Fig 1: Experimental set-up by Miller to prove the synthesis of some biologically useful molecules in the presence of molecules in the atmosphere and energy sources available.

The prebiotic synthesis of monosaccharides (formose reaction)

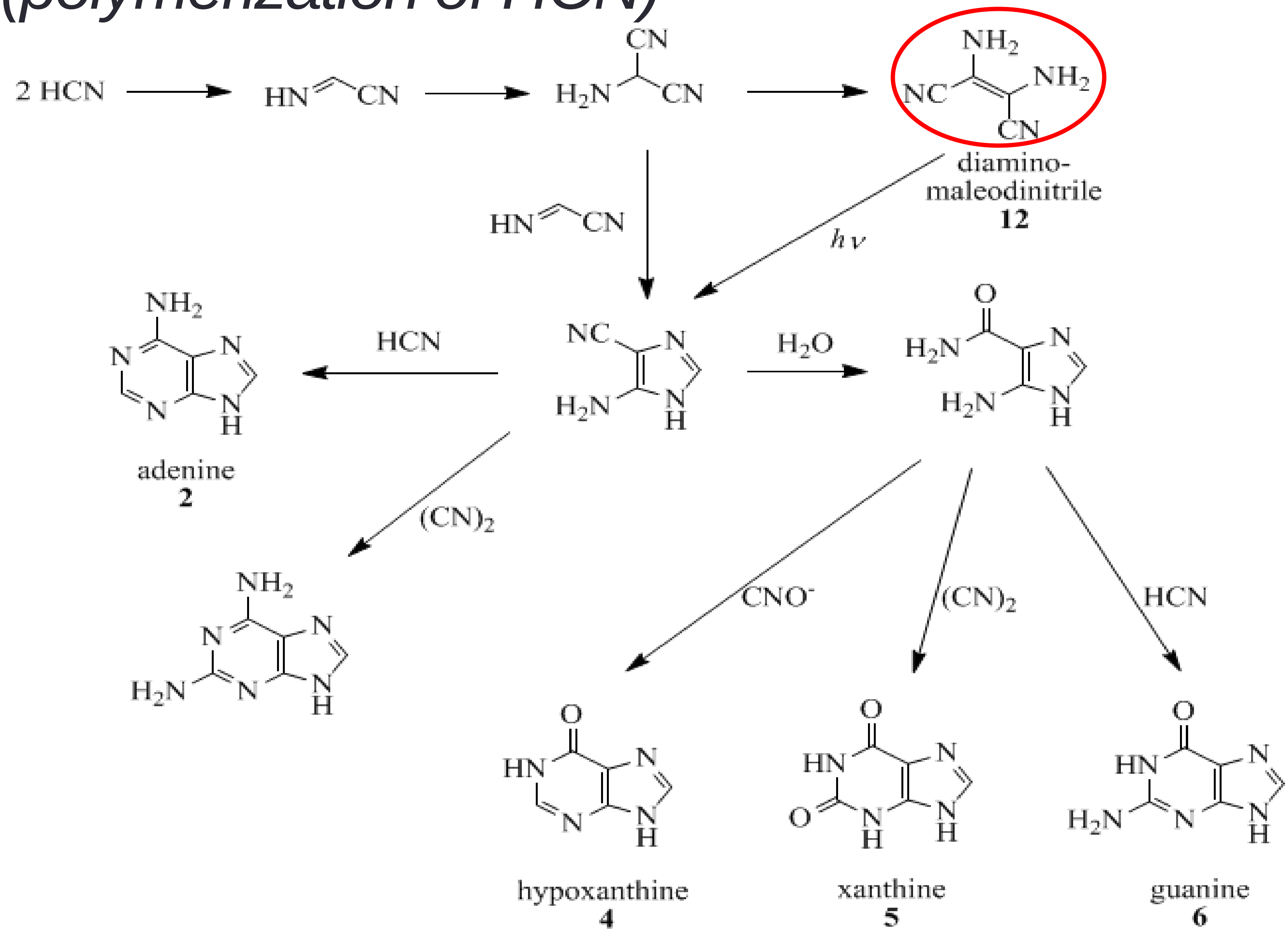


The prebiotic synthesis of amino acids (Strecker synthesis)

- Amino acids could have been formed through the Strecker synthesis in which an aldehyde reacted with HCN.
- The Strecker synthesis is made up of the following steps;
  - Ammonia reacts with an aldehyde to form an imine
  - The addition of a cyanide to the imine
  - Hydrolysis of the aminonitrile to give the corresponding amino acid.



The prebiotic synthesis of nucleotide bases
(polymerization of HCN)



The prebiotic synthesis of fatty acids

- High temperature and high hydrogen pressures were required for the synthesis of fatty acids.

- The problem with the suggested mode of fatty acid formation is that the elevated temperature for the synthesis could not have been attained in the primitive times over an extended period.

Why the primitive atmosphere was said to be reducing

- There was little or no oxygen present, so there was no ozone layer to block the UV radiation from sunlight as occurs now.

- The matter from which the earth was formed was mostly hydrogen, a good reductant.

- Meteorites contain iron either as metallic Fe or Fe^{2+}.

- Carbon was also present as elemental carbon, carbides or hydrocarbons.

Prebiotic soup

- The biologically important compounds formed, due to the absence of oxygen in the atmosphere were spared any oxidative alteration.

- So these could persist and be washed by rain into the oceans for their concentrations to build up forming the prebiotic or primerval soup or Haldane’s soup.

- Watch this video: www.youtube.com/watch?v=j3eTJuUdfds.

Polymerization and condensing agents

- Polymerization is the coming together of several monomers to form more complex molecules.
- Through such a process polypeptides, polynucleolides and polysaccharides could be formed.
- If two molecules of glucose, for example, join together, the elements forming water should be removed from the two molecules.
- How could this be achieved in a prebiotic soup which is predominantly made up of water?
- Glucose + Glucose $\rightleftharpoons$ Disaccharide + H_2O

- The forward reaction is a condensation reaction but the backward reaction is hydrolytic.

- The condensation reaction would be thermodynamically favoured if the water formed by the condensation can be removed by evaporation or by the use of condensing agents.

- In the use of such condensing agents, there would be two advantages.
  - There is the formation of a high-energy intermediate, thereby shifting the equilibrium in favour of the condensation, allowing the reaction to take place in the aqueous medium.
  - Secondly, the intermediate formed is usually more reactive than the unmodified monomers.

- Therefore, the forward condensation reaction was coupled to uptake or the removed water by condensing agent.

- Such condensing agents typically had carbon atom linked by energetic double bonds to two nitrogen atoms (-N=C=N-) e.g. carbodiimide of the general formula, R-N=C=N-R.

- The free energy of hydration of the condensing agent drives the reaction.

- Other condensing agents in the prebiotic soup could have been cyanogen (N≡C-C≡N), cyanamide ($N \equiv CNH_2$), cyanoacetylene (N≡C-C≡CH) and diaminomaleonitrile.

- Polyphosphates like ATP could also be used as condensing agents.

- These polyphosphates were also energy sources used by living organisms.

Polypeptides and polynucleotides

- Various studies have gone into how two important biopolymers, polynucleotides and proteins were formed.
- The polymerization process per se might not have been the problem but the real problem was the competition by water molecules in the coupling process.
- One way of lowering the amount of water in the vicinity was through evaporation to concentrate the reactants while removing H_2O from the product
  - (what happens to other biological monomers like HCN, formaldehyde, NH_3, which are themselves volatile?)

- Another way of achieving polymerization was heating to dryness.
  - Critics argued that those high temperatures could not have existed over extended region of the earth’s surface.
  - A prolonged exposure to the high temperatures could cause the decomposition of the peptides formed.

- One other effective way for concentrating prebiological molecules was the adsorption of molecules on the surface of minerals like micahs, clays (made up of silicates attached to cations) and kaolin.
  - The abundance of positive and negative charges on clays, apart from binding charged molecules, also enabled them serve as primitive catalytic centres for reactions.

- There could be both non-instructed and template-directed synthesis of polypeptides and polynucleotides.

- **The non-instructed synthesis** of the two polymers could be achieved by dry heating or by the addition of a condensing agent such as a polyphosphate or cyanamide.

- **The template-directed synthesis** of polypeptides can be divided into two categories:
  - The synthesis of activated amino acids on a clay 'template' where no sequence preference is shown.
  - Synthesis that is directed by a nucleic acid template.

- Template-directed polynucleotide synthesis could use imidazole-activated monomers in the presence of divalent cations.

- Which of the two is more primitive; protein or nucleic acids?

- Proteins have structural and catalytic functions while the nucleic acids are informational molecules.

- Nucleotides also serve as coenzymes, aiding catalytic action of enzymes (e.g. ribozyme).

- A more plausible reasoning is that proteins and nucleic acids evolved in parallel.

- The ability of polynucleotide to replicate could be coupled to the ability of polypeptide to act a catalyst.

- The polynucleotide could specify polypeptide by a process of translation, while the polypeptide in turn, would catalyse the replication of the polynucleotide and possibly the translation process.

- The discovery of ribozyme (RNA enzyme) has added another dimension.

- It is now being argued that ribozyme originated before translation systems.

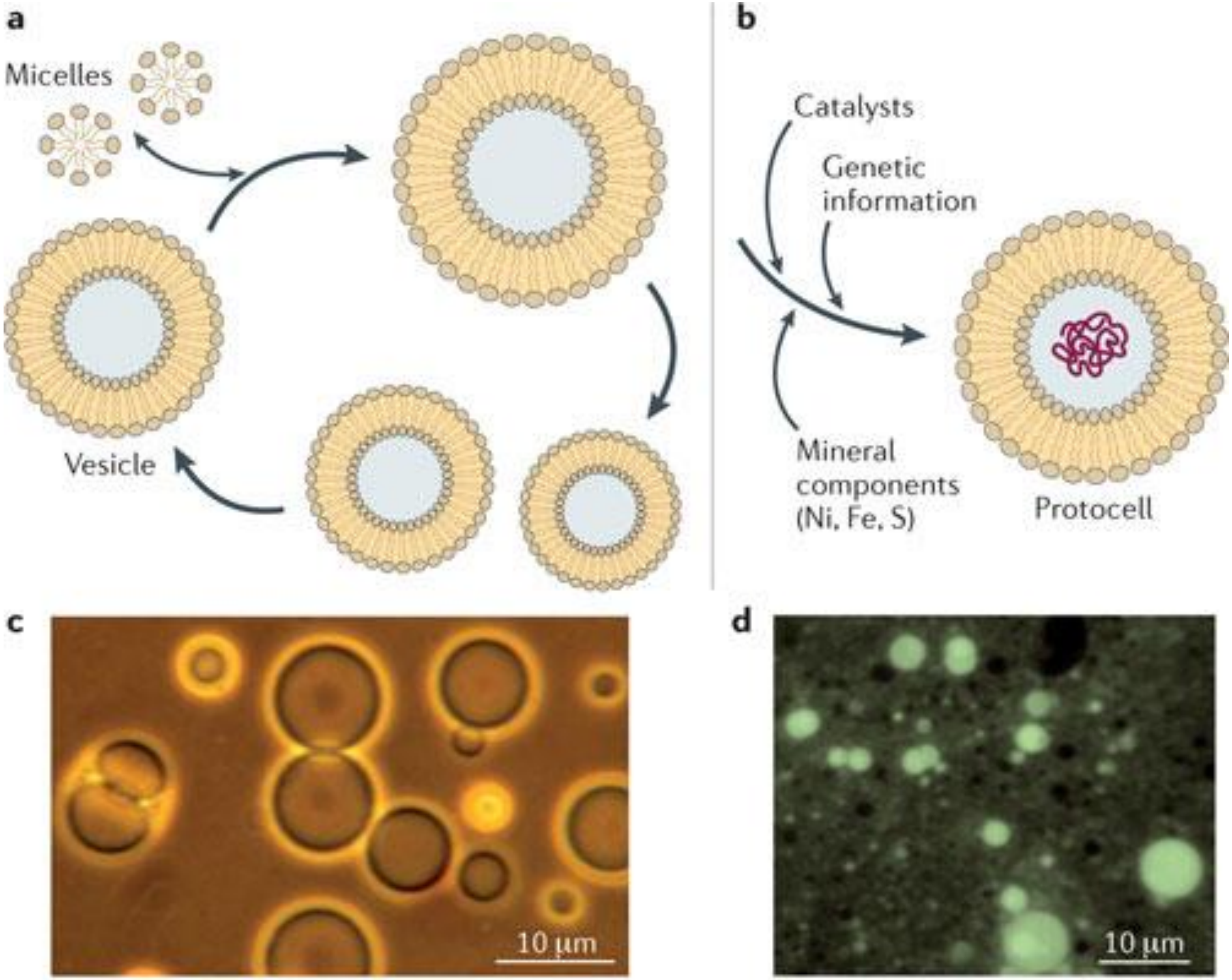
- It was after translation to form protein enzymes that the majority of ribozymes were replaced by more efficient protein enzymes.

Formation of cells and membranes

- The simplest structure that shows the evidence of life is a cell.

- A cell is a compartment, and should have a membrane to separate it from its surroundings so that it is not diluted out of existence.
  - Oparin and Fox independent investigations
  - Oparin suggested that the first cells emerged when a boundary or membrane formed around some molecules possessing catalytic activity, most probably proteins.
  - He called his ‘cells’ protobionts.
  - The protobionts were formed through a process of coacervation.

- This phenomenon takes place in an aqueous solution of highly hydrated polymers.
- It involves the spontaneous separation of one phase of aqueous solution of polymers into two phases;
  - one phase having higher polymer concentration,
  - and the other phase with low polymer concentration.
- The droplets could interact with their aqueous environment to acquire other compounds to make the droplets grow.
- Some of the resulting progeny droplets which retain catalyst-substrate nature of parent droplet, could grow to give another generation of droplet.


a
Micelles
Vesicle
b
Catalysts
Genetic information
Mineral components (Ni, Fe, S)
Protocell
c
10 μm
d
10 μm

- The shortcoming of Oparin's coacervate droplets is that they were formed from materials such as gum arabic, histone and albumin which had already been formed by living systems.

- Fox's thermal proteinoids were another type of micro-spheroidal aggregates.
  - Under suitable conditions, the proteinoids form microspheres several micrometres in diameter which grow and eventually bud.
  - These microspheres have a two-layer membrane similar to that of bacteria.

  - The problem with the membranes of Fox's proteinoids was that they were too leaky.

Development of Metabolic Pathways

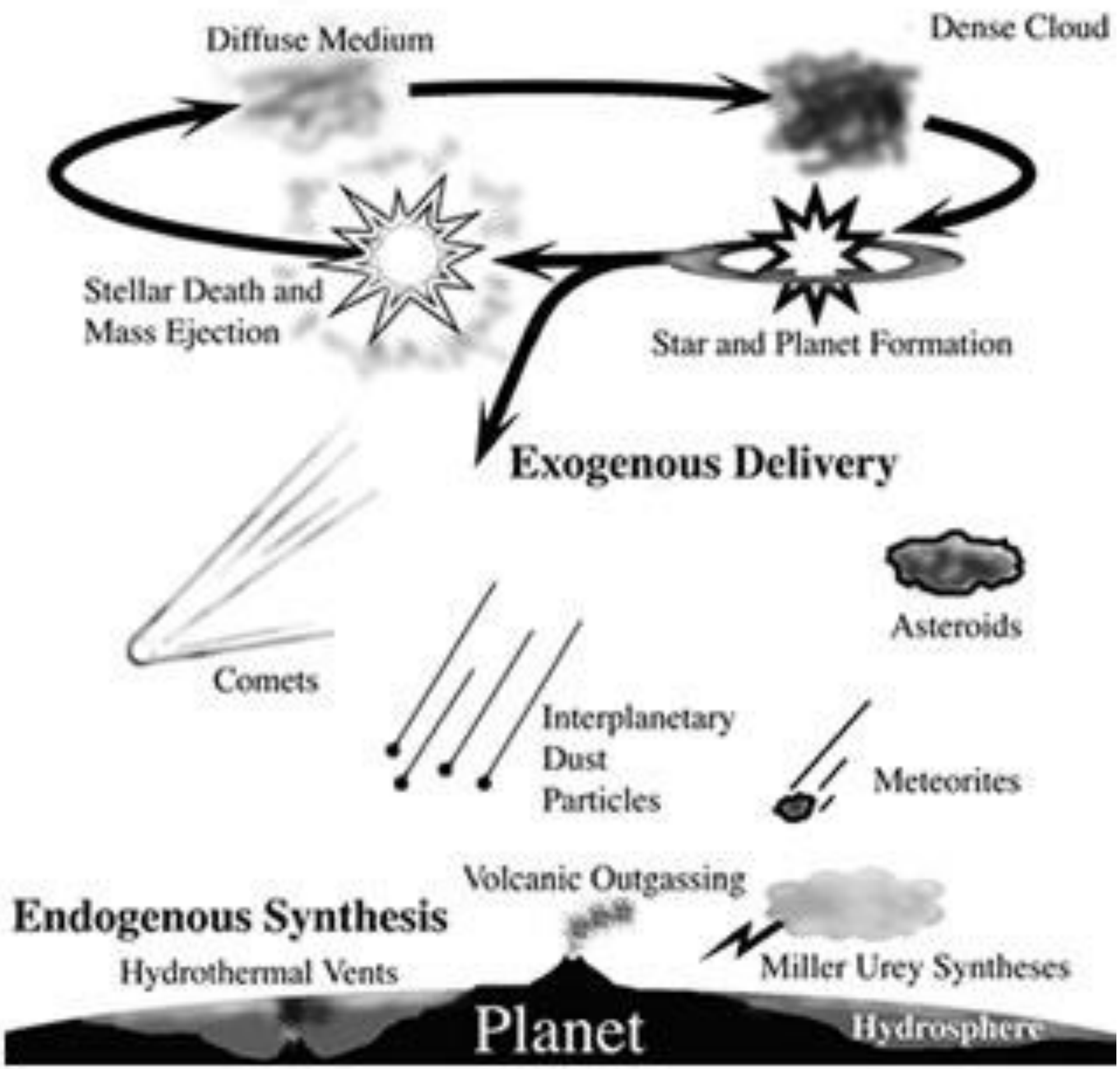
- Competition for nutrients led to the development of metabolic pathways.
- The polymerization reactions evolved were dependent on the environment to supply the necessary monomeric units and the energy-rich compounds such as ATP or polyphosphates that powered these reactions.
- As the essential components in the prebiotic soup became scarce, organisms developed the enzymatic systems that could synthesise these substances from simpler but more abundant precursors.
- As a result, energy-producing metabolic pathways arose.
- Such pathways consumed other pre-existing energy-rich substances.

- As these became increasingly scarce, the photosynthetic system was evolved to take advantage of the sun whose energy supply was inexhaustible.
  - In photosynthesis, reducing agents such as H_2S was initially used, until this reductant was exhausted.
  - This led to the refinement of the photosynthetic apparatus to utilize a more ubiquitous reducing agent, H_2O.
  - But the use of water brought in its trail, the production of highly reactive O_2, as a by-product.

- To circumvent any oxidative damage due to the accumulation of O_2, a much more efficient form of energy metabolism that used the newly available O_2 as an oxidizing agent was adopted.

- Oxygen was only a minor component of the atmosphere until when photosynthetic organisms began to produce oxygen from the oxidation of water.
- It was after this time that the ozone layer was formed to serve as a shield against UV rays from the sun.
- The shield was not present on the primitive earth when there was little atmospheric oxygen.

Summary



Diffuse Medium
Dense Cloud
Stellar Death and
Mass Ejection
Star and Planet Formation
Exogenous Delivery
Asteroids
Comets
Interplanetary
Dust
Particles
Meteorites
Volcanic Outgassing
Endogenous Synthesis
Hydrothermal Vents
Miller Urey Syntheses
Planet
Hydrosphere